# Stock Assessment and Fishery Evaluation Report for the <br> KING AND TANNER CRAB FISHERIES of the <br> Bering Sea and Aleutian Islands Regions 

## 2017 Final Crab SAFE

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## Table of Contents

Summary ..... 3
Introduction ..... 3
Stock Status definitions ..... 5
Status Determination Criteria ..... 6
Crab Plan Team Recommendations ..... 14
Stock Status Summaries ..... 15
Stock Assessment Section

1. EBS snow crab ..... 45
2. Bristol Bay red king crab ..... 159
3. EBS Tanner crab ..... 309
4. Pribilof Islands red king crab ..... 951
5. Pribilof Islands blue king crab ..... 991
6. Saint Matthew blue king crab ..... 1103
7. Norton Sound red king crab ..... 1185
8. Aleutian Islands golden king crab assessment ..... 1257
9. Pribilof Islands golden king crab ..... 1485
10. Western Aleutian Islands (Adak) red king crab ..... 1549
Appendix: Crab Economic Summary ..... 1601

# 2017 Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries in the Bering Sea and Aleutian Islands 

## Introduction

The annual stock assessment and fishery evaluation (SAFE) report is a requirement of the North Pacific Fishery Management Council's Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs (FMP), and a federal requirement [50 CFR Section 602.12(e)]. The SAFE report summarizes the current biological and economic status of fisheries, total allowable catch (TAC) or Guideline Harvest Level (GHL), and analytical information used for management decisions. Additional information on Bering Sea/Aleutian Islands (BSAI) king and Tanner crab is available on the National Marine Fisheries Service (NMFS) web page at http://www.fakr.noaa.gov and the Alaska Department of Fish and Game (ADF\&G) Westward Region Shellfish web page at: http://www.cf.adfg.state.ak.us/region4/shellfsh/shelhom4.php.

Paralithodes camtschaticus, stocks (Bristol Bay, Pribilof Islands, Norton Sound and Adak), 2 blue king crab, Paralithodes platypus, stocks (Pribilof Islands and St Matthew Island), 2 golden (or brown) king crab, Lithodes aequispinus, stocks (Aleutian Islands and Pribilof Islands), southern Tanner crab Chionoecetes bairdi hereafter referred to as Tanner crab, and snow crab Chionoecetes opilio. All other crab stocks in the BSAI are exclusively managed by the State of Alaska (SOA).

The Crab Plan Team (CPT) annually assembles the SAFE report with contributions from ADF\&G and the NMFS. This SAFE report is presented to the North Pacific Fishery Management Council (NPFMC) and is available to the public on the NPFMC web page at:
http://fakr.noaa.gov/npfmc/membership/plan_teams/CRAB_team.htm.
Due to a process to accommodate specific fishery and data availability needs to determine overfishing level (OFL) determinations, and annual catch limit (ACL) requirements, the CPT reviews assessments in a staggered time frame. Additionally, based upon consideration of stock prioritization including assessment methods and data availability, some stocks are assessed on an annual basis while others are assessed less frequently. The CPT reviews one assessment in January (Norton Sound red king crab), two assessments in May on a three-year cycle (WAI red king crab and Pribilof Islands golden king crab) and the remaining assessments (Bristol Bay red king crab, EBS snow crab, EBS Tanner crab, Saint Matthew blue king crab, Pribilof Island red king crab and Pribilof Island blue king crab, Aleutian Islands golden king crab,) in September (Table 1). Pribilof red king crab is assessed biennially while Pribilof blue king crab is assessed on a three-year cycle. Stocks can be assessed more frequently on a case-by-case basis should data indicate that it is necessary.

Table 1 Ten BSAI crab stocks: Schedule for review by the CPT and SSC and Assessment frequency

|  | CPT review and <br> recommendations | SSC review and <br> recommendations <br> to Council | Assessment <br> frequency | Year of <br> next |
| :--- | :--- | :--- | :--- | :--- | :--- |
| Assessment |  |  |  |  |

Based upon the assessment frequency described in Table 1, the CPT provides recommendations on OFL, acceptable biological catch (ABC) and stock status specifications for review by the NPFMC Science and Statistical Committee (SSC) in February (NSRKC) and June (WAIRKC, PIGKC) and October (BBRKC, EBS Snow crab, EBS Tanner crab, SMBKC, PIRKC, PIBKC, AIGKC). The rationale for this staggered review process is the following: The stocks with summer fisheries as well as those established on catch data only have specifications set in June. The stocks which employ data from the EBS NMFS trawl survey thus cannot be assessed until survey data are available in early September. Summer catch data for NSRKC however are not available in time for fall specifications, nor is assessing this stock with the June timing feasible as the CDQ fishery can open as early as May thus this stock is assessed in the winter. Additional information on the OFL and ABC determination process is contained in this report.

The CPT met from September 18-21, 2017 in Seattle, WA to review the final stock assessments as well as additional related issues, in order to provide the recommendations and status determinations contained in this SAFE report. This final 2017 Crab SAFE report contains all recommendations for all 10 stocks including those whose OFL and ABC were previously determined in February and June 2017. This SAFE report will be presented to the NPFMC in October for their annual review of the status of BSAI Crab stocks. Members of the team who participated in this review include the following: Bob Foy (Chair), Karla Bush (Vice-Chair), Katie Pavlof, Miranda Westphal, Brian Garber-Yonts, Ginny Eckert, Krista Milani, André Punt, Buck Stockhausen, Ben Daly, Martin Dorn, Shareef Siddeek, Jack Turnock and Diana Stram.

## Stock Status Definitions

The FMP (incorporating all changes made following adoption of Amendment 24) contains the following stock status definitions:

Acceptable biological catch (ABC) is a level of annual catch of a stock that accounts for the scientific uncertainty in the estimate of OFL and any other specified scientific uncertainty and is set to prevent, with a greater than 50 percent probability, the OFL from being exceeded. The ABC is set below the OFL.

ABC Control Rule is the specified approach in the five-tier system for setting the maximum permissible ABC for each stock as a function of the scientific uncertainty in the estimate of OFL and any other specified scientific uncertainty.

Annual catch limit (ACL) is the level of annual catch of a stock that serves as the basis for invoking accountability measures. For EBS crab stocks, the ACL will be set at the ABC.

Total allowable catch (TAC) is the annual catch target for the directed fishery for a stock, set to prevent exceeding the ACL for that stock and in accordance with section 8.2.2 of the FMP.

Guideline harvest level (GHL) means the preseason estimated level of allowable fish harvest which will not jeopardize the sustained yield of the fish stocks. A GHL may be expressed as a range of allowable harvests for a species or species group of crab for each registration area, district, subdistrict, or section.

Maximum sustainable yield (MSY) is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions. MSY is estimated from the best information available.
$\underline{F}_{\text {msy }}$ control rule means a harvest strategy which, if implemented, would be expected to result in a longterm average catch approximating MSY.
$\underline{B}_{M S Y}$ stock size is the biomass that results from fishing at constant $\mathrm{F}_{\text {MSY }}$ and is the minimum standard for a rebuilding target when a rebuilding plan is required.

Maximum fishing mortality threshold (MFMT) is defined by the Foft control rule, and is expressed as the fishing mortality rate.

Minimum stock size threshold (MSST) is one half the $B_{M S Y}$ stock size.
Overfished is determined by comparing annual biomass estimates to the established MSST. For stocks where MSST (or proxies) are defined, if the biomass drops below the MSST (or proxy thereof) then the stock is considered to be overfished. For crab stocks, biomass for determining overfished status is estimated on February 15 of the current year and compared to the MSST established by the NPFMC in October of the previous year.

Overfishing is defined as any amount of catch in excess of the overfishing level (OFL). The OFL is calculated by applying abundance estimates to the Foft control rule which is annually estimated according the tier system (see Chapter 6.0 in the FMP).

## Status Determination Criteria

The FMP defines the following status determination criteria and the process by which these are defined following adoption of Amendment 24 and 38.

Status determination criteria for crab stocks are calculated using a five-tier system that accommodates varying levels of uncertainty of information. The five-tier system incorporates new scientific information and provides a mechanism to continually improve the status determination criteria as new information becomes available. Under the five-tier system, overfishing and overfished criteria and ABC levels for most stocks are annually formulated. The ACL for each stock equals the ABC for that stock. Each crab stock is annually assessed to determine its status and whether (1) overfishing is occurring or the rate or level of fishing mortality for the stock is approaching overfishing, (2) the stock is overfished or the stock is approaching an overfished condition, and (3) the catch has exceeded the ACL.

For crab stocks, the OFL equals the maximum sustainable yield (MSY) and is derived through the annual assessment process, under the framework of the tier system. Overfishing is determined by comparing the OFL with the catch estimates for that crab fishing year. For the previous crab fishing year, NMFS will determine whether overfishing occurred by comparing the previous year's OFL with the catch from the previous crab fishing year. For the previous crab fishing year, NMFS will also determine whether the ACL was exceeded by comparing the ACL with the catch estimates for that crab fishing year. Catch includes all fishery removals, including retained catch and discard losses, for those stocks where non-target fishery removal data are available. Discard losses are determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the OFL and ACL will be set for and compared to the retained catch.

The NMFS will determine whether a stock is in an overfished condition by comparing annual biomass estimates to the established MSST. For stocks where MSST (or proxies) are defined, if the biomass drops below the MSST (or proxy thereof) then the stock is considered to be overfished. MSSTs or proxies are set for stocks in Tiers 1-4. For Tier 5 stocks, it is not possible to set an MSST because there are no reliable estimates of biomass.

If overfishing occurred or the stock is overfished, section 304(e)(3)(A) of the Magnuson-Stevens Act, as amended, requires the NPFMC to immediately end overfishing and rebuild affected stocks.

The Magnuson-Stevens Act requires that FMPs include accountability measures to prevent ACLs from being exceeded and to correct overages of the ACL if they do occur. Accountability measures to prevent TACs and GHLs from being exceeded have been used under this FMP for the management of the BSAI crab fisheries and will continue to be used to prevent ACLs from being exceeded. These include: individual fishing quotas and the measures to ensure that individual fishing quotas are not exceeded, measures to minimize crab bycatch in directed crab fisheries, and monitoring and catch accounting measures. Accountability measures in the harvest specification process include downward adjustments to the ACL and TAC in the fishing year after an ACL has been exceeded.

Annually, the NPFMC, SSC, and CPT will review (1) the stock assessment documents, (2) the OFLs and ABCs, and TACs or GHLs, (3) NMFS's determination of whether overfishing occurred in the previous crab fishing year, (4) NMFS's determination of whether any stocks are overfished and (5) NMFS's determination of whether catch exceeded the ACL in the previous crab fishing year.

Optimum yield is defined in Chapter 4 of the FMP. Information pertaining to economic, social and ecological factors relevant to the determination of optimum yield is provided in several sections of the FMP, including sections 7.2 (Management Objectives), Chapter 11, Appendix D (Biological and Environmental Characteristics of the Resource), and Appendix H (Community Profiles).

For each crab fishery, the optimum yield range is 0 to < OFL catch. For crab stocks, the OFL is the annualized MSY and is derived through the annual assessment process, under the framework of the tier system. Recognizing the relatively volatile reproductive potential of crab stocks, the cooperative management structure of the FMP, and the past practice of restricting or even prohibiting directed harvests of some stocks out of ecological considerations, this optimum yield range is intended to facilitate the achievement of the biological objectives and economic and social objectives of the FMP (see sections 7.2.1 and 7.2.2) under a variety of future biological and ecological conditions. It enables the SOA to determine the appropriate TAC levels below the OFL to prevent overfishing or address other biological concerns that may affect the reproductive potential of a stock but that are not reflected in the OFL itself. Under FMP section 8.2.2, the SOA establishes TACs at levels that maximize harvests, and associated economic and social benefits, when biological and ecological conditions warrant doing so.

## Five-Tier System

The OFL and ABC for each stock are estimated for the upcoming crab fishing year using the five-tier system, detailed in Table 6-1 and 6-2. First, a stock is assigned to one of the five tiers based on the availability of information for that stock and model parameter choices are made. Tier assignments and model parameter choices are recommended through the CPT process to the SSC. The SSC recommends tier assignments, stock assessment and model structure, and parameter choices, including whether information is "reliable," for the assessment authors to use for calculating the proposed OFLs and ABCs based on the five-tier system.

For Tiers 1 through 4, once a stock is assigned to a tier, the determination of stock status level is based on recent survey data and assessment models, as available. The stock status level determines the equation used in calculating the Fofl. Three levels of stock status are specified and denoted by "a," "b," and "c" (see Table 6-1). The F $\mathrm{F}_{\text {MSY }}$ control rule reduces the $\mathrm{F}_{\mathrm{OfL}}$ as biomass declines by stock status level. At stock status level "a," current stock biomass exceeds the $B_{M S Y}$. For stocks in status level "b," current biomass is less than $B_{M S Y}$ but greater than a level specified as the "critical biomass threshold" $(\beta)$.

In stock status level "c," the ratio of current biomass to $B_{M S Y}$ (or a proxy for $B_{M S Y}$ ) is below $\beta$. At stock status level "c," directed fishing is prohibited and an Fofl at or below Fmsy would be determined for all other sources of fishing mortality in the development of the rebuilding plan. The Council will develop a rebuilding plan once a stock level falls below the MSST.

For Tiers 1 through 3, the coefficient $\alpha$ is set at a default value of 0.1 , and $\beta$ set at a default value of 0.25 , with the understanding that the SSC may recommend different values for a specific stock or stock complex as merited by the best available scientific information.

In Tier 4, a default value of natural mortality rate (M) or an M proxy, and a scalar, $\gamma$, are used in the calculation of the Foft.

In Tier 5, the OFL is specified in terms of an average catch value over an historical time period, unless the SSC recommends an alternative value based on the best available scientific information.

Second, the assessment author prepares the stock assessment and calculates the proposed OFLs by applying the $\mathrm{F}_{\mathrm{OFL}}$ and using the most recent abundance estimates. The assessment authors calculate the proposed ABCs by applying the ABC control rule to the proposed OFL.

Stock assessment documents shall:

- use risk-neutral assumptions;
- specify how the probability distribution of the OFL used in the ABC control rule is calculated for each stock; and
- specify the factors influencing scientific uncertainty that are accounted for in calculation of the probability distribution of the OFL.

Second, the CPT annually reviews stock assessment documents, the most recent abundance estimates, the proposed OFLs and ABCs, and complies the SAFE. The CPT then makes recommendations to the SSC on the OFLs, ABCs, and any other issues related to the crab stocks.

Third, the SSC annually reviews the SAFE report, including the stock assessment documents, recommendations from the CPT, and the methods to address scientific uncertainty.

In reviewing the SAFE, the CPT and the SSC shall evaluate and make recommendations, as necessary, on:

- the assumptions made for stock assessment models and estimation of OFLs;
- the specifications of the probability distribution of the OFL;
- the methods to appropriately quantify uncertainty in the ABC control rule; and
- the factors influencing scientific uncertainty that the SOA has accounted for and will account for on an annual basis in TAC setting.

The SSC will then set the final OFLs and ABCs for the upcoming crab fishing year. The SSC may set an ABC lower than the result of the ABC control rule, but it must provide an explanation for setting the ABC less than the maximum ABC .

As an accountability measure, the total catch estimate used in the stock assessment will include any amount of harvest that may have exceeded the ACL in the previous fishing season. For stocks managed under Tiers 1 through 4, this would result in a lower maximum ABC in the subsequent year, all else being equal, because maximum ABC varies directly with biomass. For Tier 5 stocks, the information used to establish the ABC is insufficient to reliably estimate abundance or discern the existence or extent of biological consequences caused by an overage in the preceding year. Consequently, the subsequent year's maximum ABC will not automatically decrease. However, when the ACL for a Tier 5 stock has been exceeded, the SSC may decrease the ABC for the subsequent fishing season as an accountability measure.

## Tiers 1 through 3

For Tiers 1 through 3, reliable estimates of $\mathrm{B}, B_{M S Y}$, and $\mathrm{F}_{\mathrm{MSY}}$, or their respective proxy values, are available. Tiers 1 and 2 are for stocks with a reliable estimate of the spawner/recruit relationship, thereby enabling the estimation of the limit reference points $B_{M S Y}$ and $\mathrm{F}_{\mathrm{MSY}}$.

- Tier 1 is for stocks with assessment models in which the probability density function (pdf) of $\mathrm{F}_{\mathrm{MSY}}$ is estimated.
- Tier 2 is for stocks with assessment models in which a reliable point estimate, but not the pdf, of $\mathrm{F}_{\text {MSY }}$ is made.
- Tier 3 is for stocks where reliable estimates of the spawner/recruit relationship are not available, but proxies for $\mathrm{F}_{\text {MSY }}$ and $B_{M S Y}$ can be estimated.

For Tier 3 stocks, maturity and other essential life-history information are available to estimate proxy limit reference points. For Tier 3, a designation of the form "Fx" refers to the fishing mortality rate associated with an equilibrium level of fertilized egg production (or its proxy such as mature male biomass at mating) per recruit equal to $\mathrm{X} \%$ of the equilibrium level in the absence of any fishing.

The OFL and ABC calculation accounts for all losses to the stock not attributable to natural mortality. The OFL and ACL are total catch limits comprised of three catch components: (1) non-directed fishery discard losses; (2) directed fishery discard losses; and (3) directed fishery retained catch. To determine the discard losses, the handling mortality rate is multiplied by bycatch discards in each fishery. Overfishing would occur if, in any year, the sum of all three catch components exceeds the OFL.

## Tier 4

Tier 4 is for stocks where essential life-history, recruitment information, and understanding are insufficient to achieve Tier 3. Therefore, it is not possible to estimate the spawner-recruit relationship. However, there is sufficient information for simulation modeling that captures the essential population dynamics of the stock as well as the performance of the fisheries. The simulation modeling approach employed in the derivation of the annual OFLs captures the historical performance of the fisheries as seen in observer data from the early 1990s to present and thus borrows information from other stocks as necessary to estimate biological parameters such as $\gamma$.

In Tier 4, a default value of natural mortality rate (M) or an M proxy, and a scalar, $\gamma$, are used in the calculation of the Fofl. Explicit to Tier 4 are reliable estimates of current survey biomass and the instantaneous M. The proxy $B_{M S Y}$ is the average biomass over a specified time period, with the understanding that the Council's Scientific and Statistical Committee may recommend a different value for a specific stock or stock complex as merited by the best available scientific information. A scalar, $\gamma$, is multiplied by M to estimate the $\mathrm{F}_{\text {OFL }}$ for stocks at status levels "a" and "b," and $\gamma$ is allowed to be less than or greater than unity. Use of the scalar $\gamma$ is intended to allow adjustments in the overfishing definitions to account for differences in biomass measures. A default value of $\gamma$ is set at 1.0 , with the understanding that the Council's Scientific and Statistical Committee may recommend a different value for a specific stock or stock complex as merited by the best available scientific information.

If the information necessary to determine total catch OFLs and ACLs is available for a Tier 4 stock, then the OFL and ACL will be total catch limits comprised of three catch components: (1) non-directed fishery discard losses; (2) directed fishery discard losses; and (3) directed fishery retained catch. If the information necessary to determine total catch OFLs and ACLs is not available for a Tier 4 stock, then the OFL and ACL are determined for retained catch. In the future, as information improves, data would be available for some stocks to allow the formulation and use of selectivity curves for the discard fisheries (directed and non-directed losses) as well as the directed fishery (retained catch) in the models. The resulting OFL and ACL from this approach, therefore, would be the total catch OFL and ACL.

## Tier 5

Tier 5 stocks have no reliable estimates of biomass and only historical catch data are available. For Tier 5 stocks, the OFL is set equal to the average catch from a time period determined to be representative of the production potential of the stock, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information. The ABC control rule sets the maximum ABC at less than or equal to 90 percent of the OFL and the ACL equals the ABC.

For Tier 5 stocks where only retained catch information is available, the OFL and ACL will be set for the retained catch portion only, with the corresponding limits applying to the retained catch only. For Tier 5 stocks where information on bycatch mortality is available, the OFL and ACL calculations could include
discard losses, at which point the OFL and ACL would be applied to the retained catch plus the discard losses from directed and non-directed fisheries.

Figure 1. Overfishing control rule for Tiers 1 through 4. Directed fishing mortality is 0 below $\beta$.


Table 1. Five-Tier System for setting overfishing limits (OFLs) and Acceptable Biological Catches (ABCs) for crab stocks. The tiers are listed in descending order of information availability. Table 2 contains a guide for understanding the five-tier system.

| Information available | Tier | Stock status level | FofL | ABC control rule |
| :---: | :---: | :---: | :---: | :---: |
| $B, \quad B_{M S Y}, \quad F_{M S Y}$, and pdf of $F_{M S Y}$ |  | a. $\frac{B}{B_{m s y}}>1$ | $F_{O F L}=\mu_{A}=\text { arithmetic }$ <br> mean of the pdf |  |
|  |  | b. $\beta<\frac{B}{B_{\text {msy }}} \leq 1$ | $F_{O F L}=\mu_{A} \frac{B / B_{m s y}-\alpha}{1-\alpha}$ | $\mathrm{ABC} \leq\left(1-\mathrm{b}_{\mathrm{y}}\right) *$ OFL |
|  |  | c. $\frac{B}{B_{\text {msy }}} \leq \beta$ | Directed fishery $\mathrm{F}=0$ <br> $\mathrm{F}_{\mathrm{OFL}} \leq \mathrm{F}_{\mathrm{MSY}}{ }^{\dagger}$ |  |
| B, $\mathrm{B}_{\text {MSY }}, \mathrm{F}_{\text {MSY }}$ | 2 | a. $\frac{B}{B_{m s y}}>1$ | $F_{\text {OFL }}=F_{\text {msy }}$ |  |
|  |  | b. $\quad \beta<\frac{B}{B_{m s y}} \leq 1$ | $F_{O F L}=F_{m s y} \frac{B / B_{m s y}-\alpha}{1-\alpha}$ | $\mathrm{ABC} \leq\left(1-\mathrm{b}_{\mathrm{y}}\right) *$ OFL |
|  |  | c. $\frac{B}{B_{m s y}} \leq \beta$ | Directed fishery $\mathrm{F}=0$ $\mathrm{F}_{\mathrm{OFL}} \leq \mathrm{F}_{\mathrm{MSY}}{ }^{\dagger}$ |  |
| B, $\mathrm{F}_{35 \%}{ }^{*}$, $\mathrm{B}_{35 \%}{ }^{*}$ | 3 | a. $\frac{B}{B_{35 \%^{*}}}>1$ | $F_{\text {OFL }}=F_{35 \%} *$ |  |
|  |  | b. $\beta<\frac{B}{B_{35 \%} *} \leq 1$ | $F_{O F L}=F_{35 \%}^{*} \frac{\frac{B}{B_{35 \%}^{*}}-\alpha}{1-\alpha}$ | $\mathrm{ABC} \leq\left(1-\mathrm{b}_{\mathrm{y}}\right) *$ OFL |
|  |  | c. $\frac{B}{B_{35 \%} *} \leq \beta$ | Directed fishery $\mathrm{F}=0$ <br> $\mathrm{F}_{\mathrm{OFL}} \leq \mathrm{FMSY}^{\dagger}$ |  |

Table 1 (continued)

$B, M,$| $B_{m s y^{\text {prox }}}$ | 4 |
| :--- | :--- |
|  | a. $^{B_{m s y^{\text {prox }}}}$ |$>1 \quad F_{O F L}=\gamma M$

b. $\beta<\frac{B}{B_{m s y^{p r o x}}} \leq 1 \quad F_{O F L}=\gamma M \frac{B / B_{m s y^{\text {prox }}}-\alpha}{1-\alpha} \quad \mathrm{ABC} \leq\left(1-\mathrm{b}_{y}\right) * \mathrm{OFL}$
c. $B_{m s y^{p r o x}} \quad \mathrm{~F}_{\mathrm{OFL}} \leq \mathrm{F}_{\mathrm{MSY}}{ }^{\dagger}$

| Stocks with no 5 <br> reliable <br> estimates of <br> biomass or M. | OFL $=$ average catch from <br> a time period to be <br> determined, unless the SSC |  |
| :--- | :--- | :--- |
|  | recommends an alternative <br> value based on the best <br> available scientific <br> information. |  |

*35\% is the default value unless the SSC recommends a different value based on the best available scientific information.
$\dagger$ An $F_{O F L} \leq F_{M S Y}$ will be determined in the development of the rebuilding plan for an overfished stock.

Table 2. A guide for understanding the five-tier system.

- $\quad \mathrm{F}_{\text {OFL }}$ - the instantaneous fishing mortality ( F ) from the directed fishery that is used in the calculation of the overfishing limit (OFL). Foft is determined as a function of:
- $\mathrm{F}_{\text {MSY }}$ - the instantaneous F that will produce MSY at the MSY-producing biomass
- A proxy of $\mathrm{F}_{\mathrm{MSY}}$ may be used; e.g., $\mathrm{F}_{\mathrm{x} \%}$, the instantaneous F that results in $\mathrm{x} \%$ of the equilibrium spawning per recruit relative to the unfished value
- B - a measure of the productive capacity of the stock, such as spawning biomass or fertilized egg production.
- A proxy of B may be used; e.g., mature male biomass
- $B_{M S Y}$ - the value of B at the MSY-producing level
- A proxy of $B_{M S Y}$ may be used; e.g., mature male biomass at the MSYproducing level
- $\beta$ - a parameter with restriction that $0 \leq \beta<1$.
- $\alpha$ - a parameter with restriction that $0 \leq \alpha \leq \beta$.
- The maximum value of $\mathrm{F}_{\text {OFL }}$ is $\mathrm{F}_{\text {MSY }} . \mathrm{F}_{\text {OFL }}=\mathrm{F}_{\text {MSY }}$ when $\mathrm{B}>B_{M S Y}$.
- $\mathrm{F}_{\text {OFL }}$ decreases linearly from $\mathrm{F}_{\text {MSY }}$ to $\mathrm{F}_{\mathrm{MSY}} \cdot(\beta-\alpha) /(1-\alpha)$ as B decreases from $B_{M S Y}$ to $\beta \cdot B_{M S Y}$
- When $\mathrm{B} \leq \beta \cdot B_{M S Y}, \mathrm{~F}=0$ for the directed fishery and $\mathrm{F}_{\mathrm{OFL}} \leq \mathrm{F}_{\mathrm{MSY}}$ for the non-directed fisheries, which will be determined in the development of the rebuilding plan.
- The parameter, $\beta$, determines the threshold level of $B$ at or below which directed fishing is prohibited.
- The parameter, $\alpha$, determines the value of FofL when $B$ decreases to $\beta \cdot B_{M S Y}$ and the rate at which Fofl decreases with decreasing values of B when $\beta \cdot B_{M S Y}<\mathrm{B} \leq B_{M S Y}$.
- Larger values of $\alpha$ result in a smaller value of $\mathrm{F}_{\mathrm{OFL}}$ when B decreases to $\beta \cdot B_{\text {MSY }}$.
- Larger values of $\alpha$ result in $\mathrm{F}_{\text {OFL }}$ decreasing at a higher rate with decreasing values of B when $\beta \cdot B_{M S Y}<\mathrm{B} \leq B_{M S Y}$.
- The parameter, $\mathrm{b}_{\mathrm{y}}$, is the value for the annual buffer calculated from a $\mathrm{P}^{*}$ of 0.49 and a probability distribution for the OFL that accounts for scientific uncertainty in the estimate of OFL.
- $\mathrm{P}^{*}$ is the probability that the estimate of ABC , which is calculated from the estimate of OFL, exceeds the "true" OFL (noted as OFL') ( $\mathrm{P}\left(\mathrm{ABC}>\mathrm{OFL}^{\prime}\right.$ ').


## Crab Plan Team Recommendations

Table 3 lists the team's recommendations for 2017/2018 on Tier assignments, model parameterizations, time periods for reference biomass estimation or appropriate catch averages, OFLs and ABCs. The team recommends four stocks be placed in Tier 3 (EBS snow crab, Bristol Bay red king crab, EBS Tanner crab and Aleutian Island golden king crab), four stocks in Tier 4 (St. Matthew blue king crab, Pribilof Islands blue king crab, Pribilof Islands red king crab, and Norton Sound red king crab) and two stocks in Tier 5 (Pribilof Islands golden king crab, and Adak red king crab). Table 4 lists those stocks for which the team recommends an ABC less than the maximum permissible ABC for 2017/18. Stock status in relation to status determination criteria are evaluated in this report (Table 5). Status of stocks in relation to status determination criteria for stocks in Tiers 3 and 4 are shown in Figure 2. EBS Tanner crab and Pribilof Island red king crab are estimated to be above $B_{M S Y}$ for 2017/18 while EBS snow crab, Bristol Bay red king crab, Saint Matthew blue king crab and Norton Sound red king crab are estimated below $B_{M S Y}$. Pribilof Islands blue king crab stock remains overfished and estimated to be well below its MSST.

The CPT has general recommendations for all assessments and specific comments related to individual assessments. All recommendations are for consideration for the 2018 assessments. The general comments are listed below while the comments related to individual assessments are contained within the summary of CPT deliberations and recommendations contained in the stock specific summary section. Additional details regarding recommendations are contained in the Crab Plan Team Report (September 2017 CPT Report).

## General recommendations for all assessments

1. The CPT recommends that all assessment authors document assumptions and simulate data under those assumptions to test the ability of the model to estimate key parameters in an unbiased manner. These simulations would be used to demonstrate precision and bias in estimated model parameters.
2. The CPT recommends that weighting factors be expressed as sigmas or CVs or effective sample sizes. The team requests all authors to follow the Guidelines for SAFE preparation and to follow the Terms of Reference as listed therein as applicable by individual assessment for both content and diagnostics.
3. Authors should focus on displaying information on revised models as compared to last year's model rather than focusing on aspects of the assessment that have not changed from the previous year.
4. The current approach for fitting length-composition data accounts for sampling error but ignores the fact that selectivity among size classes is not constant within years; a small change in the selectivity on small animals could lead to a very large change in the catch of such animals (as may have happened for NSRKC). Authors are encouraged to develop approaches for accounting for this source of process error. This issue is generic to assessments of crab and groundfish stocks.
5. Authors are reminded that assessments should include the time series of stock estimates at the time of survey for at least the author's recommended model in that year.
6. Consider stepwise changes to data as individual model runs instead of changing multiple parameters at once so that changes in model performance may be attributed to specific data

By convention the CPT used the following conversions to include tables in both lb and t in the status summary sections:

- million lb to 1000 t [/2.204624]
- 1000 t to million lb [/0.453592]


## Stock Status Summaries

## 1 Eastern Bering Sea Snow crab

## Fishery information relative to OFL setting

Total catch mortality in $2016 / 17$ was $11,000 \mathrm{t}$ (with discard mortality rates applied), while the retained catch in the directed fishery was $9,700 \mathrm{t}$. This was below the $2016 / 17 \mathrm{OFL}$ of $23,700 \mathrm{t}$. Snow crab bycatch occurs in the directed fishery and to a lesser extent in the groundfish trawl fisheries. Estimates of trawl bycatch in recent years are less than $1 \%$ of the total snow crab catch. Estimates of stock status were above the $B_{M S Y}$ proxy for this stock ( $B_{35 \%}$ ) in 2010/11-2012/13, but below the $B_{M S Y}$ proxy more recently. For 2017/18, the ratio of projected MMB ( 99.6 t ) fishing at the $\mathrm{F}_{\text {OFL }}$ to $B_{M S Y}(139,400 \mathrm{t})$ remains less than 1 but above 0.5 .

## Data and assessment methodology

The stock assessment is based on a size- and sex-structured model in which crabs are categorized into immature or mature and new or old shell. The model is fitted to abundance and size frequency data from the NMFS trawl survey, total catch data from the directed fishery, bycatch data from the trawl fishery, size frequency data for male retained catch in the directed fishery, and male and female bycatch in the directed and trawl fisheries. The model is also fitted to biomass estimates and size frequency data from the 2009 and 2010 BSFRF surveys. Updated data in the model include biomass and length frequency data from the 2017 NMFS Eastern Bering Sea trawl survey, retained and discard catch and length frequencies from the 2016/17 directed fishery, and discard catch and length frequencies from the 2016/17 groundfish fisheries.

The model estimation structure was similar to the 2016 assessment incorporating the status determination and OFL calculations directly within the model code which allowed the author to employ a Bayesian approach to determining OFL, by using Markov Chain Monte Carlo (MCMC) techniques to sample the posterior distributions of relevant quantities that more fully incorporated model uncertainty than was possible with the methods used previously. In this assessment, a jittering approach within a maximum likelihood framework was also used.

The assessment author examined eight model runs based on six model scenarios in this assessment. Model M16.D16 was equivalent to the September 2016 assessment model. Model M16.D17 included new survey data. Model M16.D17a dropped survey data prior to 1982 due to catchability coefficients prior to 1982 in spite of a smaller surveyed area. A larger model change was made in M17A.D17a to change the survey selectivity periods to before and after 1987 which is in line with the survey station distribution. M17Aa.D17a also included estimating the BSFRF data in logit space with a penalty because those parameters were hitting bounds. M17Ab.D17a was a separate model run provided in an appendix that considered the posterior distribution based on an alternate minimum of the likelihood function that produced bimodal management quantities. The results of this additional run differed substantially from the original run indicating that the posterior was not adequately sampled in either MCMC run based on M17Aa.D17a. Model M17B.D17a fit a straight line for growth removing data associated with the two smallest length bins. This model was not considered due to poor estimates of the probability of maturing and survey selectivity. Model M17C.D17a was recommended by the author and estimated M for females in addition to males and immature crab. All models except M17C.D17a had significant bimodal posterior distributions in reference points. The CPT concurred with the author recommended model M17C.D17a due to the large improvement in likelihood estimates and the lack of the bimodal posterior issues.

## Stock biomass and recruitment trends

Survey mature male biomass based on a maturity ogive decreased from $167,100 \mathrm{t}$ in 2011 to $97,500 \mathrm{t}$ in 2013, increased to $163,500 \mathrm{t}$ in 2014, fell to $63,200 \mathrm{t}$ in 2016, and then increased to $83,960 \mathrm{t}$ in 2017. The 2017 model estimates of mature male biomass showed trends similar to survey biomass during 2011-2017, except that the model failed to match the 1 -year spike in survey biomass observed in 2014. Observed survey mature female biomass rose quickly from $52,200 \mathrm{t}$ in 2009 to $175,800 \mathrm{t}$ in 2011, its highest value since 1991, decreased steadily to $55,400 \mathrm{t}$ in 2016, then increased to $106,800 \mathrm{t}$ in 2017. Although the model matches the observed mature female survey biomass fairly well in 2016 and 2017, the model estimates do not follow the observed rise and fall that started in 2009; instead, they indicate that mature female biomass was fairly constant across the 2009-2016 time period. The model estimates a 3 -year trend of increasing recruitment starting in 2014, with very high values for 2016 (> 6 million), and then decreases in 2017. This increase is supported by the associated NMFS EBS survey size compositions, particularly for males.

## Tier determination/Plan Team discussion and resulting OFL/ABC determination Status and catch specifications

The CPT recommends that the EBS snow crab is a Tier 3 stock so the OFL will be determined by the FofL control rule using $\mathrm{F}_{35 \%}$ as the proxy for $\mathrm{F}_{\mathrm{MSY}}$. The proxy for $B_{M S Y}\left(B_{35 \%}\right)$ is the mature male biomass at mating ( 139.4 thousand t ) based on average recruitment over 1978 to 2017. Consequently, the minimum stock size threshold (MSST) is 69.7 thousand t . The CPT recommends that the ABC be less than maximum permissible ABC. The CPT recommends increasing the buffer previously used for snow crab ( $10 \%$ ) to $20 \%$ for setting the 2017/18 ABC. The recommended increase is due to model uncertainties and contradictions between model trends and survey and fishery observations. In addition, model uncertainty is greater for 2017/18 because the chosen model had questionable selectivity estimates for mature females.

Historical status and catch specifications for snow crab (thousand t). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | 71.5 | 126.5 | 24.5 | 24.5 | 28.1 | 78.1 | 70.3 |
| $2014 / 15$ | 78.9 | 168.0 | 30.8 | 30.8 | 34.3 | 69.0 | 62.1 |
| $2015 / 16$ | 75.8 | 91.6 | 18.4 | 18.4 | 21.4 | 83.1 | 62.3 |
| $2016 / 17$ | 69.7 | 94.4 | 9.7 | 9.7 | 11.0 | 23.7 | 21.3 |
| $2017 / 18$ |  | 99.6 |  |  |  | 28.4 | 22.7 |

Historical status and catch specifications for snow crab (million lb). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

| Year | MSST | Biomass <br> $($ MMB $)$ | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | 157.6 | 279.0 | 54.0 | 54.0 | 62.0 | 172.2 | 155.0 |
| $2014 / 15$ | 173.9 | 370.4 | 67.9 | 67.9 | 75.4 | 152.1 | 137.0 |
| $2015 / 16$ | 167.1 | 201.9 | 40.6 | 40.6 | 47.2 | 183.2 | 137.4 |
| $2016 / 17$ | 153.7 | 208.1 | 21.4 | 21.4 | 24.3 | 52.3 | 47.0 |
| $2017 / 18$ |  | 219.6 |  |  |  | 62.6 | 50.1 |

## 2 Bristol Bay Red King Crab

## Fishery information relative to OFL setting.

The commercial harvest of Bristol Bay red king crab (BBRKC) dates to the 1930s, and the fishery was initially prosecuted mostly by foreign fleets, but shifted to a largely domestic fishery in the early 1970s. Retained catch peaked in 1980 at 129.9 million lb ( 58.9 thousand t), but harvests dropped sharply in the early 1980s, and population abundance has remained at relatively low levels over the last two decades compared to those seen in the 1970s. The fishery is managed for a total allowable catch (TAC) coupled with restrictions for sex (males only), a minimum size for legal retention ( $6.5-\mathrm{in}$ carapace width; $135-\mathrm{mm}$ carapace length is used a proxy for 6.5 -in carapace width in the assessment), and season (no fishing during mating/molting periods). In addition to the retained catch that occurs during the commercial fishery, which is limited by the TAC, there is also retained catch that occurs in the ADF\&G cost-recovery fishery.

The current SOA harvest strategy allows a maximum harvest rate of $15 \%$ of mature-sized ( $\geq 120 \mathrm{~mm} \mathrm{CL}$ ) males, but also incorporates a maximum harvest rate of $50 \%$ of legal males and a threshold of 8.4 million mature-sized ( $\geq 90 \mathrm{~mm} \mathrm{CL}$ ) females and 14.5 million lb ( 6.6 thousand t ) of effective spawning biomass (ESB), to prosecute a fishery. Annual non-retained catch of female and sublegal male RKC during the fishery averaged less than 3.9 million lb ( 8.6 thousand t ) since data collection began in 1990. Total catch (retained and bycatch mortality) increased from 16.9 million lb ( 7.6 thousand t ) in 2004/05 to 23.4 million lb ( 10.6 thousand t ) in 2007/08, but has decreased since then; retained catch in $2016 / 17$ was 8.64 million lb ( 3.92 thousand t ) and total catch mortality was 9.44 million lb ( 4.28 thousand t ).

## Data and assessment methodology

The stock assessment is based on a sex- and size-structured population dynamics model incorporating data from the NMFS eastern Bering Sea trawl survey, the Bering Sea Fisheries Research Foundation (BSFRF) trawl survey, landings of commercial catch, at-sea observer sampling, and dockside retained catch sampling. In the model recommended by the CPT, annual stock abundance was estimated for male and female crabs $\geq 65-\mathrm{mm}$ carapace length from 1975 to the time of the 2017 survey and mature male (males $\geq 120 \mathrm{~mm} \mathrm{CL}$ ) biomass was projected to 15 February 2018. Catch data (retained catch numbers, retained catch weight, and pot lifts by statistical area and landing date) from the directed fishery, which targets males $\geq 135 \mathrm{~mm}$ ( 6.5 in carapace length), were obtained from ADF\&G fish tickets and reports, red king crab and Tanner crab fisheries bycatch data from the ADF\&G observer database, and groundfish trawl bycatch data from the NMFS groundfish observer database. NMFS trawl survey data were updated with data from the 2017 survey and new estimates of survey variance provided by NMFS; catch and bycatch data were updated with data from the 2016/17 crab fishery year. The estimate of biomass from the BSFRF survey for 2016 was updated to reflect correction of a calculation error.

Three principal model scenarios were evaluated in the 2017 assessment: Scenario 2a, a minor revision to the Scenario 2 from the 2016 assessment, and two new model scenarios that 1) explored alternative ways to incorporate groundfish fisheries bycatch into the assessment (Scenario 2b) and 2) removed constraints on model parameters (Scenario 2d) . Scenario 2 b was identical to scenario 2a, except that it separated bycatch of BBRKC in the groundfish fisheries by gear type (trawl and fixed) and fit these data using separate likelihood components. Scenario 2d was identical to 2 b , but dropped the prior on trawl survey catchability from the double-bag experiment and used a logit transformation to ensure survey catchability was less than or equal to 1 . The authors also evaluated the application of two approaches developed by Chris Francis to iteratively adjust the sample sizes applied to size composition data for each of the major alternative scenarios.

The CPT selected model 2 b as its recommended model as the basis for status determination and OFL setting. The six model scenarios that included iterative re-weighting applied to size composition data (2a1, 2a2, $2 \mathrm{~b} 1,2 \mathrm{~b} 2,2 \mathrm{~d} 1,2 \mathrm{~d} 2$ ) were not selected because the iterative re-weighting resulted in greatly reduced effective sample sizes that led to problems with model convergence and parameter estimation. Scenario 2d implements the recommendation that the prior for survey catchability be removed because it only accounts for one factor impacting catchability. In particular, the prior ignores the impact of availability, which would be expected to reduce survey catchability. The BSFRF survey data suggest that the NMFS survey catchability is less than $1(\sim 0.6)$. However, Scenario 2d led to an estimate of survey catchability equal to the upper bound of 1 (and would have been even higher had the bound not been imposed). In addition, the uncertainty associated with the estimated parameter value was extremely large. Scenario 2d also underpredicted most of the BSFRF survey estimates while over-predicting most of the recent NMFS survey estimates. Although Scenario $2 b$ also had an estimated value for NMFS survey catchability close to 1 , it was lower than that for Scenario 2d and had a much smaller associated uncertainty. In addition, because the prior on NMFS survey catchability was informed by experimental results, it was felt that dropping the prior was equivalent to removing data from the assessment. The CPT speculates that the high NMFS survey catchability is a consequence of the model needing to replicate the rapid decline in survey abundance in the 1980s given the observed catches. Thus, the CPT selected Scenario 2b as its recommended model.

## Stock biomass and recruitment trends

Model (scenario 2b) estimates of total survey biomass increased from 252 thousand $t$ in 1975 to 297 thousand t in 1977 , fell to 34.6 thousand t in 1985, generally increased to 91.9 thousand t in 2008 , and subsequently declined to 60.3 thousand $t$ in 2017 . Estimated recruitment was high during the 1970 s and early 1980s and has been generally low since 1985. The near-term outlook for this stock is a continued gradual declining trend. Recruitment has been poor (less than the mean from 1984-2016) since 2006. The 2011 survey produced a high catch of juvenile males and females $<65 \mathrm{~mm} \mathrm{CL}$ in one survey tow, but that catch did not track into the 2012-2017 surveys. The survey area-swept estimates for abundance and biomass in 2015-2017 were more consistent with previous surveys, in comparison to 2014, when the estimates were anomalously high.

## Tier determination/Plan Team discussion and resulting OFL and ABC determination

Bristol Bay red king crab is in Tier 3. Based on the author's discussion regarding an apparent reduction in stock productivity associated with the $1976 / 77$ climate regime shift in the EBS, the CPT recommends computing average recruitment as has been done in recent assessments (i.e., based on model recruitment using the time period 1984 (corresponding to fertilization in 1977) to the last year of the assessment) pending a more comprehensive discussion on this topic at the January 2018 CPT meeting. The estimated $B_{35 \%}$ is 25.1 thousand t . MMB projected for $2017 / 18$ is 21.31 thousand $\mathrm{t}, 85 \%$ of $B_{35 \%}$. Consequently, the BBRKC stock is in Tier 3b in 2017/18.

The CPT recommends that the OFL for $2017 / 18$ be set according to model scenario $2 b$, for which the calculated OFL is 5.60 thousand $\mathrm{t}(12.35$ million lb$)$. The team recommends that the ABC for $2017 / 18$ be set below the maximum permissible ABC . The team recommends that a $10 \%$ buffer from the OFL be used to set the ABC at 5.04 thousand t ( 11.11 million lb ).

MMB for 2016/17 was estimated to be 25.81 thousand $t$ and above MSST ( 12.53 thousand t ); hence the stock was not overfished in 2016/17. The total catch in 2016/17 (4.28 thousand t) was less than the 2016/17 OFL ( 6.64 thousand t ); hence overfishing did not occur in 2016/17. The stock at 2017/18 time of mating is projected to be above the MSST and $85 \%$ of $B_{35 \%}$ (see above); hence the stock is not approaching an overfished condition in 2017/18.

Historical status and catch specifications for Bristol Bay red king crab (thousand t). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | 12.85 | 27.12 | 3.90 | 3.99 | 4.56 | 7.07 | 6.36 |
| $2014 / 15$ | 13.03 | 27.25 | 4.49 | 4.54 | 5.44 | 6.82 | 6.14 |
| $2015 / 16$ | 12.89 | 27.68 | 4.52 | 4.61 | 5.34 | 6.73 | 6.06 |
| $2016 / 17$ | 12.53 | 25.81 | 3.84 | 3.92 | 4.28 | 6.64 | 5.97 |
| $2016 / 17$ |  | 21.31 |  |  |  | 5.60 | 5.04 |

Historical status and catch specifications for Bristol Bay red king crab (million lb). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | 28.3 | 59.9 | 8.60 | 8.80 | 10.05 | 15.58 | 14.02 |
| $2014 / 15$ | 28.7 | 60.1 | 9.99 | 10.01 | 11.99 | 15.04 | 13.53 |
| $2015 / 16$ | 28.4 | 61.0 | 9.97 | 10.17 | 11.77 | 14.84 | 13.36 |
| $2015 / 16$ | 27.6 | 56.9 | 8.47 | 8.65 | 9.45 | 14.63 | 13.17 |
| $2016 / 17$ |  | 47.0 |  |  |  | 12.35 | 11.11 |

## 3 Eastern Bering Sea Tanner crab

## Fishery information relative to OFL setting.

Eastern Bering Sea (EBS) Tanner crab are caught in directed Tanner crab fisheries, as bycatch in the groundfish fisheries, scallop fisheries, as bycatch in the directed Tanner crab fishery (mainly as nonretained females and sublegal males), and other crab fisheries (notably, eastern Bering Sea snow crab and, to a lesser extent, Bristol Bay red king crab). A single OFL is set for Tanner crab in the EBS. Under the Crab Rationalization Program, ADF\&G sets separate TACs for directed fisheries east and west of $166^{\circ} \mathrm{W}$ longitude. The mature male biomass was estimated to be below the Minimum Stock Size Threshold ( $0.5 B_{M S Y}$ ) in February 2010 (the assumed time of mating) based on trends in mature male biomass from the survey, and NMFS declared the stock overfished in September 2010. The directed fishery was closed from 2010/11 through 2012/13 crab fishery years.

NMFS determined the stock was not overfished in 2012 based on a new assessment model with a revised estimate of $B_{M S Y}$. The directed fishery was open for the 2013/14 to 2015/16 seasons with a total allowable catch (TAC) of $1,410 \mathrm{t}$ in 2013/14, 6,850 t in 2014/15, and $8,920 \mathrm{t}$ in 2015/16. The total retained catch in 2015/16 (8,910 t) was the largest taken in the fishery since 1992/93. In 2016/17, ADF\&G determined that mature female biomass did not meet the criteria for opening a fishery according to the regulatory harvest strategy, and the TAC was set at zero. Consequently, there was no directed harvest in 2016/17.

## Data and assessment methodology

The SSC accepted a size-structured assessment model for use in harvest specifications in 2012, and classified the EBS Tanner stock as a Tier 3 stock. This year's assessment used a new modeling framework, TCSAM02, which was endorsed by the SSC in June. TCSAM02 is similar to previous Tanner crab assessment models, but includes improvements to the modeling of fishery and population processes. The model is structured by crab size, sex, shell condition, and maturity. The model uses available data on quantity and size-composition from: the NMFS trawl survey; landings and discards by the directed fishery; bycatch in the Bristol Bay red king crab, EBS snow crab, and groundfish fisheries. The model includes prior distributions on parameters related to natural mortality and catchability, and penalties on changes in recruitment and in the proportion maturing. Input data sets were updated with the most recent information, including the NMFS EBS trawl survey in 2017; bycatch, and size composition data from the 2016/17 crab fisheries; and data on Tanner crab bycatch in the groundfish fisheries in 2016/17. A new data set was added which reflects Tanner crab growth in the eastern Bering Sea.

## Stock biomass and recruitment trends

The MMB at the time of mating is estimated to have been highest early in the early 1970s (approximately 300 thousand t ), with secondary peaks in 1989 (60 thousand t ) and 2008-2009 (57-58 thousand t ). The estimated MMB at time of mating in 2016/17 was 77.96 thousand $t$ and the projection for the 2017/18 time of mating is 43.31 thousand t . Estimates of recruitment since 1999 have been generally low relative to the peaks estimated for the period prior to 1990. There was a relatively strong recruitment estimated for 2017, but this estimate is very uncertain and will need to be confirmed by subsequent assessments.

## Tier determination/Plan Team discussion and resulting OFL and ABC determination

The CPT recommends the OFL for this stock be based on the Tier 3 control rule. Application of the Tier 3 control rule requires a set of years for defining $\mathrm{R}_{\text {MSY }}$, the mean recruitment corresponding to $B_{M S Y}$ under prevailing environmental conditions. The recommended time period for defining $\mathrm{R}_{\text {MSY }}$ is 1982-2017; the 1982-and-onwards time period has been used in previous OFL determination and follows the most-recent recommendation of the SSC.

Based on the estimated biomass at 15 February 2017, the stock is at Tier 3 level a. The Fmsy proxy ( $\mathrm{F}_{35 \%}$ ) is $0.75 \mathrm{yr}^{-1}$, and the 2017/18 Fofl is $0.75 \mathrm{yr}^{-1}$ under the Tier 3 level a OFL Control Rule, which results in a total male and female OFL of 25.42 thousand t . The CPT recommends a $20 \%$ buffer to account for model uncertainty and stock productivity uncertainty be applied to the OFL, to set $\mathrm{ABC}=20.33$ thousand t . The $20 \%$ buffer is the same that the SSC recommended for determination of the 2016/17 ABC.

Historical status and catch specifications for Eastern Bering Sea Tanner crab (thousand t). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

| Year | MSST | Biomass <br> (MMB) | TAC (East + <br> West) | Retained <br> Catch | Total <br> Catch <br> Mortality | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | 16.98 | 72.70 | 1.41 | 1.26 | 2.78 | 25.35 | 17.82 |
| $2014 / 15$ | 13.40 | 71.57 | 6.85 | 6.16 | 9.16 | 31.48 | 25.18 |
| $2015 / 16$ | 12.82 | 73.93 | 8.92 | 8.91 | 11.38 | 27.19 | 21.75 |
| $2016 / 17$ | 14.58 | 77.96 | 0.00 | 0.00 | 1.14 | 25.61 | 20.49 |
| $2017 / 18$ |  | 43.31 |  |  |  | 25.42 | 20.33 |

Historical status and catch specifications for Eastern Bering Sea Tanner crab (million lb). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

| Year | MSST | Biomass <br> (MMB) | TAC (East + <br> West) | Retained <br> Catch | Total <br> Catch <br> Mortality | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | 37.43 | 160.28 | 3.12 | 2.78 | 6.13 | 55.89 | 39.29 |
| $2014 / 15$ | 29.53 | 157.78 | 15.10 | 13.58 | 20.19 | 69.40 | 55.51 |
| $2015 / 16$ | 28.27 | 162.99 | 19.67 | 19.64 | 25.09 | 59.94 | 47.95 |
| $2016 / 17$ | 32.15 | 171.87 | 0.00 | 0.00 | 2.52 | 56.46 | 45.17 |
| $2017 / 18$ |  | 95.49 |  |  |  | 56.03 | 44.83 |

## 4 Pribilof Islands red king crab

## Fishery information relative to OFL setting

The Pribilof Islands red king crab fishery began in 1973 as bycatch during the blue king crab fishery. In 1993 and 1994 the red king crab fishery was open to directed fishing, and blue king crab was closed. From 1995 through 1998, combined Pribilof Islands red and blue king crab GHLs were used. Declines in crab abundance of both red and blue king crab stocks from 1996 to 1998 resulted in poor fishery performance with annual harvests below the GHLs. The Pribilof red king crab fishery has been closed since 1999 due to uncertainty in estimated red king crab abundance and concerns for bycatch mortality of blue king crab, which is overfished and severely depressed. Fishery closures near the Pribilof Islands have resulted in low bycatch, recent bycatch has been well below the OFL, ranging from 0.32 to $13.1 \mathrm{t}(<0.001$ to 0.029 million pounds; 2012/13-2016/17).

## Data and assessment methodology

The 2017 assessment is based on trends in male mature biomass (MMB) at the time of mating inferred from NMFS bottom trawl survey from 1975-2017 and commercial catch and observer data from 1973/74 to 2016/17. Two assessment methods using a Tier 4 harvest control rule were presented for evaluation: one calculated an annual index of MMB derived as the 3-yr running average using inverse variance weighting, and the second was a random effects model. The random effects model was presented with three variations: 1) $\lambda$ fixed, 2) a prior on $\lambda$ estimated from bootstrap (with $C V=2.24$ ) and 2 ) a prior on $\lambda$ with $C V$ 4.0.

## Stock biomass and recruitment trends

Male and female abundance varies widely over the history of the survey time series and uncertainty around area-swept estimates of abundance are large due to relatively low sample sizes. Recruitment for this stock is generally low and episodic. Numbers at length vary dramatically from year to year; however, two (possibly three) cohorts can be seen moving through the length frequencies over time. $\mathrm{MMB}_{\text {mating }}$ increased over 2012 to 2016. Estimates for the 3 -year moving average for $\mathrm{MMB}_{\text {mating }}$ in recent years approached those estimated during the early 1990 s, peaking in 2014/15 at $9,963 \mathrm{t}$ ( 21.96 million pounds).

## Tier determination/Plan Team discussion and resulting OFL and ABC determination

The CPT recommended the Tier 4 stock status determination and selected the random effects model with a prior on $\lambda$ estimated from a simple exponential model. A bootstrap analysis was used to obtain a prior $\mathrm{CV}=2.24$. This model was selected because it is a better smoother of extreme survey values. For 2017/18 the $B_{M S Y}=4,604 \mathrm{t}$ ( 10.15 million pounds) derived as the mean $\mathrm{MMB}_{\text {mating }}$ from 1991/92 to 2016/17 from the random effects model. Male mature biomass at the time of mating for 2017/18 was estimated at 3,364 t ( 7.416 million pounds). The $B / B_{M S Y}=0.73$ and $F_{\text {OFL }}=0.13$. $B / B_{M S Y \text { Proxy }}$ is $<1$, therefore the stock status level is Tier $4 b$. For the 2017/17 fishery, the OFL is 482 t ( 1.063 million lb). The CPT recommended a $25 \%$ buffer for an ABC from the OFL as in previous years.

Historical status and catch specifications for Pribilof Islands red king crab (t). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

| Year | MSST | Biomass <br> $\left(\right.$ MMB $_{\text {mating })}$ | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | 2,582 | 4,679 | 0 | 0 | 2.25 | 903 | 718 |
| $2014 / 15$ | 2,871 | 8,894 | 0 | 0 | 1.76 | 1,359 | 1,019 |
| $2015 / 16$ | 2,756 | 9,062 | 0 | 0 | 0.32 | 2,119 | 1,467 |
| $2016 / 17$ | 2,302 | 4,788 | 0 | 0 | 0.49 | 1,492 | 1,096 |
| $2017 / 18$ |  | 3,364 |  |  |  | 482 | 362 |
| $2018 / 19$ |  |  |  |  |  | 482 | 362 |

Historical status and catch specifications for Pribilof Islands red king crab (million lb). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | 5.66 | 10.32 | 0 | 0 | 0.005 | 1.99 | 1.58 |
| $2014 / 15$ | 6.33 | 19.61 | 0 | 0 | 0.002 | 3.00 | 2.25 |
| $2015 / 16$ | 6.23 | 19.98 | 0 | 0 | $<0.001$ | 4.67 | 3.23 |
| $2016 / 17$ | 5.07 | 10.56 | 0 | 0 | 0.001 | 3.22 | 2.42 |
| $2017 / 18$ |  | 7.42 |  |  |  | 1.06 | 0.80 |
| $2018 / 19$ |  |  |  |  |  | 1.06 | 0.80 |

The stock was above MSST in 2016/17 and is hence not overfished. Overfishing did not occur during the 2016/17 fishing year.

## $5 \quad$ Pribilof Islands blue king crab

## Fishery information relative to OFL setting.

The Pribilof Islands blue king crab fishery began in 1973, with peak landings of 11.0 million lb during the 1980/81 season. A steep decline in landings occurred after the 1980/81 season. Directed fishery harvest from 1984/85 until 1987/88 was annually less than 1.0 million lb with low CPUE. The fishery was closed from 1988/89 through 1994/95 fishing seasons. The fishery reopened for the 1995/96 to 1998/99 seasons. Fishery harvests during this period ranged from 1.3 to 2.5 million lb . The fishery closed again for the 1999/00 season due to declining stock abundance and has remained closed to the present.

The stock was declared overfished in 2002 and a rebuilding plan implemented in 2004. The rebuilding plan closed directed fishing for Pribilof blue king crab until the stock was rebuilt. In 2009, NMFS determined the stock would not meet its 10-year rebuilding horizon. Subsequently, Amendment 43 to the King and Tanner Crab FMP and Amendment 103 to the BSAI Groundfish FMP were approved by the Secretary of Commerce in 2014. This action, a revised rebuilding plan, closed the Pribilof Island Habitat Conservation Zone to Pacific cod pot fishing, which accounts for the highest recent rates of bycatch of this stock. This area was already closed to groundfish trawl fishing. To prevent overfishing in the future, ADF\&G will implement closure areas for the commercial crab fisheries to reduce the blue king crab bycatch. NMFS recently implemented a procedure to account for blue king crab bycatch in the groundfish fisheries inseason and will take inseason action to prevent overfishing.

## Data and assessment methodology

The calculation of the 2017/18 survey biomass uses the stock area definition established in 2012/13 that includes an additional 20 nm strip east of the Pribilof District. This assessment uses the 2016/17 methodology to project MMB and calculate $B_{M S Y}$. Prior to 2016/17, MMB for the current year was estimated from the NMFS EBS bottom trawl survey using a three-year running average weighted by the inverse of the variance of the area-swept estimate. The new methodology to calculate MMB and $B_{M S Y}$ was recommended by the CPT and uses a random effects model to smooth the survey time series. This model smooths the MMB estimates without low abundance estimates having undue influence. Differences in abundance estimates from the two methods were largest during periods of high inter-annual variability. Differences between the methods were small in recent years. Results from this method are shown starting with the 2015/16 MMB and 2016/2017 projected MMB.

## Stock biomass and recruitment trends

The $2017 / 18$ MMB at mating is projected to be $230 t$, which is approximately $6 \%$ of the proxy for $B_{M S Y}$. The Pribilof blue king crab stock biomass continues to be low with no indication of recruitment.

## Tier determination/Plan Team discussion and resulting OFL and ABC determination

This stock is recommended for placement into Tier 4. $B_{M S Y}$ was estimated using the time periods 1980/811984/85 and 1990/91-1997/98. This range was chosen because it eliminates periods of extremely low abundance that may not be representative of the production potential of the stock. $B_{M S Y}$ is estimated at 4,108 t ( 9.06 million pounds) for 2017/18.

Because the projected 2017/18 estimate of MMB is less than $25 \% B_{M S Y}$, the stock is in stock status c and the directed fishery F is 0 . However, an Fofl must be determined for the non-directed catch. Ideally this should be based on the rebuilding strategy. For this stock, the Foft is based on average groundfish bycatch between 1999/00 and 2005/06. The recommended OFL for 2017/18 is 1.16 t ( 0.0026 million lb).

The CPT recommended setting the ABC less than the maximum permissible by employing a $25 \%$ buffer on the OFL. This recommendation was based upon continuing concerns with stock status and consistency with relative buffer levels for other stocks for which the OFL is based upon average catch.

Historical status and catch specifications for Pribilof Islands blue king crab (t). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | 2,001 | 225 | Closed | 0 | 0.03 | 1.16 | 1.04 |
| $2014 / 15$ | 2,055 | 344 | Closed | 0 | 0.07 | 1.16 | 0.87 |
| $2015 / 16$ | 2,058 | 361 | Closed | 0 | 1.18 | 1.16 | 0.87 |
| $2016 / 17$ | 2,054 | 232 | Closed | 0 | 0.38 | 1.16 | 0.87 |
| $2017 / 18$ |  | 230 |  |  |  | 1.16 | 0.87 |
| $2018 / 19$ |  |  |  |  | 1.16 | 0.87 |  |
| $2019 / 20$ |  |  |  |  |  | 1.16 | 0.87 |

Historical status and catch specifications for Pribilof Islands blue king crab (million lb). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | 4.411 | 0.496 | Closed | 0 | 0.0001 | 0.0026 | 0.002 |
| $2014 / 15$ | 4.531 | 0.758 | Closed | 0 | 0.0002 | 0.0026 | 0.002 |
| $2015 / 16$ | 4.537 | 0.796 | Closed | 0 | 0.0026 | 0.0026 | 0.002 |
| $2016 / 17$ | 4.528 | 0.511 | Closed | 0 | 0.0008 | 0.0026 | 0.002 |
| $2017 / 18$ |  | 0.507 |  |  |  | 0.0026 | 0.002 |
| $2018 / 19$ |  |  |  |  |  | 0.0026 | 0.002 |
| $2019 / 20$ |  |  |  |  |  | 0.0026 | 0.002 |

The total catch for $2016 / 17(0.38 \mathrm{t}, 0.0008$ million lb) was less than the $2016 / 17 \mathrm{OFL}(1.16 \mathrm{t}, 0.0026$ million lb) so overfishing did not occur during $2016 / 17$. The $2017 / 18$ projected MMB estimate of $230 \mathrm{t}(0.507$ million lb) is below the proxy for MSST $\left(\mathrm{MMB} / B_{M S Y}=0.06\right)$ so the stock is projected to continue to be in an overfished condition.

## 6 St. Matthew blue king crab

## Fishery information relative to OFL setting

The fishery was prosecuted as a directed fishery from 1977 to 1998. Harvests peaked in 1983/84 when $4,288 \mathrm{t}(9.453$ million lb) were landed by 164 vessels. Harvest was fairly stable from 1986/87 to 1990/91, averaging $568 \mathrm{t}(1.252$ million lb$)$ annually. Harvest increased to a mean catch of $1,496 \mathrm{t}(3.298$ million lb) during the 1991/92 to 1998/99 seasons until the fishery was declared overfished and closed in 1999 when the stock size estimate was below the MSST. In November of 2000, Amendment 15 to the FMP was approved to implement a rebuilding plan for the St. Matthew Island blue king crab stock. The rebuilding plan included a harvest strategy identified in regulation by the Alaska Board of Fisheries, an area closure to control bycatch, and gear modifications. In 2008/09 and 2009/10, the MMB was estimated to be above $B_{M S Y}$ for two years and the stock declared rebuilt in 2009.

The fishery re-opened in 2009/10 with a TAC of $529 \mathrm{t}(1.166$ million lb) and 209 t ( 0.461 million lb) of retained catch were harvested. The 2010/11 TAC was 726 t ( 1.601 million lb) and the fishery reported a retained catch of 573 t ( 1.263 million lb). The 2011/12 harvest of 853 t ( 1.881 million lb) represented $80 \%$ of the $1,152 \mathrm{t}$ ( 2.540 million lb) TAC. In 2012/13, by contrast, harvesters landed $99 \%$ ( $733 \mathrm{t}, 1.616$ million lb ) of a reduced TAC of 740 t ( 1.630 million lb ), though fishery efficiency, at about 10 crab per pot, was little changed from what it had been in each of the previous three years. The directed fishery was closed in 2013/14 due to declining trawl survey estimates of abundance and concerns about the health of the stock. The directed fishery resumed again in 2014/15 with a TAC of 300 t ( 0.655 million pounds), but the fishery performance was relatively poor with the retained catch of 140 t ( 0.309 million pounds). The TAC in 2015/16 was 190 t ( 0.410 million pounds) with a retained catch of 47 t ( 0.105 million pounds). The fishery was closed in 2016/17. Bycatch of non-retained blue king crab has occurred in the St. Matthew blue king crab fishery, the eastern Bering Sea snow crab fishery, and trawl and fixed-gear groundfish fisheries. Based on limited observer data, bycatch of sublegal male and female crabs in the directed blue king crab fishery off St. Matthew Island was relatively high when the fishery was prosecuted in the 1990s, and total bycatch (in terms of number of crabs captured) was often twice as high or higher than total catch of legal crabs.

## Data and assessment methodology

This assessment is conducted in the General Model for Alaska Crab Stocks (GMACS) framework, which was accepted for use by the CPT in May 2016 and the SSC in June 2016. This assessment differs from the original GMACS model in that natural and fishing mortality are continuous within 5 discrete seasons. In addition, the model estimates a dynamic $B_{0}$ computed as spawning biomass relative to spawning biomass if no fishing harvests had occurred. Season length in GMACS is controlled by changing the proportion of natural mortality that is applied during each season.

The GMACS assesses male crab $\geq 90 \mathrm{~mm}$ CL. The three length categories are: $90-104 \mathrm{~mm}$ CL; $105-119$ mm CL; and $\geq 120 \mathrm{~mm}$ CL. Males $\geq 105 \mathrm{~mm}$ CL are used as a proxy for mature males, and males $\geq 120$ mm CL are used as a proxy for legal males ( $\geq 5.5$-inch carapace width). The model incorporates the following data: (1) commercial catch data from 1978/79-1998/99, 2009/10-2012/13, 2015/16; (2) annual trawl survey data from 1978 to 2017; (3) triennial pot survey data from 1995 to 2013 and annually from 2015 to 2017; (4) bycatch data in the groundfish trawl and groundfish fixed-gear fisheries from 1991 to 2016; and (5) ADF\&G crab-observer composition data for the years 1990/91-1998/99, 2009/10-2012/13, 2014/15, and 2015/16.

The NMFS summer trawl survey data are from stations within the St. Matthew Island Section and comprise 56 stations compared to the 96 stations covered by the ADF\&G pot survey. The pot surveys occur during July and August in areas of high-relief habitat important to blue king crab (particularly females) in areas
missed by the NMFS trawl survey. Groundfish discard information for trawl and fixed gear is derived from NMFS observer data for Bering Sea reporting areas 521 and 524.

## Stock biomass and recruitment trends

Following a period of low values ( $\sim 30 \%$ of the 1978-2017 mean of 5,762 t ) after the stock was declared overfished in 1999, trawl-survey indices of stock abundance and biomass generally increased to well above average during 2007-2012. In 2013 survey biomass declined ( $\sim 40 \%$ of the mean value) but was followed by average biomass estimates in 2014 and 2015, but with survey CVs of $77 \%$ and $45 \%$, respectively). The 2016 survey biomass fell to $3,485 \mathrm{t}$ ( 7.7 million lb with a CV of $39 \%$ ), and the 2017 survey estimate declined again to $1,794 \mathrm{t}$ ( 3.955 million lb , with a CV of $60 \%$ ). This value represents $31 \%$ of the long term mean with the most recent 3 -year average surveys at $65 \%$ of the historical mean. This suggests a general decline in biomass since 2010.

Because little information about the abundance of small crab is available for this stock, recruitment has been assessed in terms of the number of male crab within the $90-104 \mathrm{~mm}$ CL size class in each year. The 2017 trawl-survey area-swept estimate of 0.091 million males in this size class is the lowest in the 40 -year time series since 1978 and only $9 \%$ of the long-term average recruitment. The 2017 abundance of this size group was also the second-lowest in the time series of the pot survey and $22 \%$ of the average.

## Tier determination/Plan Team discussion and resulting OFL and ABC determination

The stock assessment examines 4 model configurations: (1) also referred to as the "reference case," the September 2016 model with the 2017 bottom trawl survey data and the 2017 pot survey data included; (2) VAST - a geo-spatial delta-GLMM application to the BTS data; (3) Fit survey - an exploratory scenario equivalent to the reference model except the NMFS trawl survey is up-weighted by 1.5 and the ADF\&G pot survey is up-weighted by 2.0 ; and (4) Francis weights - similar to the reference model but with Francis' iterative re-weighting of the size-composition data. The assessment also evaluated reference model sensitivity to new survey data by running scenarios: (5) without the 2017 trawl survey or 2017 pot survey data included; and (6) with the trawl survey data included but without the pot survey data.

The CPT concurs with the author's recommendation to use the reference case model for the 2016/17 crab year. This stock is in Tier 4. The CPT recommended model uses the full assessment period (1978/79$2016 / 17$ ) to define the proxy for $B_{M S Y}$ in terms of average estimated $M M B_{\text {mating }}$. The projected MMB estimated for 2017/18 under the recommended model is $2,180 \mathrm{t}$ ( 4.806 million lb ) and the $\mathrm{F}_{\text {MSY }}$ proxy is the natural mortality rate ( $0.18^{-1}$ year) and $\mathrm{F}_{\text {OFL }}$ is 0.079 , resulting in a mature male biomass OFL of $123 \mathrm{t}(0.273$ million lb ). The MMB $/ B_{M S Y}$ ratio is 0.55 . The author recommended and the CPT concurred with a $20 \%$ buffer on the OFL for the ABC which was consistent with the approach used last year. The ABC based on this buffer is $99 \mathrm{t}(0.218$ million lb$)$.

Historical status and catch specifications for Saint Matthew blue king crab (thousand t). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

| Year | MSST | Biomass <br> $\left(\mathbf{M M B}_{\text {mating }}\right)$ | TAC | Retained <br> Catch | Total Male <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | 1.50 | 3.01 | 0.00 | 0.00 | 0.0003 | 0.56 | 0.45 |
| $2014 / 15$ | 1.86 | 2.48 | 0.30 | 0.14 | 0.15 | 0.43 | 0.34 |
| $2015 / 16$ | 1.84 | 2.11 | 0.19 | 0.05 | 0.05 | 0.28 | 0.22 |
| $2016 / 17$ | 1.97 | 2.23 | 0.00 | 0.00 | 0.05 | 0.14 | 0.11 |
| $2017 / 18$ |  | 2.18 |  |  |  | 0.12 | 0.10 |

Historical status and catch specifications for Saint Matthew blue king crab (million lb). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

| Year | MSST | Biomass <br> (MMB mating | TAC | Retained <br> Catch | Total Male <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | 3.4 | 6.64 | 0.00 | 0.00 | 0.0006 | 1.24 | 0.99 |
| $2014 / 15$ | 4.1 | 5.47 | 0.655 | 0.309 | 0.329 | 0.94 | 0.75 |
| $2015 / 16$ | 4.0 | 4.65 | 0.41 | 0.105 | 0.105 | 0.62 | 0.49 |
| $2016 / 17$ | 4.30 | 4.91 | 0.00 | 0.000 | 0.000 | 0.31 | 0.25 |
| $2017 / 18$ |  | 4.81 |  |  |  | 0.27 | 0.22 |

The stock was above MSST in 2016/17 and is hence not overfished. The total catch was less than the OFL in 2016/17 and hence overfishing did not occur.

## 7 Norton Sound Red King Crab

## Fishery information relative to OFL setting

This stock supports three main fisheries: summer commercial, winter commercial, and winter subsistence. The summer commercial fishery, which accounts for the majority of the catch, reached a peak in the late 1970s at a little over 2.9 million pounds retained catch. Retained catches since 1982 have been below 0.5 million pounds, averaging 0.3 million pounds, including several low years in the 1990s. As the crab population rebounded, retained catches have increased to around 0.4 million pounds in recent years.

## Data and assessment methodology

Four types of surveys have occurred periodically during the last three decades: summer trawl, summer pot, winter pot, and preseason summer pot, but none of these surveys have been conducted every year. The assessment is based on a male-only length-based model of male crab abundance that combines multiple sources of data. A maximum likelihood approach was used to estimate abundance, recruitment, and selectivity and catchability of the commercial pot gear. The model has been updated to include the following data: total catch, catch length composition, discard length composition data from the 2016 summer commercial fishery, and 2015/16 winter commercial and subsistence catch. In addition, the standardized commercial catch CPUE indices were updated to include data for 1977-2016 and the annual proportions of the commercial catch before the survey were recalculated based on fishticket data. The current model assumes a constant $M=0.18 \mathrm{yr}^{-1}$ for all length classes except the > 134mm CL length-class, which had an estimated value of $0.590 \mathrm{yr}^{-1}$. Logistic functions are used to describe fishery and survey selectivities, except for a dome-shaped function examined for the winter pot fishery.

The author summarized six model run alternatives, in conjunction with the 2016 base model (Model 0). The author recommended, and the CPT selected, Model 3 as the recommended configuration. This model estimated the molt probability for the $64-73 \mathrm{~mm}$ CL length class. Other attributes were similar to the base model from the previous assessment. Model 3 fitted the compositional data better than the 2016 base model with one additional parameter.

## Stock biomass and recruitment trends

Mature male biomass was estimated to be at an historic low in 1982 following a crash from the peak biomass in 1977. The MMB then exhibited an increase from a recent low in 1997 to a peak in 2010, before declining and then rebuilding. Estimated recruitment was weak during the late 1970s and high during the early 1980s, with a slight downward trend from 1983 to 1993. Estimated recruitment has generally been variable, with a slight increase in recent years.

## Tier determination/Plan Team discussion and resulting OFL and ABC determination

The team recommended Tier 4, stock status a, for Norton Sound red king crab. The estimated abundance and biomass in 2016 using Model 3 are: Mature male biomass on Feb. 1: 5.14million lb ( 2.33 thousand t ).

The $B_{M S Y}$ proxy, calculated as the average of mature male biomass on Feb. 1 during 1980-2017, was $B_{M S Y}$ proxy $=4.62$ million lb . The $\mathrm{F}_{\text {MSY proxy }}$ is $M=0.18 \mathrm{yr}^{-1}$ and the $\mathrm{F}_{\mathrm{OFL}}=0.18 \mathrm{yr}^{-1}$, because the 2017 mature male biomass is larger than $B_{M S Y}$ proxy, with the CPT choosing the default of gamma $=1.0$.

The maximum permissible ABC would be 0.66 million lb , based on projected retained catch on July 1. The OFL is retained catch OFL although a total catch OFL is computed as part of the assessment. The CPT recommended an ABC less than the maximum permissible due to concerns with model specification, unresolved competing hypotheses about whether the lack of large animals in catches and surveys is due to higher mortality or migration from the area, lack of bycatch data as well as issues noted with the $M$
employed for the largest length group. The CPT recommended an $\mathrm{ABC}=80 \%$ of the OFL ( $20 \%$ buffer) of 0.54 million lb .

Status and catch specifications (1000t). Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

| Year | MSST | Biomass <br> (MMB) | GHL | Retained <br> Catch $^{\mathbf{1}}$ | Total <br> Catch $^{2}$ | Retained <br> Catch <br> OFL | Retained <br> Catch <br> ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | 0.93 | 2.27 | 0.23 | 0.16 | 0.16 | 0.26 | 0.24 |
| $2014 / 15$ | 0.96 | 1.68 | 0.17 | 0.18 | 0.18 | 0.21 | 0.19 |
| 2015 | 1.09 | 2.33 | 0.18 | 0.18 | 0.24 | 0.33 | 0.26 |
| 2016 | 1.03 | 2.66 | 0.24 | 0.23 | 0.24 | 0.32 | 0.26 |
| 2017 | 1.05 | 2.33 | 0.50 | 0.49 | 0.50 | 0.30 | 0.24 |

1: Summer commercial fishery.
2: Summer commercial fishery, winter commercial fishery and subsistence fishery.

Status and catch specifications (million lb.) Shaded values are new estimates or projections based on the current assessment. Other table entries are based on historical assessments and are not updated except for total and retained catch.

| Year | MSST | Biomass <br> (MMB) | GHL | Retained <br> Catch $^{1}$ | Total <br> Catch $^{2}$ | Retained <br> Catch <br> OFL | Retained <br> Catch <br> ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | 2.06 | 5.00 | 0.50 | 0.35 | 0.35 | 0.58 | 0.52 |
| $2014 / 15$ | 2.11 | 3.71 | 0.38 | 0.39 | 0.39 | 0.46 | 0.42 |
| 2015 | 2.41 | 5.13 | 0.39 | 0.40 | 0.52 | 0.72 | 0.58 |
| 2016 | 2.26 | 5.87 | 0.52 | 0.51 | 0.52 | 0.71 | 0.57 |
| 2017 | 2.31 | 5.14 | 0.23 | 0.22 | 0.24 | 0.67 | 0.54 |

1: Summer commercial fishery.
2: Summer commercial fishery, winter commercial fishery and subsistence fishery.

Total retained catch during 2016/17 did not exceed the OFL for this stock, thus overfishing is not occurring. Stock biomass is above MSST; thus, the stock is not overfished.

## 8 Aleutian Islands Golden King Crab

## Fishery information relative to OFL setting

The directed fishery has been prosecuted annually since the 1981/82 season. Retained catch peaked in $1986 / 87$ at 14.7 million lb and averaged 11.9 million lb over the $1985 / 86-1989 / 90$ seasons. Average harvests dropped sharply from 1989/90 to 1990/91 to a level of 6.9 million lb for the period 1990/911995/96. Management based on a formally established GHL began with the $1996 / 97$ season. The 5.9 million lb GHL established for the 1996/97 season, which was based on the previous five-year average catch, was subsequently reduced to 5.7 million lb beginning in 1998/99. The GHL (or TAC, since 2005/06) remained at 5.700 million lb for 2007/08, but was increased to 5.985 million lb for the 2008/09-2011/12 seasons, and to 6.290 million lb starting with the 2012/13 season. The TAC was reduced to 5.545 million lb for the 2016/17 season. This fishery is rationalized under the Crab Rationalization Program.

Non-retained bycatch occurs mainly in the directed fishery, and to a minor extent in other crab fisheries. Bycatch also occurs in fixed-gear and trawl groundfish fisheries although that bycatch is low relative to bycatch in the directed fishery. Total annual non-retained catch of golden king crab during crab fisheries decreased relative to the retained catch after the 1990s. Bycatch in the post-rationalized fishery (2005/062016/17) has ranged from 2.5 million lb in 2005/06 ( $46 \%$ of the retained catch) to 3.2 million lb for 2013/14 ( $50 \%$ of the retained catch). Estimated total mortality (retained catch plus bycatch in crab and groundfish fisheries) ranged from 5.8 to 9.4 million lb since 1995/96.

## Data and assessment methodology

The assessment for AI golden king crab establishes a single OFL and ABC for the whole stock however separate models are evaluated for EAG and WAG owing to different spatial trends in the fishery. Through the 2016/17 fishing year, the assessment was based on a Tier 5 methodology applied to data from ADF\&G fish tickets, size-frequencies from samples of landed crabs, at-sea observations from pot lifts sampled during the fishery, and bycatch estimates from the groundfish fisheries. The modeling framework has been under development for several years, with model assumptions and data inputs refined by reviews by the SSC and CPT. The modeling framework was recommended by the CPT in September 2016 and approved by the SSC in October 2016 for use in the 2017/18 specifications cycle.

The model-based stock assessment involves fitting male-only population dynamics models to data on catches and discards in the directed fishery, discards in the groundfish fishery, standardized indices of abundance based on observer data, fish ticket CPUE data, length-frequency data for the directed fishery (landing and total catch), and mark-recapture data. These data are available through the 2015/16 season.

The assessment author examined 11 model scenarios for this assessment. Model 1 assumed that the proportion mature was a logistic function of length, was fitted to observer CPUE data for 1995/96 - 2015/16 and fish ticket data from $1985 / 86$ to $1998 / 99$, and fixed $M$ for both stocks to be $0.224 \mathrm{yr}^{-1}$. Models $2-11$ varied the assumptions of Model 1 by: omitting the fish ticket data (Model 2), including additional observer CPUE data for 1991/92-1994/95 (Model 3), considering three rather than two selectivity patterns (Model 4), assuming higher and lower values for $M$ (Models 5 and 6), assuming knife-edged maturity at 111 mm CL (Model 9), area-specific values for $M$ (Model 10), and area-specific values of $M$ with knife-edged maturity at 111 mm CL (Model 11). Models 7 and 8 are identical to Model 1, except they consider different definitions for the mean recruitment used to define $B_{M S Y}$. The CPT recommended Model 9 which concurs with the author's recommendation, noting that the data on maturity at length were not reliable enough to estimate a logistic function which forms the basis for models other than Model 9 and 11 but could estimate a knife-edged length at maturity. Model 9 was preferred to Model 11 because the evidence for area differences in $M$ is weak.

This is the only crab assessment that relies solely on fishery CPUE as an index of abundance, with the CPUE index standardization process subject to past CPT and SSC review. The CPT recommended that the model be used to provide management reference points based on the Tier 3 control rule in January 2017 and this tier recommendation was endorsed by the SSC in February 2017.

An industry-ADF\&G collaborative survey was implemented for this stock in 2015.

## Stock biomass and recruitment trends

Estimated mature male biomass (MMB) for the EAG decreased from high levels until the 1990s after which the trend has been increasing. In contrast, the MMB for WAG increased from a low in the 1990s until 2007/08 and then declined again. Recruitment for the EAG is variable with a generally increasing trend while recruitment for WAG is lower in recent years than during the 1980s. Stock trends reflected the fishery standardized CPUE trends in both areas.

## Summary of major changes

The assessment is based on a male-only population dynamics model rather than the Tier 5 methodology. The changes to the assessment from the January 2017 modeling workshop were specification of maturity-at-length and refinement of the proposed models.

## Tier determination/Plan Team discussion and resulting OFL and ABC determination

The CPT recommends that this stock be managed as a Tier 3 stock in 2017/18. A single OFL and ABC is defined for AIGKC. However, separate models are available by area. The CPT considered two ways for computing an OFL for AIGKC.

- Apply the OFL control rule by area and sum the OFLs by area.
- Determine stock status for the stock by adding the estimates of current MMB and $B_{M S Y}$ by area. This stock status is then used to determine the ratio of $F_{\mathrm{OFL}}$ to $F_{35 \%}$ by area, which is then used to calculate the OFLs by area which are then added together to calculate an OFL for the entire stock.

The CPT recommended the second alternative because it relies on a single stock status determination rather than for area specific status determinations for the EAG and WAG. In contrast, use of the first alternative would lead to the EAG area being in tier 3a and the WAG area being in tier 3b, which would not result in a unique tier level for the stock. The SSC concurred with this approach.

The CPT recommends that the $B_{M S Y \text { proxy }}$ for the Tier 3 harvest control rule be based on the average recruitment from 1987-2012, years for which recruitment is relatively precisely estimated.

Status and catch specifications (1000 t) of Aleutian Islands golden king crab.

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch $^{\mathbf{a}}$ | Total <br> Catch $^{\mathbf{a}}$ | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | N/A | N/A | 2.853 | 2.894 | 3.192 | 5.69 | 5.12 |
| $2014 / 15$ | N/A | N/A | 2.853 | 2.771 | 3.079 | 5.69 | 4.26 |
| $2015 / 16$ | N/A | N/A | 2.853 | 2.729 | 3.073 | 5.69 | 4.26 |
| $2016 / 17$ | N/A | N/A | 2.515 | 2.593 | 2.829 | 5.69 | 4.26 |
| $2017 / 18^{\text {b }}$ | 6.044 | 14.205 |  |  |  | 6.048 | 4.838 |

a. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.
b. Approach 2 above.

Status and catch specifications (million lb) of Aleutian Islands golden king crab.

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch $^{\mathbf{a}}$ | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | N/A | N/A | 6.290 | 6.38 | 7.04 | 12.54 | 11.28 |
| $2014 / 15$ | N/A | N/A | 6.290 | 6.11 | 6.79 | 12.53 | 9.40 |
| $2015 / 16$ | N/A | N/A | 6.290 | 6.016 | 6.78 | 12.53 | 9.40 |
| $2016 / 17$ | N/A | N/A | 5.545 |  |  | 12.53 | 9.40 |
| $2017 / 18^{\mathrm{b}}$ | 13.325 | 31.315 |  |  |  | 13.33 | 10.67 |

a. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.
b. Approach 2 above.

Overfishing did not occur during 2015/16 because the estimated total catch did not exceed the Tier 5 overfishing limit (OFL) of 12.53-million lb ( 5.69 kt ).

## Additional Plan Team recommendations

The CPT recommended that for the next assessment, the assessment author pre-specify the maturity ogive rather than estimating it along with other model parameters, and consider estimating rather the prespecifying the 1960 recruitment, which would then be used to calculate $B_{M S Y}$. The CPT was informed about analyses to explore the impact of changes to the area fished. Further work was encouraged on this topic, which will help the CPT understand the extent of uncertainty associated with the assessment.

While the CPT recommended the use of the second alternative OFL calculation as listed above, the calculations for the OFL and ABC based upon the first alternative are shown below.

Status and catch specifications (1000 t) of Aleutian Islands golden king crab

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch $^{\mathbf{a}}$ | Total <br> Catch $^{\mathbf{a}}$ | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2017 / 18$ | 6.044 | 14.233 |  |  |  | 6.018 | 4.815 |

Status and catch specifications (million lb) of Aleutian Islands golden king crab

| Year | MSST | Biomass <br> $(M M B)$ | TAC | Retained <br> Catch $^{\mathbf{a}}$ | Total <br> Catch $^{\mathbf{a}}$ | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2017 / 18 \mathrm{c}$ | 13.325 | 31.378 |  |  |  | 13.27 | 10.61 |

## 9 Pribilof District Golden King Crab

## Fishery information relative to OFL setting

The Pribilof District golden king crab fishery began in the 1981/82 season, but is currently managed by calendar year. The directed fishery mainly occurs in Pribilof Canyon of the continental slope. Peak directed harvest was 0.856 million lb ( 388 t ) by 50 vessels during the 1983/84 season; fishery participation has since been sporadic and retained catches vary from 0 to 0.342 million $\mathrm{lb}(155 \mathrm{t})$. A guideline harvest level (GHL) was first established in 1999 at 0.200 million lb ( 91 t ) and the fishery has been managed with a GHL of 0.150 million $\mathrm{lb}(68 \mathrm{t})$ since 2000. No directed fishery occurred during 2006-2009, but one vessel landed catch in 2010, two vessels landed catch in 2011, and one vessel landed catch each year from 2012 to 2014. No vessels participated in the directed fishery during 2015 or 2016. Discarded (non-retained) catch has occurred in the directed golden king crab fishery, the eastern Bering Sea snow crab fishery, the Bering Sea grooved Tanner crab fishery, and in Bering Sea groundfish fisheries. Estimates of annual total fishery mortality during 2001-2016 due to crab fisheries range from 00.160 million lb ( 73 t ). There was no discarded catch during crab fisheries in 2016. Estimates of annual fishery mortality during 1991/92-2016 due to groundfish fisheries range from $<0.001$ to 0.019 million lb ( 8.84 t ). Total fishery mortality in groundfish fisheries during the 2016 crab fishing year was 0.24 t .

## Data and assessment methodology

There is no assessment model for this stock. Fish ticket and observer data are available, size-frequency data from samples of landed crabs, and pot lifts sampled during the fishery, and from the groundfish fisheries. Much of the directed fishery data are confidential due to low participation levels. A random effects model using slope survey data was explored; however, the model fit was poor for mature and legal size male, likely due to small number of data points and the high variance.

## Stock biomass and recruitment trends

There is no stock biomass data used in this Tier 5 assessment.

## Tier determination/Plan Team discussion and resulting OFL and ABC determination

The CPT recommends this stock be managed under Tier 5 in 2018, 2019, and 2020. The CPT concurs with the author's recommended status quo OFL of 0.20 million lb and an ABC of 0.15 million lb . The ABC was derived by applying a $25 \%$ buffer of the OFL, $\mathrm{ABC}=0.75 *$ OFL, the same buffer used for other Tier 5 stocks with similar levels of concern. The 2018-2020 OFL calculation is the same as recommended by the SSC for 2012-2017:
$\mathrm{OFL}_{2018-2020}=\left(1+\mathrm{R}_{2001-2010}\right) * \mathrm{RET}_{1993-1998}+\mathrm{BM}_{\mathrm{NC}, 1994-1998}+\mathrm{BM}_{\mathrm{GF}, 1992 / 93-1998 / 99}$
where,

- $\mathrm{R}_{2001-2010}$ is the average of the estimated annual ratio of lb of bycatch mortality to lb of retained in the directed fishery during 2001-2010.
- $\mathrm{RET}_{1993-1998}$ is the average annual retained catch in the directed crab fishery during 1993-1998.
- $\mathrm{BM}_{\mathrm{NC}, 1994-1998}$ is the estimated average annual bycatch mortality in non-directed crab fisheries during 1994-1998.
- $\mathrm{BM}_{\mathrm{GF}, 1992 / 93-1998 / 99}$ is the estimated average annual bycatch mortality in groundfish fisheries during 1992/93-1998/99.

Status and catch specifications ( $t$ ) of Pribilof District golden king crab.

| Calendar <br> Year | MSST | Biomass <br> (MMB) | GHL | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| 2013 | N/A | N/A | 68 | Conf. | Conf. | 91 | 82 |
| 2014 | N/A | N/A | 68 | Conf. | Conf. | 91 | 82 |
| 2015 | N/A | N/A | 59 | 0 | 1.92 | 91 | 68 |
| 2016 | N/A | N/A | 59 | 0 | 0.24 | 91 | 68 |
| 2017 | N/A | N/A | 59 |  |  | 93 | 70 |
| 2018 | N/A | N/A |  |  |  | 93 | 70 |
| 2019 | N/A | N/A |  |  |  | 93 | 70 |
| 2020 | N/A | N/A |  |  |  | 93 | 70 |

N/A = not available
Conf. = confidential
$\mathrm{TBA}=$ to be announced

Status and catch specifications (millions lb) of Pribilof District golden king crab.

| Calendar <br> Year | MSST | Biomass <br> (MMB) | GHL | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| 2013 | N/A | N/A | 150,000 | Conf. | Conf. | 0.20 | 0.18 |
| 2014 | N/A | N/A | 150,000 | Conf. | Conf. | 0.20 | 0.18 |
| 2015 | N/A | N/A | 130,000 | 0 | 0.004 | 0.20 | 0.15 |
| 2016 | N/A | N/A | 130,000 | 0 | $<0.001$ | 0.20 | 0.15 |
| 2017 | N/A | N/A | 130,000 |  |  | 0.20 | 0.15 |
| 2018 | N/A | N/A |  |  |  | 0.20 | 0.15 |
| 2019 | N/A | N/A |  |  |  | 0.20 | 0.15 |
| 2020 | N/A | N/A |  |  |  | 0.20 | 0.15 |

$\mathrm{N} / \mathrm{A}=$ not available
Conf. = confidential
TBA $=$ to be announced

## 10 Western Aleutian Islands red king crab

## Fishery information relative to OFL and ABC setting

The domestic fishery has been prosecuted every season from 1960/61 to 1995/96. During the early years of the fishery through the late 1970s, most or all of the retained catch was harvested in the area between $172^{\circ}$ W longitude and $179^{\circ} 15^{\prime}$ W longitude. Peak harvest occurred during the $1964 / 65$ season with a retained catch of 21.19 million lb . As the annual retained catch decreased into the mid-1970s and the early-1980s, the area west of $179^{\circ} 15^{\prime} \mathrm{W}$ longitude began to account for a larger portion of the retained catch. After 1995/96, the fishery was opened only occasionally. There was an exploratory fishery in 1998/99, three commissioner's permit fisheries in limited areas during 2000/01-2002/03 to allow for ADF\&G-Industry surveys, and two commercial fisheries with a GHL of 0.5 million lb in 2002/03 and 2003/04 in the Petrel Bank area. The fishery has been closed since 2003/04.

Retained catch from 1985/86 to 1994/95 averaged 0.94 million lb, but the retained catch during the 1995/96 season dropped to 0.04 million lb. Most of the catch since the 1990/91 season was harvested in the Petrel Bank area (between $179^{\circ} \mathrm{W}$ longitude and $179^{\circ} \mathrm{E}$ longitude) and the last two commercial fishery seasons were opened only in the Petrel Bank area with 0.51 million lb in 2002/03 and 0.48 million lb in 2003/04. Non-retained catch of red king crabs occurs in both the directed red king crab fishery, the Aleutian Islands golden king crab fishery, and in groundfish fisheries. Estimated bycatch mortality in the crab fisheries during the 1995/96 to 2015/16 seasons averaged 0.002 million lb in crab fisheries and 0.020 million lb in groundfish fisheries. Estimated annual total fishing mortality from 1995/96 to 2015/16 averaged 0.079 million lb . The average retained catch during that period was 0.060 million lb . This fishery is rationalized under the Crab Rationalization Program only for the area west of $179^{\circ} \mathrm{W}$ longitude.

## Data and assessment methodology

The 1960/61 to 2007/08 time series of retained catch (number and pounds of crabs), effort (vessels, landings and pot lifts), average weight and average carapace length of landed crabs, and catch-per-unit effort (number of crabs per pot lift) are available. Bycatch from crab fisheries from 1995/96 to 2016/17 and from groundfish fisheries from 1993/94 to 2016/17 are available. There is no assessment model for this stock. The standardized surveys of the Petrel Bank area conducted by ADF\&G in 2006 and 2009 and the ADF\&GIndustry Petrel Bank surveys conducted in 2001 were too limited in geographic scope and too infrequent for reliable estimation of abundance for the entire western Aleutian Islands area.

## Stock biomass and recruitment trends

Estimates of stock biomass, recruitment trends, and current levels relative to virgin or historic levels are not available for this stock. The fishery has been closed since 2003/04 due to apparent poor recruitment. A 2009 survey conducted by ADF\&G in the Petrel Bank area encountered an ageing population of legal male crab occurring in a more limited area and at lower densities than were found in a 2006 survey and provided no expectations for recruitment. A test fishery conducted by a commercial vessel during October-December 2009 in the area west of Petrel Bank yielded only one legal male red king crab. A cooperative red king crab survey was performed by the Aleutian Islands King Crab Foundation and ADF\&G in the Petrel Bank area in November 2016 averaged less than one crab per pot lift suggesting that the stock is in poor condition.

## Tier determination/Plan Team discussion and resulting OFL and ABC determination

The CPT recommends that this stock be managed under Tier 5 for the 2017/18, 2018/19, and 2019/20 seasons. The CPT concurs with the assessment author's recommendation of an OFL based on the 1995/962007/08 average total catch following the recommendation of the SSC in June 2010 to set the time period for computing the OFL at 1995/96-2007/08. The CPT recommends an OFL for 2017/18 to 2019/20 of 0.123867 million lb.

The CPT continues to have concerns regarding the depleted condition of this stock. Groundfish bycatch in recent years has accounted for the majority of the total catch. The CPT recommends an ABC of 0.030967 million lb for $2017 / 18$, 2018/19, and $2019 / 20$ which is equivalent to a $75 \%$ buffer on OFL. The recommended ABC is less than that which was recommended by the SSC for 2012/13-2016/17 because 1) the industry has not expressed interest in a small test fishery, and 2) because the stock is severely depressed as indicated by the 2016 Petrel survey (CPT minutes for May 2017).

Status and catch specifications t of Western Aleutian Islands red king crab.

| Fishing <br> Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | N/A | N/A | Closed | 0 | $<1$ | 56 | 34 |
| $2014 / 15$ | N/A | N/A | Closed | 0 | $<1$ | 56 | 34 |
| $2015 / 16$ | N/A | N/A | Closed | 0 | 1.3 | 56 | 34 |
| $2016 / 17$ | N/A | N/A | Closed | 0 | $<1$ | 56 | 34 |
| $2017 / 18$ | N/A | N/A |  |  |  | 56 | 14 |
| $2018 / 19$ | N/A | N/A |  |  |  | 56 | 14 |
| $2019 / 20$ | N/A | N/A |  |  |  | 56 | 14 |

Status and catch specifications (million lb) of Western Aleutian Islands red king crab.

| Fishing <br> Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2013 / 14$ | N/A | N/A | Closed | 0 | 0.00073 | 0.124 | 0.074 |
| $2014 / 15$ | N/A | N/A | Closed | 0 | 0.00047 | 0.124 | 0.074 |
| $2015 / 16$ | N/A | N/A | Closed | 0 | 0.00296 | 0.124 | 0.074 |
| $2016 / 17$ | N/A | N/A | Closed | 0 | 0.00045 | 0.124 | 0.074 |
| $2017 / 18$ | N/A | N/A |  |  |  | 0.124 | 0.074 |
| $2018 / 19$ | N/A | N/A |  |  |  | 0.124 | 0.074 |
| $2019 / 20$ | N/A | N/A |  |  |  | 0.124 | 0.074 |

## Figures and Tables

## EBS crab stocks



Figure 1. Status of 7 Bering Sea crab stocks in relation to status determination criteria ( $B_{M S Y}$, MSST, overfishing). Note that information is insufficient to assess Tier 5 stocks according to these criteria (WAIRKC, AIGKC, PIGKC).

Table 3. Crab Plan Team recommendations for September 2017. Note that recommendations for stocks 7, 8, 9, 10 represent those final values recommended by the SSC in February and June 2017. (Note: diagonal fill indicates parameters are not applicable for that tier.) Biomass units are 1000 t .

| Chapter | Stock | Tier | Status $(a, b, c)$ | Foft | Bmsror BMSY proxy | Years ${ }^{[1]}$ (biomass or catch) | $2017 / 18^{[2]}$ <br> MMB | 2017/18 <br> MMB / <br> MMBMSY | Y | Mortality (M) | $\begin{gathered} 2017 / 18^{[3]} \\ \text { OFL } \end{gathered}$ | $\begin{gathered} 2017 / 18 \\ \text { ABC } \end{gathered}$ | ABC Buffer |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | EBS snow crab | 3 |  | 0.89 | 139.4 | 1979-current [recruitment] | 99.6 | 0.71 |  | 0.23(females) <br> 0.417 (imm) <br> 0.259 (mat males) | 28.41 | 25.6 | 20\% |
| 2 | BB red king crab | 3 | b | 0.24 | 25.1 | 1984-current [recruitment] | 21.31 | 0.85 |  | 0.18 default; estimated | 5.6 | 5.04 | 10\% |
| 3 | EBS Tanner crab | 3 | b | 0.75 | 29.17 | 1982-current | 43.31 | 1.49 |  | 0.34 (females), <br> 0.25 (mat male), 0.247 (imm males and female | 25.42 | 20.33 | 10\% |
| 4 | Pribilof Islands red king crab | 4 | a | 0.18 | 4.6 | $\begin{aligned} & \hline 1991 / 92- \\ & 2016 / 17 \\ & \hline \end{aligned}$ | 3.36 | 0.73 | 1 | 0.18 | 0.48 | 0.36 | 20\% |
| 5 | Pribilof Islands blue king crab | 4 | c | 0.18 | 4.11 | $\begin{aligned} & 1980 / 81- \\ & 1984 / 85 \& \\ & 1990 / 91- \\ & 1997 / 98 \end{aligned}$ | 0.23 | 0.05 | 1 | 0.18 | 0.00116 | 0.00087 | 25\% |
| 6 | St. Matthew Island blue king crab | 4 | b | 0.079 | 3.93 | 1978-current | 2.18 | 0.55 | 1 | 0.18 | 0.12 | 0.09 | 20\% |
| 7 | Norton Sound red king crab | 4 | a | 0.18 | 2.1 | 1980-current | 2.33 | 1.11 | 1 | 0.18 | 0.3 | 0.24 | 20\% |
| 8 | Al golden king crab | 3 | a | $\begin{aligned} & \hline \text { EAG } \\ & (0.75) \\ & \text { WAG } \\ & (0.68) \end{aligned}$ | 12.09 | $\begin{aligned} & 1987 / 88- \\ & 2012 / 13 \end{aligned}$ | 14.21 | 1.17 |  | 0.22 | 6.05 | 4.54 | 25\% |
| 9 | Pribilof Islands golden king crab | 5 |  |  |  | See intro chapter |  |  |  |  | 0.09 | 0.07 | 25\% |
| 10 | Western AI red king crab | 5 |  |  |  | $\begin{aligned} & \text { 1995/96- } \\ & \text { 2007/08 } \end{aligned}$ |  |  |  |  | 0.06 | 0.01 | 75\% |

[^1] 1976-1979; 1985 to 1993 and 1968-1975; 1994-2013. See assessment for mortality rates associated with these time periods.

Table 4. Maximum permissible ABCs for 2017/18 ${ }^{[1]}$ and Crab Plan Team recommended ABCs for those stocks where the Plan Team recommendation is below the maximum permissible $A B C^{[2]}$ as defined by Amendment 38 to the Crab FMP. Note that the rationale is provided in the individual introduction chapters for recommending an $A B C$ less than the maximum permissible for these stocks.

|  |  |  |  |
| :--- | :---: | :---: | :---: |
| Stock | Tier | MaxABC $(1000 \mathrm{t})$ | 2016 |
| EBS Snow Crab 1000 t$)$ |  |  |  |
| Bristol Bay red king crab | 3 | 28.4 | 25.6 |
| EBS Tanner Crab | 3 | 5.6 | 5.04 |
| Pribilof Islands red king crab | 3 | 25.57 | 20.33 |
| Pribilof Islands blue king crab | 4 | 0.39 | 0.36 |
| Saint Matthew blue king crab | 4 | 0.00116 | 0.00087 |
| Norton Sound red king crab | 4 | 0.12 | 0.09 |
| Aleutian Islands golden king crab | 4 | 0.3 | 0.24 |
| Pribilof Islands golden king crab ${ }^{[1]}$ | 3 | 6.02 | 4.54 |
| WAI red king crab | 5 | 0.08 | 0.07 |

[1] For Pribilof Islands golden king crab, this is for the 2018 calendar year instead of the 2017-2018 crab fishing year.
[2] For Tier 5 stocks this is 0.90 while all other stocks $\mathrm{P}^{*}$.

Table 5. Stock status in relation to status determination criteria for 2016/17 as estimated in September 2017. (Note: shaded portion indicates parameters not applicable for this tier level).

| Chapter | Stock | Tier | MSST | $B_{M S Y}$ Or <br> $B_{M S Y \text { proxy }}$ | $\begin{gathered} 2015 / 16^{1} \\ M M B \end{gathered}$ | 2016/17 <br> MMB / MMB MSY | $\begin{gathered} 2016 / 17 \\ \text { OFL } 1000 \text { t } \end{gathered}$ | $\begin{aligned} & \text { 2016/17 } \\ & \text { Total catch } \end{aligned}$ | Rebuilding Status |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | EBS snow crab | 3 | 78.9 | 157.8 | 208.1 | 1.32 | 83.1 | 24.3 |  |
| 2 | BB red king crab | 3 | 13.05 | 26.1 | 25.8 | 0.99 | 6.73 | 4.28 |  |
| 3 | EBS Tanner crab | 3 | 13.4 | 26.8 | 77.96 | 2.91 | 27.18 | 1.14 |  |
| 4 | Pribilof Islands red king crab | 4 | 2.83 | 5.65 | 4.79 | 0.85 | 1.36 | 0.49 |  |
| 5 | Pribilof Islands blue king crab | 4 | 2.05 | 4.1 | 0.23 | 0.06 | 1.16 | 0.00038 | overfished |
| 6 | St. Matthew Island blue king crab | 4 | 1.86 | 3.72 | 2.23 | 0.60 | 0.28 | 0.05 |  |
| 7 | Norton Sound red king crab | 4 | 1.03 | 2.06 | 1.9 | 1.29 | 0.32 | 0.24 |  |
| 8 | Aleutian Islands golden king crab | 5 |  |  |  |  |  |  |  |
| 9 | Pribilof Islands golden king crab | 5 |  |  |  |  |  |  |  |
| 10 | Adak red king crab | 5 |  |  |  |  |  |  |  |

1-For stocks 1-6 MMB on 2/15/2016 is estimated using the current assessment in September 2016. For Norton Sound red king crab MMB on 2/1/2016 is estimated using the current assessment in January 2017.

## A stock assessment for eastern Bering Sea snow crab

Cody Szuwalski and Jack Turnock<br>September 11, 2017

## Contents

A. Summary of Major Changes ..... 5
B. CPT May 2017 comments, SSC comments, and author response: ..... 6
CPT and SSC comments ..... 6
Authors response ..... 6
C. Introduction ..... 7
Distribution ..... 7
Life history characteristics ..... 7
Natural Mortality ..... 7
Weight at length ..... 8
Maturity ..... 8
Molting probability ..... 8
Mating ratio and reproductive success ..... 9
Growth ..... 9
Management history ..... 10
ADFG harvest strategy ..... 10
History of BMSY ..... 10
Fishery history ..... 11
D. Data ..... 11
Catch data ..... 11
Survey biomass and size composition data ..... 12
Spatial distribution of survey abundance and catch ..... 12
Experimental study of survey selectivity ..... 13
E. Analytic approach ..... 13
History of modeling approaches for the stock ..... 13
Model description ..... 13
Model selection and evaluation ..... 14
Results ..... 14
Fits to data ..... 15
Survey biomass data ..... 15
Growth data ..... 15
Catch data ..... 15
Size composition data ..... 15
Estimated population processes and derived quantities ..... 15
F. Calculation of the OFL ..... 16
Methodology for OFL ..... 16
Calculated OFLs and interpretation ..... 17
G. Calculation of the ABC ..... 17
Author recommendations ..... 18

[^2]H. Data gaps and research priorities ..... 18
Data sources ..... 18
Modeling and weighting ..... 19
Scientific uncertainty ..... 19
Style ..... 19
I. Ecosystem Considerations ..... 19
J. Literature cited ..... 20
Appendix A: Model structure ..... 22
Population dynamics ..... 22
Likelihood components ..... 25

1. Stock: Eastern Bering Sea snow crab, Chionoecetes opilio.
2. Catches: trends and current levels

Retained catches increased from relatively low levels in the early 1980s (e.g. retained catch of 13.32 kt during 1981) to historical highs in the early and mid-nineties (retained catch during 1991, 1992, and 1998 were $143.02,104.68$, and 88.09 kt , respectively). The stock was declared overfished in 1999 at which time retained catches dropped to levels similar to the early 1980s (e.g. retained catch during 2000 was 11.46 kt ). Retained catches have slowly increased since 1999 as the stock rebuilt, although retained catch during 2016 was low ( 9.67 kt ).

Discard mortality is the next largest source of mortality after retained catch and approximately tracks the retained catch. The highest estimated discard mortality occurred during 1992 at 17.06 kt which was $16 \%$ of the retained catch. The most recent estimated mortality was 1.31 kt which was $14 \%$ of the retained catch.
3. Stock Biomass:

Observed mature male biomass (MMB) at the time of the survey increased from an average of 160.81 kt in the early to mid-1980s to historical highs in the early and mid-nineties (observed MMB during 1990, 1991, and 1997 were $443.79,466.61$, and 326.75 kt , respectively). The stock was declared overfished in 1999 in response to the total mature biomass dropping below the minimum stock size threshold. MMB in that year decreased to 95.85 kt . Observed MMB slowly increased after 1999, and the stock was declared rebuilt in 2011 when estimated MMB at mating was above $\mathrm{B}_{35 \%}$. However, since 2011, the stock has declined again and the observed MMB at the time of survey dropped to an all time low in 2016 of 63.21 kt .

## 4. Recruitment

Estimated recruitment shifts from a period of high recruitment to a period of low recruitment in the mid 1990s (late 1980s when lagged to fertilization). Recent estimated recruitments have generally been above the average of the 'low' period, but are still beneath the average of the 'high' recruitment period. However, a large year class recruited to the survey gear in 2014 and has persisted to the present, which suggests large exploitable biomasses may be available in the near future.
5. Management

Table 1: Historical status and catch specifications for snow crab (1,000t).

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> catch | Total <br> catch | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2011 / 2012$ | 77.3 | 165.2 | 40.3 | 40.5 | 42 | 73.5 | 66.2 |
| $2012 / 2013$ | 77.1 | 170.1 | 30.1 | 30.1 | 32.4 | 67.8 | 61 |
| $2013 / 2014$ | 71.5 | 126.5 | 24.5 | 24.5 | 27.7 | 78.1 | 69.3 |
| $2014 / 2015$ | 73.2 | 129.3 | 30.8 | 30.8 | 34.3 | 69 | 62.1 |
| $2015 / 2016$ | 75.8 | 91.6 | 18.4 | 18.4 | 21.4 | 61.5 | 55.4 |
| $2016 / 2017$ | 69.7 | 94.4 | 9.7 | 9.7 | 11 | 23.7 | 21.3 |
| $2017 / 2018$ | 69.7 | 99.6 |  |  |  | 28.4 | 25.6 |

Table 2: Historical status and catch specifications for snow crab (millions of lbs).

| Year | MSST | Biomass <br> $($ MMB $)$ | TAC | Retained <br> catch | Total <br> catch | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2011 / 2012$ | 170.4 | 364.2 | 88.85 | 89.29 | 92.59 | 162 | 145.9 |
| $2012 / 2013$ | 170 | 375 | 66.36 | 66.36 | 71.43 | 149.5 | 134.5 |
| $2013 / 2014$ | 157.6 | 278.9 | 54.01 | 54.01 | 61.07 | 172.2 | 152.8 |
| $2014 / 2015$ | 161.4 | 285.1 | 67.9 | 67.9 | 75.62 | 152.1 | 136.9 |
| $2015 / 2016$ | 167.1 | 201.9 | 40.57 | 40.57 | 47.18 | 135.6 | 122.1 |
| $2016 / 2017$ | 153.7 | 208.1 | 21.38 | 21.38 | 24.25 | 52.25 | 46.96 |
| $2017 / 2018$ | 153.7 | 219.6 |  |  |  | 62.61 | 56.44 |

6. Basis for the OFL

The OFL for 2017 from the chosen model (M17C D17a) was 28.41 kt fishing at $\mathrm{F}_{\text {OFL }}=0.89$ ( $68 \%$ of the calculated $\mathrm{F}_{35 \%}, 1.31$ ). The calculated OFL was a $20 \%$ change from the 2016 OFL of 23.7 kt . The reported OFL is the median posterior value, but differs from the ML estimate by only 0.4 kt . The projected ratio of MMB at the time of mating to $\mathrm{B}_{35 \%}$ is 0.71 .
7. Probability Density Function of the OFL

The probability density function of the OFL was characterized by using a Markov Chain Monte Carlo algorithm to sample from the a posterior distribution of the OFL. This allows all uncertainty to be propagated forward into the OFL calculation. The chosen OFL was calculated as the median of its posterior distribution.
8. Basis for ABC

The ABC for the chosen model for $2016 / 2017$ was 25.57 kt , calculated by subtracting a $10 \%$ buffer from the OFL as recommended by the SSC.

## A. Summary of Major Changes

1. Management: None
2. Input data:

Data added to the assessment included: 2017 Bering Sea survey biomass and length frequency data, 2016 directed fishery retained and discard catch and length frequencies for retained and discard catch, and groundfish discard length frequency and discard from 2016.
3. Assessment methodology:

The recommended OFL was calculated using Bayesian methodologies in 2016, which was a departure from the previous projection framework (but still provided similar management advice). Both a 'jittering' approach within a maximum likelihood framework and a Bayesian treatment of the data were completed this year. Management quantities from the selected model are reported as the medians of posterior distributions resulting from application of a Markov Chain Monte Carlo.
4. Assessment results

The updated estimates of MMB (February 15, 2016) were 94.43 which placed the stock at $67 \%$ of $\mathrm{B}_{35 \%}$. Projected MMB on February 15, 2017 from the chosen model this assessment after fishing at the OFL was 99.57 kt , which will place the stock at $71 \%$ of $\mathrm{B}_{35 \%}$. Fits to all data sources were acceptable for the chosen model and estimated population processes were credible.

## B. CPT May 2017 comments, SSC comments, and author response:

## CPT and SSC comments

Five scenarios were recommended by the CPT, based on analyses presented during the May 2017 CPT meeting:

- Leave out length bins below the kink in growth and fit one straight line for growth.
- Estimate $M$ for females, males, and immature crab. Change the prior on the multiplier to work in log space with a zero mean and an appropriate standard deviation.
- Start the model in 1982 and drop all data data before 1982.
- Split the survey selectivity periods in 1987 or 1988 - check the distribution of survey sampling to have a consistent area for each era.
- Estimate survey availability parameters for the BSFRF survey in logit space with a penalty.

The CPT also recommended resolving problems with any parameters hitting bounds.
The authors present 8 runs based on these 5 scenarios:

- "M16.D16" - Last year's accepted model fit to last year's data.
- "M16.D17" - Last year's accepted model fit to this year's data.
- "M16.D17a" - Last year's accepted model fit to this year's data, but dropping all survey data before 1982.
- "M17A.D17a" - Split survey selectivity periods in 1987, based on distribution of survey stations.
- "M17Aa.D17a" - Estimate survey availability parameters for BSFRF survey in logit space with a penalty
- "M17B.D17a" - Remove data in length bins below the kink in growth and fit a straight line for growth.
- "M17C.D17a" - Estimate M for females, males, and immature, change prior to be suitable in log space with zero mean and appropriate standard deviation. Retains all changes to this point.
- "M17BC.D17a" - Combines 'M17B.D17A' and 'M17C.D17A'

The CPT also asked for:

- Bycatch from different sources presented in a figure in the assessment chapter.
- Documentation of the jittering approach.


## Authors response

All changes were undertaken in a step-wise fashion and management quantities were calculated both via maximum likelihood methods and Bayesian methods. M17C D17a is the author preferred model based on fit to the data, number of assumptions placed on the data, and the stability of the model when jittered. Model scenarios include all CPT recommended models. 'Jittering' was performed for all models, but ultimately did not resolve all of the problems introduced by incomplete growth data (bimodal estimates of management quantities and poor convergence). Consequently, Bayesian posteriors were also used to calculated management quantities for all models.

Models in which smaller length bins were removed did not produce viable models. Removing the length bins was done to attempt to avoid the problem of estimating a breakpoint in the growth model. However, after removal of the length bins, estimates of survey selectivity and probability of maturing were no longer reasonable. It appears that the very low counts in the smallest length bins, coupled with a constant (and fairly well-informed via priors) natural mortality provided an anchor for selectivity, catchability, and maturity.

## C. Introduction

## Distribution

Snow crab (Chionoecetes opilio) are distributed on the continental shelf of the Bering Sea, Chukchi Sea, and in the western Atlantic Ocean as far south as Maine. In the Bering Sea, snow crab are distributed widely over the shelf and are common at depths less than $\sim 200$ meters (Figure $1 \&$ Figure 2). Smaller crabs tend to occupy more inshore northern regions (Figure 3) and mature crabs occupy deeper areas to the south of the juveniles (Figure 4 \& Figure 5; Zheng et al. 2001). The eastern Bering Sea population within U.S. waters is managed as a single stock; however, the distribution of the population may extend into Russian waters to an unknown degree.

## Life history characteristics

Studies relevant to key population and fishery processes are discussed below to provide background for the model description in appendix A.

## Natural Mortality

Natural mortality for snow crab in the Bering Sea is poorly known, due to relatively few targeted studies. In one of these studies, Nevissi, et al. (1995) used radiometric techniques to estimate shell age from last molt. The total sample size was 21 male crabs (a combination of Tanner and snow crab) from a collection of 105 male crabs from various hauls in the 1992 and 1993 NMFS Bering Sea survey. Representative samples for the 5 shell condition categories were collected that made up the 105 samples. The oldest looking crab within shell conditions 4 and 5 were selected from the total sample of SC4 and SC5 crabs to radiometrically age (Orensanz, Univ. of Washington, pers comm.). Shell condition 5 crab (SC5 $=$ very, very old shell) had a maximum age of 6.85 years (s.d. $0.58,95 \% \mathrm{CI}$ approximately 5.69 to 8.01 years). The average age of 6 crabs with SC4 (very old shell) and SC5, was 4.95 years (range: 2.70 to 6.85 years). Given the small sample size, this maximum age may not represent the $1.5 \%$ percentile of the population that is approximately equivalent to Hoenig's method (1983). Maximum life span defined for a virgin stock is reasonably expected to be longer than these observed maximum ages from exploited populations, particularly because fishing mortality was high before and during the time period during which this study was performed. Radiometric ages estimated by Nevissi, et al. (1995) may also be underestimated by several years, due to the continued exchange of material in crab shells even after shells have hardened (Craig Kastelle, pers. comm., Alaska Fisheries Science Center, Seattle, WA).

Tag recovery evidence from eastern Canada revealed observed maximum ages in exploited populations of 17-19 years (Nevissi, et al. 1995, Sainte-Marie 2002). A maximum time at large of 11 years for tag returns of terminally molted mature male snow crab in the North Atlantic has been recorded since tagging started about 1993 (Fonseca, et al. 2008). Fonseca, et al. (2008) estimated a maximum age of 7.8 years post terminal molt using data on dactal wear.
The mean for the prior for natural mortality used in this assessment is based on the assumption (informed by the studies above) that longevity would be at least 20 years in a virgin population of snow crab. Under negative exponential depletion, the 99th percentile corresponding to age 20 of an unexploited population corresponds to a natural mortality rate of 0.23 . Using Hoenig's (1983) method a natural mortality equal to 0.23 corresponds to a maximum age of 18 years. Consequently, natural mortality for mature females was set to $0.23 \mathrm{yr}^{-1}$ in the base model. Mature male natural mortality was estimated in the base model with a prior constraint of mean of $0.23 \mathrm{yr}^{-1}$ with a standard error equal to 0.054 (estimated from using the $95 \% \mathrm{CI}$ of +-1.7 years on maximum age estimates from dactal wear and tag return analysis in Fonseca, et al. (2008)). Natural mortality for immature males and females was estimated in the model with a mean of $0.23 \mathrm{yr}^{-1}$ and a standard error of 0.154 in all models, save M17C D17A, which used a standard error of 0.054 for immature
crab to be consistent with the rationale above for maximum age estimates. Mature female natural mortality was also estimated in M17C D17A with the same prior.

## Weight at length

Weight at length is calculated by a power function, the parameters for which were recalculated by the Kodiak lab in August 2016 and resulted in very small changes in weight at length for males, but rather large changes for females. New weight at length parameters were applied to all years of data, rather than just the most recent observations and were used starting in 2016 for calculation of the OFL. To provide context for the change, a juvenile female crab of carapace width 52.5 mm was previously estimated to weigh 65 g and now 48 g ; a mature female crab of carapace width 57.5 mm was estimated to previously weigh 102 g and now 67.7 g ; and a male of carapace width 92.5 mm was previously estimated to weigh 450 g and now weighs 451 g .

## Maturity

Maturity of females collected during the NMFS summer survey was determined by the shape of the abdomen, by the presence of brooded eggs, or egg remnants. Morphometric maturity for males was determined by chela height measurements, which were available starting from the 1989 survey (Otto 1998). Mature male biomass referenced throughout this document refers to a morphometrically mature male. A maturity curve for males was estimated using the average fraction mature based on chela height data and applied to all years of survey data to estimate mature survey numbers. The separation of mature and immature males by chela height may not be adequately refined given the current measurement to the nearest millimeter. Chela height measured to the nearest tenth of a millimeter (by Canadian researchers on North Atlantic snow crab) shows a clear break in chela height at small and large widths and shows fewer mature animals at small widths than the Bering Sea data measured to the nearest millimeter. Measurements taken in 2004-2005 on Bering Sea snow crab chela to the nearest tenth of a millimeter show a similar break in chela height to the Canadian data (Rugolo et al. 2005). The probability of maturing (which is different from the fraction mature at length) is estimated within the model for both sexes as a freely estimated (but smoothed) function of length.

## Molting probability

Bering Sea male snow crab appear to have a terminal molt to maturity based on hormone level data and findings from molt stage analysis via setagenesis (Tamone et al. 2005). The models presented here assume a terminal molt for both males and females, which is supported by research on populations in the Bering Sea and the Atlantic Ocean (e.g., Dawe, et al. 1991).

Male snow crabs that do not molt (old shell) may be important in reproduction. Paul et al. (1995) found that old shell mature male Tanner crab out-competed new shell crab of the same size in breeding in a laboratory study. Recently molted males did not breed even with no competition and may not breed until after $\sim 100$ days from molting (Paul et al. 1995). Sainte-Marie et al. (2002) stated that only old shell males take part in mating for North Atlantic snow crab. If molting precludes males from breeding for a three month period, then males that are new shell at the time of the survey (June to July), would have molted during the preceding spring (March to April), and would not have participated in mating. The fishery targets new shell males, resulting in those animals that molted to maturity and to a size acceptable to the fishery of being removed from the population before the chance to mate. However, new shell males will be a mixture of crab less than 1 year from terminal molt and $1+$ years from terminal molt due to the inaccuracy of shell condition as a measure of shell age.

Crabs in their first few years of life may molt more than once per year, however, the smallest crabs included in the model are approximately 3 to 4 years old and would be expected to molt annually. The growth transition matrix was applied to animals that molt, resulting in new shell animals. Crab that do not molt become old shell animals. Further research on the relationship between shell condition and time from last molt is needed.

## Mating ratio and reproductive success

Bering Sea snow crabs are managed using mature male biomass (MMB) as a proxy for reproductive potential. MMB is used as the currency for management because the fishery only retains male crabs. Male snow crabs are sperm conservers, using less than $4 \%$ of their sperm at each mating and females also will mate with more than one male. The amount of stored sperm and clutch fullness varies with sex ratio (Sainte-Marie 2002). If mating with only one male is inadequate to fertilize a full clutch, then females will need to mate with more than one male, necessitating a sex ratio closer to $1: 1$ in the mature population, than if one male is assumed to be able to adequately fertilize multiple females. Although mature male biomass is currently the currency of management, female biomass may also be an important indicator of reproductive potential of the stock.

Quantifying the reproductive potential of the female population from survey data can be less than straightforward. For example, full clutches of unfertilized eggs may be extruded and appear normal to visual examination, and may be retained for several weeks or months by snow crab. Resorption of eggs may occur if not all eggs are extruded resulting in less than a full clutch. Female snow crabs at the time of the survey may have a full clutch of eggs that are unfertilized, resulting in overestimation of reproductive potential. Barren females are a more obvious indication of low reproductive potential and increased in the early 1990s then decreased in the mid- 1990s then increased again in the late 1990s. The highest levels of barren females coincides with the peaks in catch and exploitation rates that occurred in 1992 and 1993 fishery seasons and the 1998 and 1999 fishery seasons. While the biomass of mature females was high in the early 1990s, it is possible the production may have been impacted by the spatial distribution of the catch and the resulting sex ratio in areas of highest reproductive potential. Biennial spawning is another confounding factor in determining the reproductive potential of snow crab. Laboratory analysis showed that female snow crab collected in waters colder than 1.5 degrees C from the Bering Sea spawn only every two years.

Further complicating the process of quantifying reproductive capacity, clutch fullness and fraction of unmated females may not account for the fraction of females that may have unfertilized eggs, since these cannot be detected by the naked eye at the time of the survey. The fraction of barren females observed in the survey may not be an accurate measure of fertilization success because females may retain unfertilized eggs for months after extrusion. To examine this hypothesis, RACE personnel sampled mature females from the Bering Sea in winter and held them in tanks until their eggs hatched in March of the same year (Rugolo et al. 2005). All females then extruded a new clutch of eggs in the absence of males. All eggs were retained until the crabs were sacrificed near the end of August. Approximately $20 \%$ of the females had full clutches of unfertilized eggs. The unfertilized eggs could not be distinguished from fertilized eggs by visual inspection at the time they were sacrificed. Indices of fertilized females based on the visual inspection method of assessing clutch fullness and percent unmated females may overestimate fertilized females and not an accurate index of reproductive success.

## Growth

Little information exists on growth for Bering Sea snow crab, though further analyses are underway. Tagging experiments were conducted on snow crab in 1980 with recoveries occurring in the Tanner crab (Chionoecetes bairdi) fishery in 1980 to 1982 (Mcbride 1982). However, data from this study are not used due to uncertainty about the effect of tagging on growth. Currently, 40 data points from 5 studies are used to estimate the post-molt length from pre-molt length for females and males (Table 4). The studies include:

1. Transit study (Rugolo unpublished data, 2003); 14 crab
2. Cooperative seasonality study (Rugolo); 6 crab
3. Dutch harbor holding study; 9 crab
4. NMFS Kodiak holding study held less than 30 days; 6 crab
5. NMFS Kodiak holding study 2016; 5 crab

Data from the NMFS Kodiak holding study 2016 are new for this year's study and up to 70 new observations will be available soon. In the "Transit study", pre- and post-molt measurements of 14 male crabs that molted soon after being captured were collected. The crabs were measured when shells were still soft because all
died after molting, so measurements may be underestimates of postmolt width (Rugolo, pers. com.). The holding studies include only data for crab held less than 30 days because growth of crabs held until the next spring's molting was much lower. Females molting to maturity were excluded from all data sets, since the molt increment is usually smaller. Crab missing more than two limbs were excluded due to other studies showing lower growth. Crab from Rugolo's seasonal study were excluded that were measured less than 3 days after molting due to difficulty in measuring soft crab accurately. In general, growth of snow crab in the Bering Sea appears to be greater than growth of some North Atlantic snow crab stocks (Sainte-Marie 1995).

## Management history

## ADFG harvest strategy

Before the year 2000, the Guideline Harvest Level (GHL) for retained crab only was a harvest rate $58 \%$ of the number of male crab over 101 mm CW estimated from the survey. The minimum legal size limit for snow crab is 78 mm , however, the snow crab market generally accepts animals greater than 101 mm . In 2000, due to the decline in abundance and the declaration of the stock as overfished, the harvest rate for calculation of the GHL was reduced to $20 \%$ of male crab over 101 mm . After 2000, a rebuilding strategy was developed based on simulations by Zheng (2002) using survey biomass estimates. The realized retained catch typically exceeded the GHL historically, resulting in exploitation rates for the retained catch on males $>101 \mathrm{~mm}$ ranging from about $10 \%$ to $80 \%$. The estimated exploitation rate for total catch divided by mature male biomass ranged from $5 \%$ to $52 \%$ for the chosen model in this assessment (Figure 6).

The harvest strategy since 2000 sets harvest rate based on estimated mature biomass. The harvest rate scales with the status of the population relative to $\mathrm{B}_{M S Y}$, which is calculated as the average total mature biomass at the time of the survey from 1983 to 1997 and MSST is one half $\mathrm{B}_{M S Y}$. The harvest rate begins at 0.10 when total mature biomass exceeded $50 \%$ MSST ( 230 million lbs) and increases linearly to 0.225 when biomass is equal to or greater than $\mathrm{B}_{M S Y}$ (Zheng et al. 2002).

$$
u= \begin{cases}\text { Bycatch } & \text { if } \frac{T M B}{T M B_{M S Y}} \leq 0.25  \tag{1}\\ \frac{0.225\left(\frac{T M B}{T M B_{M S Y}}-\alpha\right)}{1-\alpha} & \text { if } 0.25<\frac{T M B}{T M B_{M S Y}}<1 \\ 0.225 & \text { ifTMB>TMB }{ }_{M S Y}\end{cases}
$$

The maximum retained catch is set as the product of the exploitation rate, $u$, calculated from the above control rule and survey mature male biomass. If the retained catch in numbers is greater than $58 \%$ of the estimated number of new shell crabs greater than 101 mm plus $25 \%$ of the old shell crab greater than 101 mm , the catch is capped at $58 \%$.

## History of BMSY

Prior to adoption of Amendment 24, $\mathrm{B}_{M S Y}$ was defined as the average total mature biomass (males and females) estimated from the survey for the years 1983 to 1997 ( 921.6 million lbs; NPFMC 1998) and MSST was defined as $50 \%$ of $\mathrm{B}_{M S Y}$. Definitions of biological reference points based on the biomass over a range of years make a host of assumptions that may or may not be fulfilled. Currently, the biological reference point for biomass is calculated using a spawning biomass per recruit proxy, $\mathrm{B}_{35 \%}$ (Clark, 1993). $\mathrm{B}_{35 \%}$ is the biomass at which spawning biomass per recruit is $35 \%$ of unfished levels and has been shown to provide close to maximum sustainable yield for a range of steepnesses (Clark, 1993). Consequently, it is an often used target when a stock recruit relationship is unknown or unreliable.

## Fishery history

Snow crab were harvested in the Bering Sea by the Japanese from the 1960s until 1980 when the Magnuson Act prohibited foreign fishing. After the closure to foreign fleets, retained catches increased from relatively low levels in the early 1980 s (e.g. retained catch of 11.85 kt during 1982) to historical highs in the early and mid-nineties (retained catch during 1991, 1992, and 1998 were $143.02,104.68$, and 88.09 kt , respectively). The stock was declared overfished in 1999 at which time retained catches dropped to levels similar to the early 1980s (e.g. retained catch during 2000 was 11.46 kt ). Retained catches have slowly increased since 1999 as the stock rebuilt, although retained catch during 2016 was low ( 9.67 kt ).

Discard mortality is the next largest source of mortality after retained catch and approximately tracks the retained catch. The highest estimated discard mortality occurred during 1992 at 17.06 kt which was $16 \%$ of the retained catch. The most recent estimated mortality was 1.31 kt which was $14 \%$ of the retained catch.

Discard from the directed pot fishery has been estimated from observer data since 1992 and ranged from 11\% to $64 \%$ (average $33 \%$ ) of the retained catch of male crab biomass (Table 5). Female discard catch has been very low compared to male discard catch and has not been a significant source of mortality. Discard of snow crab in groundfish fisheries has been highest in the yellowfin sole trawl fishery, and decreases down through the flathead sole trawl fishery, Pacific cod bottom trawl fishery, rock sole trawl fishery, and the Pacific cod hook-and-line and pot fisheries, respectively (Figure 7). Bycatch in fisheries other than the groundfish trawl fishery has historically been relatively low, but in 2015 bycatch from sources other than the groundfish trawl fishery reached almost $\sim 25 \%$ of the reported bycatch. Size frequency data and catch per pot have been collected by observers on snow crab fishery vessels since 1992. Observer coverage has been $10 \%$ on catcher vessels larger than 125 ft (since 2001), and $100 \%$ coverage on catcher processors (since 1992).

Several modifications to pot gear have been introduced to reduce bycatch mortality. In the 1978/79 season, escape panels were introduced to pots used in the snow crab fishery to prevent ghost fishing. Escape panels consisted of an opening with one-half the perimeter of the tunnel eye laced with untreated cotton twine. The size of the cotton laced panel was increased in 1991 to at least 18 inches in length. No escape mechanisms for undersized crab were required until the 1997 season when at least one-third of one vertical surface of pots had to contain not less than 5 inches stretched mesh webbing or have no less than four circular rings of no less than $33 / 4$ inches inside diameter. In the 2001 season the escapement for undersize crab was increased to at least eight escape rings of no less than 4 inches placed within one mesh measurement from the bottom of the pot, with four escape rings on each side of the two sides of a four-sided pot, or one-half of one side of the pot must have a side panel composed of not less than $51 / 4$ inch stretched mesh webbing.

## D. Data

New time series of survey indices and size compositions were calculated from data downloaded from the AKFIN database. Bycatch data (biomass and size composition) were updated for the most recent year from the AKFIN database. Retained, total, and discarded catch (in numbers and biomass) and size composition data for each of these data sources were updated for the most recent year based on files provided by the State of Alaska.

## Catch data

Catch data and size composition of retained crab from the directed snow crab pot fishery from survey year 1978 to the 2016 were used in this analysis (Table 5). Size composition data on the total catch (retained plus discarded) in the directed crab fishery were available from survey year 1992 to 2016 . Total discarded catch was estimated from observer data from 1992 to 2016 (Table 1). The discarded male catch was estimated for survey year 1978 to 1991 in the model using the estimated fishery selectivities based on the observer data for the period of survey year 1992 to 2016. The discard catch estimate was multiplied by the assumed mortality of discards from the pot fishery. The mortality of discarded crab was $30 \%$ for all model scenarios. This
estimate differs from the currently used strategy (since 2001) to the present by ADFG to set the TAC, which assumes a discard mortality of $25 \%$ (Zheng, et al. 2002). The discards prior to 1992 may be underestimated due to the lack of escape mechanisms for undersized crab in the pots before 1997. See Table 3 for a summary of catch data.

Table 3: Data included in the assessment. Dates indicate survey year.

| Data component | Years |
| :--- | :---: |
| Retained male crab pot fishery size frequency by shell condition | $1978-2016$ |
| Discarded Males and female crab pot fishery size frequencey | $1992-2016$ |
| Trawl fishery bycatch size frequencies by sex | $1991-2016$ |
| Survey size frequencies by sex and shell condition | $1978-2017$ |
| Retained catch estimates | $1978-2016$ |
| Discard catch estimates from crab pot fishery | $1992-2016$ |
| Trawl bycatch estimates | $1973-2016$ |
| Total survey biomass estimates and coefficients of variation | $1978-2017$ |
| 2009 study area biomass estimates, CVs, and size frequencey for BSFRF and NMFS | 2009 |
| tows | 2010 |
| 2010 study area biomass estimates, CVs, and size frequencey for BSFRF and NMFS | 20 |

## Survey biomass and size composition data

Abundance was estimated from the annual eastern Bering Sea (EBS) bottom trawl survey conducted by NMFS (see Rugolo et al. 2003 for design and methods). Since 1988, the survey has sampled more stations than pre-1988 (compare Figure 8 to Figure 9)). In 1982 the survey net was changed resulting in a potential change in catchability. Consequently, survey selectivity has been historically modeled in three 'eras' in the assessment (1978-1981, 1982-1988, 1989-present, Figure 10). All survey data in this assessment used measured net widths instead of the fixed 50 ft net width based on Chilton et al.'s (2009) survey estimates. Carapace width and shell conditions were measured and reported for snow crab caught in the survey.

Mature biomass for males and females at the time of the survey were the primary indices of population size fit to in this assessment. Total survey numbers (Figure $11 \&$ Figure 12) were input to the model via the .DAT file, after which MMB and FMB at the time of the survey were calculated based on the size composition data, which were delineated by shell condition, maturity state, and sex. Distinguishing between mature and immature crab for the size composition was accomplished by demarcating any female that had eggs reported in the survey as 'mature'. Mature male size composition data were calculated by multiplying the total numbers at length for new shell male crab by a vector of observed proportion of mature males at length. The observed proportion of mature males at length was calculated by chelae height and therefore refers only to 'morphometrically' mature males. All old shell crab of both sexes were assumed to be mature. New shell crab were demarcated as any crab with shell condition index $<=2$. The biomass of new and old shell mature individuals was calculated by multiplying the vector of numbers at length by weight at length. These vectors were then summed by sex to provide the index to which the model was fit (Table 6). The size composition data were also fit within the assessment.

## Spatial distribution of survey abundance and catch

Spatial gradients exist in the survey data by maturity and size for both sexes. For example, larger males have been more prevalent on the south west portion of the shelf (Figure 4) while smaller males have been more prevalent on the north west portion of the shelf (Figure 1). Females have exhibited a similar pattern (compare Figure 2 to Figure 5). In addition to changing spatially over the size and shelf, distributions of crab
by size and maturity also changed temporally. The centroids of abundance in the summer survey moved over time (Figure $13 \&$ Figure 14). Centroids of mature female abundance early in the history of the survey were the farther south, but moved north during the 1990s. Since the late 1990s and early 2000s, the centroids moved south again, but not to the extent seen in the early 1980s. This phenomenon was mirrored in centroids of abundance for large males (Figure 14).

Centroids of the catch were generally south of 58.5 N , even when ice cover did not restrict the fishery moving farther north. This is possibly due to proximity to port and practical constraints of meeting delivery schedules. The majority of catch was taken west and north of the Pribilof Islands, but this rule has had exceptions.

The distribution of large males during the summer survey and the fishery catch are different. The origin of this difference is unknown. It is possible that crab move between the fishery and the survey, but it is also possible that fishers did not target the centroids of abundance. The underlying explanation of this phenomenon could hold implications for relative exploitation rates spatially and it has been suggested that high exploitation rates in the southern portion of the snow crab range may have resulted in a northward shift in snow crab distribution (Orensanz, 2004). Snow crab larvae likely drift north and east after hatching in spring. Snow crab appear to move south and west as they age (Parada et al., 2010), however, no tagging studies have been conducted to fully characterize the ontogenetic or annual migration patterns of this stock (Murphy et al. 2010).

## Experimental study of survey selectivity

The Bering Sea Fisheries Research Foundation (BSFRF) conducted a survey of 108 tows in 27 survey stations (hereafter referred to as the "study area") in the Bering Sea in summer 2009 (Figure 15). The BSFRF performed a similar study during 2010 in which the study area covered a larger portion of the distribution of snow crab than the 2009 study area. The mature biomass and size composition data gleaned from each of these experiments (and their complimentary NMFS survey observations; Figure 16 \& Figure 17) are incorporated into the model by fitting them as an extra survey that is linked to the NMFS survey through a shared selectivity (see appendix A for a description of the way in which the surveys are related in the assessment model). Abundances estimated by the industry surveys were generally higher than the NMFS estimates, which provides evidence that the catchability of the NMFS survey gear is less than 1. Larger females are an exceptions to this observation, but this difference may be due to different towing locations for the two nets within the study area, or to variable catchability of females due to aggregation behavior.

## E. Analytic approach

## History of modeling approaches for the stock

Historically, survey estimates of large males ( $>101 \mathrm{~mm}$ ) were the basis for calculating the Guideline Harvest Level (GHL) for retained catch. A harvest strategy was developed using a simulation model that pre-dated the current stock assessment model (Zheng et al. 2002). This model has been used to set the GHL (renamed total allowable catch, 'TAC' since 2009) by Alaska Department of Fish and Game (ADFG) since the 2000/2001 fishery. Currently, NMFS uses an integrated size-structured assessment to calculate the overfishing level (OFL), which constrains the ADFG harvest strategy.

## Model description

The integrated size-structured model used by NMFS (and presented here) was developed following Fournier and Archibald's (1982) methods, with many similarities to Methot (1990). The model was implemented using automatic differentiation software developed as a set of libraries under $\mathrm{C}++$ (ADModel Builder). ADModel

Builder can estimate a large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries.

The snow crab population dynamics model tracked the number of crab of sex $s$, shell condition $v$, maturity state $m$, during year $y$ at length $l, \mathrm{~N}_{s, v, m, y, l}$. A terminal molt was modeled in which crab move from an immature to a mature state, after which no further molting occurred. The mid-points of the size bins tracked in the model spanned from 27.5 to 132.5 mm carapace width, with 5 mm size classes. For the base assessment (M16 D17), 338 parameters were estimated. Parameters estimated within the assessment included those associated with the population processes recruitment, growth, natural mortality (subject to a fairly informative prior), fishing mortality, selectivity (fishery and survey), catchability, and maturity (also sometimes subject to a prior; see Table $7 \&$ Table 8 ). Molting probability, weight at length, discard mortality, bycatch mortality, and parameters associated with the variance in growth and proportion of recruitment allocated to size bin were estimated outside of the model or specified. See appendix A for a complete description of the population dynamics.
In its current formulation, a gap in observations of premolt sizes from $\sim 25$ to $\sim 35 \mathrm{~mm}$ carapace width impedes estimation of the change point in the growth function. This data gap results in unstable behavior of the model. In the past a 'jittering' approach was explored in order to find the parameter vector that produced the smallest negative log likelihood (Turnock, 2016). A jittering approach was implemented here by running each model to produce a .PAR file, then creating 100 replicates of a .PIN file using that .PAR file. Each .PIN file consisted of the values in the .PAR file multiplied by a random normal error term with a mean of 1 and a standard deviations of 0.1 . Each of the .PIN files were used as starting values to run the model and the output was stored and compared among model scenarios.
Samples were also drawn from the posterior distributions of estimated parameters and derived quantities used in management (e.g. MMB and OFL) via MCMC. This involved conducting 2,000,000 cycles of the MCMC algorithm, implementing a $5 \%$ burn-in period, and saving every 500th draw. Chains were then thinned until diagnostic statistics (e.g. Geweke statistics and autocorrelation) demonstrated a lack of evidence of non-convergence (if possible).

## Model selection and evaluation

Models were evaluated based on their fit to the data (Table 9), the credibility of the estimated population processes, stability of the model (Figure 18, Figure 19, Figure 20), and the strength of the influence of the assumptions of the model on the outcomes of the assessment. Maximum likelihood estimates of parameters can be seen in Table 8 and their posterior distributions can be seen in Figure 21, Figure 22, Figure 23, and Figure 24.

## Results

Several of the models exhibited unstable behavior when undergoing 'jittering' (Figure 18). Models appeared to 'converge' (i.e. small gradients) over a wide range of likelihood values and derived management quantities exhibited bimodality. This bimodality can be linked to the interaction of the change point in the growth model with a fixed natural mortality for females, because when natural mortality for mature females is estimated (M17C.D17a), the bimodality disappears (Figure 18). In addition to jittering, MCMC was performed for all models. Models in which the two smallest length bins were removed and the growth curve was estimated without a change point did not have stationary traces of the objective function (i.e. they did not converge (Figure 19) and most parameters were poorly behaved (Figure 20)). Below, the results for seven models are described. Only the total likelihoods for M16.D17, M17A.D17a, and M17Aa.D17a are directly comparable because they have the same data and weighting schemes. Individual likelihood components can be compared among models with the understanding that changing the weighting or data for one likelihood component influences others.

## Fits to data

## Survey biomass data

Fits to the survey mature male biomass were visually similar for all models for the majority of years in the the time series (Figure 25), yet model M17C.D17a fit the survey biomass better than other models according to the likelihoods (Table 9). Estimates of survey MMB in the final year ranged from 101.5 to 109.8 kt . All models overestimated the final year of survey MMB (83.9572 kt).

Fits to the survey mature female biomass were also similar for all models, particularly in recent years (Figure 25). Models in which natural mortality for mature females was estimated (M17C.D17a \& M17BC.D17a) fit the mature female biomass better than others in the earlier years. Estimates of survey MFB in the final year ranged from 131.9 to 143.7 kt . All models overestimated the final year of survey MFB (106.847 kt).

## Growth data

All models provided adequate fits to the female and male growth data, but model M17C.D17a returned the lowest likelihood for the male data and the second lowest for female (Figure 26).

## Catch data

Retained catch data were fit by all models well, with no little discernible differences among models (Figure 27). Female discard data were fit adequately given the specified uncertainty (Figure $27 \&$ (Table 9)). Male discard data during the period for which data exist (early 1990s to the present) were well fit by every model with little discernible difference (Figure 27 ). M17C.D17a returned a significantly lower likelihood for male discard data (Table 9). Fits to the trawl data were adequate for all models given the uncertainty in the data (Figure 27). Fits to the fishery CPUE data were poor for all models, but vaguely reflected the trends in observed cpue (Figure 28).

## Size composition data

Retained catch size composition data were fit well by all models (Figure 29); trawl size composition data were generally well fit, with several exceptions. All models performed similarly in fitting the trawl size composition data (Figure $30 \&$ Table 9).

Fits to the size composition data for the BSFRF data were qualitatively similar for all models (Figure $31 \&$ (Table 9)). The number of males was underestimated by the industry survey in 2009 and overestimated by the NMFS survey, while the opposite pattern was seen for females. Fits to the 2010 survey size composition data were better than the 2009 fits. Fits to female survey composition data were similar for all models in most years, although fits for the models in which lower length bins were excluded depart from the other models in some years (Figure 32). Similar patterns in fits among models can be seen for the male survey composition data (Figure 33). The distribution of residuals for male and female survey composition data for the chosen model varied by sex. Female and male size composition data from the survey sum to 1 in a given year and females tended to be overestimated (Figure 34), whereas males tended to be underestimated (Figure 35).

## Estimated population processes and derived quantities

The fits to the data were similar for all models, but the credibility of the estimated population processes varied. Estimates of mature male biomass at the time of mating varied by $6-44 \%$ among models over the history of the fishery. Projected MMB for 2017 ranged from 95.88 to 123.74 kt . Estimated mature female biomass at the time of mating varied by $6-35 \%$ over the length of the time series among models. Projected FMB for 2017 ranged from 125.7 to 189.9 kt (Figure 36). In general, estimated fishing mortality in the recent
past has been well below $\mathrm{F}_{35 \%}$, save the years 2012-2014, which were close to $\mathrm{F}_{35 \%}$. Estimated MMB has been less than $\mathrm{B}_{35 \%}$ since 2010, but never below MSST (Figure 37).

Estimates of selectivity and catchability varied widely among models (Figure 38). For models that estimated selectivity parameters in era 1 (only 2 models), catchability for males and females was essentially 1 with very narrow posteriors (Figure 22). Size at $50 \%$ selection in the survey gear during era 1 ranged from $\sim 40 \mathrm{~mm}$ to $\sim 46 \mathrm{~mm}$ for both females and males (Figure $22 \&$ Figure 23). All models estimated selectivity parameters for era 2 , and removing the 'anchor' of the survey data in era 1 resulted in lower estimated of catchability for males (e.g. 0.49 to $0.33-0.44$ ) and higher estimated catchability for females (e.g. from 0.32 to 0.38-0.52; Figure 23). Size at $50 \%$ selection in the survey gear ranged from $\sim 39 \mathrm{~mm}$ to $\sim 41 \mathrm{~mm}$ for both females and males (Figure 22 \& Figure 23). Estimated catchability for males during survey era 3 ranged from 0.52 to 0.7 ; estimated female catchability increased from 0.61 to $0.64-0.72$. Size at $50 \%$ selection in the survey gear ranged from 31 mm to 35 mm for females and 35 mm to 37 mm for males (Figure 22 \& Figure 23). BSFRF 'availability' curves varied widely from 2009 to 2010 and among models, with the availability of crab to the experimental survey generally increasing in 2010 (Figure 39).

The probability of maturing by size was fairly consistent among scenarios for both males and females, except the scenarios in which the first two length bins were removed. Aside from these two models, the probability of maturing by size for female crab was $\sim 50 \%$ at $\sim 47.5 \mathrm{~mm}$ and increased to $100 \%$ at $\sim 60 \mathrm{~mm}$ (Figure 40); the probability of maturing for male crab was $\sim 15 \%$ to $20 \%$ at $\sim 60 \mathrm{~mm}$ to 90 mm and increased sharply to $50 \%$ at $\sim 97.5 \mathrm{~mm}$, and $100 \%$ at 107.5 mm . The probability of maturity was unreasonably high for smaller length bins when the two smallest length bins were removed.

Estimated fishing mortality in the directed fishery was similar for all models (Figure 41). Total and retained fishery selectivity was very similar for all models because of the weight put on the retained catch and its associated size composition data (Figure 41). Estimated size at $50 \%$ selection in the trawl fishery varied more than selectivity in the directed fishery, ranging from 109-120 mm (Figure 41). Size at $50 \%$ selection for discarded females was similar for all models (Figure 41). See Figure 21 and Figure 22 for posterior densities for all parameters related to mortality in the different fisheries.

Patterns in recruitment were similar for all models. A period of high recruitment was observed in which 3 large cohorts passed through the population during the 1980s and into the early 1990s. Following that, a period of low recruitment persisted from the early 1990s to 2013 All models indicated a large recruitment to the survey gear occurred in the last few years (Figure 42). Recruitment entering the model was placed primarily in the first three size bins (Figure 42). Stock recruitment relationships were not apparent between the estimates of MMB and recruitment for any model (Figure 42). Relationships were not apparent between mature female biomass and recruitment either. Estimated multipliers for natural mortality ranged from 1.23 to 1.89 for immature crab, 1.06 to 1.123 for mature male crab, and 1 to 1.97 for mature females (Table 8).

## F. Calculation of the OFL

## Methodology for OFL

The OFL was calculated using proxies for biomass and fishing mortality reference points and a sloped control rule. Proxies for biomass and fishing mortality reference points were calculated using spawner-per-recruit methods (e.g. Clark, 1991). After fitting the assessment model to the data and estimating population parameters, the model was projected forward 100 years using the estimated parameters under no exploitation to determine 'unfished' mature male biomass-per-recruit. Projections were repeated in which the bisection method was used to identify a fishing mortality that reduced the mature male biomass-per-recruit to $35 \%$ of the unfished level (i.e. $\mathrm{F}_{35 \%}$ and $\mathrm{B}_{35 \%}$ ). Calculations of $\mathrm{F}_{35 \%}$ were made under the assumption that bycatch fishing mortality was equal to the estimated average value.

Calculated values of $\mathrm{F}_{35 \%}$ and $\mathrm{B}_{35 \%}$ were used in conjunction with a control rule to adjust the proportion of $\mathrm{F}_{35 \%}$ that is applied based on the status of the population relative to $\mathrm{B}_{35 \%}$ (Amendment 24, NMFS).

$$
F_{O F L}= \begin{cases}\text { Bycatch } & \text { if } \frac{M M B}{M M B_{35}} \leq 0.25  \tag{2}\\ \frac{F_{35}\left(\frac{M M B}{M M B_{35}}-\alpha\right)}{1-\alpha} & \text { if } 0.25<\frac{M M B}{M M B_{35}}<1 \\ F_{35} & \text { if } M M B>M M B_{35}\end{cases}
$$

Where MMB is the projected mature male biomass in the current survey year after fishing at the $\mathrm{F}_{\text {OFL }}$, $\mathrm{MMB}_{35 \%}$ is the mature male biomass at the time of mating resulting from fishing at $\mathrm{F}_{35 \%}, \mathrm{~F}_{35 \%}$ is the fishing mortality that reduces the mature male biomass per recruit to $35 \%$ of unfished levels, and $\alpha$ determines the slope of the descending limb of the harvest control rule (set to 0.1 here).

Previously, reference points and the OFL were calculated by fitting the model to the data, then transferring the estimated parameters to a script with a projection model in which all parameters were assumed known. The projection script began in the final year of the assessment period and was initiated by pasting the numbers at length from the report file of the assessment into a data file read in by the projection script. Reference points were calculated by projecting the population into the future under no fishing mortality (to find virgin biomass) and a fishing mortality was solved for that reduced the mature male biomass-per-recruit to $35 \%$ of virgin levels. The process was repeated to find the OFL, but, to allow for some uncertainty in the calculation, lognormal error was added to the initial numbers at length (i.e. those in the final year of assessment) and the $\mathrm{F}_{\text {OFL }}$ was calculated based on the harvest control rule outlined above. Many simulations with different lognormal errors were carried out to develop a distribution of the OFL which was then used to determine an ABC .

The previously used projection method does not propagate the uncertainty in all parameters forward, so a Bayesian methodology was included for this iteration of the assessment to more fully represent the uncertainty associated with model estimates of quantities used in management. In the Bayesian implementation of this assessment model, none of the equations changed (other than in the ways requested by the CPT), but distributions for the $\mathrm{OFL}, \mathrm{MMB}, \mathrm{B}_{35 \%}$, and $\mathrm{F}_{35 \%}$ were developed by sampling from the posterior distributions of these quantities via a Markov Chain Monte Carlo algorithm built into ADMB. Accomplishing this required building in functions to calculate reference points and extra storage space (see functions 'get_fut_mortality', 'find_OFL', 'find_F35' in the .TPL on github).

## Calculated OFLs and interpretation

Medians of the posterior densities of the OFLs calculated for the suite presented models ranged from 23.91 to 35.3 kt (Figure $43 \&$ Table 10). Differences in OFLs were a result of differences in estimated MMB (see above), calculated $\mathrm{B}_{35 \%}$ (which ranged from 134.18 to 157.14 kt ), Figure 43 ), $\mathrm{F}_{35 \%}$ (which ranged from 1.31 to $1.96 \mathrm{yr}^{-1}$, Figure 43), and $\mathrm{F}_{\text {OFL }}$ (which ranged from 0.89 to $1.33 \mathrm{yr}^{-1}$, Figure 43).

## G. Calculation of the ABC

The acceptable biological catch (ABC) was set by subtracting a $10 \%$ buffer from the OFL to account for scientific uncertainty, which was recommended by the SSC.

## Author recommendations

Models in which the lower two length bins were removed were eliminated from consideration because they did not provide credible estimates of survey selectivity and the probability of maturing. It appears low numbers of small crab in small length bins combined with a constant natural mortality informs catchability and survey selectivity. Once survey selectivity is estimated conditional upon the paucity of observations of small crab, the probability of maturing can be estimated to fit the observed mature male biomass. Consequently, efforts should be made to fill the holes in the data in this range, rather than excluding smaller length bins.

The small changes introduced to the model should all be adopted. Excluding the first survey era is advisable because it provided an artificial anchor to survey catchability, the influence of which stretched across eras. Little is known about catchability in the first era and an estimated catchability of 1 in that era is counterintuitive given the smaller size of the surveyed area. Changing the timing of the second survey era needed to be implemented because the current number of sampled stations began in 1988, not 1989. Finally, changing the BSFRF selectivities to logit space needed to be implemented because some of these parameters were consistently hitting their bounds.

Each of the CPT-recommended small changes resulted in small changes to the model output, but, even with these changes, the bimodality and instability in management quantities persisted. Estimating natural mortality for mature females removed this instability and returned an intuitive relationship between the natural mortalities of mature males and females. The bimodality in the MLEs and derived management quantities appeared originally because the change point in growth flips from one state to another and natural mortality for mature females was fixed. When mature female natural mortality is estimated, the confounded processes of growth and natural mortality can 'accommodate' one another and avoid the sharp bimodality. The largest departure from earlier models brought by estimating natural mortality for mature female was a large increase in survey catchability, but this is somewhat consistent with the BSFRF studies which generall showed higher catchability for females than males (perhaps due to aggregation behavior).
For these reasons, the authors' selected model is M17C D17a. It incorporates all the small changes suggested by the CPT, estimates natural mortality for all sex/maturity state combinations, and returns credible estimates for all population processes.

## H. Data gaps and research priorities

## Data sources

If a Bayesian paradigm is used to provide management advice, as many raw data sources as possible should be included in the assessment. Estimating parameters outside of the model and inputting them as 'known' artificially decreases the uncertainty represented in the posteriors of management quantities. Weight at length data, data used to develop priors for natural mortality and maturity, and the selectivities calculated from the BSFRF data should be considered for inclusion in the model to comprehensively represent the uncertainty in management quantities. In addition to pulling as much data into the model as possible, standardizing and automating the creation of data files from the survey and catch databases would be very useful given the short time frame of the assessment cycle.

Although estimating natural mortality for mature females eliminated the bimodality in management quantities, jittering still revealed considerable instability in the model. Additional growth data in the size bins for which pre-molt observations are absent would likely improve the stability of the model. Dr. Foy from the Kodiak lab has provided these data, but not in time for inclusion in this assessment.

## Modeling and weighting

Different weighting of likelihood components can have drastic impacts on the management advice provided from an assessment. A close look at the way CVs, sample sizes, and other weighting factors are calculated and their influence on assessment results could provide better understanding of how well the model is balanced. Standardization of the weighting schemes would also improve readability of the code (for example, some size composition data have both 'weights' and 'sample sizes').

Establishing a system for deciding to use Bayesian methods versus maximum likelihood methods would be useful given the amount of time required to perform both jittering and MCMC. If Bayesian methods are to be the mainstay of this assessment, priors for all parameters and the space in which parameters are estimated should be carefully considered. Additionally, moving to a designation of the ABC based on the posterior (similar to the p-star methods) rather than a flat percentage buffer would represent the uncertainty in the data better.

## Scientific uncertainty

Natural mortality exerts a large influence over estimated management quantities, but is poorly known. Tagging studies targeted at estimating natural mortality could be very useful and could also shed light on the migration patterns, which could help us understand the impact of the fishery (e.g. centroids of large male abundance in the survey and catch do not match-is this because the crab are moving or because the fishery operates in a specific place? The answer to this question could influence priors on catchability.) Similarly, establishing measures of reproductive capacity that include females, the spatial overlap of mature individuals, the role water temperature plays in biennial spawning, and the effectiveness of mating by size for males may allow for relationships between recruitment and mature biomass to be found (e.g. Murphy et al. 2017). In general, exploring the spatial dynamics of the population may allow for patterns and influences of the fishery and environment on the productivity of the stock to be more easily identified. Previous analyses suggest that retrospective biases may be a problem for the snow crab assessment (Szuwalski and Turnock, 2016). Retrospective biases can result from unaccounted for time-varying processes in the population dynamics of the model (Hurtado et al., 2015) and the retrospective bias in MMB for snow crab appears to result from an anomalously large estimate of survey MMB in 2014. This was likely caused by a change in catchability for that year and focused research on potential time-variation in important population processes for snow crab should be pursued to confront retrospective biases.

## Style

Although the code has been trimmed considerably over the last two years, legacy code and unused variables still exist within the assessment. Streamlining the code makes it more readable and reduces the probability of bugs. Most constants were migrated from the .TPL to the .CTL file, but parameter bounds have not yet been moved. Adjusting the manner in which output files are opened when evaluating MCMC output should also be implemented to avoid overwriting output files. A move to GMACs in 2018 will obviate the need for these corrections, however.

## I. Ecosystem Considerations

Recruitment for snow crab can be divided into two periods via regime shift algorithms (e.g. Rodionov, 2004). The shift in recruitment corresponds with a change in the Pacific Decadal Oscillation (Szuwalski and Punt, 2013), but also with a period of intense fishing mortality. Regime-based management strategies have been evaluated for snow crab, but found that only small improvements in long-term yield are derived from changing the target reference points based on a change point algorithm and those changes come at a higher risk of overfishing (Szuwalski and Punt, 2012). Given the uncertainty around whether or not the environment or
the fishery precipitated changes in recruitment, the precautionary principle guides managers to assume it is the fishery. Spatial analyses of recruitment, mature biomass, environmental drivers, and the impact of the fishery may provide insight to the population dynamics of snow crab, but modeling techniques capable of fully-spatial stock assessment are only recently feasible. The most recent large recruitment events will likely divide the recruitment time series into three periods and present an intriguing opportunity for further study of the relationship between environmental variables and recruitment success.

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## Appendix A: Model structure

## Population dynamics

Numbers of sex $s$ of shell condition $v$ and maturity state $m$ at length $l$ in the initial year of the assessment, $\mathrm{N}_{s, v, m, y=1, l}$, were calculated from an estimated vector of numbers at length $l$ by sex $s$ and maturity state $m$ for males, $\lambda_{s, m, l}$ and numbers at length $l$ by sex $s$ and shell condition $v$ for females (i.e. 2 vectors for each sex were estimated). Estimated vectors of initial numbers at length by maturity for females were calculated by splitting the estimated vectors at length by the observed proportion mature in the first year of the survey.

$$
N_{s, v, m, y=1, l}= \begin{cases}\Omega_{s, l}^{o b s} \lambda_{s, 1, l} & \text { if } \mathrm{v}=\text { new; } \mathrm{m}=\mathrm{mat}, \mathrm{~s}=\text { fem }  \tag{3}\\ 1-\Omega_{s, l}^{o b s} \lambda_{s, 1, l} & \text { if } \mathrm{v}=\text { new; } \mathrm{m}=\text { imat }, \mathrm{s}=\mathrm{fem} \\ \lambda_{s, 2, l} & \text { if } \mathrm{v}=\text { old; } \mathrm{m}=\mathrm{mat}, \mathrm{~s}=\mathrm{fem} \\ 0 & \text { if } \mathrm{v}=\text { old } ; \mathrm{m}=\text { imat }\end{cases}
$$

Initial numbers at length for males were all assumed to be new shell.

$$
N_{s, v, m, y=1, l}= \begin{cases}\lambda_{s, 1, l} & \text { if } \mathrm{v}=\mathrm{new} ; \mathrm{m}=\mathrm{mat}, \mathrm{~s}=\text { male }  \tag{4}\\ \lambda_{s, 2, l} & \text { if } \mathrm{v}=\mathrm{new} ; \mathrm{m}=\text { imat }, \mathrm{s}=\text { male } \\ 0 & \text { if } \mathrm{v}=\mathrm{old} ; \mathrm{m}=\mathrm{mat}, \mathrm{~s}=\text { male } \\ 0 & \text { if } \mathrm{v}=\mathrm{old} ; \mathrm{m}=\text { imat, } \mathrm{s}=\text { male }\end{cases}
$$

The dynamics after the initial year were described by:

$$
N_{s, v, m, y+1, l}= \begin{cases}\Omega_{s, l} \kappa_{s, l^{\prime}} Q_{s, i m a t, y, l^{\prime}} X_{s, l^{\prime}, l} & \text { if } \mathrm{v}=\mathrm{new} ; \mathrm{m}=\mathrm{mat}  \tag{5}\\ 1-\Omega_{s, l} \kappa_{s, l^{\prime}} Q_{s, i m a t, y, l^{\prime}} X_{s, l^{\prime}, l}+\operatorname{Rec}_{y}^{\epsilon} \operatorname{Pr}_{l} & \text { if } \mathrm{v}=\mathrm{new} ; \mathrm{m}=\mathrm{imat} \\ Q_{s, m a t, y, l^{\prime}} & \text { if } \mathrm{v}=\mathrm{old} ; \mathrm{m}=\mathrm{mat} \\ \left(1-\kappa_{s, l^{\prime}}\right) Q_{s, i m a t, y, l^{\prime}} & \text { if } \mathrm{v}=\mathrm{old} ; \mathrm{m}=\mathrm{imat}\end{cases}
$$

Where $\Omega_{s, l}$ was the probability of maturing at length $l$ for sex $s$ (a freely estimated vector for both males and females constrained by penalties on smoothness and a prior in some scenarios), $\kappa_{s, l^{\prime}}$ was the probability of molting for an immature crab of sex $s$ at length $l^{\prime}$ (set to 1 for all immature crab), and $\mathrm{X}_{s, l, l}$, was the size transition matrix describing the probability of transitioning from size $l$ ' to size $l$ for sex $s$. $\mathrm{Q}_{s, m, y, l}$, was the number of crab of sex $s$, maturity state $m$, and length $l$ ' surviving natural and fishing mortality during year $y$ :

$$
\begin{equation*}
Q_{s, m, y, l}=\sum_{v} N_{s, v, m, y, l} e^{Z_{s, v, m, y, l}} \tag{6}
\end{equation*}
$$

Where $\mathrm{N}_{s, v, m, y, l}$ represented the numbers, $N$, of sex $s$ during year $y$ of shell condition $v$ and maturity state $m$ at length $l$. $\mathrm{Z}_{x, v, m, y, l}$ represented the total mortality experienced by the population and consisted of the sum of instantaneous rates of natural mortality by sex and maturity state, $\mathrm{M}_{s, m}$, and fishing mortality, $\mathrm{F}_{s, f, y, l}$ from each fishery. Each fishing mortality was subject to selectivity by length $l$, which varied between sexes $s$ and fisheries $f$ (and by year $y$ if specified). $\mathrm{M}_{s, m}$ was specified in the model and a multiplier $\gamma_{n a t M, m}$
was estimated subject to constraints (see Table 7; this formulation effectively specified a mean and standard deviation for a prior distribution for M$)$.

$$
\begin{equation*}
Z_{s, v, m, y, l}=\gamma_{n a t M, m} M_{s, m}+\sum_{f} S_{s, f, y, l} F_{s, f, y, l} \tag{7}
\end{equation*}
$$

Selectivities in the directed and bycatch fisheries were estimated logistic functions of size. Different selectivity parameters were estimated for females and males in the directed fisheries ( $\mathrm{S}_{f e m, d i r, l}$ and $\mathrm{S}_{\text {male,dir,l}}$, respectively), a single selectivity for both sexes was estimated for bycatch in the groundfish trawl fishery ( $\mathrm{S}_{\text {trawl, } l}$ ), and a retention selectivity was estimated for the directed fishery for males ( $\mathrm{R}_{d i r, l}$; all females were discarded).

$$
\begin{align*}
S_{\text {male }, \text { dir }, l} & \left.=\frac{1}{\left.1+e^{-S_{\text {slope }, m, d}\left(L_{l}-S_{50, m, d}\right.}\right)}\right)  \tag{8}\\
S_{\text {fem }, \text { dir }, l} & \left.=\frac{1}{1+e^{-S_{\text {slope }, f, d}\left(L_{l}-S_{50, f, d}\right.}}\right)  \tag{9}\\
S_{\text {trawl }, l} & =\frac{1}{\left.1+e^{-S_{\text {slope }, t}\left(L_{l}-S_{50, t}\right.}\right)}  \tag{10}\\
R_{\text {dir }, l} & \left.=\frac{1}{1+e^{-S_{\text {slope }, m, d}\left(L_{l}-S_{50, m, d}\right.}}\right) \tag{11}
\end{align*}
$$

Where $\mathrm{S}_{\text {slope, s,f }}$ was the slope of the logistic curve for sex $s$ in fishery $f$ and $\mathrm{S}_{50, s, f}$ was the length at $50 \%$ selection for sex $s$ in fishery $f$. Catches for all fisheries were modeled as pulse fisheries in which all catch was removed instantaneously (i.e. no natural mortality occurred during the fishery). Catch in fishery $f$ during year $y$ was calculated as the fraction of the total fishing mortality, $\mathrm{F}_{s, f, y, l}$, applied to a given sex $s$ in a fishery $f$ times the biomass removed by all fisheries for that sex.

$$
\begin{align*}
& C_{m a l e, d i r, y}=\sum_{l} \sum_{v} \sum_{m} w_{m a l e, l} \frac{R_{l} F_{\text {male }, \text { dir }, y, l}}{F_{\text {male }, \text { dir }, y, l+F_{\text {trawl }, y, l}}} N_{\text {male }, v, m, y, l} e^{-\delta_{y} M_{s, m}}\left(1-e^{-\left(F_{\text {male }, \text { dir }, y, l}+F_{\text {trawl }, y, l)}\right)}\right.  \tag{12}\\
& C_{\text {male }, \text { tot }, y}=\sum_{l} \sum_{v} \sum_{m} w_{\text {male }, l} \frac{F_{\text {male }, \text { dir }, y, l}}{F_{\text {male }, d i r, y, l+F_{\text {trawl }, y, l}}} N_{\text {male }, v, m, y, l} e^{-\delta_{y} M_{s, m}}\left(1-e^{-\left(F_{\text {male }, \text { dir }, y, l}+F_{\text {trawl }, y, l}\right)}\right)  \tag{13}\\
& C_{f e m, d i r, y}=\sum_{l} \sum_{v} \sum_{m} w_{f e m, l} \frac{F_{f e m, d i r, y, l}}{F_{f e m, d i r, y, l+F_{t r a w l, y, l}}} N_{f e m, v, m, y, l} e^{-\delta_{y} M_{s, m}}\left(1-e^{-\left(F_{f e m, d i r, y, l}+F_{t r a w l, y, l}\right)}\right)  \tag{14}\\
& C_{m+f, t r a w l, y}=\sum_{s} \sum_{l} \sum_{v} \sum_{m} w_{s, l} N_{s, v, m, y, l} e^{-\delta_{y} M_{s, m}}\left(1-e^{-\left(F_{\text {trawl }, y, l}\right)}\right) \tag{15}
\end{align*}
$$

Where $\delta_{y}$ was the mid point of the fishery (all fisheries were assumed to occur concurrently and the midpoint was based on the directed fishery, which accounts for the vast majority of the fishing mortality) and $\mathrm{w}_{s, l}$ was the weight at length $l$ for sex $s$. Trawl data and discard data were entered into the model with an assumed mortality of $80 \%$ and $30 \%$, respectively. Fully-selected fishing mortality parameters for fishery $f$ were estimated as a logged average over a given time period ( $F_{a v g}^{l o g}$ ) with yearly deviations around that mean $\left(F_{d e v, y}^{l o g}\right)$.

$$
\begin{equation*}
F_{f, y}=e^{\left(F_{a v g, f}^{l o g}+F_{d e v, f, y}^{l o g}\right)} \tag{16}
\end{equation*}
$$

Selectivity for the survey was estimated for 3 eras in the base model: 1978-1981, 1982-1988, and 1989-present. Selectivity was assumed to be logistic and separate parameters representing the length at which selection
probability equal $50 \%$ and $95 \%$ ( $\mathrm{s}_{50, s, e}$ and $\mathrm{s}_{95, s, e}$, respectively) were estimated for males and females in the third era (1989-present). Separate catchability coefficients ( $\mathrm{q}_{s, e}$ ) were estimated for males and females in all eras.

$$
\begin{equation*}
\left.S_{s u r v, s, l, e}=\frac{q_{s, e}}{1+e^{-\log (19) \frac{L_{l}-s_{50, s, e}}{s_{95, s, e}-s_{50, s, e}}}}\right) \tag{17}
\end{equation*}
$$

Survey selectivity was informed by experimental surveys during the years 2009 and 2010. A portion of the NMFS summer survey tows were accompanied by an industry vessel using nephrops trawls with an assumed selectivity of 1 for all size classes. To represent the proportion of the population covered by the experiment, a vector was freely estimated for males, $S_{y}^{\text {freee }}$ (subject to a scaling parameter), and a logistic curve was estimated for females.

$$
S_{i n d, s, l, y}= \begin{cases}\frac{q_{\text {ind }, s, y}}{\left.1+e^{-\log (19) \frac{L_{l}-s_{50, s, y}}{s_{95, s, y}-s_{50, s, y}}}\right)} & \text { if s }=\text { female }  \tag{18}\\ q_{\text {ind }, s, y} S_{y}^{f r e e} & \text { if s = male }\end{cases}
$$

Based on this logic, after identifying the fraction of the crab at length covered by the experimental surveys, the length frequencies of the NMFS data collected simultaneously with the experimental trawls can be calculated by multiplying the numbers at length 'available' to the experimental trawls by the overall survey selectivity, $\mathrm{S}_{\text {surv,s,l,y}}$. The predicted numbers at length for the NMFS and industry data from the selectivity experiment were calculated by multiplying the respective selectivities by the survey numbers at length.

$$
\begin{equation*}
S_{n m f s, s, l, y}=S_{i n d, s, l, y} S_{s u r v, s, l, y} \tag{19}
\end{equation*}
$$

Mature male and female biomass (MMB and FMB, respectively) were fitted in the objective function and were the product of mature numbers at length during year $y$ and the weight at length, $\mathrm{w}_{s, l}$ :

$$
\begin{align*}
M M B_{y} & =\sum_{l, v} w_{\text {male }, l} N_{\text {male }, v, m a t, y, l}  \tag{20}\\
F M B_{y} & =\sum_{l, v} w_{f e m, l} N_{f e m, v, m a t, y, l}  \tag{21}\\
w_{s, l} & =\alpha_{w t, s} L_{l}^{\beta_{w t, s}} \tag{22}
\end{align*}
$$

Mature biomass can be calculated for different time through out the year, in which case the numbers at length are decremented by the estimated natural mortality. Parameters $\alpha_{w t, s}$ and $\beta_{w t, s}$ were estimated outside of the assessment model and specified in the control file.
Molting and growth occur before the survey. Immature crab were assumed to molt every year with an estimated probability of molting to maturity based on length $l$ (in all the scenarios presented here, the probability of molting was 1 for all immature animals). For crab that do molt, the growth increment within the size-transition matrix, $\mathrm{X}_{s, l, l}$, was based on a piece-wise linear relationship between predicted pre- and post-molt length, ( $\hat{L}_{s, l}^{p r e d}$ and $\hat{L}_{s, l}^{\text {post }}$, respectively) and the variability around that relationship was characterized by a discretized and renormalized gamma function, $\mathrm{Y}_{s, l, l}$.

$$
\begin{gather*}
X_{s, l, l^{\prime}}=\frac{Y_{s, l, l^{\prime}}}{\sum_{l^{\prime}} Y_{s, l, l^{\prime}}}  \tag{23}\\
Y_{s, l, l^{\prime}}=\left(\Delta_{l, l^{\prime}}\right)^{\frac{L_{s, l}-\left(\bar{L}_{l}-2.5\right)}{\beta_{s}}} \tag{24}
\end{gather*}
$$

$$
\begin{gather*}
\hat{L}_{s, l}^{p o s t, 1}=\alpha_{s}+\beta_{s, 1} L_{l}  \tag{25}\\
\hat{L}_{s, l}^{p o s t, 2}=\alpha_{s}+\delta_{s}\left(\beta_{s, 1}-\beta_{s, 2}\right)+\beta_{s, 2} L_{l}  \tag{26}\\
\hat{L}_{s, l}^{p o s t}=\hat{L}_{s, l}^{p o s t, 1}\left(1-\Phi\left(\frac{L_{l}-\delta_{a, x}}{s t g r}\right)\right)+\hat{L}_{s, l}^{p o s t, 2}\left(\Phi\left(\frac{L_{l}-\delta_{a, x}}{s t g r}\right)\right)  \tag{27}\\
\Delta_{l, l^{\prime}}=\bar{L}_{l^{\prime}}+2.5-L_{l} \tag{28}
\end{gather*}
$$

$\hat{L}_{s, l}^{p o s t, 1}$ and $\hat{L}_{s, l}^{\text {post }, 2}$ were predicted post-molt lengths from each piece of the piece-wise relationship, and $\Phi()$ was a cumulative normal distribution in which $\delta_{a, x}$ was an estimated change point.

An average recruitment for the assessment period (1978-present) and yearly deviations around this average were estimated within the assessment. The sex ratio of recruitment was assumed to be $50 / 50$ male to female. Each year's estimated recruitment was allocated to length bins based on a discretized and renormalized gamma function with parameters specified in the control file.

$$
\begin{gather*}
\operatorname{Rec}_{y}=e^{\left(\operatorname{Rec}_{a v g}+\operatorname{Rec}_{d e v, y}\right)}  \tag{29}\\
\operatorname{Pr}_{l}=\frac{\left(\Delta_{1, l}\right)^{\alpha_{r e c} / \beta_{\text {rec }}} e^{-\Delta_{1, l^{\prime}} / \beta_{\text {rec }}}}{\sum_{l^{\prime}}\left(\Delta_{1, l^{\prime}}\right)^{\alpha_{\text {rec }} / \beta_{\text {rec }}} e^{\left(-\Delta_{1, l^{\prime}} / \beta_{\text {rec }}\right)}} \tag{30}
\end{gather*}
$$

## Likelihood components

Three general types of likelihood components were used to fit to the available data (Table 11). Multinomial likelihoods were used for size composition data, log-normal likelihoods were used for indices of abundance data, and normal likelihoods were used for catch data, growth data, priors, and penalties. Multinomial likelihoods were implemented in the form:

$$
\begin{equation*}
L_{x}=\lambda_{x} \sum_{y} N_{x, y}^{e f f} \sum_{l} p_{x, y, l}^{o b s} \ln \left(\hat{p}_{x, y, l} / p_{x, y, l}^{o b s}\right) \tag{31}
\end{equation*}
$$

$\mathrm{L}_{x}$ was the likelihood associated with data component x , where $\lambda_{x}$ represented an optional additional weighting factor for the likelihood, $N_{x, y}^{e f f}$ was the effective sample sizes for the likelihood, $p_{x, y, l}^{o b s}$ was the observed proportion in size bin $l$ during year $y$ for data component $x$, and $\hat{p}_{x, y, l}$ was the predicted proportion in size bin $l$ during year $y$ for data component $x .10$ multinomial likelihood components were included in the assessment (see Table 11 for descriptions, weighting factors, and effective sample sizes).

Iterative methods for determining appropriate effective samples sizes for composition data are suggested to avoid over-weighting the size composition data and washing out the signal from the indices of abundance. Although the code has the capability to implement these methods, they were not used for this assessment.

Log normal likelihoods were implemented in the form:

$$
\begin{equation*}
L_{x}=\lambda_{x} \sum_{y} \frac{\left(\ln \left(\hat{I}_{x, y}\right)-\ln \left(I_{x, y}\right)\right)^{2}}{2\left(\ln \left(C V_{x, y}^{2}+1\right)\right)} \tag{32}
\end{equation*}
$$

$L_{x}$ was the contribution to the objective function of data component $x, \lambda_{x}$ was any additional weighting applied to the component, $\hat{I}_{x, y}$ was the predicted value of quantity $I$ from data component $x$ during year $y$,
$\mathrm{I}_{x, y}$ was the observed value of quantity $I$ from data component $x$ during year $y$ and $\mathrm{CV}_{x, y}$ was the coefficient of variation for data component $x$ during year $y .5 \log$ normal likelihood components were included in this assessment (see Table 11 for descriptions, weighting factors, and CVs).
Normal likelihoods were implemented in the form:

$$
\begin{equation*}
L_{x}=\lambda_{x} \sum_{y}\left(\hat{I}_{x, y}-I_{x, y}\right)^{2} \tag{33}
\end{equation*}
$$

$L_{x}$ was the contribution to the objective function of data component $x, \lambda_{x}$ was represents the weight applied to the data component (and can be translated to a standard deviation), $\hat{I}_{x, y}$ was the predicted value of quantity $I$ from data component $x$ during year $y, \mathrm{I}_{x, y}$ was the observed value of quantity $I$ from data component $x$ during year $y .12$ normal likelihood components were included in the "Base" assessment (see Table 11 for descriptions, weighting factors, and translated standard deviations).

Smoothing penalties were also placed on some estimated vectors of parameters in the form of normal likelihoods on the second differences of the vector. Code for this assessment can be found on github.com/szuwalski/SnowCrab2017.

Table 4: Observed growth increment data by sex

| Female premolt <br> length $(\mathrm{mm})$ | Female postmolt <br> length $(\mathrm{mm})$ | Male premolt <br> length $(\mathrm{mm})$ | Male postmolt <br> length $(\mathrm{mm})$ |
| :---: | :---: | :---: | :---: |
| 19.37 | 24.24 | 21.23 | 26.41 |
| 20.7 | 27.4 | 22.2 | 28.1 |
| 21.25 | 28.73 | 23.48 | 28.27 |
| 21.94 | 28.71 | 29.9 | 39.9 |
| 23.09 | 29.26 | 30.3 | 40.3 |
| 32.8 | 44.9 | 30.7 | 40.5 |
| 35.3 | 47.6 | 44.2 | 58.7 |
| 38.3 | 50.9 | 44.7 | 57.3 |
| 38.9 | 53 | 64.7 | 82.7 |
| 41 | 55.8 | 67.6 | 86 |
| 42.1 | 54.6 | 67.9 | 85.3 |
| 44.2 | 59.5 | 74.5 | 93.9 |
| 44.3 | 59.3 | 79.9 | 97.8 |
| 44.8 | 59.7 | 89.8 | 110 |
| 45.2 | 59.6 | 89.9 | 112.1 |
| 46.9 | 60.4 | 89.9 | 112.3 |
| 47 | 61.4 | 93.8 | 117.6 |
| 47.9 | 61.4 | 20 | 26.3 |
| 20.6 | 25.1 |  |  |
| 20.8 | 27.6 |  |  |
| 22 | 28.2 |  |  |
| 22.9 | 28.6 |  |  |
|  |  |  |  |

Table 5: Observed retained catches, discarded catch, and bycatch

| Survey year | Retained catch (kt) | Discarded females (kt) | Discarded males (kt) | Trawl bycatch (kt) |
| :---: | :---: | :---: | :---: | :---: |
| 1978 | 23.71 | 0.02 | 2.05 | 3.84 |
| 1979 | 34.03 | 0.02 | 2.56 | 3.07 |
| 1980 | 30.36 | 0.02 | 2.28 | 2.23 |
| 1981 | 13.32 | 0.01 | 1.2 | 0.93 |
| 1982 | 11.85 | 0.02 | 1.18 | 0.38 |
| 1983 | 12.16 | 0.01 | 1.15 | 0.49 |
| 1984 | 29.94 | 0.01 | 2.57 | 0.52 |
| 1985 | 44.45 | 0.01 | 3.74 | 0.45 |
| 1986 | 46.22 | 0.02 | 3.96 | 1.91 |
| 1987 | 61.4 | 0.03 | 5.14 | 0.01 |
| 1988 | 67.79 | 0.04 | 5.42 | 0.69 |
| 1989 | 73.4 | 0.05 | 6.23 | 0.8 |
| 1990 | 149.1 | 0.05 | 14.17 | 0.61 |
| 1991 | 143 | 0.06 | 11.18 | 1.88 |
| 1992 | 104.7 | 0.12 | 17.06 | 1.78 |
| 1993 | 67.94 | 0.08 | 5.32 | 1.76 |
| 1994 | 34.13 | 0.06 | 4.03 | 3.54 |
| 1995 | 29.81 | 0.02 | 5.75 | 1.34 |
| 1996 | 54.22 | 0.07 | 7.44 | 0.92 |
| 1997 | 114.4 | 0.01 | 5.73 | 1.47 |
| 1998 | 88.09 | 0.01 | 4.67 | 1.01 |
| 1999 | 15.1 | 0 | 0.52 | 0.61 |
| 2000 | 11.46 | 0 | 0.62 | 0.53 |
| 2001 | 14.8 | 0 | 1.89 | 0.39 |
| 2002 | 12.84 | 0 | 1.47 | 0.23 |
| 2003 | 10.86 | 0 | 0.57 | 0.76 |
| 2004 | 11.29 | 0 | 0.51 | 0.95 |
| 2005 | 16.77 | 0 | 1.36 | 0.36 |
| 2006 | 16.49 | 0 | 1.78 | 0.83 |
| 2007 | 28.59 | 0.01 | 2.53 | 0.43 |
| 2008 | 26.56 | 0.01 | 2.06 | 0.27 |
| 2009 | 21.78 | 0.01 | 1.23 | 0.63 |
| 2010 | 24.61 | 0.01 | 0.62 | 0.17 |
| 2011 | 40.29 | 0.18 | 1.69 | 0.16 |
| 2012 | 30.05 | 0.03 | 2.32 | 0.22 |
| 2013 | 24.49 | 0.07 | 3.27 | 0.12 |
| 2014 | 30.82 | 0.17 | 3.52 | 0.16 |
| 2015 | 18.42 | 0.07 | 2.96 | 0.16 |
| 2016 | 9.67 | 0.02 | 1.31 | 0.08 |

Table 6: Observed mature male and female biomass (1000 t) at the time of the survey and coefficients of variation.

| Survey year | Female mature biomass | Female CV | Mature male biomass | Male CV | Males $>101 \mathrm{~mm}$ <br> (kt) | Males $\underset{\text { (millions) }}{>101 \mathrm{~mm}}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1978 | 101.7 | 0.2 | 193.5 | 0.12 | 98.95 | 163.4 |
| 1979 | 216.8 | 0.2 | 241.3 | 0.12 | 105 | 169.1 |
| 1980 | 281.3 | 0.32 | 187.5 | 0.17 | 69.98 | 116.4 |
| 1981 | 123.3 | 0.17 | 113.5 | 0.11 | 23.01 | 40.38 |
| 1982 | 144.4 | 0.15 | 176.8 | 0.14 | 33.34 | 60.91 |
| 1983 | 90.13 | 0.2 | 161.6 | 0.13 | 38.09 | 70.09 |
| 1984 | 42.32 | 0.19 | 177.7 | 0.12 | 88.73 | 151.8 |
| 1985 | 6.12 | 0.2 | 71.84 | 0.11 | 43.39 | 72.84 |
| 1986 | 15.74 | 0.18 | 89.81 | 0.11 | 46.7 | 77.91 |
| 1987 | 122.6 | 0.16 | 194.6 | 0.11 | 74.44 | 128.6 |
| 1988 | 169.9 | 0.17 | 259.4 | 0.15 | 104.7 | 173.1 |
| 1989 | 264.2 | 0.25 | 299.2 | 0.11 | 92.31 | 158.9 |
| 1990 | 182.9 | 0.19 | 443.8 | 0.14 | 224.7 | 386.4 |
| 1991 | 214.9 | 0.19 | 466.6 | 0.15 | 292.2 | 452.9 |
| 1992 | 131.4 | 0.18 | 235.5 | 0.09 | 143.9 | 227.3 |
| 1993 | 132.1 | 0.16 | 183.9 | 0.1 | 78.11 | 126.7 |
| 1994 | 126.2 | 0.15 | 171.3 | 0.08 | 44.78 | 72.57 |
| 1995 | 168.7 | 0.14 | 220.5 | 0.13 | 37.75 | 65.18 |
| 1996 | 107.3 | 0.14 | 288.4 | 0.12 | 87.57 | 155.2 |
| 1997 | 103.8 | 0.2 | 326.8 | 0.1 | 168.7 | 280.6 |
| 1998 | 72.73 | 0.25 | 206.4 | 0.09 | 126.7 | 209.7 |
| 1999 | 30.89 | 0.21 | 95.85 | 0.09 | 52.53 | 85.2 |
| 2000 | 96.46 | 0.52 | 96.39 | 0.14 | 41.88 | 69.83 |
| 2001 | 77.24 | 0.28 | 136.5 | 0.12 | 41.51 | 70.69 |
| 2002 | 30.22 | 0.28 | 93.17 | 0.23 | 36.56 | 64.16 |
| 2003 | 41.71 | 0.31 | 79.07 | 0.12 | 32.57 | 55.61 |
| 2004 | 50.16 | 0.26 | 79.57 | 0.14 | 35.99 | 57.42 |
| 2005 | 64.85 | 0.17 | 123.5 | 0.11 | 40.67 | 63.26 |
| 2006 | 51.93 | 0.18 | 139.3 | 0.26 | 71.13 | 120.9 |
| 2007 | 55.89 | 0.22 | 153.1 | 0.15 | 73.62 | 127.5 |
| 2008 | 57.15 | 0.19 | 142 | 0.1 | 66.56 | 113.6 |
| 2009 | 52.16 | 0.21 | 148.2 | 0.13 | 78.92 | 129.9 |
| 2010 | 98.01 | 0.18 | 162.8 | 0.12 | 88.35 | 138.3 |
| 2011 | 175.8 | 0.18 | 167.1 | 0.11 | 94.67 | 147.6 |
| 2012 | 149.4 | 0.2 | 122.2 | 0.12 | 53.17 | 85.35 |
| 2013 | 131.4 | 0.18 | 97.46 | 0.12 | 42.93 | 71.79 |
| 2014 | 119.7 | 0.19 | 163.5 | 0.16 | 81.39 | 138.8 |
| 2015 | 85.13 | 0.17 | 80.04 | 0.12 | 35.77 | 56.11 |
| 2016 | 55.39 | 0.21 | 63.21 | 0.11 | 21.96 | 36.51 |
| 2017 | 106.8 | 0.21 | 83.96 | 0.11 | 20.52 | 35.02 |

Table 7: Parameter bounds and symbols

| Parameter | Lower | Upper | Symbol |
| :---: | :---: | :---: | :---: |
| af | -100 | 0 | $\alpha_{f}$ |
| am | -50 | 0 | $\alpha_{m}$ |
| bf | 1 | 10 | $\beta_{f, 1}$ |
| bm | 1 | 5 | $\beta_{m, 1}$ |
| b1 | 1 | 1.5 | $\beta_{f, 2}$ |
| bf1 | 1 | 2 | $\beta_{m, 2}$ |
| deltam | 10 | 50 | $\delta_{m}$ |
| deltaf | 5 | 50 | $\delta_{f}$ |
| st_gr | 0.5 | 0.5 | stgr |
| growth_beta | 0.749 | 0.751 | $\beta_{g}$ |
| mateste | -6 | -1e-10 | $\Omega_{m, l}$ |
| matestfe | -6 | -1e-10 | $\Omega_{f, l}$ |
| mean_log_rec | "-inf" | Inf | Recavg |
| rec_devf | -15 | 15 | $\operatorname{Rec}_{f, \text { dev, }}$ |
| alpha1_rec | 11.49 | 11.51 | $\alpha_{\text {rec }}$ |
| beta_rec | 3.99 | 4.01 | $\beta_{\text {rec }}$ |
| mnatlen_styr | -3 | 15 | $\lambda_{\text {male,v,l }}$ |
| fnatlen_styr | -10 | 15 | $\lambda_{\text {fem, } \mathrm{v}, \mathrm{l}}$ |
| log_avg_fmort | "-inf" | Inf | $F_{a v g, d i r}^{\text {log }}$ |
| fmort_dev | -5 | 5 | $F_{\text {dev,dir, }}^{\text {log }}$ |
| log_avg_fmortdf | -8 | -1e-04 | $F_{\text {avg,disc }}^{\text {log }}$ |
| fmortdf_dev | -15 | 15 | $F_{\text {dev,disc,y }}^{l o g}$ |
| log_avg_fmortt | -8 | -1e-04 | $\underset{\text { avg,trawl }}{\text { log }}$ |
| fmortt_dev_eral | -15 | 15 | $F_{\text {deg }}^{\text {log,trawl,era1 }}$ |
| fmortt_dev_era2 | -15 | 15 | $F_{\text {dev,trawl,era2 }}^{l o g}$ |
| log_avg_sel50_mn | 4 | 5 | $S_{50, n e w, \text { dir }}$ |
| log_avg_sel50_mo | 4 | 5 | $S_{50, o l d, d i r}$ |
| fish_slope_mn | 0.1 | 0.5 | $S_{\text {slope }, m, d}$ |
| fish_fit_slope_mn | 0.05 | 0.5 | $S_{\text {slope }, m, d}$ |
| fish_fit_sel50_mn | 85 | 120 | $S_{50, o l d, d i r}$ |
| fish_slope_mo2 | 1.9 | 2 | $S_{\text {slope }, m, d}$ |
| fish_sel50_mo2 | 159 | 160 | $S_{50, o l d, d i r}$ |
| fish_slope_mn2 | 0.01 | 2 | $S_{\text {slope }, m, d}$ |
| fish_sel50_mn2 | 100 | 160 | $S_{50, \text { old,dir }}$ |
| fish_disc_slope_f | 0.1 | 0.7 | $S_{\text {slope }, m, d}$ |
| fish_disc_sel50_f | 1 | 5 | $S_{50, \text { old,dir }}$ |
| fish_disc_slope_tf | 0.01 | 0.3 | $S_{\text {slope,trawl }}$ |
| fish_disc_sel50_tf | 30 | 120 | $S_{50, \text { trawl }}$ |
| srv1_q | 0.2 | 1 | $q_{m, \text { eral } 1 \text { surv }}$ |
| srv1_q_f | 0.2 | 1 | $q_{f, \text { era1,surv }}$ |
| srv1_sel95 | 30 | 150 | $S_{95, \text { era } 1, \text { surv }}$ |
| srv1_sel50 | 0 | 150 | $S_{50, \text { era } 1, \text { surv }}$ |
| srv2_q | 0.2 | 1 | $q_{m, \text { era2,surv }}$ |
| srv2_q_f | 0.2 | 1 | $q_{f, \text { era2,surv }}$ |
| srv2_sel95 | 50 | 160 | $S_{95, \text { era } 2, \text { surv }}$ |
| srv2_sel50 | 0 | 80 | $S_{50, \text { era2,surv }}$ |
| srv3_q | 0.2 | 1 | $q_{\text {m,era3,surv }}$ |
| srv3_sel95 | 40 | 200 | $S_{95, \text { m,era2,surv }}$ |
| srv3_sel50 | 25 | 90 | $S_{50, m, \text { era } 2, \text { surv }}$ |


| Parameter | Lower | Upper | Symbol |
| :--- | :---: | :---: | :---: |
| srv3_q_f | 0.2 | 1 | $q_{f, \text { era3,surv }}$ |
| srv3_sel95_f | 40 | 150 | $S_{95, f, \text { era } 2, \text { surv }}$ |
| srv3_sel50_f | 0 | 90 | $S_{50, f, \text { era } 2, \text { surv }}$ |
| srvind_q | 0.1 | 1 | $q_{m, 09, \text { ind }}$ |
| srvind_q_f | 0.01 | 1 | $q_{f, 09, \text { ind }}$ |
| srvind_sel95_f | 55 | 120 | $S_{95, f, 09, \text { ind }}$ |
| srvind_sel50_f | -50 | 55 | $S_{50, f, 09, \text { ind }}$ |
| srv10in_q | 0.1 | 1 | $q_{m, 10, \text { ind }}$ |
| srv10ind_q_f | 0.01 | 1 | $q_{f, 10, \text { ind }}$ |
| selsmo10ind | -4 | SelVecMaleInd09 |  |
| selsmo09ind | -4 | -0.001 | SelVecMaleInd10 |
| Mmult_imat | 0.2 | -0.001 | $\gamma_{n a t M, \text { imm }}$ |
| Mmult | 0.2 | 2 | $\gamma_{n a t M, \text { mat }, \text { m }}$ |
| Mmultf | 0.2 | 2 | $\gamma_{n a t M, \text { mat }, f}$ |
| cpueq | 0.0000877 | 0.00877 | $q_{c p u e}$ |

Table 8: Estimated parameter values by scenario (these are maximum likelihood estimates)

| Parameter | M16 D16 | M16 D17 | $\begin{gathered} \text { M16 } \\ \text { D17a } \end{gathered}$ | M17A <br> D17a | M17Aa <br> D17a | M17B <br> D17a | M17C <br> D17a | $\mathrm{M} 17 \mathrm{BC}$ D17a |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| af | -5.08 | -4.95 | -4.94 | -2.49 | -4.97 | 9.22 | -5.23 | 7.58 |
| am | -5.74 | -5.57 | -5.66 | -5.49 | -5.48 | 5.55 | -5.35 | 5.2 |
| bf | 1.53 | 1.52 | 1.52 | 1.41 | 1.52 | 1.08 | 1.53 | 1.12 |
| bm | 1.54 | 1.53 | 1.53 | 1.53 | 1.53 | 1.17 | 1.52 | 1.18 |
| b1 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | NA | 1.15 | NA |
| bf1 | 1.02 | 1.02 | 1.04 | 1 | 1.04 | NA | 1.04 | NA |
| deltam | 32.2 | 32.15 | 32.21 | 32.16 | 32.16 | NA | 32.11 | NA |
| deltaf | 34.37 | 34.41 | 34.34 | 39.01 | 34.33 | NA | 34.15 | NA |
| st_gr | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| growth_beta | vector | vector | vector | vector | vector | vector | vector | vector |
| mateste | vector | vector | vector | vector | vector | vector | vector | vector |
| matestfe | vector | vector | vector | vector | vector | vector | vector | vector |
| rec_devf | vector | vector | vector | vector | vector | vector | vector | vector |
| alpha1_rec | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 11.5 | 10.55 | 11.5 |
| beta_rec | 4 | 4 | 4 | 4 | 4 | 4 | 3.62 | 4 |
| mnatlen_styr | vector | vector | vector | vector | vector | vector | vector | vector |
| fnatlen_styr | vector | vector | vector | vector | vector | vector | vector | vector |
| log_avg_fmort | -0.15 | -0.19 | -0.27 | -0.32 | -0.3 | -0.39 | -0.24 | -0.29 |
| fmort_dev | vector | vector | vector | vector | vector | vector | vector | vector |
| log_avg_fmortdf | -6.42 | -6.38 | -6.32 | -6.32 | -6.35 | -6.89 | -5.65 | -6.21 |
| fmortdf_dev | vector | vector | vector | vector | vector | vector | vector | vector |
| log_avg_fmortt | -4.21 | -4.29 | -4.71 | -4.8 | -4.79 | -4.59 | -4.55 | -4.37 |
| fmortt_dev_era1 | vector | vector | vector | vector | vector | vector | vector | vector |
| fmortt_dev_era2 | vector | vector | vector | vector | vector | vector | vector | vector |
| log_avg_sel50_mn | 4.67 | 4.67 | 4.67 | 4.67 | 4.67 | 4.67 | 4.67 | 4.67 |
| log_avg_sel50_mo | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 4.5 | 3.85 | 4.5 |
| fish_slope_mn | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 |
| fish_fit_slope__mn | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 | 0.43 | 0.43 | 0.44 |
| fish_fit_sel50_mn | 95.78 | 95.87 | 96.09 | 96.08 | 96.06 | 96.2 | 96.01 | 96.15 |
| fish_slope_mo2 | 1.95 | 1.95 | 1.95 | 1.95 | 1.95 | 1.95 | 1.8 | 1.95 |
| fish_sel50_mo2 | 159.5 | 159.5 | 159.5 | 159.5 | 159.5 | 159.5 | 181.89 | 159.5 |
| fish_slope_mn2 | 1 | 1 | 1 | 1 | 1 | 1 | 0.89 | 1 |
| fish_sel50_mn2 | 130 | 130 | 130 | 130 | 130 | 130 | 132.85 | 130 |
| fish_disc_slope_f | 0.24 | 0.25 | 0.24 | 0.24 | 0.24 | 0.21 | 0.25 | 0.23 |
| fish_disc_sel50_f | 4.26 | 4.26 | 4.26 | 4.26 | 4.26 | 4.25 | 4.25 | 4.22 |
| fish_disc_slope_tf | 0.08 | 0.09 | 0.09 | 0.09 | 0.09 | 0.08 | 0.08 | 0.07 |
| fish_disc_sel50_tf | 114.18 | 112.97 | 109.79 | 109.37 | 109.59 | 115.18 | 113.59 | 120 |
| srv1_q | 1 | 1 | 0.6 | 0.6 | 0.6 | 0.6 | 0.61 | 0.6 |
| srv1_q_f | 1 | 1 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| srv1_sel95 | 59.89 | 60.05 | 60 | 60 | 60 | 60.14 | 70.15 | 60.14 |
| srv1_sel50 | 42.66 | 42.76 | 40 | 40 | 40 | 40.13 | 35.09 | 40.13 |
| srv2_q | 0.49 | 0.49 | 0.43 | 0.34 | 0.34 | 0.34 | 0.44 | 0.43 |
| srv2_q_f | 0.32 | 0.32 | 0.46 | 0.38 | 0.37 | 0.24 | 0.53 | 0.39 |
| srv2_sel95 | 61.3 | 61.55 | 57.17 | 56.88 | 56.72 | 63.38 | 54.99 | 50 |
| srv2_sel50 | 41.32 | 41.45 | 41.25 | 39.93 | 39.73 | 8.37 | 39.12 | 0 |
| srv3_q | 0.62 | 0.61 | 0.67 | 0.67 | 0.68 | 0.57 | 0.72 | 0.64 |
| srv3_sel95 | 57.24 | 56.05 | 56.52 | 57.39 | 57.48 | 40 | 48.34 | 40 |
| srv3_sel50 | 38.42 | 37.84 | 38.03 | 38.86 | 38.93 | 25 | 35.21 | 25 |


|  | M16 | M16 | M16 | M17A | M17Aa | M17B | M17C | M17BC |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Parameter | D16 | D17 | D17a | D17a | D17a | D17a | D17a | D17a |
| srv3__q_f | 0.49 | 0.49 | 0.54 | 0.55 | 0.54 | 0.66 | 1 | 1 |
| srv3_sel95_f | 43.09 | 42.76 | 43.09 | 44.24 | 43.67 | 150 | 45.76 | 40 |
| srv3_sel50_f | 33.27 | 33.08 | 33.28 | 34.18 | 33.84 | 0 | 35.68 | 31.14 |
| srvind_q | 0.36 | 0.36 | 0.39 | 0.39 | 0.31 | 1 | 1 | 1 |
| srvind__q_f | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.08 | 0.17 | 0.15 |
| srvind_sel95_f | 55 | 55 | 55 | 55 | 55 | 55.17 | 55 | 55.14 |
| srvind_sel50_f | 49.21 | 49.22 | 49.23 | 49.17 | 49.26 | 54.88 | 49.34 | 54.86 |
| srv10ind_q_f | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| selsmo10ind | vector | vector | vector | vector | vector | vector | vector | vector |
| selsmo09ind | vector | vector | vector | vector | vector | vector | vector | vector |
| Mmult_imat | 1.8 | 1.8 | 1.82 | 1.87 | 1.89 | 1.87 | 1.23 | 1.24 |
| Mmult | 1.13 | 1.13 | 1.08 | 1.07 | 1.06 | 1.09 | 1.16 | 1.23 |
| Mmultf | 1 | 1 | 1 | 1 | 1 | 1 | 1.55 | 1.97 |
| cpueq | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table 9: Contribution to the objective function by individual likelihood component by modeling scenario. Values in columns after Model 0 are the likelihood contribution of Model 0 minus the likelihood contribution of the model in the column. Positive values represent improvements in fit. Note that some of the model scenarios involve changing the weightings of data sources which invalidate the comparison of likelihoods for a data source among models.

| Likelihood component | $\begin{aligned} & \text { M16 } \\ & \text { D16 } \end{aligned}$ | $\begin{aligned} & \text { M16 } \\ & \text { D17 } \end{aligned}$ | $\begin{gathered} \text { M16 } \\ \text { D17a } \end{gathered}$ | M17A <br> D17a | M17Aa <br> D17a | M17B <br> D17a | $\begin{gathered} \text { M17C } \\ \text { D17a } \end{gathered}$ | M17BC D17a |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Recruitment deviations | 40.33 | 40.53 | 39.6 | 39.09 | 39.23 | 32.32 | 39.2 | 29.87 |
| Initial <br> numbers <br> old shell <br> males small <br> length bins | 2.18 | 2.17 | 4.81 | 5.09 | 5.12 | 7.49 | 4.68 | 7.08 |
| ret fishery <br> length | 382.62 | 396.03 | 304.71 | 306.59 | 307.77 | 325.78 | 304.04 | 326.43 |
| total fish <br> length (ret <br> + disc) | 821.72 | 868 | 867.11 | 866.16 | 867.03 | 881.56 | 864.32 | 881.41 |
| female fish length | 221.96 | 236.42 | 235.99 | 236.75 | 236.2 | 224.83 | 234.66 | 226.01 |
| survey <br> length | 4639.21 | 4745.85 | 4331.35 | 4345.3 | 4329.27 | 4942.45 | 4266.18 | 4792.15 |
| trawl <br> length | 290.39 | 304.29 | 308.63 | 310.19 | 310.89 | 344.22 | 268.44 | 267.58 |
| 2009 <br> BSFRF <br> length | -82.94 | -83.06 | -82.95 | -82.53 | -82.81 | -92.62 | -93.59 | -97.15 |
| 2009 NMFS <br> study area length | -67.8 | -68.02 | -67.69 | -67.66 | -67.11 | -69.25 | -74.8 | -73.83 |
| M multiplier prior | 19.81 | 19.68 | 16.84 | 18.29 | 18.74 | 19.85 | 83.42 | 64.06 |
| maturity <br> smooth | 40.77 | 40.58 | 37.64 | 41.83 | 37.05 | 43.21 | 37.12 | 39.86 |
| growth <br> males | 38.4 | 37 | 34.28 | 35.17 | 35.86 | 56.66 | 33.54 | 54.39 |
| growth females | 133.39 | 135.2 | 127.46 | 116.24 | 127.25 | 247.76 | 117.05 | 229.32 |
| $\begin{aligned} & 2009 \\ & \text { BSFRF } \end{aligned}$ | 0.21 | 0.2 | 0.27 | 0.28 | 0.25 | 0.18 | 0.38 | 0.21 |
| biomass 2009 NMFS <br> study area biomass | 0.09 | 0.08 | 0.13 | 0.15 | 0.17 | 0.02 | 0.13 | 0.06 |
| cpue q | 0.2 | 0.2 | 0.18 | 0.21 | 0.22 | 0.19 | 0.18 | 0.18 |
| retained <br> catch | 4.06 | 4.04 | 3.86 | 3.86 | 3.97 | 4.23 | 3.68 | 4.23 |
| discard catch | 152.45 | 162.45 | 154.75 | 154.02 | 156.36 | 148.71 | 135.01 | 150.44 |


| Likelihood component | $\begin{aligned} & \text { M16 } \\ & \text { D16 } \end{aligned}$ | $\begin{aligned} & \text { M16 } \\ & \text { D17 } \end{aligned}$ | $\begin{gathered} \text { M16 } \\ \text { D17a } \end{gathered}$ | $\mathrm{M} 17 \mathrm{~A}$ D17a | $\begin{aligned} & \text { M17Aa } \\ & \text { D17a } \end{aligned}$ | $\begin{gathered} \text { M17B } \\ \text { D17a } \end{gathered}$ | $\begin{gathered} \text { M17C } \\ \text { D17a } \end{gathered}$ | $\overline{\mathrm{M} 17 \mathrm{BC}}$ D17a |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| trawl catch | 8.63 | 10.12 | 6.51 | 7.89 | 8.17 | 7.43 | 7.02 | 6.94 |
| female discard catch | 6.12 | 5.71 | 5.27 | 5.3 | 5.28 | 5.41 | 5.41 | 5.35 |
| survey <br> biomass | 365.81 | 368.13 | 328.51 | 312.13 | 313.01 | 327.38 | 281.56 | 283.37 |
| F penalty | 37.39 | 38.04 | 24.63 | 25.08 | 25.51 | 24.55 | 25.11 | 26.04 |
| $\begin{aligned} & 2010 \\ & \text { BSFRF } \end{aligned}$ | 2.88 | 2.72 | 4.04 | 4.08 | 2.73 | 2.04 | 22.16 | 26.93 |
| Biomass 2010 NMFS <br> Biomass | 0.87 | 0.82 | 1.24 | 1.33 | 1.91 | 0.84 | 1.09 | 0.77 |
| Extra <br> weight <br> survey <br> lengths first year | 510.42 | 510.36 | 565.89 | 564.24 | 565.06 | 562.82 | 554.88 | 548.99 |
| 2010 <br> BSFRF <br> length | -54.58 | -54.79 | -54.36 | -54.02 | -51.86 | -58.77 | -47.77 | -62.69 |
| 2010 NMFS length | -59.21 | -59.53 | -59.08 | -58.71 | -55.77 | -43.58 | -60.22 | -57.87 |
| smooth selectivity | 3.3 | 3.3 | 3.35 | 3.34 | 1.25 | 2.71 | 2.35 | 2.68 |
| smooth <br> female <br> selectivity | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| init nos smooth constraint | 40.44 | 40.57 | 47.68 | 48.26 | 48.33 | 47.57 | 45.61 | 46.19 |
| Total | 7499.12 | 7707.09 | 7190.65 | 7187.95 | 7189.08 | 7995.99 | 7060.84 | 7729 |

Table 10: Changes in management quantities for each scenario considered. Reported management quantities are median posterior values.

| Model | MMB | B35 | F35 | FOFL | OFL |
| :--- | :---: | :---: | :---: | :---: | :---: |
| M16 D16 | 90.98 | 151.5 | 1.96 | 1.12 | 23.91 |
| M16 D17 | 104.9 | 151 | 1.9 | 1.33 | 34.04 |
| M16 D17a | 95.26 | 150 | 1.43 | 0.97 | 27.46 |
| M17A D17a | 93.86 | 148.5 | 1.41 | 0.96 | 26.99 |
| M17Aa D17a | 88.16 | 147.6 | 1.38 | 0.9 | 24.66 |
| M17B D17a | 111.3 | 157.1 | 1.54 | 1.17 | 35.3 |
| M17C D17a | 94.43 | 139.3 | 1.31 | 0.89 | 28.41 |
| M17BC D17a | 102.9 | 134.2 | 1.6 | 1.21 | 34.81 |

Table 11: Likelihoods form and weighting for each likelihood component for models in the analysis (continued below)

| Likelihood component | Form | M16 D16 | M16 D17 |
| :---: | :---: | :---: | :---: |
| Recruitment deviations | normal | 0.71 | 0.71 |
| Initial numbers old shell males small length bins | normal | 707.1 | 707.1 |
| ret fishery length | multinomial | 200 | 200 |
| total fish length (ret + disc) | multinomial | 200 | 200 |
| female fish length | multinomial | 200 | 200 |
| survey length | multinomial | 200 | 200 |
| trawl length | multinomial | 200 | 200 |
| 2009 BSFRF | multinomial | 200 | 200 |
| length 2009 NMFS study area length | multinomial | 200 | 200 |
| M multiplier prior | normal | 0.23 | 0.23 |
| maturity smooth | normal | 3.16 | 3.16 |
| growth males | normal | 0.71 | 0.71 |
| growth females | normal | 0.32 | 0.32 |
| 2009 BSFRF | lognormal | NA | NA |
| biomass |  |  |  |
| 2009 NMFS study area biomass | lognormal | NA | NA |
| cpue q | normal | 0.32 | 0.32 |
| retained catch | normal | 0.22 | 0.22 |
| discard catch | normal | 3 | 3 |
| trawl catch | normal | 0.22 | 0.22 |
| female discard catch | normal | 17 | 17 |
| survey biomass | lognormal | NA | NA |
| F penalty | normal | 0.5 | 0.5 |
| 2010 BSFRF | lognormal | NA | NA |
| Biomass |  |  |  |
| 2010 NMFS | lognormal | NA | NA |
| Biomass |  |  |  |
| Extra weight survey lengths | multinomial | 200 | 200 |
| first year |  |  |  |
| 2010 BSFRF | multinomial | 200 | 200 |
| length |  |  |  |
| 2010 NMFS | multinomial | 200 | 200 |
| length |  |  |  |
| smooth selectivity | norm2(firstdiff(firstDiff)) | 2 | 2 |
| smooth female selectivity | norm2(firstdiff(firstDiff)) | 3 | 3 |
| init nos smooth constraint | norm2(firstdifference) | 1 | 1 |


|  | M17A | M17Aa | M17B |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| M16 D17a | D17a | D17a | D17a | D17a <br> D17BC | M17a <br> D17a |
| 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 |
| 707.1 | 707.1 | 707.1 | 707.1 | 707.1 | 707.1 |
| 200 | 200 | 200 | 200 | 200 | 200 |
| 200 | 200 | 200 | 200 | 200 | 200 |
| 200 | 200 | 200 | 200 | 200 | 200 |
| 200 | 200 | 200 | 200 | 200 | 200 |
| 200 | 200 | 200 | 200 | 200 | 200 |
| 200 | 200 | 200 | 200 | 200 | 200 |
| 200 | 200 | 200 | 200 | 200 | 200 |
| 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 |
| 3.16 | 3.16 | 3.16 | 3.16 | 3.16 | 3.16 |
| 0.71 | 0.71 | 0.71 | 0.41 | 0.71 | 0.41 |
| 0.32 | 0.32 | 0.32 | 0.27 | 0.32 | 0.27 |
| NA | NA | NA | NA | NA | NA |
| NA | NA | NA | NA | NA | NA |
| 0.32 | 0.32 | 0.32 | 0.32 | 0.32 | 0.32 |
| 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 |
| 3 | 3 | 3 | 3 | 3 | 3 |
| 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 |
| 17 | 17 | 17 | 17 | 17 | 17 |
| NA | NA | NA | NA | NA | NA |
| 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| NA | NA | NA | NA | NA | NA |
| NA | NA | NA | NA | NA | NA |
| 200 | 200 | 200 | 200 | 200 | 200 |
| 200 | 200 | 200 | 200 | 200 | 200 |
| 200 | 200 | 200 | 200 | 200 | 200 |
| 2 | 2 | 2 | 2 | 2 | 2 |
| 3 | 3 | 3 | 3 | 3 | 3 |
| 1 | 1 | 1 | 1 | 1 | 1 |
|  |  |  |  |  |  |



Figure 1: Observed relative density of all males at the time of the 2017 NMFS summer survey


Figure 2: Observed relative density of all females at the time of the 2017 NMFS summer survey


Figure 3: Observed relative density of males $>77 \mathrm{~mm}$ carapace width at the time of the 2017 NMFS summer survey


Figure 4: Observed relative density of males $>101 \mathrm{~mm}$ carapace width at the time of the 2017 NMFS summer survey


Figure 5: Observed relative density of mature females at the time of the 2017 NMFS summer survey


Figure 6: Model predicted ratio of catch to mature male biomass


Figure 7: Bycatches in other fishing fleets.


Figure 8: Distribution of survey locations in 1987


Figure 9: Distribution of survey locations in 1988


Figure 10: Divisions of survey data for estimation of $q$ (MMB shown for reference) and total catches

## Total females



Figure 11: Observed relative numbers at length at the time of the survey

## Total males



Figure 12: Observed relative numbers at length at the time of the survey


Figure 13: Centroid of mature females observed in the survey over time. Dark blue indicates years early in the time series; green are the most recent years in the time series.


Figure 14: Centroid of large males observed in the survey over time. Dark blue indicates years early in the time series; green are the most recent years in the time series.


Figure 15: Location of survey selectivity experiments (2009 \& 2010; this was reproduced from the 2015 SAFE; revise this figure with BSFRF data)


Figure 16: Raw female numbers from BSFRF survey selectivity experiments (2009 \& 2010). Note a change in scale on the y-axis from 2009 to 2010


Figure 17: Raw male numbers from BSFRF survey selectivity experiments (2009 \& 2010). Note a change in scale from 2009 to 2010 on the y-axis.


Figure 18: Management quantities after jittering all models.


Figure 19: Basic MCMC diagnostics. Left colum is the density of the value of the objective function. Middle column is the trace of the objective function. Number in the upper left of each panel is the z-score of the Geweke diagnostic. Right is the autocorrelation in the objective function value.


Figure 20: Traces for parameters from each model


Figure 21: Posterior densities for estimated parameters by scenario


Figure 22: Posterior densities for estimated parameters by scenario


Figure 23: Posterior densities for estimated parameters by scenario


Figure 24: Posterior densities for estimated parameters by scenario


Figure 25: Model fits to the observed mature biomass at survey


Figure 26: Model fits to the growth data


Figure 27: Model fits to catch data


Figure 28: Model fits to pot CPUE data


Figure 29: Model fits to retained catch size composition data


Figure 30: Model fits to trawl catch size composition data


Figure 31: Model fits to size composition data from summer survey experiments (2009 \& 2010)


Figure 32: Model fits to female survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1 . Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.


Figure 33: Model fits to male survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.


Figure 34: Residuals for female survey length proportion data for the author's preferred model (3b). Open circles are positive residuals, filled are negative, and the size of the circle is proportional to the magnitude of the residual. Stars are residuals $>5$.


Figure 35: Residuals for male survey length proportion data for the author's preferred model (3b). Open circles are positive residuals, filled are negative, and the size of the circle is proportional to the magnitude of the residual. Stars are residuals $>5$.


Figure 36: Model predicted mature male biomass at mating time


Figure 37: Kobe plot for the chosen model. Vertical dashed black line represents the median posterior value for B35; Vertical dashed red line represents the overfished level, horizontal dashed black line represents F35


Figure 38: Estimated survey selectivity


Figure 39: Estimated experimental survey selectivity (availability * survey selectivity)


Figure 40: Estimated probability of maturing


Figure 41: Model predicted fishing mortalities and selectivities for all sources of mortality


Figure 42: Estimated recruitment, fits to stock recruit curve (MMB lagged 5 years), and proportions recruiting to length bin


Figure 43: Posterior densities for management quantities by scenario

# An appendix to the stock assessment for eastern Bering Sea snow crab <br> Cody Szuwalski and Jack Turnock <br> September 21, 2017 

## Contents

CPT September 2017 comments ..... 4
Results ..... 4
Fits to data ..... 4
Estimated population processes and derived quantities ..... 5
Calculated OFLs and ABC ..... 5
Author recommendations ..... 5
Notes for future assessments ..... 5

1. Stock: Eastern Bering Sea snow crab, Chionoecetes opilio.
2. Catches: trends and current levels

Retained catches increased from relatively low levels in the early 1980s (e.g. retained catch of kt during 1981) to historical highs in the early and mid-nineties (retained catch during 1991, 1992, and 1998 were 143.02, 104.68 , and 88.09 kt , respectively). The stock was declared overfished in 1999 at which time retained catches dropped to levels similar to the early 1980s (e.g. retained catch during 2000 was 11.46 kt ). Retained catches have slowly increased since 1999 as the stock rebuilt, although retained catch during 2016 was low ( 9.67 kt ).

Discard mortality is the next largest source of mortality after retained catch and approximately tracks the retained catch. The highest estimated discard mortality occurred during 1992 at 17.06 kt which was $16 \%$ of the retained catch. The most recent estimated mortality was 1.31 kt which was $14 \%$ of the retained catch.
3. Stock Biomass:

Observed mature male biomass (MMB) at the time of the survey increased from an average of 234.14 kt in the early to mid-1980s to historical highs in the early and mid-nineties (observed MMB during 1990, 1991, and 1997 were $443.79,466.61$, and 326.75 kt , respectively). The stock was declared overfished in 1999 in response to the total mature biomass dropping below the minimum stock size threshold. MMB in that year decreased to 95.85 kt . Observed MMB slowly increased after 1999, and the stock was declared rebuilt in 2011 when estimated MMB at mating was above $\mathrm{B}_{35 \%}$. However, since 2011, the stock has declined again and the observed MMB at the time of survey dropped to an all time low in 2016 of 63.21 kt .

## 4. Recruitment

Estimated recruitment shifts from a period of high recruitment to a period of low recruitment in the mid 1990s (late 1980s when lagged to fertilization). Recent estimated recruitments have generally been above the average of the 'low' period, but are still beneath the average of the 'high' recruitment period. However, a large year class recruited to the survey gear in 2014 and has persisted to the present, which suggests large exploitable biomasses may be available in the near future.
5. Management

Table 1: Historical status and catch specifications for snow crab (1,000t).

| Year | MSST | Biomass <br> $(M M B)$ | TAC | Retained <br> catch | Total <br> catch | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2011 / 2012$ | 77.3 | 165.2 | 40.3 | 40.5 | 42 | 73.5 | 66.2 |
| $2012 / 2013$ | 77.1 | 170.1 | 30.1 | 30.1 | 32.4 | 67.8 | 61 |
| $2013 / 2014$ | 71.5 | 126.5 | 24.5 | 24.5 | 27.7 | 78.1 | 69.3 |
| $2014 / 2015$ | 73.2 | 129.3 | 30.8 | 30.8 | 34.3 | 69 | 62.1 |
| $2015 / 2016$ | 75.8 | 91.6 | 18.4 | 18.4 | 21.4 | 61.5 | 55.4 |
| $2016 / 2017$ | 69.7 | 94.4 | 9.7 | 9.7 | 11 | 23.7 | 21.3 |
| $2017 / 2018$ | 69.7 | 99.6 |  |  |  | 28.4 | 22.7 |

Table 2: Historical status and catch specifications for snow crab (millions of lbs).

| Year | MSST | Biomass <br> $($ MMB $)$ | TAC | Retained <br> catch | Total <br> catch | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2011 / 2012$ | 170.4 | 364.2 | 88.85 | 89.29 | 92.59 | 162 | 145.9 |
| $2012 / 2013$ | 170 | 375 | 66.36 | 66.36 | 71.43 | 149.5 | 134.5 |
| $2013 / 2014$ | 157.6 | 278.9 | 54.01 | 54.01 | 61.07 | 172.2 | 152.8 |
| $2014 / 2015$ | 161.4 | 285.1 | 67.9 | 67.9 | 75.62 | 152.1 | 136.9 |
| $2015 / 2016$ | 167.1 | 201.9 | 40.57 | 40.57 | 47.18 | 135.6 | 122.1 |
| $2016 / 2017$ | 153.7 | 208.1 | 21.38 | 21.38 | 24.25 | 52.25 | 46.96 |
| $2017 / 2018$ | 153.7 | 219.6 |  |  |  | 62.61 | 50.04 |

6. Basis for the OFL

The OFL for 2017 from the chosen model (M17C D17a) was 28.41 kt fishing at $\mathrm{F}_{\text {OFL }}=0.89$ ( $68 \%$ of the calculated $\mathrm{F}_{35 \%}, 1.31$ ). The calculated OFL was a $20 \%$ change from the 2016 OFL of 23.7 kt . The reported OFL is the median posterior value, but differs from the ML estimate by only 1.51 kt . The projected ratio of MMB at the time of mating to $\mathrm{B}_{35 \%}$ is 0.71 .
7. Probability Density Function of the OFL

The probability density function of the OFL was characterized by using a Markov Chain Monte Carlo algorithm to sample from the a posterior distribution of the OFL. This allows all uncertainty to be propagated forward into the OFL calculation. The chosen OFL was calculated as the median of its posterior distribution.
8. Basis for ABC

The ABC for the chosen model for $2016 / 2017$ was 22.73 kt , calculated by subtracting a $20 \%$ buffer from the OFL as recommended by the CPT

## CPT September 2017 comments

Two new analyses were recommended by the CPT to be completed during the September meeting as a result of the apparent instability and bimodality of several models presented. First, a corrected jittering analysis was requested that jitters only unestimated parameters. This was completed to the satisfaction of the CPT. After seeing the results, the CPT requested an additional 2 million draws from the posterior of the model M17Aa.D17a, starting from the lower mode. This document presents three models:

- "M17Aa.D17a" - Includes all small changes from the main assessment document (replicates the results from the main document).
- "M17Ab.D17a" - Same as M17Aa.D17a, except the MCMC was started from a parameter vector associated with the lower mode of management quantities (new results).
- "M17C.D17a" - Estimate natural mortality for mature females in addition to mature males and immature males and females (replicates the results from the main document).

This document includes updated tables and figures and should be considered to supersede information found in the main assessment document.

## Results

The updated jittering analysis did not remove the bimodal behavior of M17Aa.D17a, but 'concentrated' the clusters (Figure $1 \&$ Figure 2). Running MCMC for M17Ab.D17a produced posterior distributions of the management quantities with different medians from M17Aa.D17a (Figure 3), in spite of relatively good diagnostics (Figure $4 \&$ Figure 5) . The difference between the modes of MLEs for management quantities derived from M17Aa and M17Ab appears to be a result of changes in the estimated growth function for males (Figure 6).

All of the relative qualities of the models were retained after correcting the jittering-e.g. M17C.D17a has female catchability equal to 1 (Figure 7) and M17Aa.D17a has the relationship between female and male natural mortality reversed (Table 3). M17C.D17a fit the data much better as seen through the total likelihood, in spite of a 60 point hit for estimating mature female natural mortality (Table 4).

Maximum likelihood estimates of parameters can be seen in Table 3 and their posterior distributions can be seen in Figure 8, Figure 9, Figure 10, and Figure 11.

## Fits to data

Fits to the survey mature male biomass were visually similar for all models for the majority of years in the the time series (Figure 12), yet model M17C.D17a fit the survey biomass better than other models according to the likelihoods (Table 4). All models overestimated the final year of survey MMB ( 83.9572 kt ) and MFB ( 106.847 kt ).

M17Aa.D17a and M17C.D17a provided adequate fits to the female and male growth data, but model M17Ab.D17a did not fit the male growth data well (Figure 6). Likelihoods from M17C.D17a were lowest for both growth models.

Retained catch data were fit by all models well, with no little discernible differences among models (Figure 13). Female discard data were fit adequately given the specified uncertainty (Figure $13 \&$ Table 4 ). Male discard data during the period for which data exist (early 1990s to the present) were well fit by every model with little discernible difference (Figure 13). M17Ab.D17a returned a significantly lower likelihood for male discard data (Table 4). Fits to the trawl data were adequate for all models given the uncertainty in the data (Figure 13).

Retained catch size composition data were fit well by all models (Figure 14); trawl size composition data were generally well fit in most years. All models performed similarly in fitting the trawl size composition
data (Figure 15 \& Table 4). Fits to survey size composition data were not visibly different among scenarios (Figure 16 \& Figure 17), but M17C.D17a fit the data better according to the likelihoods (Table 4).

## Estimated population processes and derived quantities

Estimates of selectivity and catchability varied less in era 2 than in era 3 (Figure 7). Estimated catchability for males during survey era 3 ranged from 0.68 to 0.75 ; estimated female catchability ranged from 0.54 to 1 . Size at $50 \%$ selection in the survey gear ranged from 33 mm to 35 mm for females and 35 mm to 38 mm for males (Figure $9 \&$ Figure 10). The probability of maturing by size was fairly consistent among scenarios for both males and females (Figure 18). Estimated fishing mortality in the directed fishery was slightly higher for M17ab.D17a than the other models (Figure 19). Total and retained fishery selectivity was very similar for all models because of the weight put on the retained catch and its associated size composition data (Figure 19).Patterns in recruitment were similar for all models, though magnitudes varied (Figure 20).

## Calculated OFLs and ABC

Medians of the posterior densities of the OFLs calculated for the suite presented models ranged from 19.64 to 28.41 kt (Figure 3 \& Table 5). Differences in OFLs were a result of differences in estimated MMB (see above), calculated $\mathrm{B}_{35 \%}$ (which ranged from 139.35 to 147.59 kt ), Figure 3 ), $\mathrm{F}_{35 \%}$ (which ranged from 1.31 to 1.51 $\mathrm{yr}^{-1}$, Figure 3), and $\mathrm{F}_{\text {OFL }}$ (which ranged from 0.89 to $0.94 \mathrm{yr}^{-1}$, Figure 3). The acceptable biological catch (ABC) was set by subtracting a $20 \%$ buffer from the OFL to account for scientific uncertainty, which was recommended by the CPT based on uncertainty around model stability this year.

## Author recommendations

M17C.D17a fits the data much better than the other two models, eliminates the bimodality, and restores the proper relationship between estimated natural mortality for females and males. However, an increase of survey catchability for females to 1 is an unfortunate knock-on effect of this model. Given this issue relates to females, rather than males, and therefore will not impact the management quantities drastically, the author chosen model is M17C.D17a.

## Notes for future assessments

Weighting growth more heavily may eliminate one of the modes in M17Aa.D17a or similar models in the future. Adding the growth data the Kodiak Lab provided may also improve this behavior of the model, though it appears that the change point in growth is out of the range in which it is currently estimated for females. If instability persists, starting MCMC chains from either extreme of the converged models and comparing chains may be a good diagnostic to identify non-convergence. Closer attention needs to be paid to weighting schemes to understand how they relate to model stabilty.

Table 3: Estimated parameter values by scenario (these are maximum likelihood estimates)

| Parameter | M17Aa D17a | M17Ab <br> D17a | M17C D17a |
| :---: | :---: | :---: | :---: |
| af | -4.96 | -5.03 | -5.26 |
| am | -12.41 | -11.37 | -5.34 |
| bf | 1.52 | 1.52 | 1.53 |
| bm | 1.84 | 1.76 | 1.52 |
| b1 | 1.15 | 1.12 | 1.15 |
| bf1 | 1.04 | 1.03 | 1.04 |
| deltam | 27.41 | 34.05 | 32.13 |
| deltaf | 34.31 | 34.37 | 34.13 |
| mateste | vector | vector | vector |
| matestfe | vector | vector | vector |
| rec_devf | vector | vector | vector |
| mnatlen_styr | vector | vector | vector |
| fnatlen_styr | vector | vector | vector |
| log_avg_fmort | -0.33 | -0.03 | -0.29 |
| fmort_dev | vector | vector | vector |
| log_avg_fmortdf | -6.34 | -6.23 | -5.66 |
| fmortdf_dev | vector | vector | vector |
| log_avg_fmortt | -4.82 | -4.49 | -4.61 |
| fmortt_dev_era1 | vector | vector | vector |
| fmortt_dev_era2 | vector | vector | vector |
| log_avg_sel50_mn | 4.67 | 4.67 | 4.67 |
| fish_slope_mn | 0.19 | 0.19 | 0.19 |
| fish_fit_slope_mn | 0.42 | 0.44 | 0.43 |
| fish_fit_sel50_mn | 96.08 | 95.72 | 96.07 |
| fish_disc_slope_f | 0.24 | 0.25 | 0.25 |
| fish_disc_sel50_f | 4.26 | 4.25 | 4.25 |
| fish_disc_slope_tf | 0.09 | 0.09 | 0.07 |
| fish_disc_sel50_tf | 109.02 | 112.53 | 112.95 |
| srv2_q | 0.34 | 0.43 | 0.43 |
| srv2_q_f | 0.35 | 0.42 | 0.51 |
| srv2_sel95 | 57.52 | 56.15 | 54.52 |
| srv2_sel50 | 39.42 | 39.65 | 38.26 |
| srv3_q | 0.68 | 0.75 | 0.71 |
| srv3_sel95 | 57.91 | 52.11 | 48.02 |
| srv3_sel50 | 38.91 | 37.43 | 34.38 |
| srv3_q_f | 0.54 | 0.61 | 1 |
| srv3_sel95_f | 43.57 | 43.88 | 45.58 |
| srv3_sel50_f | 33.76 | 34.01 | 35.22 |
| srvind_q | 1 | 1 | 1 |
| srvind__q_f | 0.11 | 0.11 | 0.17 |
| srvind_sel95_f | 55 | 55 | 55 |
| srvind_sel50_f | 49.26 | 49.17 | 49.39 |
| srv10ind_q_f | 1 | 1 | 1 |
| selsmo10ind | vector | vector | vector |
| selsmo09ind | vector | vector | vector |
| Mmult_imat | 1.87 | 2 | 1.22 |
| Mmult | 1.07 | 1.11 | 1.16 |
| Mmultf |  |  | 1.55 |


| Parameter | M17Aa | M17Ab |  |
| :--- | :---: | :---: | :---: |
| D17a | D17a | M17C D17a |  |
| cpueq | 0 | 0 | 0 |

Table 4: Contribution to the objective function by individual likelihood component by modeling scenario. Values in columns after Model 0 are the likelihood contribution of Model 0 minus the likelihood contribution of the model in the column. Positive values represent improvements in fit. Note that some of the model scenarios involve changing the weightings of data sources which invalidate the comparison of likelihoods for a data source among models.

| Likelihood component | M17Aa D17a | $\begin{gathered} \text { M17Ab } \\ \text { D17a } \end{gathered}$ | M17C D17a |
| :---: | :---: | :---: | :---: |
| Recruitment deviations | 38.37 | 39.89 | 38.81 |
| Initial numbers old shell males small length bins | 5.14 | 4.9 | 4.73 |
| ret fishery length | 309.36 | 314.94 | 305.31 |
| total fish length $(\text { ret }+ \text { disc })$ | 866.58 | 867.36 | 866.83 |
| female fish length | 236.3 | 238.49 | 233.89 |
| survey length | 4328.06 | 4340.72 | 4266.95 |
| trawl length | 311.92 | 333.95 | 265.69 |
| 2009 BSFRF | -86.59 | -87.08 | -93.56 |
| length 2009 NMFS study area length | -68.52 | -69.01 | -74.83 |
| M multiplier prior | 18.33 | 26.09 | 81.53 |
| maturity smooth | 37.72 | 35.37 | 36.73 |
| growth males | 41.81 | 46.88 | 36.46 |
| growth females | 127.54 | 124.83 | 117.57 |
| 2009 BSFRF | 0.37 | 0.47 | 0.38 |
| biomass |  |  |  |
| 2009 NMFS study area biomass | 0.09 | 0.17 | 0.12 |
| cpue q | 0.22 | 0.23 | 0.18 |
| retained catch | 3.8 | 3.62 | 3.88 |
| discard catch | 145.49 | 92.71 | 157.39 |
| trawl catch | 8.17 | 7.73 | 7.08 |
| female discard catch | 5.33 | 5.5 | 5.36 |
| survey biomass | 314.7 | 308.52 | 281.73 |
| F penalty | 25.13 | 28.87 | 24.64 |
| 2010 BSFRF | 3.83 | 6.73 | 20.78 |
| Biomass |  |  |  |
| 2010 NMFS | 1.44 | 1.87 | 1.45 |
| Biomass |  |  |  |
| Extra weight survey lengths first year | 564.67 | 562.36 | 553.32 |
| 2010 BSFRF | -49.09 | -50.56 | -49.58 |
| length |  |  |  |
| 2010 NMFS | -55.91 | -51.94 | -58.37 |
| length <br> smooth selectivity | 2.45 | 3.93 | 2.99 |


| Likelihood <br> component | M17Aa D17a | M17Ab <br> D17a | M17C D17a |
| :--- | :---: | :---: | :---: |
| smooth female <br> selectivity | 0 | 0 | 0 |
| init nos smooth <br> constraint <br> Total | 47.49 | 46.24 | 45.81 |

Table 5: Changes in management quantities for each scenario considered. Reported management quantities are median posterior values.

| Model | MMB | B35 | F35 | FOFL | OFL |
| :--- | :---: | :---: | :---: | :---: | :---: |
| M17Aa D17a | 88.16 | 147.6 | 1.38 | 0.9 | 24.66 |
| M17Ab D17a | 71.86 | 140.5 | 1.51 | 0.94 | 19.64 |
| M17C D17a | 94.43 | 139.3 | 1.31 | 0.89 | 28.41 |

Table 6: Predicted mature male (MMB), mature female (FMB), and males $>101 \mathrm{~mm}$ biomass ( 1000 t ) and numbers (in millions) at the time of the survey from the chosen model. Columns 2-5 are subject to survey selectivity; columns 6-9 are the population values (i.e. the numbers at length are not modified by multiplying them by a selectivity curve-they are estimates of the underlying population). These are maximum likelihood estimates that will differ slightly from the median posterior values.

| Survey <br> year | FMB | MMB | Male $>101$ <br> biomass | Male $>101$ <br> (millions) | FMB | MMB | Male $>101$ <br> biomass | Male $>101$ <br> (millions) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1982 | 64.58 | 125.6 | 35.69 | 67.76 | 133.9 | 289.9 | 59.48 | 113 |
| 1983 | 53.39 | 132.1 | 59.19 | 105.9 | 109.9 | 305.2 | 98.65 | 176.5 |
| 1984 | 40.97 | 139 | 80.72 | 138.9 | 84.45 | 321.2 | 134.6 | 231.5 |
| 1985 | 40.51 | 133 | 84.14 | 142.3 | 84.02 | 307.5 | 140.2 | 237.2 |
| 1986 | 51.18 | 116.8 | 50.02 | 84.3 | 106.5 | 270.3 | 115.3 | 194.3 |
| 1987 | 87.61 | 111 | 42.36 | 72.82 | 183 | 257.7 | 97.66 | 167.9 |
| 1988 | 210.4 | 189 | 36.98 | 63.99 | 212.7 | 265.2 | 85.26 | 147.5 |
| 1989 | 239.5 | 218.3 | 40.68 | 72.11 | 242.2 | 306.3 | 93.78 | 166.2 |
| 1990 | 218.5 | 282.9 | 69.54 | 121.8 | 220.6 | 396.7 | 160.3 | 280.8 |
| 1991 | 173.5 | 268.5 | 66.32 | 114.7 | 175.1 | 376.4 | 152.9 | 264.4 |
| 1992 | 138.2 | 224.9 | 53.34 | 93.08 | 139.5 | 315.2 | 123 | 214.6 |
| 1993 | 192.2 | 192.8 | 75.79 | 128.2 | 194.6 | 270.6 | 106.1 | 179.5 |
| 1994 | 219.7 | 164.8 | 45.95 | 76.84 | 222 | 231.3 | 64.31 | 107.5 |
| 1995 | 195.7 | 182.1 | 44.86 | 79.1 | 197.6 | 255.6 | 62.79 | 110.7 |
| 1996 | 153.1 | 256.4 | 106.8 | 187.5 | 154.5 | 359.4 | 149.5 | 262.4 |
| 1997 | 113.2 | 306.8 | 168.8 | 283.3 | 114.2 | 429.8 | 236.2 | 396.6 |
| 1998 | 83.85 | 232.2 | 121 | 200.8 | 84.63 | 325.4 | 169.3 | 281.1 |
| 1999 | 72.46 | 148.8 | 63.44 | 106.3 | 73.21 | 208.5 | 88.79 | 148.8 |
| 2000 | 71.87 | 120.4 | 49.1 | 81.79 | 72.64 | 168.8 | 68.73 | 114.5 |
| 2001 | 65.03 | 101.9 | 37.89 | 63.82 | 65.67 | 142.9 | 53.03 | 89.32 |
| 2002 | 54.37 | 95.1 | 35.6 | 61.31 | 54.9 | 133.3 | 49.82 | 85.82 |
| 2003 | 50.48 | 99.66 | 44.98 | 76.57 | 51.01 | 139.7 | 62.95 | 107.2 |
| 2004 | 59.15 | 100.5 | 49.87 | 83.01 | 59.83 | 140.8 | 69.8 | 116.2 |
| 2005 | 80.78 | 96.07 | 44.58 | 73.92 | 81.75 | 134.8 | 62.39 | 103.5 |
| 2006 | 88.5 | 97.77 | 39.85 | 67.53 | 89.44 | 137.2 | 55.78 | 94.51 |
| 2007 | 86.81 | 116.4 | 49.88 | 85.65 | 87.72 | 163.2 | 69.81 | 119.9 |
| 2008 | 73.82 | 135.9 | 66.18 | 113.2 | 74.53 | 190.5 | 92.63 | 158.5 |
| 2009 | 58.23 | 147 | 80.35 | 134.6 | 58.78 | 206 | 112.5 | 188.3 |
| 2010 | 60.37 | 141.4 | 80.73 | 133.8 | 61.05 | 198.1 | 113 | 187.2 |
| 2011 | 66.19 | 122.8 | 67.49 | 111.2 | 66.91 | 172 | 94.46 | 155.7 |
| 2012 | 64.36 | 91.39 | 38.45 | 64.94 | 65.02 | 128.1 | 53.81 | 90.88 |
| 2013 | 62.46 | 84.19 | 31.54 | 55.38 | 63.12 | 118.1 | 44.14 | 77.5 |
| 2014 | 63.05 | 90.83 | 39.35 | 67.58 | 63.72 | 127.4 | 55.08 | 94.58 |
| 2015 | 60.13 | 86.02 | 36.39 | 61.79 | 60.75 | 120.6 | 50.93 | 86.48 |
| 2016 | 76.31 | 89.96 | 38.84 | 65.8 | 77.23 | 126.2 | 54.36 | 92.1 |
| 2017 | 147 | 110.2 | 48.51 | 81.41 | 148.9 | 154.8 | 67.89 | 113.9 |
|  |  |  |  |  |  |  |  |  |

Table 7: Maximum likelihood estimates of predicted mature male biomass at mating, mature female biomass at mating (in 1000 t ), and recruitment (millions) from the chosen model. These are maximum likelihood estimates that will differ slightly from the median posterior values.

|  | Mature male <br> biomass | Mature <br> female <br> biomass | Recruits |
| :---: | :---: | :---: | :---: |
| 1982 | 232 | 107.1 | 265.7 |
| 1983 | 245.3 | 87.92 | 938.8 |
| 1984 | 240.8 | 67.54 | 1469 |
| 1985 | 214.4 | 67.2 | 3752 |
| 1986 | 180.1 | 85.12 | 1000 |
| 1987 | 155.5 | 146.4 | 2919 |
| 1988 | 155.6 | 170.1 | 102.3 |
| 1989 | 187.8 | 193.7 | 388.1 |
| 1990 | 192.4 | 176.5 | 451.1 |
| 1991 | 178.1 | 140 | 4020 |
| 1992 | 164.3 | 111.5 | 1047 |
| 1993 | 160.2 | 155.6 | 551.5 |
| 1994 | 158.6 | 177.4 | 139.7 |
| 1995 | 186.4 | 158 | 80.12 |
| 1996 | 251.5 | 123.5 | 129.6 |
| 1997 | 249.8 | 91.33 | 530.3 |
| 1998 | 185.4 | 67.68 | 583.2 |
| 1999 | 160.6 | 58.55 | 184.6 |
| 2000 | 130.7 | 58.09 | 178.4 |
| 2001 | 105.3 | 52.52 | 410.8 |
| 2002 | 99.73 | 43.91 | 779.7 |
| 2003 | 107 | 40.79 | 1202 |
| 2004 | 107.2 | 47.84 | 502.4 |
| 2005 | 96.79 | 65.38 | 590.7 |
| 2006 | 99.09 | 71.52 | 93.74 |
| 2007 | 109.8 | 70.15 | 135 |
| 2008 | 135 | 59.6 | 786.9 |
| 2009 | 152.3 | 47.01 | 531.1 |
| 2010 | 142.8 | 48.83 | 335.1 |
| 2011 | 104.5 | 53.41 | 472.7 |
| 2012 | 77.57 | 52 | 500.5 |
| 2013 | 75.44 | 50.47 | 311.3 |
| 2014 | 76.94 | 50.87 | 1272 |
| 2015 | 83.27 | 48.57 | 3365 |
| 2016 | 96.97 | 61.77 | 2315 |
|  |  |  |  |
|  |  | Sur | near |

Table 8: Maximum likelihood estimates of predicted total numbers (millions), not subject to survey selectivity at the time of the survey. These are maximum likelihood estimates that will differ slightly from the median posterior values.

| Survey year | Total <br> numbers |
| :---: | :---: |
| 1982 | 6.015 |
| 1983 | 4.933 |
| 1984 | 5.494 |
| 1985 | 6.971 |
| 1986 | 12.62 |
| 1987 | 11.36 |
| 1988 | 14.14 |
| 1989 | 10.55 |
| 1990 | 8.372 |
| 1991 | 6.719 |
| 1992 | 12.67 |
| 1993 | 11.32 |
| 1994 | 9.36 |
| 1995 | 7.089 |
| 1996 | 5.288 |
| 1997 | 4.031 |
| 1998 | 3.83 |
| 1999 | 3.853 |
| 2000 | 3.198 |
| 2001 | 2.697 |
| 2002 | 2.782 |
| 2003 | 3.596 |
| 2004 | 5.061 |
| 2005 | 4.758 |
| 2006 | 4.678 |
| 2007 | 3.617 |
| 2008 | 2.879 |
| 2009 | 3.645 |
| 2010 | 3.736 |
| 2011 | 3.405 |
| 2012 | 3.398 |
| 2013 | 3.462 |
| 2014 | 3.138 |
| 2015 | 4.806 |
| 2016 | 10.28 |
| 2017 | 12.31 |
|  |  |
|  |  |

M17Aa D17a
M17Ab D17a
M17C D17a


Figure 1: Management quantities after jittering all models.

F35
MMB
OFL

 M17Aa D17a



M17Ab D17a
M17C D17a

Figure 2: Management quantities after jittering all models.


Figure 3: Posterior densities for management quantities by scenario


Figure 4: Basic MCMC diagnostics. Left colum is the density of the value of the objective function. Middle column is the trace of the objective function. Number in the upper left of each panel is the z-score of the Geweke diagnostic. Right is the autocorrelation in the objective function value.


Figure 5: Traces for parameters from each model


Figure 6: Model fits to the growth data


Figure 7: Estimated survey selectivity


Figure 8: Posterior densities for estimated parameters by scenario


Figure 9: Posterior densities for estimated parameters by scenario


Figure 10: Posterior densities for estimated parameters by scenario


Figure 11: Posterior densities for estimated parameters by scenario


Figure 12: Model fits to the observed mature biomass at survey


Figure 13: Model fits to catch data


Figure 14: Model fits to retained catch size composition data


Figure 15: Model fits to trawl catch size composition data


Figure 16: Model fits to female survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1. Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.


Figure 17: Model fits to male survey size composition data. Note that male and female survey selectivity proportions at length in a given year sum to 1 . Consequently, the integral of predicted length compositions may appear to be different than the integral of the observed length composition data.


Figure 18: Estimated probability of maturing


Figure 19: Model predicted fishing mortalities and selectivities for all sources of mortality


Figure 20: Estimated recruitment, fits to stock recruit curve (MMB lagged 5 years), and proportions recruiting to length bin

# BRISTOL BAY RED KING CRAB STOCK ASSESSMENT IN FALL 2017 

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## Executive Summary

1. Stock: red king crab (RKC), Paralithodes camtschaticus, in Bristol Bay, Alaska.
2. Catches: The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs $(58,943 \mathrm{t})$. The catch declined dramatically in the early 1980s and remained at low levels during the last three decades. Catches during recent years until 2010/11 were among the high catches in last 15 years. The retained catch in 2016/17 was about 8.5 million lbs ( $3,924 \mathrm{t}$ ), below the catch in 2015/16 ( 10 million lbs). The magnitude of bycatch from groundfish trawl and fixed gear fisheries has been stable and small relative to stock abundance during the last 10 years.
3. Stock biomass: Estimated mature biomass increased dramatically in the mid-1970s and decreased precipitously in the early 1980s. Estimated mature crab abundance had increased during 1985-2009 with mature females being about three times more abundant in 2009 than in 1985 and mature males being about two times more abundant in 2009 than in 1985. Estimated mature abundance has steadily declined since 2009.
4. Recruitment: Estimated recruitment was high during 1970s and early 1980s and has generally been low since 1985 (1979 year class). During 1984-2017, only in 1984, 1986, 1995, 1999, 2002 and 2005 were estimated recruitments above the historical average for 1976-2017. Estimated recruitment was extremely low during the last nine years.
5. Management performance:

Status and catch specifications (1,000 t) (scenario 2b):

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2013 / 14$ | $12.85^{\mathrm{A}}$ | $27.12^{\mathrm{A}}$ | 3.90 | 3.99 | 4.56 | 7.07 | 6.36 |
| $2014 / 15$ | $13.03^{\mathrm{B}}$ | $27.25^{\mathrm{B}}$ | 4.49 | 4.54 | 5.44 | 6.82 | 6.14 |
| $2015 / 16$ | $12.89^{\mathrm{C}}$ | $27.68^{\mathrm{C}}$ | 4.52 | 4.61 | 5.34 | 6.73 | 6.06 |
| $2016 / 17$ | $12.53^{\mathrm{D}}$ | $25.81^{\mathrm{D}}$ | 3.84 | 3.92 | 4.28 | 6.64 | 5.97 |
| $2017 / 18$ |  | $21.31^{\mathrm{D}}$ |  |  |  | 5.60 | 5.04 |

The stock was above MSST in 2016/17 and hence was not overfished. Overfishing did not occur.

Status and catch specifications (million lbs):

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :---: | :---: | :---: | ---: | ---: | ---: | ---: | ---: |
| $2013 / 14$ | $28.3^{\mathrm{A}}$ | $59.9^{\mathrm{A}}$ | 8.60 | 8.80 | 10.05 | 15.58 | 14.02 |
| $2014 / 15$ | $28.7^{\mathrm{B}}$ | $60.1^{\mathrm{B}}$ | 9.99 | 10.01 | 11.99 | 15.04 | 13.53 |
| $2015 / 16$ | $28.4^{\mathrm{C}}$ | $61.0^{\mathrm{C}}$ | 9.97 | 10.17 | 11.77 | 14.84 | 13.36 |
| $2016 / 17$ | $27.6^{\mathrm{D}}$ | $56.9^{\mathrm{D}}$ | 8.47 | 8.65 | 9.45 | 14.63 | 13.17 |
| $2017 / 18$ |  | $47.0^{\mathrm{D}}$ |  |  |  | 12.35 | 11.11 |

Notes:
A - Calculated from the assessment reviewed by the Crab Plan Team in September 2014
B - Calculated from the assessment reviewed by the Crab Plan Team in September 2015
C - Calculated from the assessment reviewed by the Crab Plan Team in September 2016
D - Calculated from the assessment reviewed by the Crab Plan Team in September 2017
6. Basis for the OFL: All table values are in 1000 t (Scenario 2b):

| Year | Tier | BMSY | Current <br> MMB | B/BMSY <br> (MMB) | FofL | Years to <br> define <br> BMSY | Natural <br> Mortality |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2013 / 14$ | 3b | 26.4 | 25.0 | 0.95 | 0.27 | $1984-2013$ | 0.18 |
| $2014 / 15$ | $3 b$ | 25.7 | 24.7 | 0.96 | 0.28 | $1984-2014$ | 0.18 |
| $2015 / 16$ | 3b | 26.1 | 24.7 | 0.95 | 0.27 | $1984-2015$ | 0.18 |
| $2016 / 17$ | 3b | 25.8 | 24.0 | 0.93 | 0.27 | $1984-2016$ | 0.18 |
| $2017 / 18$ | 3b | 25.1 | 21.3 | 0.85 | 0.24 | $1984-2017$ | 0.18 |

Basis for the OFL: All table values are in million lbs:

| Year | Tier | BMSY | Current <br> MMB | B/BMSY <br> (MMB) | FofL | Years to <br> define <br> BMSY | Natural <br> Mortality |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2013 / 14$ | 3b | 58.2 | 55.0 | 0.95 | 0.27 | $1984-2013$ | 0.18 |
| $2014 / 15$ | $3 b$ | 56.7 | 54.4 | 0.96 | 0.28 | $1984-2014$ | 0.18 |
| $2015 / 16$ | $3 b$ | 57.5 | 54.4 | 0.95 | 0.27 | $1984-2015$ | 0.18 |
| $2016 / 17$ | 3b | 56.8 | 52.9 | 0.93 | 0.27 | $1984-2016$ | 0.18 |
| $2017 / 18$ | 3b | 55.2 | 47.0 | 0.85 | 0.24 | $1984-2017$ | 0.18 |

## A. Summary of Major Changes

1. Change to management of the fishery: None.

## 2. Changes to the input data:

a. Updating summer trawl survey data and directed pot fisheries catch and bycatch data through 2017.
b. Updating BSFRF side-by-side trawl survey data in 2016 made in May 2017. Total survey biomass decreased from 87725.1 t initially estimated in September 2016 to 77815.7 t in the final estimate, about $11.3 \%$ reduction. The initial estimate mistakenly includes the tows conducted in the recruitment study.
c. Updating groundfish fisheries bycatch data during 2009-2016 and separating bycatch data by trawl fisheries and fixed gear fisheries.

## 3. Changes to the assessment methodology:

a. Francis’ approaches for re-weighting effective sample sizes for size composition data are applied for some scenarios and are detailed in Appendix C.
b. Nine model scenarios are compared in this report (See Section E.3.a for details):

Scenario 2a: the same as Scenario 2a in the SAFE draft report in May 2017 and a minor revision of scenario 2 in the SAFE report in September 2016 with the updated data. This scenario assumes that BSFRF survey capture probabilities are 1.0 for all length groups. Under this assumption, NMFS survey selectivities are the products of crab availabilities (equal to BSFRF survey selectivities) and NMFS survey capture probabilities. A survey capture probability for a length group is simply defined as the proportion of the crab in the length group within the area-swept that is caught by the survey net.
Scenario 2a differs from scenario 2 through changing the fishing time of the groundfish fisheries bycatch from the same time as the directed pot fishery under scenario 2 to the midpoint of the crab year (the same as Tanner crab fishery bycatch) to more accurately reflect the fishing timing. Also to reduce the number of estimated parameters, all fishing mortalities for the terminal year are not estimated during parameter estimation since the fisheries have not occurred in the model for scenario 2 a .

Scenario 2a1: the same as Scenario 2a except for applying Francis' approach 1 (Appendix C) to the effective sample sizes of size composition data used in scenario 2 a .

Scenario 2a2: the same as Scenario 2a except for applying Francis' approach 2 to the effective sample sizes of size composition data used in scenario 2 a .
Scenario 2b: the same as scenario 2a except for separating groundfish fisheries bycatch by trawl fisheries and fixed gear fisheries.

Scenario 2b1: the same as Scenario $2 b$ except for applying Francis' approach 1 to the effective sample sizes of size composition data used in scenario 2 b .

Scenario 2b2: the same as Scenario $2 b$ except for applying Francis' approach 2 to the effective sample sizes of size composition data used in scenario 2 b .

Scenario 2d: the same as scenario 2 b except without trawl survey catchability prior from the double-bag experiment and for using a logit transformation to make sure trawl survey catchability be $<1.0$.
Scenario 2d1: the same as Scenario 2d except for applying Francis' approach 1 to the effective sample sizes of size composition data used in scenario 2 d .
Scenario 2d2: the same as Scenario 2d except for applying Francis' approach 2 to the effective sample sizes of size composition data used in scenario 2 d .

## 4. Changes to assessment results:

The population biomass estimates in 2017 are lower than those in 2016. Among the nine scenarios, model estimated relative survey biomasses are very similar. The absolute population biomass estimates are higher for scenarios $2 \mathrm{~b}, 2 \mathrm{~b} 1,2 \mathrm{~b} 2,2 \mathrm{a}, 2 \mathrm{a}$, and 2 a 2 than for scenarios 2 d , 2 d 1 and 2 d 2 during recent years due to slightly lower estimated trawl survey catchability values. Francis' approaches reduce effective sample sizes greatly and estimates are very difficult to converging. We recommend either scenario 2 b or 2 d for September 2017 assessment because of corrected data and refined approaches to estimation of survey catchability and more work needed for Francis' approach.

The recruitment breakpoint analysis (Appendix B) estimates 1986 as the breakpoint brood year, or 1992 recruitment year in May 2017.

## B. Responses to SSC and CPT Comments

## 1. Responses to the most recent two sets of SSC and CPT comments on assessments in general:

No response from this assessment.

## 2. Responses to the most recent two sets of SSC and CPT comments specific to this assessment:

## Response to CPT Comments (from May 2016)

"The CPT had several comments about this approach. First, it was noted at NMFS/BSRF ratios were highly variable, and that a better approach would be to consider the ratio of the NMFS survey to the sum of two surveys NMFS/(NMFS+BSFRF). Second, an attempt should be made to fit actual tow-by-tow data rather than survey aggregates. Finally, catchability for the NMFS survey was estimated to be greater than one for some model runs (this only occurred when the prior was omitted).It was suggested that catchability could be limited to values less than one by parameterizing catchability on a logit scale. The CPT concluded that these issues needed to be addressed before scenario 3 could be adopted."

The ratio of the NMFS survey to the sum of two surveys NMFS/(NMFS+BSFRF) was also evaluated in May 2016 and the results were not presented to the CPT meeting but were added to the final draft report. We agree that this approach is better than the NMFS/BSRF ratios.

Due to very small amount of crab caught in each tow, it is not feasible to fit the actual tow-bytow data.

We examined the approach to parameterize catchability on a logit scale so that it is less or equal to 1.0 in this report (scenarios 2d, 2d1, and 2d2) (September 2017).
"The CPT requests that the following models be brought forward in September 2016: scenario 1 (status quo), scenario 1n, and scenario 2. Since results from the 2016 BSFRF survey will be available on the same timetable as the 2016 NMFS survey, these data should be incorporated into scenarios $1 n$ and 2."

These three scenarios were presented in the September 2016 SAFE report.

## Response to CPT Comments (from September 2016)

"The CTP requests that model runs be provided to evaluate the impact of including or excluding the prior on catchability based on the under-bag experiment."

Among nine scenarios in this report, scenarios $2 \mathrm{a}, 2 \mathrm{a} 1,2 \mathrm{a} 2,2 \mathrm{~b}, 2 \mathrm{~b} 1$, and 2 b 2 are with the prior on catchability, and scenarios $2 \mathrm{~d}, 2 \mathrm{~d} 1$, and 2 d 2 without the prior on catchability but with a logit transformation of survey catchability parameter so that it is less than 1.0.

## Response to CPT Comments (from May 2017)

"The CPT recommended the following scenarios be evaluated for the Fall 2017 assessment:

- Scenario $2 a$
- Scenario $2 b$
- Scenario 2d

In addition, because the discard biomass time series from the groundfish fixed and trawl gear fisheries are not split by sex, these models should be brought forward using two approaches to Francis (2011) re-weighting of the size compositions: one based on weights calculated as if all the size compositions were sex-specific, and one based on weights calculated from the "extended" size compositions used in the models for the groundfish fixed gear and trawl gear bycatch size compositions. The former approach is based on the expectation of sex-specific changes in mean length, but does not reflect the loss of sex ratio information associated with splitting the size compositions by sex, whereas the latter approach incorporates this information while the weights are based on expectations for changes in size class across the "extended" size composition."

All nine scenarios in the SAFE report in September 2017 address this comment.

## Response to SSC Comments specific to this assessment (from October 2015)

"The SSC recommends that the authors examine whether or not the current time period for estimation of biological reference points is indicative of the expected range of recruitment given current environmental conditions. The SSC also notes that although no barren females were
observed, a large number of females had $3 / 4$ full clutches. This observation may suggest that the population may be undergoing environmental stress. Above average recruitment has not been observed in the last 12 years and the apparent spike in recruitment observed in the 2012 survey did not recruit to the adult population. These observations raise concerns about the future status of the stock. The SSC recommends an examination of mechanisms underlying lack of recruitment to this stock. Specifically, the SSC requests that the author uses the breakpoint analysis applied for Tanner crab to BBRKC to evaluate whether there was a detectable break in production in 2006. This analysis should be conducted as a diagnostic tool to identify possible changes in production of this stock but should not be used to change the time frame used to estimate biological reference points."

We conducted a recruitment breakpoint analysis similar to those on Tanner crab in 2013 (Appendix B). With either a Ricker or Beverton-Bolt stock-recruitment model, the estimated breakpoint brood year is 1986, or recruitment year 1992. Low recruitments in recent years are a big concern, and without a field study on the mechanisms underlying lack of recruitment to this stock, it is difficult to figure out what the real causes are. We will continue to look out for environmental data to improve understanding the recruitment dynamics of this stock.
"The SSC is supportive of continued research on trawl performance. It would be useful to examine temperature and size effects on spatial aggregation of BBRKC and the relationship between these factors and trawl performance. Given the importance of the BSFRF survey in this assessment, the SSC concurs with the CPT that further research should be conducted to assess the potential for herding with the BSFRF net. The SSC supports the CPT request for an exploration of the impact of including or excluding the prior on catchability based on the underbag experiment."

We support the continued research on trawl performance by NMFS and BSFRF.
We have nine scenarios in this report (September 2017) to examine the impact of including or excluding the prior on catchability based on the under-bag experiment: scenarios $2 \mathrm{a}, 2 \mathrm{a} 1,2 \mathrm{a} 2$, $2 \mathrm{~b}, 2 \mathrm{~b} 1$, and 2 b 2 are with the prior on catchability, and scenarios $2 \mathrm{~d}, 2 \mathrm{~d} 1$, and 2 d 2 without the prior on catchability but with a logit transformation of survey catchability parameter so that it is less than 1.0.

## Response to SSC Comments specific to this assessment (from June 2016):

"The SSC supports the CPT recommendation to bring forward three scenarios for the stock assessment in fall 2016: (1) scenario 1, which is the status quo (2015) using BSFRF data from 2007 ad 2008 in which the two surveys are treated as independent surveys and survey selectivities are estimated separately and directly in the model; (2) scenario 1n, which is the same as scenario 1 but also includes the 2013-2015 BSFRF survey data, and (3) scenario 2, which is the same as scenario 1n but assumes that the BSFRF survey has capture probabilities of 1.0 for all length groups.

When these scenarios are presented, the terms "capture probabilities" and "selectivity" should be clearly defined. In the report, their descriptions seemed somewhat confusing and contradictory. For instance, Figure 6 implies catchabilities at small sizes in the BSFRF survey
that are less than 1.0 for all scenarios, but from the text, this should not be the case. It is important that the definitions and procedures are clearly described."

We reported the results of these three scenarios in the SAFE report in September 2016 and clarified use of the terms "capture probabilities" and "selectivity" throughout the report.

## Response to SSC Comments specific to this assessment (from June 2017):

"Five model scenarios were investigated prior to the spring CPT meeting, the results of which suggested relatively minor differences with regard to management quantities. The SSC supports the CPT's and author's recommendations regarding model scenarios to bring forward this fall, which include the following: add the 2016 BSFRF data, separate bycatch components, remove the informative prior and reparameterize NMFS survey catchability to exclude values greater than 1.0, as well as alternatives for data weighting within these scenarios."

Nine scenarios in this SAFE report address this comment.
"The SSC noted that only scenarios utilizing Francis weighting methods were proposed for evaluation in the fall. As noted earlier regarding general guidance to the CPT and assessment authors, the SSC encourages stock assessment authors and the CPT to continue to consider alternative approaches, as data weighting is not a 'one-size-fits-all' problem. The best method for data weighting will depend on the quality of the data, the time-series length, the conflict among data sources and other factors unique to a specific assessment. Thus, the BBRKC stock assessment author should retain sufficient latitude to use a method appropriate for this particular assessment, noting that internal consistency is more important than blanket consistency across assessments dealing with a variety of unique data configurations and estimation issues. Evaluation of alternative data weighting approaches can be a useful diagnostic tool to better understand conflicts among data sources within the BBRKC assessment."

Authors wholeheartedly agree with this SSC comment. We used Francis' approach in this report and were a little struggled to get scenarios converged. The effective sample sizes are greatly reduced through Francis' approach. We will search for alternative approaches in the future.
"Also, the SSC encourages the BBRKC author to objectively define the terminal year of recruitment to include in reference point calculations in this assessment. For BBRKC, where all recent recruitment years have been used in the past, dropping one or more years at the end of the time-series might be warranted. A general rule could be based on the variance of the estimated recruitments and/or the youngest ages of crabs sampled by the fishing gear and/or survey gear included in the model."

This is a very good suggestion. We did not make any changes for this report due to many scenarios and will evaluate this in May 2018.

## C. Introduction

## 1. Species

Red king crab (RKC), Paralithodes camtschaticus, in Bristol Bay, Alaska.

## 2. General distribution

Red king crab inhabit intertidal waters to depths $>200 \mathrm{~m}$ of the North Pacific Ocean from British Columbia, Canada, to the Bering Sea, and south to Hokkaido, Japan, and are found in several areas of the Aleutian Islands, eastern Bering Sea, and the Gulf of Alaska.

## 3. Stock Structure

The State of Alaska divides the Aleutian Islands and eastern Bering Sea into three management registration areas to manage RKC fisheries: Aleutian Islands, Bristol Bay, and Bering Sea (Alaska Department of Fish and Game (ADF\&G) 2012). The Bristol Bay area includes all waters north of the latitude of Cape Sarichef ( $54^{\circ} 36^{\prime} \mathrm{N}$ lat.), east of $168^{\circ} 00^{\prime} \mathrm{W}$ long., and south of the latitude of Cape Newenham ( $58^{\circ} 39^{\prime} \mathrm{N}$ lat.) and the fishery for RKC in this area is managed separately from fisheries for RKC outside of this area; i.e., the red king crab in the Bristol Bay area are assumed to be a separate stock from red king crab outside of this area. This report summarizes the stock assessment results for the Bristol Bay RKC stock.

## 4. Life History

Red king crab have a complex life history. Fecundity is a function of female size, ranging from several tens of thousands to a few hundreds of thousands (Haynes 1968; Swiney et al. 2012). The eggs are extruded by females, fertilized in the spring, and held by females for about 11 months (Powell and Nickerson 1965). Fertilized eggs are hatched in the spring, most during April-June (Weber 1967). Primiparous females are bred a few weeks earlier in the season than multiparous females.

Larval duration and juvenile crab growth depend on temperature (Stevens 1990; Stevens and Swiney 2007). Male and female RKC mature at 5-12 years old, depending on stock and temperature (Loher et al. 2001; Stevens 1990) and may live $>20$ years (Matsuura and Takeshita 1990). Males and females attain a maximum size of 227 and 195 mm carapace length (CL), respectively (Powell and Nickerson 1965). Female maturity is evaluated by the size at which females are observed to carry egg clutches. Male maturity can be defined by multiple criteria including spermataphore production and size, chelae vs. carapace allometry, and participation in mating in situ (reviewed by Webb 2014). For management purposes, females $>89 \mathrm{~mm}$ CL and males $>119 \mathrm{~mm}$ CL are assumed to be mature for Bristol Bay RKC. Juvenile RKC molt multiple times per year until age 3 or 4 ; thereafter, molting continues annually in females for life and in males until maturity. Male molting frequency declines after attaining functional maturity.

## 5. Fishery

The RKC stock in Bristol Bay, Alaska, supports one of the most valuable fisheries in the United States. A review of the history of the Bristol Bay RKC fishery is provided in Fitch et al. (2012) and Otto (1989). The Japanese fleet started the fishery in the early 1930s, stopped fishing from 1940 to 1952, and resumed the fishery from 1953 until 1974. The Russian fleet fished for RKC from 1959 to 1971 . The Japanese fleet employed primarily tanglenets with a very small proportion of catch
from trawls and pots. The Russian fleet used only tanglenets. United States trawlers started fishing Bristol Bay RKC in 1947, but the effort and catch declined in the 1950s. The domestic RKC fishery began to expand in the late 1960s and peaked in 1980 with a catch of 129.95 million lbs $(58,943 \mathrm{t})$, worth an estimated $\$ 115.3$ million ex-vessel value. The catch declined dramatically in the early 1980s and has remained at low levels during the last two decades (Table 1). After the early 1980s stock collapse, the Bristol Bay RKC fishery took place during a short period in the fall (usually lasting about a week) with the catch quota based on the stock assessment conducted the previous summer (Zheng and Kruse 2002). Beginning with the 2005/2006 season, new regulations associated with fishery rationalization resulted in an increase in the duration of the fishing season (October 15 to January 15). With the implementation of crab rationalization, historical guideline harvest levels (GHL) were changed to a total allowable catch (TAC). Before rationalization, the implementation errors were quite high for some years and total actual catch from 1980 to 2007 was about $6 \%$ less than the sum of GHL/TAC over that period.

## 6. Fisheries Management

King and Tanner crab stocks in the Bering Sea and Aleutian Islands are managed by the State of Alaska through a federal king and Tanner crab fishery management plan (FMP). Under the FMP, management measures are divided into three categories: (1) fixed in the FMP, (2) frame worked in the FMP, and (3) discretion of the State of Alaska. The State of Alaska is responsible for determining and establishing the GHL/TAC under the framework in the FMP.
Harvest strategies for the Bristol Bay RKC fishery have changed over time. Two major management objectives for the fishery are to maintain a healthy stock that ensures reproductive viability and to provide for sustained levels of harvest over the long term (ADF\&G 2012). In attempting to meet these objectives, the GHL/TAC is coupled with size-sex-season restrictions. Only males $\geq 6.5$-in carapace width (equivalent to $135-\mathrm{mm}$ carapace length, CL) may be harvested and no fishing is allowed during molting and mating periods (ADF\&G 2012). Specification of TAC is based on a harvest rate strategy. Before 1990, harvest rates on legal males were based on population size, abundance of prerecruits to the fishery, and postrecruit abundance, and rates varied from less than $20 \%$ to $60 \%$ (Schmidt and Pengilly 1990). In 1990, the harvest strategy was modified, and a $20 \%$ mature male harvest rate was applied to the abundance of mature-sized ( $\geq 120-\mathrm{mm}$ CL) males with a maximum $60 \%$ harvest rate cap of legal ( $\geq 135-\mathrm{mm}$ CL) males (Pengilly and Schmidt 1995). In addition, a minimum threshold of 8.4 million mature-sized females ( $\geq 90-\mathrm{mm} \mathrm{CL}$ ) was added to existing management measures to avoid recruitment overfishing (Pengilly and Schmidt 1995). Based on a new assessment model and research findings (Zheng et al. 1995a, 1995b, 1997a, 1997b), the Alaska Board of Fisheries adopted a new harvest strategy in 1996. That strategy had two mature male harvest rates: $10 \%$ when effective spawning biomass (ESB) is between 14.5 and 55.0 million lbs and $15 \%$ when ESB is at or above 55.0 million lbs (Zheng et al. 1996). The maximum harvest rate cap of legal males was changed from $60 \%$ to $50 \%$. A threshold of 14.5 million lbs of ESB was also added. In 1997, a minimum threshold of 4.0 million lbs was established as the minimum GHL for opening the fishery and maintaining fishery manageability when the stock abundance is low. The Board modified the current harvest strategy by adding a mature harvest rate of $12.5 \%$ when the ESB is between 34.75 and 55.0 million lbs in 2003 and eliminated the minimum GHL threshold in 2012. The current harvest strategy is illustrated in Figure 1.

## D. Data

## 1. Summary of New Information

The NMFS and BSFRF trawl survey data were updated to include the survey data in 2017.
Catch and biomass data were updated to 2016/17. Groundfish fisheries bycatch data during 2009-2016 were updated and separated into trawl fisheries and fixed gear fisheries bycatches.
Data types and ranges are illustrated in Figure 2.

## 2. Catch Data

Data on landings of Bristol Bay RKC by length and year and catch per unit effort from 1960 to 1973 were obtained from annual reports of the International North Pacific Fisheries Commission (Hoopes et al. 1972; Jackson 1974; Phinney 1975) and from the ADF\&G from 1974 to 2016. Bycatch data are available starting from 1990 and were obtained from the ADF\&G observer database and reports (Gaeuman 2013). Sample sizes for catch by length and shell condition are summarized in Table 2. Relatively large samples were taken from the retained catch each year. Sample sizes for trawl bycatch were the annual sums of length frequency samples in the National Marine Fisheries Service (NMFS) database.

## (i). Catch Biomass

Retained catch and estimated bycatch biomasses are summarized in Table 1 and illustrated in Figure 2. Retained catch and estimated bycatch from the directed fishery include the general, open-access fishery (prior to rationalization), or the individual fishery quota (IFQ) fishery (after rationalization), as well as the Community Development Quota (CDQ) fishery and the ADF\&G cost-recovery harvest. Starting in 1973, the fishery generally occurred during the late summer and fall. Before 1973, a small portion of retained catch in some years was caught from April to June. Because most crab bycatch from the groundfish trawl fisheries occurred during the spring, the years in Table 1 are one year less than those from the NMFS trawl bycatch database to approximate the annual bycatch for reporting years defined as July 1 to June 30; e.g., year 2002 in Table 1 for trawl bycatch corresponds to what is reported for year 2003 in the NMFS database. Catch biomass is shown in Figure 3. Bycatch data for the cost-recovery fishery before 2006 were not available. In this report, pot fisheries include both the directed fishery and RKC bycatch in the Tanner crab pot fishery and trawl fisheries are groundfish trawl fisheries.

## (ii). Catch Size Composition

Retained catch by length and shell condition and bycatch by length, shell condition, and sex were obtained for stock assessments. From 1960 to 1966, only retained catch length compositions from the Japanese fishery were available. Retained catches from the Russian and U.S. fisheries were assumed to have the same length compositions as the Japanese fishery during this period. From 1967 to 1969 , the length compositions from the Russian fishery were assumed to be the same as those from the Japanese and U.S. fisheries. After 1969, foreign catch declined sharply and only length compositions from the U.S. fishery were used to distribute catch by length.

## (iii). Catch per Unit Effort

Catch per unit effort (CPUE) is defined as the number of retained crab per tan (a unit fishing effort for tanglenets) for the Japanese and Russian tanglenet fisheries and the number of retained crab per potlift for the U.S. fishery (Table 1). Soak time, while an important factor influencing CPUE, is difficult to standardize. Furthermore, complete historical soak time data from the U.S. fishery are not available. Based on the approach of Balsiger (1974), all fishing effort from Japan, Russia, and U.S. were standardized to the Japanese tanglenet from 1960 to 1971, and the CPUE was standardized as crab per tan. Except for the peak-to-crash years of late 1970s and early 1980s the correspondence between U.S. fishery CPUE and area-swept survey abundance is poor (Figure 4). Due to the difficulty in estimating commercial fishing catchability and crab availability to the NMFS annual trawl survey data, commercial CPUE data were not used in the model.

## 3. NMFS Survey Data

The NMFS has performed annual trawl surveys of the eastern Bering Sea since 1968. Two vessels, each towing an eastern otter trawl with an 83 ft headrope and a 112 ft footrope, conducted this multispecies, crab-groundfish survey during the summer. Stations were sampled in the center of a systematic $20 \times 20 \mathrm{~nm}$ grid overlaid in an area of $\approx 140,000 \mathrm{~nm}^{2}$. Since 1972 , the trawl survey has covered the full stock distribution except in nearshore waters. The survey in Bristol Bay occurs primarily during late May and June. Tow-by-tow trawl survey data for Bristol Bay RKC during 1975-2017 were provided by NMFS.

Abundance estimates by sex, carapace length, and shell condition were derived from survey data using an area-swept approach (Figures 5a and 5b). Spatial distributions of crab from the standard trawl surveys during recent years are shown in Appendix B. Until the late 1980s, NMFS used a post-stratification approach, but subsequently treated Bristol Bay as a single stratum; the estimates shown for Bristol Bay in Figures 4 and 5 were made without post-stratification. If multiple tows were made for a single station in a given year, the average of the abundances from all tows within that station was used as the estimate of abundance for that station. The new time series since 2015 discards all "hot spot" tows. We used the new area-swept estimates provided by NMFS in 2017.

In addition to standard surveys, NMFS also conducted some surveys after the standard surveys to better assess mature female abundance. In addition to the standard surveys conducted in early June (late May to early June in 1999 and 2000), a portion of the distribution of Bristol Bay RKC was resurveyed in 1999, 2000, 2006-2012, and 2017. Resurveys performed in late July, about six weeks after the standard survey, included 31 stations (1999), 23 stations (2000), 31 stations (2006, 1 bad tow and 30 valid tows), 32 stations (2007-2009), 23 stations (2010) and 20 stations (2011 and 2012) with high female density. The resurveys were necessary because a high proportion of mature females had not yet molted or mated when sampled by the standard survey. Differences in areaswept estimates of abundance between the standard surveys and resurveys of these same stations are attributed to survey measurement errors or to seasonal changes in distribution between survey and resurvey. More large females were observed in the resurveys than during the standard surveys in 1999 and 2000 because most mature females had not molted prior to the standard surveys. As in 2006, area-swept estimates of males $>89 \mathrm{~mm} \mathrm{CL}$, mature males, and legal males within the 32 resurvey stations in 2007 were not significantly different ( $P=0.74,0.74$ and 0.95 ; paired $t$-test of sample means) between the standard survey and resurvey tows. However, similar to 2006, area-
swept estimates of mature females within the 32 resurvey stations in 2007 were significantly different ( $P=0.03$; paired $t$-test) between the standard survey and resurvey tows. Resurvey stations were close to shore during 2010-2012, and mature and legal male abundance estimates were lower for the re-tow than the standard survey. Following the CPT recommendation, we used the standard survey data for male abundance estimates and only the resurvey data, plus the standard survey data outside the resurveyed stations, to assess female abundances during these resurvey years.

## 4. Bering Sea Fisheries Research Foundation Survey Data

The BSFRF conducted trawl surveys for Bristol Bay RKC in 2007 and 2008 with a small-mesh trawl net and 5-minute tows. The surveys occurred at similar times as the NMFS standard surveys and covered about $97 \%$ of the Bristol Bay area. Few Bristol Bay RKC were found outside of the BSFRF survey area. Because of the small mesh size, the BSFRF surveys were expected to catch more of RKC within the swept area. Crab abundances of different size groups were estimated by the kriging method. Mature male abundances were estimated to be 22.331 in 2007 and 19.747 million in 2008 with respective CVs of 0.0634 and 0.0765 . BSFRF also conducted a side-by-side survey concurrent with the NMFS trawl survey during 2013-2016 in Bristol Bay. In May 2017, survey biomass and size composition estimates from 2016 BSFRF side-by-side trawl survey data were updated. Total survey biomass decreased from 87725.1 t initially estimated in September 2016 to 77815.7 t in the final estimate in May 2017, about $11.3 \%$ reduction. The initial estimate mistakenly includes the tows conducted in the recruitment study.

## E. Analytic Approach

## 1. History of Modeling Approaches

To reduce annual measurement errors associated with abundance estimates derived from the area-swept method, ADF\&G developed a length-based analysis (LBA) in 1994 that incorporates multiple years of data and multiple data sources in the estimation procedure (Zheng et al. 1995a). Annual abundance estimates of the Bristol Bay RKC stock from the LBA have been used to manage the directed crab fishery and to set crab bycatch limits in the groundfish fisheries since 1995 (Figure 1). An alternative LBA (research model) was developed in 2004 to include small size groups for federal overfishing limits. The crab abundance declined sharply during the early 1980s. The LBA estimated natural mortality for different periods of years, whereas the research model estimated additional mortality beyond a basic constant natural mortality during 19761993. In this report, we present only the research model that was fit to the data from 1975 to 2017.

## 2. Model Description

The original LBA model was described in detail by Zheng et al. (1995a, 1995b) and Zheng and Kruse (2002). The model combines multiple sources of survey, catch, and bycatch data using a maximum likelihood approach to estimate abundance, recruitment, selectivities, catches, and bycatch of the commercial pot fisheries and groundfish trawl fisheries. A full model description is provided in Appendix A. Francis' approaches for re-weighting the effective sample sizes for size composition data are detailed in Appendix C.
a-f. See appendix A.
g. Critical assumptions of the model:
i. The base natural mortality is constant over shell condition and length and was estimated assuming a maximum age of 25 and applying the $1 \%$ rule (Zheng 2005).
ii. Survey and fisheries selectivities are a function of length and were constant over shell condition. Selectivities are also a function of sex except for trawl bycatch selectivities, which are the same for both sexes. Two different survey selectivities were estimated: (1) 1975-1981 and (2) 1982-2017, based on modifications to the trawl gear used in the assessment survey.
iii. Growth is a function of length and is assumed to not change over time for males. For females, growth-per-molt increments as a function of length were estimated for three periods (1975-1982, 1983-1993, and 1994-2017) based on sizes at maturity. Once mature, female red king crab grow with a much smaller growth increment per molt.
iv. Molting probabilities are an inverse logistic function of length for males. Females molt annually.
v. Annual fishing seasons for the directed fishery are short.
vi. The prior of survey catchability $(Q)$ was estimated to be 0.896 , based on a trawl experiment by Weinberg et al. (2004) with a standard deviation of 0.025 for some scenarios. $Q$ is assumed to be constant over time and is estimated in the model.
vii. Males mature at sizes $\geq 120 \mathrm{~mm}$ CL. For convenience, female abundance was summarized at sizes $\geq 90 \mathrm{~mm}$ CL as an index of mature females.
viii. Measurement errors were assumed to be normally distributed for length compositions and were log-normally distributed for biomasses.
h. Changes to the above since previous assessment: see Section A.3. Changes to the assessment methodology.
i. Outline of methods used to validate the code used to implement the model and whether the code is available: The code is available.

## 3. Model Selection and Evaluation

a. Alternative model configurations (scenarios):

2a. Scenario 2a is the same as Scenario 2a in the SAFE draft report in May 2017 with updated data and a minor revision of base scenario 2 in the SAFE report in September 2016. Scenario 2 a differs from scenario 2 through changing the fishing time of the groundfish fisheries bycatch from the same time as the directed pot fishery under scenario 2 to the mid-point of the crab year (the same as Tanner crab fishery bycatch) to more accurately reflect the fishing timing. Also to reduce the number of estimated parameters, all fishing mortalities for the terminal year are not estimated during parameter estimation since the fisheries have not occurred in the model in the terminal year.
Scenario 2a includes:
(1) Basic $M=0.18$, with an additional mortality level during 1980-1984 for males and two additional mortality levels (one for 1980-1984 and the other for 1976-1979 and 1985-1993) for females.
(2) Including BSFRF survey data during 2007-2008 and 2013-2016. The BSFRF survey is treated as an independent survey, and no assumption is made about the capture probabilities of the BSFRF survey. In effect, survey selectivities for both surveys are estimated separately and directly in the model.
(3) NMFS survey catchability is estimated in the model and is assumed to be constant over time. BSFRF survey catchability is assumed to be 1.0 .
(4) Two levels of molting probabilities for males: one before 1980 and one after 1979, based on survey shell condition data. Each level has two parameters.
(5) Estimating effective sample size from observed sample sizes. Effective sample sizes are estimated as $\min (0.5 *$ observed-size, N$)$ for trawl surveys and $\min \left(0.1^{*}\right.$ observed-size, N ) for catch and bycatch, where N is the maximum sample size (200 for trawl surveys, 100 for males from the pot fishery and 50 for females from pot fishery and both males and females from the groundfish fisheries. There is a justification for enforcing a maximum limit to effective sample sizes because the number of length measurements is large (Fournier at al. 1998). The effective sample sizes are plotted against the implied effective sample sizes in Figures 6 and 7, where the implied effective sample sizes are estimated as follows:
$n_{y}=\sum_{l} \hat{P}_{y, l}\left(1-\hat{P}_{y, l}\right) / \sum_{l}\left(P_{y, l}-\hat{P}_{y, l}\right)^{2}$
where $\hat{P}_{y, l}$ and $P_{y, l}$ are estimated and observed size compositions in year $y$ and length group $l$, respectively.
(6) Standard survey data for males and NMFS survey retow data (during cold years) for females.
(7) Estimating initial year length compositions.

For scenario 2a, survey abundances $\hat{N}_{s, y, l}^{b}$ (BSFRF survey) and $\hat{N}_{s, y, l}^{n}$ (NMFS survey) by sex $s$ and in year $y$ and length group $l$ are computed as follows:

$$
\begin{align*}
& \hat{N}_{s, y, l}^{b}=N_{s, y, l} l_{s, l}^{b},  \tag{2}\\
& \hat{N}_{s, y, l}^{n}=N_{s, y, l} l_{s, l}^{n},
\end{align*}
$$

where $s_{s, l}^{b}$ and $s_{s, l}^{n}$ are survey selectivities for BSFRF and NMFS surveys by sex $s$ and in length group $l$, respectively, and $N_{s, y, l}$ is the population abundance by sex $s$ and in year y and length group $l$. BSFRF survey selectivities are computed as

$$
\begin{equation*}
s_{s, l}^{b}=\frac{1}{1+e^{-\beta_{s}^{b}\left(t-L_{50, s}^{b}\right)}}, \tag{3}
\end{equation*}
$$

where $\beta$ and $L_{50}$ are parameters. Survey selectivity for the first length group ( 67.5 mm ) was assumed to be the same for both males and females, so only three parameters ( $\beta$, $L 50$ for females and $L 50$ for males) were estimated in the model for each survey. The BSFRF survey catchability is assumed to be 1.0 .

Scenario 2a assumes that the BSFRF survey capture probabilities are 1.0 for all length groups. Under this assumption, NMFS survey selectivities are the products of crab availabilities (equal to BSFRF survey selectivities) and NMFS survey capture probabilities ( $p$ ):

$$
\begin{equation*}
s_{s, l}^{n}=p_{s, l} s_{s, l}^{b} . \tag{4}
\end{equation*}
$$

Therefore, the model estimates NMFS survey capture probabilities and BSFRF survey selectivities and computes NMFS survey selectivities from these estimates. NMFS survey capture probabilities are computed as

$$
\begin{equation*}
p_{s, l}=\frac{Q}{1+e^{-\beta_{s}\left(t-L_{s 0, s}\right)}}, \tag{5}
\end{equation*}
$$

where $\beta$ and $L 50$ are parameters and similar to the survey selectivities, only three parameters ( $\beta, L 50$ for females and $L 50$ for males) were estimated in the model for each sex. $Q$ is the NMFS survey catchability and is estimated in the model with or without a prior from the double-bag experiment, depending on scenarios.

Since fishing times for both Tanner crab fishery and groundfish fishery are assumed to occur the same time, the fraction separation of fishing mortality rates for both fisheries is used to divide the total fishing mortality rate to individual fisheries, that is, $\mathrm{F}_{\mathrm{i}} / \mathrm{F}_{\text {tot }} *(1-$ $\left.\exp \left(-\mathrm{F}_{\text {tot }}\right)\right)$ for fishery i , and the sum of $\mathrm{F}_{\mathrm{i}}=\mathrm{F}_{\text {tot }}$.
2a1. Scenario 2al is the same as Scenario 2a except for applying Francis' approach 1 (Appendix C) to the effective sample sizes of size composition data used in scenario 2a.

2a2. Scenario 2 a 2 is the same as Scenario 2 a except for applying Francis' approach 2 to the effective sample sizes of size composition data used in scenario 2a.

2b. Scenario $2 b$ is the same as scenario $2 a$ except for separating groundfish fisheries bycatch by trawl fisheries and fixed gear fisheries during 2009-2016.

2b1. Scenario 2b1 is the same as Scenario 2b except for applying Francis' approach 1 to the effective sample sizes of size composition data used in scenario $2 b$.
2b2. Scenario 2 b 2 is the same as Scenario 2b except for applying Francis' approach 2 to the effective sample sizes of size composition data used in scenario 2 b .

2d. Scenario 2 d is the same as scenario 2 b except without trawl survey catchability prior from the double-bag experiment and for using a logit transformation to make sure trawl survey catchability be $<1.0$ :
$Q=\exp (x) /(1+\exp (x))$,
where $x$ is estimated as a parameter.
2d1. Scenario 2d1 is the same as Scenario 2d except for applying Francis' approach 1 to the effective sample sizes of size composition data used in scenario 2d.
2d2. Scenario 2d2 is the same as Scenario 2d except for applying Francis' approach 2 to the effective sample sizes of size composition data used in scenario 2d.
b. Progression of results: See the new results at the beginning of the report.
c. Evidence of search for balance between realistic and simpler models: NA.
d. Convergence status/criteria: ADMB default convergence criteria.
e. Sample sizes for length composition data: observed sample sizes are summarized in Table 2, and estimated implied sample sizes and effective sample sizes are illustrated in Figures 6 and 7.
f. Credible parameter estimates: All estimated parameters seem to be credible.
g. Model selection criteria: The likelihood values were used to select among alternatives that could be legitimately compared by that criterion.
h. Residual analysis: Residual plots are illustrated in figures.
i. Model evaluation is provided under Results, below.
j. Jittering: the Stock Synthesis Approach is used to do jittering to find the optimum:

The Jitter factor of 0.1 is multiplied by a random normal deviation $r d e v=N(0,1)$, to a transformed parameter value based upon the predefined parameter:

$$
\begin{equation*}
\text { temp }=0.5 \mathrm{rdev} \text { Jitter } \ln \left(\frac{P_{\max }-P_{\min }+0.0000002}{P_{v a l}-P_{\min }+0.0000001}-1\right), \tag{6}
\end{equation*}
$$

with the final jittered starting parameter value backtransformed as:

$$
\begin{equation*}
P_{\text {new }}=P_{\min }+\frac{P_{\max }-P_{\min }}{1.0+\exp (-2.0 \text { temp })} \tag{7}
\end{equation*}
$$

where $P_{\text {max }}$ and $P_{\text {min }}$ are upper and lower bounds of parameters and $P_{\text {val }}$ is the estimated parameter value before the jittering. Due to time consuming, the jittering approach is not used in this report.

## 4. Results

a. Effective sample sizes and weighting factors.
i. Estimated effective sample sizes and Francis' re-weighting effective sample sizes used for all model scenarios are summarized in Appendix D. Using Francis' approaches greatly reduce effective sample sizes.

For scenario 2b, effective sample sizes are illustrated in Figures 6 and 7.
ii. Weights are assumed to be 500 for retained catch biomass, and 100 for all bycatch biomasses, 2 for recruitment variation, and 10 for recruitment sex ratio.
iii. Initial trawl survey catchability $(Q)$ is estimated to be 0.896 with a standard deviation of 0.025 (CV about 0.03 ) based on the double-bag experiment results. These values are used as a prior for estimating $Q$ in the model for scenarios 2 a and 2 b .
b. Tables of estimates.
i. Parameter estimates for scenarios $2 b$ and $2 d$ are summarized in Tables 4 and 5.
ii. Abundance and biomass time series are provided in Table 6 for scenarios 2 b and 2d.
iii. Recruitment time series for scenarios 2 b and 2 d are provided in Table 6.
iv. Time series of catch biomass is provided in Table 1.

Negative log-likelihood values and parameter estimates are summarized in Tables 4 and 5, respectively. Length-specific fishing mortality is equal to selectivity-at-length times the full fishing mortality. Estimated full pot fishing mortalities for females and full fishing mortalities for groundfish fisheries bycatch were very low due to low bycatch as well as handling mortality rates less than 1.0. Estimated recruits varied greatly from year to year (Table 6). Estimated low selectivities for male pot bycatch, relative to the retained catch, reflected the $20 \%$ handling mortality rate (Figure 8). Both selectivities were applied to the same level of full fishing mortality. Estimated selectivities for female pot bycatch were close to 1.0 for all mature females, and the estimated full fishing mortalities for female pot bycatch were lower than for male retained catch and bycatch (Table 5).
c. Graphs of estimates.
i. Selectivities and molting probabilities by length are provided in Figures 8 and 9 for scenarios $2 \mathrm{a}, 2 \mathrm{~b}, 2 \mathrm{~b} 1$, and 2 d .

One of the most important results is estimated trawl survey selectivity (Figure 8). Survey selectivity affects not only the fitting of the data but also the absolute abundance estimates. Estimated survey selectivities in Figure 8 are generally smaller than the capture probabilities in Figure A1 because survey selectivities include capture probabilities and crab availability. The NMFS survey catchability was estimated to be 0.896 from the trawl experiment, which is higher than that roughly estimated from the BSFRF surveys (0.854). The reliability of estimated survey selectivities will greatly affect the application of the model to fisheries management. Under- or overestimates of survey selectivities will cause a systematic upward or downward bias of abundance estimates. Information about crab availability to the survey area at survey times will help estimate the survey selectivities.
For all scenarios, estimated molting probabilities during 1975-2017 (Figure 9) were generally lower than those estimated from the 1954-1961 and 1966-1969 tagging data (Balsiger 1974). Lower molting probabilities mean more oldshell crab, possibly due to changes in molting probabilities over time or shell aging errors.

Overestimates or underestimates of oldshell crab will result in lower or higher estimates of male molting probabilities.
ii. Estimated total survey biomass and mature male and female abundances are plotted in Figure 10. Absolute mature male biomasses are illustrated in Figure 11.
Model estimated relative survey biomasses are very similar among the nine scenarios and fit the survey data quite well. The absolute population biomass estimates are slightly higher for scenarios $2 \mathrm{a}, 2 \mathrm{a} 1,2 \mathrm{a} 2,2 \mathrm{~b}, 2 \mathrm{~b} 1$, and 2 b 2 than for scenarios $2 \mathrm{~d}, 2 \mathrm{~d} 1$ and 2 d 2 during recent years due to slightly lower estimates of trawl survey selectivities for scenarios 2a, 2a1, 2a2, 2b, 2b1, and 2b2. Using Francis' approaches greatly reduce effective sample sizes and result in relatively more weights to BSFRF survey length composition data and higher absolute biomass estimates in recent years. Scenarios 2 a 1 and 2 b 2 have higher mature male biomass estimates during mid and late 1970s than other scenarios, likely due to estimated higher proportions of males in initial year 1975.
Although the model did not fit the mature crab abundances directly, trends in the mature abundance estimates agree well with observed survey values except in 2014 (Figure 10b). Estimated mature crab abundance increased dramatically in the mid 1970s then decreased precipitously in the early 1980s. Estimated mature crab abundance had increased during 1985-2009 with mature females being about 3 times more abundant in 2009 than in 1985 and mature males being about 2 times more abundant in 2009 than in 1985. Estimated mature abundance has declined since 2009 (Figure 10b). Model estimates of both male and female mature abundances have steadily declined since the late 2000s. Absolute mature male biomasses for all scenarios have a similar trend over time (Figure 11).

The fit to BSFRF survey data and estimated survey selectivities are illustrated in Figures 10c-e.
iii. Estimated recruitment time series are plotted in Figure 12 for scenarios 2b and 2d.
iv. Estimated fishing mortality rates are plotted against mature male biomass in Figure 13 for scenarios 2b and 2d.
The average of estimated male recruits from 1984 to 2017 (Figure 12) and mature male biomass per recruit were used to estimate $B_{35 \%}$. Alternative periods of 1976present and 1976-1983 were compared in our report. The full fishing mortalities for the directed pot fishery at the time of fishing were plotted against mature male biomass on Feb. 15 (Figure 13). Estimated fishing mortalities in most years before the current harvest strategy was adopted in 1996 were above $F_{35 \%}$ (Figure 13). Under the current harvest strategy, estimated fishing mortalities were at or above the $F_{35 \%}$ limits in 1998, 2005, 2007-2009 for scenarios 2 b and 2 d but below the $F_{35 \%}$ limits in the other post-1995 years. The higher estimated survey selectivities from scenario 2 d result in relatively higher fishing mortalities than those with scenarios $2 \mathrm{a}, 2 \mathrm{a} 1,2 \mathrm{a} 2,2 \mathrm{~b}, 2 \mathrm{~b} 1$, and 2 b 2 .

For scenario 2 b , estimated full pot fishing mortalities ranged from 0.00 to 2.11 during 1975-2016. Estimated values were greater than 0.40 during 1975-1981, 19851987, 1993 and 2008 (Table 5, Figure 13). For scenario 2d, estimated full pot fishing
mortalities ranged from 0.00 to 2.17 during 1975-2016, with estimated values over 0.40 during 1975-1981, 1985-1987, 1993, 2005, and 2007-2008 (Figure 13). Estimated fishing mortalities for pot female and groundfish fisheries bycatches were generally less than 0.06 .
v. Estimated mature male biomass and recruitment are plotted to illustrate their relationships with scenario 2 b (Figure 14a). Annual stock productivities are illustrated in Figure 14b.

Stock productivity (recruitment/mature male biomass) was generally lower during the last 20 years (Figure 14b).
Egg clutch data collected during summer surveys may provide information about mature female reproductive conditions. Although egg clutch data are subject to rating errors as well as sampling errors, data trends over time may be useful. Proportions of empty clutches for newshell mature females $>89 \mathrm{~mm}$ CL were high in some years before 1990, but have been low since 1990 (Figure 15). The highest proportion of empty clutches (0.2) was in 1986, and primarily involved soft shell females (shell condition 1). Clutch fullness fluctuated annually around average levels during two periods: before 1991 and after 1990 (Figure 15). The average clutch fullness was similar for these two periods (Figure 15). Egg clutch fullness during the last two years is relatively low.
d. Graphic evaluation of the fit to the data.
i. Observed vs. estimated catches are plotted in Figure 16.
ii. Model fits to total survey biomass are shown in Figure 10 with a standardized residual plot in Figure 17.
iii. Model fits to catch and survey proportions by length are illustrated in Figures 1824 and residual bubble plots are shown in Figures 25-26.

The model (nine scenarios) fit the fishery biomass data well and the survey biomass reasonably well (Figures 10 and 16). Because the model estimates annual fishing mortality for directed pot male catch, undirected pot male bycatch, pot female bycatch, and trawl bycatch, the deviations of observed and predicted (estimated) fishery biomass are mainly due to size composition differences.
The model also fit the length composition data well (Figures 18-24). The model also fit the length proportions of the pot male bycatch well with two simple linear selectivity functions (Figure 21). We explored a logistic selectivity function, but due to the long left tail of the pot male bycatch selectivity, the logistic selectivity function did not fit the data well.

Modal progressions are tracked well in the trawl survey data, particularly beginning in the mid-1990s (Figures 18 and 19). Cohorts first seen in the trawl survey data in 1975, 1986, 1990, 1995, 1999, 2002 and 2005 can be tracked over time. Some cohorts can be tracked over time in the pot bycatch as well (Figure 21), but the bycatch data did not track the cohorts as well as the survey data. Groundfish trawl bycatch data provide little information to track modal progression (Figures 23 and 24).

Standardized residuals of total survey biomass and proportions of length are plotted to examine their patterns. Residuals were calculated as observed minus predicted and standardized by the estimated standard deviation. Standardized residuals of total survey biomass did not show any consistent patterns (Figure 17). Standardized residuals of proportions of survey males appear to be random over length and year (Figure 25). There is an interesting pattern for residuals of proportions of survey females. Residuals were generally negative for large-sized mature females during 1975-1987 for scenarios 2 b and 2d (Figure 26). Changes in growth over time or increased mortality may cause this pattern. The inadequacy of the model can be corrected by adding parameters to address these factors or with improved growth data.
e. Retrospective and historic analyses.

Two kinds of retrospective analyses were conducted for this report: (1) the 2017 model (scenario 2b) hindcast results and (2) historical results. The 2017 model results are based on sequentially excluding one-year of data to evaluate the current model performance with fewer data. The historical results are the trajectories of biomass and abundance from previous assessments that capture both new data and changes in methodology over time. Treating the 2017 estimates as the baseline values, we can also evaluate how well the model had done in the past.
i. Retrospective analysis (retrospective bias in base model or models).

The performance of the 2017 model includes sequentially excluding one-year of data. The model with scenario 2 b performed reasonably well during 2011-2016 with a lower terminal year estimates in 2012 and 2013 and higher estimates inn 2011 (Figures 27-28).
ii. Historic analysis (plot of actual estimates from current and previous assessments).

The model first fit the data from 1985 to 2004 in the terminal year of 2004. Thus, sequentially incrementing the terminal year provided 10 historical assessments for comparison with the 2017 assessment model results (Figure 29). The main differences of the 2004 model were weighting factors and effective sample sizes for the likelihood functions. In 2004, the weighting factors were 1,000 for survey biomass, 2,000 for retained catch biomass and 200 for bycatch biomasses. The effective sample sizes were set to be 200 for all proportion data but weighting factors of 5,2 , and 1 were also respectively applied to retained catch proportions, survey proportions and bycatch proportions. Estimates of time series of abundance in 2004 were generally higher than those estimated after 2004 (Figure 29).
In 2005, to improve the fit for retained catch data, the weight for retained catch biomass was increased to 3,000 and the weight for retained catch proportions was increased to 6 . All other weights were not changed. In 2006, all weights were reconfigured. No weights were used for proportion data, and instead, effective sample sizes were set to 500 for retained catch, 200 for survey data, and 100 for bycatch data. Weights for biomasses were changed to 800 for retained catch, 300 for survey and 50 for bycatch. The weights in 2007 were the same as 2006. Generally, estimates of time series of abundance in 2005 were slightly lower than in 2006 and

2007, and there were few differences between estimates in 2006 and 2007 (Figure 29).

In 2008, estimated coefficients of variation for survey biomass were used to compute likelihood values as suggested by the CPT in 2007. Thus, weights were reconfigured to: 500 for retained catch biomass, 50 for survey biomass, and 20 for bycatch biomasses. Effective sample size was lowered to 400 for the retained catch data. These changes were necessary for the estimation to converge and for a relatively good balanced fit to both biomasses and proportion data. Also, sizes at $50 \%$ selectivities for all fisheries data were allowed to change annually, subject to a random walk pattern, for all assessments before 2008. The 2008 model does not allow annual changes in any fishery selectivities. Except for higher estimates of abundance during the late 1980s and early 1990s, estimates of time series of abundance in 2008 were generally close to those in 2006 and 2007 (Figure 29).
During 2009-2013, the model was extended to the data through 1968. No weight factors were used for the NMFS survey biomass during 2009-2013 assessments. Since 2013, the model has fitted the data only back to 1975 for consistence of trawl survey data. Two levels of molting probabilities over time were used, shell conditions for males were combined, and length composition data of the BSFRF survey were used as well. In 2014 and 2015, the trawl survey time series were reestimated and a trawl survey catchability was estimated for some scenarios.

Overall, both historical results (historic analysis) and the 2017 model results (retrospective analysis) performed reasonably well. No great overestimates or underestimates occurred as was observed in assessments for Pacific halibut (Hippoglossus stenolepis) (Parma 1993) and some eastern Bering Sea groundfish stocks (Zheng and Kruse 2002; Ianelli et al. 2003). Since the most recent model was not used to set TAC or overfishing limits until 2009, historical implications for management from the stock assessment errors cannot be evaluated at the current time. However, management implications of the ADF\&G stock assessment model were evaluated by Zheng and Kruse (2002).
f. Uncertainty and sensitivity analyses
i. Estimated standard deviations of parameters are summarized in Table 5 for scenarios 2b and 2d. Estimated standard deviations of mature male biomass are listed in Table 6.
ii. Probabilities for trawl survey catchability $Q$ are illustrated in Figure 30 for scenarios 2 b using the momc approach; estimated $Q$ s are generally less than 1.0. Probabilities for mature male biomass and OFL in 2017 are illustrated in Figure 31 for scenarios 2 b and 2 d using the mcmc approach. The confidence intervals are quite narrow.
iii. Sensitivity analysis for handling mortality rate was reported in the SAFE report in May 2010. The baseline handling mortality rate for the directed pot fishery was set at 0.2 . A $50 \%$ reduction and $100 \%$ increase respectively resulted in 0.1 and 0.4 as alternatives. Overall, a higher handling mortality rate resulted in slightly higher estimates of mature abundance, and a lower rate resulted in a minor reduction of
estimated mature abundance. Differences of estimated legal abundance and mature male biomass were small among these handling mortality rates.
iv. Sensitivity of weights. Sensitivity of weights was examined in the SAFE report in May 2010. Weights to biomasses (trawl survey biomass, retained catch biomass, and bycatch biomasses) were reduced to $50 \%$ or increased to $200 \%$ to examine their sensitivity to abundance estimates. Weights to the penalty terms (recruitment variation and sex ratio) were also reduced or increased. Overall, estimated biomasses were very close under different weights except during the mid-1970s. The variation of estimated biomasses in the mid-1970s was mainly caused by the changes in estimates of additional mortalities in the early 1980s.
g. Comparison of alternative model scenarios

These comparisons, based on the data through 2010, were reported in the SAFE report in May 2011. Estimating length proportions in the initial year (scenario 1a) results in a better fit of survey length compositions at an expense of 36 more parameters than scenario 1 . Abundance and biomass estimates with scenario 1a are similar between scenarios. Using only standard survey data (scenario 1 b ) results in a poorer fit of survey length compositions and biomass than scenarios using both standard and re-tow data (scenarios 1, 1a, and 1c) and has the lowest likelihood value. Although the likelihood value is higher for using both standard survey and re-tow data for males (scenario 1) than using only standard survey for males (scenario 1c), estimated abundances and biomasses are almost identical. The higher likelihood value for scenario 1 over scenario 1 c is due to trawl bycatch length compositions.

In this report (September 2017), nine scenarios are compared. Model estimated relative survey biomasses are very similar among the scenarios. The absolute population biomass estimates are higher for scenarios $2 \mathrm{~b}, 2 \mathrm{~b} 1,2 \mathrm{~b} 2,2 \mathrm{a}, 2 \mathrm{a} 1$, and 2 a 2 than for scenarios $2 \mathrm{~d}, 2 \mathrm{~d} 1$ and 2 d 2 during recent years due to slightly lower estimated trawl survey catchability values. Slightly higher estimates of NMFS trawl survey catchabilities for scenario 2 a and 2 b also result in slightly lower absolute biomass than for scenarios $2 \mathrm{a} 1,2 \mathrm{a} 2$, 2 b 1 and 2 b 2 . Scenarios 2 a 1 and 2 b 2 have higher mature male biomass estimates during mid and late 1970s than other scenarios, likely due to estimated higher proportions of males in initial year 1975. Overall, the results for all nine scenarios are similar except those impacted by estimates of NMFS trawl survey catchabilities and effective sample sizes. We recommend either scenario 2b or 2d for September 2017 assessment because of corrected data and refined approaches to estimation of survey catchability and more work needed for Francis' approach.

## F. Calculation of the OFL and ABC

1. Bristol Bay RKC is currently placed in Tier 3b (NPFMC 2007).
2. For Tier 3 stocks, estimated biological reference points include $B_{35 \%}$ and $F_{35 \%}$. Estimated model parameters were used to conduct mature male biomass-per-recruit analysis.
3. Specification of the OFL:

The Tier 3 can be expressed by the following control rule:
a) $\frac{B}{B^{*}}>1$
$F_{O F L}=F^{*}$
b) $\quad \beta<\frac{B}{B^{*}} \leq 1$
$F_{O F L}=F^{*}\left(\frac{B / B^{*}-\alpha}{1-\alpha}\right)$
c) $\frac{B}{B^{*}} \leq \beta$
directed fishery $F=0$ and $F_{O F L} \leq F^{*}$

Where
$B=$ a measure of the productive capacity of the stock such as spawning biomass or fertilized egg production. A proxy of $B$, MMB estimated at the time of primiparous female mating (February 15) is used as a default in the development of the control rule.
$F^{*}=F_{35 \%}$, a proxy of $F_{M S Y}$, which is a full selection instantaneous $F$ that will produce MSY at the MSY producing biomass,
$B^{*}=B_{35 \%}$, a proxy of $B_{M S Y}$, which is the value of biomass at the MSY producing level,
$\beta=$ a parameter with restriction that $0 \leq \beta<1$. A default value of 0.25 is used.
$\alpha=$ a parameter with restriction that $0 \leq \alpha \leq \beta$. A default value of 0.1 is used.
Because trawl bycatch fishing mortality was not related to pot fishing mortality, average trawl bycatch fishing mortality during 2007 to 2016 was used for the per recruit analysis as well as for projections in the next section. Pot female bycatch fishing mortality was set equal to pot male fishing mortality times 0.02, an intermediate level during 1990-2016. Some discards of legal males occurred since the IFQ fishery started in 2005, but the discard rates were much lower during 2007-2013 than in 2005 after the fishing industry minimized discards of legal males. However, due to the high proportion of large oldshell males, the discard rate increased greatly in 2014. The average of retained selectivities and discard male selectivities during 2015-2016 were used to represent current trends for per recruit analysis and projections. Average molting probabilities during 2007-2016 were used for per recruit analysis and projections.
Average recruitments during three periods were used to estimate $B_{35 \%}$ : 1976-2017, 19842017, and 1991-2017 (Figure 12). Estimated $B_{35 \%}$ is compared with historical mature male biomass in Figure 13a. We recommend using the average recruitment during 1984-present, corresponding to the 1976/77 regime shift. Note that recruitment period 1984-present has been used since 2011 to set the overfishing limits. Several factors support our recommendation. First, estimated recruitment was lower after 1983 than before 1984, which corresponded to brood years 1978 and later, after the 1976/77 regime shift. Second, high recruitments during the late 1960s and 1970s generally occurred when the spawning stock was primarily located in the southern Bristol Bay, whereas the current spawning stock is mainly in the middle of Bristol Bay. The current flows favor larvae hatched in the southern Bristol Bay (see the section on Ecosystem Considerations for SAFE reports in 2008 and 2009). Finally, stock productivity (recruitment/mature male biomass) was higher before the 1976/1977 regime shift.

If we believe that differences in productivity and other population characteristics before 1978 were caused by fishing, not by the regime shift, then we should use the recruitment from 1976-1983 (corresponding to brood years before 1978) as the baseline to estimate B35\%. If we believe that the regime shift during 1976/77 caused the productivity differences, then we should select the recruitments from period 1984-2017 as the baseline.

The control rule is used for stock status determination. If total catch exceeds OFL estimated at $B$, then "overfishing" occurs. If $B$ equals or declines below $0.5 B_{\text {MSY }}$ (i.e., MSST), the stock is "overfished." If $B$ equals or declines below $\beta^{*} \mathrm{~B}_{\mathrm{MSY}}$ or $\beta^{*}$ a proxy $\mathrm{B}_{\mathrm{MSY}}$, then the stock productivity is severely depleted and the fishery is closed.

The estimated probability distribution of MMB in 2017 is illustrated in Figure 30. Based the SSC suggestion in 2011, $\mathrm{ABC}=0.9^{*} \mathrm{OFL}$ is used to estimate ABC .

Status and catch specifications (1,000 t) (scenario 2b):

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2013 / 14$ | $12.85^{\mathrm{A}}$ | $27.12^{\mathrm{A}}$ | 3.90 | 3.99 | 4.56 | 7.07 | 6.36 |
| $2014 / 15$ | $13.03^{\mathrm{B}}$ | $27.25^{\mathrm{B}}$ | 4.49 | 4.54 | 5.44 | 6.82 | 6.14 |
| $2015 / 16$ | $12.89^{\mathrm{C}}$ | $27.68^{\mathrm{C}}$ | 4.52 | 4.61 | 5.34 | 6.73 | 6.06 |
| $2016 / 17$ | $12.53^{\mathrm{D}}$ | $25.80^{\mathrm{D}}$ | 3.84 | 3.92 | 4.28 | 6.64 | 5.97 |
| $2017 / 18$ |  | $21.31^{\mathrm{D}}$ |  |  |  | 5.60 | 5.04 |

The stock was above MSST in 2016/17 and hence was not overfished. Overfishing did not occur.

Status and catch specifications (million lbs):

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :---: | :---: | :---: | ---: | ---: | ---: | ---: | ---: |
| $2013 / 14$ | $28.3^{\mathrm{A}}$ | $59.9^{\mathrm{A}}$ | 8.60 | 8.80 | 10.05 | 15.58 | 14.02 |
| $2014 / 15$ | $28.7^{\mathrm{B}}$ | $60.1^{\mathrm{B}}$ | 9.99 | 10.01 | 11.99 | 15.04 | 13.53 |
| $2015 / 16$ | $28.4^{\mathrm{C}}$ | $61.0^{\mathrm{C}}$ | 9.97 | 10.17 | 11.77 | 14.84 | 13.36 |
| $2016 / 17$ | $27.6^{\mathrm{D}}$ | $56.9^{\mathrm{D}}$ | 8.47 | 8.65 | 9.45 | 14.63 | 13.17 |
| $2017 / 18$ |  | $47.0^{\mathrm{D}}$ |  |  |  | 12.35 | 11.11 |

Notes:
A - Calculated from the assessment reviewed by the Crab Plan Team in September 2014
B - Calculated from the assessment reviewed by the Crab Plan Team in September 2015
C - Calculated from the assessment reviewed by the Crab Plan Team in September 2016
D - Calculated from the assessment reviewed by the Crab Plan Team in September 2017
4. Based on the $B_{35 \%}$ estimated from the average male recruitment during 1984-2017, the biological reference points and OFL were estimated in Table 4.
5. Based on the $10 \%$ buffer rule used last year, $\mathrm{ABC}=0.9^{*} \mathrm{OFL}$ (Table 4). If $\mathrm{P}^{*}=49 \%$ is used, the ABC will be higher.

## G. Rebuilding Analyses

NA.

## H. Data Gaps and Research Priorities

1. The following data gaps exist for this stock:
a. Information about changes in natural mortality in the early 1980s;
b. Un-observed trawl bycatch in the early 1980s;
c. Natural mortality;
d. Crab availability to the trawl surveys;
e. Juvenile crab abundance;
f. Female growth per molt as a function of size and maturity;
g. Changes in male molting probability over time.
2. Research priorities:
a. Estimating natural mortality;
b. Estimating crab availability to the trawl surveys;
c. Surveying juvenile crab abundance in nearshore;
d. Studying environmental factors that affect the survival rates from larvae to recruitment.

## I. Projections and Future Outlook

## 1. Projections

Future population projections primarily depend on future recruitment, but crab recruitment is difficult to predict. Therefore, annual recruitment for the projections was a random selection from estimated recruitments during 1984-2017. Besides recruitment, the other major uncertainty for the projections is estimated abundance in 2017. The 2017 abundance was randomly selected from the estimated normal distribution of the assessment model output for each replicate. Three scenarios of fishing mortality for the directed pot fishery were used in the projections:
(1) No directed fishery. This was used as a base projection.
(2) $\mathrm{F}_{40 \%}$. This fishing mortality creates a buffer between the limits and target levels.
(3) $F_{35 \%}$. This is the maximum fishing mortality allowed under the current overfishing definitions.

Each scenario was replicated 1,000 times and projections made over 10 years beginning in 2017 (Table 7).

As expected, projected mature male biomasses are much higher without the directed fishing mortality than under the other scenarios. At the end of 10 years, projected mature male biomass is above $B_{35 \%}$ for all scenarios (Table 7; Figure 32). Projected retained catch for the $F_{35 \%}$ scenario is
higher than those for the $F_{40 \%}$ scenario (Table 7, Figure 33). Due to the poor recruitment in recent years, the projected biomass and retained catch are expected to decline during the next few years.

## 2. Near Future Outlook

The near future outlook for the Bristol Bay RKC stock is a declining trend. The three recent aboveaverage year classes (hatching years 1990, 1994, and 1997) had entered the legal population by 2006 (Figure 34). Most individuals from the 1997 year class will continue to gain weight to offset loss of the legal biomass to fishing and natural mortalities. The above-average year class (hatching year 2000) with lengths centered around 87.5 mm CL for both males and females in 2006 and with lengths centered around $112.5-117.5 \mathrm{~mm}$ CL for males and around 107.5 mm CL for females in 2008 has largely entered the mature male population in 2009 and the legal population by 2014 (Figure 34). No strong cohorts have been observed in the survey data after this cohort through 2010 (Figure 34). There was a huge tow of juvenile crab of size $45-55 \mathrm{~mm}$ in 2011, but these juveniles were not tracked during 2012-2017 surveys. This single tow is unlikely to be an indicator for a strong cohort. The high survey abundance of large males and mature females in 2014 cannot be explained by the survey data during the previous years and were also inconsistent with the 20152017 survey results (Figure 34). Due to lack of recruitment, mature and legal crab should continue to decline next year. Current crab abundance is still low relative to the late 1970s, and without favorable environmental conditions, recovery to the high levels of the late 1970s is unlikely.

## J. Acknowledgements

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Table 1a. Bristol Bay red king crab annual catch and bycatch mortality biomass ( t ) from June 1 to May 31. A handling mortality rate of $20 \%$ for the directed pot, $25 \%$ for the Tanner fishery, and $80 \%$ for trawl was assumed to estimate bycatch mortality biomass.

|  | Retained Catch |  |  |  | Pot Bycatch |  | Trawl Bycat. | Tanner <br> Fishery <br> Bycat. | Total Catch |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year | U.S. | CostRecovery | Foreign | Total | Males | Females |  |  |  |
| 1953 | 1331.3 |  | 4705.6 | 6036.9 |  |  |  |  | 6036.9 |
| 1954 | 1149.9 |  | 3720.4 | 4870.2 |  |  |  |  | 4870.2 |
| 1955 | 1029.2 |  | 3712.7 | 4741.9 |  |  |  |  | 4741.9 |
| 1956 | 973.4 |  | 3572.9 | 4546.4 |  |  |  |  | 4546.4 |
| 1957 | 339.7 |  | 3718.1 | 4057.8 |  |  |  |  | 4057.8 |
| 1958 | 3.2 |  | 3541.6 | 3544.8 |  |  |  |  | 3544.8 |
| 1959 | 0.0 |  | 6062.3 | 6062.3 |  |  |  |  | 6062.3 |
| 1960 | 272.2 |  | 12200.7 | 12472.9 |  |  |  |  | 12472.9 |
| 1961 | 193.7 |  | 20226.6 | 20420.3 |  |  |  |  | 20420.3 |
| 1962 | 30.8 |  | 24618.7 | 24649.6 |  |  |  |  | 24649.6 |
| 1963 | 296.2 |  | 24930.8 | 25227.0 |  |  |  |  | 25227.0 |
| 1964 | 373.3 |  | 26385.5 | 26758.8 |  |  |  |  | 26758.8 |
| 1965 | 648.2 |  | 18730.6 | 19378.8 |  |  |  |  | 19378.8 |
| 1966 | 452.2 |  | 19212.4 | 19664.6 |  |  |  |  | 19664.6 |
| 1967 | 1407.0 |  | 15257.0 | 16664.1 |  |  |  |  | 16664.1 |
| 1968 | 3939.9 |  | 12459.7 | 16399.6 |  |  |  |  | 16399.6 |
| 1969 | 4718.7 |  | 6524.0 | 11242.7 |  |  |  |  | 11242.7 |
| 1970 | 3882.3 |  | 5889.4 | 9771.7 |  |  |  |  | 9771.7 |
| 1971 | 5872.2 |  | 2782.3 | 8654.5 |  |  |  |  | 8654.5 |
| 1972 | 9863.4 |  | 2141.0 | 12004.3 |  |  |  |  | 12004.3 |
| 1973 | 12207.8 |  | 103.4 | 12311.2 |  |  |  |  | 12311.2 |
| 1974 | 19171.7 |  | 215.9 | 19387.6 |  |  |  |  | 19387.6 |
| 1975 | 23281.2 |  | 0 | 23281.2 |  |  |  |  | 23281.2 |
| 1976 | 28993.6 |  | 0 | 28993.6 |  |  | 682.8 |  | 29676.4 |
| 1977 | 31736.9 |  | 0 | 31736.9 |  |  | 1249.9 |  | 32986.8 |
| 1978 | 39743.0 |  | 0 | 39743.0 |  |  | 1320.6 |  | 41063.6 |
| 1979 | 48910.0 |  | 0 | 48910.0 |  |  | 1331.9 |  | 50241.9 |
| 1980 | 58943.6 |  | 0 | 58943.6 |  |  | 1036.5 |  | 59980.1 |
| 1981 | 15236.8 |  | 0 | 15236.8 |  |  | 219.4 |  | 15456.2 |
| 1982 | 1361.3 |  | 0 | 1361.3 |  |  | 574.9 |  | 1936.2 |
| 1983 | 0.0 |  | 0 | 0.0 |  |  | 420.4 |  | 420.4 |
| 1984 | 1897.1 |  | 0 | 1897.1 |  |  | 1094.0 |  | 2991.1 |
| 1985 | 1893.8 |  | 0 | 1893.8 |  |  | 390.1 |  | 2283.8 |
| 1986 | 5168.2 |  | 0 | 5168.2 |  |  | 200.6 |  | 5368.8 |
| 1987 | 5574.2 |  | 0 | 5574.2 |  |  | 186.4 |  | 5760.7 |
| 1988 | 3351.1 |  | 0 | 3351.1 |  |  | 597.8 |  | 3948.9 |
| 1989 | 4656.0 |  | 0 | 4656.0 |  |  | 174.1 |  | 4830.1 |
| 1990 | 9236.2 | 36.6 | 0 | 9272.8 | 526.9 | 651.5 | 247.6 |  | 10698.7 |
| 1991 | 7791.8 | 93.4 | 0 | 7885.1 | 407.8 | 75.0 | 316.0 | 1401.8 | 10085.7 |
| 1992 | 3648.2 | 33.6 | 0 | 3681.8 | 552.0 | 418.5 | 335.4 | 244.4 | 5232.2 |
| 1993 | 6635.4 | 24.1 | 0 | 6659.6 | 763.2 | 637.1 | 426.6 | 54.6 | 8541.0 |
| 1994 | 0.0 | 42.3 | 0 | 42.3 | 3.8 | 1.9 | 88.9 | 10.8 | 147.8 |
| 1995 | 0.0 | 36.4 | 0 | 36.4 | 3.3 | 1.6 | 194.2 | 0.0 | 235.5 |
| 1996 | 3812.7 | 49.0 | 0 | 3861.7 | 164.6 | 1.0 | 106.5 | 0.0 | 4133.9 |
| 1997 | 3971.9 | 70.2 | 0 | 4042.1 | 244.7 | 19.6 | 73.4 | 0.0 | 4379.8 |
| 1998 | 6693.8 | 85.4 | 0 | 6779.2 | 959.7 | 864.9 | 159.8 | 0.0 | 8763.7 |
| 1999 | 5293.5 | 84.3 | 0 | 5377.9 | 314.2 | 8.8 | 201.6 | 0.0 | 5902.4 |
| 2000 | 3698.8 | 39.1 | 0 | 3737.9 | 360.8 | 40.5 | 100.4 | 0.0 | 4239.5 |
| 2001 | 3811.5 | 54.6 | 0 | 3866.2 | 417.9 | 173.5 | 164.6 | 0.0 | 4622.1 |
| 2002 | 4340.9 | 43.6 | 0 | 4384.5 | 442.7 | 7.3 | 155.1 | 0.0 | 4989.6 |
| 2003 | 7120.0 | 15.3 | 0 | 7135.3 | 918.9 | 430.4 | 172.3 | 0.0 | 8656.9 |
| 2004 | 6915.2 | 91.4 | 0 | 7006.7 | 345.5 | 187.0 | 119.6 | 0.0 | 7658.8 |


| 2005 | 8305.0 | 94.7 | 0 | 8399.7 | 1359.5 | 498.3 | 155.2 |  | 0.0 | 10412.8 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2006 | 7005.3 | 137.9 | 0 | 7143.2 | 563.8 | 37.0 | 116.7 |  | 3.8 | 7864.4 |
| 2007 | 9237.9 | 66.1 | 0 | 9303.9 | 1001.3 | 186.1 | 138.5 |  | 1.8 | 10631.6 |
| 2008 | 9216.1 | 0.0 | 0 | 9216.1 | 1165.5 | 148.4 | 159.5 |  | 4.0 | 10693.5 |
| 2009 | 7226.9 | 45.5 | 0 | 7272.5 | 888.1 | 85.2 | 87.2 | 5.0 | 1.6 | 8339.6 |
| 2010 | 6728.5 | 33.0 | 0 | 6761.5 | 797.5 | 122.6 | 78.7 | 2.3 | 0.0 | 7762.6 |
| 2011 | 3553.3 | 53.8 | 0 | 3607.1 | 395.0 | 24.0 | 53.8 | 9.4 | 0.0 | 4089.2 |
| 2012 | 3560.6 | 61.1 | 0 | 3621.7 | 205.2 | 12.3 | 32.4 | 14.9 | 0.0 | 3886.5 |
| 2013 | 3901.1 | 89.9 | 0 | 3991.0 | 310.6 | 99.8 | 61.9 | 39.5 | 28.5 | 4531.1 |
| 2014 | 4530.0 | 8.6 | 0 | 4538.6 | 584.7 | 86.2 | 32.0 | 82.7 | 42.0 | 5366.2 |
| 2015 | 4522.3 | 91.4 | 0 | 4613.7 | 266.1 | 222.9 | 41.7 | 67.9 | 84.2 | 5296.5 |
| 2016 | 3840.4 | 83.4 | 0 | 3923.9 | 237.4 | 87.1 | 21.0 | 14.8 | 0.0 | 4284.2 |

Table 1b. Annual retained catch (millions of crab) and catch per unit effort of the Bristol Bay red king crab fishery.

| Year | Japanese Tanglenet |  | Russian Tanglenet |  | U.S. Pot/Trawl |  | Standardized Crab/tan |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Catch | Crab/tan | Catch | Crab/tan | Catch | Crab/Potlift |  |
| 1960 | 1.949 | 15.2 | 1.995 | 10.4 | 0.088 |  | 15.8 |
| 1961 | 3.031 | 11.8 | 3.441 | 8.9 | 0.062 |  | 12.9 |
| 1962 | 4.951 | 11.3 | 3.019 | 7.2 | 0.010 |  | 11.3 |
| 1963 | 5.476 | 8.5 | 3.019 | 5.6 | 0.101 |  | 8.6 |
| 1964 | 5.895 | 9.2 | 2.800 | 4.6 | 0.123 |  | 8.5 |
| 1965 | 4.216 | 9.3 | 2.226 | 3.6 | 0.223 |  | 7.7 |
| 1966 | 4.206 | 9.4 | 2.560 | 4.1 | 0.140 | 52 | 8.1 |
| 1967 | 3.764 | 8.3 | 1.592 | 2.4 | 0.397 | 37 | 6.3 |
| 1968 | 3.853 | 7.5 | 0.549 | 2.3 | 1.278 | 27 | 7.8 |
| 1969 | 2.073 | 7.2 | 0.369 | 1.5 | 1.749 | 18 | 5.6 |
| 1970 | 2.080 | 7.3 | 0.320 | 1.4 | 1.683 | 17 | 5.6 |
| 1971 | 0.886 | 6.7 | 0.265 | 1.3 | 2.405 | 20 | 5.8 |
| 1972 | 0.874 | 6.7 |  |  | 3.994 | 19 |  |
| 1973 | 0.228 |  |  |  | 4.826 | 25 |  |
| 1974 | 0.476 |  |  |  | 7.710 | 36 |  |
| 1975 |  |  |  |  | 8.745 | 43 |  |
| 1976 |  |  |  |  | 10.603 | 33 |  |
| 1977 |  |  |  |  | 11.733 | 26 |  |
| 1978 |  |  |  |  | 14.746 | 36 |  |
| 1979 |  |  |  |  | 16.809 | 53 |  |
| 1980 |  |  |  |  | 20.845 | 37 |  |
| 1981 |  |  |  |  | 5.308 | 10 |  |
| 1982 |  |  |  |  | 0.541 | 4 |  |
| 1983 |  |  |  |  | 0.000 |  |  |
| 1984 |  |  |  |  | 0.794 | 7 |  |
| 1985 |  |  |  |  | 0.796 | 9 |  |
| 1986 |  |  |  |  | 2.100 | 12 |  |
| 1987 |  |  |  |  | 2.122 | 10 |  |
| 1988 |  |  |  |  | 1.236 | 8 |  |
| 1989 |  |  |  |  | 1.685 | 8 |  |
| 1990 |  |  |  |  | 3.130 | 12 |  |
| 1991 |  |  |  |  | 2.661 | 12 |  |
| 1992 |  |  |  |  | 1.208 | 6 |  |
| 1993 |  |  |  |  | 2.270 | 9 |  |
| 1994 |  |  |  |  | 0.015 |  |  |
| 1995 |  |  |  |  | 0.014 |  |  |
| 1996 |  |  |  |  | 1.264 | 16 |  |
| 1997 |  |  |  |  | 1.338 | 15 |  |
| 1998 |  |  |  |  | 2.238 | 15 |  |
| 1999 |  |  |  |  | 1.923 | 12 |  |
| 2000 |  |  |  |  | 1.272 | 12 |  |
| 2001 |  |  |  |  | 1.287 | 19 |  |
| 2002 |  |  |  |  | 1.484 | 20 |  |
| 2003 |  |  |  |  | 2.510 | 18 |  |
| 2004 |  |  |  |  | 2.272 | 23 |  |
| 2005 |  |  |  |  | 2.763 | 30 |  |
| 2006 |  |  |  |  | 2.477 | 31 |  |
| 2007 |  |  |  |  | 3.154 | 28 |  |
| 2008 |  |  |  |  | 3.064 | 22 |  |
| 2009 |  |  |  |  | 2.553 | 21 |  |
| 2010 |  |  |  |  | 2.410 | 18 |  |
| 2011 |  |  |  |  | 1.298 | 28 |  |
| 2012 |  |  |  |  | 1.176 | 30 |  |
| 2013 |  |  |  |  | 1.272 | 27 |  |
| 2014 |  |  |  |  | 1.501 | 26 |  |
| 2015 |  |  |  |  | 1.527 | 31 |  |
| 2016 |  |  |  |  | 1.281 | 38 |  |

Table 2. Annual sample sizes ( $>64 \mathrm{~mm} \mathrm{CL}$ ) in numbers of crab for trawl surveys, retained catch and pot and trawl fishery bycatch of Bristol Bay red king crab.

| Year | Trawl Survey |  | Retained Catch | Pot Bycatch |  | Trawl Bycatch |  | Tanner Fishery Bycatch |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Males | Females |  | Males | Females | Males | Females | Males | Females |
| 1975 | 2,943 | 2,139 | 29,570 |  |  |  |  |  |  |
| 1976 | 4,724 | 2,956 | 26,450 |  |  | 2,327 | 676 |  |  |
| 1977 | 3,636 | 4,178 | 32,596 |  |  | 14,014 | 689 |  |  |
| 1978 | 4,132 | 3,948 | 27,529 |  |  | 8,983 | 1,456 |  |  |
| 1979 | 5,807 | 4,663 | 27,900 |  |  | 7,228 | 2,821 |  |  |
| 1980 | 2,412 | 1,387 | 34,747 |  |  | 47,463 | 39,689 |  |  |
| 1981 | 3,478 | 4,097 | 18,029 |  |  | 42,172 | 49,634 |  |  |
| 1982 | 2,063 | 2,051 | 11,466 |  |  | 84,240 | 47,229 |  |  |
| 1983 | 1,524 | 944 | 0 |  |  | 204,464 | 104,910 |  |  |
| 1984 | 2,679 | 1,942 | 4,404 |  |  | 357,981 | 147,134 |  |  |
| 1985 | 792 | 415 | 4,582 |  |  | 169,767 | 30,693 |  |  |
| 1986 | 1,962 | 367 | 5,773 |  |  | 1,199 | 284 |  |  |
| 1987 | 1,168 | 1,018 | 4,230 |  |  | 723 | 927 |  |  |
| 1988 | 1,834 | 546 | 9,833 |  |  | 437 | 275 |  |  |
| 1989 | 1,257 | 550 | 32,858 |  |  | 3,147 | 194 |  |  |
| 1990 | 858 | 603 | 7,218 | 873 | 699 | 761 | 1,570 |  |  |
| 1991 | 1,378 | 491 | 36,820 | 1,801 | 375 | 208 | 396 | 885 | 2,198 |
| 1992 | 513 | 360 | 23,552 | 3,248 | 2,389 | 214 | 107 | 280 | 685 |
| 1993 | 1,009 | 534 | 32,777 | 5,803 | 5,942 |  |  | 232 | 265 |
| 1994 | 443 | 266 | 0 | 0 | 0 | 330 | 247 |  |  |
| 1995 | 2,154 | 1,718 | 0 | 0 | 0 | 103 | 35 |  |  |
| 1996 | 835 | 816 | 8,896 | 230 | 11 | 1,025 | 968 |  |  |
| 1997 | 1,282 | 707 | 15,747 | 4,102 | 906 | 1,202 | 483 |  |  |
| 1998 | 1,097 | 1,150 | 16,131 | 11,079 | 9,130 | 1,627 | 915 |  |  |
| 1999 | 764 | 540 | 17,666 | 1,048 | 36 | 2,154 | 858 |  |  |
| 2000 | 731 | 1,225 | 14,091 | 8,970 | 1,486 | 994 | 671 |  |  |
| 2001 | 611 | 743 | 12,854 | 9,102 | 4,567 | 4,393 | 2,521 |  |  |
| 2002 | 1,032 | 896 | 15,932 | 9,943 | 302 | 3,372 | 1,464 |  |  |
| 2003 | 1,669 | 1,311 | 16,212 | 17,998 | 10,327 | 1,568 | 1,057 |  |  |
| 2004 | 2,871 | 1,599 | 20,038 | 8,258 | 4,112 | 1,689 | 1,506 |  |  |
| 2005 | 1,283 | 1,682 | 21,938 | 55,019 | 26,775 | 1,815 | 1,872 |  |  |
| 2006 | 1,171 | 2,672 | 18,027 | 32,252 | 3,980 | 1,481 | 1,983 |  |  |
| 2007 | 1,219 | 2,499 | 22,387 | 59,769 | 12,661 | 1,011 | 1,097 |  |  |
| 2008 | 1,221 | 3,352 | 14,567 | 49,315 | 8,488 | 1,867 | 1,039 |  |  |
| 2009 | 830 | 1,857 | 16,708 | 52,359 | 6,041 | 1,431 | 848 |  |  |
| 2010 | 705 | 1,633 | 20,137 | 36,654 | 6,868 | 612 | 837 |  |  |
| 2011 | 525 | 994 | 10,706 | 20,629 | 1,920 | 563 | 1,068 |  |  |
| 2012 | 580 | 707 | 8,956 | 7,206 | 561 | 1,507 | 1,751 |  |  |
| 2013 | 633 | 560 | 10,197 | 13,828 | 6,048 | 4,806 | 4,198 | 218 | 596 |
| 2014 | 1,106 | 1,255 | 9,618 | 13,040 | 1,950 | 1,966 | 2,580 | 256 | 381 |
| 2015 | 600 | 677 | 11,746 | 8,037 | 5,889 | 1,150 | 3,731 | 726 | 2163 |
| 2016 | 374 | 803 | 10,811 | 9,497 | 4,216 | 1,908 | 2,879 |  |  |
| 2017 | 470 | 558 |  |  |  |  |  |  |  |

Table 3. Number of parameters and the list of likelihood components for the model (Scenarios 2a, 2a1, 2a2, 2b, 2b1, 2b2, 2d, 2d1, and 2d2).

Parameter counts
Sce. 2a, 2a1, \& 2a2 Sce. 2b, 2b1, 2b2, 2d, 2d1, \&2d2

| Fixed growth parameters | 9 | 9 |
| :--- | :--- | ---: |
| Fixed recruitment parameters | 2 | 2 |
| Fixed length-weight relationship parameters | 6 | 6 |
| Fixed mortality parameters | 4 | 4 |
| Fixed survey catchability parameter | 1 | 11 |
| Fixed high grading parameters | 11 | 11 |
| Total number of fixed parameters | 33 | 33 |
| Free survey catchability parameter | 1 |  |
| Free growth parameters | 6 | 1 |
| Initial abundance (1975) | 1 | 6 |
| Recruitment-distribution parameters | 2 | 1 |
| Mean recruitment parameters | 1 | 2 |
| Male recruitment deviations | 42 | 1 |
| Female recruitment deviations | 42 | 42 |
| Natural and fishing mortality parameters | 4 | 42 |
| Pot male fishing mortality deviations | 43 | 4 |
| Bycatch mortality from the Tanner crab fishery | 11 | 43 |
| Pot female bycatch fishing mortality deviations | 28 | 11 |
| Trawl bycatch fishing mortality deviations | 42 | 28 |
| Fixed gear bycatch fishing mortality deviations | 0 | 42 |
| Initial (1975) length compositions | 35 | 9 |
| BSFRF survey extra CV | 1 | 35 |
| Free selectivity parameters | 22 | 1 |
|  |  | 24 |
| Total number of free parameters | 281 |  |
| Total number of fixed and free parameters | 314 | 292 |

Table 4. Negative $\log$ likelihood components for scenarios $2 \mathrm{a}, 2 \mathrm{a} 1,2 \mathrm{a} 2,2 \mathrm{~b}, 2 \mathrm{~b} 1,2 \mathrm{~b} 2,2 \mathrm{~d}, 2 \mathrm{~d} 1$, and 2 d 2 and some management quantities.

Scenario

| Negative log likelihood | 2a | 2a1 | 2a2 | 2 b | 2 b 1 | 2 b 2 | 2 d | 2 d 1 | 2 d 2 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| R-variation | 87.37 | 68.19 | 63.71 | 87.22 | 66.69 | 62.99 | 87.21 | 66.22 | 62.89 |
| Length-like-retained | -1038.8 | -854.8 | -904.2 | -1038.9 | -893.7 | -895.3 | -1039.3 | -898.2 | -906.3 |
| Length-like-discmale | -1092.0 | -832.2 | -825.1 | -1092.4 | -828.8 | -822.5 | -1092.1 | -831.7 | -824.2 |
| Length-like-discfemale | -567.31 | -567.31 | -567.53 | -795.01 | -567.94 | -567.92 | -794.89 | -567.41 | -567.57 |
| Length-like-survey | -48633 | -39299 | -37689 | -48629 | -39307 | -37656 | -48631 | -39293 | -37687 |
| Length-like-disctrawl | -4107.3 | -2552.5 | -2315.8 | -3784.5 | -2912.2 | -2629.8 | -3784.4 | -2908.3 | -2615.6 |
| Length-like-discfix | 0.00 | 0.00 | 0.00 | -773.41 | -474.42 | -477.78 | -773.36 | -473.35 | -478.20 |
| Length-like-discTanner | -466.54 | -360.23 | -359.95 | -467.04 | -361.86 | -360.08 | -467.31 | -362.31 | -360.48 |
| Length-like-bsfrfsurvey | -644.79 | -559.96 | -533.44 | -645.73 | -561.12 | -535.16 | -645.92 | -565.08 | -535.70 |
| Catchbio_retained | 50.95 | 27.96 | 25.27 | 51.13 | 28.30 | 25.48 | 51.32 | 28.21 | 25.28 |
| Catchbio_discmale | 228.10 | 140.60 | 127.97 | 229.35 | 142.25 | 128.05 | 229.15 | 142.07 | 128.16 |
| Catchbio-discfemale | 0.11 | 0.05 | 0.04 | 0.11 | 0.04 | 0.04 | 0.11 | 0.04 | 0.04 |
| Catchbio-disctrawl | 0.22 | 0.02 | 0.01 | 0.22 | 0.02 | 0.02 | 0.22 | 0.02 | 0.02 |
| Catchbio-discfix | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Catchbio-discTanner | 0.12 | 0.01 | 0.00 | 0.13 | 0.01 | 0.01 | 0.14 | 0.01 | 0.00 |
| Biomass-trawl survey | 103.86 | 98.27 | 98.81 | 103.70 | 99.61 | 100.54 | 102.61 | 99.56 | 98.51 |
| Biomass-bsfrfsurvey | -7.88 | -7.52 | -8.25 | -8.29 | -7.69 | -8.38 | -8.14 | -8.08 | -8.09 |
| Q-trawl survey | 4.86 | 1.86 | 1.52 | 3.84 | 1.31 | 2.08 | 0.00 | 0.00 | 0.00 |
| Others | 16.57 | 16.61 | 16.79 | 18.05 | 18.12 | 18.05 | 18.02 | 18.23 | 18.12 |
| Total | -56066 | -44680 | -42869 | -56740 | -45558 | -43616 | -56748 | -45553 | -43651 |
| Free parameters |  |  |  |  |  |  |  |  |  |
| B35\%(t) | 281 | 281 | 281 | 292 | 292 | 292 | 292 | 292 | 292 |
| F35\% | 24613 | 25641 | 25853 | 25050 | 25664 | 26150 | 24744 | 25386 | 25349 |
| MMB2017(t) | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 | 0.29 |
| OFL2017 | 20043 | 22181 | 22629 | 21312 | 22642 | 23090 | 20814 | 21758 | 21924 |
| ABC2017(t) | 5012.3 | 5991.2 | 6212.4 | 5599.7 | 6261.1 | 6326.4 | 5393.6 | 5773.7 | 5894.3 |
| Fofl2017 | 4511.1 | 5392.0 | 5591.2 | 5039.7 | 5635.0 | 5693.8 | 4854.2 | 5196.3 | 5304.9 |
| Q82-17 | 0.23 | 0.25 | 0.25 | 0.24 | 0.25 | 0.25 | 0.24 | 0.24 | 0.25 |

Table 5(2b). Summary of estimated model parameter values and standard deviations and limits for scenario 2 b for Bristol Bay red king crab. All values are on a $\log$ scale. Male recruit in year $t$ is $\exp \left(\right.$ mean $^{\text {males }}$ t $)$, and female recruit in year $t$ is $\exp \left(\right.$ mean + males $_{t}+$ females $\left.t\right)$.

| Year | Recruits |  |  |  | F for Directed Pot Fishery |  |  |  | F for Trawl |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Females | SD | Males | SD | Males | SD | Females | SD | Estimate | SD |
| Mean | 15.796 | 0.023 | 15.796 | 0.023 | -1.680 | 0.041 | 0.012 | 0.001 | -4.621 | 0.070 |
| Limits $\uparrow$ | 13,18 |  | 13,18 |  | -3.0,0.0 |  | .001,0.1 |  | -8.5,-1.0 |  |
| Limits $\downarrow$ | -15,15 |  | -15,15 |  | -15,2.43 |  | -6.0,3.5 |  | -10,10 |  |
| 1975 |  |  |  |  | 0.820 | 0.096 |  |  |  |  |
| 1976 | -0.033 | 0.277 | 0.812 | 0.137 | 0.806 | 0.068 |  |  | 0.201 | 0.111 |
| 1977 | 0.521 | 0.161 | 0.682 | 0.103 | 0.800 | 0.059 |  |  | 0.710 | 0.107 |
| 1978 | 0.450 | 0.137 | 0.886 | 0.085 | 1.010 | 0.055 |  |  | 0.781 | 0.106 |
| 1979 | 0.727 | 0.102 | 1.145 | 0.077 | 1.304 | 0.052 |  |  | 0.949 | 0.106 |
| 1980 | 0.239 | 0.116 | 1.320 | 0.077 | 2.170 | 0.047 |  |  | 1.663 | 0.106 |
| 1981 | 0.089 | 0.149 | 0.519 | 0.103 | 2.425 | 0.009 |  |  | 1.203 | 0.107 |
| 1982 | 0.105 | 0.055 | 2.107 | 0.051 | 0.576 | 0.049 |  |  | 2.378 | 0.107 |
| 1983 | 0.034 | 0.073 | 1.446 | 0.052 | -10.62 | 0.936 |  |  | 2.036 | 0.104 |
| 1984 | 0.484 | 0.060 | 1.488 | 0.049 | 0.725 | 0.056 |  |  | 3.089 | 0.104 |
| 1985 | 0.119 | 0.200 | -0.582 | 0.122 | 0.808 | 0.064 |  |  | 1.935 | 0.106 |
| 1986 | 0.582 | 0.061 | 0.765 | 0.047 | 1.339 | 0.062 |  |  | 1.000 | 0.107 |
| 1987 | -0.047 | 0.144 | -0.117 | 0.074 | 0.944 | 0.058 |  |  | 0.585 | 0.106 |
| 1988 | 0.301 | 0.176 | -0.815 | 0.107 | -0.026 | 0.050 |  |  | 1.367 | 0.102 |
| 1989 | 0.105 | 0.158 | -0.672 | 0.089 | 0.063 | 0.047 |  |  | -0.073 | 0.102 |
| 1990 | -0.023 | 0.071 | 0.470 | 0.046 | 0.668 | 0.043 | 1.987 | 0.080 | 0.299 | 0.102 |
| 1991 | -0.071 | 0.098 | 0.012 | 0.056 | 0.647 | 0.045 | -0.137 | 0.080 | 0.634 | 0.104 |
| 1992 | -0.584 | 0.427 | -1.744 | 0.171 | 0.132 | 0.047 | 2.167 | 0.081 | 0.687 | 0.103 |
| 1993 | -0.263 | 0.101 | -0.223 | 0.056 | 0.786 | 0.049 | 2.045 | 0.081 | 1.111 | 0.104 |
| 1994 | -0.451 | 0.475 | -2.094 | 0.198 | -4.356 | 0.049 | 1.421 | 0.113 | -0.655 | 0.103 |
| 1995 | 0.021 | 0.041 | 1.349 | 0.036 | -4.707 | 0.046 | 1.541 | 0.119 | -0.058 | 0.102 |
| 1996 | -0.872 | 0.288 | -0.467 | 0.113 | -0.161 | 0.043 | -3.653 | 0.140 | -0.673 | 0.103 |
| 1997 | -0.931 | 0.425 | -1.335 | 0.167 | -0.052 | 0.044 | -1.006 | 0.085 | -1.036 | 0.103 |
| 1998 | -0.330 | 0.128 | -0.078 | 0.068 | 0.646 | 0.044 | 2.052 | 0.078 | -0.172 | 0.102 |
| 1999 | 0.072 | 0.062 | 0.753 | 0.043 | 0.198 | 0.044 | -2.083 | 0.085 | -0.007 | 0.102 |
| 2000 | -0.125 | 0.149 | -0.181 | 0.080 | -0.179 | 0.043 | -0.275 | 0.079 | -0.825 | 0.102 |
| 2001 | 0.642 | 0.191 | -0.844 | 0.138 | -0.164 | 0.043 | 1.092 | 0.078 | -0.394 | 0.101 |
| 2002 | 0.213 | 0.057 | 1.207 | 0.041 | -0.064 | 0.043 | -2.242 | 0.086 | -0.484 | 0.101 |
| 2003 | -0.086 | 0.259 | -0.533 | 0.142 | 0.459 | 0.042 | 1.170 | 0.079 | -0.340 | 0.101 |
| 2004 | -0.230 | 0.161 | 0.200 | 0.082 | 0.315 | 0.043 | 0.378 | 0.079 | -0.707 | 0.101 |
| 2005 | 0.313 | 0.063 | 1.127 | 0.046 | 0.735 | 0.043 | 0.891 | 0.078 | -0.397 | 0.101 |
| 2006 | -0.750 | 0.177 | 0.520 | 0.064 | 0.446 | 0.043 | -1.513 | 0.080 | -0.732 | 0.101 |
| 2007 | -0.290 | 0.161 | -0.046 | 0.082 | 0.763 | 0.044 | -0.284 | 0.079 | -0.558 | 0.102 |
| 2008 | 0.138 | 0.160 | -0.507 | 0.100 | 0.846 | 0.046 | -0.597 | 0.079 | -0.410 | 0.102 |
| 2009 | 0.296 | 0.140 | -0.484 | 0.094 | 0.540 | 0.047 | -0.822 | 0.080 | -1.003 | 0.103 |
| 2010 | 0.050 | 0.100 | 0.108 | 0.063 | 0.395 | 0.048 | -0.284 | 0.080 | -1.201 | 0.104 |
| 2011 | 0.178 | 0.106 | 0.013 | 0.071 | -0.289 | 0.048 | -1.211 | 0.081 | -1.685 | 0.105 |
| 2012 | 0.031 | 0.147 | -0.352 | 0.089 | -0.399 | 0.050 | -1.753 | 0.084 | -2.225 | 0.106 |
| 2013 | -0.478 | 0.193 | -0.541 | 0.090 | -0.225 | 0.052 | 0.187 | 0.080 | -1.547 | 0.106 |
| 2014 | -0.130 | 0.367 | -1.774 | 0.185 | 0.014 | 0.055 | -0.144 | 0.081 | -2.156 | 0.108 |
| 2015 | 0.069 | 0.186 | -1.037 | 0.119 | -0.025 | 0.059 | 0.915 | 0.083 | -1.848 | 0.109 |
| 2016 | 0.236 | 0.179 | -0.964 | 0.124 | -0.110 | 0.063 | 0.160 | 0.085 | -1.442 | 0.110 |
| 2017 | -0.317 | 0.400 | -1.540 | 0.194 |  |  |  |  |  |  |

Table 5(2b) (continued). Summary of estimated model parameter values and standard deviations and limits for scenario 2 b for Bristol Bay red king crab. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

|  |  |  |  | Initial Length Composition 1975 |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Parameter | Value | SD | Limits | Length | Value | SD | Limits |
| Mm80-84 | 0.429 | 0.016 | 0.184, 1.0 | 68 | 1.158 | 0.103 | -5, 5 |
| Mf80-84 | 0.797 | 0.021 | 0.276, 1.5 | 73 | 1.188 | 0.090 | -5, 5 |
| Mf76-79,85-93 | 0.097 | 0.006 | 0.0, 0.108 | 78 | 0.528 | 0.108 | -5, 5 |
| log_betal, females | 0.324 | 0.056 | -0.67, 1.32 | 83 | 0.610 | 0.090 | -5, 5 |
| $\log _{-}$betal, males | 0.631 | 0.081 | -0.67, 1.32 | 88 | 0.429 | 0.090 | -5, 5 |
| log_betar, females | -0.616 | 0.060 | -1.14, 0.5 | 93 | 0.243 | 0.095 | -5, 5 |
| log_betar, males | -0.604 | 0.051 | -1.14, 0.5 | 98 | 0.254 | 0.094 | -5, 5 |
| Bsfrf_CV | 0.000 | 0.000 | 0.00, 0.40 | 103 | 0.044 | 0.105 | -5, 5 |
| moltp_slope, 75-78 | 0.135 | 0.018 | 0.01, 0.259 | 108 | 0.123 | 0.104 | -5, 5 |
| moltp_slope, 79-17 | 0.099 | 0.004 | 0.01, 0.259 | 113 | 0.255 | 0.101 | -5, 5 |
| log_moltp_L50, 75-78 | 4.974 | 0.011 | 4.445, 5.52 | 118 | 0.056 | 0.119 | -5, 5 |
| log_moltp_L50, 79-17 | 4.949 | 0.004 | 4.445, 5.52 | 123 | 0.100 | 0.123 | -5, 5 |
| log_N75 | 19.953 | 0.031 | 15.0, 22.0 | 128 | 0.019 | 0.138 | -5, 5 |
| log_avg_L50_ret | 4.922 | 0.002 | 4.467, 5.51 | 133 | 0.002 | 0.148 | -5, 5 |
| ret_fish_slope | 0.525 | 0.030 | 0.05, 0.70 | 138 | -0.087 | 0.138 | -5, 5 |
| pot disc.males, $\varphi$ | -0.325 | 0.014 | -0.40, 0.00 | 143 | -0.207 | 0.142 | -5, 5 |
| pot disc.males, $\kappa$ | 0.004 | 0.000 | 0.0, 0.005 | 148 | -0.395 | 0.154 | -5, 5 |
| pot disc.males, $\gamma$ | -0.015 | 0.001 | -0.025, 0.0 | 153 | -0.737 | 0.188 | -5, 5 |
| pot disc.fema., slope | 0.174 | 0.060 | 0.05, 0.43 | 158 | -1.277 | 0.262 | -5, 5 |
| log_pot disc.fema., L50 | 4.446 | 0.029 | 4.20, 4.666 | 163 | -1.277 | 0.271 | -5, 5 |
| trawl disc slope | 0.058 | 0.003 | 0.01, 0.20 | 68 | 1.620 | 0.105 | -5, 5 |
| log_trawl disc L50 | 5.113 | 0.047 | 4.50, 5.40 | 73 | 1.517 | 0.102 | -5, 5 |
| log_srv_L50, m, bsfrf | 4.309 | 0.037 | 3.59, 5.48 | 78 | 1.478 | 0.094 | -5, 5 |
| srv_slope, f, bsfrf | 0.039 | 0.007 | 0.01, 0.435 | 83 | 1.312 | 0.093 | -5, 5 |
| log_srv_L50, f, bsfrf | 4.403 | 0.063 | 4.09, 5.54 | 88 | 1.262 | 0.086 | -5, 5 |
| log_srv_L50, m, 75-81 | 4.344 | 0.010 | 4.09, 4.554 | 93 | 0.807 | 0.103 | -5, 5 |
| srv_slope, f, 75-81 | 0.072 | 0.004 | 0.01, 0.303 | 98 | 0.441 | 0.126 | -5, 5 |
| log_srv_L50, f, 75-81 | 4.468 | 0.017 | 4.09, 4.70 | 103 | 0.149 | 0.150 | -5, 5 |
| log_srv_L50, m, 82-17 | 4.403 | 0.084 | 4.09, 5.10 | 108 | -0.007 | 0.157 | -5, 5 |
| srv_slope, f, 82-17 | 0.057 | 0.008 | 0.01, 0.30 | 113 | -0.240 | 0.183 | -5, 5 |
| log_srv_L50, f, 82-17 | 4.302 | 0.051 | 4.09, 4.90 | 118 | -0.839 | 0.290 | -5, 5 |
| TC_slope, females | 0.376 | 0.131 | 0.02, 0.40 | 123 | -0.950 | 0.329 | -5, 5 |
| log_TC_L50, females | 4.534 | 0.014 | 4.24, 4.90 | 128 | -1.261 | 0.440 | -5, 5 |
| TC_slope, males | 0.250 | 0.103 | 0.05, 0.90 | 133 | -2.264 | 1.042 | -5, 5 |
| log_TC_L50, males | 4.570 | 0.019 | 4.25, 5.14 | 138 | -2.373 | 1.252 | -5, 5 |
| Q | 0.965 | 0.021 | 0.59, 1.2 | 143 | NA | NA |  |
| log_TC_F, males, 91 | -4.113 | 0.085 | -10.0, 1.00 | Fixed g | bycatch pa | neters: |  |
| log_TC_F, males, 92 | -6.086 | 0.086 | -10.0, 1.00 | log_avg | -8.133 | 0.080 |  |
| log_TC_F, males, 93 | -6.804 | 0.088 | -10.0, 1.00 | fmortf | -1.355 | 0.111 |  |
| log_TC_F, males, 13 | -8.308 | 0.091 | -10.0, 1.00 | fmortf_ | -2.232 | 0.130 |  |
| log_TC_F, males, 14 | -7.442 | 0.090 | -10.0, 1.00 | fmortf | -0.706 | 0.103 |  |
| log_TC_F, males, 15 | -7.024 | 0.091 | -10.0, 1.00 | fmortf_ | -0.166 | 0.100 |  |
| log_TC_F, females, 91 | -2.873 | 0.086 | -10.0, 1.00 | fmortf | 0.960 | 0.097 |  |
| log_TC_F, females, 92 | -4.515 | 0.086 | -10.0, 1.00 | fmortf_ | 1.771 | 0.096 |  |
| log_TC_F, females, 93 | -6.395 | 0.087 | -10.0, 1.00 | fmortf_ | 1.408 | 0.097 |  |
| log_TC_F, females, 13 | -7.726 | 0.084 | -10.0, 1.00 | fmortf | 0.320 | 0.100 |  |
| log_TC_F, females, 14 | -7.583 | 0.084 | -10.0, 1.00 | Fix_slo | 0.092 | 0.025 |  |
| log_TC_F, females, 15 | -6.553 | 0.082 | -10.0, 1.00 | $\log _{\_} 150$ | 4.633 | 0.040 |  |

Table 5(2d). Summary of estimated model parameter values and standard deviations and limits for scenario $2 d$ for Bristol Bay red king crab. All values are on a log scale. Male recruit in year $t$ is $\exp \left(\right.$ mean $^{\text {males }}$ ) $)$, and female recruit in year $t$ is $\exp \left(\right.$ mean + males $_{t}+$ females $\left.{ }_{t}\right)$.

| Year | Recruits |  |  |  | F for Directed Pot Fishery |  |  |  | F for Trawl |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Females | SD | Males | SD | Males | SD | Females | SD | Estimate | SD |
| Mean | 15.782 | 0.022 | 15.782 | 0.022 | -1.653 | 0.037 | 0.012 | 0.001 | -4.584 | 0.066 |
| Limits $\uparrow$ | 13,18 |  | 13,18 |  | -3.0,0.0 |  | .001,0.1 |  | -8.5,-1.0 |  |
| Limits $\downarrow$ | -15,15 |  | -15,15 |  | -15,2.43 |  | -6.0,3.5 |  | -10,10 |  |
| 1975 |  |  |  |  | 0.805 | 0.096 |  |  |  |  |
| 1976 | -0.029 | 0.275 | 0.816 | 0.138 | 0.786 | 0.067 |  |  | 0.184 | 0.111 |
| 1977 | 0.519 | 0.161 | 0.686 | 0.103 | 0.779 | 0.057 |  |  | 0.691 | 0.107 |
| 1978 | 0.451 | 0.137 | 0.885 | 0.086 | 0.988 | 0.053 |  |  | 0.762 | 0.105 |
| 1979 | 0.727 | 0.102 | 1.144 | 0.077 | 1.281 | 0.049 |  |  | 0.931 | 0.105 |
| 1980 | 0.236 | 0.116 | 1.319 | 0.077 | 2.148 | 0.045 |  |  | 1.653 | 0.105 |
| 1981 | 0.088 | 0.149 | 0.516 | 0.103 | 2.425 | 0.009 |  |  | 1.211 | 0.107 |
| 1982 | 0.106 | 0.055 | 2.104 | 0.051 | 0.585 | 0.049 |  |  | 2.386 | 0.107 |
| 1983 | 0.034 | 0.073 | 1.444 | 0.052 | -10.61 | 0.925 |  |  | 2.037 | 0.104 |
| 1984 | 0.482 | 0.060 | 1.491 | 0.049 | 0.724 | 0.056 |  |  | 3.091 | 0.104 |
| 1985 | 0.123 | 0.199 | -0.586 | 0.122 | 0.812 | 0.064 |  |  | 1.940 | 0.106 |
| 1986 | 0.580 | 0.061 | 0.766 | 0.046 | 1.344 | 0.062 |  |  | 1.007 | 0.107 |
| 1987 | -0.046 | 0.144 | -0.117 | 0.074 | 0.948 | 0.058 |  |  | 0.591 | 0.106 |
| 1988 | 0.301 | 0.176 | -0.817 | 0.107 | -0.027 | 0.050 |  |  | 1.367 | 0.102 |
| 1989 | 0.105 | 0.158 | -0.674 | 0.090 | 0.059 | 0.047 |  |  | -0.076 | 0.102 |
| 1990 | -0.023 | 0.071 | 0.467 | 0.046 | 0.667 | 0.043 | 1.992 | 0.080 | 0.299 | 0.102 |
| 1991 | -0.072 | 0.098 | 0.008 | 0.056 | 0.652 | 0.045 | -0.136 | 0.080 | 0.640 | 0.104 |
| 1992 | -0.569 | 0.421 | -1.747 | 0.171 | 0.140 | 0.046 | 2.167 | 0.081 | 0.693 | 0.103 |
| 1993 | -0.269 | 0.101 | -0.225 | 0.056 | 0.798 | 0.048 | 2.041 | 0.081 | 1.125 | 0.104 |
| 1994 | -0.429 | 0.469 | -2.103 | 0.198 | -4.345 | 0.048 | 1.419 | 0.114 | -0.647 | 0.103 |
| 1995 | 0.018 | 0.041 | 1.346 | 0.036 | -4.703 | 0.045 | 1.545 | 0.119 | -0.057 | 0.102 |
| 1996 | -0.873 | 0.286 | -0.464 | 0.112 | -0.159 | 0.043 | -3.647 | 0.140 | -0.673 | 0.103 |
| 1997 | -0.925 | 0.420 | -1.335 | 0.167 | -0.049 | 0.043 | -1.003 | 0.085 | -1.035 | 0.103 |
| 1998 | -0.336 | 0.128 | -0.076 | 0.068 | 0.651 | 0.044 | 2.051 | 0.078 | -0.166 | 0.102 |
| 1999 | 0.067 | 0.062 | 0.755 | 0.043 | 0.203 | 0.044 | -2.083 | 0.085 | -0.002 | 0.102 |
| 2000 | -0.130 | 0.149 | -0.178 | 0.079 | -0.176 | 0.043 | -0.273 | 0.079 | -0.824 | 0.102 |
| 2001 | 0.640 | 0.192 | -0.845 | 0.139 | -0.162 | 0.043 | 1.094 | 0.078 | -0.395 | 0.101 |
| 2002 | 0.207 | 0.057 | 1.210 | 0.040 | -0.063 | 0.043 | -2.240 | 0.086 | -0.486 | 0.101 |
| 2003 | -0.085 | 0.259 | -0.536 | 0.143 | 0.458 | 0.042 | 1.174 | 0.080 | -0.340 | 0.101 |
| 2004 | -0.235 | 0.161 | 0.201 | 0.082 | 0.315 | 0.042 | 0.382 | 0.079 | -0.707 | 0.101 |
| 2005 | 0.311 | 0.063 | 1.126 | 0.046 | 0.736 | 0.043 | 0.892 | 0.078 | -0.395 | 0.101 |
| 2006 | -0.751 | 0.177 | 0.520 | 0.064 | 0.447 | 0.043 | -1.511 | 0.080 | -0.731 | 0.101 |
| 2007 | -0.297 | 0.161 | -0.043 | 0.082 | 0.764 | 0.043 | -0.284 | 0.079 | -0.556 | 0.102 |
| 2008 | 0.132 | 0.160 | -0.503 | 0.100 | 0.852 | 0.045 | -0.601 | 0.079 | -0.406 | 0.102 |
| 2009 | 0.293 | 0.140 | -0.481 | 0.094 | 0.546 | 0.046 | -0.828 | 0.080 | -0.999 | 0.103 |
| 2010 | 0.046 | 0.100 | 0.111 | 0.063 | 0.401 | 0.047 | -0.289 | 0.080 | -1.198 | 0.104 |
| 2011 | 0.175 | 0.106 | 0.015 | 0.071 | -0.285 | 0.048 | -1.215 | 0.082 | -1.685 | 0.104 |
| 2012 | 0.030 | 0.147 | -0.351 | 0.089 | -0.397 | 0.049 | -1.755 | 0.084 | -2.227 | 0.106 |
| 2013 | -0.480 | 0.193 | -0.539 | 0.090 | -0.223 | 0.051 | 0.184 | 0.080 | -1.549 | 0.106 |
| 2014 | -0.124 | 0.365 | -1.774 | 0.185 | 0.016 | 0.055 | -0.147 | 0.082 | -2.159 | 0.108 |
| 2015 | 0.065 | 0.186 | -1.033 | 0.119 | -0.023 | 0.059 | 0.913 | 0.083 | -1.851 | 0.109 |
| 2016 | 0.237 | 0.180 | -0.963 | 0.124 | -0.108 | 0.063 | 0.157 | 0.086 | -1.445 | 0.110 |
| 2017 | -0.301 | 0.396 | -1.539 | 0.194 |  |  |  |  |  |  |

Table 5(2d) (continued). Summary of estimated model parameter values and standard deviations and limits for scenario 2d for Bristol Bay red king crab. For initial year length composition deviations, the first 20 length groups are for males and the last 16 length groups are for females.

|  |  |  |  | Initial Length Composition 1975 |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Parameter | Value | SD | Limits | Length | Value | SD | Limits |
| Mm80-84 | 0.430 | 0.016 | 0.184, 1.0 | 68 | 1.161 | 0.103 | -5, 5 |
| Mf80-84 | 0.798 | 0.021 | 0.276, 1.5 | 73 | 1.192 | 0.089 | -5, 5 |
| Mf76-79,85-93 | 0.098 | 0.006 | 0.0, 0.108 | 78 | 0.533 | 0.108 | -5, 5 |
| log_betal, females | 0.325 | 0.056 | -0.67, 1.32 | 83 | 0.615 | 0.090 | -5, 5 |
| $\log _{-}$betal, males | 0.636 | 0.080 | -0.67, 1.32 | 88 | 0.434 | 0.090 | -5, 5 |
| log_betar, females | -0.615 | 0.061 | -1.14, 0.5 | 93 | 0.249 | 0.095 | -5, 5 |
| log_betar, males | -0.600 | 0.051 | -1.14, 0.5 | 98 | 0.259 | 0.093 | -5, 5 |
| Bsfrf_CV | 0.000 | 0.000 | 0.00, 0.40 | 103 | 0.050 | 0.105 | -5, 5 |
| moltp_slope, 75-78 | 0.136 | 0.018 | 0.01, 0.259 | 108 | 0.129 | 0.104 | -5, 5 |
| moltp_slope, 79-14 | 0.100 | 0.004 | 0.01, 0.259 | 113 | 0.261 | 0.101 | -5, 5 |
| log_moltp_L50, 75-78 | 4.976 | 0.011 | 4.445, 5.52 | 118 | 0.062 | 0.119 | -5, 5 |
| log_moltp_L50, 79-14 | 4.951 | 0.004 | 4.445, 5.52 | 123 | 0.104 | 0.123 | -5, 5 |
| log_N75 | 19.945 | 0.031 | 15.0, 22.0 | 128 | 0.023 | 0.138 | -5, 5 |
| log_avg_L50_ret | 4.922 | 0.002 | 4.467, 5.51 | 133 | 0.005 | 0.148 | -5, 5 |
| ret_fish_slope | 0.524 | 0.030 | 0.05, 0.70 | 138 | -0.085 | 0.138 | -5, 5 |
| pot disc.males, $\varphi$ | -0.322 | 0.013 | -0.40, 0.00 | 143 | -0.205 | 0.142 | -5, 5 |
| pot disc.males, $\kappa$ | 0.004 | 0.000 | 0.0, 0.005 | 148 | -0.395 | 0.154 | -5, 5 |
| pot disc.males, $\gamma$ | -0.015 | 0.001 | -0.025, 0.0 | 153 | -0.737 | 0.188 | -5, 5 |
| pot disc.fema., slope | 0.171 | 0.059 | 0.05, 0.43 | 158 | -1.279 | 0.263 | -5, 5 |
| log_pot disc.fema., L50 | 4.448 | 0.030 | 4.20, 4.666 | 163 | -1.280 | 0.272 | -5, 5 |
| trawl disc slope | 0.058 | 0.003 | 0.01, 0.20 | 68 | 1.618 | 0.105 | -5, 5 |
| log_trawl disc L50 | 5.118 | 0.048 | 4.50, 5.40 | 73 | 1.517 | 0.102 | -5, 5 |
| log_srv_L50, m, bsfrf | 4.304 | 0.036 | 3.59, 5.48 | 78 | 1.478 | 0.094 | -5, 5 |
| srv_slope, f, bsfrf | 0.037 | 0.006 | 0.01, 0.435 | 83 | 1.312 | 0.093 | -5, 5 |
| log_srv_L50, f, bsfrf | 4.403 | 0.066 | 4.09, 5.54 | 88 | 1.262 | 0.087 | -5, 5 |
| log_srv_L50, m, 75-81 | 4.344 | 0.010 | 4.09, 4.554 | 93 | 0.808 | 0.103 | -5, 5 |
| srv_slope, f, 75-81 | 0.071 | 0.004 | 0.01, 0.303 | 98 | 0.442 | 0.126 | -5, 5 |
| log_srv_L50, f, 75-81 | 4.467 | 0.017 | 4.09, 4.70 | 103 | 0.149 | 0.151 | -5, 5 |
| log_srv_L50, m, 82-14 | 4.437 | 0.075 | 4.09, 5.10 | 108 | -0.007 | 0.158 | -5, 5 |
| srv_slope, f, 82-14 | 0.058 | 0.007 | 0.01, 0.30 | 113 | -0.241 | 0.184 | -5, 5 |
| log_srv_L50, f, 82-14 | 4.316 | 0.045 | 4.09, 4.90 | 118 | -0.841 | 0.291 | -5, 5 |
| TC_slope, females | 0.376 | 0.131 | 0.02, 0.40 | 123 | -0.953 | 0.331 | -5, 5 |
| log_TC_L50, females | 4.534 | 0.014 | 4.24, 4.90 | 128 | -1.266 | 0.444 | -5, 5 |
| TC_slope, males | 0.246 | 0.101 | 0.05, 0.90 | 133 | -2.279 | 1.060 | -5, 5 |
| 1 g _TC_L50, males | 4.572 | 0.019 | 4.25, 5.14 | 138 | -2.392 | 1.279 | -5, 5 |
| Logit Q parameter | 2.993 | 118.57 | -4.5, 10.96 | 143 | NA | NA |  |
| log_TC_F, males, 91 | -4.080 | 0.082 | -10.0, 1.00 | Fixed g | bycatch pa | neters: |  |
| log_TC_F, males, 92 | -6.052 | 0.084 | -10.0, 1.00 | log_avg | -8.106 | 0.080 |  |
| log_TC_F, males, 93 | -6.766 | 0.085 | -10.0, 1.00 | fmortf | -1.353 | 0.111 |  |
| log_TC_F, males, 13 | -8.280 | 0.090 | -10.0, 1.00 | fmortf_ | -2.230 | 0.130 |  |
| log_TC_F, males, 14 | -7.414 | 0.088 | -10.0, 1.00 | fmortf | -0.706 | 0.103 |  |
| log_TC_F, males, 15 | -6.996 | 0.090 | -10.0, 1.00 | fmortf_ | -0.166 | 0.100 |  |
| log_TC_F, females, 91 | -2.848 | 0.085 | -10.0, 1.00 | fmortf | 0.959 | 0.097 |  |
| log_TC_F, females, 92 | -4.490 | 0.085 | -10.0, 1.00 | fmortf_ | 1.770 | 0.096 |  |
| log_TC_F, females, 93 | -6.369 | 0.086 | -10.0, 1.00 | fmortf_ | 1.407 | 0.097 |  |
| log_TC_F, females, 13 | -7.708 | 0.083 | -10.0, 1.00 | fmortf | 0.319 | 0.100 |  |
| log_TC_F, females, 14 | -7.566 | 0.083 | -10.0, 1.00 | Fix_slo | 0.090 | 0.024 |  |
| log_TC_F, females, 15 | -6.536 | 0.081 | -10.0, 1.00 | log_150 | 4.636 | 0.041 |  |

Table 6(2b). Annual abundance estimates (million crab), mature male biomass (MMB, 1000 t ), and total survey biomass (1000t) for red king crab in Bristol Bay estimated by length-based analysis (scenario 2) from 1975-2017. Mature male biomass for year $t$ is on Feb. 15, year $t+1$. Size measurements are mm carapace length.

| Year (t) | Males |  |  |  | Females <br> Mature <br> $(>89 \mathrm{~mm})$ | Total Recruits | Total Survey Biomass |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\begin{gathered} \text { Mature } \\ (>119 \mathrm{~mm}) \end{gathered}$ | $\begin{gathered} \text { Legal } \\ (>134 \mathrm{~mm}) \end{gathered}$ | $\begin{gathered} \text { MMB } \\ (>119 \mathrm{~mm}) \end{gathered}$ | SD MMB |  |  | Model Est. (>64 mm) | Area-Swept ( $>64 \mathrm{~mm}$ ) |
| 1975 | 55.605 | 29.131 | 81.728 | 4.958 | 69.633 |  | 251.709 | 202.731 |
| 1976 | 60.936 | 35.586 | 91.447 | 4.195 | 105.743 | 32.116 | 288.834 | 331.868 |
| 1977 | 62.265 | 38.209 | 94.265 | 3.524 | 130.640 | 38.466 | 297.283 | 375.661 |
| 1978 | 67.674 | 39.009 | 96.262 | 2.944 | 123.172 | 45.109 | 286.652 | 349.545 |
| 1979 | 63.250 | 40.140 | 80.639 | 2.474 | 105.965 | 69.874 | 261.837 | 167.627 |
| 1980 | 44.669 | 32.562 | 22.332 | 0.840 | 95.596 | 61.586 | 222.496 | 249.322 |
| 1981 | 13.474 | 7.719 | 6.322 | 0.345 | 44.377 | 25.482 | 90.173 | 132.669 |
| 1982 | 6.427 | 2.487 | 6.775 | 0.346 | 20.631 | 125.730 | 44.413 | 143.740 |
| 1983 | 6.056 | 2.634 | 7.834 | 0.350 | 13.545 | 62.622 | 39.407 | 49.320 |
| 1984 | 6.002 | 2.873 | 6.058 | 0.344 | 14.289 | 84.159 | 40.885 | 155.311 |
| 1985 | 7.314 | 2.417 | 10.112 | 0.494 | 13.839 | 8.604 | 34.634 | 34.535 |
| 1986 | 11.990 | 4.636 | 14.881 | 0.738 | 20.318 | 43.413 | 46.376 | 48.158 |
| 1987 | 15.429 | 6.662 | 21.341 | 0.923 | 24.100 | 12.594 | 53.122 | 70.263 |
| 1988 | 16.232 | 9.024 | 27.234 | 1.030 | 28.791 | 7.539 | 57.308 | 55.372 |
| 1989 | 17.644 | 10.848 | 30.898 | 1.086 | 26.250 | 7.806 | 60.651 | 55.941 |
| 1990 | 17.822 | 11.860 | 28.697 | 1.106 | 22.263 | 22.926 | 61.050 | 60.321 |
| 1991 | 14.411 | 10.591 | 23.700 | 1.090 | 20.050 | 14.166 | 55.492 | 85.055 |
| 1992 | 11.308 | 8.451 | 21.535 | 1.048 | 19.747 | 1.973 | 49.400 | 37.687 |
| 1993 | 11.845 | 7.624 | 18.891 | 1.025 | 17.578 | 10.254 | 47.458 | 53.703 |
| 1994 | 11.621 | 6.979 | 24.365 | 1.054 | 14.380 | 1.461 | 41.781 | 32.335 |
| 1995 | 12.099 | 8.796 | 27.144 | 1.029 | 13.930 | 56.431 | 48.278 | 38.396 |
| 1996 | 12.116 | 9.422 | 25.118 | 0.980 | 19.349 | 6.442 | 55.725 | 44.649 |
| 1997 | 11.368 | 8.477 | 23.265 | 0.939 | 28.249 | 2.659 | 59.710 | 85.277 |
| 1998 | 15.626 | 8.184 | 25.495 | 1.019 | 26.369 | 11.524 | 62.804 | 85.176 |
| 1999 | 17.239 | 9.760 | 29.978 | 1.124 | 22.992 | 31.913 | 62.690 | 65.604 |
| 2000 | 15.324 | 11.144 | 29.878 | 1.119 | 25.370 | 11.381 | 65.081 | 68.342 |
| 2001 | 14.292 | 10.661 | 28.736 | 1.078 | 29.521 | 9.038 | 67.670 | 53.188 |
| 2002 | 15.918 | 10.177 | 30.583 | 1.073 | 29.236 | 54.220 | 72.051 | 69.786 |
| 2003 | 16.660 | 10.983 | 29.260 | 1.057 | 34.780 | 8.152 | 76.951 | 116.794 |
| 2004 | 14.880 | 10.434 | 27.220 | 1.016 | 42.196 | 15.880 | 78.602 | 131.910 |
| 2005 | 17.262 | 9.913 | 27.573 | 1.032 | 40.370 | 52.982 | 83.512 | 107.341 |
| 2006 | 17.552 | 10.487 | 29.638 | 1.078 | 44.207 | 17.950 | 86.700 | 95.676 |
| 2007 | 17.028 | 11.076 | 27.006 | 1.095 | 51.198 | 12.102 | 91.822 | 104.841 |
| 2008 | 18.697 | 10.318 | 28.320 | 1.211 | 48.212 | 9.380 | 91.911 | 114.430 |
| 2009 | 19.947 | 11.156 | 32.260 | 1.376 | 43.911 | 10.472 | 89.581 | 91.673 |
| 2010 | 18.964 | 12.422 | 32.564 | 1.466 | 40.493 | 16.563 | 87.419 | 81.642 |
| 2011 | 16.380 | 12.058 | 32.719 | 1.478 | 38.642 | 16.108 | 84.017 | 67.053 |
| 2012 | 14.920 | 11.562 | 31.523 | 1.453 | 38.311 | 10.354 | 83.075 | 61.248 |
| 2013 | 14.622 | 10.799 | 30.376 | 1.454 | 37.431 | 6.835 | 81.440 | 62.410 |
| 2014 | 14.650 | 10.365 | 29.148 | 1.496 | 34.531 | 2.310 | 77.849 | 114.103 |
| 2015 | 13.830 | 9.982 | 27.725 | 1.542 | 30.416 | 5.318 | 72.318 | 64.240 |
| 2016 | 12.499 | 9.447 | 25.804 | 1.564 | 26.513 | 6.266 | 66.256 | 61.231 |
| 2017 | 10.653 | 8.633 | 21.312 | 1.202 | 24.149 | 2.686 | 60.268 | 52.922 |

Table 6(2d). Annual abundance estimates (million crab), mature male biomass (MMB, 1000 t ), and total survey biomass (1000t) for red king crab in Bristol Bay estimated by length-based analysis (scenario 2d) from 1975-2017. Mature male biomass for year $t$ is on Feb. 15, year $t+1$. Size measurements are mm carapace length.

| Year (t) | Males |  |  |  | FemalesMature <br> $(>89 \mathrm{~mm})$ | Total Recruits | Total Survey Biomass |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\begin{gathered} \text { Mature } \\ (>119 \mathrm{~mm}) \end{gathered}$ | $\begin{gathered} \text { Legal } \\ (>134 \mathrm{~mm}) \end{gathered}$ | $\begin{gathered} \text { MMB } \\ (>119 \mathrm{~mm}) \end{gathered}$ | SD MMB |  |  | Model Est. (>64 mm) | Area-Swept ( $>64 \mathrm{~mm}$ ) |
| 1975 | 55.181 | 28.862 | 80.871 | 4.868 | 68.875 |  | 258.686 | 202.731 |
| 1976 | 60.500 | 35.327 | 90.622 | 4.121 | 104.651 | 31.872 | 296.909 | 331.868 |
| 1977 | 61.823 | 37.953 | 93.471 | 3.457 | 129.165 | 38.027 | 305.504 | 375.661 |
| 1978 | 67.177 | 38.749 | 95.460 | 2.874 | 121.635 | 44.519 | 294.382 | 349.545 |
| 1979 | 62.750 | 39.874 | 79.902 | 2.406 | 104.512 | 68.830 | 268.628 | 167.627 |
| 1980 | 44.253 | 32.317 | 21.998 | 0.799 | 94.153 | 60.600 | 227.861 | 249.322 |
| 1981 | 13.288 | 7.627 | 6.097 | 0.303 | 43.619 | 25.041 | 91.978 | 132.669 |
| 1982 | 6.274 | 2.417 | 6.560 | 0.309 | 20.234 | 123.733 | 44.608 | 143.740 |
| 1983 | 5.913 | 2.566 | 7.631 | 0.317 | 13.281 | 61.639 | 39.559 | 49.320 |
| 1984 | 5.875 | 2.810 | 5.880 | 0.315 | 14.021 | 83.152 | 41.110 | 155.311 |
| 1985 | 7.157 | 2.358 | 9.835 | 0.448 | 13.599 | 8.474 | 34.818 | 34.535 |
| 1986 | 11.740 | 4.535 | 14.439 | 0.663 | 19.972 | 42.837 | 46.690 | 48.158 |
| 1987 | 15.102 | 6.504 | 20.735 | 0.817 | 23.688 | 12.428 | 53.469 | 70.263 |
| 1988 | 15.874 | 8.814 | 26.530 | 0.905 | 28.287 | 7.426 | 57.689 | 55.372 |
| 1989 | 17.269 | 10.607 | 30.131 | 0.946 | 25.770 | 7.693 | 61.129 | 55.941 |
| 1990 | 17.445 | 11.600 | 27.889 | 0.953 | 21.832 | 22.559 | 61.553 | 60.321 |
| 1991 | 14.053 | 10.321 | 22.887 | 0.933 | 19.638 | 13.910 | 55.799 | 85.055 |
| 1992 | 10.972 | 8.183 | 20.747 | 0.894 | 19.317 | 1.952 | 49.494 | 37.687 |
| 1993 | 11.503 | 7.367 | 18.104 | 0.870 | 17.176 | 10.068 | 47.509 | 53.703 |
| 1994 | 11.267 | 6.727 | 23.545 | 0.893 | 14.030 | 1.442 | 41.708 | 32.335 |
| 1995 | 11.760 | 8.539 | 26.342 | 0.872 | 13.598 | 55.425 | 48.371 | 38.396 |
| 1996 | 11.797 | 9.169 | 24.351 | 0.831 | 18.930 | 6.373 | 55.959 | 44.649 |
| 1997 | 11.065 | 8.234 | 22.531 | 0.797 | 27.672 | 2.627 | 59.961 | 85.277 |
| 1998 | 15.257 | 7.950 | 24.681 | 0.860 | 25.843 | 11.354 | 63.115 | 85.176 |
| 1999 | 16.829 | 9.501 | 29.080 | 0.950 | 22.525 | 31.460 | 62.984 | 65.604 |
| 2000 | 14.936 | 10.861 | 28.993 | 0.950 | 24.874 | 11.234 | 65.437 | 68.342 |
| 2001 | 13.931 | 10.376 | 27.889 | 0.918 | 28.968 | 8.892 | 68.099 | 53.188 |
| 2002 | 15.558 | 9.904 | 29.745 | 0.915 | 28.698 | 53.453 | 72.565 | 69.786 |
| 2003 | 16.307 | 10.722 | 28.446 | 0.904 | 34.159 | 8.020 | 77.559 | 116.794 |
| 2004 | 14.548 | 10.182 | 26.444 | 0.871 | 41.453 | 15.651 | 79.208 | 131.910 |
| 2005 | 16.909 | 9.669 | 26.785 | 0.881 | 39.663 | 52.109 | 84.177 | 107.341 |
| 2006 | 17.185 | 10.240 | 28.823 | 0.924 | 43.430 | 17.698 | 87.348 | 95.676 |
| 2007 | 16.657 | 10.820 | 26.184 | 0.938 | 50.304 | 11.930 | 92.529 | 104.841 |
| 2008 | 18.276 | 10.050 | 27.415 | 1.036 | 47.373 | 9.252 | 92.576 | 114.430 |
| 2009 | 19.478 | 10.859 | 31.255 | 1.185 | 43.143 | 10.341 | 90.199 | 91.673 |
| 2010 | 18.496 | 12.095 | 31.527 | 1.273 | 39.791 | 16.349 | 88.044 | 81.642 |
| 2011 | 15.945 | 11.720 | 31.713 | 1.296 | 37.985 | 15.901 | 84.609 | 67.053 |
| 2012 | 14.527 | 11.237 | 30.579 | 1.288 | 37.675 | 10.219 | 83.722 | 61.248 |
| 2013 | 14.259 | 10.499 | 29.488 | 1.304 | 36.823 | 6.748 | 82.131 | 62.410 |
| 2014 | 14.307 | 10.089 | 28.306 | 1.360 | 33.977 | 2.284 | 78.549 | 114.103 |
| 2015 | 13.507 | 9.726 | 26.928 | 1.419 | 29.931 | 5.261 | 72.983 | 64.240 |
| 2016 | 12.198 | 9.205 | 25.056 | 1.454 | 26.093 | 6.184 | 66.873 | 61.231 |
| 2017 | 10.382 | 8.405 | 20.814 | 1.126 | 23.773 | 2.669 | 60.831 | 52.922 |

Table 7(2b). Comparison of projected mature male biomass (1000 t) on Feb. 15, retained catch (1000 t), their $95 \%$ limits, and mean fishing mortality with no directed fishery, $\mathrm{F}_{40 \%}$, and $\mathrm{F}_{35 \%}$ harvest strategy with $\mathrm{F}_{35 \%}$ constraint during 2017-2026. Parameter estimates with scenario 2 are used for the projection.

| No Directed Fishery |  |  |  |  |  |  |
| :---: | :--- | ---: | ---: | ---: | ---: | ---: |
| Year | MMB | $95 \%$ LCI | $95 \%$ UCI | Catch | $95 \%$ LCI | $95 \%$ UCI |
| 2017 | 26.310 | 23.719 | 28.757 | 0.000 | 0.000 | 0.000 |
| 2018 | 25.868 | 23.321 | 28.274 | 0.000 | 0.000 | 0.000 |
| 2019 | 25.350 | 22.853 | 27.709 | 0.000 | 0.000 | 0.000 |
| 2020 | 24.805 | 22.432 | 27.316 | 0.000 | 0.000 | 0.000 |
| 2021 | 26.554 | 22.133 | 36.148 | 0.000 | 0.000 | 0.000 |
| 2022 | 30.811 | 22.341 | 49.368 | 0.000 | 0.000 | 0.000 |
| 2023 | 35.911 | 22.448 | 60.877 | 0.000 | 0.000 | 0.000 |
| 2024 | 41.038 | 23.713 | 70.650 | 0.000 | 0.000 | 0.000 |
| 2025 | 45.760 | 25.333 | 78.897 | 0.000 | 0.000 | 0.000 |
| 2026 | 49.955 | 26.680 | 85.860 | 0.000 | 0.000 | 0.000 |
|  |  |  |  |  |  |  |
|  |  |  | F40\% |  |  |  |
| 2017 | 21.981 | 20.158 | 23.665 | 4.465 | 3.672 | 5.252 |
| 2018 | 18.845 | 17.476 | 20.094 | 3.238 | 2.735 | 3.724 |
| 2019 | 16.757 | 15.642 | 17.767 | 2.448 | 2.101 | 2.778 |
| 2020 | 15.364 | 14.354 | 16.580 | 1.968 | 1.713 | 2.252 |
| 2021 | 16.352 | 13.274 | 23.896 | 1.961 | 1.451 | 3.227 |
| 2022 | 19.337 | 12.876 | 33.427 | 2.458 | 1.311 | 4.734 |
| 2023 | 22.430 | 13.092 | 40.377 | 3.243 | 1.285 | 6.517 |
| 2024 | 24.947 | 13.938 | 43.503 | 3.999 | 1.388 | 8.018 |
| 2025 | 26.226 | 15.000 | 47.101 | 4.599 | 1.601 | 8.656 |
| 2026 | 27.928 | 15.453 | 49.508 | 5.002 | 1.802 | 9.333 |
|  |  |  |  |  |  |  |
|  |  |  | F35\% |  |  |  |
| 2017 | 21.339 | 19.616 | 22.926 | 5.127 | 4.231 | 6.014 |
| 2018 | 17.968 | 16.717 | 19.104 | 3.545 | 3.014 | 4.056 |
| 2019 | 15.820 | 14.818 | 16.725 | 2.607 | 2.254 | 2.941 |
| 2020 | 14.444 | 13.521 | 15.592 | 2.065 | 1.806 | 2.355 |
| 2021 | 15.435 | 12.466 | 22.807 | 2.062 | 1.513 | 3.439 |
| 2022 | 18.316 | 12.089 | 31.744 | 2.645 | 1.365 | 5.335 |
| 2023 | 21.187 | 12.329 | 37.890 | 3.535 | 1.345 | 7.308 |
| 2024 | 23.414 | 13.155 | 41.078 | 4.362 | 1.465 | 8.990 |
| 2025 | 24.898 | 14.135 | 43.504 | 4.986 | 1.714 | 9.510 |
| 2026 | 25.839 | 14.579 | 45.380 | 5.379 | 1.901 | 10.226 |
|  |  |  |  |  |  |  |



Figure 1. Current harvest rate strategy (line) for the Bristol Bay red king crab fishery and annual prohibited species catch (PSC) limits (numbers of crab) of Bristol Bay red king crab in the groundfish fisheries in zone 1 in the eastern Bering Sea. Harvest rates are based on current-year estimates of effective spawning biomass (ESB), whereas PSC limits apply to previous-year ESB.

## Data by type and year



Figure 2. Data types and ranges used for the stock assessment.


Figure 3. Retained catch biomass and bycatch mortality biomass ( t ) for Bristol Bay red king crab from 1953 to 2016. Handling mortality rates were assumed to be 0.2 for the directed pot fishery 0.25 for the Tanner crab fishery and 0.8 for the trawl fisheries.


Figure 4. Comparison of survey legal male abundances and catches per unit effort for Bristol Bay red king crab from 1968 to 2016.


Figure 5a. Survey abundances by 5-mm carapace length bin for male Bristol Bay red king crab from 1968 to 2017.


Figure 5b. Survey abundances by 5 mm carapace length bin for female Bristol Bay red king crab from 1968 to 2017.


Figure 6. Relationship between implied effective sample sizes (section 3(a)(5)(i)) and effective sample sizes (see effective sample sizes for scenario $2 b$ ) for length/sex composition data with scenario 2 b : trawl survey data.


Figure 7. Relationship between implied effective sample sizes (section 3(a)(5)(i)) and effective sample sizes (see effective sample sizes for scenario $2 b$ ) for length/sex composition data with scenario 2 b : directed pot fishery data.


Figure $8 \mathrm{a}(2 \mathrm{~b})$. Estimated trawl survey selectivities under scenario 2b. Pot, fixed gear and trawl handling mortality rates were assumed to be 0.20 .5 and 0.8 , respectively.


Figure $8 \mathrm{a}(2 \mathrm{~d})$. Estimated trawl survey selectivities under scenario 2d. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.


Figure 8b. Comparisons of estimated NMFS trawl survey selectivities for period 1982-2017 under scenarios $2 \mathrm{a}, 2 \mathrm{~b}, 2 \mathrm{~b} 1$, and 2 d . Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.


Figure 8c. Estimated pot fishery selectivities and groundfish trawl bycatch selectivities under scenario 2 b . Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.


Figure 9(2b). Comparison of estimated probabilities of molting of male red king crab in Bristol Bay for different periods. Molting probabilities for periods 1954-1961 and 1966-1969 were estimated by Balsiger (1974) from tagging data. Molting probabilities for 1975-2017 were estimated with a length-based model with pot handling mortality rate of 0.2 under scenario 2 b .


Figure 10a. Comparisons of area-swept estimates of total survey biomass and model prediction for model estimates in 2017 under scenarios 2a, 2a1, 2a2, 2b, 2b1, 2b2, 2d, 2d1, and 2d2. Pot, fixed gear, and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively. The error bars are plus and minus 2 standard deviations.


Figure 10b. Comparisons of area-swept estimates of male ( $>119 \mathrm{~mm}$ ) and female ( $>89 \mathrm{~mm}$ ) abundance and model prediction for model estimates in 2017 under scenarios $2 \mathrm{a}, 2 \mathrm{~b}, 2 \mathrm{~b} 1$, and 2 d . Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.


Figure 10c. Comparisons of total survey biomass estimates by the BSFRF survey and the model for model estimates in 2017 (scenarios 2a, 2a1, 2a2, 2b, 2b1, 2b2, 2d, 2d1, and 2d2). The error bars are plus and minus 2 standard deviations of scenario $2 b$.


Figure 10d. Comparisons of estimated BSFRF survey selectivities with scenarios 2a, 2b, 2b1, and 2 d . The catchability is assumed to be 1.0.


Figure $10 \mathrm{e}(2 \mathrm{a}, 2 \mathrm{~b} \& 2 \mathrm{~d})$. Comparisons of length compositions by the BSFRF survey and the model estimates during 2007-2008 and 2013-2016 with scenarios 2a (solid black), 2b (dashed red), and 2d (green lines).


Figure $10 \mathrm{e}(2 \mathrm{~b}, 2 \mathrm{~b} 1 \& 2 \mathrm{~b} 2)$. Comparisons of length compositions by the BSFRF survey and the model estimates during 2007-2008 and 2013-2016 with scenarios 2 b (solid black), 2 b 1 (dashed red), and 2b2 (green lines).


Figure 11. Estimated absolute mature male biomasses during 1975-2017 for scenarios 2a, 2a1, 2a2, 2b, 2b1, 2b2, 2d, 2d1, and 2 d 2 .


Figure 12(2b). Estimated recruitment time series during 1976-2017 with scenario 2b. Mean male recruits during 1984-2016 was used to estimate $B_{35 \%}$.


Figure 12(2d). Estimated recruitment time series during 1976-2017 with scenario 2d. Mean male recruits during 1984-2017 was used to estimate B35\%.


Figure 13(2b). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2016 under scenario 2b. Average of recruitment from 1984 to 2017 was used to estimate $B_{\text {MSY }}$. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.


Figure 13(2d). Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1975-2016 under scenario 2d. Average of recruitment from 1984 to 2017 was used to estimate BMSY. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.


Figure 14a. Relationships between mature male biomass on Feb. 15 and total recruits at age 5 (i.e., 6 -year time lag) for Bristol Bay red king crab with pot handling mortality rate of 0.2 under scenario 2 b . Numerical labels are years of mating, and the vertical dotted line is the estimated $\mathrm{B}_{35 \%}$ based on the mean recruitment level during 1984 to 2017.


Figure 14b. Relationships between log recruitment per mature male biomass and mature male biomass on Feb. 15 for Bristol Bay red king crab with pot handling mortality rate of 0.2 under scenario 2b. Numerical labels are years of mating, and the line is the regression line for data of 1978-2011.


Figure 15. Average clutch fullness and proportion of empty clutches of newshell (shell conditions 1 and 2) mature female crab $>89 \mathrm{~mm}$ CL from 1975 to 2017 from survey data. Oldshell females were excluded.


Figure 16a. Observed and predicted catch mortality biomass under scenarios 2 a (solid black), 2 b (dashed red), and 2d (green lines). Mortality biomass is equal to caught biomass times a handling mortality rate. Pot handling mortality rate is 0.2 .


Figure 16b. Observed and predicted bycatch mortality biomass from groundfish fisheries and the Tanner crab fishery under scenarios 2 a (solid black), 2 b (dashed red), and 2 d (green lines). Mortality biomass is equal to caught biomass times a handling mortality rate. Trawl handling mortality rate is 0.8 , fixed gear handling mortality rate is 0.5 , and Tanner crab pot handling mortality is 0.25 . Trawl bycatch biomass was 0 before 1976 .


Figure 17(2b). Standardized residuals of total survey biomass under scenario 2b. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.


Figure 17(2d). Standardized residuals of total survey biomass under scenario 2d. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.


Figure $18(2 \mathrm{a}, 2 \mathrm{~b} \& 2 \mathrm{~d})$. Comparison of area-swept and model estimated survey length frequencies of Bristol Bay male red king crab by year under scenarios 2 a (solid black), 2 b (dashed red), and 2d (green lines). Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 .


Figure 18(2b, 2b1 \& 2b2). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay male red king crab by year under scenarios 2 b (solid black), 2 b 1 (dashed red), and 2 b 2 (green lines). Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 .


Figure 19(2a, 2b \& 2d). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crab by year under scenarios 2a(solid black), 2b (dashed red), and 2d (green lines). Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 .


Figure 19(2b, 2b1 \& 2b2). Comparison of area-swept and model estimated survey length frequencies of Bristol Bay female red king crab by year under scenarios 2 b (solid black), 2 b 1 (dashed red), and 2 b 2 (green lines). Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 .


Figure $20(2 \mathrm{a}, 2 \mathrm{~b} \& 2 \mathrm{~d})$. Comparison of observed and model estimated retained length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under scenarios 2 a (solid black), 2 b (dashed red), and 2 d (green lines). Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 .


Figure 21(2a, 2b \& 2d). Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the directed pot fishery under scenarios 2 a (solid black), 2b (dashed red), and 2d (green lines). Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 .


Figure $22(2 \mathrm{a}, 2 \mathrm{~b} \& 2 \mathrm{~d})$. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the directed pot fishery under scenarios 2 a (solid black), 2b (dashed red), and 2d (green lines). Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 .


Figure $23(2 \mathrm{a}, 2 \mathrm{~b} \& 2 \mathrm{~d})$. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish trawl fisheries under scenarios 2 a (solid black), 2 b (dashed red), and 2 d (green lines). Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 .


Figure $23(2 \mathrm{a}, 2 \mathrm{~b} \& 2 \mathrm{~d})$. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish trawl fisheries under scenarios 2 a (solid black), 2 b (dashed red), and 2 d (green lines). Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 .


Figure $24(2 \mathrm{~b} 1,2 \mathrm{~b} \& 2 \mathrm{~d})$. Comparison of observer and model estimated discarded length frequencies of Bristol Bay male red king crab by year in the groundfish fixed gear fisheries under scenarios 2 b 1 (solid black), 2b (dashed red), and 2d (green lines). Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 .


Figure $24(2 \mathrm{~b} 1,2 \mathrm{~b} \& 2 \mathrm{~d})$. Comparison of observer and model estimated discarded length frequencies of Bristol Bay female red king crab by year in the groundfish fixed gear fisheries under scenarios 2 b 1 (solid black), 2 b (dashed red), and 2d (green lines). Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 .


Figure $24(2 \mathrm{a}, 2 \mathrm{~b} \& 2 \mathrm{~d})$. Comparison of observer and model estimated discarded length frequencies of Bristol Bay red king crab by year in the Tanner crab fishery under scenarios 2 a (solid black), 2 b (dashed red), and 2 d (green lines). Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 .

Scenario 2a, Trawl Survey Males
clr $\bullet<0 \bullet>0$
Residual $0.5-1.0 \bigcirc 1.5 \bigcirc 2.0 \bigcirc 2.5$


Figure 25(2a). Standardized residuals of proportions of survey male red king crab by year and carapace length (mm) under scenario 2 a . Green circles are positive residuals, and red circles are negative residuals. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.

Scenario 2b, Trawl Survey Males


Figure 25(2b). Standardized residuals of proportions of survey male red king crab by year and carapace length (mm) under scenario 2 b . Green circles are positive residuals, and red circles are negative residuals. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.

Scenario 2d, Trawl Survey Males


Figure 25(2d). Standardized residuals of proportions of survey male red king crab by year and carapace length (mm) under scenario 2d. Green circles are positive residuals, and red circles are negative residuals. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.

Scenario 2a, Trawl Survey Females


Figure 25(2a). Standardized residuals of proportions of survey female red king crab by year and carapace length ( mm ) under scenario 2 a . Green circles are positive residuals, and red circles are negative residuals. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.

Scenario 2b, Trawl Survey Females


Figure 25(2b). Standardized residuals of proportions of survey female red king crab by year and carapace length ( mm ) under scenario 2 b . Green circles are positive residuals, and red circles are negative residuals. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.

Scenario 2d, Trawl Survey Females


Figure 25(2d). Standardized residuals of proportions of survey female red king crab by year and carapace length ( mm ) under scenario 2d. Green circles are positive residuals, and red circles are negative residuals. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.


Figure 27. Comparison of hindcast estimates of mature male biomass on Feb. 15 (top) and total abundance (bottom) of Bristol Bay red king crab from 1975 to 2017 made with terminal years 20112017 with scenario 2b. These are results of the 2017 model. Legend shows the terminal year. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.


Figure 28. Comparison of hindcast estimates of total recruitment for scenario 2 b of Bristol Bay red king crab from 1976 to 2017 made with terminal years 2011-2017. These are results of the 2017 model. Legend shows the terminal year. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.


Figure 29. Comparison of estimates of legal male abundance (top) and mature males (bottom) of Bristol Bay red king crab from 1968 to 2017 made with terminal years 2004-2017 with the base scenarios. Scenario 2 b is used for 2017. These are results of historical assessments. Legend shows the year in which the assessment was conducted. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.


Figure 30. Probability distributions of estimated trawl survey catchability ( $Q$ ) under scenario 2 b with the mcmc approach. Pot, fixed gear and trawl handling mortality rates were assumed to be 0.2 , 0.5 and 0.8 , respectively.


Figure $31 \mathrm{a}(2 \mathrm{~b} \& 2 \mathrm{~d})$. Probability distributions of estimated mature male biomass on Feb. 15, 2017 with $\mathrm{F}_{35 \%}$ under scenarios 2 b (upper panel) and 2d (lower panel) with the mcmc approach. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.


Figure $31 \mathrm{~b}(2 \mathrm{~b} \& 2 \mathrm{~d}$ ). Probability distributions of the 2017 estimated OFL with scenarios 2 b (upper panel) and 2d (lower panel) with the mcmc approach. Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively.


Figure 32(2b \& 2d). Projected mature male biomass on Feb. 15 with $F_{40 \%}$ and $F_{35 \%}$ harvest strategy during 2017-2026. Input parameter estimates are based on scenarios $2 b$ (upper panel) and 2d (lower panel). Pot, fixed gear and trawl handling mortality rates were assumed to be 0.2 , 0.5 and 0.8 , respectively, and the confidence limits are for the $F_{35 \%}$ harvest strategy.


Figure 33(2b\&2d). Projected retained catch biomass with $F_{40 \%}$ and $F_{35 \%}$ harvest strategy during 2017-2126. Input parameter estimates are based on scenarios 2b (upper panel) and 2d (lower panel). Pot, fixed gear and trawl handling mortality rates were assumed to be $0.2,0.5$ and 0.8 , respectively, and the confidence limits are for the $F_{35 \%}$ harvest strategy.


Figure 34. Length frequency distributions of male (top panel) and female (bottom panel) red king crab in Bristol Bay from NMFS trawl surveys during 2013-2017. For purposes of these graphs, abundance estimates are based on area-swept methods.

## Appendix A. Description of the Bristol Bay Red King Crab Model

## a. Model Description

## i. Population model

The original LBA model was described in detail by Zheng et al. (1995a, 1995b) and Zheng and Kruse (2002). Crab abundances by carapace length and shell condition in any one year are modeled to result from abundances in the previous year minus catch and handling and natural mortalities, plus recruitment, and additions to or losses from each length class due to growth:

$$
\begin{align*}
& N_{l, t+1}^{s}=\sum_{l^{\prime}=1}^{l}\left\{P_{l^{\prime}, l, t}^{s}\left[\left(N_{l^{\prime}, t}^{s}+O_{l^{\prime}, t}^{s}\right) e^{-M_{t}^{s}}-\left(C_{l^{\prime}, t}^{s}+D_{l^{\prime}, t}^{s}\right) e^{\left(y_{t}-1\right) M_{t}^{s}}-T_{l^{\prime}, t}^{s} e^{\left(j_{t}-1\right) M_{t}^{s}}\right] m_{l^{\prime}, t}^{s}\right\}+R_{t+1}^{s} U_{l}^{s}  \tag{A1}\\
& O_{l, t+1}^{s}=\left[\left(N_{l, t}^{s}+O_{l, t}^{s}\right) e^{-M_{t}^{s}}-\left(C_{l, t}^{s}+D_{l, t}^{s}\right) e^{\left(y_{t}-1\right) M_{t}^{s}}-T_{l, t}^{s} e^{\left(j_{t}-1\right) M_{t}^{s}}\right]\left(1-m_{l, t}^{s}\right)
\end{align*}
$$

where $N_{l, t}^{s}$ is the number of new shell crab of sex $s$ in length-class $l$ at the start of year $t, O_{l, t}^{s}$ the number of old shell crab of sex $s$ in length-class $l$ at the start of year $t, P_{l^{\prime}, l, s}^{s}$ the proportion during year $t$ of an animals of sex $s$ in length-class $l$ ' which grow into length-class $l$ given that they moulted, $M_{t}^{s}$ the rate of natural mortality on animals of sex $s$ during year $t, m_{l, t}^{s}$ the probability that an animal of sex $s$ in length-class $l$ will moult during year $t, R_{t+1}^{s}$ the recruitment [to the model] of animals of sex $s$ during year $t, U_{l}^{s}$ the proportion of recruits of sex $s$ which recruit to length-class $l, C_{l, t}^{s}$ the retained catch (in numbers) of animals of sex $s$ in length-class $l$ during year $t, D_{l, t}^{s}$ the discarded catch of animals of sex $s$ in length-class $l$ during year $t$ in the directed fishery, $T_{l, t}^{s}$ the discarded catch of animals of sex $s$ in length-class $l$ during year $t$ in the Tanner crab fishery and the groundfish fisheries, $y_{t}$ the time in years between survey and the directed pot fishery during year $t$, and $j_{t}$ the time in years between survey and the Tanner and groundfish fisheries during year $t$.
The minimum carapace length for both males and females is set at 65 mm , and crab abundance is modeled with a length-class interval of 5 mm . The last length class includes all crab $\geq 160-\mathrm{mm}$ CL for males and $\geq 140-\mathrm{mm}$ CL for females. Thus, length classes/groups are 20 for males and 16 for females. Since females moult annually (Powell 1967), females have only the first part of the equation (A1).
The growth increment is assumed to be gamma distributed with mean which depends linearly on pre-moult length, i.e.:

$$
\begin{equation*}
P_{l, l^{\prime}, t}^{s}=\int_{L_{1}-\Delta L / 2}^{L_{1}+\Delta L / 2} \frac{x^{\alpha_{L_{l}, x}^{s},} e^{x / \beta^{s}}}{\left(\beta^{s}\right)^{\alpha_{L l, t}} \Gamma\left(\alpha_{L_{1}, t}^{s}\right)} d x \quad \alpha_{L_{1}, t}^{s} \beta^{s}=a_{t}^{s}+b_{t}^{s} L_{l} \tag{A2}
\end{equation*}
$$

where $L_{l}$ is the mid-point of length-class $l, \Delta L$ the width of each size-class ( 5 mm carapace length), $a_{t}^{s}, b_{t}^{s}$ the parameters of the length-growth increment relationship for sex $s$ and year $t$, and $\beta^{s}$ the parameter determining the variance of the growth increment. Growth is timeinvariant for males, and specified for three time-blocks for females (1968-82; 1983-93; 19942017) based on changes to the size at maturity for females. The probability of moulting as a function of length for males is given by an inverse logistic function, i.e.:

$$
\begin{equation*}
m_{l}=\frac{1}{1+e^{\tilde{\beta}\left(L_{l}-L_{s_{0}}\right)}} \tag{A3}
\end{equation*}
$$

where $\tilde{\beta}, L_{50}$ are the parameters which determine the relationship between length and the probability of moulting.
Recruitment is defined as recruitment to the model and survey gear rather than recruitment to the fishery. Recruitment is separated into a time-dependent variable, $R_{t+1}^{s}$, and size-dependent variables, $U_{l}^{s}$, representing the proportion of recruits belonging to each length class. $R_{t+1}^{s}$ is assumed to consist of crab at the recruiting age with different lengths and thus represents year class strength for year $t$. The proportion of recruits by length-class, $U_{l}^{s}$, is described using a gamma distribution with parameters $\alpha_{l}^{s}$ and $\beta_{l}^{s}$. Because of different growth rates, recruitment is estimated separately for males and females under a constraint of approximately equal sex ratios of recruitment over time.

## ii. Catches and Fisheries Selectivities

Before 1990, no observed bycatch data were available in the directed pot fishery; the crab that were discarded and died in those years were estimated as the product of handling mortality rate, legal harvest rates, and mean length-specific selectivities. It is difficult to estimate bycatch from the Tanner crab fishery before 1991. A reasonable index to estimate bycatch fishing mortalities is potlifts of the Tanner crab fishery within the distribution area of Bristol Bay red king crab. Thus, bycatch fishing mortalities from the Tanner crab fishery before 1991 were estimated to be proportional to the smoothing average of potlifts east of $163^{\circ} \mathrm{W}$. The smoothing average is equal to $\left(P_{t-2}+2 P_{t-1}+3 P_{t}\right) / 6$ for the potlifts in year t . The smoothing process not only smoothes the annual number of potlifts, it also indexes the effects of lost pots during the previous years. All bycatches are death catches because the model fits the estimated observed death bycatches.
The catch (by sex) in numbers by the directed fishery is:

$$
\begin{equation*}
G_{l, t}^{s}=\left(N_{l, t}^{s}+O_{l, t}^{s}\right) e^{-y_{t} M_{t}^{s}}\left(1-e^{-F_{l, t}^{s}}\right) \tag{A4}
\end{equation*}
$$

where $F_{l, t}^{s}$ is the fishing mortality rate during year $t$ on animals of sex $s$ in length-class $l$ due to the directed fishery:
$F_{l, t}^{s}= \begin{cases}{\left[\left(S_{l}^{\text {dir,land }}\left(1+h_{t} \phi\right)+S_{l}^{\text {dir,disc,mal }}\right] F_{t}^{\text {dir }}\right.} & \text { if } s=\text { mal } \\ S_{l}^{\text {dir,disc, fem }} F_{t}^{\text {diss, fem }} & \text { if } s=\text { fem }\end{cases}$
where $S_{l}^{\text {dir,land }}$ is the selectivity pattern for the landings by the directed fishery, $S_{l}^{\text {dir,disc,s }}$ the selectivity pattern for the discards in the directed fishery by sex, $F_{t}^{\text {dir }}$ the fully-selected fishing mortality during year $t$ (on males), $F_{t}^{\text {discfem }}$ the fully-selected fishing mortality on female animals during year $t$ related to discards in the directed fishery, $\phi$ the handling mortality (the proportion of animals which die due to being returned to the water following capture), and $h_{t}$ the rate of high-grading during year $t$, i.e. discards of animals which can be legally-retained by the directed pot fishery (non-zero only for 2005-2016).

There are no landings of females in a male-only fishery, while the landings $C$ of males in the directed fishery and discards $D$ of males in the directed fishery are:
$C_{l, t}^{\text {mal }}=\left(N_{l, t}^{\text {mal }}+O_{l, t}^{\text {mal }}\right) e^{-y_{t} M_{t}^{\text {mal }}}\left(1-e^{-S_{l}^{\text {difl.mad }} t_{t}^{\text {dir }}}\right)$
$D_{l, t}^{\mathrm{mal}}=G_{l, t}^{\mathrm{mal}}-C_{l, t}^{\mathrm{mal}}$
The catch (by sex) in numbers by the Tanner crab and groundfish fisheries in length-class $l$ during year $t$ is given by:
$T_{l, t}^{s}=\left(N_{l, t}^{s}+O_{l, t}^{s}\right) e^{-j_{t} M_{t}^{s}} e^{-F_{l, t}^{s}}\left(1-e^{-\tilde{F}_{l, t}^{s}}\right)$
where $\tilde{F}_{l, t}^{s}$ is the fishing mortality rate during year $t$ on animals of sex $s$ in length-class $l$ due to the Tanner crab and groundfish fisheries:
$\widetilde{F}_{l, t}^{s}=S_{l}^{\text {Tanner,s }} F_{t}^{\text {Tanner,s }}+S_{l}^{\text {trawl }} F_{t}^{\text {trawl }}+S_{l}^{f i x} F_{t}^{\text {fix }}$
where $S_{l}^{\text {Tanner,s }}$ is the selectivity pattern for the discards in the Tanner crab fishery by sex, $F_{t}^{\text {Tanner,s }}$ the fully-selected fishing mortality during year $t$ on animals of sex $s$ during year $t$ due to this fishery, $S_{l}^{\text {trawl }}$ the selectivity pattern for the bycatch in the groundfish trawl fishery, $F_{t}^{\text {trawl }}$ the fully-selected fishing mortality due to the groundfish trawl fishery, $S_{l}^{f i x}$ the selectivity pattern for the bycatch in the groundfish fixed gear fishery, and $F_{t}^{\text {fix }}$ the fully-selected fishing mortality due to the groundfish fixed gear fishery.

The bycatches by sex are estimated from the Tanner crab fishery, $T C_{l, t}^{s}$, groundfish trawl fishery, $G T_{l, t}^{s}$, and groundfish fixed gear fishery, $G F_{l, t}^{s}$, as follow:

$$
\begin{align*}
& T C_{l, t}^{s}=\left(N_{l, t}^{s}+O_{l, t}^{s}\right) e^{-j_{t} M_{t}^{s}} e^{-F_{l, t}^{s}}\left(1-e^{-\widetilde{F}_{l, t}^{s}}\right) S_{l}^{\text {Tanner,s,s}} F_{t}^{\text {Tanner,s,s}} / \widetilde{F}_{l, t}^{s} \\
& G T_{l, t}^{s}=\left(N_{l, t}^{s}+O_{l, t}^{s}\right) e^{-j_{l} M_{t}^{s}} e^{-F_{l, t}^{s}}\left(1-e^{-\widetilde{F}_{l, t}^{s}}\right) S_{l}^{\text {trawl }} F_{t}^{\text {trawl }} / \widetilde{\widetilde{l}}_{l, t}^{s}  \tag{A9}\\
& G F_{l, t}^{s}=\left(N_{l, t}^{s}+O_{l, t}^{s}\right) e^{-j_{l} M_{t}^{s}} e^{-F_{l, t}^{s}}\left(1-e^{-\widetilde{F}_{l, t}^{s}}\right) S_{l}^{\text {fixed }} F_{t}^{\text {fixed }} / \widetilde{F}_{l, t}^{s}
\end{align*}
$$

For scenarios separating mature and immature crab, discarded female bycatch in numbers is separated into immature and mature bycatches. The female bycatches in the directed fishery in length-class $l$ and during year $t, D_{l, t}^{i}$ and $D_{l, t}^{m}$, and $T_{l, t}^{i}$ and $T_{l, t}^{m}$, are:

$$
\begin{align*}
& D_{l, t}^{i}=N_{l, t}^{i} e^{-y_{t} M_{t}^{l e m}}\left(1-e^{-F_{l, t}^{f, m}}\right)  \tag{A10}\\
& D_{l, t}^{m}=N_{l, t}^{m} e^{-y_{t} M_{t}^{l e m}}\left(1-e^{-F_{l, t}^{f e m}}\right)
\end{align*}
$$

The female bycatches (by maturity) in numbers by the Tanner crab and groundfish fisheries in length-class $l$ during year $t$ for scenario 2 are given by:

$$
\begin{align*}
& T_{l, t}^{i}=N_{l, t}^{i} e^{-j_{t} M_{t}^{l e m}} e^{-F_{l_{l, t}^{f e m}}^{f e n}}\left(1-e^{-\widetilde{F}_{l, t}^{\text {fem }}}\right)  \tag{A11}\\
& T_{l, t}^{m}=N_{l, t}^{m} e^{-j_{t} M_{t}^{f e m}} e^{-F_{l, t, t}^{f e m}}\left(1-e^{-\widetilde{F}_{l, t}^{f(t)}}\right)
\end{align*}
$$

Retained selectivity, $S^{\text {dir,land }}$, selectivity for females in the directed fishery, $S^{\text {dir,disc,fem }}$, selectivities for males and females in the groundfish trawl and fixed gear fisheries, $S^{\text {trawl }}$ and $S^{f i x}$, and selectivity for males and females in the Tanner crab fishery, $S^{\text {Tanner, } s}$, are all assumed to be logistic functions of length:

$$
\begin{equation*}
S_{l}^{\text {type }}=\frac{1}{1+e^{-\beta^{\text {type }}\left(t-L_{50}^{\text {type }}\right)}} \tag{A12}
\end{equation*}
$$

Different sets of parameters $\left(\beta, L_{50}\right)$ are estimated for retained males, female pot bycatch, male and female trawl bycatch, and discarded males and females from the Tanner crab fishery.

Male pot bycatch selectivity in the directed fishery is modeled by two linear functions:
$s_{l}=\varphi+\kappa l, \quad$ if $l<135 \mathrm{~mm} \mathrm{CL}$,
$s_{l}=s_{l-1}+5 \gamma$, if $l>134 \mathrm{~mm} \mathrm{CL}$
where $\varphi, \kappa, \gamma$ are parameters.

## iii. Trawl Survey Selectivities

Trawl survey selectivities are estimated as

$$
\begin{equation*}
S_{l, t}^{s}=\frac{Q}{1+e^{-\beta_{t}^{s}\left(t-L_{50, t}^{s}\right)}} \tag{A14}
\end{equation*}
$$

with different sets of parameters ( $\beta, L_{50}$ ) estimated for males and females as well as two different periods (1975-81 and 1982-17). Survey selectivity for the first length group ( 67.5 mm ) was assumed to be the same for both males and females, so only three parameters ( $\beta, L_{50}$ for females and $L_{50}$ for males) were estimated in the model for each of the four periods. Parameter $Q$ was called the survey catchability that was estimated based on a trawl experiment by Weinberg et al. (2004; Figure A1). $Q$ was assumed to be constant over time.
Assuming that the BSFRF survey caught all crab within the area-swept, the ratio between NMFS abundance and BSFRF abundance is a capture probability for the NMFS survey net. The Delta method was used to estimate the variance for the capture probability. A maximum likelihood method was used to estimate parameters for a logistic function as an estimated capture probability curve (Figure A1). For a given size, the estimated capture probability is smaller based
on the BSFRF survey than from the trawl experiment, but the $Q$ value is similar between the trawl experiment and the BSFRF surveys (Figure A1). Because many small-sized crab are likely in the shallow water areas that are not accessible for the trawl survey, NMFS trawl survey selectivity consists of capture probability and crab availability.

## iv. Estimating Bycatch Fishing Mortalities for Years without Observer Data

Observer data are not available for the directed pot fishery before 1990 and the Tanner crab fishery before 1991. There are also extremely low observed bycatches in the Tanner crab fishery during 1994 and 2006-2009. Bycatch fishing mortalities for male and females during 1975-1989 in the directed pot fishery were estimated as

$$
\begin{equation*}
F_{t}^{d i s c, s}=r^{s} F_{t}^{d i r} \tag{A15}
\end{equation*}
$$

where $r^{s}$ is the median ratio of estimated bycatch discard fishing mortalities to the estimated directed pot fishing mortalities during 1990-2004 for sex s. Directed pot fishing practice has changed after 2004 due to fishery rationalization.

We used pot fishing effort (potlifts) east of $163^{\circ} \mathrm{W}$ in the Tanner crab fishery to estimate red king crab bycatch discard fishing mortalities in that fishery when observer data are not available (1975-1990, 1994, 2006-2009):

$$
\begin{equation*}
F_{t}^{\text {Tanner }, s}=a^{s} E_{t} \tag{A16}
\end{equation*}
$$

where $a^{s}$ is the mean ratio of estimated Tanner crab fishery bycatch fishing mortalities to fishing efforts during 1991-1993 for sex s, and $E_{t}$ is Tanner crab fishery fishing efforts east of $163^{\circ} \mathrm{W}$ in year $t$. Due to fishery rationalization after 2004, we used the data only during 1991-1993 to estimate the ratio.
b. Software Used: AD Model Builder (Fournier et al. 2012).

## c. Likelihood Components

A maximum likelihood approach was used to estimate parameters. For length compositions ( $p_{l, t, s, s h}$ ), the likelihood functions are :

$$
\begin{align*}
& R f=\prod_{l=1}^{L} \prod_{t=1}^{T} \prod_{s=1}^{2} \prod_{s h=1}^{2} \frac{\left\{\exp \left[-\frac{\left(p_{l, t, s, s h}-\hat{p}_{l, t, s, s h}\right)^{2}}{2 \sigma^{2}}\right]+0.01\right\}}{\sqrt{2 \pi \sigma^{2}}}  \tag{A17}\\
& \sigma^{2}=\left[\hat{p}_{l, t, s, s h}\left(1-\hat{p}_{l, t, s, s h}\right)+0.1 / L\right] / n
\end{align*}
$$

where $L$ is the number of length groups, $T$ the number of years, and $n$ the effective sample size, which was estimated for trawl survey and pot retained catch and bycatch length composition data from the directed pot fishery, and was assumed to be 50 for groundfish trawl and Tanner crab fisheries bycatch length composition data.

The weighted negative log likelihood functions are:

Length compositions: $-\sum \ln \left(R f_{i}\right)$
Biomasses otherthan survey: $\lambda_{j} \sum\left[\ln \left(C_{t} / \hat{C}_{t}\right)^{2}\right]$
NMFS surveybiomass: $\sum\left[\ln \left(B_{t} / \hat{B}_{t}\right)^{2} /\left(2 \ln \left(C V_{t}^{2}+1\right)\right)\right]$
BSFRF mature males: $\quad \sum\left[\ln \left(\ln \left(C V_{t}^{2}+1\right)\right)^{0.5}+\ln \left(B_{t} / \hat{B}_{t}\right)^{2} /\left(2 \ln \left(C V_{t}^{2}+1\right)\right)\right]$
$R$ variation: $\lambda_{R} \sum\left[\ln \left(R_{t} / \bar{R}\right)^{2}\right]$
$R$ sexratio: $\quad \lambda_{s}\left[\ln \left(\bar{R}_{M} / \bar{R}_{F}\right)^{2}\right]$
Trawl bycatch fishing mortalities : $\lambda_{t}\left[\ln \left(F_{t, t} / \bar{F}_{t}\right)^{2}\right]$
Pot female bycatch fishing mortalities: $\lambda_{p}\left[\ln \left(F_{t, f} / \bar{F}_{f}\right)^{2}\right]$
Trawl survey catchability: $(Q-\hat{Q})^{2} /\left(2 \sigma^{2}\right)$
where $R_{t}$ is the recruitment in year $t, \bar{R}$ the mean recruitment, $\bar{R}_{M}$ the mean male recruitment, $\bar{R}_{F}$ the mean female recruitment, $\bar{F}_{t}$ the mean trawl bycatch fishing mortality, $\bar{F}_{f}$ the mean pot female bycatch fishing mortality, $Q$ summer trawl survey catchability, and $\sigma$ the estimated standard deviation of $Q$ (all scenarios) or each of six growth increment parameters for scenario 2 .
For BSFRF total survey biomass, $C V$ is the survey $C V$ plus $A V$, where $A V$ is additional $C V$ and estimated in the model.

Weights $\lambda_{j}$ are assumed to be 500 for retained catch biomass, and 100 for all bycatch biomasses, 2 for recruitment variation, 10 for recruitment sex ratio, 0.2 for pot female bycatch fishing mortality, and 0.1 for trawl bycatch fishing mortality. These $\lambda_{j}$ values represent prior assumptions about the accuracy of the observed catch biomass data.

## d. Population State in Year 1.

The total abundance and proportions for the first year are estimated in the model.

## e. Parameter estimation framework:

i. Parameters estimated independently

Basic natural mortality, length-weight relationships, and mean growth increments per molt were estimated independently outside of the model. Mean length of recruits to the model depends on growth and was assumed to be 72.5 for both males and females. High grading parameters $h_{t}$ were estimated to be 0.2785 in 2005, 0.0440 in 2006, 0.0197 in 2007, 0.0198 in 2008, 0.0337 in 2009, 0.0153 in 2010, 0.0113 in 2011, 0.0240 in 2012, 0.0632 in 2013, 0.1605 in 2014, 0.07 in 2015, and 0.0826 in 2016, based on the proportions of discarded legal males to total caught legal males. Handling mortality rates were set to 0.2 for the directed pot fishery, 0.25 for the Tanner crab fishery, 0.5 for the groundfish fixed gear fishery, and 0.8 for the groundfish trawl fishery.

## (1). Natural Mortality

Based on an assumed maximum age of 25 years and the $1 \%$ rule (Zheng 2005), basic $M$ was estimated to be 0.18 for both males and females. Natural mortality in a given year, $M_{t}$, equals to $M+M m_{t}$ (for males) or $M+M f_{t}$ (females). One value of $M m_{t}$ during 19801985 was estimated and two values of $M f_{t}$ during 1980-1984 and 1976-79, 1985-93 were estimated in the model for scenarios.

## (2). Length-weight Relationship

Length-weight relationships for males and females were as follows:
Immature Females: $\quad W=0.000408 L^{3.127956}$
Ovigerous Females: $W=0.003593 L^{2.666076}$
Males: $\quad W=0.0004031 L^{3.141334}$
where $W$ is weight in grams, and $L$ CL in mm.

## (3). Growth Increment per Molt

A variety of data are available to estimate male mean growth increment per molt for Bristol Bay RKC. Tagging studies were conducted during the 1950s, 1960s and 1990s, and mean growth increment per molt data from these tagging studies in the 1950s and 1960s were analyzed by Weber and Miyahara (1962) and Balsiger (1974). Modal analyses were conducted for the data during 1957-1961 and the 1990s (Weber 1967; Loher et al. 2001). Mean growth increment per molt may be a function of body size and shell condition and vary over time (Balsiger 1974; McCaughran and Powell 1977); however, for simplicity, mean growth increment per molt was assumed to be only a function of body size in the models. Tagging data were used to estimate mean growth increment per molt as a function of pre-molt length for males (Figure A2). The results from modal analyses of 1957-1961 and the 1990s were used to estimate mean growth increment per molt for immature females during 1975-1993 and 1994-2017, respectively, and the data presented in Gray (1963) were used to estimate those for mature females for scenarios 1, 1n and 2 (Figure A2). To make a smooth transition of growth increment per molt from immature to mature females, weighted growth increment averages of $70 \%$ and $30 \%$ at 92.5 mm CL pre-molt length and $90 \%$ and $10 \%$ at 97.5 mm CL were used, respectively, for mature and immature females during 1983-1993. These percentages are roughly close to the composition of maturity. During 1975-1982, females matured at a smaller size, so the growth increment per molt as a function of length was shifted to smaller increments. Likewise, during 1994-2017, females matured at a slightly higher size, so the growth increment per molt was shifted to high increments for immature crab (Figure A2). Once mature, the growth increment per molt for male crab decreases slightly and annual molting probability decreases, whereas the growth increment for female crab decreases dramatically but annual molting probability remains constant at 1.0 (Powell 1967).

## (4). Sizes at Maturity for Females

The NMFS collected female reproductive condition data during the summer trawl surveys. Mature females are separated from immature females by a presence of egg clutches or egg cases. Proportions of mature females at $5-\mathrm{mm}$ length intervals were
summarized and a logistic curve was fitted to the data each year to estimate sizes at $50 \%$ maturity. Sizes at $50 \%$ maturity are illustrated in Figure A3 with mean values for three different periods (1975-82, 1983-93, and 1994-2017).

## (5). Sizes at Maturity for Males

Although size at sexual maturity for Bristol Bay red king crab males has been estimated (Paul et al. 1991), there are no data for estimating size of functional maturity collected in the natural environment. Sizes at functional maturity for Bristol Bay male RKC have been assumed to be 120 mm CL (Schmidt and Pengilly 1990). This is based on mating pair data collected off Kodiak Island (Figure A4). Sizes at maturity for Bristol Bay female RKC are about 90 mm CL, about 15 mm CL less than Kodiak female RKC (Pengilly et al. 2002). The size ratio of mature males to females is 1.3333 at sizes at maturity for Bristol Bay RKC, and since mature males grow at much larger increments than mature females, the mean size ratio of mature males to females is most likely larger than this ratio. Size ratios of the large majority of Kodiak mating pairs were less than 1.3333, and in some bays, only a small proportion of mating pairs had size ratios above 1.3333 (Figure A4).

In the laboratory, male RKC as small as 80 mm CL from Kodiak and Southeast Alaska can successfully mate with females (Paul and Paul 1990). But few males less than 100 mm CL were observed to mate with females in the wild. Based on the size ratios of males to females in the Kodiak mating pair data, setting 120 mm CL as a minimum size of functional maturity for Bristol Bay male RKC is proper in terms of managing the fishery.

## (6). Potential Reasons for High Mortality during the Early 1980s

Bristol Bay red king crab abundance had declined sharply during the early 1980s. Many factors have been speculated for this decline: (i) completely wiped out by fishing: the directed pot fishery, the other directed pot fishery (Tanner crab fishery), and bottom trawling; and (ii) high fishing and natural mortality. With the survey abundance, harvest rates in 1980 and 1981 were among the highest, thus the directed fishing definitely had a big impact on the stock decline, especially legal and mature males. However, for the sharp decline during 1980-1984 for males, 3 out of 5 years had low mature harvest rates. During the 1981-1984 decline for females, 3 out of 4 years had low mature harvest rates. Also pot catchability for females and immature males are generally much lower than for legal males, so the directed pot fishing alone cannot explain the sharp decline for all segments of the stock during the early 1980s.
Red king crab bycatch in the eastern Bering Sea Tanner crab fishery is another potential factor (Griffin et al. 1983). The main overlap between Tanner crab and Bristol Bay red king crab is east of $163^{\circ} \mathrm{W}$. No absolute red king crab bycatch estimates are available until 1991. So there are insufficient data to fully evaluate the impact. Retained catch and potlifts from the eastern Bering Sea Tanner crab fishery are illustrated in Figure A5. The observed red king crab bycatch in the Tanner crab fishery during 1991-1993 and total potlifts east of $163^{\circ} \mathrm{W}$ during 1968 to 2005 were used to estimate the bycatch mortality in the current model. Because winter sea surface temperatures and air temperatures were warmer (which means a lower handling mortality rate) and there were fewer potlifts during the early 1980s than during the early 1990s, bycatch in the Tanner crab fishery is unlikely to have been a main factor for the sharp decline of Bristol Bay red king crab.

Several factors may have caused increases in natural mortality. Crab diseases in the early 1980s were documented by Sparks and Morado (1985), but inadequate data were collected to examine their effects on the stock. Stevens (1990) speculated that senescence may be a factor because many crab in the early 1980s were very old due to low temperatures in the 1960s and early 1970s. The biomass of the main crab predator, Pacific cod, increased about 10 times during the late 1970s and early 1980s. Yellowfin sole biomass also increased substantially during this period. Predation is primarily on juvenile and molting/softshell crab. But we lack stomach samples in shallow waters (juvenile habitat) and during the period when red king crab molt. Also cannibalism occurs during molting periods for red king crab. High crab abundance in the late 1970s and early 1980s may have increased the occurrence of cannibalism.

Overall, the likely causes for the sharp decline in the early 1980s are combinations of the above factors, such as pot fisheries on legal males, bycatch, and predation on females and juvenile and sublegal males, senescence for older crab, and disease for all crab. In our model, we estimated one mortality parameter for males and another for females during 1980-1984. We also estimated a mortality parameter for females during 1976-1979 and 1985-1993. These three mortality parameters are additional to the basic natural mortality of $0.18 \mathrm{yr}^{-1}$, all directed fishing mortality, and non-directed fishing mortality. These three mortality parameters could be attributed to natural mortality as well as undocumented non-directed fishing mortality. The model fit the data much better with these three parameters than without them.
ii. Parameters estimated conditionally

The following model parameters were estimated for male and female crab: total recruits for each year (year class strength $R_{t}$ for $t=1976$ to 2017), total abundance in the first year (1975), growth parameter $\beta$, and recruitment parameter $\beta_{r}$ for males and females separately. Molting probability parameters $\beta$ and $L_{50}$ were also estimated for male crab. Estimated parameters also include $\beta$ and $L_{50}$ for retained selectivity, $\beta$ and $L_{50}$ for potdiscarded female selectivity, $\beta$ and $L_{50}$ for pot-discarded male and female selectivities from the eastern Bering Sea Tanner crab fishery, $\beta$ and $L_{50}$ for groundfish trawl discarded selectivity, $\varphi, \kappa$ and $\gamma$ for pot-discarded male selectivity, and $\beta$ for trawl survey selectivity and $L_{50}$ for trawl survey male and females separately. The NMFS survey catchabilities $Q$ for some scenarios were also estimated. Three selectivity parameters were estimated for the survey data from the Bering Fisheries Research Foundation. Annual fishing mortalities were also estimated for the directed pot fishery for males (1975-2016), potdiscarded females from the directed fishery (1990-2016), pot-discarded males and females from the eastern Bering Sea Tanner crab fishery (1991-93, 2013-15), and groundfish trawl discarded males and females (1976-2016). Three additional mortality parameters for $M m_{t}$ and $M f_{t}$ were also estimated. Some estimated parameters were constrained in the model. For example, male and female recruitment estimates were forced to be close to each other for a given year.

## f. Definition of model outputs.

i. Biomass: two population biomass measurements are used in this report: total survey biomass (crab $>64 \mathrm{~mm} \mathrm{CL}$ ) and mature male biomass (males $>119 \mathrm{~mm} \mathrm{CL}$ ). Mating time is assumed to Feb. 15.
ii. Recruitment: new entry of number of males in the $1^{\text {st }}$ seven length classes (65-99 mm CL ) and new entry of number of females in the $1^{\text {st }}$ five length classes ( $65-89 \mathrm{~mm} C L$ ).
iii. Fishing mortality: full-selected instantaneous annual fishing mortality rate at the time of fishery.


Figure A1. Estimated capture probabilities for NMFS Bristol Bay red king crab trawl surveys by Weinberg et al. (2004) and the Bering Sea Fisheries Research Foundation surveys.


Figure A2. Mean growth increments per molt for Bristol Bay red king crab. Note: "tagging"--based on tagging data; "mode"---based on modal analysis. The female growth increments per molt are for scenarios $1,1 \mathrm{n}$ and 2 .


Figure A3. Estimated sizes at 50\% maturity for Bristol Bay female red king crab from 1975 to 2008. Averages for three periods (1975-82, 1983-93, and 1994-08) are plotted with a line.


Figure A4. Histograms of carapace lengths (CL) and CL ratios of males to females for male shell ages $\leq 13$ months of red king crab males in grasping pairs; Powell's Kodiak data. Upper plot: all locations and years pooled; middle plot: location 11; lower plot: locations 4 and 13. Sizes at maturity for Kodiak red king crab are about 15 mm larger than those for Bristol Bay red king crab. (Doug Pengilly, ADF\&G, pers. comm.).


Figure A5. Retained catch and potlifts for total eastern Bering Sea Tanner crab fishery (upper plot) and the Tanner crab fishery east of $163^{\circ} \mathrm{W}$ (bottom).

## Appendix B. Recruitment Breakpoint Analysis

## Introduction

SSC asked authors to conduct a recruitment breakpoint analysis similar to that conducted for eastern Bering Sea Tanner crab in 2013 (Stockhausen 2013). We obtained the R codes from Dr. William (Buck) Stockhausen of NMFS and slightly modified them to conduct the analysis for Bristol Bay red king crab for better understanding the temporal change of stock productivity and the recruitment time series used for overfishing/overfished definitions. Results from assessment model scenario 2d were used for this analysis. We are very grateful for the help of Dr. Stockhausen for this analysis.

## Methods

The methods are the same as Punt et al. (2014) and Stockhausen (2013). Stock productivity is represented by $\ln (R / M M B)$, where $R$ is recruitment and MMB is mature male biomass, with recruitment lagging to the brood year of mature biomass. Let $y_{t}=\ln (R / M M B)$ and $y_{t}$ can be estimated directly from the stock assessment model as observed values or from a stockrecruitment model as $\hat{y}_{t}$. For Ricker stock-recruitment models,
$\hat{y}_{t}=\alpha_{1}+\beta_{1} \cdot M M B \quad t<b$,
$\hat{y}_{t}=\alpha_{2}+\beta_{2} \cdot M M B \quad t \geq b$,
where $\alpha_{1}$ and $\beta_{1}$ are the Ricker stock-recruit function parameters for the early time period before the potential breakpoint in year $b$ and $\alpha_{2}$ and $\beta_{2}$ are the parameters for the time period after the breakpoint in year $b$. For Beverton-Holt stock-recruitment models,
$\hat{y}_{t}=\alpha_{1}-\log \left(1+e^{\beta_{1}} \cdot M M B\right) \quad t<b$,
$\hat{y}_{t}=\alpha_{2}+\log \left(1+e^{\beta_{2}} \cdot M M B\right) \quad t \geq b$,
where $\alpha_{1}$ and $\beta_{1}$ are the Beverton-Holt stock-recruit function log-transformed parameters for the early time period before the potential breakpoint in year $b$ and $\alpha_{2}$ and $\beta_{2}$ are the log-transformed parameters for the time period after the breakpoint in year $b$.

A maximum likelihood approach was used to estimate stock-recruitment model and error parameters. Because $y_{t}$ is measured with error, the negative log-likelihood function is

$$
\begin{equation*}
-\ln (L)=0.5 \cdot \ln (|\boldsymbol{\Omega}|)+0.5 \cdot \sum_{t} \sum_{j}\left(y_{t}-\hat{y}_{t}\right) \cdot\left[\mathbf{\Omega}^{-1}\right]_{t, j} \cdot\left(y_{j}-\hat{y}_{j}\right), \tag{3}
\end{equation*}
$$

where $\Omega$ contains observation and process error as
$\boldsymbol{\Omega}=\mathbf{O}+\mathbf{P}$,
where $\mathbf{O}$ is the observation error covariance matrix estimated from the stock assessment model and $\mathbf{P}$ is the process error matrix and is assumed to reflect a first-order autoregressive process to have $\sigma^{2}$ on the diagonal and $\sigma^{2} \rho^{|t-j|}$ on the off-diagonal elements. $\sigma^{2}$ represents process error variance and $\rho$ represents the degree of autocorrelation.

For each candidate breakpoint year $b$, the negative $\log$ likelihood value of equation (3) was minimized with respect to the six model parameters: $\alpha_{1}, \beta_{1}, \alpha_{2}, \beta_{2}, \ln (\sigma)$ and $\tan (\rho)$. The minimum time span considered as a potential regime was 5 years. Each brood year from 1980 to 2005 was evaluated as a potential breakpoint $b$ using time series of $\ln (\mathrm{R} / \mathrm{MMB})$ and MMB for brood years 1975-2010. A model with no breakpoint was also evaluated. Models with different breakpoints were then ranked using AICc (AIC corrected for small sample size; Burnham and Anderson 2004),

$$
\begin{equation*}
A I C_{c}=-2 \cdot \ln (L)+\frac{2 \cdot k \cdot(k+1)}{n-k-1} \tag{5}
\end{equation*}
$$

where $k$ is the number of parameters and $n$ is the number of observations. Using AICc, the model with the smallest AICc is regarded as the "best" model among the set of models evaluated. Different models can be compared in terms of $\theta_{m}$, the relative probability (odds) that the model with the minimum AICc score is a better model than model $m$, where

$$
\begin{equation*}
\theta_{m}=\exp \left(\left[\left(A I C c_{m}-A I C c_{\min }\right) / 2\right] .\right. \tag{6}
\end{equation*}
$$

## Results

Results are summarized in Tables B1-B4 and Figures B1-B6. Discarding the implausible breakpoint year of 1980 for the Ricker model due to implausible stock-recruitment model parameters, both Ricker model and Beverton-Holt model result in the same breakpoint brood year of 1986, which corresponds to recruitment year of 1992. The model with no breakpoint (i.e., a single time period) is about 5 times less probable than the 1986 breakpoint model for BevertonHolt stock-recruitment models and about eight times less probable for Ricker stock-recruitment relationships, which may suggest a possible change in stock productivity from the early high period to the recent low period. Alternative breakpoint brood years of 1980-1985 for both Ricker and Beverton-Holt models are also reasonably reported. Both Ricker and Beverton-Holt stockrecruitment models fit the data poorly.

## Discussion

A recruitment breakpoint analysis was conducted on Bristol Bay red king crab by Punt et al. (2014) with data from 1968 to 2010 to estimate a breakpoint brood year of 1984, corresponding to recruitment year of 1990, which is two years earlier than our estimate, even though our results show that brood year of 1984 is also a likely breakpoint. The different time series of data may explain the different results. Our data start in 1975 and have only two brood-year data points before the regime shift of 1976/77 and thus we cannot detect any stock productivity changes due to the 1976/77 regime shift because of lack of data. Without the early data, the fits of stockrecruitment models to the data are also more poorly.
Time series of estimated recruitment during 1984-present have been used to compute Bmsy proxy. The mean recruitment with scenario 2 d during 1984-present is 17.77 million of crab, compared with the mean recruitment of 15.45 million of crab during 1992-present, about $13.0 \%$ reduction (Figure 12(2d)). If the estimated breakpoint year is used to set the new recruitment time series, estimated Bmsy proxy will be correspondingly lower than the current estimated value.

## References

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Punt, A.E., C.S. Szuwalski, and W. Stockhausen. 2014. An evaluation of stock-recruitment proxies and environmental change points for implementing the US Sustainable Fisheries Act. Fisheries Research 157:28-40.

Stockhausen, W.T. 2013 Recruitment Analysis for Stock Status Determination and Harvest Recommendations. Appendix to: 2013 Stock Asssessment and Fishery Evaluation Report for the Tanner Crab Fisheries in the Bering Sea and Aleutian Islands Regions. In: Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions. North Pacific Fishery Management Council, Anchorage. pp.450-478.

Table B1. Results of the breakpoint analysis, with AICc and the relative probability (odds) against the Ricker stock-recruitment model being correct by breakpoint year. The model with no breakpoint is listed first in the table. The "best" model is shaded with a plausible stockrecruitment model. Years are brood year.

| Year | AlCc | Odds |
| ---: | :--- | ---: |
| NA | 46.4933 | 15.0232 |
| 1980 | 41.0741 | 1.0000 |
| 1981 | 43.5372 | 3.4266 |
| 1982 | 43.4335 | 3.2535 |
| 1983 | 43.5460 | 3.4417 |
| 1984 | 43.5839 | 3.5075 |
| 1985 | 43.0025 | 2.6227 |
| 1986 | 42.4169 | 1.9570 |
| 1987 | 45.4294 | 8.8255 |
| 1988 | 46.1588 | 12.7097 |
| 1989 | 49.4106 | 64.6036 |
| 1990 | 46.6891 | 16.5684 |
| 1991 | 47.9850 | 31.6723 |
| 1992 | 48.2826 | 36.7550 |
| 1993 | 48.0169 | 32.1822 |
| 1994 | 48.9392 | 51.0375 |
| 1995 | 48.9373 | 50.9899 |
| 1996 | 49.2335 | 59.1297 |
| 1997 | 48.8284 | 48.2862 |
| 1998 | 48.8394 | 48.5532 |
| 1999 | 48.8440 | 48.6658 |
| 2000 | 46.3349 | 13.8795 |
| 2001 | 45.4607 | 8.9648 |
| 2002 | 45.5360 | 9.3088 |
| 2003 | 45.9752 | 11.5951 |
| 2004 | 46.2300 | 13.1701 |
| 2005 | 45.8085 | 10.6673 |

Table B2. Parameter estimates and standard deviations for the Ricker stock-recruitment model with no breakpoint (first row) and the single breakpoint models (by year of breakpoint). The "best" model is shaded. Years are brood year.

| Year | $\alpha_{1}$ | std.dev. | $\alpha_{2}$ | std.dev. | $\beta_{1}$ | std.dev. | $\beta_{2}$ | std.dev. | $\ln (\sigma)$ | std.dev. | $\tan (\rho)$ | std.dev. |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
|  |  |  |  | -0.523 | 0.319 |  |  | 0.005 | 0.008 | 0.001 | 0.122 | 0.191 | 0.285 |
| 1980 | -7.356 | 5.342 | 0.708 | 0.505 | -0.077 | 0.061 | 0.061 | 0.021 | -0.117 | 0.122 | -0.052 | 0.286 |  |
| 1981 | 0.428 | 1.239 | 0.688 | 0.494 | 0.012 | 0.016 | 0.062 | 0.021 | -0.111 | 0.122 | -0.102 | 0.279 |  |
| 1982 | 0.517 | 0.750 | 0.615 | 0.540 | 0.013 | 0.010 | 0.060 | 0.022 | -0.112 | 0.122 | -0.100 | 0.275 |  |
| 1983 | 0.337 | 0.582 | 0.675 | 0.602 | 0.011 | 0.008 | 0.062 | 0.024 | -0.111 | 0.122 | -0.107 | 0.273 |  |
| 1984 | 0.265 | 0.493 | 0.747 | 0.694 | 0.010 | 0.008 | 0.065 | 0.028 | -0.111 | 0.122 | -0.108 | 0.274 |  |
| 1985 | 0.512 | 0.431 | 0.035 | 0.872 | 0.013 | 0.007 | 0.037 | 0.034 | -0.118 | 0.122 | -0.116 | 0.275 |  |
| 1986 | 0.500 | 0.397 | -0.677 | 1.148 | 0.013 | 0.007 | 0.011 | 0.044 | -0.132 | 0.122 | -0.083 | 0.281 |  |
| 1987 | 0.179 | 0.380 | 0.578 | 1.468 | 0.009 | 0.007 | 0.057 | 0.056 | -0.088 | 0.122 | -0.102 | 0.273 |  |
| 1988 | 0.089 | 0.392 | 0.706 | 1.693 | 0.009 | 0.007 | 0.062 | 0.064 | -0.081 | 0.121 | 0.002 | 0.279 |  |
| 1989 | -0.174 | 0.384 | 0.819 | 1.738 | 0.007 | 0.007 | 0.063 | 0.066 | -0.038 | 0.121 | -0.029 | 0.281 |  |
| 1990 | -0.069 | 0.389 | 1.505 | 1.759 | 0.008 | 0.007 | 0.093 | 0.067 | -0.076 | 0.122 | 0.080 | 0.274 |  |
| 1991 | -0.173 | 0.385 | 1.457 | 1.805 | 0.007 | 0.008 | 0.090 | 0.069 | -0.057 | 0.122 | 0.088 | 0.272 |  |
| 1992 | -0.342 | 0.374 | 2.270 | 1.875 | 0.005 | 0.008 | 0.118 | 0.071 | -0.051 | 0.122 | 0.090 | 0.271 |  |
| 1993 | -0.354 | 0.358 | 2.646 | 2.036 | 0.005 | 0.007 | 0.131 | 0.076 | -0.054 | 0.121 | 0.068 | 0.270 |  |
| 1994 | -0.259 | 0.357 | 1.700 | 2.961 | 0.006 | 0.008 | 0.097 | 0.109 | -0.042 | 0.121 | 0.079 | 0.283 |  |
| 1995 | -0.290 | 0.344 | 2.037 | 3.181 | 0.006 | 0.007 | 0.109 | 0.116 | -0.041 | 0.121 | 0.064 | 0.276 |  |
| 1996 | -0.336 | 0.333 | 2.213 | 3.163 | 0.006 | 0.007 | 0.114 | 0.116 | -0.036 | 0.121 | -0.036 | 0.121 |  |
| 1997 | -0.236 | 0.342 | -0.002 | 3.514 | 0.007 | 0.008 | 0.038 | 0.127 | -0.048 | 0.122 | 0.111 | 0.292 |  |
| 1998 | -0.293 | 0.322 | 1.265 | 4.351 | 0.006 | 0.007 | 0.082 | 0.156 | -0.044 | 0.121 | 0.060 | 0.272 |  |
| 1999 | -0.298 | 0.312 | 0.359 | 5.150 | 0.006 | 0.007 | 0.051 | 0.183 | -0.045 | 0.121 | 0.041 | 0.270 |  |
| 2000 | -0.249 | 0.294 | 2.030 | 5.027 | 0.006 | 0.007 | 0.116 | 0.179 | -0.082 | 0.122 | 0.013 | 0.268 |  |
| 2001 | -0.260 | 0.275 | 2.972 | 4.984 | 0.006 | 0.006 | 0.153 | 0.178 | -0.096 | 0.122 | -0.060 | 0.268 |  |
| 2002 | -0.281 | 0.269 | 2.991 | 5.003 | 0.005 | 0.006 | 0.155 | 0.179 | -0.095 | 0.122 | -0.076 | 0.269 |  |
| 2003 | -0.312 | 0.268 | 3.717 | 5.370 | 0.005 | 0.006 | 0.183 | 0.193 | -0.089 | 0.122 | -0.079 | 0.270 |  |
| 2004 | -0.336 | 0.266 | 4.122 | 5.359 | 0.005 | 0.006 | 0.200 | 0.193 | -0.086 | 0.122 | -0.078 | 0.267 |  |
| 2005 | -0.338 | 0.261 | 2.435 | 5.684 | 0.005 | 0.006 | 0.143 | 0.203 | -0.093 | 0.122 | -0.082 | 0.267 |  |

Table B3. Results of the breakpoint analysis, with AICc and the relative probability (odds) against the Beverton-Holt stock-recruitment model being correct by breakpoint year. The model with no breakpoint is listed first in the table. The "best" model is shaded. Years are brood year.

| Year | AlCc | Odds |
| ---: | :--- | ---: |
| NA | 45.3981 | 5.0697 |
| 1980 | 43.8995 | 2.3964 |
| 1981 | 42.3954 | 1.1297 |
| 1982 | 42.3742 | 1.1177 |
| 1983 | 42.5415 | 1.2153 |
| 1984 | 42.6196 | 1.2637 |
| 1985 | 42.6775 | 1.3008 |
| 1986 | 42.1516 | 1.0000 |
| 1987 | 45.3144 | 4.8618 |
| 1988 | 45.9970 | 6.8395 |
| 1989 | 49.1365 | 32.8664 |
| 1990 | 47.0869 | 11.7947 |
| 1991 | 48.2198 | 20.7824 |
| 1992 | 49.4103 | 37.6892 |
| 1993 | 49.4378 | 38.2106 |
| 1994 | 49.0962 | 32.2110 |
| 1995 | 49.2897 | 35.4830 |
| 1996 | 49.7282 | 44.1816 |
| 1997 | 48.3534 | 22.2179 |
| 1998 | 48.8959 | 29.1420 |
| 1999 | 48.7480 | 27.0641 |
| 2000 | 46.5764 | 9.1378 |
| 2001 | 45.9210 | 6.5844 |
| 2002 | 45.8966 | 6.5046 |
| 2003 | 46.4147 | 8.4280 |
| 2004 | 46.6195 | 9.3366 |
| 2005 | 45.6408 | 5.7238 |

Table B4. Parameter estimates and standard deviations for the Beverton-Holt stock-recruitment model with no breakpoint (first row) and the single breakpoint models (by year of breakpoint). The "best" model is shaded. Years are brood year.

| Year | $\alpha_{1}$ | std.dev. | $\alpha_{2}$ | std.dev. | $\beta_{1}$ | std.dev. | $\beta_{2}$ | v. | $\ln (\sigma)$ st | std.dev. | $\tan (\rho)$ | dev. |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | -0.159 | 0.894 |  |  | -3.713 | 2.225 | -0.005 | 50.123 | 0.215 | $5 \quad 0.295$ |
| 1980 | -0.625 | 0.391 | 7.820 | 66.239 | -11.19 | 60.247 | 5.471 | 66.254 | -0.101 | 10.123 | -0.164 | $4 \quad 0.282$ |
| 1981 | 1.500 | 4.577 | 7.493 | 50.669 | -2.440 | 5.381 | 5.185 | 50.685 | -0.129 | 90.122 | -0.078 | $8 \quad 0.287$ |
| 1982 | 0.796 | 1.109 | 6.982 | 47.358 | -3.321 | 1.661 | 4.681 | 47.381 | -0.129 | $9 \quad 0.122$ | -0.097 | $7 \quad 0.276$ |
| 1983 | 0.460 | 0.724 | 7.357 | 43.960 | -3.817 | 1.354 | 5.044 | 43.974 | -0.126 | $6 \quad 0.122$ | -0.108 | 80.275 |
| 1984 | 0.349 | 0.586 | 8.411 | 65.301 | -3.999 | 1.241 | 6.091 | 65.308 | -0.126 | $6 \quad 0.122$ | -0.111 | $1 \quad 0.274$ |
| 1985 | 0.666 | 0.573 | 0.959 | 3.804 | -3.492 | 1.065 | -1.508 | 4.519 | -0.123 | 30.122 | -0.108 | 80.276 |
| 1986 | 0.647 | 0.530 | -0.690 | 1.307 | -3.514 | 1.031 | -4.454 | 5.662 | -0.135 | 50.122 | -0.080 | $0 \quad 0.280$ |
| 1987 | 0.292 | 0.483 | 5.501 | 41.505 | -3.983 | 1.175 | 3.163 | 41.573 | -0.092 | 20.122 | -0.096 | $6 \quad 0.274$ |
| 1988 | 0.227 | 0.528 | 6.910 | 83.603 | -3.992 | 1.316 | 4.571 | 83.636 | -0.084 | $4 \quad 0.121$ | 0.031 | 10.276 |
| 1989 | -0.005 | 0.560 | 5.507 | 42.863 | -4.127 | 1.569 | 3.080 | 42.939 | -0.042 | 20.121 | 0.007 | $7 \quad 0.280$ |
| 1990 | 0.103 | 0.571 | 5.404 | 31.615 | -4.034 | 1.491 | 3.066 | 31.672 | -0.071 | 10.122 | 0.107 | $7 \quad 0.279$ |
| 1991 | 0.016 | 0.593 | 5.997 | 43.869 | -4.059 | 1.603 | 3.631 | 43.913 | -0.05 | $4 \quad 0.122$ | 0.107 | $7 \quad 0.276$ |
| 1992 | -0.179 | 0.584 | 6.277 | 42.024 | -4.316 | 1.863 | 3.830 | 42.059 | -0.037 | $7 \quad 0.122$ | 0.115 | $5 \quad 0.277$ |
| 1993 | -0.194 | 0.571 | 6.265 | 41.986 | -4.334 | 1.867 | 3.820 | 42.021 | -0.037 | $7 \quad 0.122$ | 0.121 | 10.277 |
| 1994 | -0.049 | 0.608 | 4.133 | 30.922 | -4.054 | 1.719 | 1.753 | 31.120 | -0.040 | $0 \quad 0.122$ | 0.135 | $\begin{array}{ll}5 & 0.282\end{array}$ |
| 1995 | -0.090 | 0.592 | 4.862 | 43.254 | -4.112 | 1.752 | 2.481 | 43.386 | -0.038 | 80.122 | 0.118 | $8 \quad 0.279$ |
| 1996 | -0.143 | 0.583 | 4.980 | 43.179 | -4.170 | 1.810 | 2.577 | 43.299 | -0.033 | 30.121 | -0.033 | 30.121 |
| 1997 | -0.027 | 0.598 | 0.689 | 17.930 | -4.018 | 1.685 | -1.771 | 21.766 | -0.052 | 20.122 | 0.129 | $9 \quad 0.297$ |
| 1998 | -0.112 | 0.548 | 3.575 | 39.931 | -4.175 | 1.718 | 1.269 | 40.335 | -0.047 | $7 \quad 0.122$ | 0.078 | $8 \quad 0.275$ |
| 1999 | -0.124 | 0.528 | 1.114 | 24.395 | -4.213 | 1.703 | -1.266 | 27.474 | -0.050 | $0 \quad 0.121$ | 0.051 | 10.273 |
| 2000 | -0.096 | 0.481 | 3.838 | 44.284 | -4.274 | 1.592 | 1.729 | 44.563 | -0.084 | $4 \quad 0.122$ | 0.030 | 0.272 |
| 2001 | -0.117 | 0.449 | 5.966 | 109.07 | -4.344 | 1.556 | 3.936 | 109.14 | -0.094 | $4 \quad 0.122$ | -0.033 | 30.270 |
| 2002 | -0.133 | 0.450 | 4.710 | 58.628 | -4.345 | 1.571 | 2.726 | 58.765 | -0.094 | $4 \quad 0.122$ | -0.038 | $8 \quad 0.269$ |
| 2003 | -0.150 | 0.470 | 4.518 | 51.104 | -4.308 | 1.611 | 2.561 | 51.245 | -0.086 | $6 \quad 0.122$ | -0.031 | 10.269 |
| 2004 | -0.169 | 0.476 | 4.207 | 43.439 | -4.307 | 1.638 | 2.300 | 43.595 | -0.082 | 20.121 | -0.036 | $6 \quad 0.269$ |
| 2005 | -0.176 | 0.459 | 2.668 | 27.512 | -4.331 | 1.609 | 0.892 | 27.915 | -0.096 | 60.122 | -0.058 | $8 \quad 0.268$ |



Figure B1. Results from the Ricker stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint model (horizontal solid line) relative to the model with the smallest AICc score. The dashed lines indicate the value for the model with the lowest AICc score. Not shown are 1breakpoint models with high odds ( $>10$ ) of being incorrect.


Figure B2. Fits for Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.


Figure B2. Continue.


Figure B2. Continue.


MMB
Figure B2. Continue.


Figure B3. Fits on the arithmetic scale for Ricker models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.


Figure B3. Continue.


Figure B3. Continue.


MMB (1000's t)
Figure B3. Continue.


Figure B4. Results from the B-H stock-recruit breakpoint analysis. Upper graph: AICc vs. year of breakpoint for the 1-breakpoint models (circles) and AICc for the model with no breakpoint (horizontal line). Lower graph: probabilistic odds for all 1-breakpoint models (circles) and the no breakpoint model (horizontal solid line) relative to the model with the smallest AICc score. The dashed lines indicate the value for the model with the lowest AICc score (breakpoint in 1986). Not shown are 1-breakpoint models with high odds $(>10)$ of being incorrect.


Figure B5. Fits for B-H models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.


Figure B5. Continue.


Figure B5. Continue.


MMB
Figure B5. Continue.


Figure B6. Fits on the arithmetic scale for B-H models with no breakpoint (upper left graph) and with 1-breakpoint for break years 1975-2005. For 1-breakpoint models, the pre-break data (circles) and model fit (line) are shown in red, whereas the post-break data and fit are shown in black.


Figure B6. Continue.


Figure B6. Continue.


MMB (1000's t)
Figure B6. Continue.

## Appendix C. Francis' Approaches for Re-weighting Effective Sample Sizes

The Francis' (2011) mean length based method to estimate the effective sample size re-weighing multiplier W [i.e., Francis TA1.8 method, 2011] uses:

Observed mean length for year $t$,
$\overline{l_{t}}=\sum_{i=1}^{n} l_{t, i} \times P_{t, i}$
Predicted mean length for year $t$,
$\hat{\bar{l}_{t}}=\sum_{i=1}^{n} l_{t, i} \times \hat{P}_{t, i}$
Variance of the predicted mean length in year $t$,

$$
\begin{equation*}
\operatorname{var}\left(\hat{\bar{l}}_{t}\right)=\frac{\sum_{i=1}^{n} \hat{P}_{t, i}\left(l_{t, i}-\hat{l}_{t}\right)^{2}}{S_{t}} \tag{C.3}
\end{equation*}
$$

Francis' reweighting parameter $W$,

$$
\begin{equation*}
W=\frac{1}{\operatorname{var}\left\{\frac{\hat{\bar{l}}_{t}-\hat{l}_{t}}{\sqrt{\operatorname{var}\left(\hat{l}_{t}\right)}}\right\}} \tag{C.4}
\end{equation*}
$$

where $\hat{P}_{t, i}$ and $P_{t, i}$ are the estimated and observed proportions of catches or survey abundances during year $t$ in length-class $i, l_{t, i}$ is the mid length of the length-class $i$ during year $t, S_{t}$ is the effective sample size in year $t, \hat{\bar{l}}_{t}$ and $\overline{l_{t}}$ are predicted and observed mean lengths of catches or survey abundances during year $t$, and $W$ is the re-weighting multiplier of Stage-1 effective sample sizes.
$S_{t}$ is related to the initial input (Stage-1) effective sample size according to:

$$
\begin{equation*}
S_{t, i}=W_{i} \tau_{1, t} \tag{C.5}
\end{equation*}
$$

where $S_{t, i}$ is the effective sample size for year $t$ in iteration $i, W_{i}$ is the Francis weight calculated using Equation C. 4 during iteration $i$, and $\tau_{1, t}$ is the initial input effective sample size for year $t$ for a size composition.

There are two issues for applying Francis' approach to Bristol Bay red king crab: first, some observed sample sizes are very large, like 58097, and some ways to scale down are needed for the initial run. This issue itself is a challenging task. We simply use the same approach as scenarios $2 \mathrm{a}, 2 \mathrm{~b}$ and 2 d to scale down the observed sample sizes for the initial run: sample sizes are equal to $\min \left(0.5^{*}\right.$ observed-size, N$)$ for trawl surveys and $\min \left(0.1^{*}\right.$ observed-size, N$)$ for catch and bycatch, where N is the maximum sample size ( 200 for trawl surveys, 100 for males from the pot fishery and 50 for females from pot fishery and both males and females from the groundfish fisheries).

Second, length composition values, $P$, are computed with both sexes combined for survey and groundfish fisheries bycatch data. Mean lengths in equations C. 1 and C. 2 can be computed with two approaches:

1. Both male and female length compositions are stacked into a vector used to compute a mean length for both sexes for each of survey and groundfish fisheries bycatch datasets.

For example, in year $t, \mathbf{P}_{\mathbf{t}}^{\mathbf{m}}$ and $\mathbf{P}_{\mathbf{t}}^{\mathbf{f}}$ are male and female length compositions, and
$\mathbf{P}_{\mathbf{t}}^{\mathbf{m}}=\left[m_{1}, m_{2}, \ldots, m_{20}\right], \mathbf{P}_{\mathbf{t}}^{\mathbf{f}}=\left[f_{1}, f_{2}, \ldots, f_{16}\right]$, where $m_{i}$ and $f_{i}$ are length proportions for length group $i$ with corresponding mid length, $l_{i}$, then, the stacked vector, $\boldsymbol{P}_{\boldsymbol{t}}$ in year $t, \boldsymbol{P}_{t}=\left[\mathbf{P}_{\mathbf{t}}^{\mathbf{m}}, \mathbf{P}_{\mathbf{t}}^{\mathbf{f}}\right]$, and $\sum \boldsymbol{P} \boldsymbol{t}=\sum\left(\mathbf{P}_{\mathbf{t}}^{\mathbf{m}}+\mathbf{P}_{\mathbf{t}}^{\mathbf{f}}\right)=1.0$. Therefore, $\boldsymbol{P}_{\mathbf{t}}=\left[m_{1}, m_{2}, \ldots, m_{20}, f_{1}, f_{2}, \ldots, f_{16}\right]$ with mid length vector as $\left[l_{1} l_{2}, \ldots, l_{20}, l_{1}, l_{2}, \ldots, l_{16}\right]$. A re-weighting factor for both sexes is computed.
2. Sex-specific length compositions are normalized so that the sum is equal to 1.0 for each sex for each of survey and groundfish fisheries bycatch datasets. The normalized length compositions are used to estimate mean lengths.

Using the above example, the normalized length composition vectors are
$\mathbf{P}_{\mathbf{t}}^{\mathrm{m}}=\mathbf{P}_{\mathbf{t}}^{\mathrm{m}} / \sum \mathbf{P}_{\mathbf{t}}^{\mathrm{m}}$, and $\mathbf{P}_{\mathbf{t}}^{\mathrm{f}}=\mathbf{P}_{\mathbf{t}}^{\mathrm{f}} / \sum \mathbf{P}_{\mathbf{t}}^{\mathrm{f}}$. Two different re-weighting factors are computed for both sexes.

These two approaches are called as Francis' approaches 1 and 2 in this report. Generally, it takes three or four iterations to obtain stable estimates of effective sample sizes for length composition data.

## References

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124-1138.

## Appendix D. Estimated Effective Sample Sizes for Nine Model Scenarios

Table D1. Estimated effective sample sizes for scenario 2A.

| Year | Trawl survey |  | BSFRF <br> Females | Males | Retained <br> Males | Pot discard |  | Trawl discard |  | Tanner discard |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Females | Males |  |  |  | Females | Males | Females | Males | Females | Males |
| 1975 | 200 | 200 |  |  | 100 |  |  |  |  |  |  |
| 1976 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |
| 1977 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |
| 1978 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |
| 1979 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |
| 1980 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |
| 1981 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |
| 1982 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |
| 1983 | 200 | 200 |  |  |  |  |  | 50 | 50 |  |  |
| 1984 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |
| 1985 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |
| 1986 | 184 | 200 |  |  | 100 |  |  | 28 | 50 |  |  |
| 1987 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |
| 1988 | 200 | 200 |  |  | 100 |  |  | 28 | 44 |  |  |
| 1989 | 200 | 200 |  |  | 100 |  |  | 19 | 50 |  |  |
| 1990 | 200 | 200 |  |  | 100 | 50 | 87 | 50 | 50 |  |  |
| 1991 | 200 | 200 |  |  | 100 | 38 | 100 | 40 | 21 | 50 | 50 |
| 1992 | 180 | 200 |  |  | 100 | 50 | 100 | 11 | 21 | 50 | 28 |
| 1993 | 200 | 200 |  |  | 100 | 50 | 100 |  |  | 27 | 23 |
| 1994 | 133 | 200 |  |  |  |  |  | 25 | 33 |  |  |
| 1995 | 200 | 200 |  |  |  |  |  | 4 | 10 |  |  |
| 1996 | 200 | 200 |  |  | 100 | 1 | 23 | 50 | 50 |  |  |
| 1997 | 200 | 200 |  |  | 100 | 50 | 100 | 48 | 50 |  |  |
| 1998 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |
| 1999 | 200 | 200 |  |  | 100 | 4 | 100 | 50 | 50 |  |  |
| 2000 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |
| 2001 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |
| 2002 | 200 | 200 |  |  | 100 | 30 | 100 | 50 | 50 |  |  |
| 2003 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |
| 2004 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |
| 2005 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |
| 2006 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |
| 2007 | 200 | 200 | 200 | 200 | 100 | 50 | 100 | 50 | 50 |  |  |
| 2008 | 200 | 200 | 200 | 200 | 100 | 50 | 100 | 50 | 50 |  |  |
| 2009 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |
| 2010 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |
| 2011 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |
| 2012 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |
| 2013 | 200 | 200 | 57 | 95 | 100 | 50 | 100 | 50 | 50 | 50 | 22 |
| 2014 | 200 | 200 | 103 | 109 | 100 | 50 | 100 | 50 | 50 | 38 | 26 |
| 2015 | 200 | 200 | 92 | 106 | 100 | 50 | 100 | 50 | 50 | 50 | 50 |
| 2016 | 200 | 187 | 99 | 48 | 100 | 50 | 100 | 50 | 50 |  |  |
| 2017 | 200 | 200 |  |  |  |  |  |  |  |  |  |

Table D2. Estimated effective sample sizes for scenario 2A1.

| Year | Trawl survey |  | BSFRF <br> Females | Males | Retained Males | Pot discard |  | Trawl discard |  | Tanner discard |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Females | Males |  |  |  | Females | Males | Females | Males | Females | Males |
| 1975 | 34 | 34 |  |  | 31 |  |  |  |  |  |  |
| 1976 | 34 | 34 |  |  | 31 |  |  | 4 | 4 |  |  |
| 1977 | 34 | 34 |  |  | 31 |  |  | 4 | 4 |  |  |
| 1978 | 34 | 34 |  |  | 31 |  |  | 4 | 4 |  |  |
| 1979 | 34 | 34 |  |  | 31 |  |  | 4 | 4 |  |  |
| 1980 | 34 | 34 |  |  | 31 |  |  | 4 | 4 |  |  |
| 1981 | 34 | 34 |  |  | 31 |  |  | 4 | 4 |  |  |
| 1982 | 34 | 34 |  |  | 31 |  |  | 4 | 4 |  |  |
| 1983 | 34 | 34 |  |  |  |  |  | 4 | 4 |  |  |
| 1984 | 34 | 34 |  |  | 31 |  |  | 4 | 4 |  |  |
| 1985 | 34 | 34 |  |  | 31 |  |  | 4 | 4 |  |  |
| 1986 | 31 | 34 |  |  | 31 |  |  | 2 | 4 |  |  |
| 1987 | 34 | 34 |  |  | 31 |  |  | 4 | 4 |  |  |
| 1988 | 34 | 34 |  |  | 31 |  |  | 2 | 4 |  |  |
| 1989 | 34 | 34 |  |  | 31 |  |  | 2 | 4 |  |  |
| 1990 | 34 | 34 |  |  | 31 | 7 | 14 | 4 | 4 |  |  |
| 1991 | 34 | 34 |  |  | 31 | 5 | 16 | 3 | 2 | 10 | 12 |
| 1992 | 31 | 34 |  |  | 31 | 7 | 16 | 1 | 2 | 10 | 7 |
| 1993 | 34 | 34 |  |  | 31 | 7 | 16 |  |  | 5 | 6 |
| 1994 | 23 | 34 |  |  |  |  |  | 2 | 3 |  |  |
| 1995 | 34 | 34 |  |  |  |  |  | 0 | 1 |  |  |
| 1996 | 34 | 34 |  |  | 31 | 0 | 4 | 4 | 4 |  |  |
| 1997 | 34 | 34 |  |  | 31 | 7 | 16 | 4 | 4 |  |  |
| 1998 | 34 | 34 |  |  | 31 | 7 | 16 | 4 | 4 |  |  |
| 1999 | 34 | 34 |  |  | 31 | 1 | 16 | 4 | 4 |  |  |
| 2000 | 34 | 34 |  |  | 31 | 7 | 16 | 4 | 4 |  |  |
| 2001 | 34 | 34 |  |  | 31 | 7 | 16 | 4 | 4 |  |  |
| 2002 | 34 | 34 |  |  | 31 | 4 | 16 | 4 | 4 |  |  |
| 2003 | 34 | 34 |  |  | 31 | 7 | 16 | 4 | 4 |  |  |
| 2004 | 34 | 34 |  |  | 31 | 7 | 16 | 4 | 4 |  |  |
| 2005 | 34 | 34 |  |  | 31 | 7 | 16 | 4 | 4 |  |  |
| 2006 | 34 | 34 |  |  | 31 | 7 | 16 | 4 | 4 |  |  |
| 2007 | 34 | 34 | 66 | 66 | 31 | 7 | 16 | 4 | 4 |  |  |
| 2008 | 34 | 34 | 66 | 66 | 31 | 7 | 16 | 4 | 4 |  |  |
| 2009 | 34 | 34 |  |  | 31 | 7 | 16 | 4 | 4 |  |  |
| 2010 | 34 | 34 |  |  | 31 | 7 | 16 | 4 | 4 |  |  |
| 2011 | 34 | 34 |  |  | 31 | 7 | 16 | 4 | 4 |  |  |
| 2012 | 34 | 34 |  |  | 31 | 7 | 16 | 4 | 4 |  |  |
| 2013 | 34 | 34 | 19 | 31 | 31 | 7 | 16 | 4 | 4 | 10 | 5 |
| 2014 | 34 | 34 | 34 | 36 | 31 | 7 | 16 | 4 | 4 | 7 | 6 |
| 2015 | 34 | 34 | 30 | 35 | 31 | 7 | 16 | 4 | 4 | 10 | 12 |
| 2016 | 34 | 32 | 33 | 16 | 31 | 7 | 16 | 4 | 4 |  |  |
| 2017 | 34 | 34 |  |  |  |  |  |  |  |  |  |

Table D3. Estimated effective sample sizes for scenario 2A2.

| Year | Trawl survey |  | BSFRF <br> Females | Males | Retained Males | Pot discard |  | Trawl discard |  | Tanner discard |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Females | Males |  |  |  | Females | Males | Females | Males | Females | Males |
| 1975 | 32 | 24 |  |  | 32 |  |  |  |  |  |  |
| 1976 | 32 | 24 |  |  | 32 |  |  | 3 | 5 |  |  |
| 1977 | 32 | 24 |  |  | 32 |  |  | 3 | 5 |  |  |
| 1978 | 32 | 24 |  |  | 32 |  |  | 3 | 5 |  |  |
| 1979 | 32 | 24 |  |  | 32 |  |  | 3 | 5 |  |  |
| 1980 | 32 | 24 |  |  | 32 |  |  | 3 | 5 |  |  |
| 1981 | 32 | 24 |  |  | 32 |  |  | 3 | 5 |  |  |
| 1982 | 32 | 24 |  |  | 32 |  |  | 3 | 5 |  |  |
| 1983 | 32 | 24 |  |  |  |  |  | 3 | 5 |  |  |
| 1984 | 32 | 24 |  |  | 32 |  |  | 3 | 5 |  |  |
| 1985 | 32 | 24 |  |  | 32 |  |  | 3 | 5 |  |  |
| 1986 | 30 | 24 |  |  | 32 |  |  | 2 | 5 |  |  |
| 1987 | 32 | 24 |  |  | 32 |  |  | 3 | 5 |  |  |
| 1988 | 32 | 24 |  |  | 32 |  |  | 2 | 4 |  |  |
| 1989 | 32 | 24 |  |  | 32 |  |  | 1 | 5 |  |  |
| 1990 | 32 | 24 |  |  | 32 | 7 | 14 | 3 | 5 |  |  |
| 1991 | 32 | 24 |  |  | 32 | 5 | 16 | 3 | 2 | 10 | 12 |
| 1992 | 29 | 24 |  |  | 32 | 7 | 16 | 1 | 2 | 10 | 7 |
| 1993 | 32 | 24 |  |  | 32 | 7 | 16 |  |  | 5 | 6 |
| 1994 | 21 | 24 |  |  |  |  |  | 2 | 3 |  |  |
| 1995 | 32 | 24 |  |  |  |  |  | 0 | 1 |  |  |
| 1996 | 32 | 24 |  |  | 32 | 0 | 4 | 3 | 5 |  |  |
| 1997 | 32 | 24 |  |  | 32 | 7 | 16 | 3 | 5 |  |  |
| 1998 | 32 | 24 |  |  | 32 | 7 | 16 | 3 | 5 |  |  |
| 1999 | 32 | 24 |  |  | 32 | 1 | 16 | 3 | 5 |  |  |
| 2000 | 32 | 24 |  |  | 32 | 7 | 16 | 3 | 5 |  |  |
| 2001 | 32 | 24 |  |  | 32 | 7 | 16 | 3 | 5 |  |  |
| 2002 | 32 | 24 |  |  | 32 | 4 | 16 | 3 | 5 |  |  |
| 2003 | 32 | 24 |  |  | 32 | 7 | 16 | 3 | 5 |  |  |
| 2004 | 32 | 24 |  |  | 32 | 7 | 16 | 3 | 5 |  |  |
| 2005 | 32 | 24 |  |  | 32 | 7 | 16 | 3 | 5 |  |  |
| 2006 | 32 | 24 |  |  | 32 | 7 | 16 | 3 | 5 |  |  |
| 2007 | 32 | 24 | 58 | 41 | 32 | 7 | 16 | 3 | 5 |  |  |
| 2008 | 32 | 24 | 58 | 41 | 32 | 7 | 16 | 3 | 5 |  |  |
| 2009 | 32 | 24 |  |  | 32 | 7 | 16 | 3 | 5 |  |  |
| 2010 | 32 | 24 |  |  | 32 | 7 | 16 | 3 | 5 |  |  |
| 2011 | 32 | 24 |  |  | 32 | 7 | 16 | 3 | 5 |  |  |
| 2012 | 32 | 24 |  |  | 32 | 7 | 16 | 3 | 5 |  |  |
| 2013 | 32 | 24 | 16 | 20 | 32 | 7 | 16 | 3 | 5 | 10 | 5 |
| 2014 | 32 | 24 | 30 | 22 | 32 | 7 | 16 | 3 | 5 | 7 | 6 |
| 2015 | 32 | 24 | 27 | 22 | 32 | 7 | 16 | 3 | 5 | 10 | 12 |
| 2016 | 32 | 23 | 29 | 10 | 32 | 7 | 16 | 3 | 5 |  |  |
| 2017 | 32 | 24 |  |  |  |  |  |  |  |  |  |

Table D4. Estimated effective sample sizes for scenarios 2B and 2D.

| Year | Trawl survey |  | BSFRF <br> Fem. | Ma. | Ret. <br> Ma. | Pot discard |  | Trawl gear |  | Fixed gear |  | Tanner discard |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Fem. | Ma. |  |  |  | Fem. | Ma. | Fem. | Ma. | Fem. | Ma. | Fem. | Ma. |
| 1975 | 200 | 200 |  |  | 100 |  |  |  |  |  |  |  |  |
| 1976 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |  |  |
| 1977 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |  |  |
| 1978 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |  |  |
| 1979 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |  |  |
| 1980 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |  |  |
| 1981 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |  |  |
| 1982 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |  |  |
| 1983 | 200 | 200 |  |  |  |  |  | 50 | 50 |  |  |  |  |
| 1984 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |  |  |
| 1985 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |  |  |
| 1986 | 184 | 200 |  |  | 100 |  |  | 28 | 50 |  |  |  |  |
| 1987 | 200 | 200 |  |  | 100 |  |  | 50 | 50 |  |  |  |  |
| 1988 | 200 | 200 |  |  | 100 |  |  | 28 | 44 |  |  |  |  |
| 1989 | 200 | 200 |  |  | 100 |  |  | 19 | 50 |  |  |  |  |
| 1990 | 200 | 200 |  |  | 100 | 50 | 87 | 50 | 50 |  |  |  |  |
| 1991 | 200 | 200 |  |  | 100 | 38 | 100 | 40 | 21 |  |  | 50 | 50 |
| 1992 | 180 | 200 |  |  | 100 | 50 | 100 | 11 | 21 |  |  | 50 | 28 |
| 1993 | 200 | 200 |  |  | 100 | 50 | 100 |  |  |  |  | 27 | 23 |
| 1994 | 133 | 200 |  |  |  |  |  | 25 | 33 |  |  |  |  |
| 1995 | 200 | 200 |  |  |  |  |  | 4 | 10 |  |  |  |  |
| 1996 | 200 | 200 |  |  | 100 | 1 | 23 | 50 | 50 |  |  |  |  |
| 1997 | 200 | 200 |  |  | 100 | 50 | 100 | 48 | 50 |  |  |  |  |
| 1998 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |  |  |
| 1999 | 200 | 200 |  |  | 100 | 4 | 100 | 50 | 50 |  |  |  |  |
| 2000 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |  |  |
| 2001 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |  |  |
| 2002 | 200 | 200 |  |  | 100 | 30 | 100 | 50 | 50 |  |  |  |  |
| 2003 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |  |  |
| 2004 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |  |  |
| 2005 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |  |  |
| 2006 | 200 | 200 |  |  | 100 | 50 | 100 | 50 | 50 |  |  |  |  |
| 2007 | 200 | 200 | 200 | 200 | 100 | 50 | 100 | 50 | 50 |  |  |  |  |
| 2008 | 200 | 200 | 200 | 200 | 100 | 50 | 100 | 50 | 50 |  |  |  |  |
| 2009 | 200 | 200 |  |  | 100 | 50 | 100 | 49 | 50 | 36 | 50 |  |  |
| 2010 | 200 | 200 |  |  | 100 | 50 | 100 | 44 | 46 | 40 | 15 |  |  |
| 2011 | 200 | 200 |  |  | 100 | 50 | 100 | 21 | 23 | 50 | 34 |  |  |
| 2012 | 200 | 200 |  |  | 100 | 50 | 100 | 13 | 15 | 50 | 50 |  |  |
| 2013 | 200 | 200 | 57 | 95 | 100 | 50 | 100 | 18 | 31 | 50 | 50 | 50 | 22 |
| 2014 | 200 | 200 | 103 | 109 | 100 | 50 | 100 | 9 | 17 | 50 | 50 | 38 | 26 |
| 2015 | 200 | 200 | 92 | 106 | 100 | 50 | 100 | 20 | 21 | 50 | 50 | 50 | 50 |
| 2016 | 200 | 187 | 99 | 48 | 100 | 50 | 100 | 17 | 44 | 50 | 50 |  |  |
| 2017 | 200 | 200 |  |  |  |  |  |  |  |  |  |  |  |

Table D5. Estimated effective sample sizes for scenario 2B1.


Table D6. Estimated effective sample sizes for scenario 2B2.

| Year | Trawl survey |  | BSFRF <br> Fem. | Ma. | Ret. <br> Ma. | Pot discard |  | Trawl gear |  | Fixed gear |  |  | Tanner discard |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Fem. | Ma. |  |  |  | Fem. | Ma. | Fem. | Ma. | Fem. |  | Ma. | Fem. | Ma. |
| 1975 | 32 | 24 |  |  | 32 |  |  |  |  |  |  |  |  |  |
| 1976 | 32 | 24 |  |  | 32 |  |  | 4 | 11 |  |  |  |  |  |
| 1977 | 32 | 24 |  |  | 32 |  |  | 4 | 11 |  |  |  |  |  |
| 1978 | 32 | 24 |  |  | 32 |  |  | 4 | 11 |  |  |  |  |  |
| 1979 | 32 | 24 |  |  | 32 |  |  | 4 | 11 |  |  |  |  |  |
| 1980 | 32 | 24 |  |  | 32 |  |  | 4 | 11 |  |  |  |  |  |
| 1981 | 32 | 24 |  |  | 32 |  |  | 4 | 11 |  |  |  |  |  |
| 1982 | 32 | 24 |  |  | 32 |  |  | 4 | 11 |  |  |  |  |  |
| 1983 | 32 | 24 |  |  |  |  |  | 4 | 11 |  |  |  |  |  |
| 1984 | 32 | 24 |  |  | 32 |  |  | 4 | 11 |  |  |  |  |  |
| 1985 | 32 | 24 |  |  | 32 |  |  | 4 | 11 |  |  |  |  |  |
| 1986 | 30 | 24 |  |  | 32 |  |  | 3 | 11 |  |  |  |  |  |
| 1987 | 32 | 24 |  |  | 32 |  |  | 4 | 11 |  |  |  |  |  |
| 1988 | 32 | 24 |  |  | 32 |  |  | 2 | 10 |  |  |  |  |  |
| 1989 | 32 | 24 |  |  | 32 |  |  | 2 | 11 |  |  |  |  |  |
| 1990 | 32 | 24 |  |  | 32 | 7 | 14 | 4 | 11 |  |  |  |  |  |
| 1991 | 32 | 24 |  |  | 32 | 5 | 16 | 4 | 5 |  |  |  | 10 | 12 |
| 1992 | 29 | 24 |  |  | 32 | 7 | 16 | 1 | 5 |  |  |  | 10 | 7 |
| 1993 | 32 | 24 |  |  | 32 | 7 | 16 |  |  |  |  |  | 5 | 6 |
| 1994 | 21 | 24 |  |  |  |  |  | 2 | 7 |  |  |  |  |  |
| 1995 | 32 | 24 |  |  |  |  |  | 0 | 2 |  |  |  |  |  |
| 1996 | 32 | 24 |  |  | 32 | 0 | 4 | 4 | 11 |  |  |  |  |  |
| 1997 | 32 | 24 |  |  | 32 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 1998 | 32 | 24 |  |  | 32 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 1999 | 32 | 24 |  |  | 32 | 1 | 16 | 4 | 11 |  |  |  |  |  |
| 2000 | 32 | 24 |  |  | 32 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2001 | 32 | 24 |  |  | 32 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2002 | 32 | 24 |  |  | 32 | 4 | 16 | 4 | 11 |  |  |  |  |  |
| 2003 | 32 | 24 |  |  | 32 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2004 | 32 | 24 |  |  | 32 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2005 | 32 | 24 |  |  | 32 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2006 | 32 | 24 |  |  | 32 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2007 | 32 | 24 | 65 | 39 | 32 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2008 | 32 | 24 | 65 | 39 | 32 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2009 | 32 | 24 |  |  | 32 | 7 | 16 | 4 | 11 |  | 5 | 3 |  |  |
| 2010 | 32 | 24 |  |  | 32 | 7 | 16 | 4 | 10 |  | 6 | 1 |  |  |
| 2011 | 32 | 24 |  |  | 32 | 7 | 16 | 2 | 5 |  | 8 | 2 |  |  |
| 2012 | 32 | 24 |  |  | 32 | 7 | 16 | 1 | 3 |  | 8 | 3 |  |  |
| 2013 | 32 | 24 | 18 | 19 | 32 | 7 | 16 | 2 | 7 |  | 8 | 3 | 10 | 5 |
| 2014 | 32 | 24 | 33 | 21 | 32 | 7 | 16 | 1 | 4 |  | 8 | 3 | 7 | 6 |
| 2015 | 32 | 24 | 30 | 21 | 32 | 7 | 16 | 2 | 5 |  | 8 | 3 | 10 | 12 |
| 2016 | 32 | 23 | 32 | 9 | 32 | 7 | 16 | 1 | 10 |  | 8 | 3 |  |  |
| 2017 | 32 | 24 |  |  |  |  |  |  |  |  |  |  |  |  |

Table D7. Estimated effective sample sizes for scenario 2D1.


Table D8. Estimated effective sample sizes for scenario 2D2.

| Year | Trawl survey |  | BSFRF <br> Fem. | Ma. | Ret. <br> Ma. | Pot discard |  | Trawl gear |  | Fixed gear |  |  | Tanner discard |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Fem. | Ma. |  |  |  | Fem. | Ma. | Fem. | Ma. | Fem. |  | Ma. | Fem. | Ma. |
| 1975 | 32 | 24 |  |  | 33 |  |  |  |  |  |  |  |  |  |
| 1976 | 32 | 24 |  |  | 33 |  |  | 4 | 11 |  |  |  |  |  |
| 1977 | 32 | 24 |  |  | 33 |  |  | 4 | 11 |  |  |  |  |  |
| 1978 | 32 | 24 |  |  | 33 |  |  | 4 | 11 |  |  |  |  |  |
| 1979 | 32 | 24 |  |  | 33 |  |  | 4 | 11 |  |  |  |  |  |
| 1980 | 32 | 24 |  |  | 33 |  |  | 4 | 11 |  |  |  |  |  |
| 1981 | 32 | 24 |  |  | 33 |  |  | 4 | 11 |  |  |  |  |  |
| 1982 | 32 | 24 |  |  | 33 |  |  | 4 | 11 |  |  |  |  |  |
| 1983 | 32 | 24 |  |  |  |  |  | 4 | 11 |  |  |  |  |  |
| 1984 | 32 | 24 |  |  | 33 |  |  | 4 | 11 |  |  |  |  |  |
| 1985 | 32 | 24 |  |  | 33 |  |  | 4 | 11 |  |  |  |  |  |
| 1986 | 29 | 24 |  |  | 33 |  |  | 2 | 11 |  |  |  |  |  |
| 1987 | 32 | 24 |  |  | 33 |  |  | 4 | 11 |  |  |  |  |  |
| 1988 | 32 | 24 |  |  | 33 |  |  | 2 | 9 |  |  |  |  |  |
| 1989 | 32 | 24 |  |  | 33 |  |  | 2 | 11 |  |  |  |  |  |
| 1990 | 32 | 24 |  |  | 33 | 7 | 14 | 4 | 11 |  |  |  |  |  |
| 1991 | 32 | 24 |  |  | 33 | 5 | 16 | 3 | 4 |  |  |  | 10 | 12 |
| 1992 | 29 | 24 |  |  | 33 | 7 | 16 | 1 | 5 |  |  |  | 10 | 7 |
| 1993 | 32 | 24 |  |  | 33 | 7 | 16 |  |  |  |  |  | 5 | 6 |
| 1994 | 21 | 24 |  |  |  |  |  | 2 | 7 |  |  |  |  |  |
| 1995 | 32 | 24 |  |  |  |  |  | 0 | 2 |  |  |  |  |  |
| 1996 | 32 | 24 |  |  | 33 | 0 | 4 | 4 | 11 |  |  |  |  |  |
| 1997 | 32 | 24 |  |  | 33 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 1998 | 32 | 24 |  |  | 33 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 1999 | 32 | 24 |  |  | 33 | 1 | 16 | 4 | 11 |  |  |  |  |  |
| 2000 | 32 | 24 |  |  | 33 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2001 | 32 | 24 |  |  | 33 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2002 | 32 | 24 |  |  | 33 | 4 | 16 | 4 | 11 |  |  |  |  |  |
| 2003 | 32 | 24 |  |  | 33 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2004 | 32 | 24 |  |  | 33 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2005 | 32 | 24 |  |  | 33 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2006 | 32 | 24 |  |  | 33 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2007 | 32 | 24 | 66 | 39 | 33 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2008 | 32 | 24 | 66 | 39 | 33 | 7 | 16 | 4 | 11 |  |  |  |  |  |
| 2009 | 32 | 24 |  |  | 33 | 7 | 16 | 4 | 11 |  | 5 | 3 |  |  |
| 2010 | 32 | 24 |  |  | 33 | 7 | 16 | 4 | 10 |  | 6 | 1 |  |  |
| 2011 | 32 | 24 |  |  | 33 | 7 | 16 | 2 | 5 |  | 8 | 2 |  |  |
| 2012 | 32 | 24 |  |  | 33 | 7 | 16 | 1 | 3 |  | 8 | 3 |  |  |
| 2013 | 32 | 24 | 19 | 19 | 33 | 7 | 16 | 2 | 7 |  | 8 | 3 | 10 | 5 |
| 2014 | 32 | 24 | 34 | 21 | 33 | 7 | 16 | 1 | 4 |  | 8 | 3 | 7 | 6 |
| 2015 | 32 | 24 | 30 | 21 | 33 | 7 | 16 | 2 | 4 |  | 8 | 3 | 10 | 12 |
| 2016 | 32 | 23 | 33 | 9 | 33 | 7 | 16 | 1 | 9 |  | 8 | 3 |  |  |
| 2017 | 32 | 24 |  |  |  |  |  |  |  |  |  |  |  |  |

# 2017 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions 

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#### Abstract

THIS INFORMATION IS DISTRIBUTED SOLELY FOR THE PURPOSE OF PREDISSEMINATION PEER REVIEW UNDER <br> APPLICABLE INFORMATION QUALITY GUIDELINES. IT HAS NOT BEEN FORMALLY DISSEMINATED BY NOAA FISHERIES/ALASKA FISHERIES SCIENCE CENTER AND SHOULD NOT BE CONSTRUED TO REPRESENT ANY AGENCY DETERMINATION OR POLICY


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## Executive Summary

## 1. Stock: species/area.

Southern Tanner crab (Chionoecetes bairdi) in the eastern Bering Sea (EBS).
2. Catches: trends and current levels.

Legal-sized male Tanner crab are caught and retained in the directed (male-only) Tanner crab fishery in the EBS. The directed fishery was opened in 2013/14 for the first time since 2009/10 because the stock was not overfished in 2012/13 (Stockhausen et al., 2013) and stock metrics met the State of Alaska (SOA) criteria for opening the fishery in 2013/14. TAC was set at $1,645,000 \mathrm{lbs}\left(746 \mathrm{t}\right.$ ) for the area west of $166^{\circ}$ W and at $1,463,000 \mathrm{lbs}$ ( 664 t ) for the area east of $166^{\circ} \mathrm{W}$ in the SOA’s Eastern Subdistrict of the Bering Sea District Tanner crab Registration Area J. The fisheries opened on October 15 and closed on March 31. On closing, $79.6 \%$ ( 594 t ) of the TAC was taken in the western area while $98.6 \%$ ( 654 t ) was taken in the eastern area. Prior to the closures, the retained catch averaged 770 t per year between 2005/062009/10.

Following the 2014 assessment (Stockhausen, 2014), TAC was set at $6,625,000 \mathrm{lbs}(2,329 \mathrm{t})$ for the area west of $166^{\circ} \mathrm{W}$ and at $8,480,000 \mathrm{lbs}(3,829 \mathrm{t})$ for the area east of $166^{\circ} \mathrm{W}$. On closing, $77.5 \%(2,329 \mathrm{t})$ of the TAC was taken in the western area while $99.6 \%(3,829 \mathrm{t})$ were taken in the eastern area.

Following the 2015 assessment (Stockhausen, 2015), TAC was set at 11,272,000 lbs (5,113 t) for the eastern area and $8,396,000 \mathrm{lbs}(3,808 \mathrm{t})$ for the western area. On closing, essentially $100 \%$ of the TAC was taken in both areas ( $11,268,885 \mathrm{lbs}$ [ $5,111 \mathrm{t}$ ] in the eastern area, $8,373,493 \mathrm{lbs}$ [ $3,798 \mathrm{t}$ ] in the western area based on the $5 / 20 / 2016$ in-season catch report).

Following the 2016 assessment (Stockhausen, 2016), the Alaska Department of Fish and Game (ADFG) determined that mature female Tanner crab biomass did not meet their criteria for opening a fishery; thus, the fishery was closed and the TAC was set to 0 . No directed harvest occurred in 2016/17.

Non-retained females and sub-legal males are caught in the directed fishery, when it occurs, as bycatch and discarded. Because it was closed, no bycatch occurred in the directed fishery in 2016/17. Tanner crab are also caught as bycatch in the snow crab and Bristol Bay red king crab fisheries, in the groundfish fisheries and, to a minor extent, in the scallop fishery. Over the last five years, the snow crab fishery has been the major source of Tanner crab bycatch among these fisheries, averaging $1,500 \mathrm{t}$ for the 5 -year period 2012/13-2016/17. Bycatch in the snow crab fishery in 2016/17 was $2,592 \mathrm{t}$. The groundfish fisheries have been the next major source of Tanner crab bycatch over the same five year time period, averaging 360 t . Bycatch in the groundfish fisheries in 2016/17 was 318 t . The Bristol Bay red king crab fishery has typically been the smallest source of Tanner crab bycatch among these fisheries, averaging 85
t over the 5-year time period, although 297 t caught and discarded in 2014/15. In 2016/17, this fishery accounted for $180 t$ of Tanner crab bycatch.

In order to account for mortality of discarded crab, handling mortality rates are assumed to be $32.1 \%$ for Tanner crab discarded in the crab fisheries, $50 \%$ for Tanner crab in the groundfish fisheries using fixed gear, and $80 \%$ for Tanner crab discarded in the groundfish fisheries using trawl gear to account for differences in gear and handling procedures used in the various fisheries.
3. Stock biomass: trends and current levels relative to virgin or historic levels

For EBS Tanner crab, spawning stock biomass is expressed as mature male biomass (MMB) at the time of mating (mid-February). From the author's preferred model (Model B2b), estimated MMB for 2016/17 was 78.0 thousand t (Table 34, Figures 217-220 in Appendix F). This was smaller than those for 2014/15 and 2015/16 (84.8 and 83.8 thousand $t$, respectively), but larger than that for 2013/14 ( 70.6 thousand $t$ ). MMB may have had a recent peak in 2014/15, but it remains above the very low levels seen in the mid1990s to early 2000s (1990 to 2005 average: 36.5 thousand t) and the 2014/15 estimate is the largest since 1978/79. However, it is considerably below model-estimated historic levels in the early 1970s when MMB peaked at $\sim 259$ thousand t (1971).
4. Recruitment: trends and current levels relative to virgin or historic levels.

From the author's preferred model (Model B2b), the estimated total recruitment for 2017/18 (the number of crab entering the population on July 1) is 414.88 million crab (Table 37, Figures 213-216 in Appendix F), however, this value is highly uncertain. The average recruitment during the recent 2012/13-2016/17 period was 74.0 million crab. The longterm (1982+) mean is 214.0 million crab.

## 5. Management performance

Historical status and catch specifications for eastern Bering Sea Tanner crab.
(a) in 1000's t.

| Year | MSST | Biomass <br> (MMB) | TAC <br> (East + West) | Retained <br> Catch | Total Catch <br> Mortality | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2013 / 14$ | 16.98 | $72.70^{\mathrm{A}}$ | 1.41 | 1.26 | 2.78 | 25.35 | 17.82 |
| $2014 / 15$ | 13.40 | $71.57^{\mathrm{A}}$ | 6.85 | 6.16 | 9.16 | 31.48 | 25.18 |
| $2015 / 16$ | 12.82 | $73.93^{\mathrm{A}}$ | 8.92 | 8.91 | 11.38 | 27.19 | 21.75 |
| $2016 / 17$ | $14.58^{\mathrm{C}}$ | $77.96^{\mathrm{A}}$ | 0 | 0 | 1.14 | 25.61 | 20.49 |
| $2017 / 18$ |  | $43.31^{\mathrm{B}}$ |  |  |  | $25.42^{\mathrm{C}}$ | $20.33^{\mathrm{C}}$ |

(b) in millions lbs.

| Year | MSST | Biomass <br> (MMB) | TAC <br> (East + West) | Retained <br> Catch | Total Catch <br> Mortality | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2013 / 14$ | 37.43 | $160.28^{\mathrm{A}}$ | 3.11 | 2.78 | 6.14 | 55.89 | 39.29 |
| $2014 / 15$ | 29.53 | $157.78^{\mathrm{A}}$ | 15.10 | 13.58 | 20.19 | 69.40 | 55.51 |
| $2015 / 16$ | 28.27 | $162.99^{\mathrm{A}}$ | 19.67 | 19.64 | 25.09 | 59.94 | 47.95 |
| $2016 / 17$ | $32.15^{\mathrm{C}}$ | $171.87^{\mathrm{A}}$ | 0 | 0 | 2.52 | 56.46 | 45.17 |
| $2017 / 18$ |  | $95.49^{\mathrm{B}}$ |  |  |  | $56.03^{\mathrm{C}}$ | $44.83^{\mathrm{C}}$ |

[^3]6. Basis for the OFL
a) in 1000's t.

| Year | Tier ${ }^{\text {A }}$ | $\mathrm{B}_{\mathrm{MSY}}{ }^{\text {A }}$ | $\begin{aligned} & \text { Current } \\ & \text { MMB }^{\mathbf{A}} \\ & \hline \end{aligned}$ | B/B MSY $^{\text {A }}$ | $\begin{aligned} & \mathbf{F O F L}^{\mathbf{A}} \\ & \left(\mathrm{yr}^{-1}\right) \\ & \hline \end{aligned}$ | Years to define B $_{\mathrm{MSY}^{\text {A }}}$ | Natural Mortality ${ }^{\mathrm{A}, \mathrm{B}}$ $\left(\mathrm{yr}^{-1}\right)$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2013/14 | 3 a | 33.54 | 59.35 | 1.77 | 0.73 | 1982-2013 | 0.23 |
| 2014/15 | 3 a | 29.82 | 63.80 | 2.14 | 0.61 | 1982-2014 | 0.23 |
| 2015/16 | 3 a | 26.79 | 53.70 | 2.00 | 0.58 | 1982-2015 | 0.23 |
| 2016/17 | 3 a | 25.65 | 45.34 | 1.77 | 0.79 | 1982-2016 | 0.23 |
| 2017/18 | 3a | 29.17 | 43.31 | 1.49 | 0.75 | 1982-2017 | 0.23 |

b) in millions lbs.

| Year | Tier ${ }^{\text {a }}$ | $\mathrm{BmSY}^{\text {a }}$ | $\begin{aligned} & \text { Current } \\ & \text { MMB }^{\mathbf{A}} \end{aligned}$ | B/BMSY ${ }^{\text {A }}$ | $\begin{aligned} & \mathbf{F}_{\mathrm{FOLL}^{\mathrm{A}}}^{\left(\mathrm{yr}^{-1}\right)} \\ & \hline \end{aligned}$ | Years to define B $_{\text {MSY }}{ }^{\text {A }}$ | $\begin{gathered} \text { Natural } \\ \text { Mortality }{ }^{\mathrm{A}, \mathrm{~B}} \\ \left(\mathrm{yr}^{-1}\right) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2013/14 | 3 a | 73.94 | 130.84 | 1.77 | 0.73 | 1982-2013 | 0.23 |
| 2014/15 | 3 a | 65.74 | 140.66 | 2.14 | 0.61 | 1982-2014 | 0.23 |
| 2015/16 | 3 a | 59.06 | 118.38 | 2.00 | 0.58 | 1982-2015 | 0.23 |
| 2016/17 | 3 a | 56.54 | 99.95 | 1.77 | 0.79 | 1982-2016 | 0.23 |
| 2017/18 | 3 a | 64.30 | 95.49 | 1.49 | 0.75 | 1982-2017 | 0.23 |

A-Calculated from the assessment reviewed by the Crab Plan Team in 20 XX of $20 \mathrm{XX} /(\mathrm{XX}+1)$ or based on the author's preferred model for 2016/17.
B—Nominal rate of natural mortality. Actual rates used in the assessment are estimated and may be different.
Current male spawning stock biomass (MMB), as projected for 2017/18, is estimated at 43.31 thousand t . $B_{\text {MSY }}$ for this stock is calculated to be 29.17 thousand t , so MSST is 14.58 thousand t . Because current MMB > MSST, the stock is not overfished. Total catch mortality (retained + discard mortality in all fisheries, using a discard mortality rate of 0.321 for pot gear and 0.8 for trawl gear) in 2016/17 was 1.14 thousand $t$, which was less than the OFL for 2016/17 ( 25.61 thousand $t$ ); consequently overfishing did not occur. The OFL for 2017/18 based on the author's preferred model (Model B2b) is 25.42 thousand $t$. The $\mathrm{ABC}_{\text {max }}$ for 2017/18, based on the p* ABC , is 25.57 thousand t . In 2014, the SSC adopted a $20 \%$ buffer to calculate ABC for Tanner crab to incorporate concerns regarding model uncertainty for this stock. Based on this buffer, the ABC would be 20.33 thousand $t$.

## 7. Rebuilding analyses summary.

The EBS Tanner crab stock was found to be above MSST (and $\mathrm{B}_{\mathrm{MSY}}$ ) in the 2012 assessment (Rugolo and Turnock, 2012b) and was subsequently declared rebuilt. The stock remains not overfished. Consequently no rebuilding analyses were conducted.

## A. Summary of Major Changes

1. Changes (if any) to the management of the fishery.

At the March, 2015 SOA Board of Fish (BOF) meeting, the Board adopted a revised harvest strategy for Tanner crab in the Bering Sea District ${ }^{1}$, wherein the TAC for the area east of $166^{\circ} \mathrm{W}$ longitude would be based on a minimum preferred harvest size of 127 mm CW ( 5.0 inches), including the lateral spines. Formerly, this calculation was based on a minimum preferred size of 140 mm CW ( 5.5 inches). The TAC in the area west of $166^{\circ} \mathrm{W}$ longitude continues to be based on a minimum preferred harvest size of 127 mm CW (including lateral spines).

The directed Tanner crab fisheries in the EBS (i.e., east and west of $166^{\circ} \mathrm{W}$ longitude) were closed in 2016/17 because mature female Tanner crab biomass in 2016 failed to meet the criteria defined in the SOA's harvest strategy to open the fisheries. [Note: These criteria were not among the changes to the harvest strategy adopted by the BOF in March, 2015.]

## 2. Changes to the input data

The following table summarizes data sources that have been updated for this assessment:
Updated data sources.

| Data source | Data types | Time frame | Notes | Agency |
| :--- | :--- | :--- | :--- | :--- |
| NMFS EBS Bottom | area-swept abundance, biomass | $1975-2017$ | recalculated, new | NMFS |
| Trawl Survey | size compositions |  |  | NMFS, BSFRF |
| NMFS/BSFRF | molt-increment data | $2014-16$ | new | ADFG |
| Directed fishery | retained catch (numbers, biomass) | $2005 / 06-2016 / 17$ | updated, new | ADFG |
|  | retained catch size compositions | $2013 / 14-2015 / 16$ | updated | ADFG |
|  | effort | $2015 / 16,2016 / 17$ | updated, new | ADFG |
|  | total catch (abundance, biomass) | $2015 / 16,2016 / 17$ | updated, new | ADFG |
| total catch size compositions | $2015 / 16,2016 / 17$ | updated, new | ADFG |  |
|  | effort | $1990 / 91-2013 / 14$ | updated, new | ADFG |
| Snow Crab Fishery | total bycatch (abundance, biomass) | $1990 / 91-2016 / 17$ | updated, new | ADFG |
| Bristol Bay | effort | $2016 / 17$ | new | ADFG |
| Red King Crab Fishery | total bycatch (abundance, biomass) | $1990 / 91-2013 / 14$ | updated, new | ADFG |
|  | total bycatch size compositions | $2016 / 17$ | updated, new | new |
| Groundfish Fisheries | total bycatch (abundance, biomass) | $1991 / 92-2016 / 17$ | updated, new | NMFS/AKFIN |
| (all gear types) | total bycatch size compositions | $1991 / 92-2016 / 17$ | updated, new | ADFG |
| Groundfish Fixed-Gear | total bycatch (abundance, biomass) | $1991 / 92--2016 / 17$ | new | NMFS/AKFIN |
| Fisheries | total bycatch size compositions | $1991 / 92--2016 / 17$ | new | Nempositions |
| Groundfish Trawl | total bycatch (abundance, biomass) | $1991 / 92--2016 / 17$ | new | NMFS/AKFIN |
| Fisheries | total bycatch size compositions | $1991 / 92--2016 / 17$ | new |  |

## 3. Changes to the assessment methodology.

Following a considerable development effort and substantial review by the CPT at the January 2017 Modeling Workshop and the May 2017 CPT Meeting, with additional review by the SSC at its February and June 2017 meetings, a new modeling "framework", TCSAM02, was recommended by the CPT at its May 2017 meeting (and approved by the SSC at its June 2017 meeting) for use in this assessment. TCSAM02, while based on the previous assessment model (TCSAM2013), constitutes a completely rewritten code library for the Tanner crab assessment model. Results presented at the May CPT meeting

[^4]demonstrated that TCSAM02 could be configured to exactly match results from the TCSAM2013 code, thus providing continuity with the old model code. However, demonstrating this "exact equivalence" required some minor modifications to the 2016 assessment model. These changes were reviewed and approved at the May CPT meeting, with the understanding that the "exactly equivalent" TCSAM02 model would be the base model for this assessment (rather than the 2016 assessment model).

The changes from the 2016 assessment model to the "exactly equivalent" base model are discussed in detail in the May CPT report (Stockhausen, 2017) and included: 1) removing a size-specific reclassification of "old shell" males with regards to the survey data used in the model; 2) fitting to total capture size composition data, rather than trying to incorporate handling mortality prior to fitting the data; 3) fitting to total capture biomass, rather than mortality; 4) seasonally applying natural mortality rates for mature crab from spring to summer to crab that underwent terminal molt in the spring; 5) basing aggregated survey biomass on 1 -mm size bins, not the 5 mm size bins used to fit size compositions; 6) using a more-precise value to convert from pounds to kilograms; 7) setting bycatch capture rates in the Bristol Bay red king crab fishery explicitly to 0 for years when the fishery was closed, 8) using the estimated median (rather than the mean) size-at- $50 \%$ selected for males in the directed fishery after 1990 to males in the directed fishery prior to 1991; and 9) using the estimated median (rather than the mean) bycatch F for the groundfish fisheries post-1972 as the value pre-1973. The resulting model is the base model, B0, for this assessment.

The author's preferred model, B2b, builds on B0 principally by: 1) fitting EBS model-increment data inside the model to inform growth parameters, b) estimating separate retention functions for three time periods (pre-1997/98, 2005/06-2009/10, and 2013/14-2015/16), and c) estimating the asymptotic value for the fraction of male crab retained in the directed fishery (in the same three time periods as (b)), rather than assuming it was 1 (i.e., $100 \%$ retention at large sizes).

## 4. Changes to the assessment results

Results from the author's preferred model this year (Model B2b) are reasonably similar to those from the previous assessment, considering the large number of changes in the model. Perhaps the largest change is due to somewhat higher recruitment estimates in this year's preferred model. Average recruitment (1982present) was estimated at 182 million in last year's model, whereas it was estimated at 214 million in the author's preferred model this year. $\mathrm{B}_{\text {MSY }}$ was consequently estimated somewhat larger than last year
( 29.17 thousand t vs. 25.65 thousand t ) and $\mathrm{F}_{\text {MSY }}$ was smaller ( $0.75 \mathrm{yr}^{-1}$ this year vs. $0.79 \mathrm{yr}^{-1}$ last year).

## B. Responses to SSC and CPT Comments

1. Responses to the most recent two sets of SSC and CPT comments on assessments in general. [Note: for continuity with the previous assessment, the following includes unaddressed comments prior to the most recent two sets of comments.]

June 2017 SSC Meeting
The SSC requested an evaluation of all parameters estimated to be at or very near bounds, or substantially limited by priors (unless those priors can be logically defended).

Response: An initial approach to evaluating parameters at or near bounds using ADMB’s likelihood profiling capability revealed that errors had apparently been introduced to the profiling algorithm in a recent version (11.2) of the ADMB libraries. These errors have subsequently been resolved, and will be incorporated in the next scheduled version release (11.7). However, likelihood profiling results from the author's version ( $11.5 / 11.6$ ) would provide erroneous results.

May 2017 Crab Plan Team Meeting
No general comments.
October 2016 SSC Meeting
No general comments.
September 2016 Crab Plan Team Meeting
No general comments.
2. Responses to the most recent two sets of SSC and CPT comments specific to the assessment. [Note: for continuity with the previous assessment, the following includes comments prior to the most recent two sets of comments.]

June 2017 SSC Meeting
The SSC endorsed the CPT suggestions from its May meeting.
Response: none.
The SSC requested an evaluation of all parameters estimated to be at or very near bounds, or substantially limited by priors (unless those priors can be logically defended).
Response: See response above to general comments from the June 2017 SSC Meeting.

## May2017 Crab Plan Team Meeting

The CPT noted that the EBS growth data should be used in the assessment if at all possible, that the growth increment function should be adopted, and that the scale parameter should be estimated rather than being set to 0.75 .
Response: All three requests have been addressed in the assessment (Model B1 and subsequent models).
The CPT noted that there was a tendency for the model to overpredict the abundance of large crab and recommended that the issue be evaluated by modeling retention with a logistic curve that asymptotes to a value less than one.
Response: The option of fitting a retention curve that asymptotes less than one has been implemented in the model framework. Models B2a, B2b and B3 incorporate this option and address this issue. Results from these models suggest that retention is indeed asymptotically less than one.

The CPT outlined the base model to be used for this assessment, based on results presented by the author for a suite of models.
Response: The base model recommended by the CPT is the base model used here (Model B0).

The CPT outlined a number of alternative models built on its recommended base model to be evaluated. Response: Models B1, B2, and B3 were evaluated for this assessment. Requests to address time-varying retention and potential less-than-complete retention of legal-size crab were also addressed (models B2, B2a, and B2b). It was not possible to address the potential use of Francis-style iterative re-weighting for size composition data.

October 2016 SSC Meeting
Comment: "The SSC endorses all of the CPT recommendations with respect to the poor fits to some of the retained catch time series, poor fits to the size composition data for retained catch and survey data, and issues with the total directed fishery selectivity curve for males (in particular the 1996 'outlier')." Response: With respect to the 1996 'outlier', this was a result of the combination of a very small sample size for the 1996 size compositions and the using the mean size-st-50\%-selected for 1991-1996 as the value for the size-at-50\%-selected prior to 1991. Because the sample size for 1996 was small, the 1996 size-at-50\%-selected essentially became a free parameter uninformed by the 1996 data but sensitive to changes in the overall likelihood through changes in the mean value. Regarding the other issues, see the responses to CPT comments below.

## September 2016 CPT Meeting

Comment: "The model fits total catch well, but does a poorer job in fitting retained catch, catch of females, and catch in the bycatch fisheries."
Response: Catch of females was improved by estimating a female-specific offset to fully-selected male capture rates in the fisheries. There appears to be a conflict in the model between fitting total (male) catch and retained catch in the directed fishery. In this assessment, I've explored the use of varying the estimated retention function annually and within time blocks, as well as the possibility that retention is not $100 \%$ for the largest male crab (i.e., the retention function asymptotes at less than 1 ). These options seem to reduce the conflict, but not eliminate it.

## C. Introduction

## 1. Scientific name.

Chionocoetes bairdi.Tanner crab is one of five species in the genus Chionoecetes (Rathbun, 1924). The common name "Tanner crab" for C. bairdi (Williams et al. 1989) was recently modified to "southern Tanner crab" (McLaughlin et al. 2005). Prior to this change, the term "Tanner crab" had also been used to refer to other members of the genus, or the genus as a whole. Hereafter, the common name "Tanner crab" will be used in reference to "southern Tanner crab".

## 2. Description of general distribution

Tanner crabs are found in continental shelf waters of the north Pacific. In the east, their range extends as far south as Oregon (Hosie and Gaumer 1974) and in the west as far south as Hokkaido, Japan (Kon 1996). The northern extent of their range is in the Bering Sea (Somerton 1981a), where they are found along the Kamchatka peninsula (Slizkin 1990) to the west and in Bristol Bay to the east.

In the eastern Bering Sea (EBS), the Tanner crab distribution may be limited by water temperature (Somerton 1981a). The unit stock is that defined across the geographic range of the EBS continental shelf, and managed as a single unit (Fig. 1). C. bairdi is common in the southern half of Bristol Bay, around the Pribilof Islands, and along the shelf break, although males less than the industry-preferred size ( $>125 \mathrm{~mm}$ CW) and ovigerous and immature females of all sizes are distributed broadly from southern Bristol Bay northwest to St. Matthew Island (Rugolo and Turnock, 2011a). The southern range of the cold water congener the snow crab, C. opilio, in the EBS is near the Pribilof Islands (Turnock and Rugolo, 2011). The distributions of snow and Tanner crab overlap on the shelf from approximately $56^{\circ}$ to $60^{\circ} \mathrm{N}$, and in this area, the two species hybridize (Karinen and Hoopes 1971).

## 3. Evidence of stock structure

Tanner crabs in the EBS are considered to be a separate stock distinct from Tanner crabs in the eastern and western Aleutian Islands (NPFMC 1998). Somerton (1981b) suggests that clinal differences in some biological characteristics may exist across the range of the unit stock. These conclusions may be limited since terminal molt at maturity in this species was not recognized at the time of that analysis, nor was stock movement with ontogeny considered. Biological characteristics estimated based on comparisons of length frequency distributions across the range of the stock, or on modal length analysis over time may be confounded as a result.

Although the State of Alaska's (SOA) harvest strategy and management controls for this stock are different east and west of $166^{\circ} \mathrm{W}$, the unit stock of Tanner crab in the EBS appears to encompass both regions and comprises crab throughout the geographic range of the NMFS bottom trawl survey. Evidence is lacking that the EBS shelf is home to two distinct, non-intermixing, non-interbreeding stocks that should be assessed and managed separately.

## 4. Life history characteristics

## a. Molting and Shell Condition

Tanner crabs, like all crustaceans, normally exhibit a hard exoskeleton of chitin and calcium carbonate. This hard exoskeleton requires individuals to grow through a process referred to as molting, in which the individual sheds its current hard shell, revealing a new, larger exoskeleton that is initially soft but which rapidly hardens over several days. Newly-molted crab in this "soft shell" phase can be vulnerable to predators because they are generally torpid and have few defenses if discovered. Subsequent to hardening, an individual's shell provides a settlement substrate for a variety of epifaunal "fouling" organisms such as barnacles and bryozoans. The degree of hard-shell fouling was once thought to correspond closely to post-molt age and led to a classification of Tanner crab by shell condition (SC) in survey and fishery data similar to that described in the following table (NMFS/AFSC/RACE, unpublished):

| Shell Condition <br> Class | $\quad$ Description |
| :---: | :--- |
| 0 | pre-molt and molting crab |
| 1 | carapace soft and pliable |
| 2 | carapace firm to hard, clean |
| 3 | carapace hard; topside usually yellowish brown; thoracic sternum and underside of legs yellow <br> with numerous scratches; pterygostomial and bronchial spines worn and polished; dactyli on <br> meri and metabranchial region rounded; epifauna (barnacles and leech cases) usually present <br> but not always. |
| 5 | carapace hard, topside yellowish-brown to dark brown; thoracic sternum and undersides of legs <br> data yellow with many scratches and dark stains; pterygostomial and branchial spines rounded <br> with tips sometimes worn off; dactyli very worn, sometimes flattened on tips; spines on meri <br> and metabranchial region worn smooth, sometimes completely gone; epifauna most always <br> present (large barnacles and bryozoans). |
| 5 | conditions described in Shell Condition 4 above much advanced; large epifauna almost <br> completely covers crab; carapace is worn through in metabranchial regions, pterygostomial <br> branchial spines, or on meri; dactyli flattened, sometimes worn through, mouth parts and eyes <br> sometimes nearly immobilized by barnacles. |

Although these shell classifications continue to be applied to crab in the field, it has been shown that there is little real correspondence between post-molt age and shell classifications SC 3 through 5, other than that they indicate that the individual has probably not molted within the previous year (Nevisi et al, 1996). In this assessment, crab classified into SCs 3-5 have been aggregated as "old-shell" crab, indicating that these are crab likely to have not molted within the previous year. In a similar fashion, crab classified in SCs 0-2 have been combined as "new shell" crab, indicating that these are crab have certainly (SCs 0 and 1 ), or are likely to have (SC 2), molted within the previous year.

## b. Growth

Work by Somerton (1981a) estimated growth for EBS Tanner crab based on modal size frequency analysis of Tanner crab in survey data assuming no terminal molt at maturity. Somerton's approach did not directly measure molt increments and his findings are constrained by not considering that the progression of modal lengths between years was biased because crab ceased growing after their terminal molt to maturity.

Growth in immature Tanner crab larger than approximately 25 mm CW proceeds by a series of annual molts, up to a final (terminal) molt to maturity (Tamone et al., 2007). Rugolo and Turnock (2012a) derived growth relationships for male and female Tanner crab used as priors for estimated growth parameters in this (and previous) assessments from data on observed growth in males to approximately 140 mm carapace width (CW) and in females to approximately 115 mm CW that were collected near Kodiak Island in the Gulf of Alaska (Munk, unpublished.; Donaldson et al. 1981). Rugolo and Turnock (2010) compared the resulting growth per molt (gpm) relationships with those of Stone et al. (2003) for Tanner crab in southeast Alaska in terms of the overall pattern of gpm over the size range of crab and found that the pattern of gpm for both males and females was characterized by a higher rate of growth to an intermediate size ( $90-100 \mathrm{~mm}$ CW) followed by a decrease in growth rate from that size thereafter. Similarly-shaped growth curves were found by Somerton (1981a) and Donaldson et al. (1981), as well.

Molt increment data was collected for Tanner crab in the EBS during 2015, 2016, and 2017 in cooperative research between NMFS and the Bering Sea Research Foundation (R. Foy, NMFS, pers. comm.). Preliminary analysis of the data suggests it is not substantially different from that obtained near Kodiak Island (see Appendix D). However, this data is incorporated for the first time to inform inferred growth trajectories within several of the alternative models evaluated in this assessment.

## c. Weight at Size

Weight-at-size relationships used in this assessment were revised in 2014 based on a comprehensive reevaluation of data from the NMFS EBS Bottom Trawl Survey (Daly et al., 2014). Weight-at-size is described by a power-law model of the form $w=a \cdot z^{b}$, where $w$ is weight in kg and $z$ is size in mm CW (Daly et al., 2016; table below). Parameter values are presented in the following table:

| sex | maturity | $a$ | $b$ |
| :---: | :---: | :---: | :---: |
| males |  | 0.000270 | 3.022134 |
| females | immature <br> (non-ovigerous) <br> mature <br> (ovigerous) | 0.000562 | 2.816928 |

## d. Maturity and Reproduction

It is now generally accepted that both Tanner crab males (Tamone et al. 2007) and females (Donaldson and Adams 1989) undergo a terminal molt to maturity, as in most majid crabs. Maturity in females can be determined visually rather unambiguously from the relative size of the abdomen. Females usually undergo their terminal molt from their last juvenile, or pubescent, instar while being grasped by a male (Donaldson and Adams 1989). Subsequent mating takes place annually in a hard shell state (Hilsinger 1976) and after extruding the female's clutch of eggs. While mating involving old-shell adult females has been documented (Donaldson and Hicks 1977), fertile egg clutches can be produced in the absence of males by using sperm stored in the spermathacae (Adams and Paul 1983, Paul and Paul 1992). Two or more consecutive egg fertilization events can follow a single copulation using stored sperm to selffertilize the new clutch (Paul 1982, Adams and Paul 1983), although egg viability decreases with time and age of the stored sperm (Paul 1984).

Maturity in males can be classified either physiologically or morphometrically, but is not as easily determined as with females. Physiological maturity refers to the presence or absence of spermataphores in the gonads whereas morphometric maturity refers to the presence or absence of a large claw (Brown and Powell 1972). During the molt to morphometric maturity, there is a disproportionate increase in the size of the chelae in relation to the carapace (Somerton 1981a). While many earlier studies on Tanner crabs assumed that morphometrically mature male crabs continued to molt and grow, there is now substantial evidence supporting a terminal molt for males (Otto 1998, Tamone et al. 2007). A consequence of the terminal molt in male Tanner crab is that a substantial portion of the population may never achieve legal size (NPFMC 2007).

Although observations are lacking in the EBS, seasonal differences have been observed between mating periods for pubescent and multiparous females in the Gulf of Alaska and Prince William Sound. There, pubescent molting and mating takes place over a protracted period from winter through early summer, whereas multiparous mating occurs over a relatively short period during mid April to early June (Hilsinger 1976, Munk et al. 1996, and Stevens 2000). In the EBS, egg condition for multiparous Tanner crabs assessed between April and July 1976 also suggested that hatching and extrusion of new clutches for this maturity state began in April and ended sometime in mid-June (Somerton 1981a).

## e. Fecundity

A variety of factors affect female fecundity, including somatic size, maturity status (primiparous vs. multiparous), age post terminal molt, and egg loss (NMFS 2004). Of these factors, somatic size is the most important, with estimates of 89 to 424 thousand eggs for females 75 to 124 mm CW , respectively (Haynes et al. 1976). Maturity status is another important factor affecting fecundity, with primiparous females being only $\sim 70 \%$ as fecund as equal size multiparous females (Somerton and Meyers 1983). The number of years post maturity molt, and whether or not, a female has had to use stored sperm from that first mating can also affect egg counts (Paul 1984, Paul and Paul 1992). Additionally, older senescent
females often carry small clutches or no eggs (i.e., are barren) suggesting that female crab reproductive output is a concave function of age (NMFS 2004).

## f. Size at Maturity

Rugolo and Turnock (2012b) estimated size at $50 \%$ mature for females (all shell classes combined) from data collected in the NMFS bottom trawl survey at 68.8 mm CW, and 74.6 mm CW for new shell females. For males, Rugolo and Turnock (2012a) estimated classification lines using mixture-of-tworegressions analysis to define morphometric maturity for the unit Tanner crab stock, and for the sub-stock components east and west of $166^{\circ} \mathrm{W}$, based on chela height and carapace width data collected during the 2008 NMFS bottom trawl survey. These rules were then applied to historical survey data from 1990-2007 to apportion male crab as immature or mature based on size (Rugolo and Turnock, 2012b). Rugolo and Turnock (2012a) found no significant differences between the classification lines of the sub-stock components (i.e., east and west of $166^{\circ} \mathrm{W}$ ), or between the sub-stock components and that of the unit stock classification line. Size at $50 \%$ mature for males (all shell condition classes combined) was estimated at 91.9 mm CW, and at 104.4 mm CW for new shell males. By comparison, Zheng and Kruse (1999) used knife-edge maturity at $>79 \mathrm{~mm}$ CW for females and $>112 \mathrm{~mm}$ CW for males in development of the current SOA harvest strategy.

Some preliminary work towards incorporating chela height measurements on male crab directly into the assessment has been done, but not completed. One concern is the representativeness of this data for the entire stock, given the somewhat haphazard nature of collections in previous years. To address this issue, substantial effort was devoted during the 2017 NMFS EBS bottom trawl survey to obtain chela heights on all male Tanner crab collected during the survey (R. Foy, NMFS, pers. comm.). However, this data is not yet available to incorporate into the assessment.

## g. Mortality

Due to the lack of age information for crab, Somerton (1981a) estimated mortality separately for individual EBS cohorts of immature and adult Tanner crab. Somerton postulated that age five crab (mean CW $=95 \mathrm{~mm}$ ) were the first cohort to be fully recruited to the NMFS trawl survey sampling gear and estimated an instantaneous natural mortality rate of 0.35 for this size class using catch curve analysis. Using this analysis with two different data sets, Somerton estimated natural mortality rates of adult male crab from the fished stock to range from 0.20 to 0.28 . When using CPUE data from the Japanese fishery, estimates of M ranged from 0.13 to 0.18 . Somerton concluded that estimates of M from 0.22 to 0.28 obtained from models that used both the survey and fishery data were the most representative.

Rugolo and Turnock (2011a) examined empirical evidence for reliable estimates of oldest observed age for male Tanner crab. Unlike its congener the snow crab, information on longevity of the Tanner crab is lacking. They reasoned that longevity in a virgin population of Tanner crab would be analogous to that of the snow crab, where longevity would be at least 20 years, given the close analogues in population dynamic and life-history characteristics (Turnock and Rugolo 2011a). Employing 20 years as a proxy for longevity and assuming that this age represented the upper 98.5th percentile of the distribution of ages in an unexploited population, M was estimated to be 0.23 based on Hoenig's (1983) method. If 20 years was assumed to represent the $95 \%$ percentile of the distribution of ages in the unexploited stock, the estimate for M was 0.15 . Rugolo and Turnock (2011a) adopted $\mathrm{M}=0.23$ for both male and female Tanner because the value corresponded with the range estimated by Somerton (1981a), as well as the value used in the analysis to estimate new overfishing definitions underlying Amendment 24 to the Crab Fishery Management Plan (NPFMC 2007).

## 5. Brief summary of management history.

A complete summary of the management history is provided in the ADFG Area Management Report appended to the annual SAFE. Fisheries have historically taken place for Tanner crab throughout their
range in Alaska, but currently only the fishery in the EBS is managed under a federal Fishery Management Plan (FMP; NPFMC 2011). The plan defers certain management controls for Tanner crab to the State of Alaska, with federal oversight (Bowers et al. 2008). The State of Alaska manages Tanner crab based on registration areas divided into districts. Under the FMP, the state can adjust districts as needed to avoid overharvest in a particular area, change size limits from other stocks in the registration area, change fishing seasons, or encourage exploration (NPFMC 2011).

The Bering Sea District of Tanner crab Registration Area J (Figure 1) includes all waters of the Bering Sea north of Cape Sarichef at $54^{\circ} 36^{\prime}$ N and east of the U.S.-Russia Maritime Boundary Line of 1991. This district is divided into the Eastern and Western Subdistricts at $173^{\circ} \mathrm{W}$. The Eastern Subdistrict is further divided at the Norton Sound Section north of the latitude of Cape Romanzof and east of $168^{\circ} \mathrm{W}$ and the General Section to the south and west of the Norton Sound Section (Bowers et al. 2008). In this report, I use the terms "east region" and "west region" as shorthand to refer to the regions demarcated by $166^{\circ} \mathrm{W}$.

In March 2011, the Alaska Board of Fisheries (BOF) approved a new minimum size limit harvest strategy for Tanner crab effective for the 2011/12 fishery. Prior to this change, the minimum legal size limit was $5.5 "$ ( 138 mm CW) throughout the Bering Sea District. The new regulations established different minimum size limits east and west of $166^{\circ} \mathrm{W}$. The minimum size limit for the fishery to the east of $166^{\circ} \mathrm{W}$ is now $4.8^{\prime \prime}$ ( 122 mm CW ) and that to the west is $4.4^{\prime \prime}$ ( 112 mm CW ), where the size measurement includes the lateral spines. For economic reasons, fishers may adopt larger minimum sizes for retention of crab in both areas, and the SOA's harvest strategy and total allowable catch (TAC) calculations are based on assumed minimum preferred sizes that are larger than the legal minimums. In 2011, these minimum preferred sizes were set at 5.5 " ( 140 mm CW ) in the east and 5 " ( 127 mm CW ) in the west, including the lateral spines. In 2015, following a petition by the crab industry, the BOF revised the minimum preferred size for TAC calculations in the area east of $166^{\circ} \mathrm{W}$ longitude to 5 " ( 127 mm CW ), the same as that in the western area. These new "preferred" sizes were used to set the TAC for the 2015/16 fishery season.

In assessments prior to 2016, the term "legal males" was used to refer to male crab $\geq 138 \mathrm{~mm} \mathrm{CW}$ (not including the lateral spines), although this was not strictly correct as it referred to the industry's "preferred" crab size in the east region, as well as to the minimum size in the east used in the SOA's harvest strategy for TAC setting. In this assessment, I use the term "legal males" to refer to crab 125 mm CW, the minimum "preferred" size used in both eastern and western areas the SOA's harvest strategy, and larger.

Landings of Tanner crab in the Japanese pot and tangle net fisheries were reported in the period 19651978, peaking at 19.95 thousand t in 1969. The Russian tangle net fishery was prosecuted during 19651971 with peak landings in 1969 at 7.08 thousand t. Both the Japanese and Russian Tanner crab fisheries were displaced by the domestic fishery by the late-1970s (Table 1; Figure 3). Foreign fishing for Tanner crab ended in 1980.

The domestic Tanner crab pot fishery developed rapidly in the mid-1970s (Tables 1 and 2; Figure 3). Domestic US landings were first reported for Tanner crab in 1968 at 0.46 thousand $t$ taken incidentally to the EBS red king crab fishery. Tanner crab was targeted thereafter by the domestic fleet and landings rose sharply in the early 1970s, reaching a high of 30.21 thousand $t$ in 1977/78. Landings fell sharply after the peak in 1977/78 through the early 1980s, and domestic fishing was closed in 1985/86 and 1986/87 due to depressed stock status. In 1987/88, the fishery reopened and landings rose again in the late-1980s to a second peak in 1990/91 at 18.19 thousand t , and then fell sharply through the mid-1990s. The domestic Tanner crab fishery was closed between 1996/97 and 2004/05 as a result of conservation concerns regarding depressed stock status. It re-opened in 2005/06 and averaged 0.77 thousand $t$ retained catch between 2005/06-2009/10 (Tables 1 and 2). For the 2010/11-2012/13 seasons, the State of Alaska closed
directed commercial fishing for Tanner crab due to estimated female stock metrics being below thresholds adopted in the state harvest strategy. However, these thresholds were met in fall 2013 and the directed fishery was opened in 2013/14. TAC was set at 1,645,000 lbs (746 t) for the area west of $166^{\circ} \mathrm{W}$ and at $1,463,000 \mathrm{lbs}\left(664 \mathrm{t}\right.$ ) for the area east of $166^{\circ} \mathrm{W}$ in the State of Alaska’s Eastern Subdistrict of Tanner crab Registration Area J. The fisheries opened on October 15 and closed on March 31. On closing, 79.6\% ( 594 t ) of the TAC had been taken in the western area while $98.6 \%$ ( 654 t ) had been taken in the eastern area. Prior to the closures, the retained catch averaged 770 t per year between 2005/06-2009/10. In 2014, TAC was set at $6,625,000 \mathrm{lbs}\left(3,005 \mathrm{t}\right.$ ) for the area west of $166^{\circ} \mathrm{W}$ and at $8,480,000 \mathrm{lbs}(3,846 \mathrm{t})$ for the area east of $166^{\circ} \mathrm{W}$. On closing, $77.5 \%(2,329 \mathrm{t})$ of the TAC was taken in the western area while $99.6 \%$ ( $3,829 \mathrm{t}$ ) were taken in the eastern area. In 2015, TAC was set at $8,396,000 \mathrm{lbs}(3,808 \mathrm{t})$ in the western area and $11,272,000 \mathrm{lbs}(5,113 \mathrm{t})$ in the eastern area. On closing, essentially $100 \%$ of the TAC was taken in each area ( $3,798 \mathrm{t}$ in the west, $5,111 \mathrm{t}$ in the east). The total retained catch in 2015/16 ( $8,910 \mathrm{t}$ ) was the largest taken in the fishery since 1992/93 (Tables 1, 2; Figure 2). The directed fisheries in both areas were closed in 2016/17 because mature female biomass in the NMFS EBS Bottom Trawl Survey did not exceed the threshold set in the SOA's harvest strategy to allow them to open. Total retained catch was thus 0 in 2016/17.

Bycatch and discard losses of Tanner crab originate from the directed pot fishery, non-directed snow crab and Bristol Bay red king crab pot fisheries, and the groundfish fisheries (Tables 3 and 4; Figures 5-7). Bycatch estimates are converted to discard mortality using assumed handling mortality rates of $32.1 \%$ for bycatch in the crab fisheries and $80 \%$ for bycatch in the groundfish fisheries. Bycatch was persistently high during the early-1970s; a subsequent peak mode of discard losses occurred in the early-1990s. In the early-1970s, the groundfish fisheries contributed significantly to total bycatch losses (although bycatch in the crab fisheries was undocumented at the time). From 1992/93 (when reliable crab fishery bycatch estimates are first available) to 2004/05, the groundfish fisheries accounted for the largest proportion of discard mortality. Since 2005/06, however, the crab fisheries have accounted for the largest proportion.

## D. Data

## 1. Summary of new information

Because the directed fisheries were closed in 2016/17, retained catch abundance and biomass for the previous year were both 0 and no retained catch size composition data was available. Similarly, total catch (retained + discards) abundance and biomass in the directed fishery were both 0 for 2016/17, and no total catch size composition data from at-sea sampling was available. Updated estimates of total retained biomass and abundance in the 2015/16 directed fisheries, as well as retained size frequencies by shell condition, based on fish ticket data and dockside observer sampling were provided by ADFG (B. Daly, ADFG, pers. comm.).

ADFG also provided estimates of Tanner crab bycatch (abundance, biomass and size compositions) in the 2016/17 snow crab and Bristol Bay red king crab fisheries by several categories (e.g., by sex and shell condition), as well as updated estimates of total bycatch abundance and biomass, total fishery (potlifts) and observer sampling (pots examined) effort in both fisheries for 1990/91 to 2015/16.

Tanner crab bycatch data in the groundfish fisheries (abundance, biomass, size compositions) were extracted for 1991/92-2016/17 from the groundfish observer and AKRO databases on AKFIN. One model scenario for this assessment explored the use of fitting gear-specific data types, but most scenarios fit the data aggregated over gear types (see below). More details of this data are discussed in Appendix A.

Swept-area abundance, biomass and size composition data from the 2017 NMFS EBS Bottom Trawl Survey were added to the assessment. Survey results for the assessment were calculated directly from the survey "crab haul" data files and station strata file to incorporate assessment criteria (e.g., excluding crab $<25 \mathrm{~mm}$ CW, aggregating crab > 185 mm CW into the upper-most size bin in size compositions) and
facilitate comparisons across multiple areas and population categories. More details are provided in Appendices B and C.

For the first time, molt increment data from growth studies conducted in the EBS as cooperative research by NMFS and BSFRF are fit in a number of the model scenarios included in this assessment. These data are examined in more detail in Appendix D.

The following table summarizes data sources that have been updated for this assessment:

| Data source | Data types | Time frame | Notes | Agency |
| :---: | :---: | :---: | :---: | :---: |
| NMFS EBS Bottom Trawl Survey | area-swept abundance, biomass size compositions | 1975-2017 | recalculated, new | NMFS |
| NMFS/BSFRF | molt-increment data | 2014-16 | new | NMFS, BSFRF |
| Directed fishery | retained catch (numbers, biomass) retained catch size compositions effort <br> total catch (abundance, biomass) <br> total catch size compositions | $\begin{aligned} & 2005 / 06-2016 / 17 \\ & 2013 / 14-2015 / 16 \\ & 2015 / 16,2016 / 17 \\ & 2015 / 16,2016 / 17 \\ & 2015 / 16,2016 / 17 \\ & \hline \end{aligned}$ | updated, new updated updated, new updated, new updated, new | ADFG <br> ADFG <br> ADFG <br> ADFG <br> ADFG |
| Snow Crab Fishery | effort <br> total bycatch (abundance, biomass) <br> total bycatch size compositions | $\begin{gathered} 1990 / 91-2013 / 14 \\ 1990 / 91-2016 / 17 \\ 2016 / 17 \\ \hline \end{gathered}$ | updated, new updated, new new | $\begin{aligned} & \mathrm{ADFG} \\ & \mathrm{ADFG} \\ & \mathrm{ADFG} \end{aligned}$ |
| Bristol Bay <br> Red King Crab Fishery | effort <br> total bycatch (abundance, biomass) <br> total bycatch size compositions | $\begin{gathered} \hline 1990 / 91-2013 / 14 \\ 1990 / 91-2016 / 17 \\ 2016 / 17 \\ \hline \end{gathered}$ | updated, new <br> updated, new <br> new | $\begin{aligned} & \mathrm{ADFG} \\ & \mathrm{ADFG} \\ & \mathrm{ADFG} \end{aligned}$ |
| Groundfish Fisheries <br> (all gear types) | total bycatch (abundance, biomass) <br> total bycatch size compositions | $\begin{aligned} & 1991 / 92-2016 / 17 \\ & 1991 / 92-2016 / 17 \\ & \hline \end{aligned}$ | updated, new updated, new | NMFS/AKFIN |
| Groundfish Fixed-Gear Fisheries | total bycatch (abundance, biomass) total bycatch size compositions | $\begin{aligned} & 1991 / 92--2016 / 17 \\ & \text { 1991/92--2016/17 } \end{aligned}$ | new <br> new | NMFS/AKFIN |
| Groundfish Trawl <br> Fisheries | total bycatch (abundance, biomass) total bycatch size compositions | $\begin{aligned} & \text { 1991/92--2016/17 } \\ & \text { 1991/92--2016/17 } \end{aligned}$ | new <br> new | NMFS/AKFIN |

The following table summarizes the data coverage in the assessment model (color shading highlights different model time periods and data components):


## 2. Data presented as time series

For the data presented in this document, the convention is that 'year' refers to the year in which the NMFS bottom trawl survey was conducted (nominally July 1, yyyy), and fishery data are those subsequent to the survey (July 1, yyyy to June 30, yyyy+1)--e.g., 2015/16 indicates the 2015 bottom trawl survey and the winter 2015/16 fishery.

## a. Total catch

Retained catch in the directed fisheries for Tanner crab conducted by the foreign fisheries (Japan and Russia) and the domestic fleet, starting in 1965/66, is presented in Table 1 and Figure 2 by fishery year. More detailed information on retained catch in the directed domestic pot fishery is provided in Table 2, which lists total annual catches in numbers of crab and biomass (in lbs), as well as the SOA's Guideline Harvest Level (GHL) or Total Allowable Catch (TAC) , number of vessels participating in the directed fishery, and the fishery season. Information from the Community Development Quota (CDQ) is included in the totals starting in 2005/06.

Directed fisheries for Tanner crab in the EBS began in 1965. Retained catch has followed a "boom-andbust" cycle over the years, with the fishery experiencing periods of rapidly increasing catches followed by rapidly declining ones, after which it is closed for a time during which the stock partially recovers. Retained catch increased rapidly from 1965 to 1975, reaching $\sim 25,000 \mathrm{t}$ in 1970. It declined to $\sim 13,000 \mathrm{t}$ in 1973/74 coinciding with the termination of Russian fishing and the beginning of the domestic pot fishery. It increased again, this time to its highest level, in 1977/78 ( $\sim 35,000 \mathrm{t}$ ) as the domestic fishery developed rapidly, but it subsequently declined again and the fishery was closed in 1985/86 and 1986/87. In the late 1980s and early 1990s, the fishery experienced another, somewhat smaller, "boom" followed by a "bust" and closure of the fishery from 1997/98 to 2004/05. From 2005/06 to 2009/10, the fishery experienced its smallest boom-and-bust cycle, peaking at only $\sim 1,000 \mathrm{t}$ retained catch, and was closed again from 2010/11 to 2012/13. The fishery was re-opened in 2013/14, and retained catch increased each subsequent year until 2016/17 as TACs increased (Figures 2 and 6). The retained catch for 2015/16 (8,910 t) was the largest since 1992/1993 ( 15,920 t; Table 1). However, the TAC for both directed fisheries was set at 0, and both fisheries closed for the year, by ADFG prior to the start of the 2016/17 fishing season because mature female biomass in the 2016 NMFS EBS bottom trawl survey did not meet the SOA's criteria for opening the fisheries.

## b. Information on bycatch and discards

Annual bycatch (discards) of Tanner crab are provided in Tables 3 and 4 and Figures 3-5 based on ADFG crab observer sampling, starting in 1992/93 for the directed Tanner crab fishery, the snow crab fishery, and the BBRKC fishery. Annual discards for the groundfish fisheries, based on NMFS groundfish observer programs, are also provided starting in 1973/74, but sex is undifferentiated. A value of 0.321 is used for "handling mortality" in the crab fisheries to convert observed bycatch to (unobserved) mortality (Stockhausen, 2014). For the groundfish fisheries, values of $0.5,0.8$, and 0.8 for handling mortality are used to reflect differences in gear effects and on-deck operations compared with the crab fleets for fixed gear fleets, trawl gear fleets, and aggregated gear fleets, respectively.

Estimated bycatch mortality in the groundfish fisheries (without distinguishing gear type) was highest ( $\sim 15,000 \mathrm{t}$ ) in the early 1970s, but was substantially reduced by1977 to $\sim 2,000 \mathrm{t}$ with the curtailment of foreign fishing fleets. It declined further in the 1980s (to $\sim 500 \mathrm{t}$ ) but increased somewhat in the late 1980s to a peak of $\sim 2,000 \mathrm{t}$ in the early 1990s before undergoing a slow but rather steady decline to the present ( 255 t in 2016/17). Since reliable at-sea ADFG crab observer data has been available (1992), the snow crab fishery has consistently accounted for the highest fraction of bycatch mortality among the crab fisheries, followed by the directed fishery and the BBRKC fishery (Table 4, Figure 4). Estimated bycatch mortality was highest for all crab fisheries in the early 1990s ( $\sim 12,000 t$ total) but subsequently declined as (presumably) the stock declined and the directed fishery was curtailed. Since the directed fishery re-
opened in 2013/14, bycatch mortality has averaged 325 t in the directed fishery, 554 t in the snow crab fishery, 32 t in the BBRKC fishery, and 309 t in the groundfish fisheries.

In the crab fisheries, the largest component of bycatch occurs on males. In the early 1990s, female bycatch ranged between 6 and $40 \%$ of the bycatch in the directed and snow crab fisheries. Since the directed fishery re-opened in 2013/14, the fraction of bycatch that is female has ranged between $2 \%$ and $6 \%$ in the directed fishery, between 0.3 and $3 \%$ in the BBRKC fishery, and has been below $1 \%$ in the snow crab fishery. Estimates of total groundfish bycatch are not currently available by sex.
c. Catch-at-size for fisheries, bycatch, and discards

Retained (male) catch-at-size in the directed Tanner crab fishery from ADFG crab observer sampling is presented in Figure 6 by fishery region (and total) for the two most recent periods the fishery was open (spanning 2005/06-2015/16). These appear to indicate a shift to retaining somewhat smaller minimum sizes since 2013/14, compared with 2005/06-2009/10. In fact, the BOF in 2014/15, in response to a petition by industry, changed its harvest strategy for calculating TACs to reflect a smaller minimum industry-preferred size of 125 mm CW east of 166W longitude.

Size compositions expanded to total catch (retained + discards) from at-sea crab fishery observer sampling in the directed fishery are presented by shell condition and fishery region in Figure 7 for male crab and in Figure 8 for female crab. The male size compositions suggest that about half the males caught in the directed fishery in 2015/16 were less than the minimum preferred size of 125 mm CW. If old shell males really are males at least one year past their terminal molt (as assumed in the assessment model), the size compositions for these crab suggest that $30-50 \%$ of these crab (which will not grow) are less than the preferred size.

Size compositions expanded to total bycatch of Tanner crab in the snow crab fishery, based on at-sea crab fishery observer sampling, are presented by sex and shell condition in Figure 9. Because this fishery is prosecuted further north and west, on average, than the directed fishery, its bycatch composition consists of somewhat smaller males than in the directed fishery. Conversely, the expanded bycatch size compositions for the BBRKC fishery tend to be shifted toward somewhat larger males than the directed fisheries because the BBRKC fishery is prosecuted further to the south and east on average than the directed fishery (Figure 10). Figure 11 presents size compositions expanded to total bycatch based on observer sampling in the groundfish fisheries for 1991/92 to the present. Size compositions prior to 1991/92 have not been expanded to total bycatch; thus, the scales are incompatible with those after 1990/91. Male bycatch size compositions in the snow crab fishery clearly reflect some sort of "domeshaped" selectivity pattern (as assumed in the assessment model), with selectivity small for small and large males and highest for intermediate-sized males. In contrast, the BBRKC fishery appears to catch mostly larger Tanner crab males (consistent with asymptotic selection), while the groundfish fisheries take a wide range of sizes as bycatch.

Raw and input sample sizes (number of individuals measured) for the various fisheries are presented in Tables 5-9.

## d. Survey biomass estimates

Time series trends from the NMFS EBS bottom trawl survey suggest the Tanner crab stock in the EBS has undergone decadal-scale fluctuations (Table 10, Figure 12; see also Appendix B, Figures 1-12). Estimated biomass of mature crab in the survey time series started at its maximum (277,000 t) in 1975, decreased rapidly to a low ( $17,000 \mathrm{t}$ ) in 1986, and rebounded quickly to a smaller peak ( $157,000 \mathrm{t}$ ) in 1991. After 1991, mature survey biomass decreased again, reaching a minimum of 13,100 t in 1998. Recovery following this decline was slow and mature survey biomass did not peak again until 2008 ( $82,900 \mathrm{t}$ ), after which it has fluctuated more rapidly-decreasing within two years by almost $50 \%$ and reaching a minimum in $2010(44,600 \mathrm{t})$, followed by an increase of almost $50 \%$ to reach a peak in 2014
( $97,300 \mathrm{t}$ ). The most recent trend (2014-2017) has been a declining one (Figures 12 and 13). Trends in the male and female components of mature survey biomass, as well as legal male abundance, have primarily been in synchrony with one another (Appendix B, Figures 5, 6, 9 and 10), as have changes in the eastern and western fishery regions (east and west of $166^{\circ} \mathrm{W}$ longitude; Figures 14 and 15; Appendix B, Figures 5,6 ), although the magnitudes differ.

## e. Survey catch-at-length

Plots of survey size compositions for male crab, expanded to total abundance by shell condition and fishery region, in Figures 16 and 17. The absence of small (new shell) crab in the eastern region since 2009 is notable, as is the progression of a possible cohort (with two size modes) through the new shell size classes in both regions starting in 2009 that starts to show up, but much reduced in amplitude, in the old shell crab size comps in 2014. Plots of survey size compositions for female crab, expanded to total abundance by maturity status (based on morphometric characteristics) and fishery region, are shown in Figures 18 and 19. Similar to males, a cohort progression of immature females starting in 2009 is evident in both regions, although it is much clearer in the eastern region. It can also be tracked into the mature female size comps starting in 2013. A potential new cohort is also evident in the size comps for both sexes in the western region, but not the eastern region, in 2017.

Observed sample sizes for the size compositions, aggregated to the EBS regional level used in the assessment, are presented in Table 11. Given the large number of individuals sampled, a sample size of 200 is used to fit survey size compositions in the assessment model to prevent convergence issues associated with using the actual sample sizes.
f. Other time series data.

Spatial patterns of abundance in the 1975-2017 NMFS bottom trawl surveys are mapped in Appendix C for immature males, mature males, immature females, mature females and legal males. There is some suggestion that an extensive cold pool in the middle region of the EBS shelf may act to diminish relative crab densities in this region, particularly for mature males (e.g., Appendix C: compare 1984, Figure 11 vs. 2016, Figure 43).

Annual effort in the snow crab and BBRKC fisheries is used in the model to "project" bycatch fishing mortality rates backward in time from the period when data on bycatch in these fisheries exists (1992present). A table of annual effort (number of potlifts) is provided for the snow crab and BBRKC fisheries (Table 12).

## 3. Data which may be aggregated over time:

a. Growth-per-molt

Sex-specific growth curves derived by Rugolo and Turnock (2010) provide the basis for priors on sexspecific growth estimated within the assessment model. Molt increment data is now available to fit in the model (see Appendix D), but it is assumed to reflect growth rates over the entire model period.

## b. Weight-at size

Weight-at-size relationships used in the assessment model for males, immature females, and mature females is depicted in Figure 21.
c. Size distribution at recruitment

The assumed size distribution for recruits to the population in the assessment model is presented in Figure 22.
4. Information on any data sources that were available, but were excluded from the assessment. The 1974 NMFS trawl survey was dropped entirely from the standardized survey dataset in 2015 due to inconsistencies in spatial coverage with the standardized dataset. Chela height data from the NMFS survey are not yet fit in the model, although a subset of the available data forms the basis for the maturity ogive used to assign a probability of maturity to male crab collected in NMFS surveys. Data collected on Tanner crab abundance and size compositions collected in BSFRF surveys are not yet incorporated in the assessment.

## E. Analytic Approach

## 1. History of modeling approaches for this stock

Prior to the 2012 stock assessment, Tanner crab was managed as a Tier-4 stock using a survey-based assessment approach (Rugolo and Turnock 2011b). The Tier 3 Tanner Crab Stock Assessment Model (TCSAM) was developed by Rugolo and Turnock and presented for review in February 2011 to the Crab Modeling Workshop (Martel and Stram 2011), to the SSC in March 2011, to the CPT in May 2011, and to the CPT and SSC in September 2011. The model was revised after May 2011 and the report to the CPT in September 2011 (Rugolo and Turnock 2011a) described the developments in the model per recommendations of the CPT, SSC and Crab Modeling Workshop through September 2011. In January 2012, the TCSAM was reviewed at a second Crab Modeling Workshop. Model revisions were made during the Workshop based on consensus recommendations. The model resulting from the Workshop was presented to the SSC in January 2012. Recommendations from the January 2012 Workshop and the SSC, as well as the authors' research plans, guided changes to the model. A model incorporating all revisions recommended by the CPT, the SSC and both Crab Modeling Workshops was presented to the SSC in March 2012.

In May 2012 and June 2012, respectively, the TCSAM was presented to the CPT and SSC to determine its suitability for stock assessment and the rebuilding analysis (Rugolo and Turnock 2012b). The CPT agreed that the model could be accepted for management of the stock in the 2011/12 cycle, and that the stock should be promoted to Tier-3 status. The CPT also agreed that the TCSAM could be used as the basis for rebuilding analyses to underlie a rebuilding plan developed in 2012. In June 2012, the SSC reviewed the model and accepted the recommendations of the CPT. The Council subsequently approved the SSC recommendations in June 2012. For 2011/12, the Tanner crab was assessed as a Tier-3 stock and the model was used for the first time to estimate status determination criteria and overfishing levels.

Modifications have been made to the TCSAM computer code to improve code readability, computational speed, model output, and user friendliness without altering its underlying dynamics and overall framework. A detailed description of the 2013 model (TCSAM2013) is presented in Appendix 3 of the 2014 SAFE chapter (Stockhausen, 2014). Following the 2014 assessment, the model code was put under version control using "git" software and is publicly available for download from the GitHub website ${ }^{2}$.

A new model "framework", TCSAM02, has been under development for the past two years. In May 2017, the CPT reviewed this framework and recommended its use in this assessment. At its June 2017 meeting, the SSC concurred. The new framework is a completely-rewritten basis for the Tanner crab model: substantially different model scenarios can be created and run by editing model configuration files rather than modifying the underlying code itself. Most importantly, no time blocks are "hard-wired" into the code-any time blocks are defined in the configuration files. In addition, the new frame work can incorporate new data types (e.g., molt increment data), new survey data (e.g., the BSFRF surveys), and new fishery data (e.g., bycatch in the groundfish fisheries by gear type). The new model framework also incorporates status determination and OFL calculation directly within a model run, so a follow-on, stand-
${ }^{2}$ https://github.com/wStockhausen/wtsTCSAM2013.git
alone projection model does not need to be run, as with TCSAM2013. This approach has the added benefit of allowing a more complete characterization of model uncertainty in the OFL calculation, because the OFL calculations can now be included in Markov Chain Monte Carlo (MCMC) evaluation of a model's posterior probability distribution. Although TCSAM02 is a new model framework, it was demonstrated at the May 2017 CPT meeting that it could exactly reproduce an "exactly equivalent" model developed using the old TCSAM2013 model code. This "exactly equivalent" model, while not identical to the 2016 assessment model, provides the base model (B0) for this assessment.

The code for the TCSAM02 model framework is publicly available on GitHub ${ }^{3}$.

## 2. Model Description

a. Overall modeling approach

TCSAM02 is a stage/size-based population dynamics model that incorporates sex (male, female), shell condition (new shell, old shell), and maturity (immature, mature) as different categories into which the overall stock is divided on a size-specific basis. For details of the model, the reader is referred to Appendix E.

In brief, crab enter the modeled population as recruits following the size distribution in Figure 22. An equal ( $50: 50$ ) sex ratio is assumed at recruitment, and all recruits begin as immature, new shell crab. Within a model year, new shell, immature recruits are added to the population numbers-at-sex/shell condition/maturity state/size remaining on July 1 from the previous year. These are then projected forward to Feb. 15 ( $\delta t=0.625 \mathrm{yr}$ ) and reduced for the interim effects of natural mortality. Subsequently, the various fisheries that either target Tanner crab or catch them as bycatch are prosecuted as pulse fisheries (i.e., instantaneously). Catch by sex/shell condition/maturity state/size in the directed Tanner crab, snow crab, BBRKC, and groundfish fisheries is calculated based on fishery-specific stage/sizebased selectivity curves and fully-selected fishing mortalities and removed from the population. The numbers of surviving immature, new shell crab that will molt to maturity are then calculated based on sex/size-specific probabilities of maturing, and growth (via molt) is calculated for all surviving new shell crab. Crab that were new shell, mature crab become old shell, mature crab (i.e., they don't molt) and old shell crab remain old shell. Population numbers are then adjusted for the effects of maturation, growth, and change in shell condition. Finally, population numbers are reduced for the effects of natural mortality operating from Feb. 15 to July 1 ( $\delta t=0.375$ yr) to calculate the population numbers (prior to recruitment) on July 1.

Model parameters are estimated using a maximum likelihood approach, with Bayesian-like priors on some parameters and penalties for smoothness and regularity on others. Data components in the base model entering the likelihood include fits to mature survey biomass, survey size compositions, retained catch, retained catch size compositions, bycatch mortality in the bycatch fisheries, and bycatch size compositions in the bycatch fisheries.

## b. Changes since the previous assessment.

As noted above, this assessment uses the TCSAM02 model framework, a completely re-written basis for the Tanner crab assessment. Substantive changes from the 2016 TCSAM2013 assessment model to the base model addressed here (with 2016 data: B0.2016) were fully documented in a set of incrementalchange models in the May 2017 report to the CPT (Stockhausen, 2017). These are summarized here briefly in the following table:

[^5]| TCSAM2013 <br> Model | Incremental change |
| :---: | :--- |
| AM | 2016 assessment model |
| AMa | AM + removed size-specific "old shell" re-classification for input data |
| AMb | AMa + fit to total capture (not mortality) size compositions |
| AMc | AMb + fit to total capture (not mortality) biomass |
| AMd | AMc + apply seasonal M after molt-to-maturity |
| B0 | same as AMd |
| B1 | B0 + fit to input survey biomass based on 1-mm size bins |
| B2 | B1 + using 2.20462262 to convert from kg to lbs |
| B3 | B2 + capture rates in RKF not explicitly set to 0 for 1984,1985 and 1994, 1995 |
| B4 | B3 + corrected retained size comps for 2015/16 |
| B5 | B4 + using median size-at-50\% selected for TCF males pre1991 (not average) |
| B6 | B5 + using post-1972 median F for GTF before 1973 (not average) |

The TCSAM2013 model B6 was demonstrated to be "exactly equivalent" to the TCSAM02 base model for this assessment, B0, using 2016 data.

## i. Methods used to validate the code used to implement the model

The TCSAM02 model framework was demonstrated to produce results that were exactly equivalent to those from the 2016 assessment model incorporating the changes listed in the previous table. TCSAM02 also underwent a review in July 2017 conducted by the Center for Independent Experts.

## 3. Model Selection and Evaluation

## a. Description of alternative model configurations

The following tables provide a summary of the baseline model configuration, B0, for this assessment.

Model B0: Model description of population processes and survey characteristics.

| process | time blocks | description |
| :---: | :---: | :---: |
| Population rates and quantities |  |  |
| Population built from annual recruitment |  |  |
| Recruitment | 1949-1974 | In-scale mean + annual devs constrained as AR1 process |
|  | 1975-2017 | In-scale mean + annual devs |
| Growth | 1949-2016 | sex-specific |
|  |  | mean post-molt size: power function of pre-molt size priors on mean post-molt parameters from Kodiak growth data post-molt size: gamma distribution conditioned on pre-molt size |
| Maturity | 1949-2016 | sex-specific |
|  |  | size-specific probability of terminal molt |
|  |  | logit-scale parameterization |
| Natural mortalty | $\begin{aligned} & \text { 1949-1979, } 1 \\ & 1980-1984 \end{aligned}$ | estimated sex/maturity state-specific multipliers on base rate priors on multipliers based on uncertainty in max age estimated "enhanced mortality" period multipliers |
| Surveys |  |  |
| NMFS EBS trawl survey |  |  |
| male survey q | 1975-1981 | In-scale |
|  | 1982+ | In-scale w/ prior based on Somerton's underbag experiment |
| female survey $q$ | 1975-1981 | In-scale |
|  | 1982+ | In-scale w/ prior based on Somerton's underbag experiment |
| male selectivity | 1975-1981 | ascending logistic |
|  | 1982+ | ascending logistic |
| female selectivity | 1975-1981 | ascending logistic |
|  | 1982+ | ascending logistic |

Model B0: Model description of fishery characteristics.

| Fishery/process | time blocks | description |
| :--- | :--- | :--- |
| TCF | directed Tanner crab fishery |  |
| capture rates | pre-1965 | male nominal rate |
|  | $1965-2016$ | male In-scale mean + annual devs |
|  | $1949-2016$ | In-scale female offset |
| male selectivity | $1949-1990$ | ascending logistic |
|  | $1991-1996$ | annually-varying ascending logistic |
|  | $2005-2016$ | annually-varying ascending logistic |
| female selectivity | $1949-2016$ | ascending logistic |
| male retention | $1949-1990$ | ascending logistic |
|  | $1991-2016$ | ascending logistic |
|  | bycatch in snow crab fishery |  |
| SCF | pre-1978 | nominal rate on males |
| capture rates | $1979-1991$ | extrapolated from effort |
|  | $1992-2016$ | male In-scale mean + annual devs |
|  | $1949-2016$ | In-scale female offset |
| male selectivity | $1949-1996$ | dome-shaped |
|  | $1997-2004$ | dome-shaped |
|  | $2005-2016$ | dome-shaped |
| female selectivity | $1949-1996$ | ascending logistic |
|  | $1997-2004$ | ascending logistic |
|  | $2005-2016$ | ascending logistic |

The following alternative model scenarios were evaluated as part of this assessment:
Description of the alternative model scenarios evaluated for this assessment. The number of estimated parameters and the final value of the objective function for each converged model are also listed. B2b is the author's preferred model.

| model <br> scenario | number of <br> parameters | objective <br> function value | description |
| :--- | :---: | :---: | :--- |
| B0.2016 | 332 | $2,665.27$ | "fully-equivalent" model from May 2017 CPT meeting |
| B0 | 336 | $2,765.43$ | Base model for 2017 assessment (B0.2016 + 2017 data) |
| B0a | 336 | $2,763.31$ | B0 + new growth parameterization (growth data not fit) |
| B1 | 337 | $3,109.39$ | B0 + fit to EBS growth data, drop riors on growth, estimate growth scale parameter |
| B1a | 337 | $3,108.64$ | B1 + new growth parameterization |
| B1b | 337 | $3,110.35$ | B1a + new parameterization for RKF selectivity |
| B1c | 337 | $8,367.14$ | B1b + 20 x higher likelihood weight on EBS growth data |
| B2 | 350 | $2,872.42$ | B1b + annual devs on retention function z50's |
| B2a | 353 | $2,870.33$ | B2 + 3 time blocks for asymptotic retention level |
| B2b | 344 | $2,894.80$ | B2a + 3 time blocks for retention function substituted for annual devs |
| B3 | 391 | $2,381.20$ | B2b + bycatch in groundfish fisheries by gear type (1991+) |

Scenario B0.2016 is the baseline model scenario without the updated and new data for 2017. It is identical to the "exactly equivalent" model from the May 2017 CPT meeting. Scenario B0 is the baseline model with new and updated data for 2017. Scenario B0a introduces a new parameterization for mean growth to address CPT and SSC concerns with B0.2016 and previous assessments that some growth parameters ended up at one of the bounds set on them.

The "old" parameterization for mean growth estimated the asymptote (a) and slope (b) of the following log-log (or power law, on the arithmetic scale) model for post-molt size in terms of pre-molt size:

$$
\begin{equation*}
\ln \left(\bar{z}_{\text {post }}\right)=a+b \cdot \ln \left(z_{\text {pre }}\right) \tag{1}
\end{equation*}
$$

Note that the interpretation of $a$ here is that $e^{a}$ is the mean post-molt size for a crab of pre-molt size 1 . The "new" parameterization for mean growth estimates the mean post-molt sizes ( $\bar{z}_{\text {post }_{\text {min }}}$ and $\bar{z}_{\text {post }}^{\text {max }}$ $)$ at two pre-molt sizes $\left(z_{p r e_{m i n}}\right.$ and $\left.z_{p r e_{m a x}}\right)$ based on an alternative form for the linear (in ln-space) relationship:

The new parameters are much more easily interpreted, as would priors put on them. I chose 25 mm CW for $z_{\text {pre }}{ }_{\text {min }}$ for both sexes, and 100 and 125 mm CW for $z_{\text {pre }}$ max for females and males, respectively, so the estimated parameters are the mean post-molt sizes corresponding to the associated $z_{\text {pre }}$ 's. No priors were placed on the new parameters in scenario B0a.

Scenario B1 and subsequent scenarios included the molt-increment data from the EBS in their model fitting procedures. B1 used the "old" growth parameterization, but the priors placed on the growth parameters were removed and the scale parameter for the growth model's gamma probability distribution was estimated. Scenario B1a replaced the "old" growth parameterization with the new parameterization.

Several of the parameters estimated for the ascending logistic functions used to describe bycatch selectivity in the BBRKC fishery (denoted RKF here) also had a tendency to end up at one of the bounds placed on them in the B0 scenarios and previous assessment models. Scenario B1b introduced a new parameterization for an ascending logistic curve based on the size-at-95\%-selected ( $z_{95}$ ) and the ln-scale interval between the sizes at $50 \%$-selected and $95 \%$-selected $\left(\ln \left(\Delta z_{95-50}\right)\right)$, rather than the more common size-at- $50 \%$-selected and scale parameter, to try to eliminate this behavior.

In scenarios B1, B1a and B1b, the EBS molt-increment data was added to the model objective function using a log-likelihood function appropriate for a gamma distribution without any additional weighting (i.e., a likelihood weight of 1 ). However, it is unclear whether or not this is an appropriate weight for this data vis-à-vis other components contributing to the objective function. To explore the implications of increasing the weight placed on the molt-increment data in fitting the model, scenario B1c increased the weight on the molt-increment data in the likelihood by a factor of 20 (essentially decreasing variances by a factor of 4.5). As discussed below, this model performed unsatisfactorily and subsequent scenarios (B2, B2a, B2b and B3) kept the weight on the molt-increment data in the likelihood at 1.

Scenario B2 was based on scenario B1b, but allowed the value of the size-at-50\% retention for males in the directed fishery to vary annually during the 1991/92-2015/16 time period. Scenario B2a built on B2 by estimating parameters reflecting the maximum fraction of crab retained in the directed fishery in three time periods: 1) 1965/66-1996/97, 2) 2005/06-2009/10, and 3) 2013/14-2015/16. The latter two time blocks reflect potentially different fleet composition and fishing practices following fishery closures (1997/98-2004/05, 2010/11-2012/13) and rationalization of the fishery (2005). Scenario B2b attempted to reduce the number of parameters used to model retention in the directed fishery by replacing the annual deviations in size-at-50\%-retention from 1991/92 to 2015/16 with the three time blocks associated with the maximum retention parameters (1965/66-1996/97, 2005/06-2009/10, and 2013/14-2015/16) for the same reasons.

Finally, scenario B3, otherwise based on B2b, decomposed the bycatch in the groundfish fisheries after 1990/91 into fixed gear and trawl gear components to try to better resolve handling mortality on discarded Tanner crab in these fisheries. In prior scenarios, bycatch in the groundfish fisheries was aggregated across gear types and a handling mortality rate appropriate to trawl gear (80\%) was assumed to apply to the total. In B3, bycatch in the fixed gear fleets was separated from that in the trawl gear fleets and a separate handling mortality rate (equal to the handling mortality rate for crab pot gear, $32.1 \%$ ) was assumed to apply. Separate sex-specific selectivity functions were estimated in two time blocks (1991/921996/97 and 1997/98-2016/17) for each gear type. Ascending logistic functions were used for all six fixed gear selectivity functions, as well as the three trawl gear selectivities applied to females. Dome-shaped double-logistic functions were fit to the three trawl gear selectivity functions applied to males.
b. Progression of results from the previous assessment to the preferred base model

The following table summarizes basic model results from the 2016 assessment model (2016AM) and the 11 scenarios considered here:

| model <br> scenario | number of parameters | objective function | average recruitment millions | Final MMB 1000's t | B0 1000's t | Bmsy 1000's t | Fmsy | MSY 1000's t | Fofl | $\begin{gathered} \text { OFL } \\ \text { 1000's t } \end{gathered}$ | projected MMB <br> 1000's t | projected <br> MMB / <br> Bmsy | projected MMB / Final MMB |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2016AM | 341 | 2,406.75 | 182.27 | 73.90 | 73.29 | 25.65 | 0.79 | 11.13 | 0.79 | 25.61 | 45.34 | 1.77 | 0.61 |
| B02016 | 332 | 2,665.27 | 175.94 | 85.19 | 75.83 | 26.54 | 0.93 | 11.21 | 0.93 | 27.38 | 45.47 | 1.71 | 0.53 |
| B0 | 336 | 2,765.43 | 174.64 | 68.57 | 76.90 | 26.91 | 0.92 | 11.21 | 0.92 | 21.87 | 36.88 | 1.37 | 0.54 |
| B0a | 336 | 2,763.31 | 172.24 | 66.92 | 75.27 | 26.35 | 0.93 | 11.10 | 0.93 | 21.40 | 35.82 | 1.36 | 0.54 |
| B1 | 337 | 3,109.39 | 194.58 | 74.26 | 79.67 | 27.89 | 0.94 | 11.48 | 0.94 | 24.02 | 39.72 | 1.42 | 0.53 |
| B1a | 337 | 3,108.64 | 194.80 | 73.82 | 79.22 | 27.73 | 0.94 | 11.46 | 0.94 | 23.90 | 39.40 | 1.42 | 0.53 |
| B1b | 337 | 3,110.35 | 195.26 | 73.83 | 79.14 | 27.70 | 0.95 | 11.47 | 0.95 | 23.95 | 39.35 | 1.42 | 0.53 |
| B1c | 337 | 8,367.14 | 270.31 | 98.70 | 91.09 | 31.88 | 1.21 | 13.08 | 1.21 | 35.57 | 49.19 | 1.54 | 0.50 |
| B2 | 350 | 2,872.42 | 198.97 | 74.51 | 80.14 | 28.05 | 0.74 | 11.58 | 0.74 | 23.20 | 40.59 | 1.45 | 0.54 |
| B2a | 353 | 2,870.33 | 208.35 | 78.73 | 82.38 | 28.83 | 0.75 | 12.03 | 0.75 | 24.74 | 42.57 | 1.48 | 0.54 |
| B2b | 344 | 2,894.80 | 213.95 | 80.57 | 83.34 | 29.17 | 0.75 | 12.25 | 0.75 | 25.42 | 43.31 | 1.49 | 0.54 |
| B3 | 391 | 2,381.20 | 263.90 | 87.47 | 88.82 | 31.09 | 0.89 | 13.40 | 0.89 | 29.76 | 44.67 | 1.44 | 0.51 |

The author's preferred model, B2b, is highlighted for reference. The number of estimated parameters reported in the table is larger for the 2016 assessment model than B02016 because the final "dev" in a TCSAM02 devs vector is not counted as an estimable parameter (the vector is constrained to sum to 0 ) whereas it was counted in the 2016 assessment model based on TCSAM2013.

All new model scenarios were evaluated using 200 runs with jittered initial parameter values to select the run with the smallest objective function value and smallest maximum gradient. For each model, the selected run was re-run to invert the hessian and obtain standard deviations for parameter estimates. All models resulted in hessians that were invertible and provided uncertainty estimates associated with the parameter estimates.

Results of the progression from the 2016 assessment model to the base model here using the 2016 data, B0.2016, were presented and discussed at the May 2017 CPT meeting (Stockhausen, 2017). Results from the model progression from B0.2016 to B3 are presented in Appendix F.

## c. Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models.

The characteristics of retention of male crab in the directed fishery in the base model, B0, were assumed to be different before and after 1991, primarily reflecting changes in fleet composition and effort, and parameters describing two independent logistic functions were estimated for those time periods. Model B2 allowed potentially-annual changes in the retention curve after 1991 by estimating annual deviations in the size-at-50\%-retained. Because B2 was possibly over-parameterized, model B2b eliminated the annual deviations and instead estimated parameters for independent retention functions in three time blocks across 1991-present (1991-1996, 2005-2009, 2013-2015).

## d. Convergence status and convergence criteria

Convergence in all models was assessed by running each model at least 200 times with randomly-selected ("jittered") initial parameter values for each run. For each model, a number of these jitter runs failed, primarily because the initial values for the growth parameters resulted in the mean post-molt size being smaller than the pre-molt size. Of those that converged, the run with the smallest objective function value and smallest maximum gradient was selected as the "converged" model, if it was also possible to invert the associated hessian and obtain standard deviation estimates for parameter values. Theoretically, all gradients at a minimum of the objective function would be zero. However, because numerical methods have finite precision, the numerical search for the minimum is terminated after achieving a minimum threshold for the max gradient or exceeding the maximum number of iterations. Typically, 5-10 jittered runs converged to the same minimum value, but sets of runs also converged to larger valuesemphasizing the need to jitter to evaluate convergence to the minimum objective function value in the first place.

## e. Sample sizes assumed for the compositional data

Input sample sizes used for compositional data are listed in Tables 5-9 for fishery-related size compositions. Input sample sizes for all survey size compositions were set to 200, which was also the maximum allowed for the fishery-related sample sizes. Otherwise, input sample sizes were scaled as described in Stockhausen (2014, Appendix 5):

$$
S S_{y}^{i n p}=\min \left(200, \frac{S S_{y}}{(\overline{S S} / 200)}\right)
$$

where $\overline{S S}$ was the mean sample size for all males from dockside sampling in the directed fishery.

## f. Parameter sensibility

Limits were placed on all estimated parameters in all model scenarios primarily to provide ranges for jittering initial parameter values. Although these limits, for the most part, did not constrain parameter estimates in the converged models, some parameters were found to be at, or very close, to one of the bounds placed on them. These parameters are listed for the alternative scenarios in Tables 13 and 14 (values for all parameters are listed in Tables 15-24). The CPT and SSC have both expressed concerns regarding parameters estimated at their bounds, as such results frequently violate assumptions regarding model convergence, parameter uncertainty estimates, and suggest that model suitability may be improved by widening the bounds or re-parameterizing the model.

Models B3 and B1c had the most parameters at a bound (19 and 13, respectively), while B2 had the least (9)(Tables 13 and 14). The author's preferred model, B2b, had 11, but the two parameters that differed from B2 in this regard were the logit-scale probability of terminal model in the largest size class (the parameters for both models essentially yielded a probability of 1 ; Table 17) and the descending slope of the dome-shaped bycatch selectivity for males in the snow crab fishery ( $\mathrm{pS4} 41]$; Table ).

In Table 13, the logit-scale parameters pLgtRet[1], pLgtPrM2M[1], and pLgtPrM2M[2] are estimated at one of the bounds placed on them. For these parameters, being at the upper bound (15) suggests the parameter could be replaced by 1 on the arithmetic scale without affecting the remaining parameters whereas those that are at the lower bound ( -15 ) could be replaced by 0 on the arithmetic scale. The result would be, for the model scenarios concerned, assuming max retention prior to 1997 is $100 \%$ (i.e., 1 ; pLgtRet[1]), the probability of terminal molt for males in the largest model size class ( $180+\mathrm{mm}$ CW) is $100 \%$ (pLgtPrM2M[1]), and the probability of terminal molt for females in the smallest size class (25-30 mm CW ) is 0 (pLgtPrM2M[2]).

That the growth parameters (pGrA, pGrB, and pGrBeta) are estimated at their bounds in some scenarios is somewhat concerning, but the problems with pGrA and pGrB have been dealt with by re-parameterizing mean post-molt size as a function of pre-molt size from Equation 1 (scenarios B0.2016, B0, B1) above to Equation 2 (scenarios B0a, B1a, and subsequent ones). Of more concern is that $\mathrm{pLnQ}[1]$ and $\mathrm{pLnQ}[2]$, the ln -scale parameters for survey catchability for both males and females in the pre-1982 period, are estimated at the lower bound in all scenarios considered here. The lower limit corresponds to a survey " q " of 0.5 , and the models all want go lower, but this is likely to result in increased population abundance/biomass estimates in the pre-1982 period.

A number of selectivity parameters are also estimated at, or very close to, one of the bounds placed on them (Table 14). Most selectivity functions in all scenarios were ascending logistic functions, which would be expected to increase from near 0 at small crab sizes to 1 at large crab sizes. Upper limits on size-related selectivity parameters for female crab reflect the fact that they attain smaller final sizes than males, so their associated selectivity functions should asymptote at smaller sizes. In general, bounds on selectivity parameters were selected to reflect these characteristics. That parameters associated with sizes
at 50\%-selected or 95\%-selected (pS[1], pS1[22], pS1[23], pS1[24], pS1[25], pS1[26], pS1[27], pS1[33], $\mathrm{pS} 2[1], \mathrm{pS} 2[2], \mathrm{pS} 2[4]$ ) end up at their upper bounds suggests that the associated fully-selected fishery capture rate or survey catchability may be confounded with value for selectivity in the largest size bin. This is certainly the case for bycatch selectivity for females in the BBRKC fishery. It also appears that the re-parameterization of bycatch selectivity for the BBRKC fishery from size-at-50-\%-selected ( $z_{50}$ ) and slope to size-at-95\%-selected ( $z_{95}$ ) and increment from $z_{50}$ to $Z_{95}$ rarely succeeded in moving the estimated parameters away from the bounds.

Estimates of parameter uncertainty, approximations calculated by inverting the model hessian and using the "delta" method, were obtained from each converged model's ADMB "std" file (Tables 15-24). Extremely large uncertainties were obtained for parameters related to the NMFS trawl survey selectivity for females after 1981 for scenario B0a (Table 27) and the slope of bycatch selectivity for females in the groundfish trawl gear fleet during 1991-1996 for scenario B3 (Table 24).
g. Criteria used to evaluate the model or to choose among alternative models

Criteria used to evaluate the alternative models were based primarily on: 1) goodness of fit and likelihood criteria, 2) parameter sensibility, and 3) biological realism.

The author's preferred model, B2b, fits the EBS growth data and has reasonable parameter estimates. It is more parsimonious than models B2 and B2a, using fewer parameters to model time-varying retention in the directed fishery.

## h. Residual analysis

Residuals for the author's preferred model, Model B2b, are discussed below under the Results section.

## i. Evaluation of the model(s)

Of the models evaluated with data for 2017, B0 provided a link to the "exactly equivalent" TCSAM02 model presented at the May 2017 CPT meeting (B0.2016 here). Model B0a tested a new parameterization of mean growth designed to eliminate estimated growth parameters constrained by their bounds (it did). Model B1 introduced fitting molt-increment data for the EBS for the first time, but used the "old" growth parameterization of B0 for consistency with that scenario-with the continued result of growth parameters hitting their bounds. Model B1a used the new parameterization of mean growth and again eliminated the problem with growth parameters estimated at their bounds. By incorporating the growth data and removing the issue with some estimated parameters hitting one of their bounds, B1a became the de facto "model to beat". Model B1b was an attempt to eliminate additional parameters hitting their bounds by introducing re-parameterized logistic selectivity functions for bycatch in the BBRKC fishery. Although these changes proved unsuccessful, B1b was essentially identical to B1a and formed the basis for scenario B2. Scenario B1c was an unsuccessful attempt to put more emphasis on fitting the growth data in the model-the large weight placed on the growth data forced a number of parameters to one of their bounds and resulted in generally poorer fits to other data components (NMFS trawl survey size compositions for immature crab being the exceptions; Tables 25 and 26). Scenario B2 introduced annually-varying retention curves which, not surprisingly, improved the fit to retained catch size compositions dramatically over scenario B1b (187 likelihood units) but also improved fits to retained catch biomass ( 30 likelihood units), total catch biomass of both males and females in the directed fishery ( 36 likelihood units), and total catch size compositions for males in the directed fishery (Tables 25 and 26). Scenario B2a allowed maximum retention to be less than 1, and estimated logit-scale parameters reflecting this for three different time periods. This improved fits to retained catch biomass and size compositions (12 likelihood units) and size compositions for immature males in the NMFS trawl survey (8 likelihood units), but degraded the fit to total catch biomass of females in the directed fishery (27 likelihood units). Scenario B2b attempted to simplify B2a by reducing the allowed variability in the retention function for the directed fishery from annual changes in size-at-50\%-retained to changes
between three time blocks coinciding with changes in the directed fishery. This resulted in an improved fit to the retained catch size compositions over B2a (9 likelihood units), but worse fits to retained catch biomass, female total catch biomass in the directed fishery, and total catch size compositions for males in the directed fishery ( 25 likelihood units). Scenario B3 disaggregated bycatch in the groundfish fisheries by gear type after 1990/91 to try to disentangle potential changes in bycatch selectivity in the groundfish fisheries due to changes in the relative amount of Tanner crab taken by the trawl- and fixed-gear fleets. B3 was not really successful, resulting in the largest number of parameters at bounds among the 11 model scenarios.

## 4. Results (best model(s))

Model B2b was selected as the author's preferred model for the 2017 assessment.
a. List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties.
Input and effective sample sizes for size composition data fit in the model are listed in Tables 27-32 from the 2016 assessment model and Model B2b. A weighting factor of 20 (corresponding to a standard deviation of 0.158 ) was applied to all fishery catch biomass likelihood components to achieve close fits to catch biomass time series.

## b. Tables of estimates:

## i. All parameters

Parameter estimates and associated standard errors, based on inversion of the converged model's Hessian, are listed in Tables 15-24.
ii. Abundance and biomass time series, including spawning biomass and MMB. Estimates for mature survey biomass, by sex, are listed in Table 33 and for mature biomass at mating, by sex, in Table 34 for the 2016 assessment model and the author's preferred model, B2b. Numbers at size for females and males are given by year in 5 mm CW size bins for scenario B2b in Tables 35 and 36, respectively.

## iii. Recruitment time series

The estimated recruitment time series from the 2016 assessment and Model B2b are listed in Table 37.
iv. Time series of catch divided by biomass.

A comparison of catch divided by biomass (i.e., exploitation rate) from the 2016 assessment and Model B2b is listed in Table 34.

## c. Graphs of estimates

Direct comparisons between the 2016 assessment model and scenario B2b are not available because the 2016 assessment model results files are incompatible with the R packages developed to plot TCSAM02 model results. Instead, comparisons between B0.2016, the "exactly equivalent" model and B2b are provided (along with results from the other scenarios) in Appendix F. However, results from B0.2016, although very similar in most respects, are not identical to the 2016 assessment model results.
i. Fishery and survey selectivities, molting probabilities, and other schedules depending on parameter estimates.
Estimated natural mortality rates are shown in Figure F1 (i.e., Appendix F, Figure 1). Mortality rates are assumed equal by sex for immature crab, but are allowed to differ by sex for mature crab. Mortality rates for mature crab were estimated by sex across two time periods: 1949-1979/80+1985/86-2016/17 and 1980/81-1984/85. The latter period has been identified as a period of high natural mortality in the BBRKC stock (Zheng et al., 2012) and was identified as a separate period for Tanner crab in the 2012
assessment. The following table summarizes the estimated rates by stock component for B0.2016 and B2b:

| Stock component | Normal period |  | High Mortality |  |
| :--- | :--- | :--- | :--- | :--- |
|  | B0.2016 | B2b | B0.2016 | B2b |
| immature crab | 0.23 | 0.23 | 0.23 | 0.23 |
| mature females | 0.33 | 0.32 | 0.46 | 0.42 |
| mature males | 0.26 | 0.26 | 0.72 | 0.69 |

Estimated sex- and size-specific probabilities of the terminal molt-to-maturity (Figure F2) are quite similar for all the models, with the exceptions that the curves are right-shifted to larger sizes in scenarios B1c and B3.

Mean growth curves from scenarios B0.2016 and B2b are nearly identical for males and very similar for females, although B2b estimates slightly smaller growth increments at large sizes relative to B0.2016 (Figure F3). A similar result holds for the distribution of post-molt sizes conditioned on pre-molt size (Figures F4-F11). Mean growth curves in both scenarios appear to overestimate the molt increment at the largest pre-molt size in both the EBS data (fit in B2b, Figures F13-F15) and the Kodiak data (Figures F6F18) for males, and to a lesser extent for females.

Estimated catchability in the NMFS trawl survey (Figure F169) is smaller in B2b in the standardized net period (1982+) for both males and females ( 0.64 and 0.40 , respectively) than in B0.2016 ( 0.72 and 0.50 ). The associated selectivity curves estimated in the two scenarios are quite similar, although female selectivity post-1981 is slightly higher at small sizes in B2b compared with B0.2016, while the opposite true for males Figure F170).

## iii. Estimated full selection F over time

Estimated time series of fully-selected F (capture rates, not mortality) on males in the directed fishery and bycatch in the snow crab, BBRKC and groundfish fisheries are compared among the model scenarios in Figures F171-F176. Rates for the directed fishery (Figure 174) are generally similar between B0.2016 and B2b, except during the period 1978/79-1979/80, when they are substantially higher in B0. 2016 (Figure F158). For the bycatch fisheries, F's tend to be slightly higher across the model time period for B0.2016 compared with B2b (Figures F171-173).
ii. Estimated male, female, mature male, total and effective mature biomass time series Time series of recruitment estimates from the model scenarios evaluated here are illustrated in Figure F213-F216. The time series for scenarios B0.2016 and B2b are quite similar in trend and timing of fluctuations, but B2b tends to estimate somewhat higher peaks than B0.2016. B2b estimates a large spike in recruitment occurred this last year.

As with recruitment, estimates of population abundance time series from B0.2016 and B2b exhibit very similar patterns of variability, although B2b tends to be slightly higher than B0.2016 in almost all years (Figures F221-224).

As with population abundance, estimates of mature biomass time series from the B0.2016 and B2b also exhibit similar patterns of variability (Figures 217-220), being basically smoothed versions of the population abundance trajectories.
iv. Estimated fishing mortality versus estimated spawning stock biomass

See Section F (Calculation of the OFL; Figure 27).
v. Fit of a stock-recruitment relationship, if feasible.

Not available.

## e. Evaluation of the fit to the data:

i. Graphs of the fits to observed and model-predicted catches

Model fit to retained catch is shown in Figures F31-F32 for all scenarios. The fits are generally very good, but B2b fits the retained catch abundance almost perfectly in recent years (Figure F31), while B0. 2016 overestimates retained catch in 2005/06-2009/10 and underestimates during 2013/14-2015/6.

Fits to total catch data from the directed fishery are also better in recent years for B2b compared with B0.2016, although the differences are fairly small (Figures F34-F35). Fits to total male bycatch data in the snow crab fishery is very good for both B0.2016 and B2b (Figures F36-F37). Fits to the BBRKC fishery male bycatch data are also good, although they look somewhat worse because the values are small relative to the assumed uncertainties. (Figures F40-F41).

Fits to female bycatch data in all the crab fisheries (Figures F34-F37, F40-F41) tend to be very good because the majority of the estimates are well within the confidence intervals assumed for the data, but this is because female bycatch levels in all the crab fisheries are much smaller than the assumed uncertainty level associated with the total catch data. When the fits are poor, it is because the observed female bycatch is larger than the uncertainty associated with it and its temporal pattern does not track that of male bycatch-in the model, the predicted female bycatch is constrained to follow the same temporal pattern as males.

Bycatch in the groundfish fisheries is not sex-specific. Fits to total bycatch mortality in the groundfish fisheries are very good both B2b and B0.2016 (Figures F38-39). Both models nicely capture the peak at the beginning of the time series, followed by the rapid decline and subsequent fluctuations. Since 2008/09, total bycatch has been less than 500 t and B2b has predicted it slightly better than B0.2016

The "goodness of fit" to the fishery catch data, as it influence the likelihoods in models, is also evident of plots of z-scores for the fishery catch data (Figures F33, F46-49). Almost all the z-scores are < 1, indicating that little improvement to the current fits in terms of absolute (rather than relative) error will occur without changing the assumed uncertainty levels for the fishery data. The two z-scores that are greater than 1 in magnitude both occur in 1994/94 for females, one in the directed fishery and the other in the snow crab fishery.

## ii. Graphs of model fits to survey numbers

Time series of observed biomass of mature crab in the NMFS bottom trawl surveys are compared by sex with model-predicted values in Figures F28-F29. None of the scenarios completely follow the wide swings in biomass before 1995, but that is partly because the observed survey biomass gives conflicting information in the male and female time series, particularly in 1975 and in the early 1980s. The models do a better job of capturing the swing from low to high biomass in the mid-1980s to early 1990s, but all overestimate the valley in 1986 and underestimate the peak in 1991. More recently, the fits of all scenarios are pretty good but still don't quite capture the full extent of swings in biomass (Figure F29).

## iii. Graphs of model fits to catch proportions by size class

Model fits to proportions at size for retained catch are summarized in Figures F106 and F110 as Pearson's residuals. Compared with B0.2016, B2b fits the retained catch much better than B0.2016. The pattern of over-predicting the retained catch proportions for smaller males and under-predicting proportions for larger males is much reduced in the period prior to 2011, as is the opposite pattern of over-predicting retained catch proportions for large crab during 2013/14-2015/16.

Similar improvement is not evident in the fits to proportions at size for total catch in the directed fishery (Figures F118-F126). B2b fits the proportions at length somewhat better before 1996/97 than B0.2016 does, but little change is evident in the more recent time periods when the directed fishery was prosecuted. There also appears to be little change (if any) in the fits to proportions at size for bycatch in the snow crab fishery (Figures F129 and 137). For the BBRKC fishery, B2b fits the proportions-at-size slightly worse than B0.2016 for 1992/93 and 1993/94, but otherwise the fits are almost identical (Figures 151 and 159). Finally, B2b shows an improvement in the fits to proportions-at-size for larger-sized crab bycatch in the groundfish fisheries in the 1990-2005 time period, but with a corresponding worsening of the fits for smaller-sized crab in this time period (Figures F140 and F148).

## iv. Graphs of model fits to survey proportions by size class

Model fits to proportions-at-size in the NMFS trawl survey for immature male crab show little change from B0.2016 to B2b (Figures F61 and F69), although there is a small improvement fitting proportions for crab larger than 100 mm CW for 2013-2015-but with a corresponding worsening for small crab < 30 mm CW. The fits to mature male proportions-at-size (Figures F72 and F80) indicate virtually no change between the two model scenarios. Similar results hold for fits to both immature and mature female proportions-at-size (Figures F83 and F91, F94 and F102 respectively).

## v. Marginal distributions for the fits to the compositional data.

Marginal plots of the composition data from the NMFS survey indicate almost no differences between scenarios B0.2016 and B2b (Figure F52). Both scenarios exhibit a small tendency to under-predict the proportions of larger immature crab and over-predict the proportions of larger mature crab-and slightly more so for males than females.

The marginal plot of the retained catch composition data (Figure 53) indicates B2b fits the marginal retained catch composition data much better (almost exactly) than B0.2016 does, which over-predicts proportions at small crab sizes ( $<140 \mathrm{~mm}$ CW) and under-predicts proportions of larger crab.

The marginal plots of the total catch composition data in the directed fishery (Figure F57) indicate B2b and B0. 2016 fit the marginal female composition data equally well. For males, B2b provides a better fit to the peak of the distribution than B0.2016 does, but both scenarios under-predict the proportions in the $125-135 \mathrm{~mm}$ CW range and over-predict them for larger crab.

The marginal plots for bycatch size compositions in the snow crab fishery (Figure 56) are essentially identical for scenarios B2b and B0.2016 for both males and females, and both fit the distributions well, except at the peak of the female distribution ( 85 mm CW), where both under-estimate the proportions. For bycatch in the BBRKC fishery (Figure 55), B2b and B0. 2016 both fit the female marginal size composition data equally well, but both similarly under-predict proportions of small males ( $<125 \mathrm{~mm}$ CW) caught in the fishery while over-predicting proportions of medium-sized males ( $130-155 \mathrm{~mm}$ CW) and under-predicting proportions for large crabs ( $>155 \mathrm{~mm}$ CW). For the groundfish fishery (Figure F54), both scenarios tended to slightly under-predict male proportions at small sizes ( $<75 \mathrm{~mm} \mathrm{CW}$ ) but over predict proportions at medium sizes ( $75-110 \mathrm{~mm}$ CW). For females, the opposite was true as both under-predicted proportions for small females ( $<60 \mathrm{~mm} \mathrm{CW}$ ) but over-predicted proportions for mediumsized females ( $60-80 \mathrm{~mm} \mathrm{CW}$ ).

## vi. Plots of implied versus input effective sample sizes and time-series of implied effective sample sizes.

Time series of implied effective sample sizes using the McAllister-Ianelli method are shown for retained catch (Figure F116), total catch size compositions in the directed fishery (Figure F163), bycatch size compositions in the snow crab, BBRKC and groundfish fisheries (Figures 164-166), and the NMFS EBS bottom trawl survey (Figure F104). For the most part, the implied effective sample sizes tend to be substantially larger than the input values.
vii. Tables of the RMSEs for the indices (and a comparison with the assumed values for the coefficients of variation assumed for the indices).
Tables of the RMSEs for the indices were not completed for the assessment, but will be provided at the May 2018 CPT meeting.
viii. Quantile-quantile ( $q-q$ ) plots and histograms of residuals (to the indices and compositional data) to justify the choices of sampling distributions for the data. Quantile-quantile ( $\mathrm{q}-\mathrm{q}$ ) plots and histograms of residuals were not completed for the assessment, but will be provided at the May 2018 CPT meeting.
f. Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments).
i. Retrospective analysis (retrospective bias in base model or models).

Retrospective analyses were not completed for the assessment, but will be provided at the May 2018 CPT meeting.
ii. Historical analysis (plot of actual estimates from current and previous assessments). An historical analysis was not completed for the assessment due to incompatibilities between TCSAM02 and formats of previous assessment results. One will be provided at the May 2018 CPT meeting.
g. Uncertainty and sensitivity analyses

MCMC runs were completed for scenarios B0, B2b and B3 to explore model uncertainty. Each model was run for a single chain, which was set to run 10 million iterations, keeping results for every $1,000^{\text {th }}$ to reduce serial autocorrelation, with a burn-in period of 2,000 iterations. After $\sim 48$ hours, the runs were stopped at about 4.5 million iterations. Mixing appeared to be sufficient, but this can be difficult to evaluate with only single chains. These runs provide empirical posterior distributions for model parameters and selected derived quantities, including OFL-related quantities.

Time constraints did not allow a full exploration of the MCMC results. Summary results for the objective function and parameters related to survey catchability and selectivity are shown in Figure 23. As noted above, based on the trace for the objective function, mixing seems to have been sufficient. The posterior distributions for the survey parameters show the impact of the bounds placed on several of the parameters and support continued investigation and further model development to improve their characteristics: their distributions are skewed, with multiple maxima and minima. However, a similar plot for OFL-related quantities (Figure 24) indicates that they are much closer to normally-distributed and do not exhibit unexpected correlation structures (e.g., Fofl and Fmsy are expected to be highly correlated).

## F. Calculation of the OFL and ABC

## 1. Status determination and OFL calculation

EBS Tanner crab was elevated to Tier 3 status following acceptance of the TCSAM by the CPT and SSC in 2012. Based upon results from the model, the stock was subsequently declared rebuilt and not
overfished. Consequently, EBS Tanner crab is assessed as a Tier 3 stock for status determination and OFL setting.

The (total catch) OFL for 2016/17 was 25.61 thousand t while the total catch mortality was 1.14 thousand t , based on applying discard mortality rates of 1.000 for retained catch, 0.321 to bycatch in the crab fisheries, and 0.800 to bycatch in the groundfish fisheries to the reported catch by fleet for 2016/17
(Tables 1 and 4). Therefore overfishing did not occur.
Amendment 24 to the NPFMC fishery management plan (NPFMC 2007) revised the definitions for overfishing for EBS crab stocks. The information provided in this assessment is sufficient to estimate overfishing limits for Tanner crab under Tier 3. The OFL control rule for Tier 3 is (Figure 25):

and is based on an estimate of "current" spawning biomass at mating ( $B$ above, taken as MMB at mating in the assessment year) and spawning biomass per recruit (SBPR)-based proxies for F MSy and $B_{\text {MSY. }}$. In the above equations, $\alpha=0.1$ and $\beta=0.25$. For Tanner crab, the proxy for $F_{\text {MSY }}$ is $F_{35 \%}$, the fishing mortality that reduces the SBPR to $35 \%$ of its value for an unfished stock. Thus, if $\phi(F)$ is the SBPR at fishing mortality $F$, then $\mathrm{F}_{35 \%}$ is the value of fishing mortality that yields $\phi(F)=0.35 \cdot \phi(0)$. The Tier 3 proxy for $\mathrm{B}_{\text {MSY }}$ is $\mathrm{B}_{355}$, the equilibrium biomass achieved when fishing at $\mathrm{F}_{35 \%}$, where $\mathrm{B}_{35 \%}$ is simply $35 \%$ of the unfished stock biomass. Given an estimate of average recruitment, $\bar{R}$, then $B_{35 \%}=0.35 \cdot \bar{R} \cdot \phi(0)$.

Thus Tier 3 status determination and OFL setting for 2017/18 require estimates of $B=\mathrm{MMB}_{2017 / 18}$ (the projected MMB at mating time for the coming year), $\mathrm{F}_{35}$, spawning biomass per recruit in an unfished stock ( $\phi(0)$ ), and $\bar{R}$. Current stock status is determined by the ratio $B / B_{35 \%}$ for Tier 3 stocks. If the ratio is greater than 1, then the stock falls into Tier 3 a and $\mathrm{F}_{\text {OFL }}=\mathrm{F}_{\text {MSY }}=\mathrm{F}_{35 \%}$. If the ratio is less than one but greater than $\beta$, then the stock falls into Tier 3 b and Foft is reduced from $\mathrm{F}_{35 \%}$ following the descending limb of the control rule (Figure 25). If the ratio is less than $\beta$, then the stock falls into Tier 3c and directed fishing must cease. In addition, if $B$ is less than $1 / 2 \mathrm{~B}_{35 \%}$ (the minimum stock size threshold, MSST), the stock must be declared overfished and a rebuilding plan subsequently developed.

In 2015, the SOA’s Board of Fish, under petition from the commercial Tanner crab fishing industry, changed the minimum preferred size for crab in the area east of $166^{\circ} \mathrm{W}$ longitude in calculations used for setting TACs from 138 mm CW (not including lateral spines) to 125 mm CW. The minimum preferred size in the area west of $166^{\circ} \mathrm{W}$ remained the same ( 125 mm CW). In previous assessments, an attempt was made to account for retention of slightly ( 10 mm CW) smaller crab in the directed fishery in the western area. Because the preferred size is now the same in both areas, the OFL is calculated assuming both selectivity (as previously) and retention (new) curves are the same in both areas.

In previous years, a separate "projection model" has been used to determine OFL based on results from the assessment model. The estimated coefficient of variation for the estimate of final MMB was used to characterize model uncertainty and provided a calculational basis for determining an empirical probability density function (pdf) for OFL based on sampling final MMB from its assumed pdf. With the transition to TCSAM02, OFL is calculated within the assessment model based on equilibrium calculations for $\mathrm{F}_{\text {oft }}$
and projecting the state of the population at the end of the modeled time period one year forward assuming fishing mortality at Foft. Using MCMC, one can thus estimate the pdf of OFL (and related quantities of interest) incorporating full model uncertainty.

To calculate the Fofs, the fishery capture rate for males in the directed fishery is adjusted until the longterm (equilibrium) MMB-at-mating is $35 \%$ of its unfished value. This calculation also depends on the assumed bycatch F's on Tanner crab in the snow crab, BBRKC and groundfish fisheries. This year, the average F over the last 5 years for each of the bycatch fisheries is used in the calculations. In previous years, a different approach was used to determine the F to use for the snow crab fishery. For that fishery, the ratio of the Fofs from the snow crab assessment author's preferred model to the average F over the last 5 years was used to scale the 5 -year average bycatch F on Tanner crab. For last year's assessment, the snow crab Fofl was $1.24 \mathrm{yr}^{-1}$ (Szuwalski, 2016) and the 5 -year average F is $0.979 \mathrm{yr}^{-1}$, resulting in a scaling factor of 1.27. For this assessment, the snow crab assessment author's preferred Fofl was $0.89 \mathrm{yr}^{-}$ ${ }^{1} \mathrm{~T}$ and the five-year average was 1.05 (Cody Szuwalski, UCSB, pers. comm.), resulting in a scaling factor of 1.18. However, this scaling was not operational for TCSAM02 models at the time of this assessment, so the unscaled 5 -year average bycatch F in the snow crab fishery was used instead.

Selectivity curves in the bycatch fisheries were set using the average curves over the last 5 years for each fishery, the same approach as in previous assessments (Rugolo and Turnock, 2012b; Stockhausen 2015).

Results from OFL calculations from the converged model run for each scenario (i.e., based on the MLE solution, not MCMC) are compared for illustrative purposes in Table 39. Scenario B1c stands out particularly from the others because estimated average recruitment and $\mathrm{F}_{\text {OFL }}$ are quite a bit larger than for the other scenarios. The other scenarios appear to fall into two general groupings: 1) B0.2016, B0, B0a, B1, B1a, and B1b and 2) B2, B2a, B2b, and B3. The former group exhibits somewhat lower estimated average recruitments and higher F msy's $^{\text {'s than the latter. Primarily because estimated average recruitments }}$ are higher, the second group yields higher B0's, BmsY's, MSY's, and OFLs.

The determination of $\mathrm{B}_{\mathrm{MSY}}=\mathrm{B}_{35 \%}$ for Tanner crab depends on the selection of an appropriate time period over which to calculate average recruitment $(\bar{R})$. After much discussion in 2012 and 2013, the SSC endorsed an averaging period of 1982+. Starting the average recruitment period in 1982 is consistent with a 5-6 year recruitment lag from 1976/77, when a well-known climate regime shift occurred in the EBS (Rodionov and Overland, 2005) that may have affected stock productivity. The value of $\bar{R}$ for this period from the author's preferred model is 213.95 million. The estimates of average recruitment are reasonably similar between the 2016 assessment model and the author's preferred model (Table 37). The value of $\mathrm{B}_{\mathrm{MSY}}=\mathrm{B}_{35 \%}$ for $\bar{R}$ is 25.42 thousand t , which is almost identical to that from the 2016 assessment (25.65 thousand t ).

Once $\mathrm{F}_{\text {ofL }}$ is determined using the control rule (Figure 25), the (total catch) OFL can be calculated based on projecting the population forward one year assuming that $F=$ Fofs. In the absence of uncertainty, the OFL would then be the predicted total catch taken when fishing at $F=\mathrm{F}_{\text {ofl }}$. When uncertainty (e.g. assessment uncertainty, variability in future recruitment) is taken into account, the OFL is taken as the median total catch when fishing at $F=\mathrm{F}_{\text {oft }}$.

The total catch (biomass), including all bycatch of both sexes from all fisheries, was estimated using

$$
C=\sum_{f} \sum_{x} \sum_{z} \frac{F_{f, x, Z}}{F_{,, x, Z}} \cdot\left(1-e^{-F_{,, x, z}}\right) \cdot w_{x, z} \cdot\left[e^{-M_{x} \cdot \delta t} \cdot N_{x, Z}\right]
$$

where $C$ is total catch (biomass), $F_{f, x, z}$ is the fishing mortality in fishery $f$ on crab in size bin $z$ by sex $(x)$, $F_{,, x, z}=\sum_{f} F_{f, x, z}$ is the total fishing mortality by sex on crab in size bin $z, w_{x, z}$ is the mean weight of crab
in size bin $z$ by sex, $M_{x}$ is the sex-specific rate of natural mortality, $\delta t$ is the time from July 1 to the time of the fishery ( 0.625 yr ), and $N_{\chi, z}$ is the numbers by sex in size bin $z$ on July 1,2016 as estimated by the assessment model.

Assessment model uncertainty was included in the calculation of OFL using MCMC. Conceptually, a random draw from the assessment model's joint posterior distribution for the estimated parameters was taken, and the $\mathrm{B}_{0}$, $\mathrm{F}_{\mathrm{MSY}}$, $\mathrm{B}_{\text {MSY }}$, $\mathrm{F}_{\text {ofL }}$, OFL, and "current" MMB for 2017/18 were calculated based on resulting model parameter values. This would be repeated a large number of times to approximate the distribution of OFL given the full model uncertainty. In practice, a single (due to time constraints) chain of over 4 million MCMC steps was generated, with the OFL and associated quantities calculated at each step. The chain was initialized from the converged model state using a "burn in" of 2,000 steps and subsequently thinned by a factor of 1,000 to reduce serial autocorrelation in the MCMC sampling. This resulted in about 4,500 MCMC samples with which to characterize the distribution of the OFL. The median value of this distribution was taken as the OFL for 2017/18. Thus, the OFL for 2017/18 from the author's preferred model (Model B2b) is $\mathbf{2 5 . 4 2}$ thousand $\mathbf{t}$ (Figure 26). This value for the OFL is identical (to two decimal places) to the value calculated using the converged model parameters (i.e., the "MLE" estimate of OFL).

The $\mathrm{B}_{\text {msy }}$ proxy, $\mathrm{B}_{35 \%}$, from the author's preferred model is 29.17 thousand t , so MSST $=0.5 \mathrm{~B}_{\text {MSY }}=$ 14.58 thousand t . Because current $B=43.31$ thousand $\mathrm{t}>$ MSST, the stock is not overfished. The population state (directed F vs. MMB) is plotted for each year from 1965/66-2016/17 in Figure 27 against the Tier 3 harvest control rule.

## 2. $A B C$ calculation

Amendments 38 and 39 to the Fishery Management Plan (NPFMC 2010) established methods for the Council to set Annual Catch Limits (ACLs). The Magnuson-Stevens Act requires that ACLs be established based upon an acceptable biological catch (ABC) control rule that accounts for scientific uncertainty in the OFL such that ACL=ABC and the total allowable catch (TAC) and guideline harvest levels (GHLs) be set below the ABC so as not to exceed the ACL. ABCs must be recommended annually by the Council's SSC.

Two methods for establishing the ABC control rule are: 1) a constant buffer where the ABC is set by applying a multiplier to the OFL to meet a specified buffer below the OFL; and 2) a variable buffer where the ABC is set based on a specified percentile $\left(\mathrm{P}^{*}\right)$ of the distribution of the OFL that accounts for uncertainty in the OFL. $\mathrm{P}^{*}$ is the probability that ABC would exceed the OFL and overfishing occur. In 2010, the NPFMC prescribed that ABCs for BSAI crab stocks be established at $\mathrm{P}^{*}=0.49$ (following Method 2). Thus, annual ACL=ABC levels should be established such that the risk of ovefishing, P[ABC>OFL], is $49 \%$. In 2014, however, the SSC adopted a buffer of $20 \%$ on OFL for the Tanner crab stock for calculating ABC. Here, ABCs are provided based on both methods.

For the author's preferred model, Model C, the P* ABC ( ABC $_{\max }$ ) is 25.37 thousand t while the $20 \%$ Buffer ABC is 20.33 thousand t . The author remains concerned that the OFL calculation, based on $\mathrm{F}_{35 \%}$ as a proxy for $\mathrm{F}_{\text {MSY }}$, is overly optimistic regarding the actual productivity of the stock. Fishery-related mortality similar to the $P^{*}$ ABC level has occurred only in the latter half of the 1970s and in 1992/93, coincident with collapses in stock biomass to low levels. This suggests that $\mathrm{F}_{35 \%}$ may not be a realistic proxy for $\mathrm{F}_{\text {MSY }}$ and/or that MMB may not be a good proxy for reproductive success, as are currently assumed for this stock. Given this uncertainty concerning the stock, the author recommends using the $\mathbf{2 0 \%}$ buffer previously adopted by the SSC for this stock to calculate ABC. Consequently, the author's recommended ABC is 20.33 thousand $t$.

## G. Rebuilding Analyses

Tanner crab is not currently under a rebuilding plan. Consequently no rebuilding analyses were conducted.

## H. Data Gaps and Research Priorities

Information on growth-per-molt has been collected in the EBS on Tanner crab and incorporated into the assessment. More data regarding temperature-dependent effects on molting frequency would be helpful to assess potential impacts of the EBS cold pool on the stock. Information on temperature-dependent changes in crab movement and survey catchability would also be of value. In addition, it would be extremely worthwhile to develop a "better" index of reproductive potential than MMB that can be calculated in the assessment model and to revisit the issue of MSY proxies for this stock.

The characterization of fisheries in the assessment model needs to be carefully reconsidered. How, and whether or not, the East $166^{\circ} \mathrm{W}$ and West $166^{\circ} \mathrm{W}$ directed fisheries should be explicitly represented in the assessment model should be addressed. In addition, the question of whether or not bycatch in the groundfish fisheries should be split into pot- and trawl-related components should be resolved.

With the implementation of TCSAM02, several research avenues can be explored much more efficiently: 1) time-varying growth; 2) incorporating chela height data for male maturity classification, 3) decomposing the currently "lumped" directed fishery into its eastern and western components, and 4) incorporating the BSFRF surveys into the assessment. Development of a fully-Gmacs version of the Tanner crab model will also begin.

## I. Ecosystem Considerations

Mature male biomass is currently used as the "currency" of Tanner crab spawning biomass for assessment purposes. However, its relationship to stock-level rates of egg production, perhaps an ideal measure of stock-level reproductive capacity, is unclear. Thus, use of MMB to reflect Tanner crab reproductive potential may be misleading as to stock health. Nor is it likely that mature female biomass has a clear relationship to annual egg production. For Tanner crab, the fraction of barren mature females by shell condition appears to vary on a decadal time scale (Rugolo and Turnock, 2012), suggesting a potential climatic driver.

## 1. Ecosystem Effects on Stock

Time series trends in prey availability or abundance are generally unknown for Tanner crab because typical survey gear is not quantitative for Tanner crab prey. On the other hand, Pacific cod (Gadus macrocephalus) is thought to account for a substantial fraction of annual mortality on Tanner crab (Aydin et al., 2007). Total P. cod biomass is estimated to have been slowly declining from 1990 to 2008, during the time frame of a collapse in the Tanner crab stock, but has been increasing rather rapidly since 2008 (Thompson and Lauth, 2012). This suggests that the rates of "natural mortality" used in the stock assessment for the period post-1980 may be underestimates (and increasingly biased low if the trend in P. cod abundance continues). This trend is definitely one of potential concern.

## 2. Effects of Tanner crab fishery on ecosystem

Potential effects of the Tanner crab fishery on the ecosystem are considered in the following table:

| Effects of Tanner crab fishery on ecosystem |  |  |  |
| :--- | :--- | :--- | :--- |
| Indicator | Observation | Interpretation | Evaluation |
| Fishery contribution to bycatch |  |  |  |
| Prohibited species | salmon are unlikely to be <br> trapped inside a pot when | unlikely to have <br> substantial effects at the <br> stock level | minimal to none |


|  | it is pulled, although halibut can be |  |  |
| :---: | :---: | :---: | :---: |
| Forage (including herring, Atka mackerel, cod and pollock) | Forage fish are unlikely to be trapped inside a pot when it is pulled | unlikely to have substantial effects | minimal to none |
|  | crab pots have a very | unlikely to be having |  |
| HAPC biota | small footprint on the bottom | substantial effects postrationalization | minimal to none |
| Marine mammals and birds | crab pots are unlikely to attract birds given the depths at which they are fished | unlikely to have substantial effects | minimal to none |
| Sensitive non-target species | Non-targets are unlikely to be trapped in crab pot gear in substantial numbers | unlikely to have substantial effects | minimal to none |
| Fishery concentration in space and time | time following rationalization of the fishery | unlikely to be having substantial effects | probably of little concern |
| Fishery effects on amount of large size target fish | Fishery selectively removes large males | May impact stock reproductive potential as large males can mate with a wider range of females | possible concern |
| Fishery contribution to discards and offal production | discarded crab suffer some mortality | May impact female spawning biomass and numbers recruiting to the fishery | possible concern |
| Fishery effects on age-atmaturity and fecundity | none | unknown | possible concern |

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Table 1. Retained catch (males) in directed Tanner crab fisheries. ..... 46
Table 2. Retained catch (males) in the US domestic pot fishery. Information from the CommunityDevelopment Quota (CDQ) fisheries is included in the table for fishery years 2005/06 to the present.Number of crabs caught and harvest includes deadloss. The "Fishery Year" YYYY/YY+1 runs from July1, YYYY to June 30, YYYY+1. The ADFG year (in parentheses, if different from the "Fishery Year")indicates the year ADFG assigned to the fishery season in compiled reports.47
Table 3. Total bycatch (discards, 1000’s t) of Tanner crab in various fisheries ..... 48
Table 4. Bycatch (discard) mortality (1000's t) of Tanner crab in various fisheries. Discard mortality wascalculated assuming mortality rates of 0.321 in the crab fisheries and 0.80 in the groundfish fisheries.... 49Table 5. Sample sizes for retained catch-at-size in the directed fishery. $\mathrm{N}=$ number of individuals. $\mathrm{N}^{`}=$scaled sample size used in assessment. The directed fishery was closed in 2016/17.50
Table 6. Sample sizes for total catch-at-size in the directed fishery, from crab observer sampling. $\mathrm{N}=$ number of individuals. $\mathrm{N}^{`}=$ scaled sample size used in assessment. ..... 51
Table 7. Sample sizes for total bycatch-at-size in the snow crab fishery, from crab observer sampling. $\mathrm{N}=$ number of individuals. $\mathrm{N}^{`}=$ scaled sample size used in assessment. ..... 52
Table 8. Sample sizes for total bycatch-at-size in the BBRKC fishery, from crab observer sampling. $\mathrm{N}=$ number of individuals. $\mathrm{N}^{`}=$ scaled sample size used in assessment. ..... 53
Table 9. Sample sizes for total catch-at-size in the groundfish fisheries, from groundfish observer sampling. $\mathrm{N}=$ number of individuals. $\mathrm{N}^{`}=$ scaled sample size used in the assessment. ..... 54
Table 10. Trends in mature and total Tanner crab biomass (1000's t) in the NMFS summer bottom trawl survey. ..... 55
Table 11. Sample sizes for NMFS survey size composition data. In the assessment model, an effective sample size of 200 is used for all survey-related compositional data ..... 56
Table 12. Effort data (1000's potlifts) in the snow crab and BBRKC fisheries. ..... 57
Table 13.Non-selectivity parameters estimated within 1\% of bounds. ..... 58
Table 14.Selectivity-related parameters estimated within $1 \%$ of bounds. ..... 59
Table 15. Comparison of estimated growth and natural mortality parameters for all model scenarios ..... 60
Table 16. Comparison of recruitment parameter estimates from all model scenarios. ..... 61
Table 17. Comparison of logit-scale parameters for the probability of terminal molt ..... 62
Table 18. Comparison of NMFS survey catchability parameters for all model scenarios ..... 63
Table 19. Comparison of NMFS survey selectivity parameters for all model scenarios. ..... 64
Table 20. Comparison of fishery capture rate and max retention parameter estimates for all fisheries for all model scenarios. ..... 65
Table 21. Comparison of selectivity and retention function parameter estimates for the directed Tanner crab fishery (TCF) for all model scenarios. ..... 66
Table 22. Comparison of selectivity parameter estimates for the snow crab fishery (SCF) for all model scenarios ..... 67
Table 23. Comparison of selectivity parameter estimates for the BBRKC fishery (RKF) for all model scenarios ..... 68
Table 24. Comparison of selectivity parameter estimates for the groundfish fisheries (GTF) for all model scenarios. ..... 69
Table 25. Objective function data components from the model scenarios. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: BBRKC fishery; GTF: groundfish fisheries ..... 70Table 26. Differences between objective function data components from the model scenarios. TCF:directed Tanner crab fishery; SCF: snow crab fishery; RKF: BBRKC fishery; GTF: groundfish fisheries.Green highlights indicate differences smaller than -5 likelihood units. Red highlights indicate differencesgreater than 5 likelihood units71Table 27. Effective sample sizes used for NMFS EBS trawl survey size composition data for the 2016assessment model (2016AM) and the author's preferred model (Model B2b). Effective sample sizes wereestimated using the McAllister-Ianelli approach.72

Table 28. Effective sample sizes used for retained catch size composition data from the directed fishery for the 2016 assessment model (2016AM) and the author's preferred model (Model B2b). Effective sample sizes were estimated using the McAllister-Ianelli approach.
Table 29. Effective sample sizes used for total catch size composition data from the directed fishery for the 2016 assessment model (2016AM) and the author's preferred model (Model B2b). Effective sample sizes were estimated using the McAllister-Ianelli approach.73

Table 30. Effective sample sizes used for bycatch size composition data from the snow crab fishery for the 2016 assessment model (2016AM) and the author's preferred model (Model B2b). Effective sample sizes were estimated using the McAllister-Ianelli approach.
Table 31. Effective sample sizes used for bycatch size composition data from the BBRKC fishery for the 2016 assessment model (2016AM) and the author’s preferred model (Model B2b). Effective sample sizes were estimated using the McAllister-Ianelli approach. .75
Table 32. Effective sample sizes used for bycatch size composition data from the groundfish fisheries for the 2016 assessment model (2016AM) and the author’s preferred model (Model B2b). Effective sample sizes were estimated using the McAllister-Ianelli approach. 75
Table 33. Comparison of fits to mature survey biomass by sex (in 1000's t) from the 2016 assessment model (2016AM) and the author's preferred model (B2b). ..... 76
Table 34. Comparison of estimates of mature biomass-at-mating by sex (in 1000's t) from the 2016 assessment model (2016AM) and the author's preferred model (B2b). ..... 77
Table 35. Estimated population size (millions) for females on July 1 of year. from the author's preferred model, Model B2b. ..... 78
Table 36. Estimated population size (millions) for males on July 1 of year. from the author's preferred mode, Model B2b ..... 79
Table 37. Comparison of estimates of recruitment (in millions) from the 2016 assessment model (2016AM) and the author's preferred model (Model B2b). ..... 80
Table 38. Comparison of exploitation rates (i.e., catch divided by biomass) from the 2016 assessment model (2016AM) and the author's preferred model (Model B2b). ..... 81Table 39. Values required to determine Tier level and OFL for the models considered here. These valuesare presented only to illustrate the effect of incremental changes in the model scenarios. Results from theauthor's preferred model (Model B2b) are highlighted in green.82
Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008). ..... 83
Figure 2. Upper: retained catch (males, 1000’s t) in the directed fisheries (US pot fishery [green bars],Russian tangle net fishery [red bars], and Japanese tangle net fisheries [blue bars]) for Tanner crab since1965/66. Lower: Retained catch (males, 1000's t) in directed fishery since 2001/02. The directed fisherywas closed from 1996/97 to 2004/05, from 2010/11 to 2012/13, and in 2016/17.84
Figure 3. Upper: Tanner crab discards (males and females, 1000’s t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Discard reporting began in 1973 for the groundfish fisheries and in 1992 for the crab fisheries. Lower: detail since 2001. ..... 85
Figure 4. Upper: Tanner crab discard mortality (males and females, 1000's t) in the directed Tanner crab,snow crab, Bristol Bay red king crab, and groundfish fisheries. Assumed handling mortality rates of 0.321for the crab fisheries and 0.80 for the groundfish fisheries were applied to discard biomass to obtaindiscard mortality. Lower: detail since 200186
Figure 5. Retained and discard catch mortality (1000's t) in the directed, snow crab, BBRKC and groundfish fisheries. Handling mortality rates of 0.321 for the crab fisheries and 0.8 for the groundfish fisheries were applied to estimated discards. ..... 87
Figure 6. Size compositions, by 5 mm CW bins and expanded to total retained catch, for retained (male) crab in the directed Tanner crab pot fisheries since 2006/07, from dockside crab fishery observer sampling. Fishing occurred only east of $166^{\circ} \mathrm{W}$ in 2009/10. The entire fishery was closed in 2010/11- 2012/13 and in 2016/17. Note scale change in 2014/15. ..... 88
Figure 7. Male Tanner crab catch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling. Note that the directed fishery was closed in 2010/11-2012/13 and in 2016/17. ..... 89
Figure 8. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling. Note that the directed fishery was closed in 2010/11-2012/13 and in 2016/17. ..... 90
Figure 9. Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the snow crab pot fishery, from at-sea crab fishery observer sampling. ..... 91
Figure 10. Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the BBRKC pot fishery, from at-sea crab fishery observer sampling. ..... 92
Figure 11. Normalized Tanner crab bycatch size compositions in the groundfish fisheries, from groundfish observer sampling. Size compositions have been normalized to sum to 1 for each year. ..... 93
Figure 12. Trends in survey biomass for mature male and female Tanner crab, and in abundance for industry preferred-size ( $\geq 125 \mathrm{~mm}$ CW) males, based on the NMFS EBS bottom trawl survey. ..... 94
Figure 13. Percent change in mature male biomass, mature female biomass, total mature biomass and abundance of legal crab observed in the NMFS bottom trawl survey during the past five surveys. ..... 94
Figure 14. Trends in survey biomass for male Tanner crab in areas east and west of $166^{\circ} \mathrm{W}$ longitude, based on the NMFS EBS bottom trawl survey. ..... 95
Figure 15. Trends in survey biomass for female Tanner crab in areas east and west of $166^{\circ} \mathrm{W}$ longitude, based on the NMFS EBS bottom trawl survey. ..... 96
Figure 16. Numbers at size (millions) by area and shell condition for male Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW ..... 97
Figure 17. Numbers at size (millions) by area and shell condition for male Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW, since 2005. ..... 97
Figure 18. Numbers at size (millions) by area and shell condition for female Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW. ..... 98
Figure 19. Numbers at size (millions) by area and shell condition for female Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW, since 2005 ..... 98
Figure 20. Average bottom temperatures ( ${ }^{\circ} \mathrm{C}$ ) in the NMFS EBS summer trawl survey for 1975-2017. .. ..... 99
Figure 21. Size-weight relationships developed from NMFS EBS summer trawl survey data. ..... 99
Figure 22. Assumed size distribution for recruits entering the population. ..... 100

Figure 23. MCMC results from scenario B2b, the author's preferred model, for survey catchability and selectivity parameters.
Figure 24. MCMC results from scenario B2b, the author's preferred model, for OFL-related quantities.
Figure 25. The Foft harvest control rule.............................................................................................. 103
Figure 26. The OFL and ABC from the author's preferred model, scenario B2b. .................................. 103
Figure 27. Quad plot for the author's preferred model, scenario B2b. ................................................... 104

Tables
Table 1. Retained catch (males) in directed Tanner crab fisheries.

| Eastern Bering Sea Chionoecetes bairdi Retained Catch (1,000's t) |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| Year | US Pot | Japan | Russia | Total |
| 1965/66 | -- | 1.17 | 0.75 | 1.92 |
| 1966/67 | -- | 1.69 | 0.75 | 2.44 |
| 1967/68 | -- | 9.75 | 3.84 | 13.60 |
| 1968/69 | 0.46 | 13.59 | 3.96 | 18.00 |
| 1969/70 | 0.46 | 19.95 | 7.08 | 27.49 |
| 1970/71 | 0.08 | 18.93 | 6.49 | 25.49 |
| 1971/72 | 0.05 | 15.90 | 4.77 | 20.71 |
| 1972/73 | 0.10 | 16.80 | -- | 16.90 |
| 1973/74 | 2.29 | 10.74 | -- | 13.03 |
| 1974/75 | 3.30 | 12.06 | -- | 15.24 |
| 1975/76 | 10.12 | 7.54 | -- | 17.65 |
| 1976/77 | 23.36 | 6.66 | -- | 30.02 |
| 1977/78 | 30.21 | 5.32 | -- | 35.52 |
| 1978/79 | 19.28 | 1.81 | -- | 21.09 |
| 1979/80 | 16.60 | 2.40 | -- | 19.01 |
| 1980/81 | 13.47 | -- | -- | 13.43 |
| 1981/82 | 4.99 | -- | -- | 4.99 |
| 1982/83 | 2.39 | -- | -- | 2.39 |
| 1983/84 | 0.55 | -- | -- | 0.55 |
| 1984/85 | 1.43 | -- | -- | 1.43 |
| 1985/86 | 0.00 | -- | -- | 0.00 |
| 1986/87 | 0.00 | -- | -- | 0.00 |
| 1987/88 | 1.00 | -- | -- | 1.00 |
| 1988/89 | 3.15 | -- | -- | 3.18 |
| 1989/90 | 11.11 | -- | -- | 11.11 |
| 1990/91 | 18.19 | -- | -- | 18.19 |
| 1991/92 | 14.42 | -- | -- | 14.42 |
| 1992/93 | 15.92 | -- | -- | 15.92 |
| 1993/94 | 7.67 | -- | -- | 7.67 |
| 1994/95 | 3.54 | -- | -- | 3.54 |
| 1995/96 | 1.92 | -- | -- | 1.92 |
| 1996/97 | 0.82 | -- | -- | 0.82 |
| 1997/98 | 0.00 | -- | -- | 0.00 |
| 1998/99 | 0.00 | -- | -- | 0.00 |
| 1999/00 | 0.00 | -- | -- | 0.00 |
| 2000/01 | 0.00 | -- | -- | 0.00 |
| 2001/02 | 0.00 | -- | -- | 0.00 |
| 2002/03 | 0.00 | -- | -- | 0.00 |
| 2003/04 | 0.00 | -- | -- | 0.00 |
| 2004/05 | 0.00 | -- | -- | 0.00 |
| 2005/06 | 0.43 | -- | -- | 0.43 |
| 2006/07 | 0.96 | -- | -- | 0.96 |
| 2007/08 | 0.96 | -- | -- | 0.96 |
| 2008/09 | 0.88 | -- | -- | 0.88 |
| 2009/10 | 0.60 | -- | -- | 0.60 |
| 2010/11 | 0.00 | -- | -- | 0.00 |
| 2011/12 | 0.00 | -- | -- | 0.00 |
| 2012/13 | 0.00 | -- | -- | 0.00 |
| 2013/14 | 1.25 | -- | -- | 1.25 |
| 2014/15 | 6.16 | -- | -- | 6.16 |
| 2015/16 | 8.91 | -- | -- | 8.91 |
| 2016/17 | 0.00 | -- | -- | 0.00 |

Table 2. Retained catch (males) in the US domestic pot fishery. Information from the Community Development Quota (CDQ) fisheries is included in the table for fishery years 2005/06 to the present. Number of crabs caught and harvest includes deadloss. The "Fishery Year" YYYY/YY+1 runs from July 1, YYYY to June 30, YYYY+1. The ADFG year (in parentheses, if different from the "Fishery Year") indicates the year ADFG assigned to the fishery season in compiled reports.

| year (ADFG year) | Total <br> Crab <br> (no.) | Total Harvest <br> (lbs) | GHL/TAC (millions lbs) | Vessels <br> (no.) | Season |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1968/69 (1969) | 353,300 | 1,008,900 |  |  |  |
| 1969/70 (1970) | 482,300 | 1,014,700 |  |  |  |
| 1970/71 (1971) | 61,300 | 166,100 |  |  |  |
| 1971/72 (1972) | 42,061 | 107,761 |  |  |  |
| 1972/73 (1973) | 93,595 | 231,668 |  |  |  |
| 1973/74 (1974) | 2,531,825 | 5,044,197 |  |  |  |
| 1974/75 | 2,773,770 | 7,028,378 |  | 28 |  |
| 1975/76 | 8,956,036 | 22,358,107 |  | 66 |  |
| 1976/77 | 20,251,508 | 51,455,221 |  | 83 |  |
| 1977/78 | 26,350,688 | 66,648,954 |  | 120 |  |
| 1978/79 | 16,726,518 | 42,547,174 |  | 144 |  |
| 1979/80 | 14,685,611 | 36,614,315 | 28-36 | 152 | 11/01-05/11 |
| 1980/81 (1981) | 11,845,958 | 29,630,492 | 28-36 | 165 | 01/15-04/15 |
| 1981/82 (1982) | 4,830,980 | 11,008,779 | 12-16 | 125 | 02/15-06/15 |
| 1982/83 (1983) | 2,286,756 | 5,273,881 | 5.6 | 108 | 02/15-06/15 |
| 1983/84 (1984) | 516,877 | 1,208,223 | 7.1 | 41 | 02/15-06/15 |
| 1984/85 (1985) | 1,272,501 | 3,036,935 | 3 | 44 | 01/15-06/15 |
| 1985/86 (1986) |  |  | -clos |  |  |
| 1986/87 (1987) |  |  | ----clos |  |  |
| 1987/88 (1988) | 957,318 | 2,294,997 | 5.6 | 98 | 01/15-04/20 |
| 1988/89 (1989) | 2,894,480 | 6,982,865 | 13.5 | 109 | 01/15-05/07 |
| 1989/90 (1990) | 9,800,763 | 22,417,047 | 29.5 | 179 | 01/15-04/24 |
| 2015/16 | 16,608,625 | 40,081,555 | 42.8 | 255 | 11/20-03/25 |
| 1991/92 | 12,924,102 | 31,794,382 | 32.8 | 285 | 11/15-03/31 |
| 1992/93 | 15,265,865 | 35,130,831 | 39.2 | 294 | 11/15-03/31 |
| 1993/94 | 7,235,898 | 16,892,320 | 9.1 | 296 | 11/01-11/10, 11/20-01/01 |
| 1994/95 (1994) | 3,351,639 | 7,766,886 | 7.5 | 183 | 11/01-11/21 |
| 1995/96 (1995) | 1,877,303 | 4,233,061 | 5.5 | 196 | 11/01-11/16 |
| 1996/97 (1996) | 734,296 | 1,806,077 | 6.2 | 196 | 11/01-11/05, 11/15-11/27 |
| 1997/98-2004/05 |  |  | --clos |  |  |
| 2005/06 | 443,978 | 952,887 | 1.7 | 49 | 10/15-03/31 |
| 2006/07 | 927,086 | 2,122,589 | 3.0 | 64 | 10/15-03/31 |
| 2007/08 | 927,164 | 2,106,655 | 5.7 | 50 | 10/15-03/31 |
| 2008/09 | 830,363 | 1,939,571 | 4.3 | 53 | 10/15-03/31 |
| 2009/10 | 485,676 | 1,327,952 | 1.3 | 45 | 10/15-03/31 |
| 2010/11 |  |  | -----clos | ------------ |  |
| 2011/12 | $\qquad$ |  |  |  |  |
| 2012/13 |  |  |  |  |  |
| 2013/14 | 1,426,670 | 2,751,124 | 3.108 | 32 | 10/15-03/31 |
| 2014/15 | 7,442,931 | 13,576,105 | 15.105 | 100 | 10/15-03/31 |
| 2015/16 | 10,856,418 | 19,642,462 | 19.668 | 112 | 10/15-03/31 |
| 2016/17 | closed |  |  |  |  |

Table 3. Total bycatch (discards, 1000's t) of Tanner crab in various fisheries.

| Discards ( $\mathbf{1 , 0 0 0}$ 's t) of Tanner Crab by Fishery |  |  |  |  |  |  |  | $\begin{gathered} \text { Total Discards } \\ \left(\mathbf{1}, \mathbf{0 0}{ }^{\prime} \mathrm{s} \mathrm{t}\right) \\ \hline \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Tanner Crab |  | Snow Crab |  | Red King Crab |  | Groundfish |  |
| Year | Male | Female | Male | Female | Male | Female | All |  |
| 1973/74 |  |  |  |  |  |  | 17.735 | 17.735 |
| 1974/75 |  |  |  |  |  |  | 24.449 | 24.449 |
| 1975/76 |  |  |  |  |  |  | 9.408 | 9.408 |
| 1976/77 |  |  |  |  |  |  | 4.699 | 4.699 |
| 1977/78 |  |  |  |  |  |  | 2.776 | 2.776 |
| 1978/79 |  |  |  |  |  |  | 1.869 | 1.869 |
| 1979/80 |  |  |  |  |  |  | 3.397 | 3.397 |
| 1980/81 |  |  |  |  |  |  | 2.114 | 2.114 |
| 1981/82 |  |  |  |  |  |  | 1.474 | 1.474 |
| 1982/83 |  |  |  |  |  |  | 0.449 | 0.449 |
| 1983/84 |  |  |  |  |  |  | 0.671 | 0.671 |
| 1984/85 |  |  |  |  |  |  | 0.644 | 0.644 |
| 1985/86 |  |  |  |  |  |  | 0.399 | 0.399 |
| 1986/87 |  |  |  |  |  |  | 0.649 | 0.649 |
| 1987/88 |  |  |  |  |  |  | 0.640 | 0.640 |
| 1988/89 |  |  |  |  |  |  | 0.463 | 0.463 |
| 1989/90 |  |  |  |  |  |  | 0.671 | 0.671 |
| 1990/91 |  |  |  |  |  |  | 0.943 | 0.943 |
| 1991/92 |  |  |  |  |  |  | 2.545 | 2.545 |
| 1992/93 | 6.175 | 1.005 | 25.759 | 1.787 | 1.188 | 0.029 | 2.865 | 38.808 |
| 1993/94 | 3.870 | 1.028 | 14.530 | 1.814 | 2.967 | 0.198 | 1.511 | 25.917 |
| 1994/95 | 3.130 | 1.270 | 7.124 | 1.271 | 0.000 | 0.000 | 2.096 | 14.892 |
| 1995/96 | 2.762 | 1.760 | 4.797 | 1.759 | 0.000 | 0.000 | 1.678 | 12.756 |
| 1996/97 | 0.116 | 0.045 | 0.833 | 0.229 | 0.027 | 0.004 | 1.638 | 2.892 |
| 1997/98 | 0.000 | 0.000 | 1.750 | 0.226 | 0.165 | 0.003 | 1.531 | 3.675 |
| 1998/99 | 0.000 | 0.000 | 1.989 | 0.175 | 0.119 | 0.003 | 1.321 | 3.607 |
| 1999/00 | 0.000 | 0.000 | 0.695 | 0.145 | 0.076 | 0.004 | 0.744 | 1.665 |
| 2000/01 | 0.000 | 0.000 | 0.146 | 0.022 | 0.067 | 0.002 | 0.801 | 1.037 |
| 2001/02 | 0.000 | 0.000 | 0.323 | 0.011 | 0.043 | 0.002 | 1.070 | 1.449 |
| 2002/03 | 0.000 | 0.000 | 0.557 | 0.037 | 0.062 | 0.003 | 0.584 | 1.242 |
| 2003/04 | 0.000 | 0.000 | 0.193 | 0.026 | 0.056 | 0.003 | 0.488 | 0.767 |
| 2004/05 | 0.000 | 0.000 | 0.078 | 0.014 | 0.048 | 0.003 | 0.795 | 0.937 |
| 2005/06 | 0.462 | 0.044 | 0.968 | 0.043 | 0.042 | 0.002 | 0.603 | 2.164 |
| 2006/07 | 1.370 | 0.355 | 1.462 | 0.169 | 0.026 | 0.003 | 0.623 | 4.008 |
| 2007/08 | 2.041 | 0.097 | 1.872 | 0.102 | 0.056 | 0.009 | 0.895 | 5.073 |
| 2008/09 | 0.431 | 0.014 | 1.119 | 0.050 | 0.269 | 0.004 | 0.612 | 2.498 |
| 2009/10 | 0.071 | 0.002 | 1.324 | 0.014 | 0.150 | 0.001 | 0.377 | 1.940 |
| 2010/11 | 0.000 | 0.000 | 1.344 | 0.016 | 0.033 | 0.001 | 0.231 | 1.625 |
| 2011/12 | 0.000 | 0.000 | 2.119 | 0.014 | 0.017 | 0.000 | 0.248 | 2.398 |
| 2012/13 | 0.000 | 0.000 | 1.187 | 0.009 | 0.042 | 0.001 | 0.256 | 1.495 |
| 2013/14 | 0.387 | 0.023 | 1.832 | 0.015 | 0.113 | 0.001 | 0.447 | 2.818 |
| 2014/15 | 2.515 | 0.039 | 5.383 | 0.050 | 0.296 | 0.001 | 0.455 | 8.738 |
| 2015/16 | 3.045 | 0.059 | 3.919 | 0.017 | 0.205 | 0.006 | 0.326 | 7.576 |
| 2016/17 | 0.000 | 0.000 | 2.576 | 0.017 | 0.176 | 0.004 | 0.318 | 3.091 |

Table 4. Bycatch (discard) mortality (1000's $t$ ) of Tanner crab in various fisheries. Discard mortality was calculated assuming mortality rates of 0.321 in the crab fisheries and 0.80 in the groundfish fisheries.

| Discard Mortality (1,000's t) of Tanner Crab by Fishery |  |  |  |  |  |  |  | $\begin{array}{\|c} \hline \text { Total Discard } \\ \text { Mortality } \\ (\mathbf{1 , 0 0 0} \text { 's t) } \\ \hline \end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Tanner Crab |  | Snow Crab |  | Red King Crab |  | Groundfish |  |
| Year | Male | Female | Male | Female | Male | Female | All |  |
| 1973/74 |  |  |  |  |  |  | 14.188 | 14.188 |
| 1974/75 |  |  |  |  |  |  | 19.559 | 19.559 |
| 1975/76 |  |  |  |  |  |  | 7.526 | 7.526 |
| 1976/77 |  |  |  |  |  |  | 3.759 | 3.759 |
| 1977/78 |  |  |  |  |  |  | 2.221 | 2.221 |
| 1978/79 |  |  |  |  |  |  | 1.495 | 1.495 |
| 1979/80 |  |  |  |  |  |  | 2.718 | 2.718 |
| 1980/81 |  |  |  |  |  |  | 1.691 | 1.691 |
| 1981/82 |  |  |  |  |  |  | 1.179 | 1.179 |
| 1982/83 |  |  |  |  |  |  | 0.359 | 0.359 |
| 1983/84 |  |  |  |  |  |  | 0.537 | 0.537 |
| 1984/85 |  |  |  |  |  |  | 0.515 | 0.515 |
| 1985/86 |  |  |  |  |  |  | 0.319 | 0.319 |
| 1986/87 |  |  |  |  |  |  | 0.519 | 0.519 |
| 1987/88 |  |  |  |  |  |  | 0.512 | 0.512 |
| 1988/89 |  |  |  |  |  |  | 0.370 | 0.370 |
| 1989/90 |  |  |  |  |  |  | 0.537 | 0.537 |
| 1990/91 |  |  |  |  |  |  | 0.755 | 0.755 |
| 1991/92 |  |  |  |  |  |  | 2.036 | 2.036 |
| 1992/93 | 1.982 | 0.322 | 8.269 | 0.574 | 0.381 | 0.009 | 2.292 | 13.830 |
| 1993/94 | 1.242 | 0.330 | 4.664 | 0.582 | 0.952 | 0.063 | 1.209 | 9.043 |
| 1994/95 | 1.005 | 0.408 | 2.287 | 0.408 | 0.000 | 0.000 | 1.677 | 5.784 |
| 1995/96 | 0.887 | 0.565 | 1.540 | 0.565 | 0.000 | 0.000 | 1.342 | 4.898 |
| 1996/97 | 0.037 | 0.014 | 0.267 | 0.074 | 0.009 | 0.001 | 1.310 | 1.713 |
| 1997/98 | 0.000 | 0.000 | 0.562 | 0.073 | 0.053 | 0.001 | 1.225 | 1.913 |
| 1998/99 | 0.000 | 0.000 | 0.638 | 0.056 | 0.038 | 0.001 | 1.057 | 1.791 |
| 1999/00 | 0.000 | 0.000 | 0.223 | 0.047 | 0.025 | 0.001 | 0.595 | 0.891 |
| 2000/01 | 0.000 | 0.000 | 0.047 | 0.007 | 0.021 | 0.001 | 0.641 | 0.717 |
| 2001/02 | 0.000 | 0.000 | 0.104 | 0.004 | 0.014 | 0.001 | 0.856 | 0.977 |
| 2002/03 | 0.000 | 0.000 | 0.179 | 0.012 | 0.020 | 0.001 | 0.467 | 0.678 |
| 2003/04 | 0.000 | 0.000 | 0.062 | 0.008 | 0.018 | 0.001 | 0.391 | 0.480 |
| 2004/05 | 0.000 | 0.000 | 0.025 | 0.004 | 0.015 | 0.001 | 0.636 | 0.682 |
| 2005/06 | 0.148 | 0.014 | 0.311 | 0.014 | 0.014 | 0.001 | 0.483 | 0.983 |
| 2006/07 | 0.440 | 0.114 | 0.469 | 0.054 | 0.008 | 0.001 | 0.498 | 1.585 |
| 2007/08 | 0.655 | 0.031 | 0.601 | 0.033 | 0.018 | 0.003 | 0.716 | 2.057 |
| 2008/09 | 0.138 | 0.004 | 0.359 | 0.016 | 0.086 | 0.001 | 0.489 | 1.095 |
| 2009/10 | 0.023 | 0.001 | 0.425 | 0.005 | 0.048 | 0.000 | 0.301 | 0.803 |
| 2010/11 | 0.000 | 0.000 | 0.431 | 0.005 | 0.011 | 0.000 | 0.185 | 0.632 |
| 2011/12 | 0.000 | 0.000 | 0.680 | 0.004 | 0.006 | 0.000 | 0.199 | 0.889 |
| 2012/13 | 0.000 | 0.000 | 0.381 | 0.003 | 0.013 | 0.000 | 0.205 | 0.603 |
| 2013/14 | 0.124 | 0.007 | 0.588 | 0.005 | 0.036 | 0.000 | 0.357 | 1.119 |
| 2014/15 | 0.807 | 0.012 | 1.728 | 0.016 | 0.095 | 0.000 | 0.364 | 3.023 |
| 2015/16 | 0.977 | 0.019 | 1.258 | 0.005 | 0.066 | 0.002 | 0.261 | 2.588 |
| 2016/17 | 0.000 | 0.000 | 0.827 | 0.005 | 0.056 | 0.001 | 0.255 | 1.144 |

Table 5. Sample sizes for retained catch-at-size in the directed fishery. $\mathrm{N}=$ number of individuals. $\mathrm{N}^{`}=$ scaled sample size used in assessment. The directed fishery was closed in 2016/17.

| year | new + old shell |  |
| :---: | ---: | ---: |
|  | N | $\mathrm{N}^{\prime}$ |
| $1980 / 81$ | 13,310 | 97.8 |
| $1981 / 82$ | 11,311 | 83.1 |
| $1982 / 83$ | 13,519 | 99.3 |
| $1983 / 84$ | 1,675 | 12.3 |
| $1984 / 85$ | 2,542 | 18.7 |
| $1988 / 89$ | 12,380 | 91.0 |
| $1989 / 90$ | 4,123 | 30.3 |
| $1990 / 91$ | 120,676 | 200.0 |
| $1991 / 92$ | 126,299 | 200.0 |
| $1992 / 93$ | 125,193 | 200.0 |
| $1993 / 94$ | 71,622 | 200.0 |
| $1994 / 95$ | 27,658 | 200.0 |
| $1995 / 96$ | 1,525 | 11.2 |
| $1996 / 97$ | 4,430 | 32.6 |
| $2005 / 06$ | 705 | 5.2 |
| $2006 / 07$ | 2,940 | 21.6 |
| $2007 / 08$ | 6,935 | 51.0 |
| $2008 / 09$ | 3,490 | 25.6 |
| $2009 / 10$ | 2,417 | 17.8 |
| $2013 / 14$ | 4,760 | 35.0 |
| $2014 / 15$ | 14,055 | 103.3 |
| $2015 / 16$ | 24,420 | 200.0 |
| $2016 / 17$ | -- | - |

Table 6. Sample sizes for total catch-at-size in the directed fishery, from crab observer sampling. $\mathrm{N}=$ number of individuals. $\mathrm{N}^{`}=$ scaled sample size used in assessment.

|  | N |  |  |  |
| :---: | ---: | ---: | ---: | ---: |
| year | males | females | males | N females |
| $1991 / 92$ | 31,252 | 5,605 | 200.0 | 40.2 |
| $1992 / 93$ | 54,836 | 8,755 | 200.0 | 62.8 |
| $1993 / 94$ | 40,388 | 10,471 | 200.0 | 75.1 |
| $1994 / 95$ | 5,792 | 2,132 | 42.6 | 15.3 |
| $1995 / 96$ | 5,589 | 3,119 | 41.1 | 22.4 |
| $1996 / 97$ | 352 | 168 | 2.6 | 1.2 |
| $2005 / 06$ | 19,715 | 1,107 | 144.9 | 7.9 |
| $2006 / 07$ | 24,226 | 4,432 | 178.0 | 31.8 |
| $2007 / 08$ | 61,546 | 3,318 | 200.0 | 23.8 |
| $2008 / 09$ | 29,166 | 646 | 200.0 | 4.6 |
| $2009 / 10$ | 17,289 | 147 | 127.0 | 1.1 |
| $2013 / 14$ | 17,287 | 710 | 127.0 | 5.2 |
| $2014 / 15$ | 85,114 | 1,191 | 200.0 | 8.8 |
| $2015 / 16$ | 119,846 | 1,622 | 200.0 | 11.9 |
| $2016 / 17$ | -- | - | - | -- |

Table 7. Sample sizes for total bycatch-at-size in the snow crab fishery, from crab observer sampling. $\mathrm{N}=$ number of individuals. $\mathrm{N}^{`}=$ scaled sample size used in assessment.

| year | N |  |  |  |
| :---: | ---: | ---: | ---: | ---: |
|  | males | females | malesN' <br> females |  |
| $1992 / 93$ | 6,280 | 859 | 46.4 | 6.3 |
| $1993 / 94$ | 6,969 | 1,542 | 51.5 | 11.4 |
| $1994 / 95$ | 2,982 | 1,523 | 22.0 | 11.2 |
| $1995 / 96$ | 1,898 | 428 | 14.0 | 3.2 |
| $1996 / 97$ | 3,265 | 662 | 24.1 | 4.9 |
| $1997 / 98$ | 3,970 | 657 | 29.3 | 4.9 |
| $1998 / 99$ | 1,911 | 324 | 14.1 | 2.4 |
| $1999 / 00$ | 976 | 82 | 7.2 | 0.6 |
| $2000 / 01$ | 1,237 | 74 | 9.1 | 0.5 |
| $2001 / 02$ | 3,113 | 160 | 23.0 | 1.2 |
| $2002 / 03$ | 982 | 118 | 7.2 | 0.9 |
| $2003 / 04$ | 688 | 152 | 5.1 | 1.1 |
| $2004 / 05$ | 848 | 707 | 6.3 | 5.2 |
| $2005 / 06$ | 9,792 | 368 | 72.3 | 2.7 |
| $2006 / 07$ | 10,391 | 1,256 | 76.7 | 9.3 |
| $2007 / 08$ | 13,797 | 728 | 101.9 | 5.4 |
| $2008 / 09$ | 8,455 | 722 | 62.4 | 5.3 |
| $2009 / 10$ | 11,057 | 474 | 81.6 | 3.5 |
| $2010 / 11$ | 12,073 | 250 | 89.1 | 1.8 |
| $2011 / 12$ | 9,453 | 189 | 69.8 | 1.4 |
| $2012 / 13$ | 7,336 | 190 | 54.2 | 1.4 |
| $2013 / 14$ | 12,932 | 356 | 95.5 | 2.6 |
| $2014 / 15$ | 24,877 | 804 | 183.7 | 5.9 |
| $2015 / 16$ | 19,838 | 230 | 146.5 | 1.7 |
| $2016 / 17$ | 19,346 | 804 | 142.8 | 1.7 |

Table 8. Sample sizes for total bycatch-at-size in the BBRKC fishery, from crab observer sampling. $\mathrm{N}=$ number of individuals. $\mathrm{N}^{`}=$ scaled sample size used in assessment.

| year | N <br> females |  | malesnales <br> females |  |
| :---: | ---: | ---: | ---: | ---: |
| $1992 / 93$ | 2,056 | 105 | 15.1 | 0.8 |
| $1993 / 94$ | 7,359 | 1,196 | 54.1 | 8.8 |
| $1996 / 97$ | 114 | 5 | 0.8 | 0.0 |
| $1997 / 98$ | 1,030 | 41 | 7.6 | 0.3 |
| $1998 / 99$ | 457 | 20 | 3.4 | 0.1 |
| $1999 / 00$ | 207 | 14 | 1.5 | 0.1 |
| $2000 / 01$ | 845 | 44 | 6.2 | 0.3 |
| $2001 / 02$ | 456 | 39 | 3.4 | 0.3 |
| $2002 / 03$ | 750 | 50 | 5.5 | 0.4 |
| $2003 / 04$ | 555 | 46 | 4.1 | 0.3 |
| $2004 / 05$ | 487 | 44 | 3.6 | 0.3 |
| $2005 / 06$ | 983 | 70 | 7.3 | 0.5 |
| $2006 / 07$ | 798 | 76 | 5.9 | 0.6 |
| $2007 / 08$ | 1,399 | 91 | 10.3 | 0.7 |
| $2008 / 09$ | 3,797 | 121 | 28.0 | 0.9 |
| $2009 / 10$ | 3,395 | 72 | 25.1 | 0.5 |
| $2010 / 11$ | 595 | 30 | 4.4 | 0.2 |
| $2011 / 12$ | 344 | 4 | 2.5 | 0.0 |
| $2012 / 13$ | 618 | 48 | 4.6 | 0.4 |
| $2013 / 14$ | 2,110 | 60 | 15.6 | 0.4 |
| $2014 / 15$ | 3,110 | 32 | 23.0 | 0.2 |
| $2015 / 16$ | 2,176 | 182 | 16.1 | 1.3 |
| $2016 / 17$ | 3,048 | 245 | 22.5 | 1.8 |
|  |  |  |  |  |

Table 9. Sample sizes for total catch-at-size in the groundfish fisheries, from groundfish observer sampling. $\mathrm{N}=$ number of individuals. $\mathrm{N}^{`}=$ scaled sample size used in the assessment.

| year | N |  | N' |  |
| :---: | :---: | :---: | :---: | :---: |
|  | males | females | males | females |
| 1973/74 | 3,155 | 2,277 | 23.3 | 16.8 |
| 1974/75 | 2,492 | 1,600 | 18.4 | 11.8 |
| 1975/76 | 1,251 | 839 | 9.2 | 6.2 |
| 1976/77 | 6,950 | 6,683 | 51.3 | 49.3 |
| 1977/78 | 10,685 | 8,386 | 78.9 | 61.9 |
| 1978/79 | 18,596 | 13,665 | 137.3 | 100.9 |
| 1979/80 | 19,060 | 11,349 | 140.7 | 83.8 |
| 1980/81 | 12,806 | 5,917 | 94.5 | 43.7 |
| 1981/82 | 6,098 | 4,065 | 45.0 | 30.0 |
| 1982/83 | 13,439 | 8,006 | 99.2 | 59.1 |
| 1983/84 | 18,363 | 8,305 | 135.6 | 61.3 |
| 1984/85 | 27,403 | 13,771 | 200.0 | 101.7 |
| 1985/86 | 23,128 | 12,728 | 170.7 | 94.0 |
| 1986/87 | 14,860 | 7,626 | 109.7 | 56.3 |
| 1987/88 | 23,508 | 15,857 | 173.6 | 117.1 |
| 1988/89 | 10,586 | 7,126 | 78.2 | 52.6 |
| 1989/90 | 59,943 | 41,234 | 200.0 | 200.0 |
| 1990/91 | 23,545 | 11,212 | 173.8 | 82.8 |
| 1991/92 | 6,806 | 3,477 | 50.2 | 25.7 |
| 1992/93 | 3,027 | 1,109 | 22.3 | 8.2 |
| 1993/94 | 1,217 | 358 | 9.0 | 2.6 |
| 1994/95 | 3,628 | 1,820 | 26.8 | 13.4 |
| 1995/96 | 3,896 | 2,666 | 28.8 | 19.7 |
| 1996/97 | 8,264 | 3,375 | 61.0 | 24.9 |
| 1997/98 | 9,835 | 3,859 | 72.6 | 28.5 |
| 1998/99 | 11,937 | 4,310 | 88.1 | 31.8 |
| 1999/00 | 10,687 | 4,411 | 78.9 | 32.6 |
| 2000/01 | 12,746 | 2,988 | 94.1 | 22.1 |
| 2001/02 | 15,478 | 2,859 | 114.3 | 21.1 |
| 2002/03 | 15,208 | 3,099 | 112.3 | 22.9 |
| 2003/04 | 9,441 | 2,664 | 69.7 | 19.7 |
| 2004/05 | 13,805 | 4,441 | 101.9 | 32.8 |
| 2005/06 | 17,682 | 3,654 | 130.5 | 27.0 |
| 2006/07 | 15,855 | 3,016 | 117.1 | 22.3 |
| 2007/08 | 16,066 | 3,786 | 118.6 | 28.0 |
| 2008/09 | 26,095 | 4,185 | 192.7 | 30.9 |
| 2009/10 | 19,036 | 2,694 | 140.5 | 19.9 |
| 2010/11 | 15,122 | 2,260 | 111.6 | 16.7 |
| 2011/12 | 16,115 | 4,237 | 119.0 | 31.3 |
| 2012/13 | 12,983 | 3,080 | 95.9 | 22.7 |
| 2013/14 | 28,781 | 6,064 | 200.0 | 44.8 |
| 2014/15 | 39,119 | 4,212 | 200.0 | 31.1 |
| 2015/16 | 27,427 | 5,734 | 200.0 | 42.3 |
| 2016/17 | 17,768 | 4,193 | 131.2 | 31.0 |

Table 10. Trends in mature and total Tanner crab biomass (1000's t) in the NMFS summer bottom trawl survey.

| Observed Survey Mature Male and Female Biomass and Legal Make Abunda nce |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| Year | Mature Biomass (1000 t) |  |  | Legalmales$\left(10^{6}\right.$ crab $)$ |
|  | Make | Female | Total |  |
| 1974 | - | - | - | - |
| 1975 | 246.00 | 31.42 | 277.42 | 233.52 |
| 1976 | 126.25 | 31.16 | 157.40 | 117.83 |
| 1977 | 111.27 | 38.57 | 149.84 | 97.63 |
| 1978 | 77.91 | 25.75 | 103.66 | 66.95 |
| 1979 | 32.62 | 19.32 | 51.94 | 25.10 |
| 1980 | 86.81 | 63.78 | 150.59 | 54.20 |
| 1981 | 50.25 | 42.58 | 9283 | 28.81 |
| 1982 | 51.66 | 64.14 | 11581 | 26.14 |
| 1983 | 29.90 | 20.43 | 50.33 | 17.71 |
| 1984 | 25.80 | 14.91 | 40.72 | 14.18 |
| 1985 | 11.86 | 5.55 | 17.42 | 7.86 |
| 1986 | 13.31 | 3.37 | 16.67 | 4.81 |
| 1987 | 24.55 | 5.14 | 29.69 | 15.92 |
| 1988 | 61.01 | 25.37 | 86.38 | 35.53 |
| 1989 | 93.28 | 19.40 | 112.68 | 71.81 |
| 1990 | 97.84 | 37.69 | 135.54 | 79.15 |
| 1991 | 112.61 | 44.76 | 157.37 | 86.11 |
| 1992 | 105.50 | 26.23 | 131.72 | 92.78 |
| 1993 | 62.05 | 11.64 | 73.69 | 52.30 |
| 1994 | 43.82 | 9.85 | 53.67 | 36.49 |
| 1995 | 32.70 | 12.40 | 45.09 | 26.50 |
| 1996 | 27.53 | 9.58 | 37.11 | 22.77 |
| 1997 | 11.26 | 3.40 | 14.66 | 6.95 |
| 1998 | 10.86 | 2.28 | 13.14 | 6.09 |
| 1999 | 13.00 | 3.83 | 16.83 | 5.17 |
| 2000 | 16.88 | 4.13 | 21.01 | 10.46 |
| 2001 | 18.68 | 4.56 | 23.24 | 12.18 |
| 2002 | 18.95 | 4.47 | 23.42 | 10.88 |
| 2003 | 24.59 | 8.40 | 32.99 | 12.69 |
| 2004 | 27.04 | 4.73 | 31.77 | 11.48 |
| 2005 | 45.16 | 11.58 | 56.74 | 28.41 |
| 2006 | 67.87 | 14.94 | 8281 | 36.86 |
| 2007 | 69.50 | 13.44 | 82.93 | 34.40 |
| 2008 | 65.13 | 11.66 | 76.79 | 40.43 |
| 2009 | 38.15 | 8.48 | 46.63 | 24.71 |
| 2010 | 39.10 | 5.47 | 44.57 | 28.18 |
| 2011 | 43.27 | 5.41 | 48.68 | 28.84 |
| 2012 | 42.20 | 12.36 | 54.56 | 18.54 |
| 2013 | 67.01 | 17.85 | 84.86 | 30.33 |
| 2014 | 82.42 | 14.86 | 97.29 | 46.64 |
| 2015 | 62.95 | 11.21 | 74.16 | 43.76 |
| 2016 | 61.62 | 7.63 | 69.25 | 38.55 |
| 2017 | 50.17 | 7.11 | 57.28 | 32.71 |

Table 11. Sample sizes for NMFS survey size composition data. In the assessment model, an effective sample size of 200 is used for all survey-related compositional data.

| year | number of hauls | females |  |  |  |  |  | males |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | immature |  | mature |  |  |  | $$ |  | mature sell shell |  |  |  |
|  |  | new shell <br> number of nonzero number of hauls crab |  | new shell |  | old shell |  |  |  |  |  |  |  |
|  |  |  |  | nonzero | number of | nonzero | of |  |  | nonze | numb | nonze | mber of |
|  |  |  |  | hauls | crab | hauls | crab |  |  | hauls | crab | hauls | crab |
| 1975 | 136 | 73 | 1,040 | 91 | 1,861 | 39 | 706 | 127 | 2,895 | 127 | 3,993 | 80 | 399 |
| 1976 | 214 | 87 | 1,095 | 91 | 1,304 | 39 | 311 | 130 | 2,023 | 130 | 2,469 | 47 | 242 |
| 1977 | 155 | 66 | 765 | 76 | 1,183 | 60 | 738 | 114 | 1,778 | 114 | 1,971 | 79 | 485 |
| 1978 | 230 | 87 | 1,932 | 82 | 638 | 65 | 1,307 | 147 | 2,957 | 147 | 1,570 | 104 | 700 |
| 1979 | 307 | 71 | 725 | 62 | 735 | 42 | 341 | 138 | 1,805 | 138 | 808 | 68 | 306 |
| 1980 | 320 | 101 | 1,476 | 95 | 1,471 | 49 | 570 | 164 | 4,602 | 164 | 2,359 | 71 | 569 |
| 1981 | 305 | 71 | 579 | 79 | 1,319 | 94 | 1,206 | 158 | 3,809 | 158 | 2,293 | 116 | 886 |
| 1982 | 342 | 85 | 814 | 72 | 457 | 103 | 2,384 | 181 | 1,751 | 181 | 1,371 | 147 | 2,082 |
| 1983 | 353 | 102 | 2,108 | 56 | 201 | 102 | 2,154 | 166 | 2,484 | 166 | 983 | 132 | 1,181 |
| 1984 | 355 | 135 | 1,867 | 53 | 284 | 94 | 1,531 | 171 | 1,965 | 171 | 490 | 126 | 1,399 |
| 1985 | 353 | 140 | 846 | 52 | 228 | 65 | 601 | 179 | 1,060 | 179 | 381 | 86 | 459 |
| 1986 | 353 | 162 | 1,581 | 64 | 191 | 68 | 331 | 213 | 2,141 | 213 | 528 | 115 | 468 |
| 1987 | 355 | 189 | 4,230 | 105 | 445 | 73 | 392 | 226 | 4,659 | 226 | 1,306 | 103 | 498 |
| 1988 | 370 | 206 | 3,733 | 149 | 1,753 | 100 | 530 | 252 | 5,627 | 252 | 2,210 | 101 | 475 |
| 1989 | 373 | 204 | 3,264 | 144 | 1,241 | 108 | 882 | 237 | 4,977 | 237 | 3,201 | 135 | 1,067 |
| 1990 | 370 | 197 | 3,105 | 155 | 1,502 | 126 | 1,511 | 247 | 5,107 | 247 | 3,149 | 151 | 1,342 |
| 1991 | 371 | 159 | 2,227 | 138 | 1,283 | 141 | 2,568 | 227 | 4,361 | 227 | 2,692 | 181 | 2,893 |
| 1992 | 355 | 107 | 1,494 | 119 | 820 | 123 | 2,205 | 215 | 2,958 | 215 | 2,047 | 177 | 1,924 |
| 1993 | 374 | 99 | 865 | 96 | 545 | 122 | 1,337 | 207 | 2,051 | 207 | 1,677 | 180 | 1,865 |
| 1994 | 374 | 97 | 909 | 52 | 148 | 104 | 1,293 | 175 | 1,281 | 175 | 724 | 174 | 1,827 |
| 1995 | 375 | 113 | 830 | 35 | 140 | 107 | 1,057 | 153 | 958 | 153 | 220 | 137 | 1,611 |
| 1996 | 374 | 114 | 869 | 57 | 109 | 98 | 963 | 148 | 1,069 | 148 | 222 | 134 | 1,414 |
| 1997 | 375 | 116 | 1,325 | 62 | 168 | 83 | 504 | 161 | 1,336 | 161 | 289 | 125 | 582 |
| 1998 | 374 | 146 | 1,704 | 53 | 160 | 73 | 344 | 176 | 2,032 | 176 | 396 | 128 | 624 |
| 1999 | 372 | 137 | 2,608 | 52 | 255 | 85 | 510 | 170 | 2,816 | 170 | 550 | 124 | 567 |
| 2000 | 371 | 142 | 2,249 | 61 | 242 | 55 | 345 | 188 | 2,836 | 188 | 628 | 133 | 653 |
| 2001 | 374 | 164 | 3,675 | 83 | 364 | 72 | 644 | 211 | 4,036 | 211 | 629 | 145 | 817 |
| 2002 | 374 | 154 | 3,583 | 81 | 350 | 70 | 500 | 186 | 3,912 | 186 | 458 | 154 | 1,089 |
| 2003 | 375 | 153 | 2,830 | 111 | 923 | 83 | 752 | 203 | 4,754 | 203 | 900 | 153 | 1,349 |
| 2004 | 374 | 173 | 3,563 | 90 | 427 | 80 | 656 | 236 | 4,568 | 236 | 1,027 | 179 | 1,873 |
| 2005 | 372 | 201 | 3,349 | 103 | 634 | 74 | 928 | 254 | 4,496 | 254 | 1,280 | 185 | 1,753 |
| 2006 | 375 | 210 | 4,355 | 143 | 1,332 | 125 | 1,327 | 254 | 6,224 | 254 | 1,757 | 211 | 4,054 |
| 2007 | 375 | 185 | 2,420 | 138 | 1,311 | 136 | 1,396 | 261 | 4,697 | 261 | 1,982 | 201 | 2,907 |
| 2008 | 374 | 153 | 1,747 | 104 | 580 | 120 | 1,783 | 240 | 3,127 | 240 | 2,116 | 196 | 2,146 |
| 2009 | 375 | 171 | 2,408 | 75 | 363 | 115 | 1,317 | 216 | 2,879 | 216 | 1,144 | 187 | 1,954 |
| 2010 | 375 | 186 | 3,171 | 67 | 245 | 104 | 941 | 223 | 3,654 | 223 | 1,268 | 166 | 1,702 |
| 2011 | 375 | 193 | 5,044 | 90 | 471 | 102 | 705 | 210 | 6,095 | 210 | 1,115 | 167 | 1,941 |
| 2012 | 375 | 195 | 3,577 | 100 | 942 | 97 | 720 | 215 | 5,526 | 215 | 1,564 | 139 | 1,296 |
| 2013 | 375 | 163 | 2,900 | 116 | 1,417 | 101 | 1,002 | 207 | 5,592 | 207 | 2,675 | 137 | 1,344 |
| 2014 | 375 | 165 | 2,207 | 98 | 482 | 121 | 1,584 | 222 | 4,746 | 222 | 3,286 | 167 | 2,829 |
| 2015 | 375 | 118 | 1,455 | 60 | 445 | 94 | 1,363 | 225 | 2,737 | 225 | 1,859 | 200 | 2,817 |
| 2016 | 375 | 110 | 1,372 | 56 | 370 | 82 | 1,248 | 222 | 2,235 | 222 | 1,170 | 218 | 3,668 |
| 2017 | 375 | 129 | 2,027 | 50 | 213 | 99 | 1,125 | 185 | 2,233 | 185 | 423 | 204 | 3,529 |

Table 12. Effort data (1000's potlifts) in the snow crab and BBRKC fisheries.

| Effort (1000's Potlifts) |  |  | Effort (1000's Potlifts) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Year | BBRKC Fishery | Snow Crab Fishery | Year | BBRKC Fishery | Snow Crab Fishery |
| 1951/52 |  |  | 1986/87 | 175.753 | 616.113 |
| 1952/53 |  |  | 1987/88 | 220.971 | 747.395 |
| 1953/54 | 30.083 | - | 1988/89 | 146.179 | 665.242 |
| 1954/55 | 17.122 | - | 1989/90 | 205.528 | 912.718 |
| 1955/56 | 28.045 | - | 1990/91 | 262.761 | 1382.908 |
| 1956/57 | 41.629 | - | 1991/92 | 227.555 | 1278.502 |
| 1957/58 | 23.659 | - | 1992/93 | 206.815 | 969.209 |
| 1958/59 | 27.932 | - | 1993/94 | 254.389 | 716.524 |
| 1959/60 | 22.187 | - | 1994/95 | 0.697 | 507.603 |
| 1960/61 | 26.347 | - | 1995/96 | 0.547 | 520.685 |
| 1961/62 | 72.646 | - | 1996/97 | 77.081 | 754.14 |
| 1962/63 | 123.643 | - | 1997/98 | 91.085 | 930.794 |
| 1963/64 | 181.799 | - | 1998/99 | 145.689 | 945.533 |
| 1964/65 | 180.809 | - | 1999/00 | 151.212 | 182.634 |
| 1965/66 | 127.973 | - | 2000/01 | 104.056 | 191.2 |
| 1966/67 | 129.306 | - | 2001/02 | 66.947 | 326.977 |
| 1967/68 | 135.283 | - | 2002/03 | 72.514 | 153.862 |
| 1968/69 | 184.666 | - | 2003/04 | 134.515 | 123.709 |
| 1969/70 | 175.374 | - | 2004/05 | 97.621 | 75.095 |
| 1970/71 | 168.059 | - | 2005/06 | 116.32 | 117.375 |
| 1971/72 | 126.305 | - | 2006/07 | 72.404 | 86.288 |
| 1972/73 | 208.469 | - | 2007/08 | 113.948 | 140.857 |
| 1973/74 | 194.095 | - | 2008/09 | 139.937 | 163.537 |
| 1974/75 | 212.915 | - | 2009/10 | 118.521 | 136.477 |
| 1975/76 | 205.096 | - | 2010/11 | 131.627 | 147.244 |
| 1976/77 | 321.01 | - | 2011/12 | 45.166 | 270.602 |
| 1977/78 | 451.273 | - | 2012/13 | 38.159 | 225.489 |
| 1978/79 | 406.165 | 190.746 | 2013/14 | 45.927 | 225.245 |
| 1979/80 | 315.226 | 255.102 | 2014/15 | 57.725 | 279.183 |
| 1980/81 | 567.292 | 435.742 | 2015/16 | 48.665 | 199.133 |
| 1981/82 | 536.646 | 469.091 | 2016/17 | 33.165 | 118.548 |

Table 13.Non-selectivity parameters estimated within $1 \%$ of bounds.

| category | name | case | test | bound description |
| :---: | :---: | :---: | :---: | :---: |
| fisheries | plgtRet[1] | B2a | at upper bound | 15 |
|  |  | B2b | at upper bound | 15 TCF: logit-scale max retention (pre-1997) |
|  |  | B3 | at upper bound | 15 |
| population processes | pGrA[1] | B1 | at lower bound | 0.3 a coefficient, males |
|  |  | B0 | at upper bound | 0.7 |
|  | pGrA[2] | B0. 2016 | at upper bound | 0.7 a coefficient, females |
|  |  | B1 | at upper bound | 0.7 |
|  | pGrBeta[1] | B1c | at lower bound | $0.5$ |
|  | pGrBeta[1] | B3 | at lower bound | 0.5 growth scale parameter |
|  | pLgtPrM2M[1] | B0 | at upper bound | 15 |
|  |  | B0.2016 | at upper bound | 15 |
|  |  | B0a | at upper bound | 15 |
|  |  | B1 | at upper bound | 15 |
|  |  | B1a | at upper bound | 15 |
|  |  | B1b | at upper bound | 15 pr (terminal molt, males) |
|  |  | B1c | at upper bound | 15 |
|  |  | B2 | at upper bound | 15 |
|  |  | B2a | at upper bound | 15 |
|  |  | B2b | at upper bound | 15 |
|  |  | B3 | at upper bound | 15 |
|  | pLgtPrM2M[2] | B0 | at lower bound | -15 |
|  |  | B0.2016 | at lower bound | -15 |
|  |  | B0a | at lower bound | -15 |
|  |  | B1 | at lower bound | -15 |
|  |  | B1a | at lower bound | -15 |
|  |  | B1b | at lower bound | -15 pr(terminal molt, females) |
|  |  | B1c | at lower bound | -15 |
|  |  | B2 | at lower bound | -15 |
|  |  | B2a | at lower bound | -15 |
|  |  | B2b | at lower bound | -15 |
|  |  | B3 | at lower bound | -15 |
| surveys | pLnQ[1] | B0 | at lower bound | -0.693 |
|  |  | B0.2016 | at lower bound | -0.693 |
|  |  | B0a | at lower bound | -0.693 |
|  |  | B1 | at lower bound | -0.693 |
|  |  | B1a | at lower bound | -0.693 |
|  |  | B1b | at lower bound | -0.693 NMFS survey Q: males, pre-1982 |
|  |  | B1c | at lower bound | -0.693 |
|  |  | B2 | at lower bound | -0.693 |
|  |  | B2a | at lower bound | -0.693 |
|  |  | B2b | at lower bound | -0.693 |
|  |  | B3 | at lower bound | -0.693 |
|  | pLnQ[3] | B0 | at lower bound | -0.693 |
|  |  | B0.2016 | at lower bound | -0.693 |
|  |  | B0a | at lower bound | -0.693 |
|  |  | B1 | at lower bound | -0.693 |
|  |  | B1a | at lower bound | -0.693 |
|  |  | B1b | at lower bound | -0.693 NMFS survey Q: females, pre-1982 |
|  |  | B1c | at lower bound | -0.693 |
|  |  | B2 | at lower bound | -0.693 |
|  |  | B2a | at lower bound | -0.693 |
|  |  | B2b | at lower bound | -0.693 |
|  |  | B3 | at lower bound | -0.693 |

Table 14.Selectivity-related parameters estimated within $1 \%$ of bounds.

| name | case | test | bound | label |
| :---: | :---: | :---: | :---: | :---: |
| pS1[1] | B1c | at upper bound | 90 | z50 for NMFS survey selectivity (males, pre-1982) |
| pS1[19] | B0a | at lower bound | 40 | z50 for GTF.AllGear selectivity (males, pre-1987) |
| pS1[20] | B0 | at lower bound | 40 | z50 for GTF.AllGear selectivity (males, 1987-1996) |
|  | B0.2016 | at lower bound | 40 |  |
|  | B0a | at lower bound | 40 |  |
|  | B1 | at lower bound | 40 |  |
|  | B1a | at lower bound | 40 |  |
|  | B1b | at lower bound | 40 |  |
|  | B1c | at lower bound | 40 |  |
|  | B2 | at lower bound | 40 |  |
|  | B2a | at lower bound | 40 |  |
|  | B2b | at lower bound | 40 |  |
| pS1[22] | B3 | at upper bound | 180 | z95 for RKF selectivity (males, 1997-2004) |
| pS1[23] | B0 | at upper bound | 150 | z50 for RKF selectivity (males, 1997-2004) |
|  | B0. 2016 | at upper bound | 150 |  |
|  | B0a | at upper bound | 150 |  |
|  | B1 | at upper bound | 150 |  |
|  | B1a | at upper bound | 150 |  |
|  | B1b | at upper bound | 180 |  |
|  | B1c | at upper bound | 180 |  |
|  | B2 | at upper bound | 180 | z95 for RKF selectivity (males, 1997-2004) |
|  | B2a | at upper bound | 180 |  |
|  | B2b | at upper bound | 180 |  |
|  | B3 | at upper bound | 180 | z95 for RKF selectivity (males, 2005+) |
| pS1[24] | B0 | at upper bound | 150 | z50 for RKF selectivity (males, 2005+) |
|  | B0. 2016 | at upper bound | 150 |  |
|  | B0a | at upper bound | 150 |  |
|  | B1 | at upper bound | 150 |  |
|  | B1a | at upper bound | 150 |  |
|  | B1b | at upper bound | 180 |  |
|  | B1c | at upper bound | 180 |  |
|  | B2 | at upper bound | 180 |  |
|  | B2a | at upper bound | 180 |  |
|  | B2b | at upper bound | 180 |  |
| pS1[25] | B0a | at upper bound | 150 | z50 for RKF selectivity (females, pre-1997) |
| pS1[26] | B3 | at upper bound | 140 | z95 for RKF selectivity (females, 2005+) |
| pS1[27] | B0 | at upper bound | 170 | 250 for RKF selectivity (females, 2005+) |
|  | B1 | at upper bound | 170 |  |
|  | B1a | at upper bound | 170 |  |
|  | B1b | at upper bound | 140 |  |
|  | B1c | at upper bound | 140 |  |
|  | B2 | at upper bound | 140 |  |
|  | B2a | at upper bound | 140 |  |
|  | B2b | at upper bound | 140 |  |
| pS1[29] | B3 | at lower bound | 40 | z50 for GTF.AllGear selectivity (females, pre-1987) |
| pS1[30] | B3 | at lower bound | 40 | z50 for GTF.AllGear selectivity (females, 1987-1990) |
| pS1[33] | B3 | at upper bound | 120 | z50 for GTF.FixedGear selectivity (females, 1991-1996) |
| pS1[4] | B3 | at lower bound | -50 | z50 for NMFS survey selectivity (females, 1982+) |
| pS2[1] | B3 | at upper bound | 100 | z95-z50 for NMFS survey selectivity (males, pre-1982) |
| pS2[2] | B1c | at upper bound | 100 | z95-z50 for NMFS survey selectivity (males, 1982+) |
| pS2[4] | B0 | at upper bound | 100 | z95-z50 for NMFS survey selectivity (females, 1982+) |
|  | B0.2016 | at upper bound | 100 |  |
|  | B1 | at upper bound | 100 |  |
|  | B1a | at upper bound | 100 |  |
|  | B1b | at upper bound | 100 |  |
|  | B1c | at upper bound | 100 |  |
|  | B2 | at upper bound | 100 |  |
|  | B2a | at upper bound | 100 |  |
|  | B2b | at upper bound | 100 |  |
|  | B3 | at upper bound | 100 |  |
| pS3[4] | B3 | at upper bound | 4.5 | $\ln (\mathrm{dz50}$-az50) for GTF.FixedGear selectivity (males, 1991-1996) |
| pS4[1] | B0 | at upper bound | 0.5 | descending slope for SCF selectivity (males, pre-1997) |
|  | B0.2016 | at upper bound | 0.5 |  |
|  | B0a | at upper bound | 0.5 |  |
|  | B1 | at upper bound | 0.5 |  |
|  | B1a | at upper bound | 0.5 |  |
|  | B1b | at upper bound | 0.5 |  |
|  | B1c | at upper bound | 0.5 |  |
|  | B2b | at upper bound | 0.5 |  |
|  | B3 | at upper bound | 0.5 |  |
| pS4[4] | B3 | at upper bound | 0.5 | descending slope for GTF.FixedGear selectivity (males, 1991-1996) |
| pS4[5] | B3 | at lower bound | 0.1 | descending slope for GTF.FixedGear selectivity (males, 1997+) |

Table 15. Comparison of estimated growth and natural mortality parameters for all model scenarios.


Table 16. Comparison of recruitment parameter estimates from all model scenarios.


Table 17. Comparison of logit-scale parameters for the probability of terminal molt.


Table 18. Comparison of NMFS survey catchability parameters for all model scenarios.

|  | - |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 0.63 |  |  | ama |  |  |  |  | , 6 as |  |  | diavo | dich |  |  |  |  | ana | 0, | amo | ${ }^{6}$ |  |
| survey: males, $1982+$ | ${ }_{\text {a }}$ |  | ${ }^{0.333}$ | $\xrightarrow{\text { no.as }}$ | - | ${ }^{\text {a,ams }}$ | ${ }_{0}^{0.363}$ | ${ }_{\text {a }}^{\text {a }}$ | ${ }_{\text {a }}^{0.3588}$ |  | ${ }_{\text {a }}^{0.35}$ |  | ${ }_{0}^{0.524}$ | anas) | ${ }_{0}^{0.371}$ | ${ }_{0}^{0.052}$ | 0.418 | ${ }_{0}^{0.035}$ | 0.433 | ${ }^{\text {a.ase }}$ | ${ }^{0.488}$ | a, |
|  | 0.709 | a,06 | ${ }_{0}^{0.091}$ |  | ${ }^{0}$ | ${ }_{\text {and }}$ |  | ${ }_{\text {and }}^{\text {anden }}$ | ${ }_{\text {a }}^{0.083}$ | $\xrightarrow{\text { anamo }}$ | cose | ${ }_{\text {a }}^{\substack{\text { ancas }}}$ | ${ }_{\text {-1.as }}$ | ${ }_{\text {a }}^{\text {and }}$ | ${ }_{0}^{0.0 .83}$ | $\xrightarrow{\text { anamo }}$ | ${ }_{\text {a }}^{0}$ | ${ }_{\text {and }}^{\substack{\text { a.ano } \\ \text { and }}}$ | ${ }^{\text {and }}$ | 0 |  |  |

Table 19. Comparison of NMFS survey selectivity parameters for all model scenarios.


Table 20. Comparison of fishery capture rate and max retention parameter estimates for all fisheries for all model scenarios.


Table 21. Comparison of selectivity and retention function parameter estimates for the directed Tanner crab fishery (TCF) for all model scenarios.


Table 22. Comparison of selectivity parameter estimates for the snow crab fishery (SCF) for all model scenarios.


Table 23. Comparison of selectivity parameter estimates for the BBRKC fishery (RKF) for all model scenarios.


Table 24. Comparison of selectivity parameter estimates for the groundfish fisheries (GTF) for all model scenarios.


Table 25. Objective function data components from the model scenarios. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: BBRKC fishery; GTF: groundfish fisheries.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

Table 26. Differences between objective function data components from the model scenarios. TCF: directed Tanner crab fishery; SCF: snow crab fishery; RKF: BBRKC fishery; GTF: groundfish fisheries. Green highlights indicate differences smaller than -5 likelihood units. Red highlights indicate differences greater than 5 likelihood units.

| category | fleet | catch.type | data.type | x | maturity | B0-80.2016 | B0a-B0 | B1-80a | B1a-81 | B1b-B1a | B1c-B1b | B2-81b | B2a-B2 | B2b-B2a | B3-82b |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| effort data | RKF | fishery |  | all sexes | all maturity states | 93.81 | 1.27 | 13.32 | 0.69 | 12.16 | 6.42 | 38.16 | -23.40 | -4.93 | -26.42 |
| effort data | SCF | fishery |  | all sexes | all maturity states | 55.83 | -13.48 | 34.21 | -5.96 | -0.37 | 82.09 | 32.60 | -20.05 | -28.22 | 36.87 |
| fisheres data | GT.FFixedGear | total catch | abundance | all sexes | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.36 |
| fisheries data | GT.FFixedGear | total catch | biomass | all sexes | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.30 |
| fisheries data | GT.FFixedGear | total catch | n.at. 2 | female | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9.10 |
| fisheries data | GTF.fixedGear | total catch | n.at. 2 | male | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.31 |
| fisheres data | GTF.Trawl Gear | total catch | abundance | all sexes | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 3.60 |
| fisheries data | GTF.TrawlGear | total catch | biomass | all sexes | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.87 |
| fisheries data | GTF.Trawl Gear | total catch | n.at. 2 | female | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 14.65 |
| fisheries data | GTF.TTawlGear | total catch | n.at. 2 | male | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 9.62 |
| fisheries data | GTF.All ${ }^{\text {ear }}$ | total catch | abundance | all sexes | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| fisheries data | GTF.AllGear | total catch | biomass | all sexes | all maturity states | -0.37 | 0.02 | -0.08 | 0.01 | 0.00 | -0.10 | 0.01 | -0.01 | 0.00 | -1.14 |
| fisheries data | GTF.AllGear | total catch | n.at.z | female | all maturity states | 41.65 | 2.87 | 0.17 | 0.91 | 0.01 | 6.05 | 1.03 | 0.16 | 0.85 | -233.63 |
| fisheries data | GTF.All $e a r$ | total catch | n.at.z | male | all maturity states | 8.33 | -2.82 | 8.40 | -0.57 | 0.10 | 13.98 | 1.62 | -0.03 | 2.00 | -261.01 |
| fisheries data | RKF | total catch | abundance | female | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| fisheries data | RKF | total catch | abundance | male | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| fisheries data | RKF | total catch | biomass | female | all maturity states | -0.02 | 0.11 | -0.14 | 0.00 | 0.00 | -0.01 | -0.01 | 0.00 | 0.00 | -0.01 |
| fisheries data | RKF | total catch | biomass | male | all maturity states | 0.33 | -0.02 | 0.15 | 0.02 | 0.26 | 0.06 | 0.54 | -0.21 | -0.12 | -0.43 |
| fisheries data | RKF | total catch | n.at. 2 | female | all maturity states | 0.72 | 0.09 | -0.11 | 0.00 | 0.04 | 0.01 | -0.01 | 0.01 | 0.00 | -0.01 |
| fisheries data | RKF | total catch | n.at. 2 | male | all maturity states | 6.63 | -0.61 | 2.55 | -0.21 | 1.06 | 1.18 | 4.33 | -3.82 | 0.23 | -1.38 |
| fisheries data | SCF | total catch | abundance | female | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| fisheries data | SCF | total catch | abundance | male | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| fisheries data | SCF | total catch | biomass | female | all maturity states | -0.13 | 0.13 | 0.65 | 0.05 | -0.01 | 1.68 | 0.42 | 0.23 | 0.23 | -0.29 |
| fisheries data | SCF | total catch | biomass | male | all maturity states | 0.17 | 0.00 | -0.06 | 0.00 | 0.00 | -0.09 | -0.06 | 0.04 | 0.02 | -0.09 |
| fisheries data | SCF | total catch | n.at.z | female | all maturity states | 0.08 | -0.04 | -0.15 | -0.01 | 0.00 | -0.06 | -0.09 | 0.09 | 0.08 | -0.74 |
| fisheries data | SCF | total catch | n.at. 2 | male | all maturity states | 3.20 | -0.33 | -1.91 | -0.44 | -0.01 | -1.56 | 0.17 | -0.02 | 1.22 | -3.93 |
| fisheries data | TCF | retained catch | abundance | female | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| fisheres data | TCF | retained catch | abundance | male | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| fisheres data | TCF | retained catch | biomass | female | all maturity states | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| fisheries data | TCF | retained catch | biomass | male | all maturity states | -0.78 | -0.13 | 1.65 | -0.08 | 0.01 | 3.20 | -29.62 | -5.69 | 7.89 | -2.08 |
| fisheres data | TCF | retained catch | n.at.z | male | all maturity states | 4.48 | -0.39 | 2.56 | -0.48 | 0.01 | -5.95 | -187.16 | -6.74 | -8.85 | -6.34 |
| fisheries data | TCF | total catch | biomass | female | all maturity states | -1.25 | 0.42 | 0.65 | 0.10 | 0.03 | 1.90 | -23.66 | 26.71 | 5.24 | -0.90 |
| fisheries data | TCF | total catch | biomass | male | all maturity states | -0.41 | -0.11 | 0.69 | -0.06 | 0.00 | 1.15 | -12.14 | 0.20 | 1.91 | -0.31 |
| fisheries data | TCF | total catch | n.at.z | female | all maturity states | -0.14 | 0.48 | -0.19 | 0.07 | -0.01 | 0.12 | -0.21 | 0.24 | 0.02 | -0.03 |
| fisheres data | TCF | total catch | n.at. 2 | male | all maturity states | -2.85 | 1.77 | -3.65 | 0.72 | 0.00 | -5.02 | -12.63 | 0.08 | 12.23 | 0.07 |
| growth data |  |  | EBS | female | immature | 0.00 | 0.00 | 127.32 | 0.19 | -0.05 | 2,201.11 | 1.21 | -1.35 | -0.40 | -9.85 |
| growth data |  |  | EBS | male | immature | 0.00 | 0.00 | 191.47 | 0.19 | -0.13 | 2,957.73 | 2.04 | -3.01 | 0.04 | -20.02 |
| surves data | NMFS trawl survey | index catch | biomass | female | mature | -1.76 | -1.58 | 9.44 | -0.19 | 0.06 | 9.56 | -0.97 | 1.91 | 0.16 | 12.60 |
| surveys data | NMFS trawl survey | index catch | biomass | male | mature | 3.36 | -1.74 | 14.00 | -0.36 | 0.01 | 26.23 | -0.35 | 1.53 | -0.80 | -25.75 |
| survess data | NMFS trawl survey | index catch | n.at. 2 | female | immature | 2.13 | -19.03 | -18.12 | -5.83 | 0.10 | -25.57 | 3.66 | -1.48 | 0.13 | 2.42 |
| surveys data | NMFS traw survey | index catch | n.at.z | female | mature | 10.30 | -1.50 | 38.16 | 0.78 | 0.24 | 53.38 | -0.56 | 1.13 | -0.50 | -40.96 |
| survey data | NMFS trawl survey | index catch | n.at.z | male | immature | 19.33 | 9.24 | -59.01 | 3.78 | -0.34 | -27.74 | 7.20 | -7.95 | 2.73 | 34.18 |
| surveys data | NMFS trawl survey | index catch | n.at.z | male | mature | -4.92 | 2.73 | 34.84 | 0.29 | -0.29 | 25.90 | -5.36 | 1.39 | -3.24 | -23.68 |

Table 27. Effective sample sizes used for NMFS EBS trawl survey size composition data for the 2016 assessment model (2016AM) and the author's preferred model (Model B2b). Effective sample sizes were estimated using the McAllister-Ianelli approach.

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Table 28. Effective sample sizes used for retained catch size composition data from the directed fishery for the 2016 assessment model (2016AM) and the author's preferred model (Model B2b). Effective sample sizes were estimated using the McAllister-Ianelli approach.

| year | 2016AM <br> input <br> effective |  | Model B2b <br> input <br> effective |  |
| :--- | ---: | ---: | ---: | ---: |
| 1980 | 97.8 | 20.2 | 97.8 | 26.0 |
| 1981 | 83.1 | 805.1 | 83.1 | 1690.2 |
| 1982 | 99.3 | 1622.3 | 99.3 | 1469.8 |
| 1983 | 12.3 | 50.3 | 12.3 | 48.9 |
| 1984 | 18.7 | 342.1 | 18.7 | 476.3 |
| 1988 | 91.0 | 141.1 | 91.0 | 134.8 |
| 1989 | 30.3 | 1042.2 | 30.3 | 1665.1 |
| 1990 | 200.0 | 263.6 | 200.0 | 267.8 |
| 1991 | 200.0 | 20.7 | 200.0 | 154.8 |
| 1992 | 200.0 | 17.8 | 200.0 | 96.0 |
| 1993 | 200.0 | 23.2 | 200.0 | 138.2 |
| 1994 | 200.0 | 47.8 | 200.0 | 149.2 |
| 1995 | 11.2 | 15.5 | 11.2 | 186.9 |
| 1996 | 32.6 | 12.6 | 32.6 | 185.5 |
| 2005 | 5.2 | 6.6 | 5.2 | 14.2 |
| 2006 | 21.6 | 15.0 | 21.6 | 303.6 |
| 2007 | 51.0 | 17.0 | 51.0 | 1927.1 |
| 2008 | 25.6 | 19.3 | 25.6 | 967.2 |
| 2009 | 17.8 | 70.6 | 17.8 | 128.0 |
| 2013 | 35.0 | 141.1 | 35.0 | 705.1 |
| 2014 | 103.3 | 34.5 | 103.3 | 209.2 |
| 2015 | 200.0 | 39.3 | 200.0 | 157.8 |

Table 29. Effective sample sizes used for total catch size composition data from the directed fishery for the 2016 assessment model (2016AM) and the author’s preferred model (Model B2b). Effective sample sizes were estimated using the McAllister-Ianelli approach.

| year | 2016AM |  |  |  | Model B2b |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | female input effective |  | male |  | female |  | male |  |
|  |  |  | input | effective | input | effective | input | ective |
| 1991 | 41.2 | 322.9 | 200.0 | 12.0 | 41.2 | 512.9 | 200.0 | 1325.1 |
| 1992 | 64.3 | 940.8 | 200.0 | 13.3 | 64.3 | 459.3 | 200.0 | 120.2 |
| 1993 | 76.9 | 296.2 | 200.0 | 12.9 | 76.9 | 346.3 | 200.0 | 266.9 |
| 1994 | 15.7 | 78.7 | 42.6 | 10.9 | 15.7 | 58.5 | 42.6 | 592.5 |
| 1995 | 22.9 | 152.1 | 41.1 | 80.8 | 22.9 | 90.4 | 41.1 | 298.0 |
| 1996 | 2.5 | 149.0 | 5.0 | 37.2 | 2.5 | 261.0 | 5.0 | 30.9 |
| 2005 | 8.1 | 34.3 | 144.9 | 7.8 | 8.1 | 39.4 | 144.9 | 97.5 |
| 2006 | 32.6 | 279.0 | 178.0 | 65.0 | 32.6 | 422.5 | 178.0 | 287.6 |
| 2007 | 24.4 | 310.7 | 200.0 | 10.2 | 24.4 | 317.5 | 200.0 | 374.4 |
| 2008 | 4.7 | 41.7 | 200.0 | 13.8 | 4.7 | 45.8 | 200.0 | 1150.1 |
| 2009 | 1.1 | 28.2 | 127.0 | 10.9 | 1.1 | 24.4 | 127.0 | 164.7 |
| 2013 | 5.2 | 82.1 | 127.0 | 15.7 | 5.2 | 64.7 | 127.0 | 1339.7 |
| 2014 | 8.8 | 208.1 | 200.0 | 7.6 | 8.8 | 188.6 | 200.0 | 199.5 |
| 2015 | 11.9 | 69.6 | 200.0 | 6.1 | 11.9 | 73.0 | 200.0 | 127.6 |

Table 30. Effective sample sizes used for bycatch size composition data from the snow crab fishery for the 2016 assessment model (2016AM) and the author’s preferred model (Model B2b). Effective sample sizes were estimated using the McAllister-Ianelli approach.

| year | 2016AM |  |  |  | Model B2b |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | female input effective |  | male |  | female input effective |  | male input effective |  |
| 1992 | 6.3 | 16.5 | 46.1 | 185.3 | 6.3 | 18.3 | 46.1 | 191.7 |
| 1993 | 11.3 | 27.4 | 51.2 | 170.8 | 11.3 | 30.7 | 51.2 | 118.1 |
| 1994 | 11.2 | 49.6 | 21.9 | 42.6 | 11.2 | 40.7 | 21.9 | 38.1 |
| 1995 | 3.1 | 38.1 | 13.9 | 122.2 | 3.1 | 41.8 | 13.9 | 87.3 |
| 1996 | 4.9 | 36.2 | 24.0 | 290.7 | 4.9 | 46.1 | 24.0 | 281.4 |
| 1997 | 4.8 | 134.6 | 29.2 | 345.9 | 4.8 | 111.2 | 29.2 | 446.9 |
| 1998 | 2.4 | 19.5 | 14.0 | 617.1 | 2.4 | 21.4 | 14.0 | 1013.9 |
| 1999 | 0.6 | 27.6 | 7.2 | 134.1 | 0.6 | 30.2 | 7.2 | 131.6 |
| 2000 | 0.5 | 29.9 | 9.1 | 224.8 | 0.5 | 30.5 | 9.1 | 273.2 |
| 2001 | 1.2 | 139.0 | 22.9 | 1123.1 | 1.2 | 121.1 | 22.9 | 558.4 |
| 2002 | 0.9 | 45.2 | 7.2 | 61.9 | 0.9 | 45.4 | 7.2 | 59.5 |
| 2003 | 1.1 | 43.8 | 5.1 | 102.8 | 1.1 | 44.8 | 5.1 | 109.2 |
| 2004 | 5.2 | 30.1 | 6.2 | 24.5 | 5.2 | 30.6 | 6.2 | 23.0 |
| 2005 | 2.7 | 95.1 | 72.0 | 127.4 | 2.7 | 158.0 | 72.0 | 122.6 |
| 2006 | 9.2 | 33.6 | 76.4 | 86.8 | 9.2 | 51.8 | 76.4 | 77.1 |
| 2007 | 5.3 | 28.8 | 101.4 | 455.6 | 5.3 | 45.6 | 101.4 | 380.5 |
| 2008 | 5.3 | 18.4 | 62.1 | 92.9 | 5.3 | 14.7 | 62.1 | 95.9 |
| 2009 | 3.5 | 31.0 | 81.2 | 430.0 | 3.5 | 20.6 | 81.2 | 456.1 |
| 2010 | 1.8 | 87.0 | 88.7 | 339.6 | 1.8 | 74.0 | 88.7 | 370.0 |
| 2011 | 1.4 | 53.7 | 69.5 | 186.9 | 1.4 | 61.7 | 69.5 | 231.5 |
| 2012 | 1.4 | 49.1 | 53.9 | 139.7 | 1.4 | 46.5 | 53.9 | 205.9 |
| 2013 | 2.6 | 128.8 | 95.0 | 222.5 | 2.6 | 210.5 | 95.0 | 248.2 |
| 2014 | 5.9 | 118.9 | 182.8 | 525.0 | 5.9 | 65.1 | 182.8 | 537.6 |
| 2015 | 1.7 | 61.8 | 145.8 | 475.2 | 1.7 | 111.3 | 146.5 | 519.1 |
| 2016 |  |  |  |  | 1.7 | 115.7 | 142.8 | 448.6 |

Table 31. Effective sample sizes used for bycatch size composition data from the BBRKC fishery for the 2016 assessment model (2016AM) and the author’s preferred model (Model B2b). Effective sample sizes were estimated using the McAllister-Ianelli approach.

| year | 2016AM |  |  |  | Model B2b |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | female input effective |  | male input effective |  | female input effective |  | male input effective |  |
| 1992 | 0.8 | 47.2 | 15.1 | 154.7 | 0.8 | 83.0 | 15.1 | 34.6 |
| 1993 | 8.8 | 326.2 | 54.1 | 432.7 | 8.8 | 279.5 | 54.1 | 34.7 |
| 1996 | 0.0 | 3.8 | 0.8 | 60.8 | 0.0 | 3.4 | 0.8 | 13.2 |
| 1997 | 0.3 | 17.3 | 7.6 | 24.7 | 0.3 | 24.3 | 7.6 | 20.3 |
| 1998 | 0.1 | 19.3 | 3.4 | 67.2 | 0.1 | 20.9 | 3.4 | 58.3 |
| 1999 | 0.1 | 16.6 | 1.5 | 63.0 | 0.1 | 17.4 | 1.5 | 50.3 |
| 2000 | 0.3 | 37.0 | 6.2 | 190.0 | 0.3 | 40.4 | 6.2 | 130.2 |
| 2001 | 0.3 | 46.9 | 3.4 | 131.0 | 0.3 | 50.5 | 3.4 | 112.0 |
| 2002 | 0.4 | 45.9 | 5.5 | 110.4 | 0.4 | 36.4 | 5.5 | 85.5 |
| 2003 | 0.3 | 49.0 | 4.1 | 76.5 | 0.3 | 53.5 | 4.1 | 57.0 |
| 2004 | 0.3 | 22.2 | 3.6 | 41.5 | 0.3 | 20.6 | 3.6 | 31.1 |
| 2005 | 0.5 | 8.2 | 7.2 | 38.4 | 0.5 | 12.7 | 7.2 | 37.8 |
| 2006 | 0.6 | 19.7 | 5.9 | 20.1 | 0.6 | 23.9 | 5.9 | 20.3 |
| 2007 | 0.7 | 64.9 | 10.3 | 79.0 | 0.7 | 102.1 | 10.3 | 73.0 |
| 2008 | 0.9 | 55.9 | 27.9 | 79.8 | 0.9 | 92.4 | 27.9 | 76.0 |
| 2009 | 0.5 | 119.6 | 24.9 | 21.6 | 0.5 | 108.0 | 24.9 | 20.5 |
| 2010 | 0.2 | 29.0 | 4.4 | 49.8 | 0.2 | 36.0 | 4.4 | 46.3 |
| 2011 | 0.0 | 6.4 | 2.5 | 63.8 | 0.0 | 6.0 | 2.5 | 59.8 |
| 2012 | 0.4 | 9.3 | 4.5 | 65.1 | 0.4 | 6.8 | 4.5 | 55.2 |
| 2013 | 0.4 | 14.3 | 15.5 | 83.7 | 0.4 | 9.7 | 15.5 | 94.4 |
| 2014 | 0.2 | 23.2 | 22.9 | 139.6 | 0.2 | 19.2 | 22.9 | 156.6 |
| 2015 | 0.2 | 66.4 | 22.9 | 163.2 | 1.3 | 86.7 | 16.1 | 140.0 |
| 2016 |  |  |  |  | 1.8 | 19.2 | 22.5 | 22.0 |

Table 32. Effective sample sizes used for bycatch size composition data from the groundfish fisheries for the 2016 assessment model (2016AM) and the author’s preferred model (Model B2b). Effective sample sizes were estimated using the McAllister-Ianelli approach.

Table 33. Comparison of fits to mature survey biomass by sex (in 1000's t) from the 2016 assessment model (2016AM) and the author's preferred model (B2b).

| year | mature female biomass (Kt) |  |  | mature male biomass (Kt) |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | observed | 2016AM | Model B2b | observed | 2016AM | Model B2b |
| 1975 | 31.4 | 47.8 | 47.6 | 246.0 | 148.1 | 151.1 |
| 1976 | 31.2 | 42.0 | 42.2 | 126.2 | 133.6 | 135.4 |
| 1977 | 38.6 | 35.8 | 36.8 | 111.3 | 105.5 | 108.1 |
| 1978 | 25.8 | 32.7 | 34.1 | 77.9 | 75.1 | 79.4 |
| 1979 | 19.3 | 34.7 | 35.8 | 32.6 | 67.0 | 71.2 |
| 1980 | 63.8 | 36.5 | 38.8 | 86.8 | 63.0 | 74.2 |
| 1981 | 42.6 | 31.5 | 35.7 | 50.3 | 53.8 | 65.6 |
| 1982 | 64.1 | 25.7 | 26.1 | 51.7 | 68.1 | 71.8 |
| 1983 | 20.4 | 19.2 | 19.9 | 29.9 | 49.1 | 53.0 |
| 1984 | 14.9 | 14.5 | 15.1 | 25.8 | 32.6 | 36.0 |
| 1985 | 5.6 | 11.7 | 12.1 | 11.9 | 23.0 | 24.9 |
| 1986 | 3.4 | 12.3 | 12.3 | 13.3 | 28.8 | 30.2 |
| 1987 | 5.1 | 14.3 | 14.0 | 24.6 | 40.7 | 40.8 |
| 1988 | 25.4 | 17.0 | 16.2 | 61.0 | 55.2 | 55.2 |
| 1989 | 19.4 | 19.8 | 18.4 | 93.3 | 70.2 | 68.3 |
| 1990 | 37.7 | 21.4 | 19.8 | 97.8 | 74.4 | 73.2 |
| 1991 | 44.8 | 21.2 | 19.7 | 112.6 | 64.8 | 67.4 |
| 1992 | 26.2 | 19.1 | 17.8 | 105.5 | 60.1 | 60.5 |
| 1993 | 11.6 | 15.3 | 14.6 | 62.0 | 45.1 | 46.5 |
| 1994 | 9.8 | 11.6 | 11.3 | 43.8 | 32.9 | 34.9 |
| 1995 | 12.4 | 8.6 | 8.6 | 32.7 | 23.9 | 25.7 |
| 1996 | 9.6 | 6.5 | 6.7 | 27.5 | 17.3 | 19.1 |
| 1997 | 3.4 | 5.1 | 5.3 | 11.3 | 13.9 | 15.8 |
| 1998 | 2.3 | 4.3 | 4.5 | 10.9 | 12.5 | 13.9 |
| 1999 | 3.8 | 4.0 | 4.1 | 13.0 | 12.4 | 13.3 |
| 2000 | 4.1 | 4.3 | 4.2 | 16.9 | 14.1 | 14.3 |
| 2001 | 4.6 | 4.7 | 4.6 | 18.7 | 17.4 | 17.2 |
| 2002 | 4.5 | 5.2 | 5.2 | 19.0 | 20.0 | 20.8 |
| 2003 | 8.4 | 6.0 | 6.1 | 24.6 | 23.7 | 25.1 |
| 2004 | 4.7 | 7.2 | 7.4 | 27.0 | 29.0 | 31.2 |
| 2005 | 11.6 | 8.3 | 8.7 | 45.2 | 36.3 | 38.6 |
| 2006 | 14.9 | 9.3 | 9.9 | 67.9 | 41.0 | 45.7 |
| 2007 | 13.4 | 10.6 | 11.1 | 69.5 | 45.4 | 51.3 |
| 2008 | 11.7 | 10.8 | 11.3 | 65.1 | 51.3 | 57.4 |
| 2009 | 8.5 | 9.6 | 10.1 | 38.2 | 50.7 | 57.6 |
| 2010 | 5.5 | 8.1 | 8.6 | 39.1 | 44.3 | 51.0 |
| 2011 | 5.4 | 7.7 | 8.0 | 43.3 | 38.8 | 44.4 |
| 2012 | 12.4 | 9.8 | 9.5 | 42.2 | 39.4 | 42.9 |
| 2013 | 17.8 | 13.5 | 12.4 | 67.0 | 53.4 | 53.5 |
| 2014 | 14.9 | 15.6 | 13.9 | 82.4 | 71.1 | 68.9 |
| 2015 | 11.2 | 14.6 | 12.9 | 62.9 | 72.2 | 70.0 |
| 2016 | 7.6 | 12.4 | 10.9 | 61.6 | 59.1 | 58.4 |
| 2017 | 7.1 |  | 9.1 | 50.2 |  | 50.4 |

Table 34. Comparison of estimates of mature biomass-at-mating by sex (in 1000's t) from the 2016 assessment model (2016AM) and the author's preferred model (B2b).

| year | MMB (1000's t) |  | MFB (1000's t) |  | year | MMB (1000's t) |  | MFB (1000's t) |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 2016AM | Model B2b | 2016AM | Model B2b |  | 2016AM | Model B2b | 2016AM | Model B2b |
| 1949 | 0.0 | 0.0 | 0.0 | 0.0 | 1986 | 32.6 | 39.3 | 20.6 | 25.7 |
| 1950 | 0.0 | 0.0 | 0.0 | 0.0 | 1987 | 44.4 | 51.5 | 23.8 | 29.3 |
| 1951 | 0.1 | 0.1 | 0.3 | 0.2 | 1988 | 58.5 | 68.3 | 28.5 | 33.9 |
| 1952 | 1.2 | 0.8 | 1.1 | 0.8 | 1989 | 63.3 | 74.4 | 32.6 | 38.2 |
| 1953 | 4.1 | 3.1 | 2.2 | 1.8 | 1990 | 54.3 | 68.6 | 34.3 | 40.6 |
| 1954 | 7.8 | 6.6 | 3.2 | 2.9 | 1991 | 52.5 | 65.9 | 34.0 | 40.2 |
| 1955 | 10.6 | 9.7 | 4.0 | 3.7 | 1992 | 45.2 | 56.6 | 30.6 | 36.0 |
| 1956 | 12.7 | 12.1 | 4.5 | 4.3 | 1993 | 39.5 | 48.8 | 25.0 | 29.7 |
| 1957 | 14.4 | 14.0 | 5.0 | 4.8 | 1994 | 31.4 | 39.4 | 19.0 | 23.2 |
| 1958 | 15.8 | 15.6 | 5.3 | 5.2 | 1995 | 23.1 | 29.7 | 14.2 | 17.7 |
| 1959 | 17.0 | 17.0 | 5.7 | 5.7 | 1996 | 18.1 | 23.9 | 10.8 | 13.7 |
| 1960 | 18.2 | 18.4 | 6.2 | 6.2 | 1997 | 15.2 | 20.1 | 8.5 | 11.0 |
| 1961 | 19.7 | 20.1 | 6.7 | 6.8 | 1998 | 13.9 | 17.7 | 7.3 | 9.3 |
| 1962 | 21.8 | 22.4 | 7.7 | 7.9 | 1999 | 14.3 | 17.5 | 6.9 | 8.6 |
| 1963 | 25.4 | 26.3 | 9.5 | 10.1 | 2000 | 16.3 | 19.1 | 7.3 | 8.9 |
| 1964 | 32.5 | 34.2 | 13.9 | 15.1 | 2001 | 19.8 | 22.8 | 7.9 | 9.7 |
| 1965 | 47.5 | 50.6 | 24.3 | 25.9 | 2002 | 23.1 | 27.8 | 8.8 | 11.0 |
| 1966 | 84.2 | 87.8 | 43.7 | 45.1 | 2003 | 27.7 | 33.8 | 10.2 | 12.9 |
| 1967 | 136.5 | 139.7 | 68.6 | 69.3 | 2004 | 33.8 | 41.9 | 12.4 | 15.6 |
| 1968 | 200.1 | 203.2 | 89.0 | 89.9 | 2005 | 41.6 | 51.2 | 14.4 | 18.3 |
| 1969 | 235.6 | 242.7 | 98.4 | 101.0 | 2006 | 46.3 | 59.8 | 16.0 | 20.8 |
| 1970 | 244.9 | 258.2 | 98.9 | 103.7 | 2007 | 51.3 | 67.0 | 18.2 | 23.3 |
| 1971 | 240.8 | 259.6 | 96.4 | 102.5 | 2008 | 58.9 | 75.9 | 18.5 | 23.7 |
| 1972 | 236.2 | 257.6 | 93.9 | 101.2 | 2009 | 58.5 | 76.5 | 16.4 | 21.2 |
| 1973 | 235.9 | 254.3 | 92.7 | 99.1 | 2010 | 51.7 | 68.3 | 13.9 | 18.0 |
| 1974 | 229.8 | 242.0 | 89.4 | 94.6 | 2011 | 45.2 | 59.1 | 13.3 | 16.8 |
| 1975 | 219.6 | 227.0 | 83.0 | 87.7 | 2012 | 46.2 | 57.8 | 17.0 | 20.1 |
| 1976 | 179.3 | 186.3 | 71.8 | 77.6 | 2013 | 61.2 | 70.6 | 23.4 | 26.1 |
| 1977 | 119.0 | 129.8 | 60.0 | 67.5 | 2014 | 75.4 | 84.8 | 26.7 | 29.2 |
| 1978 | 81.1 | 95.7 | 55.3 | 62.8 | 2015 | 73.9 | 83.8 | 24.9 | 27.1 |
| 1979 | 54.7 | 74.5 | 57.4 | 65.3 | 2016 | -- | 78.0 | -- | 22.9 |
| 1980 | 44.9 | 70.2 | 56.0 | 67.0 |  |  |  |  |  |
| 1981 | 56.6 | 75.0 | 49.7 | 61.9 |  |  |  |  |  |
| 1982 | 54.9 | 70.1 | 40.5 | 51.2 |  |  |  |  |  |
| 1983 | 41.0 | 53.4 | 30.8 | 39.2 |  |  |  |  |  |
| 1984 | 25.7 | 34.6 | 23.1 | 29.5 |  |  |  |  |  |
| 1985 | 26.2 | 32.6 | 20.0 | 25.3 |  |  |  |  |  |

Table 35. Estimated population size (millions) for females on July 1 of year. from the author’s preferred model, Model B2b.

| year |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| ${ }_{1999}^{1999}$ | ${ }^{4.3465+50}$ | +100 | ${ }^{7}$ 7.885 500 | 为 | 806+00 | Etil | ${ }^{2946501}$ | ${ }^{1.1000101}$ | (02 | 10.02 | ${ }^{\text {4.870.03 }}$ | ${ }^{1.66503}$ | ${ }^{\text {5.55E.04 }}$ | A4E.04 | ${ }^{\text {6.01205 }}$ | ${ }^{1.555}$ | ${ }^{6,292}$ | ${ }^{201210565}$ | ${ }^{6.4080707}$ | ${ }^{202020}$ | ${ }^{\text {6,37E08 }}$ | ${ }^{1.99508}$ | ${ }^{6,22 E 09}$ | ${ }^{1.385509}$ |  | 10 | 5.70:11 | ${ }^{1.755-11}$ | ${ }^{5.366-12}$ | 12 | 13 |  |
| ${ }_{1}^{1950}$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 23 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| - |  |  |  |  |  |  |  |  |  |  | , |  |  |  | ${ }^{1.26 E 02}$ | 3, 3 Ses |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ${ }^{1953}$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1954 |  | 1.1 |  |  |  |  |  |  |  |  |  |  |  |  | 1212E+0 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1955 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1956 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1957 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ${ }^{1958}$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1999 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1960 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1961 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ${ }_{1963}$ | 1.0 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1964 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1965 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1966 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1967 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1990 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1971 | ${ }_{6} 6.05+01$ | ${ }_{1}^{1.57 t+02}$ | ${ }_{1.64}^{1.86}$ | ${ }_{1.6} 18$ | 1.53 E | 1.38 E | ${ }_{125}^{122}$ | 1.171 | 1.33 | ${ }_{1.75}^{175}$ | $1.866+$ | ${ }_{1.56}^{106}$ | 1.212 | ${ }_{8.812+01}$ |  |  | 9,32 | ${ }_{2}^{2188}$ | 3.32 | ${ }_{4}^{4.89}$ |  | 2.48 |  | ${ }_{4.76}^{4.76}$ |  |  |  | 3, 3 35508 |  |  |  | 3.5 |
| 1972 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1973 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1974 | 2.43 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1976 |  | 222 | 1.95 | 15 | 1.0 | ${ }^{7} \mathbf{7}$ [88 | 5.68 | 4.9 | 6.5 | 1.05 |  |  |  | 7.0 | ${ }_{4}^{564}$ | 23 | 7. | 1.89 |  |  |  |  |  |  |  |  |  |  |  |  |  | ${ }_{2}^{2135-10}$ |
| 197 | 7338 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1978 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1979 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1980 | 8.34 | 2.12 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 19 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1983 | ${ }_{3} 1.75$ | ${ }_{8.55 E}^{185}$ | ${ }_{6,8}^{23}$ | ${ }_{4}^{26}$ | ${ }_{3}^{2} 0$ | ${ }_{2}^{2011}$ | ${ }_{2}^{2}$ | ${ }_{1}^{2}$ | ${ }_{2}^{28}$ | ${ }_{4}^{6}$ | ${ }_{6}^{6} 14$ |  | ${ }_{4} 8.8$ | ${ }_{3,85}^{50.8}$ | ${ }_{2} 26$ | ${ }_{1.3}^{1.6}$ |  | ${ }_{1.12}^{12}$ | ${ }_{2,0}^{2,20}$ |  |  |  | ${ }_{6}^{1 / 3} \mathbf{6}$ |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1986 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ${ }_{\substack{1987 \\ 1988}}$ |  | 9.986 | ${ }^{9} 75$ | ${ }_{8.3}^{9.3}$ | 7.7 | ${ }^{7} 718$ | 6.5 |  |  |  |  |  |  | ${ }_{27}^{23}$ |  |  |  |  |  |  |  |  |  |  |  |  |  | 1.6 |  |  |  |  |
| $1 \begin{aligned} & 1988 \\ & 1989\end{aligned}$ | ${ }_{131}$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1990 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1991 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ${ }_{1993}^{1992}$ |  | ${ }_{\substack{6.8 \\ 6.8}}^{1}$ |  | ${ }_{\substack{73 \\ 6,7 \\ \hline \\ \hline}}$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1994 |  | 8.90 |  | 7.55 | 6.29 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | ${ }^{1.122}$ | 5.72 |  |  | 9 |  |  |  | 2. |  |  |  |  | 3,08 |  |  |  |  |
| 1997 |  | 2.96 | 2.48 | 18 | 128 | 9.80 | 8.0 |  |  | ${ }_{1.4}^{1.6}$ | ${ }_{1.2}^{203}$ | ${ }_{1.51}^{185}$ | 1. | - | ${ }_{6}^{8.54}$ | ${ }_{\text {3, }}^{4}$ | ${ }_{1.17}^{1212}$ | ${ }_{2,87}^{3,185}$ | $\substack { \text { c. } 27 \\ \begin{subarray}{c}{\text { ¢ }{ \text { c. } 2 7 \\ \begin{subarray} { c } { \text { ¢ } } } \end{subarray}$ |  |  |  | ${ }_{2}^{2}$ |  | ${ }_{9.90}^{100}$ | ${ }_{2}^{3,18}$ |  | ${ }_{2,6}^{28}$ |  |  |  |  |
| 1998 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 19 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2000 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2001 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ${ }_{2003}^{2000}$ |  | ${ }_{6}^{2022}$ | ${ }_{5}^{3}$ |  | ${ }_{3}^{4.59}$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  | ${ }_{23}^{4.92}$ |  |  |  |  |  |  |  |  | ${ }_{1}^{1.50}$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ${ }_{2007}^{2006}$ |  | ${ }_{1.108}^{12426}$ | ${ }_{11.88}^{1.66}$ |  | ${ }_{125}^{237}$ |  |  |  |  |  |  |  |  | 1.122 er | ${ }_{1.17}^{1.012}$ |  |  | ${ }_{4}$ | ${ }^{1} 272$ |  |  |  |  |  |  |  |  |  |  |  |  |  |
| ${ }^{2008}$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2010 |  | ${ }_{9,62}^{102}$ | 9.988 |  |  |  |  |  |  |  |  |  |  | 1.1216 | 1.120 |  |  |  | 8, |  |  |  | ${ }_{\text {c, }}^{\substack{3,66}}$ |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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| 2015 2015 |  |  |  | ${ }_{1}^{1.19}$ | 1.05 | - 1.002 erol | ${ }_{1.0}^{1.10}$ |  |  |  |  |  |  | ${ }_{2}^{2}$ | ${ }_{1}^{1.4515+01}$ |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

Table 36. Estimated population size (millions) for males on July 1 of year. from the author’s preferred mode, Model B2b.

\begin{tabular}{|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|c|}
\hline year \& \& 325 \& 37.5 \& \& \& \& \& \& \& \& \& \& \& \& \& 025 \& 1075 \& \& \& \& \& \& \& \& \& \& \& 12.5 \& 17.5 \& 12.5 \& \& \\
\hline 1999 \& \({ }^{4.3465+50}\) \& 9.75 ¢ 700 \& 7.28t+00 \& 3, 3 22F+00 \& \({ }^{1.806+500}\) \& 7.51E.01 \& \({ }^{29850.01}\) \& 1.106.01 \& 3.99E:02 \& \({ }^{1.4151502}\) \& \({ }^{\text {4,870.03 }}\) \& \({ }^{1.666 .03}\) \& 5.55E54 \& \({ }^{1.84 E 04}\) \& \({ }^{\text {6,01E05 }}\) \& 1.95E.05 \&  \& \(\xrightarrow{2011065}\) \&  \& 2028:07 \& \(\underbrace{\text { ciz7e }}\) \&  \&  \& \(\xrightarrow{1.950 .09}\) \& \({ }^{5} 5\) \& \({ }_{\text {l }}^{1.851510}\) \& \& \& \&  \&  \& \({ }_{\text {1.52]-13 }}\) \\
\hline \({ }^{1950}\) \& \(4.356+00\) \& \({ }^{1.106+01}\) \& 1.04F+01 \& \({ }^{9} 3\).35 +00 \& (6.54F00 \& 4.11760 \& 2.415 \& 132E+00 \& 6,92001 \& 3,52:01 \& 1.75E:01 \& \({ }_{\text {8, }}^{8.88 .020}\) \& 4.056.02 \& 190.0.02 \& \({ }^{8.846503}\) \& 4.06603 \& \({ }_{\text {l }}^{1.85503}\) \& 8.866.04 \& 3, 3 3509 \& 1.67:04 \& \({ }^{7} 7.85\) \& - 3.255 \& \({ }^{1.435 .05}\) \& 6,25:06 \& 2.72 \& 1.17 \& 5,015:07 \& 2111:07 \& 8.70E-08 \& \& cince \& \({ }^{\text {9,555.09 }}\) \\
\hline \({ }_{1}^{1951}\) \& \& \({ }^{1.10}\) \&  \&  \& \&  \& 5.42 L \& \& 292EFOO \& \& \(1.384+00\) \& 8.588:01 \& 366:01 \& 3.28E \& \begin{tabular}{l}
1.975 \\
112 E \\
\hline
\end{tabular} \& linc \& \& \& \& \& \& \& \({ }_{463}^{1.75}\) \& \& \& \& \&  \& \& \& \& \\
\hline -1938 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline \({ }_{1}^{1954}\) \& \& \({ }_{1.188501}^{121}\) \& \& \& \& \& \& \& \& \& \& \& \&  \& \(27.55+00\) \&  \& 2 \& 2021 \& \({ }_{1.835+00}^{120}\) \& 1.06E \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 1955 \& 4.95 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 1956 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 1957 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 1958 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline -1960 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline , \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 1964 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 1965 \& 1.072 \& 275 \& \& \& \& \& \& \& \& \& \& \& \& 3.12 F01 \& 2.62 \& 2.1 \& 172 \& 15 \& 1.34 \& 1.17 \& \& \& \& \& \& \& \& 1.18 \& \& \& \& \\
\hline 1966 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 196 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 1969 \& \& 1.94 \& \& \& \& 116 \& \& \& \& \& \& \& 6.99800 \& 7.27 \& \& 7.3 \& \({ }_{6}^{681}\) \& 6.73 \& 6.62 \& \({ }_{6}^{63}\) \& \& \& \& \& \& \& 1.18 \& \& \& \& \& 5.93E.02 \\
\hline 1970 \& 7.54 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 197 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 昞 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 1974 \& \({ }_{2,43}^{2,4}\) \& \({ }_{6}^{17}\) \& \& \& \& \& \& \& \& \& \({ }_{5}^{6} 2\) \& \& \& \({ }_{5}^{6} 8\) \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 1976 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 197 \& 7.33 F-01 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& E.02 \\
\hline 1978 \& , \& 边 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 1980 \& \& 2244601 \& \& \& \({ }_{3} 13\) \& \({ }_{3,52}\) \& \& \& \& \& 528 \& \& 5.46 \& \({ }_{5}^{5} 5\) \& \({ }_{5}^{528}\) \& \& 4.9 \& \({ }_{4}^{4} 5\) \& \& \& \& \& \& \& \& \& 25 \& \& \& \& \& \({ }_{\text {c }}\) \\
\hline 1981 \& 1.36 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 1982 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline \({ }^{1983}\) \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 198 \& 4, \& lister \& , \& \& \& \& \({ }_{4,49}^{27}\) \& \& \& 2 \& \& 12 \& \& \({ }_{\substack{8 \\ 9 \\ 92 \\ \text { 22 }}}\) \& 80.0. \& \& \& \({ }_{8}^{8.692}\) \& \& \& \& \& \& 600 \& \& \& 2, 2981 \& \& \& leit \& \& 2211002 \\
\hline 19 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 198 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 198 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 1990 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline \({ }_{1991}^{1991}\) \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \&  \\
\hline 1993 \& \({ }_{2}^{284}\) \& 7.15 L \& 6.912 \& 6.64 \& \({ }_{5}^{6} 52\) \& \({ }_{4}^{6} 90\) \& 4.77 \& \& \& 5.52 \& \({ }_{6}^{6}\) \& 7 \& \& \({ }_{1}^{108}\) \& \({ }_{12}^{12}\) \& 1.38 E \& \& \& \& 1.5 \& \& \& \& \& \& \& 18 \& \& 5.590:01 \& \& \& \({ }_{\text {1.0102 }}\) \\
\hline 1994 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \({ }^{\text {6,37E }}\), 3 \\
\hline \({ }_{1}^{1996}\) \& \& \& \& \& \& \({ }_{6}^{6882}\) \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 1999 \& 1.72 \& \(4.011^{\text {P }} 01\) \& \({ }^{3,306}\) \& \({ }^{2} 414\) \& \({ }^{1.755401}\) \& 1.466 \& 1.33 \& 1.11 \& \& 7.79¢+00 \& 6.64 \& 5.73 \& \& 4.81 \& 4.75 \& 4.50 \& 4.10 \& \& \& 4.11 \& \& \& \& \& \& \& \& \({ }^{3} 82\) \& \& \& \& \\
\hline \& \&  \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 2002 \& \& 291 \& \& 4.66 \& \& \({ }_{3} 12.555_{0} 1\) \& \& 1.82 \& \& \& 1.18 \& 1.05 \& \& 8.76 \& 8.26 \& \& \& \({ }_{6}^{640}\) \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 2003 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline \({ }^{2004}\) \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline \({ }^{2005}\) \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \\
\hline 2006

2007 \& ${ }_{4}^{54}$ \& \& \& \& \& \& \& \& \& ${ }_{\text {2 }}^{2.345+01}$ \& ${ }_{1.7}^{215}$ \& ${ }_{1.80}^{193}$ \& \&  \& - 1.58 Cl \& ${ }_{1}^{1.148}$ \& \& ${ }_{1.55}^{1.29}$ \& ${ }_{1.50}^{1.29}$ \& \& \& \& \& \& \& \& \& \& \& \& \&  <br>
\hline 2008 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& <br>
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\hline 2010 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& <br>
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\hline \& \& \& \& \& \& \& \& \& \& \& ciskeren \& \& \& \& 2.506+01 \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& <br>
\hline \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& \& <br>
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\hline
\end{tabular}

Table 37. Comparison of estimates of recruitment (in millions) from the 2016 assessment model (2016AM) and the author's preferred model (Model B2b).

| year | 2016AM | Model B2b | year | 2016AM | Model B2b |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1949 | 55.50 | 56.60 | 1986 | 466.24 | 523.40 |
| 1950 | 55.65 | 56.79 | 1987 | 451.01 | 519.32 |
| 1951 | 55.99 | 57.23 | 1988 | 439.75 | 355.11 |
| 1952 | 56.62 | 58.03 | 1989 | 190.87 | 170.73 |
| 1953 | 57.66 | 59.34 | 1990 | 73.68 | 52.28 |
| 1954 | 59.30 | 61.40 | 1991 | 42.90 | 41.79 |
| 1955 | 61.84 | 64.58 | 1992 | 32.61 | 36.99 |
| 1956 | 65.80 | 69.55 | 1993 | 30.27 | 37.07 |
| 1957 | 72.11 | 77.55 | 1994 | 37.96 | 48.83 |
| 1958 | 82.65 | 91.14 | 1995 | 50.53 | 62.54 |
| 1959 | 101.70 | 116.57 | 1996 | 51.67 | 57.52 |
| 1960 | 141.25 | 172.28 | 1997 | 127.63 | 167.47 |
| 1961 | 242.89 | 318.97 | 1998 | 52.35 | 67.08 |
| 1962 | 537.86 | 719.36 | 1999 | 152.69 | 224.53 |
| 1963 | 1,177.44 | 1,400.31 | 2000 | 90.77 | 116.91 |
| 1964 | 1,614.85 | 1,665.88 | 2001 | 276.55 | 382.14 |
| 1965 | 1,449.54 | 1,395.71 | 2002 | 104.95 | 122.96 |
| 1966 | 1,119.12 | 1,093.24 | 2003 | 209.31 | 369.15 |
| 1967 | 914.80 | 942.01 | 2004 | 322.05 | 359.58 |
| 1968 | 862.81 | 936.54 | 2005 | 93.97 | 97.75 |
| 1969 | 946.34 | 1,014.71 | 2006 | 72.47 | 74.91 |
| 1970 | 1,044.72 | 983.84 | 2007 | 48.53 | 57.91 |
| 1971 | 887.85 | 835.57 | 2008 | 60.51 | 89.15 |
| 1972 | 653.80 | 552.87 | 2009 | 395.16 | 580.95 |
| 1973 | 402.42 | 359.73 | 2010 | 492.06 | 514.24 |
| 1974 | 303.08 | 317.05 | 2011 | 286.78 | 210.28 |
| 1975 | 606.32 | 625.56 | 2012 | 49.61 | 40.96 |
| 1976 | 1,093.57 | 1,243.35 | 2013 | 124.11 | 112.30 |
| 1977 | 863.94 | 956.12 | 2014 | 99.47 | 84.14 |
| 1978 | 441.60 | 421.01 | 2015 | 69.67 | 55.16 |
| 1979 | 175.21 | 177.45 | 2016 | 120.01 | 77.52 |
| 1980 | 93.15 | 108.83 | 2017 |  | 457.94 |
| 1981 | 134.32 | 177.86 |  |  |  |
| 1982 | 90.73 | 100.63 |  |  |  |
| 1983 | 345.19 | 488.86 |  |  |  |
| 1984 | 321.76 | 402.59 |  |  |  |
| 1985 | 505.73 | 541.69 |  |  |  |

Table 38. Comparison of exploitation rates (i.e., catch divided by biomass) from the 2016 assessment model (2016AM) and the author's preferred model (Model B2b).

| year | 2016AM | Model B2b | year | 2016AM | Model B2b |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1949 | 0.003 | 0.002 | 1986 | 0.027 | 0.019 |
| 1950 | 0.005 | 0.003 | 1987 | 0.042 | 0.032 |
| 1951 | 0.009 | 0.004 | 1988 | 0.052 | 0.041 |
| 1952 | 0.013 | 0.007 | 1989 | 0.117 | 0.092 |
| 1953 | 0.016 | 0.010 | 1990 | 0.197 | 0.152 |
| 1954 | 0.020 | 0.013 | 1991 | 0.171 | 0.147 |
| 1955 | 0.022 | 0.015 | 1992 | 0.208 | 0.175 |
| 1956 | 0.023 | 0.016 | 1993 | 0.153 | 0.130 |
| 1957 | 0.023 | 0.017 | 1994 | 0.118 | 0.098 |
| 1958 | 0.023 | 0.017 | 1995 | 0.110 | 0.087 |
| 1959 | 0.023 | 0.017 | 1996 | 0.073 | 0.048 |
| 1960 | 0.022 | 0.016 | 1997 | 0.047 | 0.039 |
| 1961 | 0.022 | 0.016 | 1998 | 0.037 | 0.038 |
| 1962 | 0.021 | 0.014 | 1999 | 0.019 | 0.017 |
| 1963 | 0.018 | 0.012 | 2000 | 0.018 | 0.014 |
| 1964 | 0.016 | 0.011 | 2001 | 0.023 | 0.016 |
| 1965 | 0.024 | 0.017 | 2002 | 0.016 | 0.010 |
| 1966 | 0.024 | 0.017 | 2003 | 0.011 | 0.007 |
| 1967 | 0.059 | 0.045 | 2004 | 0.011 | 0.007 |
| 1968 | 0.064 | 0.050 | 2005 | 0.018 | 0.012 |
| 1969 | 0.082 | 0.066 | 2006 | 0.025 | 0.018 |
| 1970 | 0.077 | 0.061 | 2007 | 0.027 | 0.022 |
| 1971 | 0.066 | 0.052 | 2008 | 0.020 | 0.015 |
| 1972 | 0.060 | 0.046 | 2009 | 0.017 | 0.012 |
| 1973 | 0.065 | 0.056 | 2010 | 0.009 | 0.006 |
| 1974 | 0.084 | 0.075 | 2011 | 0.010 | 0.009 |
| 1975 | 0.074 | 0.065 | 2012 | 0.006 | 0.005 |
| 1976 | 0.118 | 0.101 | 2013 | 0.018 | 0.015 |
| 1977 | 0.172 | 0.140 | 2014 | 0.060 | 0.052 |
| 1978 | 0.159 | 0.118 | 2015 | 0.082 | 0.071 |
| 1979 | 0.227 | 0.151 | 2016 | -- | 0.010 |
| 1980 | 0.160 | 0.093 |  |  |  |
| 1981 | 0.070 | 0.047 |  |  |  |
| 1982 | 0.035 | 0.025 |  |  |  |
| 1983 | 0.017 | 0.013 |  |  |  |
| 1984 | 0.033 | 0.026 |  |  |  |
| 1985 | 0.019 | 0.016 |  |  |  |

Table 39. Values required to determine Tier level and OFL for the models considered here. These values are presented only to illustrate the effect of incremental changes in the model scenarios. Results from the author's preferred model (Model B2b) are highlighted in green.

| Model <br> Scenario | average <br> recruitment <br> millions | Final | MMB | BO | Bmsy | Fmsy | MSY | Fofl | OFL | projected <br> MMB |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | projected MMB |  |  |  |  |  |  |  |  |  |
| $/ B m s y ~$ |  |  |  |  |  |  |  |  |  |  |

## Figures



Figure 1. Eastern Bering Sea District of Tanner crab Registration Area J including sub-districts and sections (from Bowers et al. 2008).


Figure 2. Upper: retained catch (males, 1000's t) in the directed fisheries (US pot fishery [green bars], Russian tangle net fishery [red bars], and Japanese tangle net fisheries [blue bars]) for Tanner crab since 1965/66. Lower: Retained catch (males, 1000's t) in directed fishery since 2001/02. The directed fishery was closed from 1996/97 to 2004/05, from 2010/11 to 2012/13, and in 2016/17.


Figure 3. Upper: Tanner crab discards (males and females, 1000’s t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Discard reporting began in 1973 for the groundfish fisheries and in 1992 for the crab fisheries. Lower: detail since 2001.


Figure 4. Upper: Tanner crab discard mortality (males and females, 1000's t) in the directed Tanner crab, snow crab, Bristol Bay red king crab, and groundfish fisheries. Assumed handling mortality rates of 0.321 for the crab fisheries and 0.80 for the groundfish fisheries were applied to discard biomass to obtain discard mortality. Lower: detail since 2001.


Figure 5. Retained and discard catch mortality ( 1000 's t ) in the directed, snow crab, BBRKC and groundfish fisheries. Handling mortality rates of 0.321 for the crab fisheries and 0.8 for the groundfish fisheries were applied to estimated discards.


Figure 6. Size compositions, by 5 mm CW bins and expanded to total retained catch, for retained (male) crab in the directed Tanner crab pot fisheries since 2006/07, from dockside crab fishery observer sampling. Fishing occurred only east of $166^{\circ} \mathrm{W}$ in 2009/10. The entire fishery was closed in 2010/112012/13 and in 2016/17. Note scale change in 2014/15.


Figure 7. Male Tanner crab catch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling. Note that the directed fishery was closed in 2010/11-2012/13 and in 2016/17.


Figure 8. Female Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the directed Tanner crab pot fishery since 2005/06, from at-sea crab fishery observer sampling. Note that the directed fishery was closed in 2010/11-2012/13 and in 2016/17.


Figure 9. Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the snow crab pot fishery, from at-sea crab fishery observer sampling.


Figure 10. Tanner crab bycatch size compositions, expanded to total catch, by 5 mm CW bins in the BBRKC pot fishery, from at-sea crab fishery observer sampling.



Figure 11. Normalized Tanner crab bycatch size compositions in the groundfish fisheries, from groundfish observer sampling. Size compositions have been normalized to sum to 1 for each year.


Figure 12. Trends in survey biomass for mature male and female Tanner crab, and in abundance for industry preferred-size ( $\geq 125 \mathrm{~mm}$ CW) males, based on the NMFS EBS bottom trawl survey.


Figure 13. Percent change in mature male biomass, mature female biomass, total mature biomass and abundance of legal crab observed in the NMFS bottom trawl survey during the past five surveys.



Figure 14. Trends in survey biomass for male Tanner crab in areas east and west of $166^{\circ} \mathrm{W}$ longitude, based on the NMFS EBS bottom trawl survey.


Figure 15. Trends in survey biomass for female Tanner crab in areas east and west of $166^{\circ} \mathrm{W}$ longitude, based on the NMFS EBS bottom trawl survey.


Figure 16. Numbers at size (millions) by area and shell condition for male Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW.


Figure 17. Numbers at size (millions) by area and shell condition for male Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW, since 2005.


Figure 18. Numbers at size (millions) by area and shell condition for female Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW.


Figure 19. Numbers at size (millions) by area and shell condition for female Tanner crab in the NMFS summer bottom trawl survey, binned by 5 mm CW, since 2005.


Figure 20. Average bottom temperatures $\left({ }^{\circ} \mathrm{C}\right)$ in the NMFS EBS summer trawl survey for 1975-2017.


Figure 21. Size-weight relationships developed from NMFS EBS summer trawl survey data.


Figure 22. Assumed size distribution for recruits entering the population.


Figure 23. MCMC results from scenario B2b, the author's preferred model, for survey catchability and selectivity parameters.


Figure 24. MCMC results from scenario B2b, the author's preferred model, for OFL-related quantities.


Figure 25. The Fofs harvest control rule.


Figure 26. The OFL and ABC from the author's preferred model, scenario B2b.


Figure 27. Quad plot for the author's preferred model, scenario B2b.

# Appendix A: Bycatch in the Groundfish Fisheries for the Tanner Crab Assessment 

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12 September, 2017

## Contents

Introduction ..... 1
Estimated total bycatch by gear type ..... 2
Estimated total catch by target type (2009/10-2016/17) ..... 4
Size frequencies from observer sampling ..... 7
Sample sizes ..... 7
Raw size frequencies ..... 9
Expansion factors ..... 10
Total bycatch size compositions ..... 17
Size compositions aggregated over gear type ..... 19
Spatial patterns of bycatch ..... 20

## Introduction

This appendix documents the calculations for the annual abundance and biomass time series and the sex-specific size compositions for Tanner crab bycatch in the groundfish fisheries used in the Tanner crab stock assessment model for 1991-2016. Briefly, total bycatch estimates for 1991-2008 were obtained from the NMFS Alaska Regional Office's (AKRO) Catch Accounting System/Blend database (CAS; Cahalan et al., 2009) and for 2009 to the present from the AKRO's Catch-in-Areas database (CIA; via AKFIN). Annual sampling data for size frequencies of Tanner crab bycatch in the EBS groundfish fisheries was extracted from the NORPAC observer database (via AKFIN) by sex, gear ("trawl" and "fixed"), ADFG stat area and NMFS reporting area. These observed size frequency data were then scaled to total estimated bycatch size compositions using year/gear/area expansion factors based on the annual total bycatch estimates from the CAS and CIA database.

Sex-specific size compositions for Tanner crab bycatch in the groundfish fisheries during 1973-1990 are also incorporated in the assessment model. These size compositions are based on data from the former "joint venture"" and foreign fishing fleets, and remain unchanged from the previous assessment.


Figure 1: Figure

## Estimated total bycatch by gear type

Figure 1. Estimated total bycatch abundance, by gear type, from the CAS/Blend and CIA databases for 1991-2016.


Figure 2: Figure

Figure 2. Estimated total bycatch biomass, by gear type, from the CAS/Blend and CIA databases for 1991-2016.

Table 1: Estimated total bycatch of Tanner crab by gear type from the combined CAS/Blend and CIA databases for 1991-2008.

|  | all |  |  | fixed |  | trawl |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | num | wgt | num | wgt | num | wgt |  |
| year | millions | 1000 's t | millions | 1000 's t | millions | 1000 's t |  |
| 1991 | 6.1125 | 2.5432 | 0.35636 | 0.14827 | 5.7561 | 2.39491 |  |
| 1992 | 6.3447 | 2.7596 | 0.23614 | 0.10271 | 6.1086 | 2.65693 |  |
| 1993 | 3.6442 | 1.7580 | 0.04869 | 0.02349 | 3.5955 | 1.73451 |  |
| 1994 | 4.6688 | 2.0960 | 0.05320 | 0.02388 | 4.6156 | 2.07211 |  |
| 1995 | 3.7164 | 1.5249 | 0.31161 | 0.12786 | 3.4048 | 1.39702 |  |
| 1996 | 3.6250 | 1.5945 | 0.26818 | 0.11796 | 3.3568 | 1.47653 |  |
| 1997 | 3.3856 | 1.1800 | 0.18346 | 0.06394 | 3.2022 | 1.11602 |  |
| 1998 | 2.9243 | 0.9350 | 0.27512 | 0.08797 | 2.6491 | 0.84707 |  |
| 1999 | 1.6541 | 0.6306 | 0.22233 | 0.08476 | 1.4318 | 0.54585 |  |
| 2000 | 1.7727 | 0.7415 | 0.12702 | 0.05313 | 1.6457 | 0.68840 |  |
| 2001 | 2.3674 | 1.1852 | 0.24904 | 0.12467 | 2.1184 | 1.06052 |  |
| 2002 | 1.2882 | 0.7191 | 0.17112 | 0.09552 | 1.1171 | 0.62355 |  |
| 2003 | 1.0908 | 0.4238 | 0.05255 | 0.02042 | 1.0382 | 0.40339 |  |
| 2004 | 1.7598 | 0.6751 | 0.16907 | 0.06486 | 1.5907 | 0.61020 |  |
| 2005 | 1.3309 | 0.6212 | 0.28508 | 0.13306 | 1.0458 | 0.48812 |  |
| 2006 | 1.3743 | 0.7171 | 0.66295 | 0.34594 | 0.7114 | 0.37120 |  |
| 2007 | 1.9757 | 0.6949 | 1.34861 | 0.47437 | 0.6270 | 0.22056 |  |
| 2008 | 1.3552 | 0.5329 | 0.73133 | 0.28755 | 0.6239 | 0.24531 |  |
| 2009 | 0.8369 | 0.3742 | 0.38142 | 0.22535 | 0.4555 | 0.14884 |  |
| 2010 | 0.5573 | 0.2314 | 0.16702 | 0.11789 | 0.3903 | 0.11347 |  |
| 2011 | 1.0228 | 0.2040 | 0.10496 | 0.07636 | 0.9178 | 0.12762 |  |
| 2012 | 0.5698 | 0.1533 | 0.06867 | 0.04608 | 0.5011 | 0.10718 |  |
| 2013 | 0.9919 | 0.3484 | 0.30248 | 0.18155 | 0.6894 | 0.16682 |  |
| 2014 | 1.0050 | 0.4357 | 0.41362 | 0.26133 | 0.5914 | 0.17440 |  |
| 2015 | 0.7191 | 0.3612 | 0.46973 | 0.27596 | 0.2494 | 0.08526 |  |
| 2016 | 0.7036 | 0.3016 | 0.25266 | 0.14943 | 0.4509 | 0.15222 |  |

## Estimated total catch by target type (2009/10-2016/17)



Figure 3. Bycatch of Tanner crab in the groundfish fisheries, by target type.
Table 2: Bycatch of Tanner crab in the groundfish fisheries, by target type. Biomass is in metric tons, numbers in 1000's of crab. Targets with less than 10 kg bycatch have been dropped.

| target | vessel count | haul count | biomass <br> $(\mathrm{t})$ | number <br> $(1000$ 's $)$ |  |
| :--- | :---: | ---: | ---: | :---: | :---: |
| Alaska Plaice - BSAI | 2009 | 0 | 0 | 0.0 | 0.0 |
|  | 2010 | 113 | 1563 | 0.6 | 3.2 |
|  | 2011 | 35 | 563 | 0.1 | 0.2 |
|  | 2012 | 181 | 2735 | 1.7 | 6.2 |
|  | 2013 | 0 | 0 | 0.0 | 0.0 |
|  | 2014 | 41 | 495 | 2.6 | 11.2 |
|  | 2015 | 84 | 1452 | 0.6 | 2.1 |
|  | 2016 | 16 | 148 | 1.1 | 1.8 |
| Arrowtooth Flounder | 2009 | 246 | 9548 | 0.7 | 1.3 |
|  | 2010 | 252 | 3555 | 2.2 | 3.5 |
|  | 2011 | 998 | 15788 | 1.0 | 2.1 |
|  | 2012 | 599 | 11571 | 0.8 | 3.4 |


|  | 2013 | 1042 | 21590 | 1.0 | 5.0 |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | 2014 | 734 | 15528 | 2.2 | 8.9 |
|  | 2015 | 552 | 11491 | 1.7 | 8.7 |
|  | 2016 | 372 | 6938 | 1.3 | 7.1 |
| Flathead Sole | 2009 | 1133 | 23983 | 15.4 | 44.6 |
|  | 2010 | 1191 | 22108 | 15.0 | 51.7 |
|  | 2011 | 496 | 8408 | 6.1 | 41.8 |
|  | 2012 | 833 | 14517 | 14.6 | 52.9 |
|  | 2013 | 845 | 15216 | 19.6 | 64.2 |
|  | 2014 | 865 | 16919 | 27.1 | 92.7 |
|  | 2015 | 500 | 8984 | 5.9 | 19.0 |
|  | 2016 | 871 | 18483 | 6.2 | 19.0 |
| Greenland Turbot - BSAI | 2009 | 0 | 0 | 0.0 | 0.0 |
|  | 2010 | 0 | 0 | 0.0 | 0.0 |
|  | 2011 | 0 | 0 | 0.0 | 0.0 |
|  | 2012 | 0 | 0 | 0.0 | 0.0 |
|  | 2013 | 0 | 0 | 0.0 | 0.0 |
|  | 2014 | 0 | 0 | 0.0 | 0.0 |
|  | 2015 | 0 | 0 | 0.0 | 0.0 |
|  | 2016 | 654 | 8410 | 0.6 | 3.6 |
| Other Flatfish - BSAI | 2009 | 0 | 0 | 0.0 | 0.0 |
|  | 2010 | 16 | 150 | 0.1 | 0.4 |
|  | 2011 | 0 | 0 | 0.0 | 0.0 |
|  | 2012 | 0 | 0 | 0.0 | 0.0 |
|  | 2013 | 0 | 0 | 0.0 | 0.0 |
|  | 2014 | 0 | 0 | 0.0 | 0.0 |
|  | 2015 | 0 | 0 | 0.0 | 0.0 |
|  | 2016 | 89 | 791 | 0.1 | 0.5 |
| Pacific Cod | 2009 | 10946 | 376241 | 243.8 | 414.2 |
|  | 2010 | 11524 | 261032 | 129.0 | 178.8 |
|  | 2011 | 14283 | 437602 | 84.0 | 117.6 |
|  | 2012 | 14959 | 452023 | 50.9 | 80.7 |
|  | 2013 | 19482 | 388896 | 186.9 | 318.9 |
|  | 2014 | 18590 | 427599 | 270.1 | 431.1 |
|  | 2015 | 17983 | 572272 | 282.8 | 483.0 |
|  | 2016 | 16127 | 351177 | 153.4 | 261.1 |
| Pollock - bottom | 2009 | 1132 | 138860 | 2.9 | 5.5 |
|  | 2010 | 1651 | 87126 | 5.9 | 14.7 |
|  | 2011 | 1467 | 62223 | 0.9 | 4.8 |
|  | 2012 | 1222 | 37912 | 1.5 | 7.5 |
|  | 2013 | 791 | 16540 | 4.2 | 14.3 |
|  | 2014 | 402 | 22662 | 2.9 | 11.3 |
|  | 2015 | 364 | 19261 | 0.4 | 1.1 |
|  | 2016 | 389 | 15392 | 1.5 | 7.5 |
| Pollock - midwater | 2009 | 7520 | 249359 | 0.2 | 0.9 |
|  | 2010 | 8297 | 252803 | 0.2 | 2.1 |
|  | 2011 | 11584 | 306397 | 0.7 | 1.8 |
|  | 2012 | 10130 | 262878 | 0.2 | 1.1 |


|  | 2013 | 10399 | 272557 | 0.4 | 1.8 |
| :--- | ---: | ---: | ---: | ---: | ---: |
|  | 2014 | 10554 | 278796 | 0.4 | 1.6 |
| Rock Sole - BSAI | 2015 | 10074 | 276591 | 0.1 | 0.5 |
|  | 2016 | 10818 | 271640 | 0.2 | 0.5 |
|  | 2009 | 2614 | 50187 | 34.8 | 73.8 |
|  | 2010 | 3232 | 56049 | 32.0 | 85.8 |
|  | 2011 | 2931 | 46400 | 26.4 | 91.1 |
|  | 2012 | 2020 | 29627 | 14.7 | 39.8 |
|  | 2013 | 3150 | 61903 | 36.5 | 108.1 |
|  | 2014 | 3237 | 72179 | 20.8 | 55.1 |
|  | 2015 | 4446 | 92725 | 8.9 | 21.9 |
|  | 2016 | 2782 | 52699 | 24.0 | 74.8 |
|  | 2009 | 23 | 97 | 0.1 | 0.2 |
|  | 2010 | 180 | 2586 | 0.1 | 0.5 |
|  | 2011 | 0 | 0 | 0.0 | 0.0 |
|  | 2012 | 0 | 0 | 0.0 | 0.0 |
|  | 2013 | 197 | 3040 | 0.1 | 0.3 |
|  | 2014 | 0 | 0 | 0.0 | 0.0 |
|  | 2015 | 0 | 0 | 0.0 | 0.0 |
|  | 2016 | 0 | 0 | 0.0 | 0.0 |
|  | 2009 | 76 | 128498 | 0.2 | 0.4 |
|  | 2010 | 67 | 182129 | 0.4 | 0.8 |
|  | 2011 | 0 | 0 | 0.0 | 0.0 |
|  | 2012 | 0 | 0 | 0.0 | 0.0 |
| Yellowfin Solefish | 2013 | 58 | 61907 | 0.2 | 0.3 |
|  | 2014 | 0 | 0 | 0.0 | 0.0 |
|  | 2015 | 0 | 0 | 0.0 | 0.0 |
|  | 2016 | 0 | 0 | 0.0 | 0.0 |
|  | 2009 | 6067 | 129005 | 76.0 | 295.9 |
|  | 2010 | 6200 | 119756 | 45.8 | 215.8 |
|  | 2011 | 6445 | 122233 | 84.8 | 762.8 |
|  | 2012 | 7348 | 138839 | 68.9 | 378.0 |
|  | 2013 | 7731 | 150735 | 99.3 | 478.8 |
|  | 2014 | 6906 | 132814 | 109.6 | 392.7 |
|  | 2015 | 8315 | 168488 | 60.5 | 182.4 |
|  | 2016 | 9078 | 175812 | 113.1 | 327.6 |

## Size frequencies from observer sampling

Observers sampled Tanner crab bycatch in the groundfish fisheries to obtain sex and size information starting in 1985. Observer coverage varied by year across target fisheries and gear types, hence "raw" size frequencies are not necessarily directly comparable across these categories. Here, I assume it is valid to aggregate observations across target fisheries and to categorize gear types as "fixed" (longline and pot gear) and "trawl" (pelagic, non-pelagic, and unspecified trawl gear) to obtain annual sex- and gear-specific observed size frequencies by NMFS reporting area.

## Sample sizes



Figure 4. Sample sizes from observer sampling for Tanner crab ( $>24 \mathrm{~mm}$ CW) bycatch size frequencies in the groundfish fisheries.

Table 3: Sample sizes from observer sampling for Tanner crab (> 24 mm CW) bycatch size frequencies in the groundfish fisheries

| all gear |  |  |  |  |  |  |  |  | fixed |  |  |  |  |  |  | trawl |  |
| ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| year | female | male | unidentified | female | male | unidentified | female | male | unidentified |  |  |  |  |  |  |  |  |
| 1991 | 3477 | 6806 | 11 | 288 | 1106 | 0 | 3189 | 5700 | 11 |  |  |  |  |  |  |  |  |
| 1992 | 1109 | 3027 | 904 | 31 | 597 | 0 | 1078 | 2430 | 904 |  |  |  |  |  |  |  |  |
| 1993 | 358 | 1217 | 0 | 25 | 683 | 0 | 333 | 534 | 0 |  |  |  |  |  |  |  |  |
| 1994 | 1820 | 3628 | 4 | 126 | 1133 | 0 | 1694 | 2495 | 4 |  |  |  |  |  |  |  |  |
| 1995 | 2666 | 3896 | 8 | 44 | 162 | 0 | 2622 | 3734 | 8 |  |  |  |  |  |  |  |  |
| 1996 | 3375 | 8264 | 30 | 439 | 2442 | 13 | 2936 | 5822 | 17 |  |  |  |  |  |  |  |  |
| 1997 | 3859 | 9835 | 18 | 217 | 1650 | 8 | 3642 | 8185 | 10 |  |  |  |  |  |  |  |  |
| 1998 | 4310 | 11937 | 14 | 571 | 3814 | 2 | 3739 | 8123 | 12 |  |  |  |  |  |  |  |  |
| 1999 | 4411 | 10687 | 14 | 633 | 3269 | 7 | 3778 | 7418 | 7 |  |  |  |  |  |  |  |  |
| 2000 | 2988 | 12746 | 14 | 193 | 5074 | 3 | 2795 | 7672 | 11 |  |  |  |  |  |  |  |  |
| 2001 | 2859 | 15478 | 9 | 272 | 6934 | 7 | 2587 | 8544 | 2 |  |  |  |  |  |  |  |  |
| 2002 | 3099 | 15208 | 11 | 821 | 8563 | 0 | 2278 | 6645 | 11 |  |  |  |  |  |  |  |  |
| 2003 | 2664 | 9441 | 8 | 921 | 4589 | 0 | 1743 | 4852 | 8 |  |  |  |  |  |  |  |  |
| 2004 | 4441 | 13805 | 6 | 559 | 5412 | 1 | 3882 | 8393 | 5 |  |  |  |  |  |  |  |  |
| 2005 | 3654 | 17682 | 6 | 388 | 8814 | 0 | 3266 | 8868 | 6 |  |  |  |  |  |  |  |  |
| 2006 | 3016 | 15855 | 17 | 821 | 9263 | 0 | 2195 | 6592 | 17 |  |  |  |  |  |  |  |  |
| 2007 | 3788 | 16071 | 24 | 1173 | 7233 | 11 | 2615 | 8838 | 13 |  |  |  |  |  |  |  |  |
| 2008 | 4189 | 26108 | 17 | 1769 | 15828 | 1 | 2420 | 10280 | 16 |  |  |  |  |  |  |  |  |
| 2009 | 2694 | 19036 | 19 | 683 | 12911 | 4 | 2011 | 6125 | 15 |  |  |  |  |  |  |  |  |
| 2010 | 2260 | 15122 | 10 | 615 | 10730 | 2 | 1645 | 4392 | 8 |  |  |  |  |  |  |  |  |
| 2011 | 4237 | 16115 | 8 | 362 | 8474 | 1 | 3875 | 7641 | 7 |  |  |  |  |  |  |  |  |
| 2012 | 3080 | 12983 | 7 | 817 | 8997 | 0 | 2263 | 3986 | 7 |  |  |  |  |  |  |  |  |
| 2013 | 6064 | 28781 | 7 | 3477 | 22347 | 3 | 2587 | 6434 | 4 |  |  |  |  |  |  |  |  |
| 2014 | 4212 | 39119 | 9 | 2012 | 33373 | 3 | 2200 | 5746 | 6 |  |  |  |  |  |  |  |  |
| 2015 | 5734 | 27427 | 51 | 5106 | 24218 | 45 | 628 | 3209 | 6 |  |  |  |  |  |  |  |  |
| 2016 | 4193 | 17768 | 1 | 1067 | 13973 | 0 | 3126 | 3795 | 1 |  |  |  |  |  |  |  |  |

## Raw size frequencies



Figure 5. Raw (unscaled) size frequencies by 1-mm size bin from observer sampling for Tanner crab bycatch in the groundfish fisheries.

## Expansion factors



Figure 6. Expansion factors from observed size frequencies to total bycatch, by gear type and reporting area.

Table 4: Observed bycatch numbers, expanded numbers, ans expansion factors from observed size frequencies to total bycatch, by gear type and reporting area.

| area | year | fixed |  |  | trawl |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | obs N | est N | expansion | obs N | est N | expansion |
| 508 | 1996 | 3 | $3.996 e-05$ | $1.332 e-05$ | - | - | - |
| 509 | 1992 | 305 | $1.489 e-03$ | $4.882 e-06$ | 436 | $9.628 e-01$ | $2.208 e-03$ |
|  | 1993 | 2 | $8.905 e-03$ | $4.453 e-03$ | 409 | $6.637 e-01$ | $1.623 e-03$ |
|  | 1994 | 180 | $1.409 e-02$ | $7.828 e-05$ | 2656 | $8.653 e-01$ | $3.258 e-04$ |
|  | 1995 | 89 | $1.372 e-01$ | $1.541 e-03$ | 3063 | $8.361 e-01$ | $2.730 e-04$ |
|  | 1996 | 1384 | $1.701 e-01$ | $1.229 e-04$ | 4759 | $1.201 e+00$ | $2.523 e-04$ |
|  | 1997 | 504 | $9.145 e-02$ | $1.815 e-04$ | 2232 | $7.372 e-01$ | $3.303 e-04$ |
|  | 1998 | 2660 | $5.640 e-02$ | $2.120 e-05$ | 4107 | $6.725 e-01$ | $1.637 e-04$ |
|  | 1999 | 1357 | $1.117 e-01$ | $8.229 e-05$ | 3621 | $4.522 e-01$ | $1.249 e-04$ |
|  | 2000 | 2536 | $4.588 e-02$ | $1.809 e-05$ | 2680 | $3.692 e-01$ | $1.378 e-04$ |
|  | 2001 | 4481 | $6.582 e-02$ | $1.469 e-05$ | 3791 | $6.609 e-01$ | $1.743 e-04$ |
|  | 2002 | 6173 | $8.000 e-02$ | $1.296 e-05$ | 3229 | $2.826 e-01$ | $8.753 e-05$ |
|  | 2003 | 2483 | $2.138 e-02$ | $8.612 e-06$ | 1549 | $1.558 e-01$ | $1.006 e-04$ |
|  | 2004 | 2445 | $4.683 e-02$ | $1.915 e-05$ | 2714 | $2.420 e-01$ | $8.918 e-05$ |
|  | 2005 | 4950 | $8.319 e-02$ | $1.681 e-05$ | 2283 | $1.994 e-01$ | $8.736 e-05$ |
|  | 2006 | 6097 | $2.892 e-01$ | $4.743 e-05$ | 1716 | $1.905 e-01$ | $1.110 e-04$ |
|  | 2007 | 13413 | $7.055 e-01$ | $1.578 e-04$ | 8118 | $1.212 e-01$ | $4.478 e-05$ |
|  | 2008 | 16302 | $2.175 e-01$ | $2.668 e-05$ | 7296 | $1.746 e-01$ | $4.786 e-05$ |
|  | 2009 | 9320 | $1.966 e-01$ | $2.109 e-05$ | 3203 | $1.483 e-01$ | $4.630 e-05$ |
|  | 2010 | 6995 | $1.120 e-01$ | $1.601 e-05$ | 2417 | $1.526 e-01$ | $6.314 e-05$ |
|  | 2011 | 5717 | $7.008 e-02$ | $1.226 e-05$ | 4310 | $3.421 e-01$ | $7.938 e-05$ |
|  | 2012 | 7647 | $5.981 e-02$ | $7.822 e-06$ | 1234 | $8.571 e-02$ | $6.946 e-05$ |
|  | 2013 | 21534 | $2.660 e-01$ | $1.235 e-05$ | 4175 | $2.828 e-01$ | $6.773 e-05$ |
|  | 2014 | 22377 | $3.223 e-01$ | $1.440 e-05$ | 2067 | $1.360 e-01$ | $6.577 e-05$ |
|  | 2015 | 13162 | $2.911 e-01$ | $2.211 e-05$ | 509 | $3.994 e-02$ | $7.847 e-05$ |
|  | 2016 | 8472 | $2.091 e-01$ | $2.468 e-05$ | 2312 | $1.565 e-01$ | $6.769 e-05$ |
| 512 | 1996 | 32 | $6.925 e-04$ | $2.164 e-05$ | - | - | - |
|  | 1998 | 7 | $1.642 e-04$ | $2.346 e-05$ | - | - | - |
|  | 2000 | 2 | $7.727 e-06$ | $3.863 e-06$ | - | - | - |
|  | 2001 | 48 | $4.370 e-04$ | $9.103 e-06$ | - | - | - |
|  | 2002 | 8 | $2.090 e-05$ | $2.612 e-06$ | - | - | - |
|  | 2003 | 5 | $2.144 e-05$ | $4.288 e-06$ | - | - | - |
|  | 2004 | 106 | $6.110 e-04$ | $5.764 e-06$ | - | - | - |
|  | 2005 | 1 | $4.933 e-07$ | $4.933 e-07$ | - | - | - |
|  | 2008 | 8 | $1.159 e-02$ | $2.898 e-03$ | - | - | - |
|  | 2009 | 13 | $3.312 e-05$ | $2.547 e-06$ | - | - | - |
|  | 2010 | 2 | $6.836 e-06$ | $3.418 e-06$ | - | - | - |
|  | 2011 | 2 | $8.076 e-04$ | $4.038 e-04$ | - | - | - |
|  | 2012 | 2 | $8.272 e-06$ | $4.136 e-06$ | - | - | - |
|  | 2013 | 440 | $3.071 e-03$ | $6.980 e-06$ | - | - | - |
|  | 2014 | 279 | $3.712 e-03$ | $1.331 e-05$ | - | - | - |
|  | 2015 | 2301 | $2.952 e-02$ | $1.283 e-05$ | - | - | - |
|  | 2016 | 917 | $1.559 e-02$ | $1.701 e-05$ | - | - | - |


| 513 | 1991 | 1 | $3.358 e-02$ | 3.358 e - 02 | 1749 | $1.556 e+00$ | 8.894e - 04 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1992 | 63 | $2.162 e-02$ | $3.432 e-04$ | 1694 | $2.006 e+00$ | $1.184 e-03$ |
|  | 1993 | 161 | $3.088 e-03$ | $1.918 e-05$ | 494 | $1.922 e+00$ | 3.892e-03 |
|  | 1994 | 314 | $7.514 e-03$ | $2.393 e-05$ | 321 | $2.950 e+00$ | 9.191e - 03 |
|  | 1995 | - | - |  | 1148 | $2.067 e+00$ | $1.800 e-03$ |
|  | 1996 | 304 | $1.658 e-02$ | $5.454 e-05$ | 1353 | $1.453 e+00$ | $1.074 e-03$ |
|  | 1997 | 147 | $2.025 e-02$ | $1.377 e-04$ | 6778 | $1.862 e+00$ | 2.746e - 04 |
|  | 1998 | 312 | $1.273 e-01$ | $4.079 e-04$ | 3928 | $1.289 e+00$ | $3.281 e-04$ |
|  | 1999 | 479 | $4.272 e-02$ | 8.918e-05 | 3744 | $4.910 e-01$ | $1.312 e-04$ |
|  | 2000 | 412 | $1.742 e-02$ | $4.228 e-05$ | 4043 | $7.239 e-01$ | $1.790 e-04$ |
|  | 2001 | 547 | $7.179 e-02$ | $1.312 e-04$ | 2955 | $6.902 e-01$ | 2.336e - 04 |
|  | 2002 | 296 | $9.489 e-03$ | $3.206 e-05$ | 1779 | $3.705 e-01$ | $2.082 e-04$ |
|  | 2003 | 2052 | $1.157 e-02$ | 5.638 - 06 | 1197 | $1.962 e-01$ | $1.639 e-04$ |
|  | 2004 | 2155 | $5.928 e-02$ | $2.751 e-05$ | 1513 | $1.160 e-01$ | $7.664 e-05$ |
|  | 2005 | 1528 | $6.638 e-02$ | $4.345 e-05$ | 3277 | $2.589 e-01$ | $7.900 e-05$ |
|  | 2006 | 1929 | $8.923 e-02$ | $4.626 e-05$ | 1377 | $1.616 e-01$ | $1.174 e-04$ |
|  | 2007 | 3828 | $1.857 e-01$ | $1.455 e-04$ | 5799 | $1.031 e-01$ | $5.332 e-05$ |
|  | 2008 | 3204 | $6.333 e-02$ | $3.953 e-05$ | 5452 | $1.403 e-01$ | $5.145 e-05$ |
|  | 2009 | 1384 | $9.890 e-02$ | 7.146e - 05 | 1979 | $1.303 e-01$ | $6.584 e-05$ |
|  | 2010 | 1103 | $2.936 e-02$ | $2.662 e-05$ | 1333 | $6.849 e-02$ | $5.138 e-05$ |
|  | 2011 | 385 | $2.892 e-03$ | $7.511 e-06$ | 6270 | $4.828 e-01$ | $7.700 e-05$ |
|  | 2012 | 257 | $9.284 e-04$ | $3.613 e-06$ | 1900 | $1.609 e-01$ | $8.466 e-05$ |
|  | 2013 | 809 | $1.788 e-03$ | $2.211 e-06$ | 2589 | $2.131 e-01$ | $8.229 e-05$ |
|  | 2014 | 2534 | $1.830 e-02$ | $7.223 e-06$ | 3198 | $2.376 e-01$ | $7.431 e-05$ |
|  | 2015 | 5213 | $1.960 e-02$ | $3.761 e-06$ | 1599 | $9.455 e-02$ | $5.913 e-05$ |
|  | 2016 | 3135 | $8.526 e-03$ | $2.720 e-06$ | 2350 | $1.671 e-01$ | $7.111 e-05$ |
| 514 | 1991 | - | - | - | 949 | $1.056 e+00$ | $1.113 e-03$ |
|  | 1992 | - | - | - | 286 | $9.474 e-01$ | $3.312 e-03$ |
|  | 1993 | - | - | - | 4 | $4.074 e-01$ | $1.018 e-01$ |
|  | 1995 | - | - | - | 2 | 1.911e-01 | $9.555 e-02$ |
|  | 1996 | - | - | - | 26 | $5.182 e-02$ | $1.993 e-03$ |
|  | 1997 | - | - | - | 29 | $2.300 e-02$ | 7.932e-04 |
|  | 1998 | - | - | - | 23 | $3.050 e-02$ | $1.326 e-03$ |
|  | 1999 | - | - | - | 18 | $7.260 e-02$ | $4.033 e-03$ |
|  | 2000 | - | - | - | 32 | $4.007 e-02$ | $1.252 e-03$ |
|  | 2001 | - | - | - | 14 | $4.354 e-03$ | $3.110 e-04$ |
|  | 2002 | - | - | - | 73 | $4.995 e-02$ | $6.843 e-04$ |
|  | 2003 | - | - | - | 549 | $1.181 e-01$ | $2.152 e-04$ |
|  | 2004 | - | - | - | 1470 | $6.136 e-01$ | $4.174 e-04$ |
|  | 2005 | - | - | - | 321 | $2.627 e-02$ | 8.184e - 05 |
|  | 2006 | - | - | - | 4 | $1.065 e-03$ | $2.662 e-04$ |
|  | 2007 | - | - | - | 1842 | $3.222 e-02$ | $3.499 e-05$ |
|  | 2008 | - | - | - | 233 | 1.078 e-02 | $4.629 e-05$ |
|  | 2009 | - | - | - | 10 | $6.687 e-04$ | $6.687 e-05$ |
|  | 2010 | - | - | - | 2 | $1.372 e-03$ | $6.860 e-04$ |
|  | 2011 | - | - | - | 5 | $7.568 e-05$ | $1.514 e-05$ |
|  | 2012 | 1 | $1.326 e-04$ | $1.326 e-04$ | 51 | $5.723 e-03$ | $1.122 e-04$ |
|  | 2013 | 2 | $2.982 e-05$ | $1.491 e-05$ | 24 | $4.440 e-03$ | $1.850 e-04$ |



|  | 2012 | 966 | $3.620 e-03$ | $3.748 e-06$ | 642 | $4.645 e-02$ | $7.236 e-05$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 2013 | 1287 | $2.410 e-02$ | $1.872 e-05$ | 412 | $1.897 e-02$ | $4.605 e-05$ |
|  | 2014 | 1973 | $1.483 e-02$ | $7.518 e-06$ | 674 | $4.635 e-02$ | $6.877 e-05$ |
|  | 2015 | 2836 | 5.141e-02 | $1.813 e-05$ | 170 | $1.072 e-02$ | $6.309 e-05$ |
|  | 2016 | 1032 | $1.372 e-02$ | $1.330 e-05$ | 673 | $3.511 e-02$ | $5.216 e-05$ |
| 518 | 1991 | - | - | - | 7 | $3.656 e-04$ | $5.223 e-05$ |
|  | 1992 | 14 | $2.840 e-03$ | $2.029 e-04$ | - | - | - |
|  | 1993 | 1 | $3.340 e-04$ | $3.340 e-04$ | - | - | - |
|  | 1994 | 11 | $1.600 e-03$ | $1.455 e-04$ | 11 | $8.027 e-03$ | $7.297 e-04$ |
|  | 1995 | 1 | $7.681 e-03$ | 7.681e-03 | - | - | - |
|  | 1996 | 189 | $1.069 e-03$ | $5.655 e-06$ | - | - | - |
|  | 1997 | 80 | $7.847 e-04$ | $9.809 e-06$ | - | - | - |
|  | 1998 | 257 | $1.950 e-03$ | $7.588 e-06$ | 7 | $9.926 e-04$ | $1.418 e-04$ |
|  | 1999 | 295 | $3.556 e-03$ | $1.205 e-05$ | 1 | $1.181 e-04$ | $1.181 e-04$ |
|  | 2000 | 2 | $1.092 e-04$ | $5.461 e-05$ | 1 | $6.297 e-04$ | $6.297 e-04$ |
|  | 2001 | 7 | $6.132 e-05$ | $8.760 e-06$ | - | - | - |
|  | 2002 | 3 | 5.681e-05 | $1.894 e-05$ | - | - |  |
|  | 2003 | 1 | $3.199 e-05$ | $3.199 e-05$ | - | - |  |
|  | 2013 | 3 | $4.346 e-04$ | $1.449 e-04$ | - | - | - |
| 519 | 1991 | - | - |  | 1 | $3.230 e-03$ | $3.230 e-03$ |
|  | 1992 | 1 | $5.590 e-03$ | $5.590 e-03$ | - | - | - |
|  | 1993 | 11 | $3.215 e-04$ | $2.922 e-05$ | 1 | $1.380 e-02$ | $1.380 e-02$ |
|  | 1994 | - | - | - | 11 | $5.127 e-03$ | $4.661 e-04$ |
|  | 1996 | 7 | $1.278 e-03$ | $1.826 e-04$ | 4 | $2.740 e-03$ | $6.849 e-04$ |
|  | 1997 | 157 | $2.234 e-02$ | $1.423 e-04$ | 3 | $2.141 e-03$ | 7.136e-04 |
|  | 1998 | 457 | $1.387 e-02$ | $3.035 e-05$ | 112 | $1.892 e-02$ | $1.690 e-04$ |
|  | 1999 | 314 | $4.562 e-03$ | $1.453 e-05$ | 516 | $2.911 e-02$ | $5.641 e-05$ |
|  | 2000 | 150 | $1.247 e-03$ | $8.313 e-06$ | 15 | $2.364 e-03$ | $1.576 e-04$ |
|  | 2001 | 130 | $6.725 e-03$ | $5.173 e-05$ | 45 | $1.161 e-02$ | $2.580 e-04$ |
|  | 2002 | 44 | $1.688 e-02$ | $3.837 e-04$ | 20 | $9.996 e-03$ | 4.998 e - 04 |
|  | 2003 | 37 | $1.136 e-02$ | $3.070 e-04$ | 81 | $1.491 e-02$ | $1.840 e-04$ |
|  | 2004 | 99 | $3.950 e-02$ | $3.990 e-04$ | 175 | $1.991 e-02$ | $1.138 e-04$ |
|  | 2005 | 47 | $3.286 e-02$ | $6.991 e-04$ | 21 | $7.500 e-03$ | $3.571 e-04$ |
|  | 2006 | 41 | 1.294e-01 | $3.157 e-03$ | 20 | $1.444 e-03$ | $7.221 e-05$ |
|  | 2007 | 78 | $2.714 e-01$ | $6.959 e-03$ | 117 | $3.238 e-03$ | $8.304 e-05$ |
|  | 2008 | 16 | $1.431 e-01$ | $1.789 e-02$ | 27 | $4.543 e-04$ | $1.682 e-05$ |
|  | 2009 | 5 | $1.863 e-03$ | $3.727 e-04$ | 4 | $3.281 e-04$ | $8.202 e-05$ |
|  | 2010 | 201 | $6.605 e-04$ | $3.286 e-06$ | 10 | $5.612 e-04$ | $5.612 e-05$ |
|  | 2011 | - | - | - | 10 | $3.908 e-04$ | $3.908 e-05$ |
|  | 2012 | 18 | $4.140 e-04$ | $2.300 e-05$ | 5 | $1.882 e-04$ | $3.764 e-05$ |
|  | 2013 | 11 | $1.120 e-04$ | $1.018 e-05$ | 3 | 3.814e-04 | $1.271 e-04$ |
|  | 2014 | 83 | $7.485 e-04$ | $9.018 e-06$ | 2 | $8.963 e-05$ | $4.481 e-05$ |
|  | 2015 | 17 | $2.520 e-03$ | $1.482 e-04$ | 3 | $3.649 e-04$ | $1.216 e-04$ |
|  | 2016 | - | - | - | 1 | $2.919 e-04$ | $2.919 e-04$ |
| 521 | 1991 | 102 | $2.080 e-01$ | $2.039 e-03$ | 2985 | $2.659 e+00$ | $8.908 e-04$ |
|  | 1992 | 96 | $1.939 e-01$ | $2.020 e-03$ | 263 | $1.309 e+00$ | $4.977 e-03$ |
|  | 1993 | 361 | $2.768 e-02$ | $7.669 e-05$ | 5 | $3.007 e-01$ | 6.014e-02 |
|  | 1994 | 348 | $1.912 e-02$ | $5.493 e-05$ | 96 | $2.081 e-01$ | $2.167 e-03$ |


|  | 1995 | 34 | $1.443 e-01$ | $4.243 e-03$ | 86 | $4.436 e-02$ | 5.158e-04 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | 1996 | 323 | $6.127 e-02$ | $1.897 e-04$ | 942 | 7.368e-02 | $7.821 e-05$ |
|  | 1997 | 257 | $2.813 e-02$ | $1.095 e-04$ | 306 | $3.165 e-02$ | $1.034 e-04$ |
|  | 1998 | 219 | $4.606 e-02$ | $2.103 e-04$ | 574 | $1.715 e-01$ | $2.987 e-04$ |
|  | 1999 | 896 | $3.074 e-02$ | $3.431 e-05$ | 489 | $4.875 e-02$ | $9.970 e-05$ |
|  | 2000 | 844 | $4.531 e-02$ | $5.369 e-05$ | 267 | $6.346 e-02$ | $2.377 e-04$ |
|  | 2001 | 357 | $5.854 e-02$ | $1.640 e-04$ | 2335 | $4.777 e-01$ | $2.046 e-04$ |
|  | 2002 | 1267 | 3.078 e-02 | $2.429 e-05$ | 2222 | $2.383 e-01$ | $1.072 e-04$ |
|  | 2003 | 401 | $4.276 e-03$ | $1.066 e-05$ | 1583 | $3.265 e-01$ | $2.063 e-04$ |
|  | 2004 | 259 | $6.907 e-03$ | $2.667 e-05$ | 1990 | $1.169 e-01$ | $5.873 e-05$ |
|  | 2005 | 840 | $2.026 e-02$ | $2.412 e-05$ | 4804 | 3.888e-01 | $8.093 e-05$ |
|  | 2006 | 697 | $6.412 e-02$ | $9.199 e-05$ | 4410 | $2.529 e-01$ | $5.734 e-05$ |
|  | 2007 | 4329 | $6.466 e-02$ | $4.481 e$ - 05 | 9558 | $1.967 e-01$ | $6.173 e-05$ |
|  | 2008 | 6072 | 5.612e-02 | 1.848 e - 05 | 5800 | $1.381 e-01$ | $4.761 e-05$ |
|  | 2009 | 1081 | $2.863 e-02$ | $2.648 e-05$ | 1770 | $8.889 e-02$ | $5.022 e-05$ |
|  | 2010 | 1013 | $4.063 e-03$ | $4.010 e-06$ | 1510 | $1.142 e-01$ | $7.564 e-05$ |
|  | 2011 | 558 | $1.238 e-02$ | $2.218 e-05$ | 603 | $6.132 e-02$ | $1.017 e-04$ |
|  | 2012 | 671 | $2.441 e-03$ | $3.638 e-06$ | 2450 | $1.987 e-01$ | $8.112 e-05$ |
|  | 2013 | 980 | $3.562 e-03$ | $3.635 e-06$ | 1741 | $1.154 e-01$ | $6.628 e-05$ |
|  | 2014 | 3269 | $2.126 e-02$ | 6.504e-06 | 1599 | $1.099 e-01$ | $6.875 e-05$ |
|  | 2015 | 1212 | $4.567 e-03$ | $3.769 e-06$ | 293 | $1.016 e-02$ | $3.469 e-05$ |
|  | 2016 | 1302 | $4.313 e-03$ | $3.313 e-06$ | 968 | $5.478 e-02$ | $5.660 e-05$ |
| 523 | 1993 | 2 | 7.714e-04 | $3.857 e-04$ | - | - | - |
|  | 1994 | 2 | 8.122e-04 | $4.061 e-04$ | - | - | - |
|  | 1995 | 2 | $3.853 e-03$ | $1.927 e-03$ | - | - | - |
|  | 1996 | 9 | $6.724 e-04$ | $7.471 e-05$ | 6 | $2.669 e-04$ | $4.448 e-05$ |
|  | 1997 | 2 | $1.235 e-03$ | $6.177 e-04$ | 25 | 1.191e-04 | $4.762 e-06$ |
|  | 1998 | 4 | $1.611 e-03$ | $4.027 e-04$ | 16 | 5.484e-04 | $3.428 e-05$ |
|  | 1999 | 9 | $1.883 e-03$ | $2.092 e-04$ | 2 | $1.180 e-05$ | $5.900 e-06$ |
|  | 2000 | 7 | $4.027 e-04$ | $5.752 e-05$ | 1 | $2.196 e-06$ | $2.196 e-06$ |
|  | 2001 | 6 | $4.038 e-04$ | $6.731 e-05$ | 6 | $3.388 e-04$ | $5.646 e-05$ |
|  | 2002 | 2 | $9.754 e-05$ | $4.877 e-05$ | 1 | $7.334 e-04$ | $7.334 e-04$ |
|  | 2003 | 4 | $4.313 e-05$ | 1.078 e - 05 | 1 | $3.156 e-06$ | $3.156 e-06$ |
|  | 2004 | 7 | $8.512 e-05$ | $1.216 e-05$ | - | - | - |
|  | 2005 | 17 | $2.907 e-04$ | $1.710 e-05$ | 1 | $4.054 e-05$ | $4.054 e-05$ |
|  | 2006 | 12 | $1.877 e-04$ | $1.564 e-05$ | - | - | - |
|  | 2007 | 12 | $1.079 e-04$ | $2.699 e-05$ | - | - | - |
|  | 2008 | 12 | $1.047 e-04$ | $1.745 e-05$ | - | - | - |
|  | 2009 | 7 | $9.055 e-05$ | $1.294 e-05$ | - | - | - |
|  | 2010 | 29 | $4.350 e-05$ | $1.500 e-06$ | - | - | - |
|  | 2011 | 21 | $1.275 e-04$ | $6.072 e-06$ | - | - | - |
|  | 2012 | 18 | $9.006 e-05$ | $5.003 e-06$ | - | - | - |
|  | 2013 | 10 | $1.651 e-04$ | $1.651 e-05$ | - | - | - |
|  | 2014 | 12 | $6.043 e-05$ | 5.036e-06 | - | - | - |
|  | 2015 | 4 | $6.020 e-05$ | $1.505 e-05$ | - | - | - |
|  | 2016 | 1 | $2.100 e-05$ | $2.100 e-05$ | - | - | - |
| 524 | 1993 | - | - | - | 1 | $9.212 e-02$ | $9.212 e-02$ |
|  | 1995 | 6 | $4.832 e-04$ | $8.053 e-05$ | 605 | $4.892 e-02$ | $8.086 e-05$ |


| 1996 | 15 | $3.624 e-04$ | $2.416 e-05$ | 162 | $3.617 e-02$ | $2.233 e-04$ |
| :--- | ---: | ---: | :--- | ---: | :--- | ---: |
| 1997 | 3 | $4.883 e-04$ | $1.628 e-04$ | 5 | $2.465 e-03$ | $4.930 e-04$ |
| 1998 | 43 | $8.597 e-03$ | $1.999 e-04$ | 25 | $1.061 e-02$ | $4.243 e-04$ |
| 1999 | 39 | $1.085 e-02$ | $2.783 e-04$ | 21 | $1.301 e-01$ | $6.194 e-03$ |
| 2000 | 1 | $1.130 e-04$ | $1.130 e-04$ | 38 | $2.441 e-02$ | $6.422 e-04$ |
| 2001 | 3 | $9.535 e-03$ | $3.178 e-03$ | 142 | $4.404 e-02$ | $3.102 e-04$ |
| 2002 | 38 | $1.415 e-02$ | $3.725 e-04$ | 132 | $3.800 e-02$ | $2.879 e-04$ |
| 2003 | 76 | $1.216 e-03$ | $1.600 e-05$ | 285 | $1.142 e-01$ | $4.008 e-04$ |
| 2004 | 140 | $8.145 e-03$ | $5.818 e-05$ | 1433 | $2.383 e-01$ | $1.663 e-04$ |
| 2005 | 51 | $3.459 e-03$ | $6.783 e-05$ | 196 | $2.320 e-02$ | $1.184 e-04$ |
| 2006 | 34 | $5.597 e-04$ | $1.646 e-05$ | 50 | $5.302 e-03$ | $1.060 e-04$ |
| 2007 | 171 | $4.982 e-03$ | $8.741 e-05$ | 232 | $1.089 e-02$ | $9.391 e-05$ |
| 2008 | 356 | $2.213 e-03$ | $1.243 e-05$ | 126 | $1.563 e-03$ | $2.481 e-05$ |
| 2009 | 196 | $3.977 e-03$ | $2.029 e-05$ | 19 | $6.764 e-04$ | $3.560 e-05$ |
| 2010 | 20 | $1.420 e-04$ | $7.098 e-06$ | 36 | $3.655 e-04$ | $1.015 e-05$ |
| 2011 | 36 | $1.072 e-04$ | $2.977 e-06$ | 7 | $4.352 e-04$ | $6.217 e-05$ |
| 2012 | 15 | $7.533 e-05$ | $5.022 e-06$ | 19 | $6.833 e-04$ | $3.596 e-05$ |
| 2013 | 20 | $9.159 e-05$ | $4.580 e-06$ | 19 | $1.031 e-03$ | $5.428 e-05$ |
| 2014 | 44 | $1.371 e-04$ | $3.115 e-06$ | - | - | - |
| 2015 | 93 | $3.482 e-04$ | $3.745 e-06$ | 44 | $2.470 e-03$ | $5.613 e-05$ |
| 2016 | 94 | $7.162 e-04$ | $7.619 e-06$ | 28 | $2.758 e-03$ | $9.851 e-05$ |

## Total bycatch size compositions



Figure 7. Total bycatch size frequencies, by year, gear type and sex.


Figure 8. Total bycatch size frequencies, by year, gear type and sex. Bubble area scales with catch abundance.

Size compositions aggregated over gear type


Figure 9. Total bycatch size frequencies, by year and sex, aggregated over gear type.

## Spatial patterns of bycatch

Spatial patterns of Tanner crab bycatch in the groundfish fisheries, by ADFG stat area for 2009-2016, are illustrated by gear type in Figures 11-12 below. Bycatch less than 0.1 t in a stat area is not shown.


Figure 10. Basemap for subsequent maps, with EBS bathymetry (blue lines), ADFG stat areas (black rectangles), and the Pribilof Islands Habitat Conservation Area (orange outline).


Figure 11 (1of 1). Bycatch of Tanner crab, by ADFG stat area, in the fixed gear groundfish fisheries.


Figure 12 (1of 1). Bycatch of Tanner crab, by ADFG stat area, in the trawl gear groundfish fisheries.

# Appendix B: NMFS Survey Data for the Tanner Crab Assessment 

William Stockhausen

14 September, 2017

## Contents

Introduction ..... 3
Annual survey abundance and biomass ..... 3
By sex ..... 4
By sex and maturity state ..... 8
Time series survey trends in industry preferred-sized males ..... 12
Size compositions ..... 16
By sex ..... 16
By shell condition for males ..... 18
By maturity state for females ..... 19
Sample sizes ..... 20
List of Tables
1 Parameters used to process crab haul data. ..... 3
2 Observed numbers of Tanner crab in the annual NMFS EBS bottom trawl survey, by sex, maturity state, and shell condition. ..... 20
2 Observed numbers of Tanner crab in the annual NMFS EBS bottom trawl survey, by sex, maturity state, and shell condition. ..... 21
3 Number of hauls, numbers of hauls with Tanner crab, and number of observed Tanner crab in the annual NMFS EBS bottom trawl survey, by sex, maturity state, and shell condition. ..... 22

## List of Figures

1 Tanner crab biomass in the NMFS EBS trawl survey, by sex and area. . . . . . . . . 4
2 Tanner crab biomass in the NMFS EBS trawl survey, by sex and area, since 2001. . 5
3 Tanner crab abundance in the NMFS EBS trawl survey, by sex and area. . . . . . . 6
4 Tanner crab abundance in the NMFS EBS trawl survey, by sex and area, since 2001. 7
5 Tanner crab biomass in the NMFS EBS trawl survey, by sex, maturity state and area. 8
6 Tanner crab biomass in the NMFS EBS trawl survey, by sex, maturity state and area, since 2001

7 Tanner crab abundance in the NMFS EBS trawl survey, by sex, maturity state and
area. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 10
8 Tanner crab abundance in the NMFS EBS trawl survey, by sex, maturity state and area, since 2001.11
9 Legal male Tanner crab biomass in the NMFS EBS trawl survey, by area. ..... 12
10 Industry-preferred male Tanner crab biomass in the NMFS EBS trawl survey, by area, since 2001. ..... 13
11 Legal male Tanner crab abundance in the NMFS EBS trawl survey, by area. ..... 14
12 Industry-preferred male Tanner crab abundance in the NMFS EBS trawl survey, by area, since 2001. ..... 15
13 Annual size compositions for Tanner crab in the NMFS EBS trawl survey, by sex and area. ..... 17
14 Annual size compositions for male Tanner crab in the NMFS EBS trawl survey, by shell condition and area. ..... 18
15 Annual size compositions for female Tanner crab in the NMFS EBS trawl survey, by shell condition and area. ..... 19

## Introduction

This report calculates NMFS survey data time series (aggregate abundance, mature biomass and size compositions) for Tanner crab based on CRABHAUL files and a haul/station strata file downloaded from AKFIN.

The survey data were processed using the following parameters:
Table 1: Parameters used to process crab haul data.

|  | Quantity | Value |
| :---: | :---: | :---: |
| 1 | min size (mm CW) | 25 |
| 2 | max size (mm CW) | 185 |
| 3 | bin size (mm CW) | 5 |
| 4 | strata type | 2015 |
| 5 | haul types | all |

## Annual survey abundance and biomass

Annual survey abundance and biomass for Tanner crab for the EBS and the areas east and west of 166 W longitude were calculated from the survey haul data as if the survey were conducted using a random-stratified sampling design (it uses a fixed grid), with survey strata defined for the Pribilof Islands high density sampling area, the St. Matthew Island high density sampling area, the standard-density sampling area west of $166^{\circ} \mathrm{W}$ longitude, and the standard-density area east of $166^{\circ} \mathrm{W}$ longitude. Abundance and biomass estimates from the four strata were then aggregated appropriately to the areas east and west of $166^{\circ} \mathrm{W}$ and to the entire EBS.

## By sex

The following plots illustrate time series trends in Tanner crab survey abundance and biomass by sex and area.


Figure 1: Tanner crab biomass in the NMFS EBS trawl survey, by sex and area.


Figure 2: Tanner crab biomass in the NMFS EBS trawl survey, by sex and area, since 2001.


Figure 3: Tanner crab abundance in the NMFS EBS trawl survey, by sex and area.


Figure 4: Tanner crab abundance in the NMFS EBS trawl survey, by sex and area, since 2001.

## By sex and maturity state

The following plots illustrate the time series trends for Tanner crab survey abundance and biomass by sex, maturity state, and area.


Figure 5: Tanner crab biomass in the NMFS EBS trawl survey, by sex, maturity state and area.


Figure 6: Tanner crab biomass in the NMFS EBS trawl survey, by sex, maturity state and area, since 2001.


Figure 7: Tanner crab abundance in the NMFS EBS trawl survey, by sex, maturity state and area.


Figure 8: Tanner crab abundance in the NMFS EBS trawl survey, by sex, maturity state and area, since 2001.

## Time series survey trends in industry preferred-sized males

The Tanner crab fishery is managed separately east and west of $166^{\circ} \mathrm{W}$ longitude, and separate TACs are set for each area. Abundance and biomass trends from the NMFS EBS bottom trawl survey are shown in subsequent figures for the current industry-preferred size of legal crab (i.e., $\geq$ 125 mm CW).


Figure 9: Legal male Tanner crab biomass in the NMFS EBS trawl survey, by area.


Figure 10: Industry-preferred male Tanner crab biomass in the NMFS EBS trawl survey, by area, since 2001.


Figure 11: Legal male Tanner crab abundance in the NMFS EBS trawl survey, by area.


Figure 12: Industry-preferred male Tanner crab abundance in the NMFS EBS trawl survey, by area, since 2001.

## Size compositions

Annual size compositions for Tanner crab in the NMFS EBS trawl survey were calculated by sex, maturity state, shell condition, and 5 mm size (carapace width) bin, excluding individuals with sizes $<25 \mathrm{~mm}$ CW and accumulating individuals in the last size bin (180-185 mm CW) for sizes $>185$ mm CW. Individuals classified in the survey as "immature, old shell" crab were assumed to really be "immature, new shell"" crab and were re-classified as such.

By sex


Figure 13: Annual size compositions for Tanner crab in the NMFS EBS trawl survey, by sex and area.

## By shell condition for males



Figure 14: Annual size compositions for male Tanner crab in the NMFS EBS trawl survey, by shell condition and area.

## By maturity state for females



Figure 15: Annual size compositions for female Tanner crab in the NMFS EBS trawl survey, by shell condition and area.

## Sample sizes

The following tables summarize sample sizes for Tanner crab in the NMFS EBS bottom trawl survey.
Table 2: Observed numbers of Tanner crab in the annual NMFS EBS bottom trawl survey, by sex, maturity state, and shell condition.

| year | female |  |  |  | male unknown |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | immature |  | mature |  |  |  |
|  | new_shell | old_shell | new_shell | old_shell | new_shell | old_shell |
| 1975 | 1,040 | 7 | 1,861 | 706 | 6,888 | 399 |
| 1976 | 1,095 | 2 | 1,304 | 311 | 4,492 | 242 |
| 1977 | 765 | 11 | 1,183 | 738 | 3,749 | 485 |
| 1978 | 1,932 | 17 | 638 | 1,307 | 4,527 | 700 |
| 1979 | 725 | 8 | 735 | 341 | 2,613 | 306 |
| 1980 | 1,476 | 15 | 1,471 | 570 | 6,961 | 569 |
| 1981 | 579 | 0 | 1,319 | 1,206 | 6,102 | 886 |
| 1982 | 814 | 9 | 457 | 2, 384 | 3,122 | 2,082 |
| 1983 | 2,108 | 5 | 201 | 2,154 | 3,467 | 1,181 |
| 1984 | 1,867 | 12 | 284 | 1,531 | 2,455 | 1,399 |
| 1985 | 846 | 1 | 228 | 601 | 1,441 | 459 |
| 1986 | 1,581 | 7 | 191 | 331 | 2, 669 | 468 |
| 1987 | 4, 230 | 0 | 445 | 392 | 5,965 | 498 |
| 1988 | 3,733 | 2 | 1,753 | 530 | 7, 837 | 475 |
| 1989 | 3, 264 | 7 | 1,241 | 882 | 8,178 | 1,067 |
| 1990 | 3, 105 | 9 | 1,502 | 1,511 | 8,256 | 1,342 |
| 1991 | 2, 227 | 32 | 1,283 | 2,568 | 7,053 | 2,893 |
| 1992 | 1,494 | 0 | 820 | 2, 205 | 5,005 | 1,924 |
| 1993 | 865 | 4 | 545 | 1,337 | 3,728 | 1,865 |
| 1994 | 909 | 12 | 148 | 1,293 | 2,005 | 1,827 |
| 1995 | 830 | 4 | 140 | 1,057 | 1,178 | 1,611 |
| 1996 | 869 | 14 | 109 | 963 | 1,291 | 1,414 |
| 1997 | 1,325 | 4 | 168 | 504 | 1,625 | 582 |
| 1998 | 1,704 | 6 | 160 | 344 | 2, 428 | 624 |
| 1999 | 2,608 | 20 | 255 | 510 | 3, 366 | 567 |
| 2000 | 2, 249 | 0 | 242 | 345 | 3,464 | 653 |
| 2001 | 3, 675 | 3 | 364 | 644 | 4,665 | 817 |
| 2002 | 3,583 | 2 | 350 | 500 | 4,370 | 1,089 |

Table 2: Observed numbers of Tanner crab in the annual NMFS EBS bottom trawl survey, by sex, maturity state, and shell condition.

| 8003 | female |  |  |  | male unknown |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | immature |  | mature |  |  |  |
|  | nee, 8 s 3 Bell | old__shell | new 923 ell | old_758ell | ne⿹\zh26, 6 , 6 Hell | oldl, 3k§ell |
| 2004 | 3, 563 | 359 | 427 | 656 | 5,595 | 1,873 |
| 2005 | 3, 349 | 3 | 634 | 928 | 5,776 | 1,753 |
| 2006 | 4, 355 | 9 | 1,332 | 1,327 | 7,981 | 4, 054 |
| 2007 | 2,420 | 10 | 1,311 | 1,396 | 6,679 | 2,907 |
| 2008 | 1,747 | 0 | 580 | 1,783 | 5,243 | 2,146 |
| 2009 | 2, 408 | 0 | 363 | 1,317 | 4, 023 | 1,954 |
| 2010 | 3,171 | 9 | 245 | 941 | 4,922 | 1,702 |
| 2011 | 5,044 | 0 | 471 | 705 | 7,210 | 1,941 |
| 2012 | 3, 577 | 34 | 942 | 720 | 7,090 | 1,296 |
| 2013 | 2,900 | 17 | 1,417 | 1,002 | 8,267 | 1,344 |
| 2014 | 2, 207 | 4 | 482 | 1,584 | 8, 032 | 2, 829 |
| 2015 | 1,455 | 0 | 445 | 1,363 | 4,596 | 2, 817 |
| 2016 | 1,372 | 1 | 370 | 1,248 | 3, 405 | 3, 668 |
| 2017 | 2,027 | 1 | 213 | 1,125 | 2,656 | 3,529 |

Table 3: Number of hauls, numbers of hauls with Tanner crab, and number of observed Tanner crab in the annual NMFS EBS bottom trawl survey, by sex, maturity state, and shell condition.

| year | Hauls | immature |  |  |  | female |  | mature |  |  |  |  | immature m |  |  |  |  | male |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | new shell |  | old shell |  |  | new shell |  |  | old shell |  |  |  |  |  |  |  | new shell |  | old shell |  |  | new shell |  | old shell |  |  |
|  |  | non-0 hauls | crab | non-0 | hauls |  |  | crab | non-0 | 0 hauls | crab | non-0 | hauls | crab | non-0 hauls | crab | non-0 | hauls | crab | non-0 hauls | crab | non-0 | hauls | crab |
| 1975 | 136 | 73 | 1,040 |  | 6 | 7 |  | 91 | 1, 861 |  | 39 | 706 | 127 | 2,895 |  | 0 | 0 | 127 | 3,993 |  | 80 | 399 |
| 1976 | 214 | 87 | 1,095 |  | 2 | 2 |  | 91 | 1, 304 |  | 39 | 311 | 130 | 2, 023 |  | 0 | 0 | 130 | 2, 469 |  | 47 | 242 |
| 1977 | 155 | 66 | 765 |  | 9 | 11 |  | 76 | 1, 183 |  | 60 | 738 | 114 | 1,778 |  | 0 | 0 | 114 | 1,971 |  | 79 | 485 |
| 1978 | 230 | 87 | 1,932 |  | 8 | 17 |  | 82 | 638 |  | 65 | 1,307 | 147 | 2,957 |  | 0 | 0 | 147 | 1,570 |  | 104 | 700 |
| 1979 | 307 | 71 | 725 |  | 8 | 8 |  | 62 | 735 |  | 42 | 341 | 138 | 1,805 |  | 0 | 0 | 138 | 808 |  | 68 | 306 |
| 1980 | 320 | 101 | 1,476 |  | 10 | 15 |  | 95 | 1,471 |  | 49 | 570 | 164 | 4,602 |  | 0 | 0 | 164 | 2,359 |  | 71 | 569 |
| 1981 | 305 | 71 | 579 |  | 0 | 0 |  | 79 | 1, 319 |  | 94 | 1,206 | 158 | 3,809 |  | 0 | 0 | 158 | 2,293 |  | 116 | 886 |
| 1982 | 342 | 85 | 814 |  | 9 | 9 |  | 72 | 457 |  | 103 | 2, 384 | 181 | 1,751 |  | 0 | 0 | 181 | 1,371 |  | 147 | 2,082 |
| 1983 | 353 | 102 | 2,108 |  | 4 | 5 |  | 56 | 201 |  | 102 | 2,154 | 166 | 2,484 |  | 0 | 0 | 166 | 983 |  | 132 | 1,181 |
| 1984 | 355 | 135 | 1,867 |  | 9 | 12 |  | 53 | 284 |  | 94 | 1,531 | 171 | 1,965 |  | 0 | 0 | 171 | 490 |  | 126 | 1,399 |
| 1985 | 353 | 140 | 846 |  | 1 | 1 |  | 52 | 228 |  | 65 | 601 | 179 | 1, 060 |  | 0 | 0 | 179 | 381 |  | 86 | 459 |
| 1986 | 353 | 162 | 1,581 |  | 4 | 7 |  | 64 | 191 |  | 68 | 331 | 213 | 2,141 |  | 0 | 0 | 213 | 528 |  | 115 | 468 |
| 1987 | 355 | 189 | 4, 230 |  | 0 | 0 |  | 105 | 445 |  | 73 | 392 | 226 | 4,659 |  | 0 | 0 | 226 | 1,306 |  | 103 | 498 |
| 1988 | 370 | 206 | 3, 733 |  | 2 | 2 |  | 149 | 1,753 |  | 100 | 530 | 252 | 5,627 |  | 0 | 0 | 252 | 2,210 |  | 101 | 475 |
| 1989 | 373 | 204 | 3, 264 |  | 4 | 7 |  | 144 | 1, 241 |  | 108 | 882 | 237 | 4,977 |  | 0 | 0 | 237 | 3, 201 |  | 135 | 1,067 |
| 1990 | 370 | 197 | 3,105 |  | 3 | 9 |  | 155 | 1,502 |  | 126 | 1,511 | 247 | 5,107 |  | 0 | 0 | 247 | 3,149 |  | 151 | 1, 342 |
| 1991 | 371 | 159 | 2,227 |  | 9 | 32 |  | 138 | 1,283 |  | 141 | 2, 568 | 227 | 4, 361 |  | 0 | 0 | 227 | 2,692 |  | 181 | 2, 893 |
| 1992 | 355 | 107 | 1,494 |  | 0 | 0 |  | 119 | 820 |  | 123 | 2, 205 | 215 | 2, 958 |  | 0 | 0 | 215 | 2, 047 |  | 177 | 1,924 |
| 1993 | 374 | 99 | 865 |  | 4 | 4 |  | 96 | 545 |  | 122 | 1,337 | 207 | 2, 051 |  | 0 | 0 | 207 | 1,677 |  | 180 | 1,865 |
| 1994 | 374 | 97 | 909 |  | 3 | 12 |  | 52 | 148 |  | 104 | 1,293 | 175 | 1,281 |  | 0 | 0 | 175 | 724 |  | 174 | 1,827 |
| 1995 | 375 | 113 | 830 |  | 4 | 4 |  | 35 | 140 |  | 107 | 1,057 | 153 | 958 |  | 0 | 0 | 153 | 220 |  | 137 | 1,611 |
| 1996 | 374 | 114 | 869 |  | 4 | 14 |  | 57 | 109 |  | 98 | -963 | 148 | 1,069 |  | 0 | 0 | 148 | 222 |  | 134 | 1,414 |
| 1997 | 375 | 116 | 1,325 |  | 2 | 4 |  | 62 | 168 |  | 83 | 504 | 161 | 1,336 |  | 0 | 0 | 161 | 289 |  | 125 | 582 |
| 1998 | 374 | 146 | 1,704 |  | 4 | 6 |  | 53 | 160 |  | 73 | 344 | 176 | 2, 032 |  | 0 | 0 | 176 | 396 |  | 128 | 624 |
| 1999 | 372 | 137 | 2,608 |  | 6 | 20 |  | 52 | 255 |  | 85 | 510 | 170 | 2, 816 |  | 0 | 0 | 170 | 550 |  | 124 | 567 |
| 2000 | 371 | 142 | 2, 249 |  | 0 | 0 |  | 61 | 242 |  | 55 | 345 | 188 | 2, 836 |  | 0 | 0 | 188 | 628 |  | 133 | 653 |
| 2001 | 374 | 164 | 3,675 |  | 3 | 3 |  | 83 | 364 |  | 72 | 644 | 211 | 4, 036 |  | 0 | 0 | 211 | 629 |  | 145 | 817 |
| 2002 | 374 | 154 | 3, 583 |  | 2 | 2 |  | 81 | 350 |  | 70 | 500 | 186 | 3, 912 |  | 0 | 0 | 186 | 458 |  | 154 | 1,089 |
| 2003 | 375 | 153 | 2, 830 |  | 3 | 4 |  | 111 | 923 |  | 83 | 752 | 203 | 4,754 |  | 0 | 0 | 203 | 900 |  | 153 | 1, 349 |
| 2004 | 374 | 173 | 3,563 |  | 10 | 359 |  | 90 | 427 |  | 80 | 656 | 236 | 4,568 |  | 0 | 0 | 236 | 1, 027 |  | 179 | 1,873 |
| 2005 | 372 | 201 | 3,349 |  | 2 | 3 |  | 103 | 634 |  | 74 | 928 | 254 | 4,496 |  | 0 | 0 | 254 | 1,280 |  | 185 | 1,753 |
| 2006 | 375 | 210 | 4,355 |  | 4 | 9 |  | 143 | 1, 332 |  | 125 | 1, 327 | 254 | 6,224 |  | 0 | 0 | 254 | 1,757 |  | 211 | 4, 054 |
| 2007 | 375 | 185 | 2, 420 |  | 6 | 10 |  | 138 | 1, 311 |  | 136 | 1,396 | 261 | 4,697 |  | 0 | 0 | 261 | 1, 982 |  | 201 | 2, 907 |
| 2008 | 374 | 153 | 1, 747 |  | 0 | 0 |  | 104 | 580 |  | 120 | 1,783 | 240 | 3,127 |  | 0 | 0 | 240 | 2,116 |  | 196 | 2,146 |
| 2009 | 375 | 171 | 2, 408 |  | 0 | 0 |  | 75 | 363 |  | 115 | 1,317 | 216 | 2, 879 |  | 0 | 0 | 216 | 1, 144 |  | 187 | 1,954 |
| 2010 | 375 | 186 | 3, 171 |  | 5 | 9 |  | 67 | 245 |  | 104 | 941 | 223 | 3,654 |  | 0 | 0 | 223 | 1,268 |  | 166 | 1,702 |
| 2011 | 375 | 193 | 5, 044 |  | 0 | 0 |  | 90 | 471 |  | 102 | 705 | 210 | 6, 095 |  | 0 | 0 | 210 | 1,115 |  | 167 | 1,941 |
| 2012 | 375 | 195 | 3,577 |  | 6 | 34 |  | 100 | 942 |  | 97 | 720 | 215 | 5,526 |  | 0 | 0 | 215 | 1, 564 |  | 139 | 1,296 |
| 2013 | 375 | 163 | 2, 900 |  | 9 | 17 |  | 116 | 1, 417 |  | 101 | 1,002 | 207 | 5,592 |  | 0 | 0 | 207 | 2, 675 |  | 137 | 1, 344 |
| 2014 | 375 | 165 | 2,207 |  | 3 | 4 |  | 98 | 482 |  | 121 | 1,584 | 222 | 4,746 |  | 0 | 0 | 222 | 3, 286 |  | 167 | 2, 829 |
| 2015 | 375 | 118 | 1,455 |  | 0 | 0 |  | 60 | 445 |  | 94 | 1,363 | 225 | 2,737 |  | 0 | 0 | 225 | 1,859 |  | 200 | 2, 817 |
| 2016 | 375 | 110 | 1,372 |  | 1 | , |  | 56 | 370 |  | 82 | 1,248 | 222 | 2, 235 |  | 0 | 0 | 222 | 1,170 |  | 218 | 3,668 |
| 2017 | 375 | 129 | 2,027 |  | 1 | 1 |  | 50 | 213 |  | 99 | 1,125 | 185 | 2,233 |  | 0 | 0 | 185 | ${ }^{1} 423$ |  | 204 | 3,529 |

# Appendix C: Tanner Crab Spatial Patterns <br> William Stockhausen <br> 14 September, 2017 

## Contents

Introduction 1
Basemap 1
Survey CPUE by sex and maturity state 2
Legal-sized males 45

## Introduction

This report creates a time series of maps of Tanner crab CPUE and bottom temperature from the NMFS EBS bottom trawl survey.

## Basemap

The following figure illustrates the base map for subsequent maps of bottom temperature and survey CPUE.


Figure 1: Basemap for future maps, with EBS bathymetry (blue lines) and the NMFS EBS bottom trawl survey station grid.

## Survey CPUE by sex and maturity state

The following maps present survey CPUE (in biomass) for immature and mature components of the Tanner crab stock by sex superimposed on bottom temperature at the time of the survey for each year of the NMFS bottom trawl survey.


Figure 2: Tanner crab crab CPUE (biomass) from the 1975 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 3: Tanner crab crab CPUE (biomass) from the 1976 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 4: Tanner crab crab CPUE (biomass) from the 1977 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 5: Tanner crab crab CPUE (biomass) from the 1978 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 6: Tanner crab crab CPUE (biomass) from the 1979 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 7: Tanner crab crab CPUE (biomass) from the 1980 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 8: Tanner crab crab CPUE (biomass) from the 1981 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 9: Tanner crab crab CPUE (biomass) from the 1982 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 10: Tanner crab crab CPUE (biomass) from the 1983 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 11: Tanner crab crab CPUE (biomass) from the 1984 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 12: Tanner crab crab CPUE (biomass) from the 1985 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 13: Tanner crab crab CPUE (biomass) from the 1986 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 14: Tanner crab crab CPUE (biomass) from the 1987 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 15: Tanner crab crab CPUE (biomass) from the 1988 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 16: Tanner crab crab CPUE (biomass) from the 1989 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 17: Tanner crab crab CPUE (biomass) from the 1990 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 18: Tanner crab crab CPUE (biomass) from the 1991 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 19: Tanner crab crab CPUE (biomass) from the 1992 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 20: Tanner crab crab CPUE (biomass) from the 1993 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 21: Tanner crab crab CPUE (biomass) from the 1994 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 22: Tanner crab crab CPUE (biomass) from the 1995 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 23: Tanner crab crab CPUE (biomass) from the 1996 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 24: Tanner crab crab CPUE (biomass) from the 1997 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 25: Tanner crab crab CPUE (biomass) from the 1998 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 26: Tanner crab crab CPUE (biomass) from the 1999 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 27: Tanner crab crab CPUE (biomass) from the 2000 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 28: Tanner crab crab CPUE (biomass) from the 2001 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 29: Tanner crab crab CPUE (biomass) from the 2002 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 30: Tanner crab crab CPUE (biomass) from the 2003 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 31: Tanner crab crab CPUE (biomass) from the 2004 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 32: Tanner crab crab CPUE (biomass) from the 2005 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 33: Tanner crab crab CPUE (biomass) from the 2006 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 34: Tanner crab crab CPUE (biomass) from the 2007 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 35: Tanner crab crab CPUE (biomass) from the 2008 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 36: Tanner crab crab CPUE (biomass) from the 2009 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 37: Tanner crab crab CPUE (biomass) from the 2010 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 38: Tanner crab crab CPUE (biomass) from the 2011 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 39: Tanner crab crab CPUE (biomass) from the 2012 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 40: Tanner crab crab CPUE (biomass) from the 2013 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 41: Tanner crab crab CPUE (biomass) from the 2014 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 42: Tanner crab crab CPUE (biomass) from the 2015 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 43: Tanner crab crab CPUE (biomass) from the 2016 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 44: Tanner crab crab CPUE (biomass) from the 2017 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.

## Legal-sized males

The following maps present survey CPUE (in biomass) for immature and mature components of the Tanner crab stock by sex superimposed on bottom temperature at the time of the survey for each year of the NMFS bottom trawl survey.


Figure 45: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 1 of 11


Figure 46: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 2 of 11


Figure 47: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 3 of 11


Figure 48: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 4 of 11


Figure 49: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 5 of 11


Figure 50: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 6 of 11


Figure 51: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 7 of 11


Figure 52: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 8 of 11


Figure 53: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 9 of 11


Figure 54: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 10 of 11


Figure 55: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 11 of 11

# Appendix C: Tanner Crab Spatial Patterns <br> William Stockhausen <br> 14 September, 2017 

## Contents

Introduction 1
Basemap 1
Survey CPUE by sex and maturity state 2
Legal-sized males 45

## Introduction

This report creates a time series of maps of Tanner crab CPUE and bottom temperature from the NMFS EBS bottom trawl survey.

## Basemap

The following figure illustrates the base map for subsequent maps of bottom temperature and survey CPUE.


Figure 1: Basemap for future maps, with EBS bathymetry (blue lines) and the NMFS EBS bottom trawl survey station grid.

## Survey CPUE by sex and maturity state

The following maps present survey CPUE (in biomass) for immature and mature components of the Tanner crab stock by sex superimposed on bottom temperature at the time of the survey for each year of the NMFS bottom trawl survey.


Figure 2: Tanner crab crab CPUE (biomass) from the 1975 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 3: Tanner crab crab CPUE (biomass) from the 1976 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 4: Tanner crab crab CPUE (biomass) from the 1977 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 5: Tanner crab crab CPUE (biomass) from the 1978 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 6: Tanner crab crab CPUE (biomass) from the 1979 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 7: Tanner crab crab CPUE (biomass) from the 1980 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 8: Tanner crab crab CPUE (biomass) from the 1981 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 9: Tanner crab crab CPUE (biomass) from the 1982 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 10: Tanner crab crab CPUE (biomass) from the 1983 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 11: Tanner crab crab CPUE (biomass) from the 1984 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 12: Tanner crab crab CPUE (biomass) from the 1985 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 13: Tanner crab crab CPUE (biomass) from the 1986 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 14: Tanner crab crab CPUE (biomass) from the 1987 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 15: Tanner crab crab CPUE (biomass) from the 1988 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 16: Tanner crab crab CPUE (biomass) from the 1989 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 17: Tanner crab crab CPUE (biomass) from the 1990 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 18: Tanner crab crab CPUE (biomass) from the 1991 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 19: Tanner crab crab CPUE (biomass) from the 1992 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 20: Tanner crab crab CPUE (biomass) from the 1993 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 21: Tanner crab crab CPUE (biomass) from the 1994 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 22: Tanner crab crab CPUE (biomass) from the 1995 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 23: Tanner crab crab CPUE (biomass) from the 1996 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 24: Tanner crab crab CPUE (biomass) from the 1997 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 25: Tanner crab crab CPUE (biomass) from the 1998 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 26: Tanner crab crab CPUE (biomass) from the 1999 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 27: Tanner crab crab CPUE (biomass) from the 2000 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 28: Tanner crab crab CPUE (biomass) from the 2001 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 29: Tanner crab crab CPUE (biomass) from the 2002 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 30: Tanner crab crab CPUE (biomass) from the 2003 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 31: Tanner crab crab CPUE (biomass) from the 2004 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 32: Tanner crab crab CPUE (biomass) from the 2005 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 33: Tanner crab crab CPUE (biomass) from the 2006 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 34: Tanner crab crab CPUE (biomass) from the 2007 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 35: Tanner crab crab CPUE (biomass) from the 2008 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 36: Tanner crab crab CPUE (biomass) from the 2009 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 37: Tanner crab crab CPUE (biomass) from the 2010 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 38: Tanner crab crab CPUE (biomass) from the 2011 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 39: Tanner crab crab CPUE (biomass) from the 2012 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 40: Tanner crab crab CPUE (biomass) from the 2013 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 41: Tanner crab crab CPUE (biomass) from the 2014 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 42: Tanner crab crab CPUE (biomass) from the 2015 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 43: Tanner crab crab CPUE (biomass) from the 2016 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.


Figure 44: Tanner crab crab CPUE (biomass) from the 2017 NMFS EBS bottom trawl survey. upper row: immature crab; lower row: mature crab; lefthand column: males; righthand column: females.

## Legal-sized males

The following maps present survey CPUE (in biomass) for immature and mature components of the Tanner crab stock by sex superimposed on bottom temperature at the time of the survey for each year of the NMFS bottom trawl survey.


Figure 45: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 1 of 11


Figure 46: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 2 of 11


Figure 47: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 3 of 11


Figure 48: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 4 of 11


Figure 49: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 5 of 11


Figure 50: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 6 of 11


Figure 51: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 7 of 11


Figure 52: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 8 of 11


Figure 53: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 9 of 11


Figure 54: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 10 of 11


Figure 55: Survey CPUE (biomass) for legal-sized male Tanner crab. Page 11 of 11

# Appendix D: Tanner crab molt increment data 

William T. Stockhausen

12 September, 2017

## Contents

Tanner crab growth data ..... 1
Mean growth ..... 2
Assessment model growth vs. growth data ..... 2
Absolute residuals ..... 3
Relative residuals ..... 5
List of Tables
1 Estimated growth parameters for the EBS molt increment data with post-molt size as a power lae of pre-molt size. ..... 2
22016 assessment model mean growth parameters. ..... 2
3 Growth parameters based on Kodiak data, used as prior means for parameters in the assessment model. ..... 2

## List of Figures

1 Tanner crab molt increment data, by region and sex. ..... 2
2 Tanner crab growth data, by region and sex. Colored lines indicate mean growth, by sex, as determined by the assessment model ..... 3
3 Absolute-scale residuals to mean growth as determined by the assessment model, by region and sex. ..... 4
4 Relative-scale residuals to mean growth as determined by the assessment model, by region and sex. ..... 6

## Tanner crab growth data

Input data file for Tanner crab growth data is '/Users/WilliamStockhausen/StockAssessments-Crab/Assessments/TannerCrab/2017-09.TannerCrab/Data/MoltIncrementData/TannerCrab.20160701.csv'. Figure 1 shows molt increment data collected from crab near Kodiak Island in the Gulf of Alaska and in the eastern Bering Sea (EBS). THe Kodiak data was collected over a $20+$ year period during opportunistic surveys and caged grow-out experiments. The EBS data was collected in 2014, 2015, and 2016 through cooperative research conducted by the AFSC/NMFS and the Bering Sea Research Foundation (BSFRF).


Figure 1: Tanner crab molt increment data, by region and sex.

## Mean growth

Sex-specific parameters for post-molt size as a power function of pre-molt size ( $z_{\text {post }}=e^{a} \cdot z_{\text {pre }}{ }^{b}$ ) were estimated in R using the glm function from the EBS data on the log-scale using the regression formula $\ln \left[z_{\text {post }}\right]=a+b \cdot \ln \left[z_{\text {pre }}\right]$. The resulting estimates

Table 1: Estimated growth parameters for the EBS molt increment data with post-molt size as a power lae of pre-molt size..

| parameter | males | females |
| :---: | :---: | :---: |
| a | 0.2708370 | 0.6106653 |
| b | 0.9922623 | 0.8975509 |

Sex-specific parameters from the 2016 assessment model reflecting estimated mean growth are listed in Table 2, where $z_{\text {post }}=e^{a} \cdot z_{\text {pre }}{ }^{b}$.

Table 2: 2016 assessment model mean growth parameters.

| parameter | males | females |
| :---: | :---: | :---: |
| a | 0.4220295 | 0.6999999 |
| b | 0.9721004 | 0.8850577 |

Growth parameters estimated from the Kodiak data, used as prior mean values for parameters in the assessment model are listed in Table 3.

Table 3: Growth parameters based on Kodiak data, used as prior means for parameters in the assessment model.


Figure 2: Tanner crab growth data, by region and sex. Colored lines indicate mean growth, by sex, as determined by the assessment model.

## Absolute residuals

Residuals to assessment model estimates are shown in Figure 3 as observed postmolt size predicted postmolt size.


Figure 3: Absolute-scale residuals to mean growth as determined by the assessment model, by region and sex.

## Relative residuals

Residuals to assessment model estimates are shown in Figure 4 as (observed postmolt size predicted postmolt size)/observed postmolt size.


Figure 4: Relative-scale residuals to mean growth as determined by the assessment model, by region and sex.

## Appendix E: TCSAM02, Version 2 of The Tanner Crab Stock Assessment Model

## Introduction

The computer code used in the last Tanner crab stock-assessment-(Stockhausen, 2016), referred to here as "TCSAM2013" (i.e., an acronym for Tanner Crab Stock Assessment Model, 2013), evolved directly from the assessment model code developed by Rugolo and Turnock (2011, 2012a) used in the 2012 stock assessment (Rugolo and Turnock, 2012b), as rewritten and revised by Stockhausen for the 2013 and subsequent stock assessments (Stockhausen et al., 2013; Stockhausen, 2014; Stockhausen, 2015; Stockhausen, 2016). TCSAM2013 is an integrated assessment model that estimates model parameters in a maximum likelihood framework using AD Model Builder C++ libraries (Fournier et al., 2012) for automatic differentiation to fit to time series of survey (fishery-independent) biomass and size compositions, retained catch biomass and size compositions in the directed fishery, and catch biomass and size compositions in several fisheries that take Tanner crab as bycatch. The computer code for the TCSAM2013 is available on GitHub (the 2016 assessment model version is on the "2016AssessmentModel" branch). While a number of model options can be configured "on-the-fly" using a control file, assessment models developed using the TCSAM2013 computer code are constrained in a number of ways, including the number of directed fisheries (1) and bycatch fisheries (3) that can be accommodated, the type of surveys that can accommodated (1), and the number and type of time blocks that are defined for model parameters (most are hard-wired in the code). Additionally, status determination and overfishing limit (OFL) calculations require a separate "projection model" code to be run using a results file from TCSAM2013.

The "TCSAM02" (Tanner Crab Stock Assessment Model, version 2) modeling framework was developed "from scratch" to eliminate many of the constraints imposed on potential future assessment models by TCSAM2013. Like TCSAM2013, TCSAM02 uses AD Model Builder libraries as the basis for model optimization using a maximum likelihood (or Bayesian) approach. The model code for TCSAM02 is available on GitHub (the current development branch is "After201705CPT").

TCSAM02 is referred to here as a "modeling framework" because, somewhat similar to Stock Synthesis (Methot and Wetzel, 2013), model structure and parameters are defined "on-the-fly" using control filesrather than editing and re-compiling the underlying code. In particular, the number of fisheries and surveys, as well as their associated data types (abundance, biomass, and /or size compositions) and the number and types of time blocks defined for every model parameter, are defined using control files in TCSAM02 and have not been pre-determined. New data types (e.g., growth data) can also be included in the model optimization with TCSAM02 that couldn't be fit with TCSAM2013, as can priors on any model parameter. Additionally, status determination and OFL calculations can be done directly within a TCSAM02 model run, rather having to run a separate "projection model". Finally, TCSAM02 can be substantially "backward compatible" with TCSAM2013.

As a result of comparisons between models based on TCSAM2013 and TCSAM02 presented at the 2017 Crab Modeling Workshop and the May 2017 Crab Plan Team (CPT) Meeting, the CPT and SSC have approved the TCSAM02 modeling framework as the basis for models to be considered during the next stock assessment (September, 2017). It should be noted, however, that TCSAM02 is only a transition to assessments based on an even more generalized model framework, Gmacs (the Generalized Model for Alaska Crab Stocks). Gmacs is intended to be used for all crab stock assessments conducted for the North

Pacific Fisheries Management Council (NPFMC), including both lithodid (king crab) and Chionoecetes (Tanner and snow crab) stocks, while TCSAM02 is specific to Chionoecetes biology (i.e., terminal molt).

## Model Description

## A. General population dynamics

TCSAM02 is a stage/size-based population dynamics model. Population abundance at the start (July 1) of year $y$ in the model, $n_{y, x, m, s, z}$, is characterized by sex $x$ (male, female), maturity state $m$ (immature, mature), shell condition $s$ (new shell, old shell), and size $z$ (carapace width, CW). Changes in abundance due to natural mortality, molting and growth, maturation, shell aging, fishing mortality and recruitment are tracked on an annual basis. Because the principal crab fisheries occur during the winter, the model year runs from July 1 to June 30 of the following calendar year.

The order of calculation steps to project population abundance from year $y$ to $y+1$ depends on the assumed timing of the fisheries ( $\delta t_{y}^{F}$ ) relative to molting/growth/mating ( $\delta t_{y}^{m}$ ) in year $y$. The steps when the fisheries occur before molting/growth/mating ( $\delta t_{y}^{F} \leq \delta t_{y}^{m}$ ) are outlined below first (Steps A1.1-A1.4), followed by the steps when molting/growth/mating occurs after the fisheries ( $\delta t_{y}^{m}<\delta t_{y}^{F}$;


Fig. 1. Timing of annual events in TCSAM02 when fisheries occur before molting/growth/mating. Steps A2.1-A2.4).

## A1. Calculation sequence when $\delta t_{\boldsymbol{y}}^{\boldsymbol{F}} \leq \boldsymbol{\delta} \boldsymbol{t}_{\boldsymbol{y}}^{\boldsymbol{m}}$

Step A1.1: Survival prior to fisheries
Natural mortality is applied to the population from the start of the model year (July 1) until just prior to prosecution of pulse fisheries for year $y$ at $\delta t_{y}^{F}$. The numbers surviving to $\delta t_{y}^{F}$ in year $y$ are given by:

| $n_{y, x, m, s, z}^{1}=e^{-M_{y, x, m, s, z} \cdot \delta t_{y}^{F}} \cdot n_{y, x, m, s, z}$ | A1.1 |
| :--- | :---: |

where $M$ represents the annual rate of natural mortality in year $y$ on crab classified as $x, m, s, z$.

## Step A1.2: Prosecution of the fisheries

The directed and bycatch fisheries are modeled as simultaneous pulse fisheries occurring at $\delta t_{y}^{F}$ in year $y$. The numbers that remain after the fisheries are prosecuted are given by:

$$
n_{y, x, m, s, z}^{2}=e^{-F_{y, x, m, s, z}^{T}} \cdot n_{y, x, m, s, z}^{1}
$$

A1. 2
where $F_{y, x, m, s, z}^{T}$ represents the total fishing mortality (over all fisheries) on crab classified as $x, m, s, z$ in year $y$.

Step A1.3: Survival after fisheries to time of molting/growth/mating
Natural mortality is again applied to the population from just after the fisheries to the time just before molting/growth/mating occurs for year $y$ at $\delta t_{y}^{m}$ (generally Feb. 15). The numbers surviving to $\delta t_{y}^{m}$ in year $y$ are given by:

| $n_{y, x, m, s, z}^{3}=e^{-M_{y, x, m, s, z} \cdot\left(\delta t_{y}^{m}-\delta t_{y}^{F}\right)} \cdot n_{y, x, m, s, z}^{2}$ | A 1.3 |
| :--- | :---: |

where, as above, $M$ represents the annual rate of natural mortality in year $y$ on crab classified as $x, m, s, z$.
Step A1.4: Molting, growth, and maturation
The changes in population structure due to molting, growth and maturation of immature (new shell) crab, as well as the change in shell condition for mature new shell (MAT, NS) crab to mature old shell (MAT, OS) crab due to aging, are given by:

| $n_{y, x, M A T, N S, z}^{4}=\phi_{y, x, z} \cdot \sum_{z^{\prime}} \Theta_{y, x, z, z^{\prime}} \cdot n_{y, x, I M M, N S, z^{\prime}}^{3}$ | A 1.4 a |
| :--- | :---: |
| $n_{y, x, I M M, N S, z}^{4}=\left(1-\phi_{y, x, z}\right) \cdot \sum_{z^{\prime}} \Theta_{y, x, z, z^{\prime}} \cdot n_{y, x, I M M, N S, z^{\prime}}^{3}$ | A 1.4 b |
| $n_{y, x, M A T, O S, z}^{4}=n_{y, x, M A T, O S, z}^{3}+n_{y, x, M A T, N S, z}^{3}$ | A 1.4 c |

where $\Theta_{y, x, z, z^{\prime}}$ is the growth transition matrix in year $y$ for an immature new shell (IMM, NS) crab of sex $x$ and pre-molt size $z$ ' to post-molt size $z$ and $\phi_{y, x, z}$ is the probability that a just-molted crab of sex $x$ and post-molt size $z$ has undergone its terminal molt to maturity (MAT). All crab that molted remain new shell (NS) crab. Additionally, all mature crab that underwent terminal molt to maturity the previous year are assumed to change shell condition from new shell to old shell (A1.4c). Note that the numbers of immature old shell (IMM, OS) crab are identically zero in the current model because immature crab are assumed to molt each year until they undergo the terminal molt to maturity; consequently, the "missing" equation for $m=I M M, s=O S$ is unnecessary.

Step A1.5: Survival to end of year, recruitment, and update to start of next year
Finally, the population abundance at the start of year $y+1$, due to natural mortality on crab from just after the time of molting/growth/mating in year $y$ until the end of the model year (June 30) and recruitment ( $R_{y, x, z}$ ) at the end of year $y$ of immature new shell (IMM, NS) crab by sex $x$ and size $z$, is given by:
$n_{y+1, x, m, s, z}=\left\{\begin{array}{ll|}\hline e^{-M_{y, x, I M M, N S, z} \cdot\left(1-\delta t_{y}^{m}\right)} \cdot n_{y, x, I M M, N S, z}^{4}+R_{y, x, z} & m=I M M, s=N S \\ e^{-M_{y, x, m, s, z} \cdot\left(1-\delta t_{y}^{m}\right)} \cdot n_{y, x, m, s, z}^{4} & \text { otherwise }\end{array} \quad\right.$ A1.5

## A2. Calculation sequence when $\delta t_{\boldsymbol{y}}^{\boldsymbol{m}}<\boldsymbol{\delta} t_{\boldsymbol{y}}^{\boldsymbol{F}}$

Step A2.1: Survival prior to molting/growth/mating
As in the previous sequence, natural mortality is first applied to the population from the start of the model year (July 1), but this time until just prior to molting/growth/mating in year $y$ at $\delta t_{y}^{m}$ (generally Feb. 15). The numbers surviving at $\delta t_{y}^{m}$ in year $y$ are given by:

$$
\begin{array}{|l|c|}
\hline n_{y, x, m, s, z}^{1}=e^{-M_{y, x, m, s, z} \cdot \delta t_{y}^{m}} \cdot n_{y, x, m, s, z} & \mathrm{~A} 2.1 \\
\hline
\end{array}
$$

where $M$ represents the annual rate of natural mortality in year $y$ on crab classified as $x, m, s, z$.

Step A2.2: Molting, growth, and maturation
The changes in population structure due to molting, growth and maturation of immature new shell (IMM, NS) crab, as well as the change in shell condition for mature new shell (MAT, NS) crab to mature old shell (MAT, OS) crab due to aging, are given by:

| $n_{y, x, M A T, N S, z}^{2}=\phi_{y, x, z} \cdot \sum_{z^{\prime}} \Theta_{y, x, z, z^{\prime}} \cdot n_{y, x, I M M, N S, z^{\prime}}^{1}$ | A2.2a |
| :--- | :---: |
| $n_{y, x, I M M, N S, z}^{2}=\left(1-\phi_{y, x, z}\right) \cdot \sum_{z^{\prime}} \Theta_{y, x, z, z^{\prime}} \cdot n_{y, x, I M M, N S, z^{\prime}}^{1}$ | A2.2b |
| $n_{y, x, M A T, O S, z}^{2}=n_{y, x, M A T, O S, z}^{1}+n_{y, x, M A T, N S, z}^{1}$ | A2.2c |

where $\Theta_{y, x, z, z^{\prime}}$ is the growth transition matrix in year $y$ for an immature new shell (IMM, NS) crab of sex $x$ and pre-molt size $z$ ' to post-molt size $z$ and $\phi_{y, x, z}$ is the probability that a just-molted crab of sex $x$ and post-molt size $z$ has undergone its terminal molt to maturity. Additionally, mature new shell (MAT, NS) crab that underwent their terminal molt to maturity the previous year are assumed to change shell condition from new shell to old shell (A2.2c). Again, the numbers of immature old shell crab are identically zero because immature crab are assumed to molt each year until they undergo the terminal molt to maturity.

Step A2.3: Survival after molting/growth/mating to prosecution of fisheries
Natural mortality is again applied to the population from just after molting/growth/mating to the time at which the fisheries occur for year $y\left(\right.$ at $\left.\delta t_{y}^{F}\right)$. The numbers surviving at $\delta t_{y}^{F}$ in year $y$ are then given by:

| $n_{y, x, m, s, z}^{3}=e^{-M_{y, x, m, s, z}\left(\delta t_{y}^{F}-\delta t_{y}^{m}\right)} \cdot n_{y, x, m, s, z}^{2}$ | A 2.3 |
| :--- | :---: |

where, as above, $M$ represents the annual rate of natural mortality in year $y$ on crab classified as $x, m, s, z$.
Step A2.4: Prosecution of the fisheries
The directed fishery and bycatch fisheries are modeled as pulse fisheries occurring at $\delta t_{y}^{F}$ in year $y$. The numbers that remain after the fisheries are prosecuted are given by:

$$
\begin{array}{l|l}
\hline n_{y, x, m, s, z}^{4}=e^{-F_{y, x, m, s, z}^{T} \cdot n_{y, x, m, s, z}^{3}} \quad \mathrm{~A} 2.4
\end{array}
$$

where $F_{y, x, m, s, z}^{T}$ represents the total fishing mortality (over all fisheries) on crab classified as $x, m, s, z$ in year $y$.

Step A2.5: Survival to end of year, recruitment, and update to start of next year
Finally, population abundance at the start of year $y+1$ due to natural mortality on crab from just after prosecution of the fisheries in year $y$ until the end of the model year (June 30) and recruitment of immature new (IMM, NS) shell crab at the end of year $y\left(R_{y, x, z}\right)$ and are given by:

$$
n_{y+1, x, m, s, z}=\left\{\begin{array}{ll}
e^{-M_{y, x, I M M, N S, z} \cdot\left(1-\delta t_{y}^{F}\right)} \cdot n_{y, x, I M M, N S, z}^{4}+R_{y, x, z} & m=I M M, s=N S \\
e^{-M_{y, x, m, s, z} \cdot\left(1-\delta t_{y}^{F}\right)} \cdot n_{y, x, m, s, z}^{4} & \text { otherwise }
\end{array} \quad \mathrm{A} 2.5\right.
$$

## B. Parameter specification

Because parameterization of many model processes (e.g., natural mortality, fishing mortality) in TCSAM02 is fairly flexible, it is worthwhile discussing how model processes and their associated parameters are configured in TCSAM02 before discussing details of the model processes themselves. Each type of model process has a set of (potentially estimable) model parameters and other information associated with it, but different "elements" of a model process can be defined that apply, for example, to different segments of the population and/or during different time blocks. In turn, several "elements" of a model parameter associated with a model process may also be defined (and applied to different elements of the process). At least one combination of model parameters and other information associated with a model process must be defined-i.e., one process element must be defined.

Model processes and parameters are configured in a "ModelParametersInfo" file, one of the three control files required for a model run (the others are the "ModelConfiguration" file and the "ModelOptions" file). As an example of the model processes and parameter specification syntax, Text Box 1 presents the part of a "ModelParametersInfo" file concerned with specifying fishing processes in the directed Tanner crab fishery.

In Text Box 1, the keyword "fisheries" identifies the model process in question. The first section, following the "PARAMETER_COMBINATIONS" keyword (up to the first set of triple blue dots), specifies the indices associated with fishing process parameters ( $\mathrm{pHM}, \mathrm{pLnC}, \mathrm{pDC} 1, \mathrm{pDC} 2, \mathrm{pDC} 3$, pDC4, pDevsLnC, pLnEffX, pLgtRet), selectivity and retention functions (idxSelFcn, idxRetFcn), and effort averaging time period (effAvgID) that apply to a single fishing process element. In this example, the indices for the selectivity and retention functions, as well as those for the effort averaging time period, constitute the "other information" specified for each fishing process element. Each fishing process element in turn applies to a specific fishery (FISHERY $=1$ indicates the directed fishery, in this case), time block (specified by YEAR_BLOCK), and components of the model population (specified by SEX, MATURITY STATE, and SHELL CONDITION). Using indices to identify which parameters and selectivity and retention functions apply to a given combination of fishery/time block/sex/maturity state/shell condition allows one to "share" individual parameters and selectivity and retention functions across different fishery/time block/sex/maturity state/shell condition combinations.

The second section (following the "PARAMETERS" keyword) determines the characteristics for each of the fishing process parameters, organized by parameter name (note: the parameters associated with the different selectivity and retention functions are specified in a different section of the ModelParametersInfo file). Here, each parameter name corresponds to an ADMB "param_init_bounded_number_vector" in the model code-the exception being pDevsLnC, which corresponds to an ADMB "param_init_bounded_vector_vector".

Each row under a "non-devs" parameter name in the fisheries section (e.g., pLnC) specifies the index used to associate an element of the parameter with the fishing processes defined in the PARAMETER_COMBINATIONS section, as well as characteristics of the element in the associated ADMB number_vector (upper and lower bounds, initial value, and initial estimation phase), various flags for initialization ("jitter", "resample"), definition of an associated prior probability distribution, and a label. Each row under a "devs" parameter name (e.g., pDevsLnC) specifies much the same information for the associated ADMB devs vector, with the "read" flag replacing the "initial value" entry. If "read?" is TRUE, then a vector of initial values is read from the file after all "info" rows for the devs parameter have
been read. The "jitter" flag (if set to TRUE) provides the ability to change the initial value for an element of a non-devs parameter using a randomly selected value based on the element's upper and lower bounds. For a devs parameter, an element with jitter set to TRUE is initialized using a vector of randomlygenerated numbers (subject to being a devs vector within the upper and lower bounds). The "resample" flag was intended to specify an alternative method to providing randomly-generated initial values (based on an element's prior probability distribution, rather than its upper and lower bounds), but this has not yet been fully implemented.

Some model processes apply only to specific segments of the population (e.g., growth only applies to immature, new shell crab). In general, though, a model process element can be defined to apply to any segment of the population (by specifying SEX, MATURITY STATE, and SHELL CONDITION appropriately) and range of years (by specifying YEAR_BLOCK). In turn, an element of a parameter may be "shared" across multiple processes by specifying the element's index in multiple rows of a PARAMETERS_COMBINATION block.


Text Box 1. Abbreviated example of process and parameter specifications in a "ModelParametersInfo" file for fishing mortality in TCSAM02. Only parameter combinations and parameters relevant to the directed fishery are shown. Input values are in black text, comments are in green, triple blue dots indicate additional input lines not shown.

## C. Model processes: natural mortality

The natural mortality rate applied to crab of sex $x$, maturity state $m$, shell condition $s$, and size $z$ in year $y$, $M_{y, x, m, s, z}$, can be specified using one of two parameterizations. The first parameterization option uses a $\ln$-scale parameterization with an option to include an inverse- size dependence using Lorenzen's approach:

| $\ln M_{y, x, m, s}=\mu_{y, x, m, s}^{0}+\sum_{i=1}^{4} \delta \mu_{y, x, m, s}^{i}$ | C.1a |
| :--- | :---: |
| $M_{y, x, m, s, z}=\left\{\begin{array}{cc\|}\exp \left(\ln M_{y, x, m, s}\right) & \text { if Lorenzen option is not selected } \\ \exp \left(\ln M_{y, x, m, s}\right) \cdot \frac{z_{\text {base }}}{z} & \text { if Lorenzen option is selected }\end{array}\right.$ | C.1b |
| C.1c |  |

where the $\mu^{0}$ and the $\delta \mu^{i}$ 's are (potentially) estimable parameters defined for time block $T$, sex $S$ (MALE, FEMALE, or ANY), maturity $M$ (IMMATURE, MATURE, or ANY), and shell condition $S$ (NEWSHELL, OLDSHELL, or ANY), and $\{y, x, m, s\}$ falls into the set $\{T, X, M, S\}$. In Eq. C.1c, $z_{\text {base }}$ denotes the specified reference size ( mm CW ) for the inverse-size dependence.

The second parameterization option uses an arithmetic parameterization in order to provide backward compatibility with the 2016 assessment model based on TCSAM2013. In TCSAM2013, the natural mortality rate $M_{y, x, m, s, z}$ was parameterized using:

| $M_{y, x, m=I M M, s, z}=M^{\text {base }} \cdot \delta M_{I M M}$ | C.2a |
| :--- | :---: |
| $M_{y, x, m=M A T, s, z}=\left\{\begin{array}{cc}M^{\text {base }} \cdot \delta M_{x, M A T} & \text { otherwise } \\ M^{\text {base }} \cdot \delta M_{x, M A T} \cdot \delta M_{x, M A T}^{T} & 1980 \leq y \leq 1984\end{array}\right.$ | C.2b |

where $M^{\text {base }}$ was a fixed value $\left(0.23 \mathrm{yr}^{-1}\right), \delta M_{I M M}$ was a multiplicative factor applied for all immature crab, the $\delta M_{x, M A T}$ were sex-specific multiplicative factors for mature crab, and the $\delta M_{x, M A T}^{T}$ were additional sex-specific multiplicative factors for mature crab during the 1980-1984 time block (which has been identified as a period of enhanced natural mortality on mature crab, the mechanisms for which are not understood). While it would be possible to replicate Eq.s C.2a and C.2b using ln-scale parameters, TCSAM2013 also placed informative arithmetic-scale priors on some of these parameters-and this could not be duplicated on the $\ln$-scale. Consequently, the second option uses the following parameterization, where the parameters (and associated priors) are defined on the arithmetic-scale:

$$
\ln M_{y, x, m, s}=\ln \left[\mu_{y, x, m, s}^{0}\right]+\sum_{i=1}^{4} \ln \left[\delta \mu_{y, x, m, s}^{i}\right] \quad \text { C.3a }
$$

A system of equations identical to C.2a-b can be achieved under the following assignments:

| $\mu_{\{y, x, m, S\} \in\{T=A L L, X=A L L, M=A L L, S=A L L\}}^{0}=M^{\text {base }}$ | C.4a |
| :--- | :---: |
| $\delta \mu_{\{y, x, m, S\} \in\{T=A L L, X=A L L, M=I M M, S=A L L\}}^{1}=\delta M_{I M M}$ | C. 4 e |
| $\delta \mu_{\{y, x, m, s\} \in\{T=A L L, X=x, M=M A T, S=A L L\}}^{1}=\delta M_{x, M A T}$ | C.4f |
| $\delta \mu_{\{y, x, m, s\} \in\{T=1980-1984, X=x, M=M A T, S=A L L\}}^{2}=\delta M_{x, M A T}^{T}$ | C. 4 g |

where unassigned $\delta \mu_{y, x, m, s}^{i}$ are set equal to 1 . Pending further model testing using alternative model configurations, the TCSAM2013 option is standard.

It is worth noting explicitly that, given the number of potential parameters above that could be used, extreme care must be taken when defining a model to achieve a set of parameters that are not confounded and are, at least potentially, estimable.

## D. Model processes: growth

Because Tanner crab are assumed to undergo a terminal molt to maturity, in TCSAM02 only immature crab experience growth. Annual growth of immature crab is implemented as using two options, the first based on a formulation used in Gmacs and the second (mainly for purposes of backward compatibility) based on that used in TCSAM2013. In TCSAM02, growth can vary by time block and sex, so it is expressed by sex-specific transition matrices for time block $t, \Theta_{t, x, z, z^{\prime}}$, that specify the probability that crab of sex $x$ in pre-molt size bin $z^{\prime}$ grow to post-molt size bin $z$ at molting.

In the Gmacs-like approach (the standard approach as of May, 2017), the sex-specific growth matrices are given by:

| $\Theta_{t, x, z, z^{\prime}}=c_{t, x, z^{\prime}} \cdot \int_{z-b i n / 2}^{z+\text { bin } / 2} \Gamma\left(\frac{z^{\prime \prime}-\bar{z}_{t, x, z^{\prime}}}{\beta_{t, x}}\right) d z^{\prime \prime}$ | Sex-specific $(x)$ transition matrix for <br> growth from pre-molt $z^{\prime}$ to post-molt $z$, <br> with $z \geq z^{\prime}$ | D.1a |
| :--- | :--- | :--- |
| $c_{t, x, z^{\prime}}=\left[\int_{z^{\prime}}^{\infty} \Gamma\left(\frac{z^{\prime \prime}-\bar{z}_{t, x, z^{\prime}}}{\beta_{t, x}}\right) d z^{\prime \prime}\right]^{-1}$ | Normalization constant so <br> $1=\sum_{z} \Theta_{t, x, z, z^{\prime}}$ | D.1b |
| $\bar{z}_{t, x, z^{\prime}}=e^{a_{t, x} \cdot z^{\prime} b_{t, x}}$ | Mean size after molt, given pre-molt size <br> $z^{\prime}$ | D.1c |

where the integral represents a cumulative gamma distribution across the post-molt ( $z$ ) size bin. This approach may have better numerical stability properties than the TCSAM2013 approach below.

The TCSAM2013 approach is an approximation to the Gmacs approach, where the sex-specific growth matrices $\Theta_{t, x, z, z^{\prime}}$ are given by

| $\Theta_{t, x, z, z^{\prime}}=c_{t, x, z^{\prime}} \cdot \Delta_{z, z^{\prime}} \alpha_{t, x, z^{\prime}}-1$ |  |  |
| :--- | :--- | :--- |
| $c^{-\frac{\Delta_{z, z^{\prime}}}{\beta_{t, x}}}$ | Sex-specific $(x)$ transition matrix for <br> growth from pre-molt $z^{\prime}$ to post-molt $z$, <br> with $z \geq z^{\prime}$ | D.2a |
| $c_{t, x, z^{\prime}}=\left[\sum_{z^{\prime}} \Delta_{z, z^{\prime}} \alpha_{t, x, z^{\prime}}-1\right.$ |  |  |
| $\left.\Delta^{-\frac{\Delta_{z, z^{\prime}}}{\beta_{t, x}}}\right]^{-1}$ | Normalization constant so <br> $1=\sum_{z} \Theta_{t, x, z, z^{\prime}}$ | D.2b |
| $\Delta_{z, z^{\prime}}=z-z^{\prime}$ | Actual growth increment | D.2c |
| $\alpha_{t, x, z^{\prime}}=\left[\bar{z}_{t, x, z^{\prime}}-z^{\prime}\right] / \beta_{t, x}$ | Mean molt increment, scaled by $\beta_{t, x}$ | D.2d |
| $\bar{z}_{t, x, z^{\prime}}=e^{a_{t, x} \cdot z^{\prime} b_{t, x}}$ | Mean size after molt, given pre-molt size <br> $z^{\prime}$ | D.2e |

In both approaches, the $a_{t, x}, b_{t, x}$, and $\beta_{t, x}$ are arithmetic-scale parameters with imposed bounds. $\Theta_{t, x, z, z^{\prime}}$ is used to update the numbers-at-size for immature crab, $n_{y, x, z}$, from pre-molt size $z^{\prime}$ to post-molt size $z$ using:

| $n_{y, x, z}^{+}=\sum_{z^{\prime}} \Theta_{t, x, z, z^{\prime}} \cdot n_{y, x, z^{\prime}}$ | numbers at size of immature crab after <br> growth | D. 3 |
| :--- | :--- | :--- |

where $y$ falls within time block $t$ (see also Eq.s A1.4a-b and A2.2a-b).
Priors using normal distributions are imposed on $a_{t, x}$ and $b_{t, x}$ in TCSAM2013, with the values of the hyper-parameters hard-wired in the model code. While priors may be defined for the associated parameters here, these are identified by the user in the model input files and are not hard-wired in the model code.

## E. Model processes: maturity (terminal molt)

Maturation of immature crab in TCSAM02 is based on a similar approach to that taken in TCSAM2013, except that the sex- and size-specific probabilities of terminal molt for immature crab, $\phi_{t, x, z}$ (where size $z$ is post-molt size), can vary by time block. After molting and growth, the numbers of (new shell) crab at post-molt size $z$ remaining immature, $n_{y, x, I M M, N S, Z}^{+}$, and those maturing, $n_{x, M A T, N S, z}^{+}$, are given by:

| $n_{y, x, I M M, N S, z}^{+}=$ | $\left(1-\phi_{t, x, z}\right) \cdot n_{y, x, I M M, N S, z}$ | crab remaining immature | E.1a |
| :--- | :---: | :--- | :--- |
| $n_{y, x, M A T, N S, z}^{+}=$ | $\phi_{t, x, z} \cdot n_{y, x, I M M, N S, z}$ | crab maturing (terminal molt) | E. 1 b |

where $y$ falls in time block $t$ and $n_{y, x, I M M, N S, Z}$ is the number of immature, new shell crab of sex $x$ at postmolt size $z$.

The sex- and size-specific probabilities of terminal molt, $\phi_{t, x, z}$, are related to logit-scale model parameters $p_{t, x, z}^{\text {mat }}$ by:

| $\phi_{t, F E M, z}=\left\{\begin{array}{lll}\frac{1}{1+e^{p_{t, F E M, z}^{\text {mat }}}} & z \leq z_{t, F E M}^{m a t} \\ 1 & z>z_{t, F E M}^{m a t}\end{array}\right.$ | female probabilities of maturing at <br> post-molt size $z$ | E.2a |
| :--- | :--- | :--- | :--- |
| $\phi_{t, M A L E, z}=\left\{\begin{array}{lll}\frac{1}{1+e^{p_{t, M A L E, z}^{\text {mat }}}} & z \leq z_{t, M A L E}^{\text {mat }} \\ 1 & z>z_{t, M A L E}^{m a t}\end{array}\right.$ | male probabilities of maturing at <br> post-molt size $z$ | E.2b |

where the $z_{t, x}^{m a t}$ are constants specifying the minimum pre-molt size at which to assume all immature crab will mature upon molting. The $z_{t, x}^{\text {mat }}$ are used here pedagogically; in actuality, the user specifies the number of logit-scale parameters to estimate (one per size bin starting with the first bin) for each sex, and this determines the $z_{t, x}^{\text {mat }}$ used above. This parameterization is similar to that implemented in TCSAM2013 for the 2016 assessment model.

Second difference penalties are applied to the parameter estimates in TCSAM2013's objective function to promote relatively smooth changes in these parameters with size. Similar penalties (smoothness, nondecreasing) can be applied in TCSAM02.

## F. Model processes: recruitment

Recruitment in TCSAM02 consists of immature new shell crab entering the population at the end of the model year (June 30). Recruitment in TCSAM02 has a similar functional form to that used in TCSAM2013, except that the sex ratio at recruitment is not fixed at $1: 1$ and multiple time blocks can be specified. In TCSAM2013, two time blocks were defined: "historical" (model start to 1974) and "current" (1975-present), with "current" recruitment starting in the first year of NMFS survey data. In TCSAM02, recruitment in year $y$ of immature new shell crab of sex $x$ at size $z$ is specified as

| $R_{y, x, z}=\dot{R}_{y} \cdot \ddot{R}_{y, x} \cdot \dddot{R}_{y, z}$ | recruitment of immature, new shell crab <br> by sex and size bin | F. 1 |
| :--- | :--- | :--- |

where $\dot{R}_{y}$ represents total recruitment in year $y$ and $\ddot{R}_{y, x}$ represents the fraction of sex $x$ crab recruiting, and $\dddot{R}_{y, z}$ is the size distribution of recruits, which is assumed identical for males and females.

Total recruitment in year $y, \dot{R}_{y}$, is parameterized as

| $\dot{R}_{y}=e^{p L n R_{t}+\delta R_{t, y}} \quad y \in t$ | total recruitment in year $y$ | F. 2 |
| :--- | :--- | :--- |

where $y$ falls within time block $t, p L n R_{t}$ is the ln-scale mean recruitment parameter for $t$, and $\delta R_{t, y}$ is an element of a "devs" parameter vector for $t$ (constrained such that the elements of the vector sum to zero over the time block).

The fraction of crab recruiting as sex $x$ in year $y$ in time block $t$ is parameterized using the logistic model

| $\ddot{R}_{y, x}=\left\{\begin{array}{cc}\frac{1}{1+e^{p L g t R x_{t}}} & x=M A L E \\ 1-\ddot{R}_{y, M A L E} & x=F E M A L E\end{array} \quad y \in t \quad\right.$ sex-specific fraction recruiting in year $y$ | F. 3 |
| :--- | :---: | :---: | :---: |

where $p L g t R x_{t}$ is a logit-scale parameter determining the sex ratio in time block $t$.
The size distribution for recruits in time block $t, \dddot{R}_{t, z}$, is assumed to be a gamma distribution and is parameterized as

| $\dddot{R}_{t, z}=c^{-1} \cdot \Delta_{z}^{\frac{\alpha_{t}}{\beta_{t}}-1} \cdot e^{-\frac{\Delta_{z}}{\beta_{t}}}$ | size distribution of recruiting crab | F .4 |
| :--- | :--- | :--- |
| $c_{t}=\sum_{z} \Delta_{z}^{\frac{\alpha_{t}}{\beta_{t}}-1} \cdot e^{-\frac{\Delta_{z}}{\beta_{t}}}$ | normalization constant so that $1=\sum_{z} \dddot{R}_{t, z}$ | F .5 |
| $\Delta_{z}=z+\delta z / 2-z_{\min }$ | offset from minimum size bin | F.6 |
| $\alpha_{t}=e^{p L n R a_{t}}$ | gamma distribution location parameter | F.7 |
| $\beta_{t}=e^{p L n R b_{t}}$ | gamma distribution shape parameter | F.8 |

where $p L n R a_{t}$ and $p L n R b_{t}$ are the $\ln$-scale location and shape parameters and the constant $\delta z$ is the size bin spacing.

A final time-blocked parameter, $p L n R C V_{t}$, is associated with the recruitment process representing the $\ln -$ scale coefficient of variation (cv) in recruitment variability in time block $t$. These parameters are used to apply priors on the recruitment "devs" in the model likelihood function.

## G. Selectivity and retention functions

Selectivity and retention functions in TCSAM02 are specified independently from the fisheries and surveys to which they are subsequently applied. This allows a single selectivity function to be "shared" among multiple fisheries and/or surveys, as well as among multiple time block/sex/maturity state/shell condition categories, if so desired.

Currently, the following functions are available for use as selectivity or retention curves in a model:

| $S_{Z}=\left\{1+e^{-\beta \cdot\left(z-z_{50}\right)}\right\}^{-1}$ | standard logistic | G. 1 |
| :---: | :---: | :---: |
| $S_{z}=\left\{1+e^{-\beta \cdot\left(z-\exp \left(\ln z_{50}\right)\right)}\right\}^{-1}$ | logistic w/ alternative parameterization | G. 2 |
| $S_{z}=\left\{1+e^{-\ln (19) \cdot \frac{\left(z-z_{50}\right)}{\Delta q_{955}-50}}\right\}^{-1}$ | logistic w/ alternative parameterization | G. 3 |
| $S_{z}=\left\{1+e^{-\ln (19) \cdot \frac{\left(z-z_{50}\right)}{\exp \left(l n \Delta A_{95}-50\right)}}\right\}^{-1}$ | logistic w/ alternative parameterization | G. 4 |
| $S_{z}=\left\{1+e^{\left.-\ln (19) \cdot \frac{\left(z-\exp \left(\ln Z_{50}\right)\right)}{\exp \left(\ln \Delta z_{95}-50\right)}\right\}^{-1}}\right.$ | logistic w/ alternative parameterization | G. 5 |
| $S_{z}=\frac{1}{1+e^{-\beta_{a} \cdot\left(z-z_{a 50}\right)}} \cdot \frac{1}{1+e^{\beta_{d} \cdot\left(z-z_{d 50}\right)}}$ | double logistic | G. 6 |
| $S_{z}=\frac{1}{1+e^{-\ln (19) \cdot \frac{\left(z-z_{a 50}\right)}{\Delta z_{a(95-50)}}} \cdot \frac{1}{1+e^{\ln (19) \cdot \frac{\left(z-z_{d 50}\right)}{\Delta z_{d(95-50)}}}} \text {. }}$ | double logistic with alt. parameterization | G. 7 |
| $\begin{aligned} & S_{z}=\frac{1}{1+e^{-\ln (19) \cdot} \cdot \frac{\left(z-z_{a 50}\right)}{\exp \left(\ln \Delta z_{a(95-50)}\right)}} \cdot \frac{1}{1+e^{\ln (19) \cdot \cdot \frac{\left(z-z_{d 50}\right)}{\exp \left(\ln \Delta z_{d(95-50)}\right)}}} \\ & \text { where } z_{d 50}=\left[z_{a 50}+\exp \left(\ln \Delta z_{a(95-50)}\right)+\exp \left(\ln \Delta z_{d(95-50)}\right)\right] \end{aligned}$ | double logistic with alt. parameterization | G. 8 |
| $\begin{gathered} S_{z}=\frac{1}{1+e^{-\ln (19) \cdot \frac{\left(z-\exp \left(\ln z_{a 50}\right)\right)}{\exp \left(\ln \Delta z_{a(95-50)}\right.}} \cdot \frac{1}{1+e^{\ln (19) \cdot} \cdot \frac{\left(z-z_{d 50}\right)}{\exp \left(\ln \Delta{ }^{2}(95-50)\right)}}} \\ \text { where } z_{d 50}=\left[\exp \left(\ln z_{a 50}\right)+\exp \left(\ln \Delta z_{a(95-50)}\right)+\exp \left(\ln \Delta z_{d(95-50)}\right)\right] \end{gathered}$ | double logistic with alt. parameterization | G. 9 |
| $S_{z}=\frac{1}{1+e^{-\beta_{a} \cdot\left(z-z_{a 50}\right)}} \cdot \frac{1}{1+e^{\beta_{d} \cdot\left(z-\left[z_{a 50}+\exp \left(\ln Z_{d 50-a 50}\right)\right]\right)}}$ | double logistic with alt. parameterization | G. 10 |

A double normal selectivity function (requiring 6 parameters to specify) has also been implemented as an alternative to the double logistic functions. In the above functions, all symbols (e.g., $\beta, z_{50}, \Delta z_{95-50}$ ) represent parameter values, except " $z$ " which represents crab size.

Selectivity parameters are defined independently of the functions themselves, and subsequently assigned. It is thus possible to "share" parameters across multiple functions. The "parameters" used in selectivity functions are further divided into mean parameters across a time block and annual deviations within a time block. To accommodate the 6-parameter double normal equation, six "mean" parameter sets ( $p S 1$, $p S 2, \ldots, p S 6$ ) and six associated sets of "devs" parameter vectors ( $p D e v s S 1, p D e v s S 2, \ldots, p D e v s S 6$ ) are defined to specify the parameterization of individual selectivity/retention functions. Thus, for example, $z_{50}$ in eq. F 1 is actually expressed as $z_{50, y}=\bar{z}_{50}+\delta z_{50, y}$ in terms of model parameters $p S 1$ and $p \operatorname{DevsS1} y_{y}$, where $\bar{z}_{50}=p S 1$ is the mean size-at- $50 \%$-selected over the time period and $\delta z_{50, y}=$ $p \operatorname{DevsS} 1_{y}$ is the annual deviation.

Finally, three different options to normalize individual selectivity curves are provided: 1) no normalization, 2 ) specifying a fully-selected size, and 3 ) re-scaling such that the maximum value of the
re-scaled function is 1 . A normalization option must be specified in the model input files for each defined selectivity/retention curve.

## H. Fisheries

Unlike TCSAM2013, which explicitly models 4 fisheries that catch Tanner crab (one as a directed fishery, three as bycatch), there is no constraint in TCSAM02 on the number of fisheries that can be incorporated in the model. All fisheries are modeled as "pulse" fisheries occurring at the same time.

TCSAM02 uses the Gmacs approach to modeling fishing mortality (also implemented in TCSAM2013). The total (retained + discards) fishing mortality rate, $F_{f, y, x, m, s, z}$, in fishery $f$ during year $y$ on crab in state $x, m, s$, and $z$ (i.e., sex, maturity state, shell condition, and size) is related to the associated fishery capture rate $\phi_{f, y, x, m, s, z}$ by

| $F_{f, y, x, m, s, z}=\left\lceil h_{f, t} \cdot\left(1-\rho_{f, y, x, m, s, z}\right)+\rho_{f, y, x, m, s, z}\right\rceil \cdot \phi_{f, y, x, m, s, z}$ | fishing mortality rate | H. 1 |
| :--- | :--- | :--- |

where $h_{f, t}$ is the handling (discard) mortality for fishery $f$ in time block t (which includes year $y$ ) and $\rho_{f, y, x, m, s, z}$ is the fraction of crabs in state $x, m, s, z$ that were caught and retained (i.e., the retention function). The retention function is assumed to be identically 0 for females in a directed fishery and for both sexes in a bycatch fishery.

In TCSAM2013, the same retention function (in each of two time blocks) was applied to male crab regardless of maturity state or shell condition. Additionally, full retention of large males was assumed, such that the retention function essentially reached 1 at large sizes. In TCSAM02, different retention functions can be applied based on maturity state and/or shell condition, and "max retention" is now an (potentially) estimable logit-scale parameter. Thus, in TCSAM02, the retention function $\rho_{f, y, x, m, s, z}$ is given by

| $\rho_{f, y, x, m, s, z}=\frac{1}{1+e^{\rho_{f, t, x, m, s}}} \cdot R_{f, y, x, m, s, z}$ | retention function | H. 2 |
| :--- | :--- | :--- |

where $f$ corresponds to the directed fishery, $y$ is in time block $t, x=\mathrm{MALE}, \rho_{f, t, x, m, s}$ is the corresponding logit-scale "max retention" parameter, and $R_{f, y, x, m, s, z}$ is the associated selectivity/retention curve.

If $n_{y, x, m, s, z}$ is the number of crab classified as $x, m, s, z$ in year $y$ just prior to the prosecution of the fisheries, then

| $c_{f, y, x, m, s, z}=\frac{\phi_{f, y, x, m, s, z}}{F_{y, x, m, s, z}^{T}} \cdot\left[1-e^{\left.-F_{y, x, m, s, z}^{T}\right] \cdot n_{y, x, m, s, z}}\right.$ | number of crab <br> captured | H. 3 |
| :--- | :--- | :--- |

is the number of crab classified in that state that were captured by fishery $f$, where $F_{y, x, m, s, z}^{T}=$ $\sum_{f} F_{f, y, x, m, s, z}$ represents the total (across all fisheries) fishing mortality on those crab. The number of crab retained in fishery $f$ classified as $x, m, s, z$ in year $y$ is given by

$$
\begin{array}{|l|l|l|}
\hline r_{f, y, x, m, s, z}=\frac{\rho_{f, y, x, m, s, z} \cdot \phi_{f, y, x, m, s, z}}{F_{y, x, m, s, z}^{T}} \cdot\left[1-e^{\left.-F_{y, x, m, s, z}^{T}\right] \cdot n_{y, x, m, s, z}}\right. & \begin{array}{l}
\text { number of } \\
\text { retained crab }
\end{array} & \text { H. } 4 \\
\hline
\end{array}
$$

while the number of discarded crab, $d_{f, y, x, m, s, z}$, is given by

$$
\begin{array}{|l|l|l|}
\hline d_{f, y, x, m, s, z}=\frac{\left(1-\rho_{f, y, x, m, s, z}\right) \cdot \phi_{f, y, x, m, s, z}}{F_{y, x, m, s, z}^{T}} \cdot\left[1-e^{\left.-F_{y, x, m, s, z}^{T}\right] \cdot n_{y, x, m, s, z}}\right. & \begin{array}{l}
\text { number of } \\
\text { discarded crab }
\end{array} & \text { H. } 5 \\
\hline
\end{array}
$$

and the discard mortality, $d m_{f, y, x, m, s, z}$, is

$$
\begin{array}{|l|l|l|}
\hline d m_{f, y, x, m, s, z}=\frac{h_{f, y} \cdot\left(1-\rho_{f, y, x, m, s, z}\right) \cdot \phi_{f, y, x, m, s, z}}{F_{y, x, m, s, z}^{T}} \cdot\left[1-e^{\left.-F_{y, x, m, s, z}^{T}\right] \cdot n_{y, x, m, s, z}}\right. & \begin{array}{l}
\text { discard } \\
\text { mortality } \\
\text { (numbers) }
\end{array} & \text { H. } 6 \\
\hline
\end{array}
$$

The capture rate $\phi_{f, y, x, m, s, z}$ ( $n o t$ the fishing mortality rate $F_{f, y, x, m, s, z}$ ) is modeled as a function separable into separate year and size components such that

| $\phi_{f, y, x, m, s, z}=\phi_{f, y, x, m, s} \cdot S_{f, y, x, m, s, z}$ | fishing capture <br> rate | H.7 |
| :--- | :--- | :--- |

where $\phi_{f, y, x, m, s}$ is the fully-selected capture rate in year $y$ and $S_{f, y, x, m, s, z}$ is the size-specific selectivity.
The fully-selected capture rate $\phi_{f, y, x, m, s}$ for $y$ in time block $t$ is parameterized in the following manner:

$$
\begin{array}{|l|c}
\hline \phi_{f, y, x, m, s}=\exp \left(\overline{\ln }_{f, t, x, m, s}+p \operatorname{Devs} C_{f, y, x, m, s}\right) & \text { H. } 8 \\
\hline
\end{array}
$$

where the $p \operatorname{Devs} C_{f, y, x, m, s}$ are elements for year $y$ in time block $t$ of a "devs" vectors representing annual variations from the $\ln$-scale mean fully-selected capture rate $\overline{\ln }_{f, t, x, m, s}$. The latter is expressed in terms of model parameters as

| $\overline{\ln }_{f, t, x, m, s}=p L n C_{f, t, x, m, s}+\sum_{i=1}^{4} \delta C_{f, t, x, m, s}^{i}$ | H. 9 |
| :--- | :--- |

where the $p \operatorname{Ln} C_{f, t, x, m, s}$ is the mean $\ln$-scale capture rate (e.g., for mature males) and the $\delta C_{f, t, x, m, s}^{i}$ are $\ln$ scale offsets.

## I. Surveys

If $n_{y, x, m, s, z}$ is the number of crab classified as $x, m, s, z$ in year $y$ just prior to the prosecution of a survey, then the survey abundance, $a_{v, y, x, m, s, z}$, of crab classified in that state by survey $v$ is given by

| $a_{v, y, x, m, s, z}=q_{v, y, x, m, s, z} \cdot n_{y, x, m, s, z}$ | survey abundance | I. |
| :--- | :--- | :---: |

where $q_{v, y, x, m, s, z}$ is the size-specific survey catchability on this component of the population.
The survey catchability $q_{v, y, x, m, s, z}$ is decomposed in the usual fashion into separate time block and size components such that, for $y$ in time block $t$ :

| $q_{v, y, x, m, s, z}=q_{v, t, x, m, s} \cdot S_{v, t, x, m, s, z}$ | survey catchability | I. 2 |
| :--- | :--- | :---: |

where $q_{v, t, x, m, s}$ is the fully-selected catchability in time block $t$ and $S_{v, t, x, m, s, z}$ is the size-specific survey selectivity.

The fully-selected catchability $q_{v, t, x, m, s}$ is parameterized in a fashion similar to that for fully-selected fishery capture rates (except that annual "devs" are not included) in the following manner:

| $q_{v, t, x, m, s}=\exp \left(p L n Q_{v, t, x, m, s}+\sum_{i=1}^{4} \delta Q_{v, t, x, m, s}^{i}\right)$ | I. 3 |
| :--- | :--- |

where the $p L n Q_{v, t, x, m, s}$ is the mean $\ln$-scale catchability (e.g., for mature males) and the $\delta Q_{v, t, x, m, s}^{i}$ are $\ln -$ scale offsets.

## J. Model fitting: objective function equations

The TCSAM02 model is fit by minimizing an objective function, $\sigma$, with additive components consisting of: 1) negative log-likelihood functions based on specified prior probability distributions associated with user-specified model parameters, and 2) several negative log-likelihood functions based on input data components, of the form:

| $\sigma=-2 \sum_{p} \lambda_{p} \cdot \ln \left(\wp_{p}\right)-2 \sum_{l} \lambda_{l} \cdot \ln \left(\mathcal{L}_{l}\right)$ | model objective function | J. 1 |
| :--- | :--- | :--- |

where $\wp_{p}$ represents the $p$ th prior probability function, $\mathcal{L}_{l}$ represents the $l$ th likelihood function, and the $\lambda$ 's represent user-adjustable weights for each component.

## Prior Probability Functions

Prior probability functions can be associated with each model parameter or parameter vector by the user in the model input files (see Section L below for examples on specifying priors).

## Likelihood Functions

The likelihood components included in the model's objective function are based on normalized size frequencies and time series of abundance or biomass from fishery or survey data. Survey data optionally consists of abundance and/or biomass time series for males, females, and/or all crab (with associated survey cv's), as well as size frequencies by sex, maturity state, and shell condition. Fishery data consists of similar data types for optional retained, discard, and total catch components.

## Size frequency components

Likelihood components involving size frequencies are based on multinomial sampling:

| $\ln (\mathcal{L})=\sum_{y} n_{y, c} \cdot \sum_{z}\left\{p_{y, c, z}^{o b s} \cdot \ln \left(p_{y, c, z}^{m o d}+\delta\right)-p_{y, c, z}^{o b s} \cdot \ln \left(p_{y, c, z}^{o b s}+\delta\right)\right\}$ | multinomial <br> log-likelihood | J. 2 |
| :--- | :--- | :--- |

where the $y$ 's are years for which data exists, " $c$ " indicates the population component classifiers (i.e., sex, maturity state, shell condition) the size frequency refers to, $n_{y, c}$ is the classifier-specific effective sample size for year $y, p_{y, c, z}^{o b s}$ is the observed size composition in size bin $z$ (i.e., the size frequency normalized to sum to 1 across size bins for each year), $p_{y, c, z}^{m o d}$ is the corresponding model-estimated size composition, and $\delta$ is a small constant. The manner in which the observed and estimated size frequencies for each data component are aggregated (e.g., over shell condition) prior to normalization is specified by the user in the model input files. Data can be entered in input files at less-aggregated levels of than will be used in the model; it will be aggregated in the model to the requested level before fitting occurs.

## Aggregated abundance/biomass components

Likelihood components involving aggregated (over size, at least) abundance and or biomass time series can be computed using one of three potential likelihood functions: the normal, the lognormal, and the "norm2". The likelihood function used for each data component is user-specified in the model input files.

The $\ln$-scale normal likelihood function is

| $\ln \left(\mathcal{L}^{N}\right)_{c}=-\frac{1}{2} \sum_{y}\left\{\frac{\left[a_{y, c}^{o b s}-a_{y, c}^{m o d}\right]^{2}}{\sigma_{y, c}^{2}}\right\}$ | normal log- <br> likelihood | J. 3 |
| :--- | :--- | :--- |

where $a_{y, c}^{o b s}$ is the observed abundance/biomass value in year $y$ for aggregation level $c, a_{y, c}^{m o d}$ is the associated model estimate, and $\sigma_{y, c}^{2}$ is the variance associated with the observation.

The ln-scale lognormal likelihood function is

| $\ln \left(\mathcal{L}^{L N}\right)_{c}=-\frac{1}{2} \sum_{y}\left\{\frac{\left[\ln \left(a_{y, c}^{o b s}+\delta\right)-\ln \left(a_{y, c}^{m o d}+\delta\right)\right]^{2}}{\sigma_{y, c}^{2}}\right\}$ | lognormal log- <br> likelihood | J. 4 |
| :--- | :--- | :--- |

where $a_{y, c}^{o b s}$ is the observed abundance/biomass value in year $y$ for aggregation level $c, a_{y, c}^{m o d}$ is the associated model estimate, and $\sigma_{y, c}^{2}$ is the $\ln$-scale variance associated with the observation.

For consistency with TCSAM2013, a third type, the "norm2", may also be specified

| $\ln \left(\mathcal{L}^{N 2}\right)_{x}=-\frac{1}{2} \sum_{y}\left[a_{y, x}^{o b s}-a_{y, x}^{m o d}\right]^{2}$ | "norm2" log-likelihood | J. 5 |
| :--- | :--- | :--- |

This is equivalent to specifying a normal log-likelihood with $\sigma_{y, x}^{2} \equiv 1.0$. This is the standard likelihood function applied tin TCSAM2013 to fishery catch time series.

## Growth data

Growth (molt increment) data represents a new data source that can be fit as part of a TCSAM02 model. Multiple datasets can be fit at the same time. This capability does not exist in TCSAM2013. The likelihood for each dataset $\left(L_{d}\right)$ is based on the same gamma distribution used in the growth model:

$$
\mathrm{L}_{d}=-\sum_{i \in d} \ln \left\{\Gamma\left(\frac{\tilde{z}_{i}-\bar{z}_{y_{i}, x_{i}, z_{i}}}{\beta_{y_{i}, x_{i}}}\right)\right\}
$$

where $z_{i}$ and $\tilde{z}_{i}$ are the pre-molt and post-molt sizes for individual $i$ (of sex $x_{i}$ collected in year $y_{i}$ ) in dataset $d$, respectively, $\bar{z}_{y_{i}, x_{i}, z_{i}}$ is the predicted mean post-molt size for individual $i$, and $\beta_{y_{i}, x_{i}}$ is the scale factor for the gamma distribution corresponding to individual $i$.

## Effort data

In both TCSAM2013 and TCSAM02, fishery-specific effort data is used to predict annual fully-selected fishery capture rates for Tanner crab bycatch in the snow crab and Bristol Bay red king crab fisheries in the period before at-sea observer data is available (i.e., prior to 1991), based on the assumed relationship

$$
F_{f, y}=q_{f} \cdot E_{f, y}
$$

where $F_{f, y}$ is the fully-selected capture rate in fishery f in year $\mathrm{y}, q_{f}$ is the estimated catchability in fishery f, and $E_{f, y}$ is the reported annual, fishery-specific effort (in pots). In TCAM2013, the fishery $q$ 's are estimated directly from the ratio of fishery mean $F$ to mean $E$ over the time period $\left(t_{f}\right)$ when at-sea observer data is available from which to estimate the $F_{f, y}$ 's as parameters:

$$
q_{f}=\frac{\sum_{y \in t_{f}} F_{f, y}}{\sum_{y \in t_{f}} E_{f, y}} .
$$

Note that, in this formulation, the fishery $q$ 's are not parameters (i.e., estimated via maximizing the likelihood) in the model. In TCSAM2013, the time period over which $q$ is estimated for each fishery is hard-wired. This approach is also available as an option in TCSAM02, although different time periods for the averaging can be specified in the model options file.

A second approach to effort extrapolation in which the fishery $q$ 's are fully-fledged parameters estimated as part of maximizing the likelihood is provided in TCSAM02 as an option, as well. In this case, the effort data is assumed to have a lognormal error distribution and the following negative log-likelihood components are included in the overall model objective function:

$$
L_{f}=\sum_{y} \frac{\left(\ln \left(E_{f, y}+\delta\right)-\ln \left(\frac{F_{f, y}}{q_{f}}+\delta\right)\right)^{2}}{2 \cdot \sigma_{f}^{2}}
$$

where $\sigma_{f}^{2}$ is the assumed $\ln$-scale variance associated with the effort data and $\delta$ is a small value so that the arguments of the $\ln$ functions do not go to zero.

## Aggregation fitting levels

A number of different ways to aggregate input data and model estimates prior to fitting likelihood functions have been implemented in TCSAM02. These include:

| Abundance/Biomass | Size Conpositions |  |
| :---: | :---: | :---: |
| by | by | extended by |
| total | total | $x$ |
| x |  | $\mathrm{x}, \mathrm{m}$ |
| $x$, mature only | X | -- |
| $x, \mathrm{~m}$ |  | m |
| $x, \mathrm{~s}$ |  | s |
| $x, m, s$ | x, m | -- |
|  |  | S |
|  | $x, \mathrm{~s}$ |  |
|  | $x, m, s$ |  |

where $x, m, s$ refer to sex, maturity state and shell condition and missing levels are aggregated over. For size compositions that are "extended by" $x, m, s$, or $\{x, m\}$, this involves appending the size compositions corresponding to each combination of "extended by" factor levels, renormalizing the extended composition to sum to 1 , and then fitting the extended composition using a multinomial likelihood.

## K. Devs vectors

For TCSAM02 to accommodate arbitrary numbers of fisheries and time blocks, it is necessary to be able to define arbitrary numbers of devs vectors. This is currently not possible in ADMB, so TCSAM02 uses an alternative implementation of "devs" vectors from that implemented in ADMB. In TCSAM02, an $n$ element "devs" vector is implemented using an ( $n-1$ )-element bounded parameter vector, with the final element of the "devs" vector defined as $-\sum_{n-1} v_{i}$, where $v_{i}$ is the ith value of the parameter (or devs) vector, so that the sum over all elements of the devs vector is identically 0 . Penalties are placed on the final element of the devs vector to ensure it is bounded in the same manner as the parameter vector.

## L. Priors for model parameters

A prior probability distribution can be specified for any element of model parameter. The following distributions are available for use as priors:

| indicator | parameters | constants | description |
| :--- | :--- | :--- | :--- |
| none | none | none | no prior applied |
| ar1_normal | $\mu, \sigma$ | none | random walk with normal deviates |
| cauchy | $x_{0}, \gamma$ | none | Cauchy pdf |
| chisquare | $v$ | none | $\chi^{2}$ pdf |
| constant | min, max | none | uniform pdf |
| exponential | $\lambda$ | none | exponential pdf |
| gamma | $r, \mu$ | none | gamma pdf |
| invchisquare | $v$ | none | inverse $\chi^{2}$ pdf |
| invgamma | $r, \mu$ | none | inverse gamma pdf |
| invgaussian | $\mu, \lambda$ | none | inverse Gaussian pdf |
| lognormal | median, CV | none | lognormal pdf |
| logscale_normal | median, CV | none | normal pdf on ln-scale |
| normal | $\mu, \sigma$ | none | normal pdf |
| scaled_invchisquare | $v, s$ | none | inverse $\chi^{2}$ scaled pdf |
| scaledCV_invchisquare | $v, C V$ | none | inverse $\chi^{2}$ pdf, scaled by CV |
| t | $v$ | none | t distribution |
| truncated_normal | $\mu, \sigma$ | min, max | truncated normal pdf |

## M. Parameters and other information determined outside the model

Several nominal model parameters are not estimated in the model, rather they are fixed to values determined outside the model. These include Tanner crab handling mortality rates for discards in the crab fisheries ( $32.1 \%$ ), the groundfish trawl fisheries ( $80 \%$ ), and the groundfish pot fisheries ( $50 \%$ ), as well the base rate for natural mortality ( $0.23 \mathrm{yr}^{-1}$ ). Sex- and maturity-state-specific parameters for individual weight-at-size have also been determined outside the model, based on fits to data collected on the NMFS EBS bottom trawl survey (Daly et al., 2016). Weight-at-size, $w_{x, m, z}$, is given by

$$
w_{x, m, z}=a_{x, m} \cdot z^{b_{x, m}}
$$

where

| sex | maturity state | $\boldsymbol{a}_{\boldsymbol{x} \boldsymbol{m}}$ | $\boldsymbol{b}_{\boldsymbol{x}, \boldsymbol{m}}$ |
| :--- | :--- | :--- | :--- |
| male | all states | 0.000270 | 3.022134 |
| female | immature | 0.000562 | 2.816928 |


|  | mature | 0.000441 | 2.898686 |
| :--- | :--- | :--- | :--- |

and size is in mm CW and weight is in kg .

## N. OFL calculations and stock status determination

Overfishing level (OFL) calculations and stock status determination for Tanner crab are based on Tier 3 considerations for crab stocks as defined by the North Pacific Fishery Management Council (NPFMC; NPFMC 2016). Tier 3 considerations require life history information such as natural mortality rates, growth, and maturity but use proxies based on a spawner-per-recruit approach for $\mathrm{F}_{\mathrm{MSY}}, \mathrm{B}_{\mathrm{MSY}}$, and MSY because there is no reliable stock-recruit relationship.


Fig. 2. The $\mathrm{F}_{\mathrm{OFL}}$ harvest control rule.

Equilibrium recruitment is assumed to be
equal to the average recruitment over a selected time period (1982-present for Tanner crab). For Tier 3 stocks, the proxy for $\mathrm{B}_{\mathrm{MSY}}$ is defined as $35 \%$ of longterm (equilibrium) mature male biomass (MMB) for the unfished stock $\left(B_{0}\right)$. The proxy $F_{\text {MSY }}$ for Tier 3 stocks is then the directed fishing mortality rate that results in $\mathrm{B}_{35 \%}$ (i.e., $\mathrm{F}_{35 \%}$ ), while the MSY proxy is the longterm total (retained plus discard) catch mortality resulting from fishing at $\mathrm{F}_{\text {MSY }}$. The OFL calculation for the upcoming year is based on a sloping harvest control rule for $\mathrm{F}_{\mathrm{OFL}}$ (Fig. 2), the directed fishing mortality rate that results in the OFL. If the "current" MMB (projected to Feb. 15 of the upcoming year under the $\mathrm{F}_{\mathrm{OFL}}$ ) is above $\mathrm{B}_{\mathrm{MSY}}\left(\mathrm{B}_{35 \%}\right)$, then $\mathrm{F}_{\mathrm{OFL}}=\mathrm{F}_{\mathrm{MSY}}=\mathrm{F}_{35 \%}$. If the current MMB is between $\beta \cdot B_{M S Y}$ and $\mathrm{B}_{\mathrm{MSY}}$, then $\mathrm{F}_{\mathrm{OFL}}$ is determined from the slope of the control rule. In either of these cases, the OFL is simply the projected total catch mortality under directed fishing at $\mathrm{F}_{\mathrm{OFL}}$. If current MMB is less than $\beta \cdot B_{M S Y}$, then no directed fishing is allowed $\left(\mathrm{F}_{\mathrm{OFL}}=0\right)$ and the OFL is set to provide for stock rebuilding with bycatch in non-directed fisheries. Note that if current MMB is less than $\mathrm{B}_{\mathrm{MSY}}$, then the process of determining $\mathrm{F}_{\mathrm{OFL}}$ is generally an iterative one.

Stock status is determined by comparing "current" MMB with the Minimum Stock Size Threshold (MSST), which is defined as $0.5 x \mathrm{~B}_{\mathrm{MSY}}$ : if "current" MMB is below the MSST, then the stock is overfished-otherwise, it is not overfished.

## N. 1 Equilibrium conditions

Both OFL calculations and stock status determination utilize equilibrium considerations, both equilibrium under unfished conditions (to determine $\mathrm{B}_{0}$ and $\mathrm{B}_{35 \%}$ ) and under fished conditions (to determine $\mathrm{F}_{35 \%}$ ). For Tier 3 stocks, because there is no reliable stock-recruit relationship, analytical solutions can be found for equilibrium conditions for any fishing mortality conditions. These solutions are described below (the notation differs somewhat from that used in previous sections).

## N.1.1 Population states

The Tanner crab population on July 1 can be characterized by abundance-at-size in four population states:
in- immature new shell crab
io- immature old shell crab
$m n$ - mature new shell crab
$m o$ - mature old shell crab
where each of these states represents a vector of abundance-at-size (i.e., a vector subscripted by size).

## N.1.2 Population processes

The following processes then describe the dynamics of the population over a year:
$S_{l}$ - survival from start of year to time of molting/growth of immature crab, possibly including fishing mortality (a diagonal matrix)
$S_{2}$ - survival after time of molting/growth of immature crab to end of year, possibly including fishing mortality (a diagonal matrix)
$\Phi$ - probability of an immature crab molting $(\operatorname{pr}(\operatorname{molt} \mid z)$, where $z$ is pre-molt size; a diagonal matrix) $(\operatorname{pr}($ molt $\mid z)$ is assumed to be 1 in TCSAM02).
$\Theta$ - probability that a molt was terminal ( $\operatorname{pr}($ molt to maturity $\mid z$, molt), where $z$ is post-molt size; a diagonal matrix)
$T$ - size transition matrix (a non-diagonal matrix)
1 - identity matrix
$R$-number of recruits by size (a vector)
The matrices above are doubly-subscripted, and $R$ is singly-subscripted, by size. Additionally, the matrices above (except for the identity matrix) can also be subscripted by population state (in, io, mn, mo) for generality. For example, survival of immature crab may differ between those that molted and those that skipped.

## N.1.3 Population dynamics

The following equations then describe the development of the population from the beginning of one year to the beginning of the next:

$$
\begin{align*}
& i n^{+}=R+S_{2 i n} \cdot\left\{\left(1-\Theta_{i n}\right) \cdot T_{i n} \cdot \Phi_{i n} \cdot S_{1 i n} \cdot i n+T_{i o} \cdot\left(1-\Theta_{i o}\right) \cdot \Phi_{i o} \cdot S_{1 i o} \cdot i o\right\}  \tag{N.1}\\
& i o  \tag{N.2}\\
& { }^{+}=S_{2 i o} \cdot\left\{\left(1-\Phi_{i n}\right) \cdot S_{1 i n} \cdot i n+\left(1-\Phi_{i o}\right) \cdot S_{1 i o} \cdot i o\right\}  \tag{N.3}\\
& m n^{+}=S_{2 m n} \cdot\left\{\Theta_{i n} \cdot T_{i n} \cdot \Phi_{i n} \cdot S_{1 i n} \cdot i n+\Theta_{i o} \cdot T_{i o} \cdot \Phi_{i o} \cdot S_{1 i o} \cdot i o\right\}  \tag{N.4}\\
& m o^{+}=S_{2 m o} \cdot\left\{S_{1 m n} \cdot m n+S_{1 m o} \cdot m o\right\}
\end{align*}
$$

where " + " indicates year +1 and all recruits $(R)$ are assumed to be new shell.

## N.1.4 Equilibrium equations

The equations reflecting equilibrium conditions (i.e., $i n^{+}=i n$, etc.) are simply:

$$
\begin{align*}
& i n=R+S_{2 i n} \cdot\left\{\left(1-\Theta_{i n}\right) \cdot T_{i n} \cdot \Phi_{i n} \cdot S_{1 i n} \cdot i n+\left(1-\Theta_{i o}\right) \cdot T_{i o} \cdot \Phi_{i o} \cdot S_{1 i o} \cdot i o\right\}  \tag{N.5}\\
& i o=S_{2 i o} \cdot\left\{\left(1-\Phi_{i n}\right) \cdot S_{1 i n} \cdot i n+\left(1-\Phi_{i o}\right) \cdot S_{1 i o} \cdot i o\right\}  \tag{N.6}\\
& m n=S_{2 m n} \cdot\left\{\Theta_{i n} \cdot T_{i n} \cdot \Phi_{i n} \cdot S_{1 i n} \cdot i n+\Theta_{i o} \cdot T_{i o} \cdot \Phi_{i o} \cdot S_{1 i o} \cdot i o\right\}  \tag{N.7}\\
& m o=S_{2 m o} \cdot\left\{S_{1 m n} \cdot m n+S_{1 m o} \cdot m o\right\} \tag{N.8}
\end{align*}
$$

where $R$ above is now the equilibrium (longterm average) number of recruits-at-size vector.

## N.1.5 Equilibrium solution

The equilibrium solution can be obtained by rewriting the above equilibrium equations as:

$$
\begin{align*}
& i n=R+A \cdot i n+B \cdot i o  \tag{N.9}\\
& i o=C \cdot i n+D \cdot i o  \tag{N.10}\\
& m n=E \cdot i n+F \cdot i o  \tag{N.11}\\
& m o=G \cdot m n+H \cdot m o \tag{N.12}
\end{align*}
$$

where $A, B, C, D, E, F, G$, and $H$ are square matrices. Solving for $i o$ in terms of in in eq. 10 , one obtains

$$
\begin{equation*}
i o=\{1-D\}^{-1} \cdot C \cdot \text { in } \tag{N.13}
\end{equation*}
$$

Plugging eq. 13 into 9 and solving for in yields

$$
\begin{equation*}
\text { in }=\left\{1-A-B \cdot[1-D]^{-1} \cdot C\right\}^{-1} \cdot R \tag{N.14}
\end{equation*}
$$

Equations 13 for io and 14 for in can simply be plugged into eq. 11 to yield $m n$ :

$$
\begin{equation*}
m n=E \cdot i n+F \cdot i o \tag{N.15}
\end{equation*}
$$

while eq. 12 can then be solved for $m o$, yielding:

$$
\begin{equation*}
m o=\{1-H\}^{-1} \cdot G \cdot m n \tag{N.16}
\end{equation*}
$$

where (for completeness):

$$
\begin{align*}
& A=S_{2 i n} \cdot\left(1-\Theta_{i n}\right) \cdot T_{i n} \cdot \Phi_{i n} \cdot S_{1 i n}  \tag{N.17}\\
& B=S_{2 i n} \cdot\left(1-\Theta_{i o}\right) \cdot T_{i o} \cdot \Phi_{i o} \cdot S_{1 i o}  \tag{N.18}\\
& C=S_{2 i o} \cdot\left(1-\Phi_{i n}\right) \cdot S_{1 i n}  \tag{N.19}\\
& D=S_{2 i o} \cdot\left(1-\Phi_{i o}\right) \cdot S_{1 i o}  \tag{N.20}\\
& E=S_{2 m n} \cdot \Theta_{i n} \cdot T_{i n} \cdot \Phi_{i n} \cdot S_{1 i n}  \tag{N.21}\\
& F=S_{2 m n} \cdot \Theta_{i o} \cdot T_{i o} \cdot \Phi_{i o} \cdot S_{1 i o}  \tag{N.22}\\
& G=S_{2 m o} \cdot S_{1 m n}  \tag{N.23}\\
& H=S_{2 m o} \cdot S_{1 m o} \tag{N.24}
\end{align*}
$$

Note that $\Theta$, the size-specific conditional probability of a molt being the terminal molt-to-maturity, is defined above on the basis of post-molt, not pre-molt, size. This implies that whether or not a molt is terminal depends on the size a crab grows into, not the size it at which it molted. An alternative approach would be to assume that the conditional probability of terminal molt is determined by pre-molt size. This would result in an alternative set of equations, but these can be easily obtained from the ones above by simply reversing the order of the terms involving $T$ and $\Theta$ (e.g., the term $\left(1-\Theta_{\text {in }}\right) \cdot T_{\text {in }}$ becomes $T_{\text {in }}$. $\left(1-\Theta_{i n}\right)$ ).

## N. 2 OFL calculations

Because a number of the calculations involved in determining the OFL are iterative in nature, the OFL calculations do not involve automatically-differentiated (AD) variables. Additionally, they are only done after model convergence or when evaluating an MCMC chain. The steps involved in calculating the OFL are outlined as follows:

1. The initial population numbers-at-sex/maturity state/shell condition/size for the upcoming year are copied to a non-AD array.
2. Mean recruitment is estimated over a pre-determined time frame (currently 1982-present).
3. The arrays associated with all population rates in the final year are copied to non-AD arrays for use in the upcoming year.
4. Calculate the average selectivity and retention functions for all fisheries over the most recent 5year period.
5. Determine the average maximum capture rates for all fisheries over the most recent 5-year period.
6. Using the equilibrium equations, calculate $\mathrm{B}_{0}$ for unfished stock $\left(\mathrm{B} 35 \%=0.35 * \mathrm{~B}_{0}\right)$.
7. Using the equilibrium equations, iterate on the maximum capture rate for males in the directed fishery to find the one ( $\mathrm{F}_{35 \%}$ ) that results in the equilibrium $\mathrm{MMB}=\mathrm{B}_{35 \%}$.
8. Calculate "current" MMB under directed fishing at $\mathrm{F}=\mathrm{F}_{35}$, by projecting initial population (1) to Feb. 15.
a. If current $\mathrm{MMB}>\mathrm{B}_{35 \%}, \mathrm{~F}_{\text {OFL }}=\mathrm{F}_{35 \%}$. The associated total catch mortality is OFL.
b. Otherwise
i. set directed F based on the harvest control rule and the ratio of the calculated current MMB to $\mathrm{B}_{35 \%}$
ii. recalculate current MMB
iii. iterate i-iii until current MMB doesn't change between iterations. Then $F_{O F L}=$ $F\left(<F_{35 \%}\right)$ and the OFL is the associated total (retained plus discard) catch mortality.

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# Appendix F: Comparisons For All Scenarios 

William Stockhausen<br>13 September, 2017

## Contents

List of Tables in Model Comparisons ..... 2
List of Figures in Model Comparisons ..... 2
Population processes ..... 8
Natural mortality ..... 8
Probability of terminal molt ..... 9
Mean growth ..... 10
Growth matrices ..... 11
Size distribution for recruits ..... 28
Model fits ..... 29
Growth data ..... 29
Survey biomass ..... 35
Fishery retained catch biomass ..... 38
Fishery total catch biomass ..... 41
Mean survey size compositions ..... 59
Fishery retained catch mean size compositions ..... 60
Fishery total catch mean size compositions ..... 61
Survey size composition residuals ..... 68
Effective Ns for survey size compositions ..... 112
Fishery retained catch size composition residuals ..... 113
Effective Ns for retained catch size compositions ..... 124
Fishery total catch size composition residuals ..... 125
Effective Ns for total catch size compositions ..... 171
Survey characteristics ..... 177
Survey catchability ..... 177
Survey selectivity functions ..... 178
Fisheries ..... 179
Fishery catchability ..... 179
Total selectivity functions ..... 185
Retention functions ..... 217
Population quantities ..... 221
Recruitment ..... 221
Mature biomass ..... 225
Population abundance ..... 229
Population biomass ..... 233
List of Tables
List of Figures
1 Estimated natural mortality rates, by year. ..... 8
2 Probability of terminal molt. ..... 9
3 Mean growth. ..... 10
4 Estimated growth matrices, as bubble plots, for scenario B0. ..... 11
5 Estimated growth matrices, as bubble plots, for scenario B0.2016. ..... 12
6 Estimated growth matrices, as bubble plots, for scenario B0a. ..... 13
7 Estimated growth matrices, as bubble plots, for scenario B1. ..... 14
8 Estimated growth matrices, as bubble plots, for scenario B1a. ..... 15
9 Estimated growth matrices, as bubble plots, for scenario B1b ..... 16
10 Estimated growth matrices, as bubble plots, for scenario B1c. ..... 17
11 Estimated growth matrices, as bubble plots, for scenario B2. ..... 18
12 Estimated growth matrices, as bubble plots, for scenario B2a. ..... 19
13 Estimated growth matrices, as bubble plots, for scenario B2b. ..... 20
14 Estimated growth matrices, as bubble plots, for scenario B3. ..... 21
15 Growth matrices for males during 1948-2016, 1948-2015, page 1. ..... 22
16 Growth matrices for males during 1948-2016, 1948-2015, page 2. ..... 23
17 Growth matrices for males during 1948-2016, 1948-2015, page 3. ..... 24
18 Growth matrices for females during 1948-2016, 1948-2015, page 1. ..... 25
19 Growth matrices for females during 1948-2016, 1948-2015, page 2. ..... 26
20 Growth matrices for females during 1948-2016, 1948-2015, page 3. ..... 27
21 Size distribution for recruits. ..... 28
22 Model fits to EBS. ..... 29
23 Negative log-likelihood values for fits to EBS ..... 30
24 Z-scores for fits to EBS. ..... 31
25 Model fits to Kodiak. ..... 32
26 Negative log-likelihood values for fits to Kodiak. ..... 33
27 Z-scores for fits to Kodiak. ..... 34
28 Comparison of observed and predicted survey biomass for NMFS trawl survey. ..... 35
29 Comparison of observed and predicted survey biomass for NMFS trawl survey. Recent time period. ..... 36
30 Z-scores for index catch biomass in NMFS trawl survey. ..... 37
31 Comparison of observed and predicted retained catch mortality for TCF. ..... 38
32 Comparison of observed and predicted retained catch mortality for TCF. Recent time period. ..... 39
33 Z-scores for retained catch biomass in TCF . ..... 40
34 Comparison of observed and predicted total catch for TCF. ..... 41
35 Comparison of observed and predicted total catch for TCF. Recent time period. ..... 42
36 Comparison of observed and predicted total catch for SCF. ..... 43
37 Comparison of observed and predicted total catch for SCF. Recent time period. ..... 44
38 Comparison of observed and predicted total catch for GTF. ..... 45
39 Comparison of observed and predicted total catch for GTF. Recent time period. ..... 46
40 Comparison of observed and predicted total catch for RKF. ..... 47
41 Comparison of observed and predicted total catch for RKF. Recent time period. ..... 48
42 Comparison of observed and predicted total catch for GF.FixedGear ..... 49
43 Comparison of observed and predicted total catch for GF.FixedGear. Recent time period ..... 50
44 Comparison of observed and predicted total catch for GF.TrawlGear ..... 51
45 Comparison of observed and predicted total catch for GF.TrawlGear. Recent time period. ..... 52
46 Z-scores for total catch biomass in TCF ..... 53
47 Z-scores for total catch biomass in SCF. ..... 54
48 Z-scores for total catch biomass in GTF ..... 55
49 Z-scores for total catch biomass in RKF ..... 56
50 Z-scores for total catch biomass in GF.FixedGear. ..... 57
51 Z-scores for total catch biomass in GF.TrawlGear. ..... 58
52 Comparison of observed and predicted mean survey size comps for NMFS trawl survey. ..... 59
53 Comparison of observed and predicted mean retained catch size comps for TCF. ..... 60
54 Comparison of observed and predicted mean total catch size comps for GTF. ..... 61
55 Comparison of observed and predicted mean total catch size comps for RKF. ..... 62
56 Comparison of observed and predicted mean total catch size comps for SCF. ..... 63
57 Comparison of observed and predicted mean total catch size comps for TCF ..... 64
58 Comparison of observed and predicted mean total catch size comps for GF.FixedGear. ..... 65
59 Comparison of observed and predicted mean total catch size comps for GF.TrawlGear. ..... 66
60 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0. ..... 68
61 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016. ..... 69
62 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0a. ..... 70
63 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1. ..... 71
64 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1a. ..... 72
65 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1b. ..... 73
66 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1c. ..... 74
67 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2. ..... 75
68 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2a. ..... 76
69 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b. ..... 77
70 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B3. ..... 78
71 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0 ..... 79
72 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016. ..... 80
73 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0a. ..... 81
74 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1. ..... 82
75 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1a. ..... 83
76 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1b. ..... 84
77 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1c. ..... 85
78 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2. ..... 86
79 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2a. ..... 87
80 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b. ..... 88
81 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B3. ..... 89
82 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0. ..... 90
83 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016. ..... 91
84 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0a. ..... 92
85 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1. ..... 93
86 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1a. ..... 94
87 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1b. ..... 95
88 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1c. ..... 96
89 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2. ..... 97
90 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2a. ..... 98
91 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b. ..... 99
92 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B3.100
93 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.101
94 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016. ..... 102
95 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0a. ..... 103
96 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1.104
97 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1a. ..... 105
98 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1b. ..... 106
99 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1c. ..... 107
100 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2.108
101 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2a. ..... 109
102 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b. ..... 110
103 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B3.111
104 Input and effective sample sizes from retained catch size compositions from the NMFS trawl survey. ..... 112
105 Pearson's residuals for proportions-at-size from the TCF for scenario B0. ..... 113
106 Pearson's residuals for proportions-at-size from the TCF for scenario B0.2016 ..... 114
107 Pearson's residuals for proportions-at-size from the TCF for scenario B0a. ..... 115
108 Pearson's residuals for proportions-at-size from the TCF for scenario B1 ..... 116
109 Pearson's residuals for proportions-at-size from the TCF for scenario B1a. ..... 117
110 Pearson's residuals for proportions-at-size from the TCF for scenario B1b. ..... 118
111 Pearson's residuals for proportions-at-size from the TCF for scenario B1c. ..... 119
112 Pearson's residuals for proportions-at-size from the TCF for scenario B2. ..... 120
113 Pearson's residuals for proportions-at-size from the TCF for scenario B2a. ..... 121
114 Pearson's residuals for proportions-at-size from the TCF for scenario B2b. ..... 122
115 Pearson's residuals for proportions-at-size from the TCF for scenario B3. ..... 123
116 Input and effective sample sizes from retained catch size compositions from the TCF fishery. ..... 124
117 Pearson's residuals for proportions-at-size from the TCF for scenario B0. ..... 125
118 Pearson's residuals for proportions-at-size from the TCF for scenario B0.2016. ..... 126
119 Pearson's residuals for proportions-at-size from the TCF for scenario B0a. ..... 127
120 Pearson's residuals for proportions-at-size from the TCF for scenario B1 ..... 128
121 Pearson's residuals for proportions-at-size from the TCF for scenario B1a. ..... 129
122 Pearson's residuals for proportions-at-size from the TCF for scenario B1b. ..... 130
123 Pearson's residuals for proportions-at-size from the TCF for scenario B1c. ..... 131
124 Pearson's residuals for proportions-at-size from the TCF for scenario B2. ..... 132
125 Pearson's residuals for proportions-at-size from the TCF for scenario B2a. ..... 133
126 Pearson's residuals for proportions-at-size from the TCF for scenario B2b. ..... 134
127 Pearson's residuals for proportions-at-size from the TCF for scenario B3. ..... 135
128 Pearson's residuals for proportions-at-size from the SCF for scenario B0. ..... 136
129 Pearson's residuals for proportions-at-size from the SCF for scenario B0.2016. ..... 137
130 Pearson's residuals for proportions-at-size from the SCF for scenario B0a. ..... 138
131 Pearson's residuals for proportions-at-size from the SCF for scenario B1. ..... 139
132 Pearson's residuals for proportions-at-size from the SCF for scenario B1a. ..... 140
133 Pearson's residuals for proportions-at-size from the SCF for scenario B1b. ..... 141
134 Pearson's residuals for proportions-at-size from the SCF for scenario B1c. ..... 142
135 Pearson's residuals for proportions-at-size from the SCF for scenario B2. ..... 143
136 Pearson's residuals for proportions-at-size from the SCF for scenario B2a. ..... 144
137 Pearson's residuals for proportions-at-size from the SCF for scenario B2b. ..... 145
138 Pearson's residuals for proportions-at-size from the SCF for scenario B3. ..... 146
139 Pearson's residuals for proportions-at-size from the GTF for scenario B0. ..... 147
140 Pearson's residuals for proportions-at-size from the GTF for scenario B0.2016 ..... 148
141 Pearson's residuals for proportions-at-size from the GTF for scenario B0a. ..... 149
142 Pearson's residuals for proportions-at-size from the GTF for scenario B1. ..... 150
143 Pearson's residuals for proportions-at-size from the GTF for scenario B1a. ..... 151
144 Pearson's residuals for proportions-at-size from the GTF for scenario B1b. ..... 152
145 Pearson's residuals for proportions-at-size from the GTF for scenario B1c. ..... 153
146 Pearson's residuals for proportions-at-size from the GTF for scenario B2. ..... 154
147 Pearson's residuals for proportions-at-size from the GTF for scenario B2a. ..... 155
148 Pearson's residuals for proportions-at-size from the GTF for scenario B2b. ..... 156
149 Pearson's residuals for proportions-at-size from the GTF for scenario B3. ..... 157
150 Pearson's residuals for proportions-at-size from the RKF for scenario B0. ..... 158
151 Pearson's residuals for proportions-at-size from the RKF for scenario B0.2016. ..... 159
152 Pearson's residuals for proportions-at-size from the RKF for scenario B0a ..... 160
153 Pearson's residuals for proportions-at-size from the RKF for scenario B1. ..... 161
154 Pearson's residuals for proportions-at-size from the RKF for scenario B1a. ..... 162
155 Pearson's residuals for proportions-at-size from the RKF for scenario B1b. ..... 163
156 Pearson's residuals for proportions-at-size from the RKF for scenario B1c. ..... 164
157 Pearson's residuals for proportions-at-size from the RKF for scenario B2. ..... 165
158 Pearson's residuals for proportions-at-size from the RKF for scenario B2a. ..... 166
159 Pearson's residuals for proportions-at-size from the RKF for scenario B2b ..... 167
160 Pearson's residuals for proportions-at-size from the RKF for scenario B3. ..... 168
161 Pearson's residuals for proportions-at-size from the GF.FixedGear for scenario B3. ..... 169
162 Pearson's residuals for proportions-at-size from the GF.TrawlGear for scenario B3 ..... 170
163 Input and effective sample sizes from total catch size compositions from the TCF fishery. ..... 171
164 Input and effective sample sizes from total catch size compositions from the SCF fishery. ..... 172
165 Input and effective sample sizes from total catch size compositions from the GTF fishery. ..... 173
166 Input and effective sample sizes from total catch size compositions from the RKF fishery. ..... 174
167 Input and effective sample sizes from total catch size compositions from the GF.FixedGear fishery. ..... 175
168 Input and effective sample sizes from total catch size compositions from the GF.TrawlGear fishery. ..... 176
169 Survey catchabilities for NMFS trawl survey. ..... 177
170 NMFS trawl survey. 1 ..... 178
171 Fishery catchabilities for GTF. ..... 179
172 Fishery catchabilities for RKF. ..... 180
173 Fishery catchabilities for SCF. ..... 181
174 Fishery catchabilities for TCF. ..... 182
175 Fishery catchabilities for GF.FixedGear. ..... 183
176 Fishery catchabilities for GF.TrawlGear ..... 184
177 Selectivity functions for GTF (1 of 6) ..... 185
178 Selectivity functions for GTF (2 of 6) ..... 186
179 Selectivity functions for $\operatorname{GTF}(3$ of 6$)$ ..... 187
180 Selectivity functions for GTF (4 of 6) ..... 188
181 Selectivity functions for $\operatorname{GTF}$ (5 of 6) ..... 189
182 Selectivity functions for GTF (6 of 6) ..... 190
183 Selectivity functions for RKF (1 of 6) ..... 191
184 Selectivity functions for $\operatorname{RKF}(2$ of 6$)$ ..... 192
185 Selectivity functions for $\operatorname{RKF}(3$ of 6$)$ ..... 193
186 Selectivity functions for $\operatorname{RKF}(4$ of 6$)$ ..... 194
187 Selectivity functions for $\operatorname{RKF}$ (5 of 6) ..... 195
188 Selectivity functions for $\operatorname{RKF}$ ( 6 of 6 ) ..... 196
189 Selectivity functions for $\operatorname{SCF}(1$ of 6$)$. ..... 197
190 Selectivity functions for $\operatorname{SCF}(2$ of 6$)$. ..... 198
191 Selectivity functions for $\operatorname{SCF}$ (3 of 6) ..... 199
192 Selectivity functions for $\operatorname{SCF}(4$ of 6 ). ..... 200
193 Selectivity functions for $\operatorname{SCF}$ ( 5 of 6 ) ..... 201
194 Selectivity functions for $\operatorname{SCF}(6$ of 6$)$. ..... 202
195 Selectivity functions for $\operatorname{TCF}$ (1 of 4) ..... 203
196 Selectivity functions for TCF(2 of 4) ..... 204
197 Selectivity functions for TCF (3 of 4) ..... 205
198 Selectivity functions for TCF (4 of 4). ..... 206
199 Selectivity functions for GF.FixedGear(1 of 5). ..... 207
200 Selectivity functions for GF.FixedGear(2 of 5). ..... 208
201 Selectivity functions for GF.FixedGear(3 of 5) ..... 209
202 Selectivity functions for GF.FixedGear(4 of 5). ..... 210
203 Selectivity functions for GF.FixedGear(5 of 5). ..... 211
204 Selectivity functions for GF.TrawlGear(1 of 5). ..... 212
205 Selectivity functions for GF.TrawlGear(2 of 5). ..... 213
206 Selectivity functions for GF.TrawlGear(3 of 5) ..... 214
207 Selectivity functions for GF.TrawlGear(4 of 5). ..... 215
208 Selectivity functions for GF.TrawlGear(5 of 5). ..... 216
209 Retention functions for TCF (1 of 4). ..... 217
210 Retention functions for $\operatorname{TCF}(2$ of 4$)$ ..... 218
211 Retention functions for $\operatorname{TCF}$ (3 of 4) ..... 219
212 Retention functions for $\operatorname{TCF}$ (4 of 4) ..... 220
213 Estimated annual recruitment. ..... 221
214 Estimated recent recruitment ..... 222
215 Estimated annual recruitment, on ln-scale ..... 223
216 Estimated recent recruitment, on $\ln$-scale ..... 224
217 Estimated annual mature biomass. ..... 225
218 Estimated recent mature biomass. ..... 226
219 Estimated annual mature biomass, on ln-scale. ..... 227
220 Estimated recent mature biomass, on ln-scale ..... 228
221 Population abundance trends. ..... 229
222 Recent population abundance trends ..... 230
223 Ln -scale population abundance trends. ..... 231
224 Recent ln-scale population abundance trends. ..... 232
225 Population biomass trends. ..... 233
226 Recent population biomass trends. ..... 234
227 Ln-scale population biomass trends. ..... 235
228 Recent ln-scale population biomass trends ..... 236

## Population processes

Figures and tables in this section present comparisons between alternative model scenarios for estimated rates (e.g., natural mortality) or other attributes (e.g., molt increments) describing inferred Tanner crab population processes.

## Natural mortality



Figure 1: Estimated natural mortality rates, by year.

## Probability of terminal molt



Figure 2: Probability of terminal molt.

## Mean growth



Figure 3: Mean growth.

## Growth matrices

Growth matrices for each model case are compared as bubble plots in the following figure.


Figure 4: Estimated growth matrices, as bubble plots, for scenario B0.


Figure 5: Estimated growth matrices, as bubble plots, for scenario B0.2016.


Figure 6: Estimated growth matrices, as bubble plots, for scenario B0a.


Figure 7: Estimated growth matrices, as bubble plots, for scenario B1.


Figure 8: Estimated growth matrices, as bubble plots, for scenario B1a.


Figure 9: Estimated growth matrices, as bubble plots, for scenario B1b.


Figure 10: Estimated growth matrices, as bubble plots, for scenario B1c.


Figure 11: Estimated growth matrices, as bubble plots, for scenario B2.


Figure 12: Estimated growth matrices, as bubble plots, for scenario B2a.


Figure 13: Estimated growth matrices, as bubble plots, for scenario B2b.


Figure 14: Estimated growth matrices, as bubble plots, for scenario B3.

The same growth matrices are compared in the following figure(s) as line plots for each pre-molt size bin, by sex.
male growth: 1948-2016, 1948-2015


Figure 15: Growth matrices for males during 1948-2016, 1948-2015, page 1.
male growth: 1948-2016, 1948-2015


Figure 16: Growth matrices for males during 1948-2016, 1948-2015, page 2.
male growth: 1948-2016, 1948-2015


Figure 17: Growth matrices for males during 1948-2016, 1948-2015, page 3.
female growth: 1948-2016, 1948-2015


Figure 18: Growth matrices for females during 1948-2016, 1948-2015, page 1.


Figure 19: Growth matrices for females during 1948-2016, 1948-2015, page 2.


Figure 20: Growth matrices for females during 1948-2016, 1948-2015, page 3.

## Size distribution for recruits



Figure 21: Size distribution for recruits.

## Model fits

## Growth data

## EBS



Figure 22: Model fits to EBS.

## EBS



Figure 23: Negative log-likelihood values for fits to EBS.

## EBS



Figure 24: Z-scores for fits to EBS.


Figure 25: Model fits to Kodiak.


Figure 26: Negative log-likelihood values for fits to Kodiak.


Figure 27: Z-scores for fits to Kodiak.

Survey biomass


Figure 28: Comparison of observed and predicted survey biomass for NMFS trawl survey.


Figure 29: Comparison of observed and predicted survey biomass for NMFS trawl survey. Recent time period.
[1] "NMFS trawl survey"

NMFS trawl survey


Figure 30: Z-scores for index catch biomass in NMFS trawl survey.

Fishery retained catch biomass


Figure 31: Comparison of observed and predicted retained catch mortality for TCF.


Figure 32: Comparison of observed and predicted retained catch mortality for TCF. Recent time period.
[1] "TCF"


Figure 33: Z-scores for retained catch biomass in TCF.

Fishery total catch biomass


Figure 34: Comparison of observed and predicted total catch for TCF.


Figure 35: Comparison of observed and predicted total catch for TCF. Recent time period.


Figure 36: Comparison of observed and predicted total catch for SCF.


Figure 37: Comparison of observed and predicted total catch for SCF. Recent time period.


Figure 38: Comparison of observed and predicted total catch for GTF.


Figure 39: Comparison of observed and predicted total catch for GTF. Recent time period.


Figure 40: Comparison of observed and predicted total catch for RKF.


Figure 41: Comparison of observed and predicted total catch for RKF. Recent time period.


Figure 42: Comparison of observed and predicted total catch for GF.FixedGear.


Figure 43: Comparison of observed and predicted total catch for GF.FixedGear. Recent time period.


Figure 44: Comparison of observed and predicted total catch for GF.TrawlGear.


Figure 45: Comparison of observed and predicted total catch for GF.TrawlGear. Recent time period.
[1] "TCF" "SCF" "GTF" "RKF"
[5] "GF.FixedGear" "GF.TrawlGear"


Figure 46: Z-scores for total catch biomass in TCF.


Figure 47: Z-scores for total catch biomass in SCF.


Figure 48: Z-scores for total catch biomass in GTF.


Figure 49: Z-scores for total catch biomass in RKF.

## GF.FixedGear



Figure 50: Z-scores for total catch biomass in GF.FixedGear.


Figure 51: Z-scores for total catch biomass in GF.TrawlGear.

## Mean survey size compositions



Figure 52: Comparison of observed and predicted mean survey size comps for NMFS trawl survey.

Fishery retained catch mean size compositions


Figure 53: Comparison of observed and predicted mean retained catch size comps for TCF.

Fishery total catch mean size compositions


Figure 54: Comparison of observed and predicted mean total catch size comps for GTF.


Figure 55: Comparison of observed and predicted mean total catch size comps for RKF.


Figure 56: Comparison of observed and predicted mean total catch size comps for SCF.


Figure 57: Comparison of observed and predicted mean total catch size comps for TCF.

## GF.FixedGear



Figure 58: Comparison of observed and predicted mean total catch size comps for GF.FixedGear.


Figure 59: Comparison of observed and predicted mean total catch size comps for GF.TrawlGear.

Survey size composition residuals




Figure 61: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016.


Figure 62: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0a.


Figure 63: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1.


Figure 64: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1a.


Figure 65: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1b.


Figure 66: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1c.


Figure 67: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2.


Figure 68: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2a.


Figure 69: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b.


Figure 70: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B3.


Figure 71: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.


Figure 72: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016.


Figure 73: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0a.


Figure 74: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1.


Figure 75: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1a.


Figure 76: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1b.


Figure 77: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1c.


Figure 78: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2.


Figure 79: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2a.


Figure 80: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b.


Figure 81: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B3.


Figure 82: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.


Figure 83: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016.


Figure 84: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0a.


Figure 85: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1.


Figure 86: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1a.


Figure 87: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1b.


Figure 88: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1c.


Figure 89: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2.


Figure 90: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2a.


Figure 91: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b.


Figure 92: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B3.


Figure 93: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.


Figure 94: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016.


Figure 95: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0a.


Figure 96: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1.


Figure 97: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1a.


Figure 98: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1b.


Figure 99: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B1c.


Figure 100: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2.


Figure 101: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2a.


Figure 102: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b.


Figure 103: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B3.

## Effective Ns for survey size compositions



Figure 104: Input and effective sample sizes from retained catch size compositions from the NNPFMC Bering Sea/Aleutian Islands Crab SAFE

Fishery retained catch size composition residuals




Figure 106: Pearson's residuals for proportions-at-size from the TCF for scenario B0.2016.


Figure 107: Pearson's residuals for proportions-at-size from the TCF for scenario B0a.


Figure 108: Pearson's residuals for proportions-at-size from the TCF for scenario B1.


Figure 109: Pearson's residuals for proportions-at-size from the TCF for scenario B1a.


Figure 110: Pearson's residuals for proportions-at-size from the TCF for scenario B1b.


Figure 111: Pearson's residuals for proportions-at-size from the TCF for scenario B1c.


Figure 112: Pearson's residuals for proportions-at-size from the TCF for scenario B2.


Figure 113: Pearson's residuals for proportions-at-size from the TCF for scenario B2a.


Figure 114: Pearson's residuals for proportions-at-size from the TCF for scenario B2b.


Figure 115: Pearson's residuals for proportions-at-size from the TCF for scenario B3.

## Effective Ns for retained catch size compositions



Figure 116: Input and effective sample sizes from retained catch size compositions from the TCNFFAC fishery. Bering Sea/Aleutian Islands Crab SAFE

Fishery total catch size composition residuals




Figure 118: Pearson's residuals for proportions-at-size from the TCF for scenario B0.2016.


Figure 119: Pearson's residuals for proportions-at-size from the TCF for scenario B0a.


Figure 120: Pearson's residuals for proportions-at-size from the TCF for scenario B1.


Figure 121: Pearson's residuals for proportions-at-size from the TCF for scenario B1a.


Figure 122: Pearson's residuals for proportions-at-size from the TCF for scenario B1b.


Figure 123: Pearson's residuals for proportions-at-size from the TCF for scenario B1c.


Figure 124: Pearson's residuals for proportions-at-size from the TCF for scenario B2.


Figure 125: Pearson's residuals for proportions-at-size from the TCF for scenario B2a.


Figure 126: Pearson's residuals for proportions-at-size from the TCF for scenario B2b.


Figure 127: Pearson's residuals for proportions-at-size from the TCF for scenario B3.


Figure 128: Pearson's residuals for proportions-at-size from the SCF for scenario B0.


Figure 129: Pearson's residuals for proportions-at-size from the SCF for scenario B0.2016.


Figure 130: Pearson's residuals for proportions-at-size from the SCF for scenario B0a.


Figure 131: Pearson's residuals for proportions-at-size from the SCF for scenario B1.


Figure 132: Pearson's residuals for proportions-at-size from the SCF for scenario B1a.


Figure 133: Pearson's residuals for proportions-at-size from the SCF for scenario B1b.


Figure 134: Pearson's residuals for proportions-at-size from the SCF for scenario B1c.


Figure 135: Pearson's residuals for proportions-at-size from the SCF for scenario B2.


Figure 136: Pearson's residuals for proportions-at-size from the SCF for scenario B2a.


Figure 137: Pearson's residuals for proportions-at-size from the SCF for scenario B2b.


Figure 138: Pearson's residuals for proportions-at-size from the SCF for scenario B3.


Figure 139: Pearson's residuals for proportions-at-size from the GTF for scenario B0.


Figure 140: Pearson's residuals for proportions-at-size from the GTF for scenario B0.2016.


Figure 141: Pearson's residuals for proportions-at-size from the GTF for scenario B0a.


Figure 142: Pearson's residuals for proportions-at-size from the GTF for scenario B1.


Figure 143: Pearson's residuals for proportions-at-size from the GTF for scenario B1a.


Figure 144: Pearson's residuals for proportions-at-size from the GTF for scenario B1b.


Figure 145: Pearson's residuals for proportions-at-size from the GTF for scenario B1c


Figure 146: Pearson's residuals for proportions-at-size from the GTF for scenario B2.


Figure 147: Pearson's residuals for proportions-at-size from the GTF for scenario B2a.


Figure 148: Pearson's residuals for proportions-at-size from the GTF for scenario B2b.


Figure 149: Pearson's residuals for proportions-at-size from the GTF for scenario B3.


Figure 150: Pearson's residuals for proportions-at-size from the RKF for scenario B0.


Figure 151: Pearson's residuals for proportions-at-size from the RKF for scenario B0.2016.


Figure 152: Pearson's residuals for proportions-at-size from the RKF for scenario B0a.


Figure 153: Pearson's residuals for proportions-at-size from the RKF for scenario B1.


Figure 154: Pearson's residuals for proportions-at-size from the RKF for scenario B1a.


Figure 155: Pearson's residuals for proportions-at-size from the RKF for scenario B1b.


Figure 156: Pearson's residuals for proportions-at-size from the RKF for scenario B1c.


Figure 157: Pearson's residuals for proportions-at-size from the RKF for scenario B2.


Figure 158: Pearson's residuals for proportions-at-size from the RKF for scenario B2a.


Figure 159: Pearson's residuals for proportions-at-size from the RKF for scenario B2b.


Figure 160: Pearson's residuals for proportions-at-size from the RKF for scenario B3.


Figure 161: Pearson's residuals for proportions-at-size from the GF.FixedGear for scenario B3.


Figure 162: Pearson's residuals for proportions-at-size from the GF.TrawlGear for scenario B3.

## Effective Ns for total catch size compositions





Figure 164: Input and effective sample sizes from total catch size compositions from the SCF fishery.


Figure 165: Input and effective sample sizes from total catch size compositions from the GTF fishery.


Figure 166: Input and effective sample sizes from total catch size compositions from the RKF fishery.


Figure 167: Input and effective sample sizes from total catch size compositions from the GF.FixedGear fishery.


Figure 168: Input and effective sample sizes from total catch size compositions from the GF.TrawlGear fishery.

## Survey characteristics

## Survey catchability



Figure 169: Survey catchabilities for NMFS trawl survey.

Survey selectivity functions


Figure 170: NMFS trawl survey. 1

## Fisheries

## Fishery catchability



Figure 171: Fishery catchabilities for GTF.


Figure 172: Fishery catchabilities for RKF.


Figure 173: Fishery catchabilities for SCF.


Figure 174: Fishery catchabilities for TCF.

## GF.FixedGear



Figure 175: Fishery catchabilities for GF.FixedGear.

## GF.TrawIGear



Figure 176: Fishery catchabilities for GF.TrawlGear.

## Total selectivity functions



Figure 177: Selectivity functions for GTF (1 of 6).


Figure 178: Selectivity functions for GTF (2 of 6).


Figure 179: Selectivity functions for GTF(3 of 6).


Figure 180: Selectivity functions for GTF (4 of 6).


Figure 181: Selectivity functions for $\operatorname{GTF}(5$ of 6$)$.


Figure 182: Selectivity functions for $\operatorname{GTF}$ (6 of 6).


Figure 183: Selectivity functions for $\operatorname{RKF}(1$ of 6$)$.


Figure 184: Selectivity functions for $\operatorname{RKF}(2$ of 6$)$.


Figure 185: Selectivity functions for $\operatorname{RKF}(3$ of 6$)$.


Figure 186: Selectivity functions for $\operatorname{RKF}$ (4 of 6).


Figure 187: Selectivity functions for $\operatorname{RKF}(5$ of 6$)$.


Figure 188: Selectivity functions for $\operatorname{RKF}(6$ of 6$)$.


Figure 189: Selectivity functions for $\operatorname{SCF}(1$ of 6$)$.


Figure 190: Selectivity functions for $\operatorname{SCF}(2$ of 6$)$.


Figure 191: Selectivity functions for $\operatorname{SCF}(3$ of 6$)$.


Figure 192: Selectivity functions for $\operatorname{SCF}$ (4 of 6).


Figure 193: Selectivity functions for $\operatorname{SCF}(5$ of 6$)$.


Figure 194: Selectivity functions for $\operatorname{SCF}$ (6 of 6).


Figure 195: Selectivity functions for $\operatorname{TCF}(1$ of 4$)$.


Figure 196: Selectivity functions for $\operatorname{TCF}(2$ of 4$)$.


Figure 197: Selectivity functions for $\operatorname{TCF}(3$ of 4$)$.


Figure 198: Selectivity functions for $\operatorname{TCF}(4$ of 4$)$.


Figure 199: Selectivity functions for GF.FixedGear(1 of 5).


Figure 200: Selectivity functions for GF.FixedGear(2 of 5).


Figure 201: Selectivity functions for GF.FixedGear(3 of 5).


Figure 202: Selectivity functions for GF.FixedGear(4 of 5).


Figure 203: Selectivity functions for GF.FixedGear(5 of 5).


Figure 204: Selectivity functions for GF.TrawlGear(1 of 5).


Figure 205: Selectivity functions for GF.TrawlGear(2 of 5).


Figure 206: Selectivity functions for GF.TrawlGear(3 of 5).


Figure 207: Selectivity functions for GF.TrawlGear(4 of 5).


Figure 208: Selectivity functions for GF.TrawlGear(5 of 5).

## Retention functions



Figure 209: Retention functions for $\operatorname{TCF}$ (1 of 4).


Figure 210: Retention functions for $\operatorname{TCF}(2$ of 4$)$.

## TCF



Figure 211: Retention functions for $\operatorname{TCF}(3$ of 4$)$.


Figure 212: Retention functions for TCF (4 of 4).

## Population quantities

Figures and tables in this section present comparisons between alternative model scenarios for estimated quantities (e.g., recruitment, abundance time series) describing the inferred Tanner crab population.

## Recruitment



Figure 213: Estimated annual recruitment.


Figure 214: Estimated recent recruitment.


Figure 215: Estimated annual recruitment, on $\ln$-scale.


Figure 216: Estimated recent recruitment, on $\ln$-scale.

## Mature biomass



Figure 217: Estimated annual mature biomass.


Figure 218: Estimated recent mature biomass.


Figure 219: Estimated annual mature biomass, on ln-scale.


Figure 220: Estimated recent mature biomass, on ln-scale.

## Population abundance



Figure 221: Population abundance trends.


Figure 222: Recent population abundance trends.


Figure 223: Ln-scale population abundance trends.


Figure 224: Recent ln-scale population abundance trends.

## Population biomass



Figure 225: Population biomass trends.


Figure 226: Recent population biomass trends.


Figure 227: Ln-scale population biomass trends.


Figure 228: Recent ln-scale population biomass trends.

# Model Comparisons: B2b vs B0. 2016 

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13 September, 2017

## Contents

List of Tables in Model Comparisons ..... 1
List of Figures in Model Comparisons ..... 2
Population processes ..... 5
Natural mortality ..... 5
Probability of terminal molt ..... 6
Mean growth ..... 7
Growth matrices ..... 8
Size distribution for recruits ..... 16
Model fits ..... 17
Growth data ..... 17
Survey biomass ..... 23
Fishery retained catch biomass ..... 26
Fishery total catch biomass ..... 29
Mean survey size compositions ..... 41
Fishery retained catch mean size compositions ..... 42
Fishery total catch mean size compositions ..... 43
Survey size composition residuals ..... 48
Effective Ns for survey size compositions ..... 56
Fishery retained catch size composition residuals ..... 57
Effective Ns for retained catch size compositions ..... 59
Fishery total catch size composition residuals ..... 60
Effective Ns for total catch size compositions ..... 68
Survey characteristics ..... 72
Survey catchability ..... 72
Survey selectivity functions ..... 73
Fisheries ..... 74
Fishery catchability ..... 74
Total selectivity functions ..... 78
Retention functions ..... 100
Population quantities ..... 104
Recruitment ..... 104
Mature biomass ..... 108
Population abundance ..... 112
Population biomass ..... 116

## List of Tables

## List of Figures

1 Estimated natural mortality rates, by year. ..... 5
2 Probability of terminal molt. ..... 6
3 Mean growth. ..... 7
4 Estimated growth matrices, as bubble plots, for scenario B2b. ..... 8
5 Estimated growth matrices, as bubble plots, for scenario B0.2016. ..... 9
6 Growth matrices for males during 1948-2016, 1948-2015, page 1. ..... 10
7 Growth matrices for males during 1948-2016, 1948-2015, page 2. ..... 11
8 Growth matrices for males during 1948-2016, 1948-2015, page 3. ..... 12
9 Growth matrices for females during 1948-2016, 1948-2015, page 1. ..... 13
10 Growth matrices for females during 1948-2016, 1948-2015, page 2. ..... 14
11 Growth matrices for females during 1948-2016, 1948-2015, page 3. ..... 15
12 Size distribution for recruits. ..... 16
13 Model fits to EBS. ..... 17
14 Negative log-likelihood values for fits to EBS. ..... 18
15 Z-scores for fits to EBS. ..... 19
16 Model fits to Kodiak ..... 20
17 Negative log-likelihood values for fits to Kodiak. ..... 21
18 Z-scores for fits to Kodiak. ..... 22
19 Comparison of observed and predicted survey biomass for NMFS trawl survey. ..... 23
20 Comparison of observed and predicted survey biomass for NMFS trawl survey. Recent time period. ..... 24
21 Z-scores for index catch biomass in NMFS trawl survey. ..... 25
22 Comparison of observed and predicted retained catch mortality for TCF. ..... 26
23 Comparison of observed and predicted retained catch mortality for TCF. Recent time period. ..... 27
24 Z-scores for retained catch biomass in TCF. ..... 28
25 Comparison of observed and predicted total catch for TCF. ..... 29
26 Comparison of observed and predicted total catch for TCF. Recent time period. ..... 30
27 Comparison of observed and predicted total catch for SCF. ..... 31
28 Comparison of observed and predicted total catch for SCF. Recent time period ..... 32
29 Comparison of observed and predicted total catch for GTF. ..... 33
30 Comparison of observed and predicted total catch for GTF. Recent time period. ..... 34
31 Comparison of observed and predicted total catch for RKF ..... 35
32 Comparison of observed and predicted total catch for RKF. Recent time period. ..... 36
33 Z-scores for total catch biomass in TCF ..... 37
34 Z-scores for total catch biomass in SCF. ..... 38
35 Z-scores for total catch biomass in GTF ..... 39
36 Z-scores for total catch biomass in RKF. ..... 40
37 Comparison of observed and predicted mean survey size comps for NMFS trawl survey. ..... 41
38 Comparison of observed and predicted mean retained catch size comps for TCF. ..... 42
39 Comparison of observed and predicted mean total catch size comps for GTF. ..... 43
40 Comparison of observed and predicted mean total catch size comps for RKF. ..... 44
41 Comparison of observed and predicted mean total catch size comps for SCF. ..... 45
42 Comparison of observed and predicted mean total catch size comps for TCF. ..... 46
43 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b. ..... 48
44 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016. ..... 49
45 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b. ..... 50
46 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016. ..... 51
47 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b. ..... 52
48 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016. ..... 53
49 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b. ..... 54
50 Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016. ..... 55
51 Input and effective sample sizes from retained catch size compositions from the NMFS trawl survey. ..... 56
52 Pearson's residuals for proportions-at-size from the TCF for scenario B2b. ..... 57
53 Pearson's residuals for proportions-at-size from the TCF for scenario B0.2016. ..... 58
54 Input and effective sample sizes from retained catch size compositions from the TCF fishery. ..... 59
55 Pearson's residuals for proportions-at-size from the TCF for scenario B2b ..... 60
56 Pearson's residuals for proportions-at-size from the TCF for scenario B0.2016. ..... 61
57 Pearson's residuals for proportions-at-size from the SCF for scenario B2b. ..... 62
58 Pearson's residuals for proportions-at-size from the SCF for scenario B0.2016. ..... 63
59 Pearson's residuals for proportions-at-size from the GTF for scenario B2b ..... 64
60 Pearson's residuals for proportions-at-size from the GTF for scenario B0.2016 ..... 65
61 Pearson's residuals for proportions-at-size from the RKF for scenario B2b ..... 66
62 Pearson's residuals for proportions-at-size from the RKF for scenario B0.2016. ..... 67
63 Input and effective sample sizes from total catch size compositions from the TCF fishery. ..... 68
64 Input and effective sample sizes from total catch size compositions from the SCF fishery. ..... 69
65 Input and effective sample sizes from total catch size compositions from the GTF fishery. ..... 70
66 Input and effective sample sizes from total catch size compositions from the RKF fishery. ..... 71
67 Survey catchabilities for NMFS trawl survey. ..... 72
68 NMFS trawl survey. 1 ..... 73
69 Fishery catchabilities for GTF. ..... 74
70 Fishery catchabilities for RKF. ..... 75
71 Fishery catchabilities for SCF. ..... 76
72 Fishery catchabilities for TCF. ..... 77
73 Selectivity functions for $\operatorname{GTF}$ (1 of 6 ) ..... 78
74 Selectivity functions for GTF (2 of 6) ..... 79
75 Selectivity functions for GTF (3 of 6) ..... 80
76 Selectivity functions for GTF (4 of 6) ..... 81
77 Selectivity functions for $\operatorname{GTF}$ ( 5 of 6 ) ..... 82
78 Selectivity functions for $\operatorname{GTF}$ ( 6 of 6 ) ..... 83
79 Selectivity functions for RKF (1 of 6 ) ..... 84
80 Selectivity functions for $\operatorname{RKF}(2$ of 6$)$ ..... 85
81 Selectivity functions for RKF (3 of 6) ..... 86
82 Selectivity functions for RKF (4 of 6) ..... 87
83 Selectivity functions for $\operatorname{RKF}$ (5 of 6) ..... 88
84 Selectivity functions for $\operatorname{RKF}$ ( 6 of 6 ) ..... 89
85 Selectivity functions for $\operatorname{SCF}$ (1 of 6 ) ..... 90
86 Selectivity functions for $\operatorname{SCF}$ (2 of 6) ..... 91
87 Selectivity functions for $\operatorname{SCF}$ (3 of 6) ..... 92
88 Selectivity functions for $\operatorname{SCF}$ (4 of 6) ..... 93
89 Selectivity functions for $\operatorname{SCF}(5$ of 6$)$ ..... 94
90 Selectivity functions for $\operatorname{SCF}$ ( 6 of 6 ) ..... 95
91 Selectivity functions for $\operatorname{TCF}(1$ of 4$)$ ..... 96
92 Selectivity functions for TCF (2 of 4) ..... 97
93 Selectivity functions for TCF (3 of 4) ..... 98
94 Selectivity functions for TCF (4 of 4) ..... 99
95 Retention functions for $\operatorname{TCF}$ (1 of 4) ..... 100
96 Retention functions for $\operatorname{TCF}(2$ of 4$)$ ..... 101
97 Retention functions for $\operatorname{TCF}(3$ of 4$)$ ..... 102
98 Retention functions for $\mathrm{TCF}(4$ of 4$)$ ..... 103
99 Estimated annual recruitment. ..... 104
100 Estimated recent recruitment ..... 105
101 Estimated annual recruitment, on $\ln$-scale. ..... 106
102 Estimated recent recruitment, on $\ln$-scale ..... 107
103 Estimated annual mature biomass. ..... 108
104 Estimated recent mature biomass. ..... 109
105 Estimated annual mature biomass, on ln-scale. ..... 110
106 Estimated recent mature biomass, on $\ln$-scale ..... 111
107 Population abundance trends. ..... 112
108 Recent population abundance trends ..... 113
109 Ln -scale population abundance trends. ..... 114
110 Recent ln-scale population abundance trends. ..... 115
111 Population biomass trends. ..... 116
112 Recent population biomass trends. ..... 117
113 Ln -scale population biomass trends. ..... 118
114 Recent $\ln$-scale population biomass trends ..... 119

## Population processes

Figures and tables in this section present comparisons between alternative model scenarios for estimated rates (e.g., natural mortality) or other attributes (e.g., molt increments) describing inferred Tanner crab population processes.

## Natural mortality



Figure 1: Estimated natural mortality rates, by year.

## Probability of terminal molt



Figure 2: Probability of terminal molt.

## Mean growth



Figure 3: Mean growth.

## Growth matrices

Growth matrices for each model case are compared as bubble plots in the following figure.


Figure 4: Estimated growth matrices, as bubble plots, for scenario B2b.


Figure 5: Estimated growth matrices, as bubble plots, for scenario B0.2016.

The same growth matrices are compared in the following figure(s) as line plots for each pre-molt size bin, by sex.
male growth: 1948-2016, 1948-2015


Figure 6: Growth matrices for males during 1948-2016, 1948-2015, page 1.
male growth: 1948-2016, 1948-2015


Figure 7: Growth matrices for males during 1948-2016, 1948-2015, page 2.
male growth: 1948-2016, 1948-2015


Figure 8: Growth matrices for males during 1948-2016, 1948-2015, page 3.
female growth: 1948-2016, 1948-2015


Figure 9: Growth matrices for females during 1948-2016, 1948-2015, page 1.


Figure 10: Growth matrices for females during 1948-2016, 1948-2015, page 2.


Figure 11: Growth matrices for females during 1948-2016, 1948-2015, page 3.

## Size distribution for recruits



Figure 12: Size distribution for recruits.

## Model fits

## Growth data

## EBS



Figure 13: Model fits to EBS.

## EBS



Figure 14: Negative log-likelihood values for fits to EBS.

## EBS



Figure 15: Z-scores for fits to EBS.


Figure 16: Model fits to Kodiak.


Figure 17: Negative log-likelihood values for fits to Kodiak.


Figure 18: Z-scores for fits to Kodiak.

## Survey biomass



Figure 19: Comparison of observed and predicted survey biomass for NMFS trawl survey.


Figure 20: Comparison of observed and predicted survey biomass for NMFS trawl survey. Recent time period.
[1] "NMFS trawl survey"


Figure 21: Z-scores for index catch biomass in NMFS trawl survey.

Fishery retained catch biomass


Figure 22: Comparison of observed and predicted retained catch mortality for TCF.


Figure 23: Comparison of observed and predicted retained catch mortality for TCF. Recent time period.
[1] "TCF"


Figure 24: Z-scores for retained catch biomass in TCF.

Fishery total catch biomass


Figure 25: Comparison of observed and predicted total catch for TCF.


Figure 26: Comparison of observed and predicted total catch for TCF. Recent time period.


Figure 27: Comparison of observed and predicted total catch for SCF.


Figure 28: Comparison of observed and predicted total catch for SCF. Recent time period.


Figure 29: Comparison of observed and predicted total catch for GTF.


Figure 30: Comparison of observed and predicted total catch for GTF. Recent time period.


Figure 31: Comparison of observed and predicted total catch for RKF.


Figure 32: Comparison of observed and predicted total catch for RKF. Recent time period.
[1] "TCF" "SCF" "GTF" "RKF"


Figure 33: Z-scores for total catch biomass in TCF.


Figure 34: Z-scores for total catch biomass in SCF.


Figure 35: Z-scores for total catch biomass in GTF.


Figure 36: Z-scores for total catch biomass in RKF.

## Mean survey size compositions



Figure 37: Comparison of observed and predicted mean survey size comps for NMFS trawl survey.

Fishery retained catch mean size compositions


Figure 38: Comparison of observed and predicted mean retained catch size comps for TCF.

Fishery total catch mean size compositions


Figure 39: Comparison of observed and predicted mean total catch size comps for GTF.


Figure 40: Comparison of observed and predicted mean total catch size comps for RKF.


Figure 41: Comparison of observed and predicted mean total catch size comps for SCF.


Figure 42: Comparison of observed and predicted mean total catch size comps for TCF.

Survey size composition residuals


Figure 43: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario ${ }^{872}$ B2 2 . ${ }^{2}$. Bering Sea/Aleutian Islands Crab SAFE


Figure 44: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016.


Figure 45: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b.


Figure 46: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016.


Figure 47: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b.


Figure 48: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016.


Figure 49: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B2b.


Figure 50: Pearson's residuals for proportions-at-size from the NMFS trawl survey for scenario B0.2016.

## Effective Ns for survey size compositions



Figure 51: Input and effective sample sizes from retained catch size compositions from the NMFSFMC Bering Sea/Aleutian Islands Crab SAFE

Fishery retained catch size composition residuals




Figure 53: Pearson's residuals for proportions-at-size from the TCF for scenario B0.2016.

Effective Ns for retained catch size compositions



Fishery total catch size composition residuals


Figure 55: Pearson's residuals for proportions-at-size from the TCF ${ }^{891}$ for scenario B2b.


Figure 56: Pearson's residuals for proportions-at-size from the TCF for scenario B0.2016.


Figure 57: Pearson's residuals for proportions-at-size from the SCF for scenario B2b.


Figure 58: Pearson's residuals for proportions-at-size from the SCF for scenario B0.2016.


Figure 59: Pearson's residuals for proportions-at-size from the GTF for scenario B2b.


Figure 60: Pearson's residuals for proportions-at-size from the GTF for scenario B0.2016.


Figure 61: Pearson's residuals for proportions-at-size from the RKF for scenario B2b.


Figure 62: Pearson's residuals for proportions-at-size from the RKF for scenario B0.2016.

## Effective Ns for total catch size compositions



Figure 63: Input and effective sample sizes from total catch size compositions from the TCF fishery. Bering Sea/Aleutian Islands Crab SAFE


Figure 64: Input and effective sample sizes from total catch size compositions from the SCF fishery.


Figure 65: Input and effective sample sizes from total catch size compositions from the GTF fishery.


Figure 66: Input and effective sample sizes from total catch size compositions from the RKF fishery.

## Survey characteristics

Survey catchability


Figure 67: Survey catchabilities for NMFS trawl survey.

Survey selectivity functions


Figure 68: NMFS trawl survey. 1

## Fisheries

## Fishery catchability



Figure 69: Fishery catchabilities for GTF.


Figure 70: Fishery catchabilities for RKF.


Figure 71: Fishery catchabilities for SCF.


Figure 72: Fishery catchabilities for TCF.

## Total selectivity functions



Figure 73: Selectivity functions for GTF (1 of 6 ).


Figure 74: Selectivity functions for $\operatorname{GTF}(2$ of 6$)$.


Figure 75: Selectivity functions for GTF(3 of 6 ).


Figure 76: Selectivity functions for GTF(4 of 6).


Figure 77: Selectivity functions for GTF(5 of 6).


Figure 78: Selectivity functions for GTF (6 of 6 ).


Figure 79: Selectivity functions for RKF (1 of 6 ).


Figure 80: Selectivity functions for $\operatorname{RKF}$ (2 of 6 ).


Figure 81: Selectivity functions for $\operatorname{RKF}$ (3 of 6 ).


Figure 82: Selectivity functions for $\operatorname{RKF}(4$ of 6 ).


Figure 83: Selectivity functions for $\operatorname{RKF}$ (5 of 6 ).


Figure 84: Selectivity functions for RKF (6 of 6).


Figure 85: Selectivity functions for $\operatorname{SCF}(1$ of 6$)$.


Figure 86: Selectivity functions for $\operatorname{SCF}(2$ of 6$)$.


Figure 87: Selectivity functions for $\operatorname{SCF}(3$ of 6$)$.


Figure 88: Selectivity functions for $\operatorname{SCF}(4$ of 6$)$.


Figure 89: Selectivity functions for $\operatorname{SCF}(5$ of 6$)$.


Figure 90: Selectivity functions for $\operatorname{SCF}(6$ of 6$)$.


Figure 91: Selectivity functions for $\operatorname{TCF}$ (1 of 4).


Figure 92: Selectivity functions for $\operatorname{TCF}$ (2 of 4).


Figure 93: Selectivity functions for $\operatorname{TCF}$ (3 of 4).


Figure 94: Selectivity functions for $\operatorname{TCF}$ (4 of 4).

## Retention functions



Figure 95: Retention functions for $\operatorname{TCF}(1$ of 4$)$.

## TCF



Figure 96: Retention functions for $\operatorname{TCF}$ (2 of 4).

## TCF



Figure 97: Retention functions for $\operatorname{TCF}$ (3 of 4).

## TCF



Figure 98: Retention functions for $\operatorname{TCF}$ (4 of 4).

## Population quantities

Figures and tables in this section present comparisons between alternative model scenarios for estimated quantities (e.g., recruitment, abundance time series) describing the inferred Tanner crab population.

## Recruitment



Figure 99: Estimated annual recruitment.


Figure 100: Estimated recent recruitment.


Figure 101: Estimated annual recruitment, on $\ln$-scale.


Figure 102: Estimated recent recruitment, on ln-scale.

## Mature biomass



Figure 103: Estimated annual mature biomass.


Figure 104: Estimated recent mature biomass.


Figure 105: Estimated annual mature biomass, on ln-scale.


Figure 106: Estimated recent mature biomass, on $\ln$-scale.

## Population abundance



Figure 107: Population abundance trends.


Figure 108: Recent population abundance trends.


Figure 109: Ln-scale population abundance trends.


Figure 110: Recent ln-scale population abundance trends.

## Population biomass



Figure 111: Population biomass trends.


Figure 112: Recent population biomass trends.


Figure 113: Ln-scale population biomass trends.


Figure 114: Recent ln-scale population biomass trends.

## 2017 Stock assessment and fishery evaluation report for the Pribilof Island red king crab fishery of the Bering Sea and Aleutian Islands regions

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## Executive summary

1. Stock: Pribilof Islands red king crab, Paralithodes camtschaticus
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch and discards have been decreasing since 2012/13, and are low relative to the OFL.
3. Stock biomass:
a. According to the random effects model, mature male biomass decreased from 2007 to 2010 and increased during 2011 through 2015, then declined in 2016 and 2017. MMB at mating was estimated to be above $\mathrm{B}_{\text {MSY }}(4,604 \mathrm{t})$ in 2016/17 at $4,788 \mathrm{t}$.
b. Observed survey mature male biomass ( $\geq 120 \mathrm{~mm}$ ) declined from $15,173 \mathrm{t}$ in 2015 to 4,150 t in 2016 and $3,658 \mathrm{t}$ in 2017. Total female biomass declined from 1,898 t in 2016 to 505 t in 2017.
4. Recruitment: No estimates of recruitment are available.
5. Recent management statistics: OFL and ABC in 2011/12 was based on the unweighted 3-year running average. Biomass in 2011/2012 and OFL and ABC from 2012/13 to 2015/16 were based on the weighted 3 -year running average using the inverse of the variance. Biomass (MMB) in $2016 / 17$ and 2017/18 is based on the random effects model (CV=2.24) estimated biomass.

Units in tons

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | ---: | ---: |
| $2011 / 12$ | 2,571 | 2,775 | 0 | 0 | 5.4 | 393 | 307 |
| $2012 / 13$ | 2,609 | 4,025 | 0 | 0 | 13.1 | 569 | 455 |
| $2013 / 14$ | 2,582 | 4,679 | 0 | 0 | 2.25 | 903 | 718 |
| $2014 / 15$ | 2,871 | 8,894 | 0 | 0 | 1.76 | 1,359 | 1,019 |
| $2015 / 16$ | 2,756 | 9,062 | 0 | 0 | 0.32 | 2,119 | 1,467 |
| $2016 / 17$ | $2,302^{\mathrm{A}}$ | $4,788^{\mathrm{A}}$ | 0 | 0 | 0.49 | 1,492 | 1,096 |
| $2017 / 18$ | $2,302^{\mathrm{A}}$ | $3,364^{\mathrm{A}}$ |  |  |  | 482 | 362 |

Units in millions of pounds

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $2011 / 12$ | 5.67 | 6.12 | 0 | 0 | 0.011 | 0.87 | 0.68 |
| $2012 / 13$ | 5.75 | 8.87 | 0 | 0 | 0.029 | 1.25 | 1.00 |
| $2013 / 14$ | 5.66 | 10.32 | 0 | 0 | 0.005 | 1.99 | 1.58 |
| $2014 / 15$ | 6.33 | 19.61 | 0 | 0 | 0.004 | 3.00 | 2.25 |
| $2015 / 16$ | 6.08 | 19.99 | 0 | 0 | $<0.001$ | 4.67 | 3.23 |
| $2016 / 17$ | $5.07^{\mathrm{A}}$ | $10.56^{\mathrm{A}}$ | 0 | 0 | 0.001 | 3.22 | 2.42 |
| $2017 / 18$ | $5.07^{\mathrm{A}}$ | $7.42^{\mathrm{A}}$ |  |  |  | 1.06 | 0.80 |

A - Based on the Random effects model (CV=2.24)

The OFL is the total catch OFL for each year. The stock was above MSST in 2016/2017 according to the random effects model $(\mathrm{CV}=2.24)$ at $4,788 \mathrm{t}(\mathrm{MSST}=2,302 \mathrm{t})$. The catch in 2016/17 ( 0.49 t ) was below the $\operatorname{OFL}(1,492 \mathrm{t})$ and the $\operatorname{ABC}(1,096 \mathrm{t})$.
6. 2017/2018 OFL projections:

All biomass in tons

| Tier | Assessment Method | OFL | $B_{\text {MSY }}$ | MMB <br> At mating ${ }^{\text {A }}$ | $B / B_{\text {MSY }}$ <br> (MMB) | MMB at mating Feb 15 2017 | $\gamma$ | Years to define $\boldsymbol{B}_{\text {MSY }}$ | F MSY | $\begin{aligned} & \mathrm{ABC} \\ & \left(\mathrm{p}^{*}=0.4\right. \\ & 9) \end{aligned}$ | $\begin{aligned} & \text { ABC } \\ & = \\ & \mathbf{0 . 7 5 *} \\ & \text { OFL } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 4b | Running Average | 330 | 5,502 | 3,139 | 0.57 | 6,445 | 1 | $\begin{aligned} & \hline 1991 / 1992- \\ & 2016 / 2017 \end{aligned}$ | 0.06 | 319 | 248 |
| 4b | Random Effects Model fixed | 442 | 4,711 | 3,274 | 0.69 | 4,683 | 1 | (MMB) <br> 1991/1992- <br> 2016/2017 <br> (MMB) | 0.12 | 428 | 332 |
| 4b | Random <br> Effects <br> Model prior <br> cv 2.24 | 482 | 4,604 | 3,364 | 0.73 | 4,788 | 1 | $\begin{aligned} & \text { 1991/1992- } \\ & 2016 / 2017 \\ & (\mathrm{MMB}) \end{aligned}$ | 0.13 | 467 | 362 |
| 4b | Random <br> Effects <br> Model prior cv 4.0 | 573 | 4,397 | 3,563 | 0.81 | 4,961 | 1 | $\begin{aligned} & \text { 1991/1992- } \\ & 2016 / 2017 \\ & (\mathrm{MMB}) \end{aligned}$ | 0.14 | 554 | 429 |
| 4b | Observed Survey | 291 | 5,502 | 2,971 | 0.54 | 3,681 | 1 | $\begin{aligned} & 1991 / 1992- \\ & 2016 / 2017 \\ & (\mathrm{MMB}) \end{aligned}$ | 0.09 | 280 | 218 |

A: Feb. 15, 2018 fishing at OFL
For the following Table units are in millions of pounds.

| Tier | Assessment Method | OFL | $\boldsymbol{B}_{\text {MSY }}$ | MMB <br> At mating ${ }^{\text {A }}$ | $B / B_{\mathrm{MSY}}$ <br> (MMB) | MMB at mating Feb 15 2017 | $\gamma$ | Years to define $B_{\text {MSY }}$ | $F_{\text {MSY }}$ | $\begin{aligned} & \mathrm{ABC} \\ & \left(\mathrm{p}^{*}=0\right. \\ & .49) \end{aligned}$ | $\begin{aligned} & \text { ABC } \\ & = \\ & = \\ & \mathbf{0 . 7 5 *} \\ & \text { OFL } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 4b | Running Average | 0.73 | 12.13 | 6.92 | 0.57 | 14.21 | 1 | $\begin{aligned} & \text { 1991/1992- } \\ & 2016 / 2017 \\ & (\mathrm{MMB}) \end{aligned}$ | 0.06 | 0.70 | 0.55 |
| 4b | Random <br> Effects <br> Model fixed | 0.97 | 10.39 | 7.22 | 0.69 | 10.32 | 1 | $\begin{aligned} & 1991 / 1992- \\ & 2016 / 2017 \\ & (\mathrm{MMB}) \end{aligned}$ | 0.12 | 0.94 | 0.73 |
| 4b | Random <br> Effects <br> Model prior <br> cv 2.24 | 1.06 | 10.15 | 7.42 | 0.73 | 10.56 | 1 | $\begin{aligned} & 1991 / 1992- \\ & 2016 / 2017 \\ & (\mathrm{MMB}) \end{aligned}$ | 0.13 | 1.03 | 0.80 |
| 4b | Random <br> Effects <br> Model prior <br> cv 4.0 | 1.26 | 9.69 | 7.85 | 0.81 | 10.94 | 1 | $\begin{aligned} & 1991 / 1992- \\ & 2016 / 2017 \\ & (\mathrm{MMB}) \end{aligned}$ | 0.14 | 1.22 | 0.95 |
| 4b | Observed Survey | 0.64 | 12.13 | 6.55 | 0.54 | 8.12 | 1 | $\begin{aligned} & 1991 / 1992- \\ & 2016 / 2017 \\ & (\mathrm{MMB}) \end{aligned}$ | 0.09 | 0.62 | 0.48 |

## A. Feb. 15, 2018 fishing at OFL

7. Probability distributions of the OFL for tier 4 methods were generated by bootstrapping values of MMB in the current year with an additional sigma of 0.3 .
8. Basis for ABC : ABCs were identified as the $49^{\text {th }}$ percentile of the distributions of the OFL given a p-star of 0.49 . In addition the ABC was estimated using a $25 \%$ buffer from the OFL as recommended by the CPT and SSC in 2016/17.

## Summary of Major Changes:

1. Management: None.
2. Input data: Survey (2017) and bycatch (2016/17) data were incorporated into the assessment.
3. Assessment methodology: The 3 -year running average and random effects models only are presented in this assessment.
4. Assessment results: Male biomass estimates from the 3 -year running average and a random effects model were fit to survey male biomass $\geq 120 \mathrm{~mm}$ with process error fixed at the value estimated from a simple exponential model and with a prior with mean equal to the process error estimated from the simple exponential model and with $\mathrm{cv}=2.24$ and $\mathrm{cv}=4.0$. Tier 4 control rules are used to estimate MMB at mating, OFL, and ABC for the four models.

## CPT comments May 2017

The CPT recommended that the author continue to develop the random effects model and consider the following for models at the September CPT:

1. Better describe the exponential smoother methods and bring forward one model with the exponential model result as a prior and one model with the process error based on the exponential model fixed.

Included are 3 runs of the random effects model: 1) fixed process error at simple exponential model value, 2 ) with cv of 2.2 in the prior, and 3 ) cv of 4.0 in the prior.
2. Status quo 3-year running average.

Included.
3. Consider fitting to the female biomass to determine if assessing the effects of single sex high biomass tows are informative for determining the observed error relative to process error.

The random effects model did not converge using female biomass. The simple exponential model was fit to female biomass to compare the estimate of process error to fitting male biomass.
4. Consider fitting spatial models (e.g., Thorson et al. 2015) to the survey data that may better account for zero tows and high biomass tows.

Not done in this assessment.

## SSC comments June 2017

There were no comments specific to the Pribilof red king crab assessment by the SSC in June 2017.

## 1. Introduction

1.1 Distribution

Red king crabs, Paralithodes camtschaticus, (Tilesius, 1815) are anomurans in the family Lithodidae and are distributed from the Bering Sea south to the Queen Charlotte Islands and to Japan in the western Pacific (Jensen 1995; Figure 1). Red king crabs have also been introduced and become established in the Barents Sea (Jørstad et al. 2002). The Pribilof Islands red king crab stock is located in the Pribilof District of the Bering Sea Management Area Q. The Pribilof District is defined as Bering Sea waters south of the latitude of Cape Newenham ( $58^{\circ} 39^{\prime} \mathrm{N}$ lat.), west of $168^{\circ} \mathrm{W}$ long., east of the United States - Russian convention line of 1867 as amended in 1991 , north of $54^{\circ} 36^{\prime} \mathrm{N}$ lat. between $168^{\circ} 00^{\prime} \mathrm{N}$ and $171^{\circ} 00^{\prime} \mathrm{W}$ long and north of $55^{\circ} 30^{\prime} \mathrm{N}$ lat. between $171^{\circ} 00^{\prime} \mathrm{W}$. long and the U.S.-Russian boundary (Figure 2).

### 1.2 Stock structure

Populations of red king crab in the eastern Bering Sea (EBS) for which genetic studies have been performed appear to be composed of four stocks: Aleutian Islands, Norton Sound, Southeast Alaska, and the rest of the EBS. Seeb and Smith (2005) reported micro-satellite samples from Bristol Bay, Port Moller, and the Pribilof Islands were divergent from the Aleutian Islands and Norton Sound. A more recent study describes the genetic distinction of Southeast Alaska red king crab compared to Kodiak and the Bering Sea; the latter two being similar (Grant and Cheng 2012).

### 1.3 Life history

Red king crabs reproduce annually and mating occurs between hard-shelled males and soft-shelled females. Red king crabs do not have spermathecae and cannot store sperm, therefore a female must mate every year to produce a fertilized clutch of eggs (Powell and Nickerson 1965). A pre-mating embrace is formed 3-7 days prior to female ecdysis, the female molts, and copulation occurs within hours. The male inverts the female so they are abdomen to abdomen and then the male extends his fifth pair of periopods to deposit sperm on the female's gonopores. Eggs are fertilized after copulation as they are extruded through the gonopores located at the ventral surface of the coxopides of the third periopods. The eggs form a spongelike mass, adhering to the setae on the pleopods where they are brooded until hatching (Powell and Nickerson 1965). Fecundity estimates are not available for Pribilof Islands red king crab, but range from 42,736 to 497,306 for Bristol Bay red king crab (Otto et al. 1990). The estimated size at 50 percent maturity of female Pribilof Islands red king crabs is approximately 102 mm carapace length (CL) which is larger than 89 mm CL reported for Bristol Bay and 71 mm CL for Norton Sound (Otto et al. 1990). Size at maturity has not been determined specifically for Pribilof Islands red king crab males, however, approximately 103 mm CL is reported for eastern Bering Sea male red king crabs (Somerton 1980). Early studies predicted that red king crab become mature at approximately age 5 (Powell 1967; Weber 1967); however, Stevens (1990) predicted mean age at recruitment in Bristol Bay to be 7 to 12 years, and Loher et al. (2001) predicted age to recruitment to be approximately 8 to 9 years after settlement. Based upon a long-term laboratory study, longevity of red king crab males is approximately 21 years and less for females (Matsuura and Takeshita 1990).

Natural mortality of Bering Sea red king crab stocks is poorly known (Bell 2006). Siddeek et al. (2002) reviewed natural mortality estimates from various sources. Natural mortality estimates based upon historical tag-recapture data range from 0.001 to 0.93 for crabs $80-169 \mathrm{~mm}$ CL with natural mortality increasing with size. Natural mortality estimates based on more recent tag-recovery data for Bristol Bay red king crab males range from 0.54 to 0.70 , however, the authors noted that these estimates appear high considering the longevity of red king crab. Natural mortality estimates based on trawl survey data vary from 0.08 to 1.21 for the size range $85-169 \mathrm{~mm}$ CL, with higher mortality for crabs $<125 \mathrm{~mm}$ CL. In an earlier analysis that utilized the same data sets, Zheng et al. (1995) concluded that natural mortality is dome shaped over length and varies over time. Natural mortality was set at 0.2 for Bering Sea king crab stocks (NPFMC 1998) and was changed to 0.18 with Amendment 24.

The reproductive cycle of Pribilof Islands red king crabs has not been established, however, in Bristol Bay, timing of molting and mating of red king crabs is variable and occurs from the end of January through the end of June (Otto et al. 1990). Primiparous (i.e. brooding their first egg clutch) Bristol Bay red king crab females extrude eggs on average 2 months earlier in the reproductive season and brood eggs longer than multiparous (i.e. brooding their second or subsequent egg clutch) females (Stevens and Swiney 2007a, Otto et al. 1990), resulting in incubation periods that are approximately eleven to twelve months in duration (Stevens and Swiney 2007a, Shirley et al. 1990). Larval hatching among red king crabs is relatively synchronous among stocks and in Bristol Bay occurs March through June with peak hatching in May and June (Otto et al. 1990), however larvae of primiparous females hatch earlier than multiparous females (Stevens and Swiney 2007b, Shirley and Shirley 1989). As larvae, red king crabs exhibit four zoeal stages and a glaucothoe stage (Marukawa 1933).

Growth parameters have not been examined for Pribilof Islands red king crabs; however they have been studied for Bristol Bay red king crab. A review by the Center for Independent Experts (CIE) reported that growth parameters are poorly known for all red king crab stocks (Bell 2006). Growth increments of immature southeastern Bering Sea red king crabs are approximately: $23 \%$ at $10 \mathrm{~mm} \mathrm{CL}, 27 \%$ at 50 mm CL, $20 \%$ at 80 mm CL and 16 mm for immature crabs over 69 mm CL (Weber 1967). Growth of males and females is similar up to approximately 85 mm CL, thereafter females grow more slowly than males (Weber 1967; Loher et al. 2001). In a laboratory study, growth of female red king crabs was reported to vary with age; during their pubertal molt (molt to maturity) females grew on average $18.2 \%$, whereas primiparous females grew 6.3\% and multiparous females grew 3.8\% (Stevens and Swiney, 2007a). Similarly, based upon tag-recapture data from 1955-1965 researchers observed that adult female growth per molt decreases with increased size (Weber 1974). Adult male growth increment averages 17.5 mm irrespective of size (Weber 1974).

Molting frequency has been studied for Alaskan red king crabs, but Pribilof Islands specific studies have not been conducted. Powell (1967) reports that the time interval between molts increases from a minimum of approximately three weeks for young juveniles to a maximum of four years for adult males. Molt frequency for juvenile males and females is similar and once mature, females molt annually and males molt annually for a few years and then biennially, triennially and quadrennial (Powell 1967). The periodicity of mature male molting is not well understood and males may not molt synchronously like females who molt prior to mating (Stevens 1990).

### 1.4 Management history

Red king crab stocks in the Bering Sea and Aleutian Islands are managed by the State of Alaska through the federal Fishery Management Plan (FMP) for Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 1998). The Alaska Department of Fish and Game (ADF\&G) has not published harvest regulations for the Pribilof district red king crab fishery. The king crab fishery in the Pribilof District began in 1973 with blue king crab Paralithodes platypus being targeted (Figure 3). A red king crab fishery in the Pribilof District opened for the first time in September 1993. Beginning in 1995, combined red and blue king crab

GHLs were established. Declines in red and blue king crab abundance from 1996 through 1998 resulted in poor fishery performance during those seasons with annual harvests below the fishery GHL. The North Pacific Fishery Management Council (NPFMC) established the Bering Sea Community Development Quota (CDQ) for Bering Sea fisheries including the Pribilof Islands red and blue king crab fisheries which was implemented in 1998. From 1999 to present the Pribilof Islands fishery was not open due to low blue king crab abundance, uncertainty with estimated red king crab abundance, and concerns for blue king crab bycatch associated with a directed red king crab fishery. Pribilof Islands blue king crab was declared overfished in September of 2002 and is still considered overfished (see Bowers et al. 2011 for complete management history).

Amendment 21a to the BSAI groundfish FMP established the Pribilof Islands Habitat Conservation Area (Figure 4) which prohibits the use of trawl gear in a specified area around the Pribilof Islands year round (NPFMC 1994). The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from impacts from trawl gear.

Pribilof Islands red king crab often occur as bycatch in the eastern Bering Sea snow crab (Chionoecetes opilio), eastern Bering Sea Tanner crab (Chionoecetes bairdi), Bering Sea hair crab (Erimacrus isenbeckii), and Pribilof Islands blue king crab fisheries (when there is one). Limited non-directed catch exists in crab fisheries and groundfish pot and hook and line fisheries (see bycatch and discards section below). However, bycatch is currently very low compared to historical levels.

## 2. Data

The standard groundfish discards time series data (updated through 2016/17) were used in this assessment. The crab fishery retained and discard catch time series were updated with 2016/2017 data. The following sources and years of data are available:

| Data source | Years available |
| :--- | :--- |
| NMFS trawl survey | $1975-2017$ |
| Retained catch | $1993-2016 / 17$ |
| Trawl bycatch | $1991-2016 / 17$ |
| Fixed gear bycatch | $1991-2016 / 17$ |
| Pot discards | $1998-2016 / 17$ |

### 2.1 Retained catch

Red king crab were targeted in the Pribilof Islands District from the 1993/1994 season to 1998/1999. Live and deadloss landings data and effort data are available during that time period (Tables 1 and 2), but no retained catch has been allowed since 1999.

### 2.2 Bycatch and discards

Non-retained (directed and non-directed) pot fishery catches are provided for sub-legal males ( $\leq 138 \mathrm{~mm}$ CL), legal males ( $>138 \mathrm{~mm} \mathrm{CL}$ ), and females based on data collected by onboard observers. Catch weight was calculated by first determining the mean weight (g) for crabs in each of three categories: legal nonretained, sublegal, and female. Length to weight parameters were available for two time periods: 1973 to 2009 (males: $\mathrm{A}=0.000361, \mathrm{~B}=3.16$; females: $\mathrm{A}=0.022863, \mathrm{~B}=2.23382$ ) and 2010 to 2013 (males: $\mathrm{A}=0.000403, \mathrm{~B}=3.141$; ovigerous females: $\mathrm{A}=0.003593$, $\mathrm{B}=2.666$; non-ovigerous females: $\mathrm{A}=0.000408$, $\mathrm{B}=3.128$ ). The average weight for each category was multiplied by the number of crabs at that CL , summed, and then divided by the total number of crabs (equation 2).

$$
\begin{equation*}
\text { Weight }(\mathrm{g})=\mathrm{A} * \mathrm{CL}(\mathrm{~mm})^{\mathrm{B}} \tag{1}
\end{equation*}
$$

$$
\begin{equation*}
\text { Mean Weight }(\mathrm{g})=\sum(\text { weight at size } * \text { number at size }) / \sum(\text { crabs }) \tag{2}
\end{equation*}
$$

Finally, weights, discards, and bycatch were the product of average weight, CPUE, and total pot lifts in the fishery. A 20\% handling mortality rate was applied to these estimates (assumed the same as Bristol Bay red king crab).

Historical non-retained catch data are available from 1998/1999 to present from the snow crab, golden king crab (Lithodes aequispina), and Tanner crab fisheries (Table 3) although data may be incomplete for some of these fisheries. Limited observer data exists prior to 1998 for catcher-processor vessels only so nonretained catch before this date are not included here. In 2016/2017 there was no catch of Pribilof Islands red king crab from crab fisheries (Table 3).

### 2.3 Groundfish pot, trawl, and hook and line fisheries

The data through 2016/2017 from the NOAA Fisheries Regional Office (J. Gasper, NMFS, personal communication) assessments of non-retained catch from all groundfish fisheries are included in this SAFE report. Groundfish catches of crab are reported for all crab combined by federal reporting areas and by State of Alaska reporting areas since 2009/2010. Catches from observed fisheries were applied to non-observed fisheries to estimate a total catch. Catch counts were converted to biomass by applying the average weight measured from observed tows from July 2011 to June 2012. Prior to 2011/2012, Areas 513 and 521 were included in the estimate, a practice that likely resulted in an overestimate of the catch of Pribilof Islands red king crab due to the extent of Area 513 into the Bristol Bay District. In 2012/2013 these data were available in State of Alaska reporting areas that overlap specifically with stock boundaries so that the management unit for each stock can be more appropriately represented. To estimate sex ratios it was assumed that the male to female ratio was one. To assess crab mortalities in these groundfish fisheries a $50 \%$ handling mortality rate was applied to pot and hook and line estimates and an $80 \%$ handling mortality rate was applied to trawl estimates.

Historical non-retained groundfish catch data are available from 1991/1992 to present (J. Mondragon, NMFS, personal communication) although sex ratios have not been determined (Table 3). Prior to 1991, data are only available in INPFC reports. Between 1991 and December 2001 bycatch was estimated using the "blend method". The blend method combined data from industry production reports and observer reports to make the best, comprehensive accounting of groundfish catch. For shoreside processors, Weekly Production Reports (WPR) submitted by industry were the best source of data for retained groundfish landings. All fish delivered to shoreside processors were weighed on scales, and these weights were used to account for retained catch. Observer data from catcher vessels provided the best data on at-sea discards of groundfish by vessels delivering to shoreside processors. Discard rates from these observer data were applied to the shoreside groundfish landings to estimate total at-sea discards from both observed and unobserved catcher vessels. For observed catcher/processors and motherships, the WPR and the Observer Reports recorded estimates of total catch (retained catch plus discards). If both reports were available, one of them was selected during the "blend method" for incorporation into the catch database. If the vessel was unobserved, only the WPR was available. From January 2003 to December 2007, a new database structure named the Catch Accounting System (CAS) led to large method change. Bycatch estimates were derived from a combination of observer and landing (catcher vessels/production data). Production data included CPs and catcher vessels delivering to motherships. To obtain fishery level estimates, CAS used a ratio estimator derived from observer data (counts of crab/kg groundfish) that is applied to production/landing information. (See http://www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-205.pdf). Estimates of crab are in numbers because the PSC is managed on numbers. There were two issues with this dataset that required estimation work outside of CAS:

1) The estimated number of crab had to be converted to weights. An average weight was calculated using groundfish observer data. This weight was specific to crab year, crab species, and fixed or
trawl gear. This average was applied to the estimated number of crab for crab year by federal reporting area.
2) In some situations, crab estimates were identified and grouped in the observed data to the genus level. These crabs were apportioned to the species level using the identified crab.

From January 2008 to 2012 the observer program changed the method in which they speciate crab to better reflect their hierarchal sampling method and to account for broken crab that in the past were only identified to genus. In addition, haul-level weights collected by the observers were used to estimate the weight of crab through CAS instead of applying an annual (global) weight factor. Spatial resolution was at federal reporting area.

Starting in 2013, a new data set based on the CAS system was made available for January 2009 to present. In 2009 reporting State statistical areas was required on groundfish production reports. The level of spatial resolution in CAS was formally federal reporting area since this the highest spatial resolution at which observer data is aggregated to create bycatch rates. The federal reporting area does not follow crab stock boundaries, in particular for species with small stock areas such as Pribilof Islands or St. Matthew Island stocks, so the new data was provided at the State reporting areas. This method uses ratio estimator (weight crab/weight groundfish) applied to the weight of groundfish reported on production/landing reports. Where possible, this dataset aggregates observer data to the stock area level to create bycatch estimates by stock area. There are instances where no observer data is available and aggregation may go outside of a stock area, but this practice is greatly reduced compared with the pre-2009 data, which at best was at the Federal reporting area level.

Total catch in 2015/16 was 0.32 t and in 2016/17 0.49 t below the 2016/17 OFL $1,492 \mathrm{t}$ and below the ABC of 1,096 t (Tables 3 and 5, Figures 13 and 14). Catch by weight in 2016/17 was $81 \%$ from non-pelagic trawl and $19 \%$ from hook and line fisheries (Table 4).

### 2.4 Catch-at-length

Catch-at-length data are not available for this fishery.

### 2.5 Survey biomass and length frequencies

The 2017 NOAA Fisheries EBS bottom trawl survey results are included in this SAFE report. Data available for estimating the abundance of crab around the Pribilof Islands are relatively sparse. Red king crab have been observed at 35 unique tows in the Pribilof District over the years 1975 to 2017 (in 22 of the 20 nm x 20 nm station grids). The number of stations at which at least one crab was observed in a given year ranges from 0 (in 1975) to 14 (in 2000 and 2013) over the period from 1975-present (Figure 5).

Observed survey biomass estimates for males $\geq 120 \mathrm{~mm}$ are used in the Tier 4 assessment as an estimate of mature male biomass and to estimate the $\mathrm{B}_{\text {MSY }}$ proxy, MMB at mating and in fitting the 3 -yr running average and the random effects model.

Historical survey data are available from 1975 to the present (Tables 6 and 7), and survey data analyses were standardized in 1980 (Stauffer, 2004). Male and female abundance varies widely over the history of the survey time series and uncertainty around area-swept estimates of abundance are large due to relatively low sample sizes (Table 7). Male crabs were observed at 9 of 35 stations in the Pribilof District during the 2015 NMFS survey (Figure 6); female crabs were observed at 5 (Figure 7). Two (possibly three) cohorts can be seen moving through the length frequencies over time (Figures 8 and 9). Numbers at length vary dramatically from year to year, but the cohorts can nonetheless also be discerned in these data (Figure 10 and Figure 11).

The centers of distribution for both males and females have moved within a 40 nm by 40 nm region around St. Paul Island. The center of the red king crab distribution moved to within 20 nm of the northeast side of St. Paul Island as the population abundance increased in the 1980's and remained in that region until the 1990's. Since then, the centers of distribution have been located closer to St. Paul Island the exception of 2000-2003 located towards the north east.

Survey abundance for males $\geq 105 \mathrm{~mm}$ declined from 3,662,609 in 2015 to 1,807,323 in 2016 and again in 2017 to $1,158,383$ (Table 6). Female biomass (all sizes) declined from 3,859 t in 2015 to $1,898 \mathrm{t}$ in 2016 and declined further in 2017 to 505 t . Survey biomass for males $\geq 120 \mathrm{~mm}$ declined from $15,173 \mathrm{t}$ in 2015 to $4,150 \mathrm{t}$ in 2016 and declined further in 2017 to $3,658 \mathrm{t}$ (Table 8).

## 3. Analytical approaches

### 3.1 History of modeling

An inverse-variance weighted 3-year running average of male biomass ( $\geq 120 \mathrm{~mm}$ ) based on densities estimated from the NMFS summer trawl survey has been used in recent years to set allowable catches. The natural mortality rate has been used as a proxy for the fishing mortality at which maximum sustainable yield occurs ( $\mathrm{F}_{\mathrm{MSY}}$ ) and target biomasses are set by identifying a range of years over which the stock was thought to be near $\mathrm{B}_{\mathrm{MSY}}$ (i.e. a tier 4 control rule).

In 2017, biomass and derived management quantities are estimated by a 3-yr running-average method and a random effects method. The Tier 4 harvest control rule (HCR) is applied to the running-average and random effects estimates of mature male biomass ( $\geq 120 \mathrm{~mm}$ ). The current year biomass estimate was projected forward to February 15 for use in the OFL control rule to estimate the OFL and ABC. The B BSY proxy for both the $3-\mathrm{yr}$ running average and the random effects model was estimated as the average of the 1991/92 to 2016/17 observed survey data projected forward to February 15, removing the observed catch.

### 3.2 Model descriptions

### 3.2.1. Running average

A 3 year running average of male biomass ( $\geq 120 \mathrm{~mm}$ ) at survey time was calculated using the weighted average with weights being the inverse of the variance,

$$
\begin{equation*}
B W R A_{t}=\frac{\sum_{t-1}^{t+1} \frac{M M B_{t}}{\sigma_{t}^{2}}}{\sum_{t-1}^{t+1} \frac{1}{\sigma_{t}^{2}}} \tag{4}
\end{equation*}
$$

Where,

$$
\begin{array}{cl}
M M B_{t} & \text { Estimated male biomass }(\geq 120 \mathrm{~mm}) \text { from the survey data } \\
\sigma_{t}^{2} & \text { The variance associated with the estimate of MMB in year } \mathrm{t}
\end{array}
$$

$w_{t}$ is calculated as the variance of the $\log$ (biomass) using the CVs of the estimates of MMB from the survey provided by the Kodiak lab:

$$
\begin{equation*}
w_{t}=\ln \left(\left(C V_{t}^{M M B}\right)^{2}+1\right) \tag{5}
\end{equation*}
$$

Where,

## $C V_{t}^{M M B} \quad$ Coefficient of variation associated with the estimate of

 MMB at time $t$
### 3.2.2 Random Effects Model

A random effects model was fit to the survey male biomass ( $\geq 120 \mathrm{~mm}$ ) for estimation of current biomass, MMB at mating, OFL and ABC (Model developed for use in NPFMC groundfish assessments). The model uses the CVs as calculated for the $3-y r$ running average. The random effects model was fit to the $\log$ of survey biomass at the time of the survey. The likelihood equation for the random effects model is,

$$
\sum_{i=1}^{y r s}\left\{0.5\left(\log \left(2 \pi \sigma_{i}^{2}\right)+\left(\frac{\left(\widehat{B}_{i}-B_{i}\right)^{2}}{\sigma_{i}^{2}}\right)\right)\right\}+\sum_{t=2}^{y r s}\left\{0.5\left(\log \left(2 \pi \sigma_{p}^{2}\right)+\left(\frac{\left(\widehat{B}_{t}-\widehat{B}_{t-1}\right)^{2}}{\sigma_{p}^{2}}\right)\right)\right\}
$$

Where,
$B_{\mathrm{i}}$ is the log of observed biomass in year i ,
$\widehat{B_{l}}$ is the model estimated log biomass in year t ,
$\sigma_{i}^{2}$ is the variance of observed log biomass in year i ,
$\sigma_{p}^{2}$ is the variance of the deviations in log survey biomass between years (i.e. process error variance), $\sigma_{p}^{2}$ was estimated as $e^{(2 \lambda)}$, where $\lambda$ is a parameter estimated in the random effects model and,

Yrs is the number of years of survey biomass values.
In the case where the random effects model does not converge due to high observation errors, an estimate of the process error is necessary to use as a prior or to fix in the model (P. Spencer pers. comm., Figure 15). A simple exponential model can be used to estimate the ratio of observation error to process error in a time series,
$\hat{z}_{t}=\alpha y_{t}+\alpha(1-\alpha) y_{t-1}+\alpha(1-\alpha)^{2} y_{t-2}+\alpha(1-\alpha)^{3} y_{t-3}+\cdots$,
Where,
$\hat{z}_{0}$ is set equal to $y_{0}$, the log of observed biomass in the first year,
$y_{t}$ is the log of observed biomass in year t and,
$\alpha$ is the parameter estimated in the model which ranges from 0 to 1 .
An estimate of the ratio of observation error $\left(\sigma_{o}^{2}\right)$ to process error $\left(\sigma_{p}^{2}\right)$ (log scale) is,

$$
\frac{\sigma_{o}^{2}}{\sigma_{p}^{2}}=\frac{(1-\alpha)}{\alpha^{2}}
$$

An estimate of $\lambda$ to use as a prior in the random effects model is,

$$
\lambda=0.5 \log \left(\sigma_{p}^{2}\right)
$$

The variance of $\alpha$ is an output of the arima function in R which was used to fit the simple exponential model. A bootstrap using the logit distribution on $\alpha$ was used to approximate the variance of $\lambda$ for use in the prior that is added to the likelihood in the random effects model,

$$
0.5 \frac{\left(\lambda-\lambda_{p}\right)^{2}}{\sigma_{\lambda}^{2}}
$$

Where,
$\lambda_{p}$ is the prior estimate of $\lambda$ from the simple exponential model
$\sigma_{\lambda}^{2}$ is the variance of $\lambda_{p}$ estimated from the parametric bootstrap.
The random effects model was run with $\lambda$ fixed at the value estimated from the simple exponential model and with $\lambda$ estimated adding the prior likelihood into the random effects model.

## 4. Model Selection and Evaluation

The running average method with a tier 4 HCR was selected in 2016 by the SSC as the model to determine the OFL and ABC based on concerns around different trends over the last decade between the integrated model and the running average and the lack of fit of the integrated model to survey abundance data. Four assessment methods are presented here for comparison: a running average with a tier 4 HCR , a random effects model with fixed $\lambda$, and a random effects model with a prior likelihood component added for $\lambda$.

### 5.0 Results

### 5.1 Tier 4

Survey mature male biomass ( $\geq 120 \mathrm{~mm}$ ) declined from 4,150 t in 2016 to $3,658 \mathrm{t}$ in 2017. The 3 - yr running average estimate of mature male biomass ( $\geq 120 \mathrm{~mm}$ ) was $3,888 \mathrm{t}$ in 2017 at the survey time, while the random effects model with process error fixed estimate was $4,163 \mathrm{t}$ (Table 8 and Figure 16). The simple exponential model estimated $\alpha=0.705$ with a standard deviation of 0.134 , which results in $\sigma_{p}^{2}=0.643$ and a $\mathrm{CV}=2.24$ (estimated from bootstrap). When process error is estimated with a prior in the random effects model with a $\mathrm{CV}=2.24$, the 2017 biomass estimate was estimated at $4,307 \mathrm{t}$. When process error is estimated with a prior in the random effects model with a CV $=4.0$, the 2017 biomass estimate was $4,633 \mathrm{t}$ and results in more smoothing of the estimates (Figure 16). The random effects model was also fit with a CV on the prior of 5.0 which resulted in the model not converging. The random effects model did not converge when trying to fit female biomass due to high observed variances similar to male biomass. The increase in CV in the prior on $\lambda$ results in lower process error and a smoother fit to biomass. The parameters and process error for the random effects models were,

| Random effects <br> Model | $\lambda$ | $\sigma_{p}^{2}$ | CV |
| :--- | :---: | :--- | :--- |
| $\lambda$ fixed | -0.221 | 0.643 | NA |
| with prior on $\lambda$ | -0.364 | 0.483 | 2.24 |
| with prior on $\lambda$ | -0.640 | 0.278 | 4 |

The simple exponential model fit to female mature biomass ( $\geq 90 \mathrm{~mm}$ ) estimated process error at 0.280 , which is lower than the process error estimated at 0.643 for the mature male biomass ( $\geq 120 \mathrm{~mm}$ ), however, similar to process error estimated in the random effects model ( 0.278 ) with prior on $\lambda=-0.221$ and $\mathrm{CV}=4$.

MMB at mating on February 15, 2017 (2016/17 crab year) was estimated at 3,681 tor the observed survey, $6,445 \mathrm{t}$ for the $3-\mathrm{yr}$ weighted average, $4,683 \mathrm{t}$ for the random effects model fixed process error, $4,788 \mathrm{t}$ for the random effects model $\mathrm{cv}=2.24$ and $4,961 \mathrm{t}$ for the random effects model $\mathrm{cv}=4.0$ (Table 9 and Figure 17). The estimation of process error in the random effects model with a $\mathrm{cv}=4.0$ results in a smoother fit to biomass than the 3 year running average or the random effects models with lower cv or fixed process error. The 3 -yr running average biomass estimate in 2016 is the weighted average of survey biomass in 2015, 2016 and 2017. The high survey biomass in 2015 results in a larger estimated biomass in 2016 (and the projected February 15, 2017 biomass) than for the random effects models which take into account the whole time series. The use of the 3 -yr running average can be thought of as imposing a prior on smoothness by using 3 biomass values for each estimate. Using more biomass values for the average would result in a smoother fit to the data as well as using the random effects model with a weaker prior. The CVs of the survey biomass range from 0.36 to 1.0 with an average of 0.67 .

## 6. Calculation of reference points

### 6.1 Tier 4 OFL and $B_{M S Y}$

Natural mortality was used as a proxy for $\mathrm{F}_{\text {MSY }}$ and a proxy for $\mathrm{B}_{\text {MSY }}$ was calculated by averaging the biomass of a predetermined period of time thought to represent the time when the stock was at $\mathrm{B}_{\text {MSY }}$ in the tier 4 HCR. The OFL was calculated by applying a fishing mortality determined by equation 4 to the mature male biomass at the time of fishing.

$$
F_{O F L}= \begin{cases}\text { Bycatch only } & \text { if } \frac{B_{\text {cur }}}{B_{M S Y \text { proxy }}} \leq \beta  \tag{4}\\ \frac{\gamma M\left(\frac{B_{\text {cur }}}{B_{M S Y} \text { proxy }}-\alpha\right)}{1-\alpha} & \text { if } \beta<\frac{B_{\text {cur }}}{B_{M S Y \text { proxy }}}<1 \\ \gamma M & \text { if } B_{\text {cur }}>B_{M S Y \text { proxy }}\end{cases}
$$

Where,

| $B_{\text {cur }}$ | Estimated mature male biomass projected to time of mating fishing at the OFL |
| :---: | :--- |
| $B_{M S Y}$ proxy | Average mature male biomass over the years 1991-present |
| $M$ | Natural mortality |
| $\alpha$ | Determines the slope of the descending limb of the HCR (0.05) |
| $\beta$ | Fraction of B $_{\text {MSY proxy }}$ below which directed fishing mortality is zero (here set to |
|  | $0.25)$ |

### 6.3 Acceptable biological catches

An acceptable biological catch (ABC) was estimated below the OFL by a proportion based a predetermined probability that the ABC would exceed the $\mathrm{OFL}\left(\mathrm{P}^{*}\right)$. Currently, $\mathrm{P}^{*}$ is set at 0.49 and represents a proportion of the OFL distribution that accounts for within assessment uncertainty $\left(\sigma_{w}\right)$ in the OFL to establish the maximum permissible $\mathrm{ABC}\left(\mathrm{ABC}_{\text {max }}\right)$. Any additional uncertainty outside of the assessment methods ( $\sigma_{b}$ ) will be considered as a recommended ABC below $\mathrm{ABC}_{\text {max }}$. Additional uncertainty will be included in the application of the ABC by adding the uncertainty components as $\sigma_{\text {total }}=\sqrt{\sigma_{b}^{2}+\sigma_{w}^{2}}$.

### 6.4 Specification of the distributions of the OFL used in the ABC

A distribution for the OFL associated with estimates of MMB from the running average method was constructed by bootstrapping values of $\mathrm{MMB}_{\text {mating }}$ (assuming that MMB is log-normally distributed) and calculating the OFL according to equation 4. Additional uncertainty ( $\sigma_{b}$ ) equal to 0.3 was added when bootstrapping values of MMB while calculating the distribution for the OFL for the tier 4 HCR. The posterior distribution for the OFL generated from the integrated assessment was used for determining the ABC.

### 6.6 Tier 4 Reference points and OFL

$\mathrm{B}_{\text {MSY }}$ was estimated at $5,502 \mathrm{t}$ using observed male survey biomass ( $\geq 120 \mathrm{~mm}$ ) from 1991/92 to 2016/17. Projected MMB for 2017/18 (on February 15, 2018 removing the OFL) calculated from the 3-year running average was $3,139 \mathrm{t}$ ( $57 \%$ of $\mathrm{B}_{\text {MSY }}$ ). Bmsy for the random effects models was estimated from model output from 1991/92 to 2016/17. The random effects model (RE) with fixed process error estimated projected MMB for 2017/18 at $3,274 \mathrm{t}\left(69 \%\right.$ of $\mathrm{B}_{\mathrm{MSY}}=4,711 \mathrm{t}$ ). The RE with $\mathrm{CV}=2.24$ estimated 2017/18 MMB at $3,364 \mathrm{t}\left(73 \%\right.$ of $\left.\mathrm{B}_{\mathrm{MSY}}=4,604 \mathrm{t}\right)$ and the RE with $\mathrm{CV}=4.0$ at $3,563 \mathrm{t}\left(67 \%\right.$ of $\left.\mathrm{B}_{\text {MSY }}=4,397 \mathrm{t}\right)$. The 2017/18 OFL for the 3 -yr weighted average was 330 t , from the random effects model (RE) with fixed process error at 442 t , the RE with $\mathrm{CV}=2.24$ at 482 t and the RE with $\mathrm{CV}=4.0$ at 573 t (see Table in item 6 of the executive summary).

### 6.7 Recommended ABCs

The ABC estimated using a $p^{*}$ of 0.49 with an additional sigma of 0.30 was 319 t for the 3 -yr running average, 428 t for the random effects model (RE) with fixed process error, 467 t for the RE with $\mathrm{CV}=2.24$ and 554 t for the RE with $\mathrm{CV}=4.0$. The ABC with a $25 \%$ buffer ( $\mathrm{ABC}=\mathrm{OFL} * 0.75$ ) (recommended by the CPT and SSC in 2015) was 248 t for the 3 -yr running average, 332 t for the random effects model (RE) with fixed process error, 362 t for the RE with $\mathrm{CV}=2.24$ and 429 t for the RE with $\mathrm{CV}=4.0$ (see Table in item 6 of the executive summary).

### 6.8 Variables related to scientific uncertainty in the OFL probability distribution

Uncertainty in estimates of stock size and OFL for Pribilof Islands red king crab was relatively high due to small sample sizes. The coefficient of variation for the estimate of mature male biomass for 2017 was 0.65 and has ranged between 0.36 and 0.92 since the 1991 peak in numbers. These CVs were calculated by assuming the data are Poisson distributed, but the data are overdispersed. Using a negative binomial (or other distribution that can allow for overdispersion) would increase the CVs. Growth and survey selectivity were estimated within the integrated assessment (and therefore uncertainty in both processes is accounted for in the posterior distributions), but maturity, survey catchability, fishery selectivity, and natural mortality were fixed. $\mathrm{F}_{\text {MSY }}$ was assumed to be equal to natural mortality and $\mathrm{B}_{\text {MSY }}$ was somewhat arbitrarily set to the average MMB over a predetermined range of years for tier 4 HCRs; both of which were assumptions that had a direct impact on the calculated OFL. Sources of mortality from discard in the crab pot fishery and the fixed gear fishery were not included in the integrated assessment because of a lack of length data to apportion removals correctly. Including these sources of mortality may alter the estimated MMB.

### 6.9 Author Recommendation

In the foreseeable future, low sample size will be a problem for the Pribilof Island red king crab, so extra precaution should be taken given the uncertainty associated with MMB estimates. In this respect, the tier 4 HCR is more precautionary in that it sets a higher MSST and a lower $\mathrm{F}_{\text {OFL, }}$ OFL, and ABC for a given MMB (Turnock, et al. 2016). If there is a particularly high estimate of MMB from the survey (often associated with high variance-see 2015 for an example), the biomass and OFL can be higher for the 3 -yr running average than the random effects models. The random effects model can be useful in these years because it smooths over fluctuations in estimates of biomass and numbers, which often appear to be the
result of measurement error The authors recommendation is to use the random effects model with $\mathrm{CV}=2.24$ in the prior on process error as this results in a more smooth fit to biomass and would be less influenced by fluctuations in biomass than the 3 -yr running average model. The $\mathrm{CV}=2.24$ is estimated from the variance of the parameter estimated from the simple exponential model while the $\mathrm{CV}=4.0$ is arbitrary and was used as a sensitivity.

Females and males experienced similar increases in abundance in the early 1990s, and only in recent years did trends in their abundances deviate from previously correlated trajectories. This suggests that some population process (e.g. natural mortality or catchability) has changed for males or females, but it is difficult to say if the change in trends was a result of a population process for females or for males (or both) changing. It is generally inadvisable to invoke time-varying population processes within an assessment for the sake of improving fits without a hypothesis behind the changes and data to corroborate it.

## 7. Data gaps and research priorities

The largest data gap is the number of observations from which the population size and biomass is extrapolated. Catch-at-length data for the trawl fishery would allow trawl fishery selectivity to be estimated and discard mortality specific to PIRKC to be incorporated into the integrated model. Simulation studies designed to prioritize research on population processes for which additional information would be beneficial in achieving more accurate estimates of management quantities could be useful for this stock (e.g. Szuwalski and Punt, 2012). Research on the probability of molting at length for males would allow the use of data specific to PIRKC in specifying molting probability in the assessment. Research aimed at the catchability and availability of PIRKC may shed some light on divergent changes in abundance in recent years.

## 8. Ecosystem Considerations

The impact of a directed fishery for Pribilof Islands red king crab on the population of Pribilof island blue king crab will likely continue to be the largest ecosystem consideration facing this fishery and preclude the possibility of a directed fishery for red king crab. Linking changes in productivity as seen in the 1980s with environmental influences is a potential avenue of research useful in selecting management strategies for crab stocks around the Pribilof Islands (e.g. Szuwalski and Punt, 2013a). It is possible that the large year class in the mid-1980s reflected changing environmental conditions, similar to proposed relationships between the Pacific Decadal Oscillation snow crab recruitment in the EBS (Szuwalski and Punt, 2013b). Ocean acidification also appears to have a large detrimental effect on red king crab (Long et al., 2012), which may impact the productivity of this stock in the future.

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## 11. Tables

Table 1. Total retained catches from directed fisheries for Pribilof Islands District red king crab (Bowers et al. 2011; D. Pengilly, ADF\&G, personal communications).

| Year | Catch (count) | Catch $(\mathrm{t})$ | Avg CPUE (legal crab count <br> pot $\left.^{-1}\right)$ |
| :--- | :--- | :--- | :--- |
| $1973 / 1974$ | 0 | 0 | 0 |
| $1974 / 1975$ | 0 | 0 | 0 |
| $1975 / 1976$ | 0 | 0 | 0 |
| $1976 / 1977$ | 0 | 0 | 0 |
| $1977 / 1978$ | 0 | 0 | 0 |
| $1978 / 1979$ | 0 | 0 | 0 |
| $1979 / 1980$ | 0 | 0 | 0 |
| $1980 / 1981$ | 0 | 0 | 0 |
| $1981 / 1982$ | 0 | 0 | 0 |
| $1982 / 1983$ | 0 | 0 | 0 |
| $1983 / 1984$ | 0 | 0 | 0 |
| $1984 / 1985$ | 0 | 0 | 0 |
| $1985 / 1986$ | 0 | 0 | 0 |
| $1986 / 1987$ | 0 | 0 | 0 |
| $1987 / 1988$ | 0 | 0 | 0 |
| $1988 / 1989$ | 0 | 0 | 0 |
| $1989 / 1990$ | 0 | 0 | 0 |
| $1990 / 1991$ | 0 | 0 | 0 |
| $1991 / 1992$ | 0 | 0 | 0 |
| $1992 / 1993$ | 0 | 0 | 0 |
| $1993 / 1994$ | 380,286 | 1183.02 | 11 |
| $1994 / 1995$ | 167,520 | 607.34 | 6 |
| $1995 / 1996$ | 110,834 | 407.32 | 3 |
| $1996 / 1997$ | 25,383 | 90.87 | $<1$ |
| $1997 / 1998$ | 90,641 | 343.29 | 3 |
| $1998 / 1999$ | 68,129 | 246.91 | 3 |
| $1999 / 2000$ | 0 | 0 | 0 |
| to | 0 |  |  |
| $2016 / 2017$ |  |  |  |

Table 2. Fishing effort during Pribilof Islands District commercial red king crab fisheries, (Bowers et al. 2011).

| Season | Number of <br> Vessels | Number of <br> Landings | Number of Pots <br> Registered | Number of Pots <br> Pulled |
| :--- | :---: | :---: | :---: | :---: |
| 1993 | 112 | 135 | 4,860 | 35,942 |
| 1994 | 104 | 121 | 4,675 | 28,976 |
| 1995 | 117 | 151 | 5,400 | 34,885 |
| 1996 | 66 | 90 | 2,730 | 29,411 |
| 1997 | 53 | 110 | 2,230 | 28,458 |
| 1998 | 57 | 57 | 2,398 | 23,381 |
| $1999-2016 / 17$ |  |  | Fishery Closed |  |

Table 3. Non-retained total catch mortalities from directed and non-directed fisheries for Pribilof Islands District red king crab. Handling mortalities (pot and hook/line $=0.5$, trawl $=0.8$ ) were applied to the catches. (Bowers et al. 2011; D. Pengilly, ADF\&G; J. Mondragon, NMFS). **From 2009/10 forward the calculation of bycatch uses the AKRO Catch Accounting System with data reported from State of Alaska reporting areas that encompass the Pribilof Islands red king crab district.

| Year | Crab pot fisheries |  |  | Groundfish fisheries |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | Legal male <br> (t) | Sublegal male | Female (t) | All fixed (t) | All trawl <br> (t) |
| 1991/1992 |  |  |  | 0.48 | 45.71 |
| 1992/1993 |  |  |  | 16.12 | 175.93 |
| 1993/1994 |  |  |  | 0.60 | 131.87 |
| 1994/1995 |  |  |  | 0.27 | 15.29 |
| 1995/1996 |  |  |  | 4.81 | 6.32 |
| 1996/1997 |  |  |  | 1.78 | 2.27 |
| 1997/1998 |  |  |  | 4.46 | 7.64 |
| 1998/1999 | 0.00 | 0.91 | 11.34 | 10.40 | 6.82 |
| 1999/2000 | 1.36 | 0.00 | 8.16 | 12.40 | 3.13 |
| 2000/2001 | 0.00 | 0.00 | 0.00 | 2.08 | 4.71 |
| 2001/2002 | 0.00 | 0.00 | 0.00 | 2.71 | 6.81 |
| 2002/2003 | 0.00 | 0.00 | 0.00 | 0.50 | 9.11 |
| 2003/2004 | 0.00 | 0.00 | 0.00 | 0.77 | 9.83 |
| 2004/2005 | 0.00 | 0.00 | 0.00 | 3.17 | 3.52 |
| 2005/2006 | 0.00 | 0.18 | 1.81 | 4.53 | 24.72 |
| 2006/2007 | 1.36 | 0.14 | 0.91 | 6.99 | 21.35 |
| 2007/2008 | 0.91 | 0.05 | 0.09 | 1.92 | 2.76 |
| 2008/2009 | 0.09 | 0.00 | 0.00 | 1.64 | 6.94 |
| **2009/2010 | 0.00 | 0.00 | 0.00 | 0.19 | 1.05 |
| 2010/2011 | 0.00 | 0.00 | 0.00 | 0.45 | 6.25 |
| 2011/2012 | 0.00 | 0.00 | 0.00 | 0.35 | 4.47 |
| 2012/2013 | 0.00 | 0.00 | 0.00 | 0.12 | 12.98 |
| 2013/2014 | 0.00 | 0.00 | 0.00 | 0.25 | 1.99 |
| 2014/2015 | 0.00 | 0.00 | 0.00 | 0.73 | 1.03 |
| 2015/2016 | 0.167 | 0.00 | 0.053 | 0.03 | 0.07 |
| 2016/2017 | 0.00 | 0.00 | 0.00 | 0.06 | 0.43 |

Table 4. Percent by weight of the Pribilof Islands red king crab bycatch using the new 2014 calculation of bycatch using AKRO Catch Accounting System with data reported from State of Alaska reporting areas that encompass the Pribilof Islands red king crab district.

| Crab fishing season | hook and line | non-pelagic trawl | pot | pelagic trawl |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | \% | \% | \% | \% | TOTAL <br> (\# crabs) |
| 2009/10 | 19 | 77 | 3 | 1 | 813 |
| 2010/11 | 10 | 90 | <1 | <1 | 3,026 |
| 2011/12 | 10 | 89 | 1 |  | 2,167 |
| 2012/13 | 1 | 99 | <1 |  | 4,517 |
| 2013/14 | 11 | 89 | 0 | 0 | 640 |
| 2014/2015 | 53 | 47 | 0 | 0 | 1,439 |
| 2015/16 | 40 | 60 | 0 | 0 | 382 |
| 2016/17 | 19 | 81 | <1 | 0 | 857 |

Table 5. Total male bycatch ( t ), Total bycatch ( t ) and total catch ( t ) with mortality applied for Pribilof red king crab from 1991 to 2016/17.

| Year | Total male bycatch ( t ) | total bycatch (t) | Total catch (t) |
| :---: | :---: | :---: | :---: |
| 1991/1992 | 46.19 | 46.19 | 46.19 |
| 1992/1993 | 192.05 | 192.05 | 192.05 |
| 1993/1994 | 132.47 | 132.47 | 1315.49 |
| 1994/1995 | 15.56 | 15.56 | 622.9 |
| 1995/1996 | 11.13 | 11.13 | 418.45 |
| 1996/1997 | 4.05 | 4.05 | 94.92 |
| 1997/1998 | 12.1 | 12.1 | 355.39 |
| 1998/1999 | 18.13 | 29.47 | 265.04 |
| 1999/2000 | 16.89 | 25.05 | 16.89 |
| 2000/2001 | 6.79 | 6.79 | 6.79 |
| 2001/2002 | 9.52 | 9.52 | 9.52 |
| 2002/2003 | 9.61 | 9.61 | 9.61 |
| 2003/2004 | 10.6 | 10.6 | 10.6 |
| 2004/2005 | 6.69 | 6.69 | 6.69 |
| 2005/2006 | 29.43 | 31.24 | 29.43 |
| 2006/2007 | 29.84 | 30.75 | 29.84 |
| 2007/2008 | 5.64 | 5.73 | 5.64 |
| 2008/2009 | 8.67 | 8.67 | 8.67 |
| **2009/2010 | 1.24 | 1.24 | 1.24 |
| **2010/2011 | 6.7 | 6.7 | 6.7 |
| **2011/2012 | 4.82 | 4.82 | 4.82 |
| **2012/2013 | 13.1 | 13.1 | 13.1 |
| 2013/2014 | 2.24 | 2.24 | 2.24 |
| 2014/2015 | 1.76 | 1.76 | 1.76 |
| 2015/2016 | 0.32 | 0.32 | 0.32 |
| 2016/2017 | 0.49 | 0.49 | 0.49 |

Table 6. Pribilof Islands District red king crab male abundance, male biomass ( $\geq 105 \mathrm{~mm}$ ), and female biomass estimated based on the NMFS annual EBS bottom trawl survey with no running average.

| Year | Total Male Abundance | Males $\geq 105 \mathrm{~mm}$ at survey <br> (t) | Total females at survey <br> (t) |
| :---: | :---: | :---: | :---: |
| 1975/1976 | 0 | 0 | 11 |
| 1976/1977 | 50778 | 165 | 102 |
| 1977/1978 | 228477 | 213 | 148 |
| 1978/1979 | 367140 | 1250 | 52 |
| 1979/1980 | 279707 | 556 | 93 |
| 1980/1981 | 400513 | 1269 | 262 |
| 1981/1982 | 80928 | 312 | 35 |
| 1982/1983 | 352166 | 1482 | 933 |
| 1983/1984 | 144735 | 553 | 309 |
| 1984/1985 | 64331 | 317 | 112 |
| 1985/1986 | 16823 | 61 | 0 |
| 1986/1987 | 38419 | 138 | 79 |
| 1987/1988 | 18611 | 54 | 31 |
| 1988/1989 | 1963775 | 525 | 836 |
| 1989/1990 | 1844076 | 1720 | 2251 |
| 1990/1991 | 6354076 | 8019 | 2723 |
| 1991/1992 | 3100675 | 4979 | 5032 |
| 1992/1993 | 1861538 | 3361 | 3432 |
| 1993/1994 | 3787997 | 10156 | 6478 |
| 1994/1995 | 3669755 | 9538 | 3964 |
| 1995/1996 | 7693368 | 18417 | 5149 |
| 1996/1997 | 683611 | 2378 | 2007 |
| 1997/1998 | 3155556 | 7254 | 1962 |
| 1998/1999 | 1192015 | 2655 | 1719 |
| 1999/2000 | 9102898 | 5751 | 5418 |
| 2000/2001 | 1674067 | 4477 | 995 |
| 2001/2002 | 6157584 | 10186 | 5774 |
| 2002/2003 | 1910263 | 7037 | 787 |
| 2003/2004 | 1506201 | 5373 | 2269 |
| 2004/2005 | 2196795 | 3622 | 1292 |
| 2005/2006 | 302997 | 1262 | 3118 |
| 2006/2007 | 1459278 | 7097 | 2183 |
| 2007/2008 | 1883489 | 5371 | 1811 |
| 2008/2009 | 1721467 | 5603 | 3017 |
| 2009/2010 | 923133 | 25645 | 826 |
| 2010/2011 | 927825 | 4449 | 840 |
| 2011/2012 | 1052228 | 3878 | 817 |
| 2012/2013 | 1609444 | 4753 | 663 |
| 2013/2014 | 1831377 | 7854 | 169 |
| 2014/2015 | 3036807 | 12129 | 1093 |
| 2015/2016 | 3662609 | 15252 | 3859 |
| 2016/2017 | 1807323 | 4619 | 1898 |

Table 7. Pribilof Islands District male red king crab abundance CV and total male and female biomass CVs estimated from the NMFS annual EBS bottom trawl survey data.

| Year | Total Male Abundance CV | Males $\geq 105 \mathrm{~mm}$ at survey CV | Total female at survey CV |
| :---: | :---: | :---: | :---: |
| 1975/1976 | 0.00 | 0.00 | 1.00 |
| 1976/1977 | 1.00 | 1.00 | 0.78 |
| 1977/1978 | 1.00 | 1.00 | 1.00 |
| 1978/1979 | 0.83 | 0.83 | 1.00 |
| 1979/1980 | 0.49 | 0.52 | 1.00 |
| 1980/1981 | 0.40 | 0.38 | 0.73 |
| 1981/1982 | 0.57 | 0.58 | 1.00 |
| 1982/1983 | 0.70 | 0.70 | 0.77 |
| 1983/1984 | 0.64 | 0.55 | 0.48 |
| 1984/1985 | 0.48 | 0.55 | 0.57 |
| 1985/1986 | 1.00 | 1.00 | 0.00 |
| 1986/1987 | 0.70 | 0.70 | 1.00 |
| 1987/1988 | 1.00 | 1.00 | 1.00 |
| 1988/1989 | 0.74 | 0.56 | 0.67 |
| 1989/1990 | 0.69 | 0.77 | 0.68 |
| 1990/1991 | 0.87 | 0.89 | 0.72 |
| 1991/1992 | 0.78 | 0.80 | 0.60 |
| 1992/1993 | 0.68 | 0.61 | 0.91 |
| 1993/1994 | 0.93 | 0.92 | 0.72 |
| 1994/1995 | 0.81 | 0.78 | 0.88 |
| 1995/1996 | 0.57 | 0.60 | 0.66 |
| 1996/1997 | 0.37 | 0.37 | 0.74 |
| 1997/1998 | 0.56 | 0.54 | 0.57 |
| 1998/1999 | 0.42 | 0.37 | 0.77 |
| 1999/2000 | 0.79 | 0.58 | 0.82 |
| 2000/2001 | 0.40 | 0.38 | 0.63 |
| 2001/2002 | 0.90 | 0.83 | 0.99 |
| 2002/2003 | 0.67 | 0.69 | 0.52 |
| 2003/2004 | 0.66 | 0.66 | 0.91 |
| 2004/2005 | 0.83 | 0.60 | 0.53 |
| 2005/2006 | 0.53 | 0.57 | 0.78 |
| 2006/2007 | 0.39 | 0.38 | 0.61 |
| 2007/2008 | 0.61 | 0.51 | 0.77 |
| 2008/2009 | 0.52 | 0.50 | 0.68 |
| 2009/2010 | 0.70 | 0.64 | 0.53 |
| 2010/2011 | 0.45 | 0.43 | 0.71 |
| 2011/2012 | 0.63 | 0.64 | 0.73 |
| 2012/2013 | 0.65 | 0.59 | 0.55 |
| 2013/2014 | 0.58 | 0.61 | 0.58 |
| 2014/2015 | 0.71 | 0.78 | 0.94 |
| 2015/2016 | 0.72 | 0.74 | 0.96 |


| $2016 / 2017$ | 0.72 | 0.69 | 0.61 |
| :--- | :--- | :--- | :--- |
| $2017 / 2018$ | 0.58 | 0.64 | 0.56 |

Table 8. Estimates of survey male $\geq 120 \mathrm{~mm}$ biomass ( t ) at the time of the survey, 3-year running weighted average, the random effects model with $\lambda$ fixed at -0.221 , the random effects model with a prior on $\lambda$ with mean $=-$ 0.221 and $\mathrm{cv}=2.24$, the random effects model with a prior on $\lambda$ with mean $=-0.221$ and $\mathrm{cv}=4.0$, and the simple exponential smooth.

| Year | $\begin{gathered} \text { MB } \\ \text { GE120 } \end{gathered}$ | $\begin{gathered} \text { CV } \\ \text { MB } \\ \text { GE120 } \end{gathered}$ | 3-yr running avg | random effects fixed $\lambda$ | $\begin{gathered} \text { random } \\ \text { effects } \\ \text { prior } \lambda \text { cv } \\ 2.24 \end{gathered}$ | $\begin{gathered} \text { random } \\ \text { effects } \\ \text { prior } \lambda \mathrm{cv} \\ 4.0 \end{gathered}$ | Simple exponential smooth |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1976/1977 | 165 | 1.00 | NA | 206 | 221 | 261 | 165 |
| 1977/1978 | 119 | 1.00 | 585 | 252 | 271 | 314 | 131 |
| 1978/1979 | 1,250 | 0.83 | 648 | 621 | 593 | 558 | 637 |
| 1979/1980 | 556 | 0.52 | 1,042 | 645 | 647 | 644 | 579 |
| 1980/1981 | 1,269 | 0.38 | 850 | 1,005 | 965 | 884 | 1,004 |
| 1981/1982 | 312 | 0.58 | 1,060 | 520 | 545 | 581 | 443 |
| 1982/1983 | 1,464 | 0.70 | 691 | 822 | 771 | 688 | 1,024 |
| 1983/1984 | 527 | 0.53 | 679 | 510 | 500 | 480 | 642 |
| 1984/1985 | 317 | 0.55 | 368 | 292 | 293 | 302 | 392 |
| 1985/1986 | 61 | 1.00 | 211 | 136 | 149 | 180 | 107 |
| 1986/1987 | 138 | 0.70 | 95 | 131 | 140 | 166 | 128 |
| 1987/1988 | 54 | 1.00 | 107 | 117 | 133 | 174 | 69 |
| 1988/1989 | 107 | 1.00 | 609 | 218 | 240 | 293 | 94 |
| 1989/1990 | 1,529 | 0.91 | 961 | 784 | 759 | 739 | 664 |
| 1990/1991 | 1,141 | 0.93 | 2,526 | 1,386 | 1,370 | 1,333 | 971 |
| 1991/1992 | 4,430 | 0.80 | 3,133 | 2,991 | 2,849 | 2,579 | 2,815 |
| 1992/1993 | 3,305 | 0.60 | 5,172 | 3,863 | 3,839 | 3,672 | 3,150 |
| 1993/1994 | 9,873 | 0.92 | 6,597 | 6,935 | 6,564 | 5,757 | 7,019 |
| 1994/1995 | 9,139 | 0.77 | 13,423 | 8,605 | 8,142 | 7,070 | 8,446 |
| 1995/1996 | 18,056 | 0.60 | 7,350 | 9,822 | 8,954 | 7,442 | 14,390 |
| 1996/1997 | 2,362 | 0.37 | 6,816 | 3,151 | 3,281 | 3,521 | 4,051 |
| 1997/1998 | 6,159 | 0.62 | 2,955 | 4,244 | 4,108 | 3,935 | 5,435 |
| 1998/1999 | 2,324 | 0.36 | 3,783 | 2,753 | 2,831 | 3,007 | 2,995 |
| 1999/2000 | 5,523 | 0.67 | 3,614 | 4,365 | 4,271 | 4,138 | 4,600 |
| 2000/2001 | 4,320 | 0.37 | 5,298 | 4,588 | 4,596 | 4,578 | 4,402 |
| 2001/2002 | 8,603 | 0.79 | 5,614 | 6,479 | 6,217 | 5,727 | 7,043 |
| 2002/2003 | 7,037 | 0.69 | 6,853 | 6,268 | 6,071 | 5,664 | 7,039 |
| 2003/2004 | 5,373 | 0.66 | 5,194 | 4,998 | 4,926 | 4,789 | 5,824 |
| 2004/2005 | 3,622 | 0.59 | 3,283 | 3,503 | 3,556 | 3,704 | 4,174 |
| 2005/2006 | 1,238 | 0.59 | 4,805 | 2,285 | 2,492 | 2,926 | 1,780 |
| 2006/2007 | 7,003 | 0.38 | 5,190 | 5,675 | 5,506 | 5,208 | 4,652 |
| 2007/2008 | 5,224 | 0.49 | 6,086 | 5,245 | 5,198 | 5,075 | 5,046 |
| 2008/2009 | 5,462 | 0.51 | 4,642 | 4,907 | 4,853 | 4,766 | 5,334 |
| 2009/2010 | 2,500 | 0.64 | 4,333 | 3,393 | 3,528 | 3,789 | 3,135 |
| 2010/2011 | 4,405 | 0.44 | 3,779 | 4,171 | 4,175 | 4,227 | 3,980 |
| 2011/2012 | 3,834 | 0.65 | 4,292 | 4,190 | 4,260 | 4,415 | 3,877 |
| 2012/2013 | 4,477 | 0.57 | 5,350 | 4,950 | 5,026 | 5,156 | 4,289 |
| 2013/2014 | 7,749 | 0.62 | 7,455 | 7,342 | 7,217 | 6,916 | 6,494 |
| 2014/2015 | 12,047 | 0.78 | 11,235 | 9,786 | 9,324 | 8,414 | 10,017 |
| 2015/2016 | 15,173 | 0.74 | 10,218 | 9,872 | 9,306 | 8,314 | 13,403 |
| 2016/2017 | 4,150 | 0.70 | 7,267 | 5,281 | 5,399 | 5,594 | 5,890 |
| 2017/2018 | 3,658 | 0.65 | 3,888 | 4,163 | 4,307 | 4,633 | 4,205 |

Table 9. MMB at mating for survey males $\geq 120 \mathrm{~mm}$, the $3-\mathrm{yr}$ running average and the random effects model fit.

|  | Projected Biomass from survey time (y) to February 15 ( $\mathrm{y}+1)$ removing catch |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | Observed survey | $\begin{aligned} & \hline \text { 3-yr } \\ & \text { weighted } \\ & \text { average } \end{aligned}$ | Random <br> Effects fixed $=-0.221$ | Random <br> Effects CV = <br> 2.24 | Random Effects CV = 4.0 |
| 1976/1977 | 146 | NA | 182 | 196 | 232 |
| 1977/1978 | 105 | 519 | 223 | 241 | 279 |
| 1978/1979 | 1,108 | 575 | 551 | 526 | 495 |
| 1979/1980 | 493 | 924 | 572 | 574 | 571 |
| 1980/1981 | 1,125 | 754 | 891 | 856 | 784 |
| 1981/1982 | 277 | 940 | 461 | 484 | 516 |
| 1982/1983 | 1,298 | 613 | 729 | 684 | 610 |
| 1983/1984 | 467 | 602 | 452 | 443 | 426 |
| 1984/1985 | 281 | 326 | 259 | 260 | 268 |
| 1985/1986 | 55 | 187 | 120 | 132 | 160 |
| 1986/1987 | 122 | 84 | 116 | 124 | 147 |
| 1987/1988 | 48 | 95 | 104 | 118 | 154 |
| 1988/1989 | 95 | 540 | 193 | 213 | 260 |
| 1989/1990 | 1,357 | 852 | 696 | 673 | 655 |
| 1990/1991 | 1,012 | 2,240 | 1,229 | 1,215 | 1,182 |
| 1991/1992 | 3,929 | 2,779 | 2,653 | 2,527 | 2,287 |
| 1992/1993 | 2,739 | 4,395 | 3,234 | 3,213 | 3,065 |
| 1993/1994 | 7,441 | 4,536 | 4,835 | 4,506 | 3,790 |
| 1994/1995 | 7,482 | 11,282 | 7,009 | 6,599 | 5,648 |
| 1995/1996 | 15,596 | 6,101 | 8,293 | 7,523 | 6,182 |
| 1996/1997 | 2,000 | 5,950 | 2,700 | 2,815 | 3,028 |
| 1997/1998 | 5,107 | 2,266 | 3,409 | 3,288 | 3,135 |
| 1998/1999 | 1,796 | 3,091 | 2,176 | 2,246 | 2,402 |
| 1999/2000 | 4,881 | 3,189 | 3,854 | 3,771 | 3,653 |
| 2000/2001 | 3,825 | 4,692 | 4,062 | 4,070 | 4,053 |
| 2001/2002 | 7,621 | 4,970 | 5,737 | 5,505 | 5,070 |
| 2002/2003 | 6,232 | 6,068 | 5,549 | 5,375 | 5,014 |
| 2003/2004 | 4,755 | 4,596 | 4,423 | 4,358 | 4,237 |
| 2004/2005 | 3,206 | 2,905 | 3,100 | 3,147 | 3,279 |
| 2005/2006 | 1,069 | 4,232 | 1,997 | 2,181 | 2,565 |
| 2006/2007 | 6,181 | 4,573 | 5,004 | 4,854 | 4,590 |
| 2007/2008 | 4,627 | 5,392 | 4,646 | 4,605 | 4,496 |
| 2008/2009 | 4,836 | 4,108 | 4,343 | 4,296 | 4,218 |
| 2009/2010 | 2,216 | 3,841 | 3,008 | 3,128 | 3,359 |
| 2010/2011 | 3,900 | 3,345 | 3,692 | 3,697 | 3,742 |
| 2011/2012 | 3,396 | 3,801 | 3,711 | 3,774 | 3,911 |
| 2012/2013 | 3,958 | 4,732 | 4,378 | 4,445 | 4,560 |
| 2013/2014 | 6,871 | 6,610 | 6,510 | 6,399 | 6,132 |
| 2014/2015 | 10,683 | 9,963 | 8,677 | 8,268 | 7,461 |
| 2015/2016 | 13,457 | 9,062 | 8,755 | 8,253 | 7,373 |
| 2016/2017 | 3,681 | 6,445 | 4,683 | 4,788 | 4,961 |

## 12. Figures



Figure 1. Red king crab distribution.


Figure 2. King crab registration area Q (Bering Sea) showing the Pribilof District.


Figure 3. Historical harvests and GHLs for Pribilof Island blue (diamonds) and red king crab (triangles) (Bowers et al. 2011).


Figure 4. The shaded area shows the Pribilof Islands Habitat Conservation area.


Figure 5. Total number of observed crab (top) and the number of tows that reported observations of crab $($ female $=$ dashed line, male $=$ solid line $)$ from 1976-2017.


Figure 6. Male red king crab relative density by station in the Pribilof Island district in 2017. Bars represent the relative magnitude of the density calculated from the NMFS trawl survey.


Figure 7. Female red king crab relative density by station in the Pribilof Island district in 2017. Bars represent the relative magnitude of the density calculated from the NMFS trawl survey.


Figure 8. Observed length frequencies (proportions sum to 1.0 ) by 5 mm length classes of Pribilof Islands male red king crab (Paralithodes camtschaticus) from 1975 to 2017.


Figure 9. Observed length frequencies (proportions sum to 1.0 ) by 5 mm length classes of Pribilof Islands female red king crab (Paralithodes camtschaticus) from 1975 to 2017.


Figure 10. Observed numbers at length by 5 mm length classes of Pribilof Islands male red king crab (Paralithodes camtschaticus) from 1975 to 2017.


Figure 11. Observed numbers at length by 5 mm length classes of Pribilof Islands female red king crab (Paralithodes camtschaticus) from 1975 to 2017.


Figure 12. Modes of the length frequency distribution for males and females plotted for two time periods over which two cohorts were observed to move through the population. Growth per molt calculated from the modes from the length frequencies with fitted linear relationship (bottom).


Figure 13. Directed fishery retained catch.


Figure 14. Total bycatch for Pribilof red king crab.

## From Spencer presentation at Wakefield 2015

A simple exponential smoothing model can give information on the ratio of variances

$$
\hat{z}_{t}=(\alpha) y_{t}+(1-\alpha)\left[\alpha y_{t-1}+\alpha(1-\alpha) y_{t-2}+\alpha(1-\alpha)^{2} y_{t-3}+\ldots\right]
$$



Figure 15. Using a simple exponential smoothing model to estimate the variance ratio of observation error and process error.

## Pribilof Red King Crab



Figure 16. Mature male biomass $(\mathrm{t})(\geq 120 \mathrm{~mm})$ at the time of the survey. Lines are the fit for the 3 year weighted average, the random effects model with process error fixed ( 0.643 ), the random effects model with cv on prior of 2.24 , the random effects model with cv on prior of 4.0 and the simple exponential model.

## Pribilof Red King Crab



Figure 17. MMB at mating ( t ) for the 3 year weighted average, the random effects model with process error fixed, the random effects model with cv on prior of 2.24 and the random effects model with cv on prior of 4.0. Bmsy is the average of the survey biomass from 1991/92 to 2016/17. MSST is $50 \%$ of Bmsy.

# 2017 Stock Assessment and Fishery Evaluation Report for the Pribilof Islands Blue King Crab Fisheries of the Bering Sea and Aleutian Islands Regions 

William T. Stockhausen<br>20 September, 2017

## Contents

Executive Summary ..... 3
A. Summary of Major Changes: ..... 6

1. Management ..... 6
2. Input data ..... 6
3. Assessment methodology ..... 6
4. Assessment results ..... 6
B. Responses to SSC and CPT Comments ..... 7
C. Introduction ..... 9
5. Stock ..... 9
6. Distribution ..... 9
7. Stock structure ..... 9
8. Life History ..... 10
9. Management history ..... 11
D. Data ..... 12
10. Summary of new information ..... 12
11. Fishery data ..... 12
12. Survey data ..... 14
E. Analytic Approach ..... 15
13. History of modeling approaches ..... 15
14. Model Description ..... 16
15. Model Selection and Evaluation ..... 16
16. Results ..... 16
F. Calculation of the OFL ..... 16
17. Tier Level: ..... 16
18. Parameters and stock sizes ..... 18
19. OFL specification ..... 18
G. Calculation of the ABC ..... 20
20. Specification of the probability distribution of the OFL used in the ABC ..... 20
21. List of variables related to scientific uncertainty considered in the OFL probability distribution ..... 20
22. List of additional uncertainties considered for alternative $\sigma_{b}$ applications to the ABC ..... 20
23. Recommendations: ..... 21
H. Rebuilding Analyses ..... 21
I. Data Gaps and Research Priorities ..... 22
Literature Cited ..... 22
Tables ..... 26
Figures ..... 36
List of Tables
1 Management performance, all units in metric tons. The OFL is a total catch OFL for each year. ..... 4
2 Management performance, all units in the table are million pounds. ..... 4
3 Management performance, all units in metric tons. The OFL is a total catch OFL for each year. ..... 5
4 Management performance, all units in the table are million pounds. ..... 5
5 Basis for the OFL (Table 3 repeated). All units in metric tons. ..... 19
6 Basis for the OFL (Table 4 repeated). All units in millions lbs ..... 19
7 Management performance (Table). All units in metric tons. The OFL is a total catch OFL for each year. ..... 21
8 Management performance (Table 2 repeated). All units in the table are million pounds. ..... 21
9 Total retained catches from directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2011; D. Pengilly and J. Webb, ADFG, personal communications). ..... 26
10 Total bycatch (non-retained catch) from the directed and non-directed fisheries for Pribilof Islands District blue king crab. Crab fishery bycatch data is not available prior to 1996/1997 (Bowers et al. 2011; D. Pengilly ADFG). Gear-specific groundfish fishery data is not available prior to 1991/1992 (J. Mondragon, NMFS). ..... 27
11 Total bycatch (discard) mortality from directed and non-directed fisheries for Pribilof Islands District blue king crab. Gear-specific handling mortalities were applied to estimates of non-retained catch from Table 2 for fixed gear (i.e., pot and hook/line; 0.2) and trawl gear (0.8). ..... 28
12 Bycatch (in kg ) of PIBKC in the groundfish fisheries, by target type. ..... 29
13 Bycatch (in kg ) of PIBKC in the groundfish fisheries, by gear type. ..... 30
14 Summary of recent NMFS annual EBS bottom trawl surveys for the Pribilof Islands District blue king crab by stock component. ..... 31
15 Abundance time series for Pribilof Islands blue king crab from the NMFS annual EBS bottom trawl survey ..... 32
16 Biomass time series for Pribilof Islands blue king crab from the NMFS annual EBS bottom trawl survey. ..... 33
17 Smoothed mature male biomass (MMB) at the time of the survey for Pribilof Islands blue king crab using using the Random Effects Model. ..... 34
18 Estimates of mature male biomass (MMB) at the time of mating for Pribilof Islands blue king crab using: (1) the "raw" survey biomass time series and (2) the survey biomass time series smoothed using the Random Effects Model. Shaded rows signify averaging time period for $B_{M S Y} /$ MSST. The 2017/18 estimates are projected values (see Appendix C).

## List of Figures

1 Distribution of blue king crab, *Paralithodes platypus*, in Alaskan waters. . . . . . 36
2 Map of the ADFG King Crab Registration Area Q (Bering Sea), showing (among others) the Pribilof District, which constitutes the stock boundary for PIBKC. The figure also indicates the additional 20 nm strip (red dotted line) added in 2013 for calculating biomass and catch data in the Pribilof District.37
3 Historical harvests and Guideline Harvest Levels (GHLs) for Pribilof Islands red and blue king crab (from Bowers et al., 2011). ..... 38
4 The shaded area shows the Pribilof Islands Habitat Conservation Zone (PIHCZ). Trawl fishing is prohibited year-round in this zone (as of 1995), as is pot fishing for Pacific cod (as of 2015). Also shown is a portion of the NMFS annual EBS bottom trawl survey grid. ..... 39
5 Time series of survey abundance for females (immature, mature, and total). ..... 40
6 Time series of survey abundance for males in several categories (immature, mature, sublegal, legal and total). ..... 41
7 Time series of survey abundance for females (immature, mature, and total). ..... 42
8 Time series of survey biomass for males in several categories (immature, mature, sublegal, legal and total). ..... 43
$9 \quad$ Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from recent NMFS EBS bottom trawl surveys. ..... 44
10 Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islands blue king crab by 5 mm length bins. The top row shows the entire time series, the bottom shows the size compositions since 1995. ..... 45
11 Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from recent NMFS EBS bottom trawl surveys. ..... 46
12 Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islandsblue king crab by 5 mm length bins. The top row shows the entire time series, thebottom shows the size compositions since 1995.47
$13 \quad F_{O F L}$ Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below $\beta$ ( $=0.25$ ). ..... 48

## Executive Summary

1. Stock: Pribilof Islands blue king crab (PIBKC), Paralithodes platypus.
2. Catches: Retained catches have not occurred since 1998/1999. Bycatch has been relatively small in recent years. No bycatch mortality was observed in 2016/17 in the crab (e.g., Tanner crab, snow crab) fisheries that incidentally take PIBKC. Bycatch mortality for PIBKC in these
fisheries was 0.166 t ( 0.0004 million lbs) in $2015 / 16$, but this was the first non-zero bycatch mortality in other crab fisheries since 2010/11. Most bycatch mortality for PIBKC occurs in the BSAI groundfish fixed gear (pot and hook-and-line) fisheries (5-year average: 0.048 t ) and trawl fisheries (5-year average: 0.309 t). In $2016 / 17$, the estimated PIBKC bycatch mortality was 0.018 t in the groundfish fixed gear fisheries and 0.364 t in the groundfish trawl fisheries.
3. Stock biomass: Stock biomass decreased between the 1995 and 2008 surveys, and continues to fluctuate at low abundances in all size classes. Any short-term trends are questionable given the high uncertainty associated with recent survey results.
4. Recruitment: Recruitment indices are not well understood for Pribilof Islands blue king crab. Pre-recruits may not be well-assessed by the survey, but have remained consistently low in the past 10 years.
5. Management performance: The stock is below MSST and consequently is overfished. Overfishing did not occur. The following results are based on determining $B_{M S Y} / \mathrm{MSST}$ by averaging the MMB-at-mating time series estimated using the smoothed survey data from a random effects model; the current $(2017 / 18)$ MMB-at-mating is also based on the smoothed survey data. [Note: MSST changed substantially between $2013 / 14$ and 2014/15 as a result of changes to the NMFS EBS trawl survey dataset used to calculate the proxy $B_{M S Y}$. MSST has changed slightly since 2014/15 due to small differences in the random effects model results with the addition of each new year of survey data.]

Table 1: Management performance, all units in metric tons. The OFL is a total catch OFL for each year.

| Year | MSST | Biomass <br> $\mathbf{( M M B}_{\text {mating }}$ | TAC | Retained <br> Catch | Total Catch <br> Mortality | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2013 / 14$ | $2,001 \mathrm{~A}$ | 225 A | closed | 0 | 0.03 | 1.16 | 1.04 |
| $2014 / 15$ | $2,055 \mathrm{~A}$ | 344 A | closed | 0 | 0.07 | 1.16 | 0.87 |
| $2015 / 16$ | $2,058 \mathrm{~A}$ | 361 A | closed | 0 | 1.18 | 1.16 | 0.87 |
| $2016 / 17$ | $2,054 \mathrm{~A}$ | 232 A | closed | 0 | 0.38 | 1.16 | 0.87 |
| $2017 / 18$ | -- | 230 B | -- | -- | -- | 1.16 | 0.87 |

Notes:
A - Based on data available to the Crab Plan Team at the time of the assessment following the end of the crab fishing year.

B - Based on data available to the Crab Plan Team at the time of the assessment for the crab fishing year.
Table 2: Management performance, all units in the table are million pounds.

| Year | MSST | Biomass <br> $\left(\mathbf{M M B}_{\text {mating }}\right.$ | TAC | Retained <br> Catch | Total Catch <br> Mortality | OFL | ABC |
| :---: | :---: | ---: | :---: | :---: | :---: | :---: | :---: |
| $2013 / 14$ | 4.411 A | 0.496 A | closed | 0 | 0.0001 | 0.0026 | 0.002 |
| $2014 / 15$ | 4.531 A | 0.758 A | closed | 0 | 0.0002 | 0.0026 | 0.002 |
| $2015 / 16$ | 4.537 A | 0.796 A | closed | 0 | 0.0026 | 0.0026 | 0.002 |
| $2016 / 17$ | 4.528 A | 0.511 A | closed | 0 | 0.0008 | 0.0026 | 0.002 |
| $2016 / 17$ | -- | 0.507 A | -- | -- | -- | 0.0026 | 0.002 |

6. Basis for the 2017/18 OFL: The OFL was based on Tier 4 considerations. The ratio of estimated $2016 / 17$ MMB-at-mating to $B_{M S Y}$ is less than $\beta$ ( 0.25 ) for the $F_{O F L}$ Control Rule, so directed fishing is not allowed. As per the rebuilding plan (NPFMC, 2014a), the OFL is based on a Tier 5 calculation of average bycatch mortalities between 1999/2000 and 2005/2006, which is a time period thought to adequately reflect the conservation needs associated with this stock and to acknowledge existing non-directed catch mortality. Using this approach, the OFL was determined to be 1.16 t for 2017/18. The following results are based on determining $B_{M S Y} /$ MSST by averaging the MMB-at-mating time series estimated using the smoothed survey data from a random effects model; the current (2017/18) MMB-at-mating is also based on the smoothed survey data.

Table 3: Management performance, all units in metric tons. The OFL is a total catch OFL for each year.

| Year | Tier | $\boldsymbol{B}_{\text {MSY }}$ | $\begin{array}{r} \text { Current } \\ \text { MMB }_{\text {mating }} \end{array}$ | $\begin{gathered} B / B_{\text {MSY }} \\ \left(\mathrm{MMB}_{\text {mating }}\right) \end{gathered}$ | $\gamma$ | Years to define $\boldsymbol{B}_{\text {MSY }}$ | Natural <br> Mortality | P* |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2013/14 | 4c | 3,988 | 278 | 0.07 | 1 | $\begin{gathered} \hline \text { 1980/81-1984/85 } \\ \& 1990 / 91-1997 / 98 \end{gathered}$ | 0.18 | $\begin{gathered} 10 \% \\ \text { buffer } \end{gathered}$ |
| 2014/15 | 4c | 4,002 | 218 | 0.05 | 1 | $\begin{gathered} \text { 1980/81-1984/85 } \\ \& 1990 / 91-1997 / 98 \end{gathered}$ | 0.18 | $\begin{gathered} 25 \% \\ \text { buffer } \end{gathered}$ |
| 2015/16 | 4 c | 4,109 | 361 | 0.09 | 1 | 1980/81-1984/85 $\& 1990 / 91-1997 / 98$ | 0.18 | $\begin{gathered} 25 \% \\ \text { buffer } \end{gathered}$ |
| 2016/17 | 4 c | 4,116 | 232 | 0.06 | 1 | $\begin{gathered} \text { 1980/81-1984/85 } \\ \& 1990 / 91-1997 / 98 \end{gathered}$ | 0.18 | $\begin{gathered} 25 \% \\ \text { buffer } \end{gathered}$ |
| 2017/18 | 4 c | 4,108 | 230 | 0.06 | 1 | 1980/81-1984/85 $\& 1990 / 91-1997 / 98$ | 0.18 | $\begin{gathered} 25 \% \\ \text { buffer } \end{gathered}$ |

Table 4: Management performance, all units in the table are million pounds.

| Year | Tier | $\boldsymbol{B}_{\text {MSY }}$ | $\begin{array}{r} \text { Current } \\ \text { MMB }_{\text {mating }} \end{array}$ | $\begin{gathered} B / B_{\mathrm{MSY}} \\ \left(\mathrm{MMB}_{\mathrm{mating}}\right) \end{gathered}$ | $\gamma$ | $\begin{gathered} \hline \text { Years to define } \\ B_{\mathrm{MSY}} \\ \hline \end{gathered}$ | Natural <br> Mortality | P* |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2013/14 | 4 c | 8.79 | 0.613 | 0.07 | 1 | $\begin{gathered} \hline \text { 1980/81-1984/85 } \\ \& 1990 / 91-1997 / 98 \end{gathered}$ | 0.18 | $\begin{gathered} 10 \% \\ \text { buffer } \end{gathered}$ |
| 2014/15 | 4 c | 8.82 | 0.481 | 0.05 | 1 | $\begin{gathered} \text { 1980/81-1984/85 } \\ \& 1990 / 91-1997 / 98 \end{gathered}$ | 0.18 | $\begin{gathered} 10 \% \\ \text { buffer } \end{gathered}$ |
| 2015/16 | 4 c | 9.06 | 0.795 | 0.09 | 1 | $\begin{gathered} \text { 1980/81-1984/85 } \\ \& 1990 / 91-1997 / 98 \end{gathered}$ | 0.18 | $\begin{gathered} 25 \% \\ \text { buffer } \end{gathered}$ |
| 2016/17 | 4 c | 9.07 | 0.511 | 0.06 | 1 | $\begin{gathered} \text { 1980/81-1984/85 } \\ \& 1990 / 91-1997 / 98 \end{gathered}$ | 0.18 | $\begin{gathered} 25 \% \\ \text { buffer } \end{gathered}$ |
| 2017/18 | 4c | 9.06 | 0.507 | 0.06 | 1 | $\begin{array}{r} 1980 / 81-1984 / 85 \\ \& 1990 / 91-1997 / 98 \\ \hline \end{array}$ | 0.18 | $\begin{gathered} 25 \% \\ \text { buffer } \end{gathered}$ |

7. Probability density function for the OFL: Not applicable for this stock.
8. $A B C$ : The ABC was calculated using a $25 \%$ buffer on the OFL , as in the previous assessments since 2015. The ABC is thus $0.87 \mathrm{t}(=0.25 \times 1.16 \mathrm{t})$.
9. Rebuilding analyses results summary: In 2009, NMFS determined that the PIBKC stock was not rebuilding in a timely manner and would not meet a rebuilding horizon of 2014. A preliminary assessment model developed by NMFS (not used in this assessment) suggested that rebuilding could occur within 50 years due to random recruitment (NPFMC, 2014a). Subsequently, Amendment 43 to the King and Tanner Crab Fishery Management Plan (Crab

FMP) and Amendment 103 to the Bering Sea and Aleutian Islands Groundfish FMP (BSAI Groundfish FMP) to rebuild the PIBKC stock were adopted by the Council in 2012 and approved by the Secretary of Commerce in early 2015. The function of these amendments is to promote bycatch reduction on PIBKC by closing the Pribilof Islands Habitat Conservation Zone to pot fishing for Pacific cod. No pot fishing for Pacific cod occurred within the Pribilof Islands Habitat Conservation Zone in 2015/16.

## A. Summary of Major Changes:

## 1. Management

In 2002, NMFS notified the NPFMC that the PIBKC stock was overfished. A rebuilding plan was implemented in 2003 that included the closure of the stock to directed fishing until the stock was rebuilt. In 2009, NMFS determined that the PIBKC stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014. Subsequently, Amendment 43 to the Crab FMP and Amendment 103 to the BSAI Groundfish FMP to rebuild the PIBKC stock were adopted by the Council in 2012 and approved by the Secretary of Commerce in early 2015. Amendment 103 closed the Pribilof Islands Habitat Conservation Zone to pot fishing for Pacific cod to promote bycatch reduction on PIBKC. Amendment 43 amended the prior rebuilding plan to incorporate new information on the likely rebuilding timeframe for the stock, taking into account environmental conditions and the status and population biology of the stock. No pot fishing for Pacific cod has occurred within the Pribilof Islands Habitat Conservation Zone since 2015/16.

## 2. Input data

Retained and discard catch time series were updated with 2015/2016 data from the crab and groundfish fisheries. Abundance and biomass for PIBKC in the annual summer NMFS EBS bottom trawl survey were updated for the 2016 survey.

## 3. Assessment methodology

There are no changes from the 2016/17 assessment. The Tier 4 approach used in this assessment for status determination, based on smoothing the raw survey biomass time series using a random effects model, is identical to that adopted by the CPT and SSC in 2015 and used in the 2015 and 2016 assessments (Stockhausen, 2015, 2016).

## 4. Assessment results

Total catch mortality in 2016/17 was 0.38 t , which DID NOT exceed the OFL (1.16 t). Consequently, overfishing DID NOT occur in 2016/17. The projected MMB-at-mating for 2017/18 decreased slightly from that in 2016/17 but remained below the MSST. Consequently, the stock remains overfished and a directed fishery is prohibited in 2017/18. The OFL, based on average catch, and ABC are identical to last year's values.

## B. Responses to SSC and CPT Comments

## CPT comments September 2015:

Specific remarks pertinent to this assessment
Use results from the random effects smoothing model to calculate both $B_{M S Y}$ and current $B$ for status determination.

Responses to CPT Comments:
Results from the random effects model were used to calculate both $B_{M S Y}$ and current $B$ for status determination.

SSC comments October 2015:
Specific remarks pertinent to this assessment
none

## CPT comments May 2016:

Specific remarks pertinent to this assessment
none

SSC comments June 2016:
Specific remarks pertinent to this assessment
none

## CPT comments September 2016:

Specific remarks pertinent to this assessment
Apply the same handling mortality to bycatch of PIBKC by fixed gear as is applied to other king crab stocks (0.2).

Responses to CPT Comments:
This assessment uses 0.2 as the handling mortality applied to all fixed gear bycatch.

SSC comments October 2016:
Specific remarks pertinent to this assessment
none

## CPT comments May 2017:

Specific remarks pertinent to this assessment none

SSC comments June 2017:
Specific remarks pertinent to this assessment none

## C. Introduction

## 1. Stock

Pribilof Islands blue king crab (PIBKC), Paralithodes platypus.

## 2. Distribution

Blue king crab are anomurans in the family Lithodidae, which also includes the red king crab (Paralithodes camtschaticus) and golden or brown king crab (Lithodes aequispinus) in Alaska. Blue king crabs are found in widely-separated populations across the North Pacific (Figure 1). In the western Pacific, blue king crabs occur off Hokkaido in Japan and isolated populations have been observed in the Sea of Okhotsk and along the Siberian coast to the Bering Straits. In North America, they are found in the Diomede Islands, Point Hope, outer Kotzebue Sound, King Island, and the outer parts of Norton Sound. In the remainder of the Bering Sea, they are found in the waters off St. Matthew Island and the Pribilof Islands. In more southerly areas, blue king crabs are found in the Gulf of Alaska in widely-separated populations that are frequently associated with fjord-like bays (Figure 1). The insular distribution of blue king crab relative to the similar but more broadly distributed red king crab is likely the result of post-glacial-period increases in water temperature that have limited the distribution of this cold-water adapted species (Somerton 1985). Factors that may be directly responsible for limiting the distribution include the physiological requirements for reproduction, competition with the more warm-water adapted red king crab, exclusion by warm-water predators, or habitat requirements for settlement of larvae (Armstrong et al 1985, 1987; Somerton, 1985).

## 3. Stock structure

Stock structure of blue king crab in the North Pacific is largely unknown. Samples were collected in 2009-2011 by a graduate student at the University of Alaska to support a genetic study on blue king crab population structure. Aspects of blue king crab harvest and abundance trends, phenotypic characteristics, behavior, movement, and genetics will be evaluated by the author following the guidelines in the AFSC report entitled "Guidelines for determination of spatial management units for exploited populations in Alaskan groundfish fishery management plans" by P. Spencer (unpublished report).

The potential for species interactions between blue king crab and red king crab as a potential reason for PIBKC shifts in abundance and distribution were addressed in a previous assessment (Foy, 2013). Foy (2013) compared the spatial extent of both speices in the Pribilof Islands from 1975 to 2009 and found that, in the early 1980's when red king crab first became abundant, blue king crab males and females dominated the 1 to 7 stations where the species co-occurred in the Pribilof Islands District. Spatially, the stations with co-occurance were all dominated by blue king crab and broadly distributed around the Pribilof Islands. In the 1990's, the red king crab population biomass increased substantially as the blue king crab population biomass decreased. During this time period, the number of stations with co-occurance remained around a maximum of 8, but they were equally dominated by both blue king crab and red king crab-suggesting a direct overlap in distribution at the scale of a survey station. During this time period, the stations dominated
by red king crab were dispersed around the Pribilof Islands. Between 2001 and 2009 the blue king crab population decreased dramatically while the red king crab fluctuated. The number of stations dominated by blue king crab in 2001-2009 was similar to that for stations dominated by red king crab for both males and females, suggesting continued competition for similar habitat. The only stations dominated by blue king crab in the latter period are to the north and east of St. Paul Island. Although blue king crab protection measures also afford protection for the red king crab in this region, red king crab stocks continue to fluctuate (more so than simply accounted for by the uncertainty in the survey).

During the years when the fishery was active (1973-1989, 1995-1999), the Pribilof Islands blue king crab (PIBKC) were managed under the Bering Sea king crab Registration Area Q Pribilof District. The southern boundary of this district is formed by a line from $5436^{\prime} \mathrm{N}$ lat., 168 W long., to 54 36 ' N lat., 171 W long., to 5530 ' N lat., 171 W. long., to 5530 ' N lat., 17330 ' E long., while its northern boundary is a line at the latitude of Cape Newenham ( $5839^{\prime} \mathrm{N}$ lat.), its eastern boundary is a line from 5436 ' N lat., 168 W long., to 5839 ' N lat., 168 W long., to Cape Newenham ( 58 $39^{\prime}$ N lat.), and its western boundary is the United States-Russia Maritime Boundary Line of 1991 (ADF\&G 2008) (Figure 2). In the Pribilof District, blue king crab occupy the waters adjacent to and northeast of the Pribilof Islands (Armstrong et al. 1987). For assessment purposes, the Pribilof District as defined in Figure 2, with the addition of a 20 nm mile strip to the east of the District (bounded by the dotted red line in Figure 2), is considered to define the stock boundary for PIBKC.

## 4. Life History

Blue king crab are similar in size and appearance, except for color, to the more widespread red king crab, but are typically biennial spawners with lesser fecundity and somewhat larger sized (ca. 1.2 mm ) eggs (Somerton and Macintosh 1983; 1985; Jensen et al. 1985; Jensen and Armstrong 1989; Selin and Fedotov 1996). Blue king crab fecundity increases with size, from approximately 100,000 embryos for a $100-110 \mathrm{~mm}$ CL female to approximately 200,000 for a female $>140-\mathrm{mm}$ CL (Somerton and MacIntosh 1985). Blue king crab have a biennial ovarian cycle with embryos developing over a 12 or 13 -month period depending on whether or not the female is primiparous or multiparous, respectively (Stevens 2006a). Armstrong et al. (1985, 1987), however, estimated the embryonic period for Pribilof blue king crab at 11-12 months, regardless of previous reproductive history. Somerton and MacIntosh (1985) placed development at 14-15 months. It may not be possible for large female blue king crabs to support the energy requirements for annual ovary development, growth, and egg extrusion due to limitations imposed by their habitat, such as poor quality or low abundance of food or reduced feeding activity due to cold water (Armstrong et al. 1987; Jensen and Armstrong 1989). Both the large size reached by Pribilof Islands blue king crab and the generally high productivity of the Pribilof area, however, argue against such environmental constraints. Development of the fertilized embryos occurs in the egg cases attached to the pleopods beneath the abdomen of the female crab and hatching occurs February through April (Stevens 2006b). After larvae are released, large female Pribilof blue king crab will molt, mate, and extrude their clutches the following year in late March through mid April (Armstrong et al. 1987).

Female crabs require an average of 29 days to release larvae, and release an average of 110,033 larvae (Stevens 2006b). Larvae are pelagic and pass through four zoeal larval stages which last about 10 days each, with length of time being dependent on temperature: the colder the temperature the slower the development and vice versa (Stevens et al. 2008). Stage I zoeae must find food within 60 hours as starvation reduces their ability to capture prey (Paul and Paul 1980) and successfully
molt. Zoeae consume phytoplankton, the diatom Thalassiosira spp. in particular, and zooplankton. The fifth larval stage is the non-feeding (Stevens et al. 2008) and transitional glaucothoe stage in which the larvae take on the shape of a small crab but retain the ability to swim by using their extended abdomen as a tail. This is the stage at which the larvae searches for appropriate settling substrate and, upon finding it, molts to the first juvenile stage and henceforth remains benthic. The larval stage is estimated to last for 2.5 to 4 months and larvae metamorphose and settle during July through early September (Armstrong et al. 1987; Stevens et al. 2008).

Blue king crab molt frequently as juveniles, growing a few mm in size with each molt. Unlike red king crab juveniles, blue king crab juveniles are not known to form pods. Female king crabs typically reach sexual maturity at approximately five years of age while males may reach maturity at six years of age (NPFMC 2003). Female size at $50 \%$ maturity for Pribilof blue king crab is estimated to be $96-\mathrm{mm}$ carapace length (CL) and size at maturity for males, estimated from chela height relative to CL, is estimated to be $108-\mathrm{mm}$ CL (Somerton and MacIntosh 1983). Skip molting occurs with increasing probability for those males larger than 100 mm CL (NMFS 2005).

Longevity is unknown for this species due to the absence of hard parts retained through molts with which to age crabs. Estimates of 20 to 30 years in age have been suggested (Blau 1997). Natural mortality for male Pribilof blue king crabs has been estimated at $0.34-0.94$ with a mean of 0.79 (Otto and Cummiskey 1990) and a range of 0.16 to 0.35 for Pribilof and St. Matthew Island stocks combined (Zheng et al. 1997). An annual natural mortality of $0.2 \mathrm{yr}^{-1}$ for all king crab species was adopted in the federal crab fishery management plan for the BSAI areas (Siddeek et al. 2002). A rate of $0.18 \mathrm{yr}^{-1}$ is currently used for PIBKC.

## 5. Management history

The blue king crab fishery in the Pribilof District began in 1973 with a reported catch of 590 t by eight vessels (Table 9; Figure 3). Landings increased during the 1970s and peaked at a harvest of $5,000 \mathrm{t}$ in the $1980 / 81$ season (Table 9; Figure 3), with an associated increase in effort to 110 vessels (ADFG 2008). The fishery occurred September through January, but usually lasted less than 6 weeks (Otto and Cummiskey 1990; ADFG 2008). The fishery was male only, and legal size was $>16.5 \mathrm{~cm}$ carapace width (NPFMC 1994). Guideline harvest levels (GHL) were 10 percent of the abundance of mature males or 20 percent of the number of legal males (ADFG 2006).

PIBKC have occurred as bycatch in the eastern Bering Sea snow crab (Chionoecetes opilio) fishery, the western Bering Sea Tanner crab (Chionoecetes bairdi) fishery, the Bering Sea hair crab (Erimacrus isenbeckii) fishery, and the Pribilof red and blue king crab fisheries (Tables 10 and 11). In addition, blue king crab have been taken as bycatch in groundfish fisheries by both fixed and trawl gear, primarily those targeting Pacific cod, flathead sole and yellowfin sole (Tables 10-12).

Amendment 21a to the BSAI Groundfish FMP prohibits the use of trawl gear in the Pribilof Islands Habitat Conservation Area (subsequently renamed the Pribilof Islands Habitat Conservation Zone in Amendment 43; Figure 4), which the amendment also established (NPFMC 1994). The amendment went into effect January 20, 1995 and protects the majority of crab habitat in the Pribilof Islands area from the impact from trawl gear.

Declines in the PIBKC stock after 1995 resulted in a closure of directed fishing from 1999 to the present. The stock was declared overfished in September 2002, and ADFG developed a rebuilding harvest strategy as part of the NPFMC comprehensive rebuilding plan for the stock. The rebuilding
plan also included the closure of the stock to directed fishing until it was rebuilt. In 2009, NMFS determined that the PIBKC stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014. Subsequently, Amendment 43 to the King and Tanner Crab Fishery Management Plan (FMP) and Amendment 103 to the BSAI Groundfish FMP to rebuild the PIBKC stock were adopted by the Council in 2012 and approved by the Secretary of Commerce in early 2015. Amendment 103 closes the Pribilof Islands Habitat Conservation Zone (Figure 4) to pot fishing for Pacific cod to promote bycatch reduction on PIBKC. Amendment 43 amends the prior rebuilding plan to incorporate new information on the likely rebuilding timeframe for the stock, taking into account environmental conditions and the status and population biology of the stock (NPFMC 2014a).

## D. Data

## 1. Summary of new information

The time series of retained and discarded catch in the crab fisheries was updated for 2016/17 from ADFG data (no retained catch, no bycatch mortality; Tables 10 and 11). The time series of discards in the groundfish pot and trawl fisheries (Tables 10 and 11) were updated for 2009/10-2016/17 using NMFS Alaska Regional Office (AKRO) estimates obtained from the AKFIN database (as updated on Aug. 30, 2017). Results from the 2017 NMFS EBS bottom trawl survey were added to the assessment (Tables 15 and 16), based on the "new" standardization described in the 2015 assessment (Stockhausen, 2015).

## 2. Fishery data

## 2.a. Retained catch

Retained pot fishery catches (live and deadloss landings data) are provided for 1973/74 to 2015/16 (Table 9, Figure 3), including the 1973/74 to 1987/88 and 1995/96 to 1998/99 seasons when blue king crab were targeted in the Pribilof Islands District. In the 1995/96 to 1998/99 seasons, blue king crab and red king crab were fished under the same Guideline Harvest Level (GHL). Total allowable catch (TAC) for a directed fishery has been set at zero since 1999/2000; there was no retained catch in the 2016/17 crab fishing season.

## 2.b. Bycatch and discards:

## Crab pot fisheries

Non-retained (directed and non-directed) pot fishery catches are provided for sublegal males (<138 mm CL), legal males ( $\geq 138 \mathrm{~mm}$ CL), and females based on data collected by onboard observers in the crab fisheries (Table 10). Catch weight was calculated by first determining the mean weight (in grams) for crabs in each of three categories: legal non-retained, sublegal, and female. The average weight for each category was then calculated from length frequency tables, where the carapace length ( $z$; in mm ) was converted to weight ( $w$; in g ) using the following equation:

$$
\begin{equation*}
w=\alpha \cdot z^{\beta} \tag{1}
\end{equation*}
$$

Values for the length-to-weight conversion parameters $\alpha$ and $\beta$ were applied across the time period: males) $\alpha=0.000508, \beta=3.106409$; females) $\alpha=0.02065, \beta=2.27$ (Daly et al. 2014). Average weights $(\bar{W})$ for each category were calculated using the following equation:

$$
\begin{equation*}
\bar{W}=\frac{\sum w_{z} \cdot n_{z}}{\sum n_{z}} \tag{2}
\end{equation*}
$$

where $w_{z}$ is crab weight-at-size $z$ (i.e., carapace length) using Equation 1, and $n_{z}$ is the number of crabs observed at that size in the category. Finally, estimated total non-retained weights for each crab fishery were the product of average weight $(\bar{W})$, CPUE based on observer data, and total effort (pot lifts) in each fishery.

Historical non-retained catch data are available from 1996/97 to present from the snow crab general, snow crab CDQ, and Tanner crab fisheries (Table 10, Bowers et al. 2011), although data may be incomplete for some of these fisheries. Prior to $1998 / 99$, limited observer data exists (for catcher-processor vessels only), so non-retained catch before this date is not included here. For this assessment, a $20 \%$ handling mortality rate was applied to the bycatch estimates to calculate non-retained crab mortality in these pot fisheries (Table 11). In previous assessments, a handling mortality rate of $50 \%$ was applied to bycatch in the pot fisheries. The revised value used here is now consistent with the rates used in other king crab assessments (e.g., Zheng et al., 2016).

No bycatch mortality occurred in the crab fisheries in 2016/17. In 2015/16, though, several PIBKC were incidentally caught in the crab fisheries, yielding an expanded estimate of 0.067 t bycatch mortality (using a handling mortality rate of $20 \%$; Table 10). Bycatch mortality during 2015/16 was the first non-zero bycatch mortality in the crab fisheries since 2010/11.

## Groundfish fisheries

The AKRO estimates of non-retained catch from all groundfish fisheries in 2016/17, as available through the AKFIN database (accessed Aug. 30, 2017), are included in this report (Tables 10-12). Updated estimates for $2009 / 10-2016 / 17$ were obtained through the AKFIN database.

Groundfish bycatch data from before 1999 are available only in INPFC reports and are not included in this assessment. Non-retained crab catch data in the groundfish fisheries are available from 1991/92 to present. Between 1991 and December 2001, bycatch was estimated using the "blend method." From January 2003 to December 2007, bycatch was estimated using the Catch Accounting System (CAS), based on substantially different methods than the "blend." Starting in January 2008, the groundfish observer program changed the method in which they speciate crab to better reflect their hierarchal sampling method and to account for broken crab that in the past were only identified to genus. In addition, the haul-level weights collected by observers were used to estimate the crab weights through CAS instead of applying an annual (global) weight factor to convert numbers to biomass. Spatial resolution was at the NMFS statistical area. Beginning in January 2009, ADFG statistical areas ( 1 ^o $\$$ longitude $\times 0.5^{\circ}$ latitude) were included in groundfish production reports and allowed an increase in the spatial resolution of bycatch estimates from the NMFS statistical areas to the state statistical areas. Bycatch estimates (2009-present) based on the state statistical areas were first provided in the 2013 assessment, and improved methods for aggregating observer data were used in the 2014 and 2015 assessments (see Stockhausen, 2015). The estimates obtained this
year are based on the same methods as those used in the 2014-2016 assessments. Detailed results from this process are presented in Appendix A.

To assess crab mortalities in the groundfish fisheries, an $80 \%$ handling mortality rate was applied to estimates of bycatch in trawl fisheries, and a $20 \%$ handling mortality rate was applied to fixed gear fisheries using pot and hook and line gear (Tables 10-11). As noted above, previous assessments used a handling mortality rate of $50 \%$ for bycatch mortality in the fixed gear fisheries.

In 2016/17, fisheries targeting rock sole (Lepidopsetta spp.) accounted for $68 \%$ of the bycatch of PIBKC in the groundfish fisheries, with fisheries targeting yellowfin sole (Limanda aspera) and Pacific cod (Gadus microcephalus) accounting for $16 \%$ each. In contrast, fisheries targeting Pacific cod accounted for $48 \%$ of the estimated total PIBKC bycatch (by weight) in the groundfish fisheries in 2015/16, with fisheries targeting yellowfin sole accounting for another 43\% (Table 12). In 2013/14 and 2014/15, bycatch of PIBKC occurred almost exclusively in the Pacific cod fisheries (99.4\% by weight, Table 4). The flathead sole (Hippoglossoides elasodon) fishery has also accounted for a substantial fraction of the bycatch at times.

Since the 2009/10 crab fishing season, Pribilof Islands blue king crab have been taken as bycatch in the groundfish fisheries only by hook and line and non-pelagic trawl gear (Table 13). Starting in 2015, as a consequence of Amendment 43 to the BSAI Groundfish FMP, the Pribilof Islands Habitat Conservation Area was formally closed to pot fishing for Pacific cod in order to promote recovery of the PIBKC stock. In 2016/17, non-pelagic trawl gear accounted for $83 \%$ (by weight) of PIBKC bycatch in the groundfish fisheries. In 2015/16, by contrast, non-pelagic trawl gear accounted for only $52 \%$ the bycatch. In 2013/14 and 2014/15, hook and line gear accounted for the total bycatch of PIBKC, while in $2012 / 13$, it accounted for only $20 \%$ of the bycatch (by weight)-whereas non-pelagic trawl gear accounted for $80 \%$. Although these appear to be large interannual changes, the actual bycatch amounts involved are fairly small and interannual variability is consequently expected to be rather high.

## 2.c. Catch-at-length

Not applicable.

## 3. Survey data

The 2017 NMFS EBS bottom trawl survey was conducted between May and August of this year. Survey results for PIBKC are based on the stock area first defined in the 2013 assessment (Foy, 2013), which includes the Pribilof District and a 20 nm strip adjacent to the eastern edge of the District (Figure 2). The adjacent area was defined as a result of the new rebuilding plan and the concern that crab outside the Pribilof District were not being accounted for in the assessment.

In 2017, the survey caught 23 blue king crab in 86 stations across the stock area, while 20, 28, and 33 crab were caught across the same stations in the 2014-2016 surveys, respectively (Table ??). Four immature males were caught in 2017, similar to numbers caught in 2014-2016 (5, 4 and 5, respectively). Four mature males (three of which was legal size) were caught in 2017, compared with 5,13 and 3 in 2014-2016, respectively. Seven immature females were caught in 2017; only one was caught in 2014 and none in 2015, but five in 2016. Finally, eight mature females were caught in 2017, compared with only 4 in 2014, 11 in 2015, and 19 in 2016.

The area-swept estimate of mature male abundance in the stock area at the time of the survey was $91,000( \pm 89,000)$, representing an increase from $56,000( \pm 62,000)$ in 2016 (Table 15). The abundance estimate for immature males in 2017 was $68,000( \pm 103,000)$, while it was $94,000( \pm 95,000)$ in 2016. The area-swept estimate for immature female abundance in 2017 was $188,000( \pm 275,000)$, larger than in $2016(132,000 \pm 130,000)$, while that for mature females was only $162,000( \pm 169,000)$, smaller than that in $2016(323,000 \pm 328,000)$. None of the changes were statistically significant.

The area-swept estimate of mature male biomass in the stock area at the time of the 2017 survey was $253 \mathrm{t}( \pm 254 \mathrm{t})$, while it was $129 \mathrm{t}( \pm 154 \mathrm{t})$ in 2016 (Table 16). The biomass estimate for immature males in 2017 was 45 t ( $\pm 68 \mathrm{t}$ ), compared with $70 \mathrm{t}( \pm 67 \mathrm{t})$ in 2016 . The area-swept estimate for immature female biomass in 2017 was $107 \mathrm{t}( \pm 170 \mathrm{t})$; in 2016, it was $49 \mathrm{t}( \pm 48 \mathrm{t})$. For mature females, the estimated swept-area biomass was $152 \mathrm{t}( \pm 166 \mathrm{t})$; in 2016 , it was $352 \mathrm{t}( \pm 340 \mathrm{t})$.
One feature that characterizes survey-based estimates of abundance and biomass for PIBKC is the large uncertainty (cv's on the order of $0.5-1$ ) associated with the estimates, which complicates the interpretation of sometimes large interannual swings in estimates (Tables 15 and 16, Figures 5-8). Estimated total abundance of male PIBKC from the NMFS EBS bottom trawl survey declined from $\sim 24$ million crab in 1975, the first year of the "standardized" survey, to $\sim 150,000$ in 2016 (the lowest estimated abundance since 2004, which was the minimum for the time series; Table 15, Figures 5 and 6). Following a general decline to a low-point in 1985 ( $\sim 500,000$ males), abundance increased by a factor of 10 in the early1990s, then generally declined (with small amplitude oscillations superimposed) to the present. Estimated female abundance generally followed a similar trend. It spiked at 180 million crab in 1980, from $\sim 13$ million crab in 1975 and only $\sim 1$ million in 1979 , then returned to more typical levels in 1981 ( $\sim 6$ million crab). More recently, abundance has fluctuated around 200,000 females. Estimated biomass for both males and females have followed similar trends similar to those in abundance (Table 16, Figures 7 and 8).

Size frequencies for males by shell condition from recent surveys (2012-2017) are illustrated in Figure 9. Size frequencies for all males across the time series are shown in Figure 10. While Figure 10 suggested a recent trend toward larger sizes in 2014-15, this does not appear to have continued in 2016. These plots provide little evidence of recent recruitment.

Size frequencies for females by shell condition are presented in Figure 11 from recent surveys (2012-2017). Size frequencies for all females are shown in 12. These also provide little indication of recent recruitment.

The small numbers of crab caught in recent surveys make it difficult to draw firm conclusions regarding spatial patterns (see figures in Appendix B). That said, the spatial pattern of PIBKC abundance in recent surveys is generally centered fairly compactly within the Pribilof District to the east of St. Paul Island (although 2015 is an exception) and north of St. George Island, within a 60 nm radius of St . Paul.

## E. Analytic Approach

## 1. History of modeling approaches

A catch survey analysis has been used for assessing the stock in the past, although it is not currently in use. In October 2013, the SSC concurred with the CPT that the PIBKC stock falls under Tier 4
for status determination but it recommended that the OFL be calculated using a Tier 5 approach, with ABC based on a $10 \%$ buffer. Subsequently, a $25 \%$ buffer has been used to calculate ABC.

In the 2013 and 2014 assessments (Foy 2013; Stockhausen 2014), "current" MMB-at-mating was projected from the time of the latest survey using an inverse-variance averaging approach to smoothing annual survey biomass estimates because the uncertainties associated with the annual estimates are extremely large. In the 2015 assessment (Stockhausen, 2015), an alternative approach to smoothing based on a Random Effects model was presented and subsequently adopted by the CPT and SSC to use in estimating $B_{M S Y}$ and "current" MMB-at-mating. The Random Effects model (Appendix C) is used in this assessment.

## 2. Model Description

See Appendix C.

## 3. Model Selection and Evaluation

Not applicable

## 4. Results

See Appendix C.

## F. Calculation of the OFL

## 1. Tier Level:

Based on available data, the author recommended classification for this stock is Tier 4 for stock status level determination defined by Amendment 24 to the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 2008a).

In Tier 4, stock status is based on the ratio of "current" spawning stock biomass ( $B$ ) to $B_{M S Y}$ (or a proxy thereof, $B_{M S Y_{\text {proxy }}}$, also referred to as $B_{R E F}$ ). MSY (maximum sustained yield) is the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions. The fishing mortality that, if applied over the long-term, would result in MSY is $F_{M S Y} . B_{M S Y}$ is the long-term average stock size when fished at FMSY, and is based on mature male biomass at the time of mating ( $M M B_{\text {mating }}$ ), which serves as an approximation for egg production. $M M B_{\text {mating }}$ is used as a basis for $B_{M S Y}$ because of the complicated female crab life history, unknown sex ratios, and male only fishery. Although $B_{M S Y}$ cannot be calculated for a Tier 4 stock, a proxy value ( $B_{M S Y_{p r o x y}}$ or $B_{R E F}$ ) is defined as the average biomass over a specified time period that satisfies the conditions under which $B_{M S Y}$ would occur (i.e., equilibrium biomass yielding MSY under an applied $F_{M S Y}$ ).

The time period for establishing $B_{M S Y_{\text {proxy }}}$ is assumed to be representative of the stock being fished at an average rate near FMSY and fluctuating around $B_{M S Y}$. The SSC has endorsed using the time periods 1980-84 and 1990-97 to calculate $B_{M S Y_{\text {proxy }}}$ for Pribilof Islands blue king crab to avoid
time periods of low abundance possibly caused by high fishing pressure. Alternative time periods (e.g., 1975 to 1979) have also been considered but rejected (Foy 2013). Considerations for choosing the current time periods included:

## A. Production potential

1) Between 2006 and 2013 the stock does appear to be below a threshold for responding to increased production based on the lack of response of the adult stock biomass to slight fluctuations in recruitment (male crab 120-134 mm) (Figure 20 in Foy 2013).
2) An estimate of surplus production $\left(A S P_{t}=M M B_{t+1}{ }^{\smile} M M B_{t}+\right.$ totalcatch $\left._{t}\right)$ suggested that only meaningful surplus existed only in the late 1970s and early 1980s while minor surplus production in the early 1990s may have led to the increases in biomass observed in the late 1990s.
3) Although a climate regime shift where temperature and current structure changes are likely to impact blue king crab larval dispersal and subsequent juvenile crab distribution, no apparent trends in production before or after 1978 were observed (Foy 2013). There are few empirical data to identify trends that may allude to a production shift. However, further analysis is warranted given the paucity of surplus production and recruitment subsequent to 1981 and the spikes in recruits (male crab 120-134 mm) /spawner (MMB) observed in the early 1990s and 2009 (Figure 21 in Foy 2013).

## B. Exploitation rates

Exploitation rates fluctuated during the open fishery periods from 1975 to 1987 and 1995 to 1998 (Figure 20 in Foy 2013) while total catch increased until 1980, before the fishery was closed in 1987, and increased again in 1995 before closing again in 1999 (Figure 22 in Foy 2013). The current $F_{M S Y_{\text {proxy }}}=M$ is 0.18 , so time periods with greater exploitation rates should not be considered to represent a period with an average rate of fishery removals.

## C. Recruitment

Subsequent to increases in exploitation rates in the late 1980s and 1990s, the quantity $\ln$ (recruits/MMB) dropped, suggesting that exploitation rates at the levels of $F_{M S Y_{p r o x y}}=M$ were not sustainable.

Thus, $M M B_{\text {mating }}$ is the basis for calculating $B_{M S Y_{\text {proxy }}}$. The formulas used to calculate $M M B_{\text {mating }}$ from MMB at the time of the survey $\left(M M B_{\text {survey }}\right)$ are documented in Appendix C. For this stock, $B_{M S Y_{\text {proxy }}}$ was calculated using the random effects model-smoothed estimates for $M M B_{\text {survey }}$ from the survey time series (Table 17) in the formula for $M M B_{\text {mating }} . B_{M S Y_{\text {proxy }}}$ is the average of $M M B_{\text {mating }}$ for the years 1980/81-1984/85 and 1990/91-1997/98 (Table 18) and was calculated as 4,108 t.

In this assessment, "current $\mathrm{B} "(B)$ is the $M M B_{\text {mating }}$ projected for 2017/18. Details of this calculation are also provided in Appendix C. For 2017/18, $B=230 \mathrm{t}$.

Overfishing is defined as any amount of fishing in excess of a maximum allowable rate, $F_{O F L}$, which would result in a total catch greater than the OFL. For Tier 4 stocks, a minimum stock size threshold (MSST) is specified as $0.5 \cdot B_{M S Y_{p r o x y}}$. If $B$ drops below the MSST, the stock is considered to be overfished.

## 2. Parameters and stock sizes

- $B_{M S Y_{\text {proxy }}}\left(B_{R E F}\right)=4,108 \mathrm{t} \cdot M=0.18 \mathrm{yr}^{\wedge}\{-1\} \cdot B=230 \mathrm{t}$


## 3. OFL specification

## 3.a. Stock status level

In the Tier 4 OFL-setting approach, the "total catch OFL" and the "retained catch OFL" are calculated by applying the $F_{O F L}$ to all crab at the time of the fishery (total catch OFL) or to the mean retained catch determined for a specified period of time (retained catch OFL).
The Tier $4 F_{O F L}$ is derived using the $F_{O F L}$ Control Rule (Figure 13), where the Stock Status Level (level a, b or c; equations 3-5) is based on the relationship of $B$ to $B_{M S Y_{p r o x y}}$.
Stock Status Level $F_{O F L}$

$$
\begin{gather*}
a . \quad B / B_{M S Y_{\text {proxy }}}>1.0 \quad F_{O F L}=\gamma \cdot M  \tag{3}\\
b . \quad \beta<B / B_{M S Y_{\text {proxy }}} \leq 1.0 \quad F_{O F L}=\gamma \cdot M\left[\left(B / B_{M S Y_{\text {proxy }}}-\alpha\right) /(1-\alpha)\right]  \tag{4}\\
c . \quad B / B_{M S Y_{\text {proxy }}} \leq \beta \quad F_{\text {directed }}=0, \quad F_{O F L} \leq F_{M S Y} \tag{5}
\end{gather*}
$$

When $\mathrm{B} / B_{M S Y_{p r o x y}}$ is greater than 1 (Stock Status Level a), $F_{O F L_{p r o x y}}$ is given by the product of a scalar ( $\gamma=1.0$, nominally) and $M$. When $B / B_{M S Y_{p r o x y}}$ is less than 1 and greater than the critical threshold $\beta(=0.25)$ (Stock Status Level b), the scalar $\alpha(=0.1)$ determines the slope of the non-constant portion of the control rule for $F_{O F L_{\text {proxy }} \text {. Directed fishing mortality is set to zero }}$ when the ratio $B / B_{M S Y_{\text {proxy }}}$ drops below $\beta$ (Stock Status Level c). Values for $\alpha$ and $\beta$ are based on a sensitivity analysis of the effects on $B / B_{M S Y_{p r o x y}}$ (NPFMC 2008a).

## 3.b. Basis for MMB-at-mating

The basis for projecting MMB from the survey to the time of mating is discussed in detail in Appendix C.

## 3.c. Specification of $F_{O F L}$, OFL and other applicable measures

Table 5: Basis for the OFL (Table 3 repeated). All units in metric tons.


Table 6: Basis for the OFL (Table 4 repeated). All units in millions lbs.


## 4. Specification of the retained catch portion of the total catch OFL

The retained portion of the catch for this stock is zero ( 0 t ).

## 5. Recommendations:

For $2017 / 18, B_{M S Y_{\text {proxy }}}=4,108 \mathrm{t}$, derived as the mean $M M B_{\text {mating }}$ from 1980/81 to $1984 / 85$ and $1990 / 91$ to $1997 / 98$ using the random effects model-smoothed survey time series. The stock demonstrated highly variable levels of MMB during both of these periods, likely leading to uncertain approximations for $B_{M S Y}$. Crabs were highly concentrated during the EBS bottom trawl surveys and male biomass estimates were characterized by poor precision due to limited numbers of tows with crab catches.
$M M B_{\text {mating }}$ for $2017 / 18$ was estimated at 230 t . The $B / B_{M S Y_{p r o x y}}$ ratio corresponding to the biomass reference is $0.06 . B / B_{M S Y_{\text {proxy }}}$ is $<\beta$, therefore the stock status level is c, $F_{\text {directed }}=0$, and $F_{O F L} \leq F_{M S Y}$ (as determined in the Pribilof Islands District blue king crab rebuilding plan). Total catch OFL calculations were explored in 2008 to adequately reflect the conservation needs
with this stock and to acknowledge the existing non-directed catch mortality (NPFMC 2008a). The preferred method was a total catch OFL equivalent to the average catch mortalities between $1999 / 2000$ and 2005/06. This period was after the targeted fishery was closed and did not include recent changes to the groundfish fishery that led to increased blue king crab bycatch. The OFL for $2017 / 18$, based on an average catch mortality, is 1.16 t .

## G. Calculation of the ABC

To calculate an Annual Catch Limit (ACL) to account for scientific uncertainty in the OFL, an acceptable biological catch (ABC) control rule was developed such that ACL=ABC. For Tier 3 and 4 stocks, the ABC is set below the OFL by a proportion based a predetermined probability that the ABC would exceed the OFL $\left(\mathrm{P}^{*}\right)$. Currently, $\mathrm{P}^{*}$ is set at 0.49 and represents a proportion of the OFL distribution that accounts for within assessment uncertainty ( $\sigma_{w}$ ) in the OFL to establish the maximum permissible $\mathrm{ABC}\left(\mathrm{ABC}_{\text {max }}\right)$. Any additional uncertainty to account for uncertainty outside of the assessment methods $\left(\sigma_{b}\right)$ is considered as a recommended ABC below $\mathrm{ABC}_{\text {max }}$. Additional uncertainty is included in the application of the ABC by adding the uncertainty components as $\sigma_{\text {total }}=\sqrt{\sigma_{w}^{2}+\sigma_{b}^{2}}$. For the PIBKC stock, the CPT has recommended, and the SSC has approved, a constant buffer of $25 \%$ to the OFL (NPFMC, 2014b).

## 1. Specification of the probability distribution of the OFL used in the ABC

The OFL was set based on a Tier 5 calculation of average catch mortalities between 1999/2000 and 2005/06 to adequately reflect the conservation needs with this stock and to acknowledge the existing non-directed catch mortality. As such, the OFL does not have an associated probability distribution.

## 2. List of variables related to scientific uncertainty considered in the OFL probability distribution

None. The OFL is based on a Tier 5 calculation and does not have an associated probability distribution. However, compared to other BSAI crab stocks, the uncertainty associated with the estimates of stock size and OFL for Pribilof Islands blue king crab is very high due to insufficient data and the small spatial extent of the stock relative to the survey sampling density. The coefficient of variation for the estimate of mature male biomass from the surveys for the most recent year is 0.51 , and has ranged between 0.17 and 1.00 since the 1980 peak in biomass.

## 3. List of additional uncertainties considered for alternative $\sigma_{b}$ applications to the ABC

Several sources of uncertainty are not included in the measures of uncertainty reported as part of the stock assessment:

- Survey catchability and natural mortality uncertainties are not estimated but rather are prespecified.
- $F_{M S Y}$ is assumed to be equal to $\gamma \cdot M$ when applying the OFL control rule, where the proportionality constant $\gamma$ is assumed to be equal to 1 and $M$ is assumed to be known.
- The coefficients of variation for the survey estimates of abundance for this stock are very high.
- $B_{M S Y}$ is assumed to be equivalent to average mature male biomass. However, stock biomass has fluctuated greatly and targeted fisheries only occurred from 1973-1987 and 1995-1998 so considerable uncertainty exists with this estimate of $B_{M S Y}$.


## 4. Recommendations:

For $2017 / 18, F_{\text {directed }}=0$ and the total catch OFL is based on catch biomass would maintain the conservation needs with this stock and acknowledge the existing non-directed catch mortality. In this case, the $A B C$ based on a $25 \%$ buffer of the average catch between 1999/2000 and 2005/2006 would be 0.87 t .

Table 7: Management performance (Table). All units in metric tons. The OFL is a total catch OFL for each year.

| Year | MSST | Biomass <br> $\left(\mathbf{M M B}_{\text {mating }}\right.$ | TAC | Retained <br> Catch | Total Catch <br> Mortality | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2013 / 14$ | $2,001 \mathrm{~A}$ | 225 A | closed | 0 | 0.03 | 1.16 | 1.04 |
| $2014 / 15$ | $2,055 \mathrm{~A}$ | 344 A | closed | 0 | 0.07 | 1.16 | 0.87 |
| $2015 / 16$ | $2,058 \mathrm{~A}$ | 361 A | closed | 0 | 1.18 | 1.16 | 0.87 |
| $2016 / 17$ | $2,054 \mathrm{~A}$ | 232 A | closed | 0 | 0.38 | 1.16 | 0.87 |
| $2017 / 18$ | -- | 230 B | -- | -- | -- | 1.16 | 0.87 |

Notes:
A - Based on data available to the Crab Plan Team at the time of the assessment following the end of the crab fishing year.
B - Based on data available to the Crab Plan Team at the time of the assessment for the crab fishing year.
Table 8: Management performance (Table 2 repeated). All units in the table are million pounds.

| Year | MSST | Biomass <br> $\mathbf{M M B}_{\text {mating }}$ | TAC | Retained <br> Catch | Total Catch <br> Mortality | OFL | ABC |
| :---: | :---: | ---: | :---: | :---: | :---: | :---: | :---: |
| $2013 / 14$ | 4.411 A | 0.496 A | closed | 0 | 0.0001 | 0.0026 | 0.002 |
| $2014 / 15$ | 4.531 A | 0.758 A | closed | 0 | 0.0002 | 0.0026 | 0.002 |
| $2015 / 16$ | 4.537 A | 0.796 A | closed | 0 | 0.0026 | 0.0026 | 0.002 |
| $2016 / 17$ | 4.528 A | 0.511 A | closed | 0 | 0.0008 | 0.0026 | 0.002 |
| $2016 / 17$ | -- | 0.507 A | -- | -- | -- | 0.0026 | 0.002 |

## H. Rebuilding Analyses

Rebuilding analyses results summary: A revised rebuilding plan analysis was submitted to the U.S. Secretary of Commerce in 2014 because NMFS determined that the stock was not rebuilding in a timely manner and would not meet the rebuilding horizon of 2014 . The Secretary approved the plan
in 2015, as well as the two amendments that implement it (Amendment 43 to the King and Tanner Crab Fishery Management Plan and Amendment 103 to the BSAI Groundfish Fishery Management Plan). These amendments impose a closure to all fishing for Pacific cod with pot gear in the Pribilof Islands Habitat Conservation Zone. This measure was designed to protect the main concentration of the stock from the fishery with the highest observed rates of bycatch (NPFMC, 2014a). The area has been closed to trawling since 1995.

## I. Data Gaps and Research Priorities

Given the large CVs associated with the survey abundance and biomass estimates for the Pribilof Islands blue king crab stock, assessment of this species might benefit from additional surveys using alternative gear at finer spatial resolution. Jared Weems, a PhD student at University of Alaska, Fairbanks, is conducting research on alternative survey designs, including visual censuses, drop camera, and collector traps to better quantify PIBKC in a study funded by NPRB. Other data gaps include stock-specific natural mortality rates and a lack of understanding regarding processes apparently preventing successful recruitment to the Pribilof District.

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## Tables

Table 9: Total retained catches from directed fisheries for Pribilof Islands District blue king crab (Bowers et al. 2011; D. Pengilly and J. Webb, ADFG, personal communications).

| Year | Retained Catch |  | $\begin{array}{r} \text { Avg. CPUE } \\ \text { legal crabs/pot } \end{array}$ |
| :---: | :---: | :---: | :---: |
|  | Abundance | Biomass (t) |  |
| 1973/1974 | 174,420 | 579 | 26 |
| 1974/1975 | 908,072 | 3,224 | 20 |
| 1975/1976 | 314,931 | 1,104 | 19 |
| 1976/1977 | 855,505 | 2,999 | 12 |
| 1977/1978 | 807,092 | 2,929 | 8 |
| 1978/1979 | 797,364 | 2,901 | 8 |
| 1979/1980 | 815,557 | 2,719 | 10 |
| 1980/1981 | 1,497,101 | 4,976 | 9 |
| 1981/1982 | 1,202,499 | 4,119 | 7 |
| 1982/1983 | 587,908 | 1,998 | 5 |
| 1983/1984 | 276,364 | 995 | 3 |
| 1984/1985 | 40,427 | 139 | 3 |
| 1985/1986 | 76,945 | 240 | 3 |
| 1986/1987 | 36,988 | 117 | 2 |
| 1987/1988 | 95,130 | 318 | 2 |
| 1988/1989 | 0 | 0 | -- |
| 1989/1990 | 0 | 0 | -- |
| 1990/1991 | 0 | 0 | -- |
| 1991/1992 | 0 | 0 | -- |
| 1992/1993 | 0 | 0 | -- |
| 1993/1994 | 0 | 0 | -- |
| 1994/1995 | 0 | 0 | -- |
| 1995/1996 | 190,951 | 628 | 5 |
| 1996/1997 | 127,712 | 425 | 4 |
| 1997/1998 | 68,603 | 232 | 3 |
| 1998/1999 | 68,419 | 234 | 3 |
| $\begin{gathered} \text { 1999/2000 - } \\ \text { 2016/2017 } \end{gathered}$ | 0 | 0 | -- |

Table 10: Total bycatch (non-retained catch) from the directed and non-directed fisheries for Pribilof Islands District blue king crab. Crab fishery bycatch data is not available prior to 1996/1997 (Bowers et al. 2011; D. Pengilly ADFG). Gear-specific groundfish fishery data is not available prior to 1991/1992 (J. Mondragon, NMFS).

| fishery year | crab (pot) fisheries (t) |  |  | groundfish fisheries (t) |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | females | legal males | sublegal males | fixed gear | trawl gear |
| 1991/92 | -- | -- | -- | 0.067 | 6.199 |
| 1992/93 | -- | -- | -- | 0.879 | 60.791 |
| 1993/94 | -- | -- | -- | 0.000 | 34.232 |
| 1994/95 | -- | -- | -- | 0.035 | 6.856 |
| 1995/96 | -- | -- | -- | 0.108 | 1.284 |
| 1996/97 | 0.000 | 0.000 | 0.807 | 0.031 | 0.067 |
| 1997/98 | 0.000 | 0.000 | 0.000 | 1.462 | 0.130 |
| 1998/99 | 3.715 | 2.295 | 0.467 | 19.800 | 0.079 |
| 1999/00 | 1.969 | 3.493 | 4.291 | 0.795 | 0.020 |
| 2000/01 | 0.000 | 0.000 | 0.000 | 0.116 | 0.023 |
| 2001/02 | 0.000 | 0.000 | 0.000 | 0.833 | 0.029 |
| 2002/03 | 0.000 | 0.000 | 0.000 | 0.071 | 0.297 |
| 2003/04 | 0.000 | 0.000 | 0.000 | 0.345 | 0.227 |
| 2004/05 | 0.000 | 0.000 | 0.000 | 0.816 | 0.002 |
| 2005/06 | 0.050 | 0.000 | 0.000 | 0.353 | 1.339 |
| 2006/07 | 0.104 | 0.000 | 0.000 | 0.138 | 0.074 |
| 2007/08 | 0.136 | 0.000 | 0.000 | 3.993 | 0.132 |
| 2008/09 | 0.000 | 0.000 | 0.000 | 0.141 | 0.473 |
| 2009/10 | 0.000 | 0.000 | 0.000 | 0.216 | 0.207 |
| 2010/11 | 0.000 | 0.000 | 0.186 | 0.039 | 0.056 |
| 2011/12 | 0.000 | 0.000 | 0.000 | 0.112 | 0.007 |
| 2012/13 | 0.000 | 0.000 | 0.000 | 0.167 | 0.669 |
| 2013/14 | 0.000 | 0.000 | 0.000 | 0.064 | 0.000 |
| 2014/15 | 0.000 | 0.000 | 0.000 | 0.144 | 0.000 |
| 2015/16 | 0.103 | 0.000 | 0.230 | 0.744 | 0.808 |
| 2016/17 | 0.000 | 0.000 | 0.000 | 0.090 | 0.455 |

Table 11: Total bycatch (discard) mortality from directed and non-directed fisheries for Pribilof Islands District blue king crab. Gear-specific handling mortalities were applied to estimates of non-retained catch from Table 2 for fixed gear (i.e., pot and hook/line; 0.2) and trawl gear (0.8).

| fishery year | crab (pot) fisheries (t) |  |  | groundfish fisheries ( t ) <br> fixed gear trawl gear |  | total bycatch mortality ( t ) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | females | legal males | sublegal males |  |  |  |
| 1991/92 | -- | -- | -- | 0.013 | 4.959 | 4.973 |
| 1992/93 | -- | -- | -- | 0.176 | 48.633 | 48.809 |
| 1993/94 | -- | -- | -- | 0.000 | 27.386 | 27.386 |
| 1994/95 | -- | -- | -- | 0.007 | 5.485 | 5.492 |
| 1995/96 | -- | -- | -- | 0.022 | 1.027 | 1.049 |
| 1996/97 | 0.000 | 0.000 | 0.161 | 0.006 | 0.054 | 0.221 |
| 1997/98 | 0.000 | 0.000 | 0.000 | 0.292 | 0.104 | 0.396 |
| 1998/99 | 0.743 | 0.459 | 0.093 | 3.960 | 0.063 | 5.319 |
| 1999/00 | 0.394 | 0.699 | 0.858 | 0.159 | 0.016 | 2.125 |
| 2000/01 | 0.000 | 0.000 | 0.000 | 0.023 | 0.018 | 0.042 |
| 2001/02 | 0.000 | 0.000 | 0.000 | 0.167 | 0.023 | 0.190 |
| 2002/03 | 0.000 | 0.000 | 0.000 | 0.014 | 0.238 | 0.252 |
| 2003/04 | 0.000 | 0.000 | 0.000 | 0.069 | 0.182 | 0.251 |
| 2004/05 | 0.000 | 0.000 | 0.000 | 0.163 | 0.002 | 0.165 |
| 2005/06 | 0.010 | 0.000 | 0.000 | 0.071 | 1.071 | 1.152 |
| 2006/07 | 0.021 | 0.000 | 0.000 | 0.028 | 0.059 | 0.108 |
| 2007/08 | 0.027 | 0.000 | 0.000 | 0.799 | 0.106 | 0.931 |
| 2008/09 | 0.000 | 0.000 | 0.000 | 0.028 | 0.378 | 0.407 |
| 2009/10 | 0.000 | 0.000 | 0.000 | 0.043 | 0.165 | 0.209 |
| 2010/11 | 0.000 | 0.000 | 0.037 | 0.008 | 0.045 | 0.090 |
| 2011/12 | 0.000 | 0.000 | 0.000 | 0.022 | 0.006 | 0.028 |
| 2012/13 | 0.000 | 0.000 | 0.000 | 0.033 | 0.535 | 0.568 |
| 2013/14 | 0.000 | 0.000 | 0.000 | 0.013 | 0.000 | 0.013 |
| 2014/15 | 0.000 | 0.000 | 0.000 | 0.029 | 0.000 | 0.029 |
| 2015/16 | 0.021 | 0.000 | 0.046 | 0.149 | 0.646 | 0.861 |
| 2016/17 | 0.000 | 0.000 | 0.000 | 0.018 | 0.364 | 0.382 |

Table 12: Bycatch (in kg ) of PIBKC in the groundfish fisheries, by target type.

| Crab <br> Fishery Year | \% bycatch (biomass) by trip target |  |  |  | total bycatch (\# crabs) |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | yellowfin <br> sole <br> \% | Pacific cod \% | flathead sole \% | rock sole \% |  |
| 2003/04 | 47 | 22 | 31 | < 1 | 252 |
| 2004/05 | <1 | 100 | <1 | <1 | 259 |
| 2005/06 | < 1 | 97 | 3 | < 1 | 757 |
| 2006/07 | 54 | 20 | <1 | 26 | 96 |
| 2007/08 | 3 | 96 | 1 | < 1 | 2,950 |
| 2008/09 | 77 | 23 | $<1$ | $<1$ | 295 |
| 2009/10 | 31 | 51 | 17 | $<1$ | 281 |
| 2010/11 | $<1$ | 39 | 59 | $<1$ | 48 |
| 2011/12 | <1 | 100 | <1 | $<1$ | 62 |
| 2012/13 | 77 | 20 | 3 | $<1$ | 410 |
| 2013/14 | <1 | 99 | $<1$ | < 1 | 39 |
| 2014/15 | <1 | 99 | <1 | <1 | 64 |
| 2015/16 | 43 | 48 | 9 | < 1 | 609 |
| 2016/17 | 16 | 16 | $<1$ | 68 | 580 |

Table 13: Bycatch (in kg) of PIBKC in the groundfish fisheries, by gear type.

| Crab <br> Fishery <br> Year | \% bycatch (biomass) by gear type |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  | non-pelagic trawl \% | pelagic <br> trawl <br> \% | hook and line \% | $\begin{gathered} \text { pot } \\ \% \end{gathered}$ | bycatch <br> (\# crabs) |
| 2003/04 | 79 | 0 | 21 | 0 | 252 |
| 2004/05 | 1 | 0 | 99 | 0 | 259 |
| 2005/06 | 3 | 0 | 18 | 79 | 757 |
| 2006/07 | 20 | 0 | 20 | 0 | 96 |
| 2007/08 | 3 | 0 | 1 | 95 | 2,950 |
| 2008/09 | 77 | 0 | 23 | 0 | 295 |
| 2009/10 | 49 | 0 | 7 | 44 | 281 |
| 2010/11 | 59 | 0 | 41 | 0 | 48 |
| 2011/12 | 6 | 0 | 94 | 0 | 62 |
| 2012/13 | 80 | 0 | 20 | 0 | 410 |
| 2013/14 | 0 | 0 | 100 | 0 | 39 |
| 2014/15 | 0 | 0 | 100 | 0 | 64 |
| 2015/16 | 52 | 0 | 48 | 0 | 609 |
| 2016/17 | 83 | 0 | 17 | 0 | 580 |

Table 14: Summary of recent NMFS annual EBS bottom trawl surveys for the Pribilof Islands District blue king crab by stock component.

|  | Stock | Number of | Tows with | Number of | Abundance (millions) |  | Biomass (mt) |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Component | tows in District | crab | crab measured | estimate | 95\% CI | estimate | 95\% CI |
| 2017 | Immature male | 86 | 2 | 4 | 0.068 | 0.103 | 45 | 68 |
|  | Mature male | 86 | 4 | 4 | 0.091 | 0.089 | 253 | 254 |
|  | Legal male | 86 | 3 | 3 | 0.072 | 0.083 | 223 | 250 |
|  | Immature female | 86 | 3 | 7 | 0.188 | 0.275 | 107 | 170 |
|  | Mature female | 86 | 4 | 8 | 0.162 | 0.169 | 152 | 166 |
| 2016 | Immature male | 86 | 4 | 5 | 0.094 | 0.095 | 70 | 67 |
|  | Mature male | 86 | 3 | 3 | 0.056 | 0.062 | 129 | 154 |
|  | Legal male | 86 | 1 | 1 | 0.019 | 0.038 | 68 | 133 |
|  | Immature female | 86 | 4 | 5 | 0.132 | 0.130 | 49 | 48 |
|  | Mature female | 86 | 7 | 19 | 0.323 | 0.328 | 352 | 340 |
| 2015 | Immature male | 86 | 2 | 4 | 0.076 | 0.113 | 82 | 120 |
|  | Mature male | 86 | 8 | 13 | 0.234 | 0.168 | 622 | 480 |
|  | Legal male | 86 | 5 | 7 | 0.125 | 0.109 | 428 | 385 |
|  | Immature female | 86 | 0 | 0 | 0.000 | 0.000 | 0 | 0 |
|  | Mature female | 86 | 4 | 11 | 0.202 | 0.260 | 160 | 207 |
| 2014 | Immature male | 86 | 3 | 5 | 0.091 | 0.105 | 83 | 102 |
|  | Mature male | 86 | 2 | 5 | 0.092 | 0.128 | 233 | 320 |
|  | Legal male | 86 | 2 | 5 | 0.092 | 0.128 | 233 | 320 |
|  | Immature female | 86 | 1 | 1 | 0.028 | 0.054 | 16 | 32 |
|  | Mature female | 86 | 3 | 4 | 0.074 | 0.088 | 91 | 108 |

Table 15: Abundance time series for Pribilof Islands blue king crab from the NMFS annual EBS bottom trawl survey.

| Year | Males |  |  |  |  |  |  |  | Females total |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | immature |  | mature |  | legal |  | total |  |  |  |
|  | abundance | cv | abundance | cv | abundance | cv | abundance | cv |  | cv |
| 1975 | 8,475,781 | 0.57 | 15,288,16¢ | 0.50 | 9,051,486 | 0.50 | 23,763,95C | 0.47 | 13,147,587 | 0.61 |
| 1976 | 4,959,559 | 0.95 | 4,782,105 | 0.45 | 4,012,289 | 0.47 | 9,741,664 | 0.59 | 8,138,538 | 0.91 |
| 1977 | 4,215,865 | 0.46 | 13,043,983 | 0.74 | 11,768,92' | 0.77 | 17,259,848 | 0.63 | 14,731,651 | 0.86 |
| 1978 | 2,421,458 | 0.50 | 6,140,638 | 0.50 | 3,922,874 | 0.62 | 8,562,096 | 0.43 | 5,987,437 | 0.66 |
| 1979 | 79,355 | 0.70 | 4,107,868 | 0.33 | 3,017,119 | 0.31 | 4,187,222 | 0.32 | 1,311,351 | 0.77 |
| 1980 | 2,732,728 | 0.47 | 7,842,342 | 0.41 | 6,244,058 | 0.42 | 10,575,07¢ | 0.40 | 183,684,143 | 0.98 |
| 1981 | 2,099,475 | 0.32 | 3,834,431 | 0.18 | 3,245,951 | 0.18 | 5,933,906 | 0.21 | 6,260,015 | 0.42 |
| 1982 | 1,371,283 | 0.28 | 2,353,813 | 0.18 | 2,071,468 | 0.19 | 3,725,096 | 0.17 | 8,713,260 | 0.63 |
| 1983 | 1,030,732 | 0.36 | 1,851,301 | 0.19 | 1,321,395 | 0.17 | 2,882,033 | 0.22 | 9,771,695 | 0.76 |
| 1984 | 517,574 | 0.40 | 770,643 | 0.22 | 558,226 | 0.25 | 1,288,217 | 0.21 | 3,234,663 | 0.37 |
| 1985 | 67,765 | 0.60 | 428,076 | 0.28 | 270,242 | 0.29 | 495,841 | 0.27 | 746,266 | 0.36 |
| 1986 | 18,904 | 1.00 | 480,198 | 0.31 | 460,311 | 0.31 | 499,102 | 0.30 | 2,138,616 | 0.88 |
| 1987 | 621,541 | 0.83 | 903,180 | 0.41 | 830,151 | 0.42 | 1,524,721 | 0.43 | 1,072,008 | 0.48 |
| 1988 | 1,238,053 | 0.84 | 237,868 | 0.51 | 237,868 | 0.51 | 1,475,921 | 0.71 | 1,363,093 | 0.64 |
| 1989 | 3,514,764 | 0.59 | 239,948 | 0.62 | 239,948 | 0.62 | 3,754,712 | 0.58 | 3,777,855 | 0.58 |
| 1990 | 2,449,864 | 0.60 | 1,470,419 | 0.63 | 571,708 | 0.54 | 3,920,283 | 0.58 | 4,223,169 | 0.56 |
| 1991 | 1,920,443 | 0.37 | 2,014,086 | 0.36 | 1,237,558 | 0.44 | 3,934,529 | 0.34 | 3,572,899 | 0.35 |
| 1992 | 2,435,796 | 0.59 | 1,935,278 | 0.42 | 1,154,465 | 0.45 | 4,371,074 | 0.48 | 3,946,863 | 0.52 |
| 1993 | 1,483,524 | 0.52 | 1,875,500 | 0.31 | 1,114,301 | 0.30 | 3,359,024 | 0.34 | 2,663,329 | 0.38 |
| 1994 | 638,520 | 0.37 | 1,294,263 | 0.34 | 935,269 | 0.34 | 1,932,783 | 0.33 | 5,191,978 | 0.44 |
| 1995 | 1,146,803 | 0.89 | 3,101,712 | 0.60 | 2,186,409 | 0.62 | 4,248,514 | 0.67 | 4,697,035 | 0.49 |
| 1996 | 719,430 | 0.63 | 1,712,015 | 0.28 | 1,269,275 | 0.26 | 2,431,445 | 0.33 | 5,321,557 | 0.46 |
| 1997 | 467,234 | 0.53 | 1,201,296 | 0.29 | 932,852 | 0.28 | 1,668,530 | 0.34 | 2,934,717 | 0.39 |
| 1998 | 949,447 | 0.46 | 967,098 | 0.25 | 797,187 | 0.25 | 1,916,545 | 0.31 | 2,329,750 | 0.37 |
| 1999 | 159,536 | 0.37 | 617,258 | 0.33 | 452,740 | 0.34 | 776,794 | 0.33 | 2,755,976 | 0.49 |
| 2000 | 163,835 | 0.56 | 725,051 | 0.30 | 527,589 | 0.30 | 888,885 | 0.31 | 1,363,070 | 0.46 |
| 2001 | 92,918 | 0.65 | 522,239 | 0.71 | 445,863 | 0.74 | 615,157 | 0.69 | 1,715,981 | 0.74 |
| 2002 | 0 | 0.00 | 225,476 | 0.47 | 207,146 | 0.49 | 225,476 | 0.47 | 1,240,582 | 0.78 |
| 2003 | 45,271 | 0.72 | 228,897 | 0.39 | 213,572 | 0.40 | 274,168 | 0.34 | 1,187,583 | 0.72 |
| 2004 | 87,651 | 0.59 | 47,905 | 0.56 | 15,584 | 1.00 | 135,556 | 0.42 | 168,094 | 0.51 |
| 2005 | 1,981,338 | 0.96 | 91,932 | 0.71 | 91,932 | 0.71 | 2,073,270 | 0.92 | 2,557,310 | 0.89 |
| 2006 | 138,118 | 0.49 | 55,579 | 0.56 | 38,242 | 0.70 | 193,697 | 0.42 | 542,588 | 0.62 |
| 2007 | 246,165 | 0.72 | 110,080 | 0.85 | 54,403 | 0.75 | 356,245 | 0.64 | 288,245 | 0.59 |
| 2008 | 233,919 | 0.93 | 18,256 | 1.00 | 18,256 | 1.00 | 252,174 | 0.86 | 779,488 | 0.75 |
| 2009 | 267,717 | 0.63 | 248,626 | 0.73 | 68,117 | 0.59 | 516,343 | 0.68 | 629,385 | 0.76 |
| 2010 | 101,151 | 0.84 | 130,465 | 0.49 | 64,703 | 0.48 | 231,616 | 0.61 | 414,660 | 0.62 |
| 2011 | 0 | 0.00 | 165,525 | 0.79 | 129,098 | 0.87 | 165,525 | 0.79 | 54,601 | 0.56 |
| 2012 | 194,522 | 1.00 | 272,233 | 0.80 | 164,165 | 0.68 | 466,755 | 0.88 | 346,777 | 0.70 |
| 2013 | 76,351 | 1.00 | 104,361 | 0.86 | 68,726 | 0.80 | 180,712 | 0.64 | 195,644 | 0.53 |
| 2014 | 90,990 | 0.59 | 91,856 | 0.71 | 91,856 | 0.71 | 182,846 | 0.57 | 102,088 | 0.51 |
| 2015 | 75,575 | 0.77 | 233,630 | 0.37 | 124,592 | 0.45 | 309,205 | 0.41 | 202,464 | 0.65 |
| 2016 | 94,022 | 0.52 | 55,852 | 0.56 | 19,345 | 1.00 | 149,874 | 0.49 | 454,450 | 0.50 |
| 2017 | 68,238 | 0.77 | 90,645 | 0.50 | 71,937 | 0.59 | 158,884 | 0.46 | 349,659 | 0.54 |

Table 16: Biomass time series for Pribilof Islands blue king crab from the NMFS annual EBS bottom trawl survey.

| Year | immatu <br> biomass ( t ) | cv | $\text { biomass ( } \mathrm{t} \text { ) }$ | cv | biomass ( t ) | cv | $\begin{array}{r} \text { total } \\ \text { biomass }(\mathrm{t}) \\ \hline \end{array}$ | cv | Femalestotalbiomass (t) $\quad \mathrm{cv}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1975 | 8,341 | 0.52 | 38,054 | 0.50 | 27,016 | 0.50 | 46,395 | 0.47 | 12,442 | 0.64 |
| 1976 | 4,129 | 0.94 | 14,059 | 0.45 | 12,649 | 0.47 | 18,188 | 0.45 | 5,792 | 0.89 |
| 1977 | 3,713 | 0.44 | 42,618 | 0.77 | 40,366 | 0.78 | 46,332 | 0.73 | 13,572 | 0.87 |
| 1978 | 2,765 | 0.51 | 17,370 | 0.56 | 13,517 | 0.64 | 20,135 | 0.51 | 6,492 | 0.72 |
| 1979 | 61 | 0.79 | 10,959 | 0.32 | 9,040 | 0.31 | 11,021 | 0.31 | 1,189 | 0.76 |
| 1980 | 2,084 | 0.49 | 23,553 | 0.43 | 20,679 | 0.45 | 25,637 | 0.42 | 212,303 | 0.98 |
| 1981 | 1,704 | 0.30 | 11,628 | 0.17 | 10,554 | 0.17 | 13,332 | 0.18 | 6,484 | 0.46 |
| 1982 | 1,152 | 0.23 | 7,389 | 0.19 | 6,893 | 0.19 | 8,541 | 0.17 | 9,377 | 0.67 |
| 1983 | 962 | 0.36 | 5,409 | 0.18 | 4,474 | 0.17 | 6,371 | 0.19 | 10,248 | 0.78 |
| 1984 | 130 | 0.36 | 2,216 | 0.23 | 1,824 | 0.25 | 2,345 | 0.22 | 3,085 | 0.38 |
| 1985 | 39 | 0.73 | 1,055 | 0.27 | 756 | 0.28 | 1,094 | 0.26 | 525 | 0.44 |
| 1986 | 4 | 1.00 | 1,505 | 0.30 | 1,473 | 0.31 | 1,508 | 0.30 | 2,431 | 0.90 |
| 1987 | 191 | 0.78 | 2,923 | 0.41 | 2,781 | 0.41 | 3,115 | 0.40 | 913 | 0.53 |
| 1988 | 170 | 0.71 | 842 | 0.53 | 842 | 0.53 | 1,012 | 0.46 | 718 | 0.47 |
| 1989 | 1,275 | 0.62 | 828 | 0.64 | 828 | 0.64 | 2,102 | 0.55 | 1,746 | 0.50 |
| 1990 | 2,004 | 0.66 | 3,078 | 0.60 | 1,514 | 0.52 | 5,082 | 0.61 | 2,929 | 0.49 |
| 1991 | 1,377 | 0.39 | 4,690 | 0.39 | 3,326 | 0.45 | 6,067 | 0.37 | 2,776 | 0.38 |
| 1992 | 1,801 | 0.51 | 4,391 | 0.42 | 3,035 | 0.45 | 6,192 | 0.43 | 2,649 | 0.46 |
| 1993 | 1,089 | 0.54 | 4,556 | 0.31 | 3,203 | 0.30 | 5,644 | 0.30 | 2,092 | 0.40 |
| 1994 | 619 | 0.39 | 3,410 | 0.34 | 2,806 | 0.35 | 4,029 | 0.34 | 4,893 | 0.44 |
| 1995 | 968 | 0.86 | 8,360 | 0.60 | 6,787 | 0.62 | 9,328 | 0.63 | 4,279 | 0.50 |
| 1996 | 745 | 0.61 | 4,641 | 0.27 | 3,873 | 0.27 | 5,386 | 0.28 | 5,585 | 0.49 |
| 1997 | 381 | 0.55 | 3,233 | 0.28 | 2,765 | 0.27 | 3,614 | 0.29 | 3,028 | 0.41 |
| 1998 | 692 | 0.41 | 2,798 | 0.25 | 2,510 | 0.25 | 3,490 | 0.25 | 2,182 | 0.39 |
| 1999 | 161 | 0.40 | 1,729 | 0.34 | 1,426 | 0.35 | 1,890 | 0.33 | 2,868 | 0.47 |
| 2000 | 113 | 0.68 | 2,091 | 0.30 | 1,746 | 0.31 | 2,205 | 0.30 | 1,462 | 0.46 |
| 2001 | 87 | 0.76 | 1,599 | 0.73 | 1,461 | 0.76 | 1,686 | 0.73 | 1,817 | 0.72 |
| 2002 | 0 | 0.00 | 680 | 0.51 | 647 | 0.52 | 680 | 0.51 | 1,401 | 0.78 |
| 2003 | 19 | 0.98 | 702 | 0.40 | 671 | 0.41 | 721 | 0.39 | 1,307 | 0.73 |
| 2004 | 36 | 0.65 | 107 | 0.58 | 48 | 1.00 | 143 | 0.46 | 123 | 0.50 |
| 2005 | 326 | 0.94 | 344 | 0.71 | 344 | 0.71 | 670 | 0.59 | 847 | 0.61 |
| 2006 | 87 | 0.58 | 166 | 0.60 | 139 | 0.70 | 253 | 0.46 | 576 | 0.71 |
| 2007 | 197 | 0.74 | 306 | 0.80 | 206 | 0.73 | 503 | 0.66 | 282 | 0.71 |
| 2008 | 212 | 0.95 | 46 | 1.00 | 46 | 1.00 | 258 | 0.80 | 672 | 0.70 |
| 2009 | 254 | 0.68 | 497 | 0.71 | 187 | 0.60 | 751 | 0.70 | 625 | 0.82 |
| 2010 | 92 | 0.85 | 303 | 0.46 | 190 | 0.48 | 395 | 0.52 | 394 | 0.63 |
| 2011 | 0 | 0.00 | 461 | 0.84 | 399 | 0.89 | 461 | 0.84 | 37 | 0.67 |
| 2012 | 165 | 1.00 | 644 | 0.74 | 459 | 0.64 | 809 | 0.79 | 237 | 0.64 |
| 2013 | 15 | 1.00 | 250 | 0.80 | 190 | 0.75 | 265 | 0.75 | 166 | 0.65 |
| 2014 | 83 | 0.62 | 233 | 0.70 | 233 | 0.70 | 317 | 0.57 | 108 | 0.53 |
| 2015 | 82 | 0.75 | 622 | 0.39 | 428 | 0.46 | 703 | 0.39 | 160 | 0.66 |
| 2016 | 70 | 0.49 | 129 | 0.61 | 68 | 1.00 | 199 | 0.52 | 401 | 0.48 |
| 2017 | 45 | 0.77 | 253 | 0.51 | 223 | 0.57 | 298 | 0.47 | 259 | 0.53 |

Table 17: Smoothed mature male biomass (MMB) at the time of the survey for Pribilof Islands blue king crab using using the Random Effects Model.


Table 18: Estimates of mature male biomass (MMB) at the time of mating for Pribilof Islands blue king crab using: (1) the "raw" survey biomass time series and (2) the survey biomass time series smoothed using the Random Effects Model. Shaded rows signify averaging time period for $B_{M S Y} / \mathrm{MSST}$. The 2017/18 estimates are projected values (see Appendix C).

| year | "Raw" Survey <br> Biomass (t) | Random Effects <br> Model (t) |
| :---: | ---: | ---: |
| $1975 / 76$ | 33,223 | 23,182 |
| $1976 / 77$ | 9,834 | 15,117 |
| $1977 / 78$ | 35,611 | 16,386 |
| $1978 / 79$ | 12,904 | 12,549 |
| $1979 / 80$ | 7,304 | 9,438 |
| $1980 / 81$ | 16,519 | 9,364 |
| $1981 / 82$ | 6,590 | 6,406 |
| $1982 / 83$ | 4,769 | 4,822 |
| $1983 / 84$ | 3,934 | 3,639 |
| $1984 / 85$ | 1,862 | 1,981 |
| $1985 / 86$ | 723 | 989 |
| $1986 / 87$ | 1,244 | 1,289 |
| $1987 / 88$ | 2,333 | 1,436 |
| $1988 / 89$ | 758 | 1,285 |
| $1989 / 90$ | 745 | 1,439 |
| $1990 / 91$ | 2,771 | 2,343 |
| $1991 / 92$ | 4,220 | 3,430 |
| $1992 / 93$ | 3,930 | 3,741 |
| $1993 / 94$ | 4,089 | 3,885 |
| $1994 / 95$ | 3,068 | 3,614 |
| $1995 / 96$ | 6,937 | 3,859 |
| $1996 / 97$ | 3,776 | 3,546 |
| $1997 / 98$ | 2,692 | 2,773 |
| $1998 / 99$ | 2,291 | 2,207 |
| $1999 / 00$ | 1,555 | 1,777 |
| $2000 / 01$ | 1,883 | 1,653 |
| $2001 / 02$ | 1,439 | 1,138 |
| $2002 / 03$ | 612 | 706 |
| $2003 / 04$ | 632 | 494 |
| $2004 / 05$ | 96 | 250 |
| $2005 / 06$ | 309 | 239 |
| $2006 / 07$ | 149 | 203 |
| $2007 / 08$ | 275 | 206 |
| $2008 / 09$ | 41 | 189 |
| $2009 / 10$ | 447 | 265 |
| $2010 / 11$ | 273 | 289 |
| $2011 / 12$ | 415 | 335 |
| $2012 / 13$ | 579 | 359 |
| $2013 / 14$ | 225 | 311 |
| $2014 / 15$ | 210 | 305 |
| $2015 / 16$ | 559 | 359 |
| $2016 / 17$ | 232 |  |
| $2017 / 18 *$ | 230 |  |

## Figures



Figure 1: Distribution of blue king crab, *Paralithodes platypus*, in Alaskan waters.


Figure 2: Map of the ADFG King Crab Registration Area Q (Bering Sea), showing (among others) the Pribilof District, which constitutes the stock boundary for PIBKC. The figure also indicates the additional 20 nm strip (red dotted line) added in 2013 for calculating biomass and catch data in the Pribilof District.


Figure 3: Historical harvests and Guideline Harvest Levels (GHLs) for Pribilof Islands red and blue king crab (from Bowers et al., 2011).


Figure 4: The shaded area shows the Pribilof Islands Habitat Conservation Zone (PIHCZ). Trawl fishing is prohibited year-round in this zone (as of 1995), as is pot fishing for Pacific cod (as of 2015). Also shown is a portion of the NMFS annual EBS bottom trawl survey grid.


Figure 5: Time series of survey abundance for females (immature, mature, and total).


Figure 6: Time series of survey abundance for males in several categories (immature, mature, sublegal, legal and total).


Figure 7: Time series of survey abundance for females (immature, mature, and total).


Figure 8: Time series of survey biomass for males in several categories (immature, mature, sublegal, legal and total).


Figure 9: Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from recent NMFS EBS bottom trawl surveys.


Figure 10: Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islands blue king crab by 5 mm length bins. The top row shows the entire time series, the bottom shows the size compositions since 1995.


Figure 11: Size frequencies by shell condition for male Pribilof Island blue king crab in 5 mm length bins from recent NMFS EBS bottom trawl surveys.


Figure 12: Size frequencies from the annual NMSF bottom trawl survey for male Pribilof Islands blue king crab by 5 mm length bins. The top row shows the entire time series, the bottom shows the size compositions since 1995.


Figure 13: $F_{O F L}$ Control Rule for Tier 4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set to 0 below $\beta(=0.25)$.

# Appendix A: PIBKC Bycatch in the Groundfish Fisheries: 2009/10-2016/17 

William Stockhausen

11 September, 2017

## Contents

Introduction ..... 1
Bycatch by gear type ..... 2
Bycatch by target type ..... 3
Spatial patterns of bycatch ..... 4

## List of Tables

1 Bycatch of PIBKC in the groundfish fisheries, by gear type. Biomass is in kilograms. 2
2 Bycatch of PIBKC in the groundfish fisheries by target type. Biomass is in kilograms. 3

## List of Figures

1 Bycatch of PIBKC in the groundfish fisheries by gear type. . . . . . . . . . . . . . . 2
2 Bycatch of PIBKC in the groundfish fisheries, by target type. . . . . . . . . . . . . . 3
3 Basemap for subsequent maps, with EBS bathymetry (blue lines), ADFG stat areas (black rectangles), and the Pribilof Islands Habitat Conservation Area (orange outline). 4
4 (1 of 4). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries. 5
5 (2 of 4). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries. 6
6 (3 of 4). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries. 7
7 (4 of 4). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries. 8
8 (1 of 4). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries. 9
9 (2 of 4). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries. 10
10 (3 of 4). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries. 11
11 (4 of 4). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries. 12

## Introduction

Bycatch of PIBKC in the groundfish fisheries during 2009/10-2016/17 was downloaded from AKFIN on Aug. 30, 2017 as file ("FromAKFIN.PIBKC.BycatchEstimates.2009-2016.csv").

## Bycatch by gear type

The bycatch of PIBKC by gear type (trawl or fixed) are presented in the following table. Catches using pelagic and non-pelagic trawl gear have been aggregated as "trawl" gear, while catches using hook-and-line (longline) and pot gear have been aggregated as "fixed" gear.

Table 1: Bycatch of PIBKC in the groundfish fisheries, by gear type. Biomass is in kilograms.

| fixed |  |  |  |  |  | trawl |  |  |  |
| :--- | :---: | ---: | ---: | :---: | ---: | :---: | ---: | ---: | :---: |
| year | vessel count | haul count | biomass | number | vessel count | haul count | biomass | number |  |
| 2009 | 4228 | 431820 | 216 | 87 | 2051 | 90347 | 207 | 193 |  |
| 2010 | 5415 | 609789 | 44 | 16 | 1858 | 38463 | 56 | 35 |  |
| 2011 | 4611 | 397979 | 112 | 54 | 1098 | 22300 | 7 | 8 |  |
| 2012 | 5024 | 502872 | 170 | 72 | 3785 | 69175 | 669 | 340 |  |
| 2013 | 8277 | 2172175 | 65 | 41 | 2247 | 35730 | 0 | 0 |  |
| 2014 | 8155 | 2026114 | 144 | 65 | 1899 | 58843 | 0 | 0 |  |
| 2015 | 7892 | 1470800 | 744 | 352 | 3198 | 68219 | 808 | 257 |  |
| 2016 | 5304 | 1189582 | 90 | 57 | 3280 | 53174 | 455 | 524 |  |



Figure 1: Bycatch of PIBKC in the groundfish fisheries by gear type.

## Bycatch by target type

Bycatch of PIBKC in the groundfish fisheries is presented by groundfish target type in this section. Groundfish targets with less than 10 kg bycatch over the 2009-2016 period have been dropped from the table and figure.

Table 2: Bycatch of PIBKC in the groundfish fisheries by target type. Biomass is in kilograms.

|  | Flathead Sole |  | Pacific Cod |  | Rock Sole - BSAI |  | Yellowfin Sole - BSAI |  |
| ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: |
| year | biomass | number | biomass | number | biomass | number | biomass | number |
| 2009 | 71 | 54 | 216 | 87 | 0 | 0 | 129 | 119 |
| 2010 | 56 | 35 | 42 | 14 | 0 | 0 | 0 | 0 |
| 2011 | 0 | 0 | 119 | 62 | 0 | 0 | 0 | 0 |
| 2012 | 24 | 12 | 170 | 72 | 0 | 0 | 645 | 328 |
| 2013 | 0 | 0 | 64 | 41 | 0 | 0 | 0 | 0 |
| 2014 | 0 | 0 | 143 | 64 | 0 | 0 | 0 | 0 |
| 2015 | 147 | 58 | 742 | 351 | 0 | 0 | 661 | 199 |
| 2016 | 0 | 0 | 89 | 56 | 368 | 432 | 87 | 92 |



Figure 2: Bycatch of PIBKC in the groundfish fisheries, by target type.

## Spatial patterns of bycatch

Spatial patterns of PIBKC bycatch, by ADFG stat area, in the groundfish fisheries are illustrated by gear type in Figures 4-5. All plots are on the same scale.


Figure 3: Basemap for subsequent maps, with EBS bathymetry (blue lines), ADFG stat areas (black rectangles), and the Pribilof Islands Habitat Conservation Area (orange outline).


Figure 4: (1 of 4). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries.


Figure 5: (2 of 4). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries.


Figure 6: (3 of 4). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries.


Figure 7: (4 of 4). Bycatch of PIBKC, by ADFG stat area, in the fixed gear groundfish fisheries.


Figure 8: (1 of 4). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries.


Figure 9: (2 of 4). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries.


Figure 10: (3 of 4). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries.


Figure 11: (4 of 4). Bycatch of PIBKC, by ADFG stat area, in the trawl gear groundfish fisheries.

# Appendix B: NMFS Survey Data for the PIBKC Assessment 

William Stockhausen

11 September, 2017

## Contents

Introduction ..... 3
Annual survey abundance and biomass ..... 3
Size compositions ..... 15
By sex ..... 15
By sex and shell condition ..... 15
Spatial patterns ..... 15
List of Tables
1 Size groupings for various components of the PIBKC stock used in this report. ..... 3
2 Sample sizes (number of survey hauls, number hauls where crab were caught, number of crab caught) for the NMFS EBS trawl survey in the Pribilof District each year, for female population components. ..... 8
3 Sample sizes (number of survey hauls, number hauls where crab were caught, number of crab caught) for the NMFS EBS trawl survey in the Pribilof District each year, for male population components. ..... 9
4 Estimated annual abundance of female PIBKC population components from the NMFS EBS trawl survey. ..... 11
5 Estimated annual abundance of male PIBKC population components from the NMFS EBS trawl survey. ..... 12
6 Estimated annual abundance of female PIBKC population components from the NMFS EBS trawl survey. ..... 13
7 Estimated annual abundance of male PIBKC population components from the NMFS EBS trawl survey. ..... 14

## List of Figures

1 Map of the Pribilof District, which defines the stock area for the Pribilof Islands blue king crab stock. The grid indicates the locations of NMFS EBS survey stations.3
2 NMFS survey abundance time series for female PIBKC. Upper plot is entire time series, lower plot since 2001 ..... 4
3 NMFS survey abundance time series for male PIBKC. Upper plot is entire time series, lower plot since 2001 ..... 5
4 NMFS survey biomass time series for female PIBKC. Upper plot is entire time series, lower plot since 2001 ..... 6
5 NMFS survey biomass time series for male PIBKC. Upper plot is entire time series, lower plot since 2001 ..... 7
10 Basemap for future maps, with EBS bathymetry (blue lines), NMFS EBS trawl survey station grid (black) lines, and the Pribilof Islands Habitat Conservation Area (orange outline). ..... 15
6 Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, over the entire survey period. ..... 16
7 Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, since 2001. ..... 17
8 Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex and shell condition, for entire survey period. ..... 18
9 Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex and shell condition, since 2000 ..... 19
11 Survey CPUE (biomass) for females PIBKC. Page 1 of 11 ..... 20
12 Survey CPUE (biomass) for females PIBKC. Page 2 of 11 ..... 20
13 Survey CPUE (biomass) for females PIBKC. Page 3 of 11 ..... 21
14 Survey CPUE (biomass) for females PIBKC. Page 4 of 11 ..... 21
15 Survey CPUE (biomass) for females PIBKC. Page 5 of 11 ..... 22
16 Survey CPUE (biomass) for females PIBKC. Page 6 of 11 ..... 22
17 Survey CPUE (biomass) for females PIBKC. Page 7 of 11 ..... 23
18 Survey CPUE (biomass) for females PIBKC. Page 8 of 11 ..... 23
19 Survey CPUE (biomass) for females PIBKC. Page 9 of 11 ..... 24
20 Survey CPUE (biomass) for females PIBKC. Page 10 of 11 ..... 24
21 Survey CPUE (biomass) for females PIBKC. Page 11 of 11 ..... 25
22 Survey CPUE (biomass) for males PIBKC. Page 1 of 11 ..... 25
23 Survey CPUE (biomass) for males PIBKC. Page 2 of 11 ..... 26
24 Survey CPUE (biomass) for males PIBKC. Page 3 of 11 ..... 26
25 Survey CPUE (biomass) for males PIBKC. Page 4 of 11 ..... 27
26 Survey CPUE (biomass) for males PIBKC. Page 5 of 11 ..... 27
27 Survey CPUE (biomass) for males PIBKC. Page 6 of 11 ..... 28
28 Survey CPUE (biomass) for males PIBKC. Page 7 of 11 ..... 28
29 Survey CPUE (biomass) for males PIBKC. Page 8 of 11 ..... 29
30 Survey CPUE (biomass) for males PIBKC. Page 9 of 11 ..... 29
31 Survey CPUE (biomass) for males PIBKC. Page 10 of 11 ..... 30
32 Survey CPUE (biomass) for males PIBKC. Page 11 of 11 ..... 30

## Introduction

This report presents results from time series of aggregate abundance, biomass and size compositions from the annual NMFS EBS bottom trawl survey for Pribilof Islands blue king crab (PIBKC), i.e. blue king crab in the Pribilof District of the eastern Bering Sea (Figure 1), based on haul data and survey strata files downloaded from AKFIN on Aug. 30, 2017.


Figure 1: Map of the Pribilof District, which defines the stock area for the Pribilof Islands blue king crab stock. The grid indicates the locations of NMFS EBS survey stations.

Aggregate (abundance, biomass) time series were calculated for different components of the PIBKC stock, including immature and mature females and immature, mature, sublegal, and legal male crab based of the following size-based criteria:

Table 1: Size groupings for various components of the PIBKC stock used in this report.

| sex | size.range | category |
| :--- | :--- | :--- |
| female | $<100 \mathrm{~mm} \mathrm{CL}$ | immature female |
| male | $<120 \mathrm{~mm} \mathrm{CL}$ | immature male |
| female | $>99 \mathrm{~mm} \mathrm{CL}$ | mature female |
| male | $>119 \mathrm{~mm} \mathrm{CL}$ | mature male |
| male | $<135 \mathrm{~mm} \mathrm{CL}$ | sublegal male |
| male | $>134 \mathrm{~mm} \mathrm{CL}$ | legal male |
| female | all | all females |
| male | all | all males |

## Annual survey abundance and biomass

Annual survey abundance and biomass for PIBKC were calculated from the survey haul data as if the survey were conducted using a random-stratified sampling design (it uses a fixed grid).

The following plots illustrate time series trends in Tanner crab survey abundance and biomass by sex and area.


Figure 2: NMFS survey abundance time series for female PIBKC. Upper plot is entire time series, lower plot since 2001.


Figure 3: NMFS survey abundance time series for male PIBKC. Upper plot is entire time series, lower plot since 2001.


Figure 4: NMFS survey biomass time series for female PIBKC. Upper plot is entire time series, lower plot since 2001.


Figure 5: NMFS survey biomass time series for male PIBKC. Upper plot is entire time series, lower plot since 2001.

The following two tables document the annual sampling effort (the number of survey hauls, the number of survey hauls with non-zero catch, and the number of crab caught) by the NMFS bottom trawl survey in the Pribilof District by PIBKC population category.

Table 2: Sample sizes (number of survey hauls, number hauls where crab were caught, number of crab caught) for the NMFS EBS trawl survey in the Pribilof District each year, for female population components.

| year |  | immature females |  | mature females |  | all females |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{aligned} & \text { non-0 } \\ & \text { hauls } \end{aligned}$ | $\begin{gathered} \text { no. } \\ \text { crab } \end{gathered}$ | $\begin{aligned} & \text { non-0 } \\ & \text { hauls } \end{aligned}$ | $\begin{gathered} \text { no. } \\ \text { crab } \end{gathered}$ | $\begin{aligned} & \text { non-0 } \\ & \text { hauls } \end{aligned}$ | $\begin{aligned} & \text { no. } \\ & \text { crab } \end{aligned}$ |
| 1975 | 45 | 6 | 72 | 7 | 193 | 9 | 265 |
| 1976 | 59 | 2 | 55 | 5 | 37 | 5 | 92 |
| 1977 | 58 | 3 | 45 | 5 | 100 | 5 | 145 |
| 1978 | 58 | 4 | 11 | 8 | 97 | 8 | 108 |
| 1979 | 58 | 3 | 4 | 3 | 21 | 5 | 25 |
| 1980 | 70 | 8 | 17 | 10 | 326 | 11 | 343 |
| 1981 | 84 | 16 | 49 | 19 | 184 | 23 | 233 |
| 1982 | 84 | 11 | 49 | 22 | 250 | 24 | 299 |
| 1983 | 86 | 8 | 23 | 16 | 280 | 18 | 303 |
| 1984 | 86 | 7 | 27 | 14 | 142 | 15 | 169 |
| 1985 | 86 | 7 | 15 | 8 | 28 | 12 | 43 |
| 1986 | 86 | 2 | 2 | 8 | 106 | 10 | 108 |
| 1987 | 86 | 5 | 23 | 7 | 35 | 11 | 58 |
| 1988 | 85 | 6 | 41 | 7 | 17 | 9 | 58 |
| 1989 | 86 | 8 | 144 | 9 | 27 | 13 | 171 |
| 1990 | 86 | 7 | 88 | 9 | 77 | 10 | 165 |
| 1991 | 85 | 10 | 57 | 12 | 105 | 15 | 162 |
| 1992 | 86 | 6 | 83 | 9 | 59 | 11 | 142 |
| 1993 | 85 | 8 | 46 | 13 | 88 | 15 | 134 |
| 1994 | 86 | 6 | 25 | 12 | 254 | 13 | 279 |
| 1995 | 86 | 5 | 43 | 11 | 215 | 12 | 258 |
| 1996 | 86 | 6 | 13 | 10 | 213 | 12 | 226 |
| 1997 | 86 | 4 | 17 | 11 | 137 | 13 | 154 |
| 1998 | 85 | 9 | 44 | 11 | 92 | 15 | 136 |
| 1999 | 86 | 3 | 10 | 10 | 145 | 10 | 155 |
| 2000 | 85 | 2 | 2 | 13 | 72 | 13 | 74 |
| 2001 | 86 | 1 | 1 | 9 | 93 | 10 | 94 |
| 2002 | 86 | 1 | 1 | 6 | 66 | 7 | 67 |
| 2003 | 86 | 4 | 4 | 7 | 69 | 9 | 73 |
| 2004 | 85 | 2 | 4 | 4 | 5 | 5 | 9 |
| 2005 | 84 | 1 | 43 | 5 | 15 | 6 | 58 |
| 2006 | 86 | 4 | 6 | 3 | 22 | 6 | 28 |
| 2007 | 86 | 2 | 6 | 3 | 10 | 5 | 16 |
| 2008 | 86 | 3 | 16 | 4 | 27 | 6 | 43 |
| 2009 | 86 | 3 | 5 | 3 | 33 | 4 | 38 |
| 2010 | 86 | 5 | 9 | 4 | 15 | 7 | 24 |
| 2011 | 86 | 2 | 2 | 1 | 1 | 3 | 3 |
| 2012 | 86 | 2 | 11 | 5 | 5 | 6 | 16 |
| 2013 | 86 | 3 | 4 | 2 | 6 | 5 | 10 |
| 2014 | 86 | 1 | 1 | 3 | 4 | 4 | 5 |
| 2015 | 86 | 2 | 2 | 4 | 9 | 4 | 11 |
| 2016 | 86 | 5 | 7 | 7 | 17 | 8 | 24 |
| 2017 | 86 | 3 | 7 | 4 | 8 | 6 | 15 |

Table 3: Sample sizes (number of survey hauls, number hauls where crab were caught, number of crab caught) for the NMFS EBS trawl survey in the Pribilof District each year, for male population components.

| year | survey number of hauls | immature males |  | mature males |  | sublegal males |  | legal males |  | all males |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | non-0 <br> hauls | $\begin{aligned} & \text { no. } \\ & \text { crab } \end{aligned}$ | non-0 <br> hauls | $\begin{gathered} \text { no. } \\ \text { crab } \end{gathered}$ | $\begin{aligned} & \text { non-0 } \\ & \text { hauls } \end{aligned}$ | no. <br> crab | $\begin{aligned} & \text { non-0 } \\ & \text { hauls } \end{aligned}$ | $\begin{aligned} & \text { no. } \\ & \text { crab } \end{aligned}$ | non-0 <br> hauls | $\begin{gathered} \text { no. } \\ \text { crab } \end{gathered}$ |
| 1975 | 45 | 11 | 305 | 13 | 553 | 11 | 530 | 13 | 328 | 13 | 858 |
| 1976 | 59 | 3 | 105 | 11 | 91 | 9 | 122 | 10 | 74 | 12 | 196 |
| 1977 | 58 | 7 | 56 | 10 | 129 | 9 | 73 | 9 | 112 | 10 | 185 |
| 1978 | 58 | 8 | 60 | 11 | 130 | 10 | 112 | 10 | 78 | 12 | 190 |
| 1979 | 58 | 2 | 2 | 14 | 90 | 8 | 25 | 13 | 67 | 14 | 92 |
| 1980 | 70 | 10 | 41 | 21 | 133 | 12 | 64 | 21 | 110 | 21 | 174 |
| 1981 | 84 | 19 | 99 | 36 | 184 | 23 | 128 | 36 | 155 | 38 | 283 |
| 1982 | 84 | 19 | 70 | 35 | 114 | 21 | 84 | 31 | 100 | 38 | 184 |
| 1983 | 86 | 15 | 47 | 32 | 93 | 18 | 74 | 29 | 66 | 35 | 140 |
| 1984 | 86 | 10 | 27 | 20 | 37 | 17 | 37 | 16 | 27 | 25 | 64 |
| 1985 | 86 | 3 | 4 | 14 | 24 | 8 | 13 | 11 | 15 | 14 | 28 |
| 1986 | 86 | 1 | 1 | 13 | 26 | 2 | 2 | 13 | 25 | 13 | 27 |
| 1987 | 86 | 5 | 34 | 15 | 50 | 6 | 38 | 14 | 46 | 16 | 84 |
| 1988 | 85 | 5 | 52 | 5 | 12 | 5 | 52 | 5 | 12 | 9 | 64 |
| 1989 | 86 | 8 | 160 | 4 | 11 | 8 | 160 | 4 | 11 | 10 | 171 |
| 1990 | 86 | 8 | 90 | 10 | 59 | 11 | 126 | 7 | 23 | 14 | 149 |
| 1991 | 85 | 16 | 92 | 19 | 103 | 20 | 129 | 14 | 66 | 22 | 195 |
| 1992 | 86 | 12 | 89 | 14 | 73 | 13 | 119 | 12 | 43 | 17 | 162 |
| 1993 | 85 | 12 | 75 | 19 | 96 | 15 | 115 | 17 | 56 | 21 | 171 |
| 1994 | 86 | 8 | 32 | 18 | 68 | 12 | 51 | 18 | 49 | 19 | 100 |
| 1995 | 86 | 7 | 66 | 18 | 177 | 15 | 118 | 14 | 125 | 19 | 243 |
| 1996 | 86 | 7 | 32 | 19 | 87 | 11 | 54 | 19 | 65 | 20 | 119 |
| 1997 | 86 | 7 | 25 | 17 | 65 | 10 | 39 | 16 | 51 | 19 | 90 |
| 1998 | 85 | 12 | 56 | 20 | 56 | 15 | 66 | 17 | 46 | 21 | 112 |
| 1999 | 86 | 7 | 9 | 13 | 34 | 9 | 18 | 11 | 25 | 15 | 43 |
| 2000 | 85 | 4 | 9 | 16 | 40 | 9 | 20 | 13 | 29 | 16 | 49 |
| 2001 | 86 | 3 | 5 | 6 | 28 | 4 | 9 | 5 | 24 | 7 | 33 |
| 2002 | 86 | 0 | 0 | 6 | 12 | 1 | 1 | 6 | 11 | 6 | 12 |
| 2003 | 86 | 2 | 2 | 7 | 14 | 3 | 3 | 7 | 13 | 9 | 16 |
| 2004 | 85 | 3 | 5 | 3 | 3 | 5 | 7 | 1 | 1 | 6 | 8 |
| 2005 | 84 | 3 | 54 | 2 | 5 | 3 | 54 | 2 | 5 | 4 | 59 |
| 2006 | 86 | 4 | 7 | 3 | 3 | 4 | 8 | 2 | 2 | 6 | 10 |
| 2007 | 86 | 4 | 14 | 2 | 6 | 4 | 17 | 2 | 3 | 4 | 20 |
| 2008 | 86 | 2 | 13 | 1 | 1 | 2 | 13 | 1 | 1 | 3 | 14 |
| 2009 | 86 | 5 | 16 | 3 | 15 | 5 | 27 | 3 | 4 | 5 | 31 |
| 2010 | 86 | 2 | 6 | 5 | 8 | 3 | 10 | 4 | 4 | 5 | 14 |
| 2011 | 86 | 0 | 0 | 3 | 9 | 2 | 2 | 2 | 7 | 3 | 9 |
| 2012 | 86 | 1 | 9 | 4 | 13 | 1 | 14 | 4 | 8 | 4 | 22 |
| 2013 | 86 | 1 | 3 | 2 | 6 | 2 | 5 | 2 | 4 | 3 | 9 |
| 2014 | 86 | 3 | 5 | 2 | 5 | 3 | 5 | 2 | 5 | 4 | 10 |
| 2015 | 86 | 2 | 4 | 8 | 13 | 6 | 10 | 5 | 7 | 9 | 17 |
| 2016 | 86 | 4 | 5 | 3 | 3 | 5 | 7 | 1 | 1 | 5 | 8 |
| 2017 | 86 | 2 | 4 | 4 | 4 | 3 | 5 | 3 | 3 | 5 | 8 |

The following two tables document the estimated annual PIBKC abundance and associated uncertainty (as the coefficient of variation) in the NMFS bottom trawl survey by PIBKC populaton category. The estimated abundance and uncertainity for each category is calculated using a sweptarea approach as if the EBS trawl survey were conducted using a stratified-random sampling design, rather than as a grid-based design. While re-calculated from the "raw" survey data using a completely independent approach, the estimates are the same (to 4 or 5 decimal places) as those provided in the annual survey Technical Memoranda.

Table 4: Estimated annual abundance of female PIBKC population components from the NMFS EBS trawl survey.

| year | immature females |  | mature females |  | all females |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | abundance millions | cV | abundance millions | cV | abundance millions | cV |
| 1975 | 2.127 | 0.740 | 11.020 | 0.687 | 13.148 | 0.608 |
| 1976 | 5.001 | 0.956 | 3.138 | 0.838 | 8.139 | 0.910 |
| 1977 | 4.064 | 0.786 | 10.667 | 0.890 | 14.732 | 0.857 |
| 1978 | 0.494 | 0.603 | 5.493 | 0.684 | 5.987 | 0.656 |
| 1979 | 0.178 | 0.604 | 1.133 | 0.838 | 1.311 | 0.767 |
| 1980 | 1.498 | 0.477 | 182.186 | 0.981 | 183.684 | 0.976 |
| 1981 | 1.176 | 0.296 | 5.084 | 0.482 | 6.260 | 0.423 |
| 1982 | 1.162 | 0.415 | 7.551 | 0.671 | 8.713 | 0.626 |
| 1983 | 0.691 | 0.673 | 9.080 | 0.771 | 9.772 | 0.763 |
| 1984 | 0.522 | 0.467 | 2.713 | 0.382 | 3.235 | 0.366 |
| 1985 | 0.260 | 0.541 | 0.486 | 0.437 | 0.746 | 0.360 |
| 1986 | 0.037 | 0.698 | 2.102 | 0.898 | 2.139 | 0.882 |
| 1987 | 0.420 | 0.754 | 0.652 | 0.599 | 1.072 | 0.478 |
| 1988 | 0.972 | 0.804 | 0.391 | 0.471 | 1.363 | 0.642 |
| 1989 | 2.991 | 0.669 | 0.787 | 0.533 | 3.778 | 0.576 |
| 1990 | 2.502 | 0.775 | 1.721 | 0.474 | 4.223 | 0.555 |
| 1991 | 1.343 | 0.455 | 2.230 | 0.389 | 3.573 | 0.353 |
| 1992 | 2.277 | 0.758 | 1.670 | 0.459 | 3.947 | 0.521 |
| 1993 | 0.911 | 0.567 | 1.752 | 0.441 | 2.663 | 0.378 |
| 1994 | 0.503 | 0.681 | 4.689 | 0.448 | 5.192 | 0.437 |
| 1995 | 0.751 | 0.808 | 3.946 | 0.521 | 4.697 | 0.491 |
| 1996 | 0.289 | 0.460 | 5.033 | 0.486 | 5.322 | 0.463 |
| 1997 | 0.320 | 0.669 | 2.614 | 0.423 | 2.935 | 0.388 |
| 1998 | 0.747 | 0.428 | 1.583 | 0.473 | 2.330 | 0.365 |
| 1999 | 0.172 | 0.789 | 2.584 | 0.477 | 2.756 | 0.490 |
| 2000 | 0.035 | 0.698 | 1.328 | 0.465 | 1.363 | 0.463 |
| 2001 | 0.019 | 1.000 | 1.697 | 0.753 | 1.716 | 0.745 |
| 2002 | 0.019 | 1.000 | 1.222 | 0.794 | 1.241 | 0.782 |
| 2003 | 0.067 | 0.483 | 1.120 | 0.764 | 1.188 | 0.721 |
| 2004 | 0.081 | 0.740 | 0.087 | 0.517 | 0.168 | 0.510 |
| 2005 | 2.268 | 1.000 | 0.289 | 0.565 | 2.557 | 0.886 |
| 2006 | 0.113 | 0.548 | 0.430 | 0.766 | 0.543 | 0.617 |
| 2007 | 0.104 | 0.842 | 0.184 | 0.813 | 0.288 | 0.592 |
| 2008 | 0.287 | 0.881 | 0.492 | 0.688 | 0.779 | 0.748 |
| 2009 | 0.086 | 0.585 | 0.543 | 0.811 | 0.629 | 0.755 |
| 2010 | 0.166 | 0.558 | 0.249 | 0.691 | 0.415 | 0.622 |
| 2011 | 0.037 | 0.698 | 0.018 | 1.000 | 0.055 | 0.563 |
| 2012 | 0.251 | 0.873 | 0.096 | 0.426 | 0.347 | 0.695 |
| 2013 | 0.089 | 0.637 | 0.107 | 0.846 | 0.196 | 0.534 |
| 2014 | 0.028 | 1.000 | 0.074 | 0.604 | 0.102 | 0.507 |
| 2015 | 0.035 | 0.699 | 0.167 | 0.671 | 0.202 | 0.655 |
| 2016 | 0.132 | 0.504 | 0.323 | 0.519 | 0.454 | 0.504 |
| 2017 | 0.188 | 0.746 | 0.162 | 0.533 | 0.350 | 0.535 |

Table 5: Estimated annual abundance of male PIBKC population components from the NMFS EBS trawl survey.

| year | immature males |  | mature males |  | sublegal males |  | legal males |  | all males |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | abundance millions | cV | abundance millions | cV | abundance millions | cV | abundance millions | cV | abundance millions | cV |
| 1975 | 8.476 | 0.567 | 15.288 | 0.502 | 14.712 | 0.479 | 9.051 | 0.501 | 23.764 | 0.466 |
| 1976 | 4.960 | 0.954 | 4.782 | 0.445 | 5.729 | 0.882 | 4.012 | 0.471 | 9.742 | 0.589 |
| 1977 | 4.216 | 0.457 | 13.044 | 0.743 | 5.491 | 0.440 | 11.769 | 0.771 | 17.260 | 0.625 |
| 1978 | 2.421 | 0.502 | 6.141 | 0.496 | 4.639 | 0.419 | 3.923 | 0.616 | 8.562 | 0.428 |
| 1979 | 0.079 | 0.704 | 4.108 | 0.326 | 1.170 | 0.449 | 3.017 | 0.310 | 4.187 | 0.324 |
| 1980 | 2.733 | 0.466 | 7.842 | 0.408 | 4.331 | 0.458 | 6.244 | 0.420 | 10.575 | 0.400 |
| 1981 | 2.099 | 0.324 | 3.834 | 0.180 | 2.688 | 0.317 | 3.246 | 0.177 | 5.934 | 0.207 |
| 1982 | 1.371 | 0.281 | 2.354 | 0.181 | 1.654 | 0.255 | 2.071 | 0.188 | 3.725 | 0.172 |
| 1983 | 1.031 | 0.357 | 1.851 | 0.186 | 1.561 | 0.309 | 1.321 | 0.170 | 2.882 | 0.220 |
| 1984 | 0.518 | 0.397 | 0.771 | 0.225 | 0.730 | 0.290 | 0.558 | 0.247 | 1.288 | 0.212 |
| 1985 | 0.068 | 0.598 | 0.428 | 0.281 | 0.226 | 0.340 | 0.270 | 0.294 | 0.496 | 0.269 |
| 1986 | 0.019 | 1.000 | 0.480 | 0.305 | 0.039 | 0.698 | 0.460 | 0.313 | 0.499 | 0.298 |
| 1987 | 0.622 | 0.834 | 0.903 | 0.414 | 0.695 | 0.748 | 0.830 | 0.416 | 1.525 | 0.434 |
| 1988 | 1.238 | 0.842 | 0.238 | 0.509 | 1.238 | 0.842 | 0.238 | 0.509 | 1.476 | 0.708 |
| 1989 | 3.515 | 0.588 | 0.240 | 0.624 | 3.515 | 0.588 | 0.240 | 0.624 | 3.755 | 0.585 |
| 1990 | 2.450 | 0.596 | 1.470 | 0.626 | 3.349 | 0.596 | 0.572 | 0.538 | 3.920 | 0.578 |
| 1991 | 1.920 | 0.373 | 2.014 | 0.363 | 2.697 | 0.332 | 1.238 | 0.444 | 3.935 | 0.343 |
| 1992 | 2.436 | 0.588 | 1.935 | 0.420 | 3.217 | 0.520 | 1.154 | 0.453 | 4.371 | 0.475 |
| 1993 | 1.484 | 0.520 | 1.876 | 0.310 | 2.245 | 0.432 | 1.114 | 0.300 | 3.359 | 0.339 |
| 1994 | 0.639 | 0.374 | 1.294 | 0.341 | 0.998 | 0.343 | 0.935 | 0.345 | 1.933 | 0.332 |
| 1995 | 1.147 | 0.889 | 3.102 | 0.600 | 2.062 | 0.744 | 2.186 | 0.615 | 4.249 | 0.675 |
| 1996 | 0.719 | 0.625 | 1.712 | 0.281 | 1.162 | 0.547 | 1.269 | 0.263 | 2.431 | 0.334 |
| 1997 | 0.467 | 0.525 | 1.201 | 0.294 | 0.736 | 0.464 | 0.933 | 0.284 | 1.669 | 0.342 |
| 1998 | 0.949 | 0.458 | 0.967 | 0.246 | 1.119 | 0.414 | 0.797 | 0.253 | 1.917 | 0.309 |
| 1999 | 0.160 | 0.373 | 0.617 | 0.334 | 0.324 | 0.388 | 0.453 | 0.345 | 0.777 | 0.327 |
| 2000 | 0.164 | 0.563 | 0.725 | 0.296 | 0.361 | 0.385 | 0.528 | 0.297 | 0.889 | 0.312 |
| 2001 | 0.093 | 0.645 | 0.522 | 0.710 | 0.169 | 0.595 | 0.446 | 0.744 | 0.615 | 0.690 |
| 2002 | 0.000 | 0.000 | 0.225 | 0.473 | 0.018 | 1.000 | 0.207 | 0.495 | 0.225 | 0.473 |
| 2003 | 0.045 | 0.717 | 0.229 | 0.389 | 0.061 | 0.589 | 0.214 | 0.402 | 0.274 | 0.341 |
| 2004 | 0.088 | 0.590 | 0.048 | 0.563 | 0.120 | 0.460 | 0.016 | 1.000 | 0.136 | 0.417 |
| 2005 | 1.981 | 0.964 | 0.092 | 0.712 | 1.981 | 0.964 | 0.092 | 0.712 | 2.073 | 0.921 |
| 2006 | 0.138 | 0.495 | 0.056 | 0.564 | 0.155 | 0.503 | 0.038 | 0.699 | 0.194 | 0.419 |
| 2007 | 0.246 | 0.717 | 0.110 | 0.854 | 0.302 | 0.644 | 0.054 | 0.745 | 0.356 | 0.639 |
| 2008 | 0.234 | 0.928 | 0.018 | 1.000 | 0.234 | 0.928 | 0.018 | 1.000 | 0.252 | 0.862 |
| 2009 | 0.268 | 0.631 | 0.249 | 0.732 | 0.448 | 0.697 | 0.068 | 0.588 | 0.516 | 0.676 |
| 2010 | 0.101 | 0.841 | 0.130 | 0.486 | 0.167 | 0.728 | 0.065 | 0.482 | 0.232 | 0.608 |
| 2011 | 0.000 | 0.000 | 0.166 | 0.792 | 0.036 | 0.698 | 0.129 | 0.868 | 0.166 | 0.792 |
| 2012 | 0.195 | 1.000 | 0.272 | 0.797 | 0.303 | 1.000 | 0.164 | 0.678 | 0.467 | 0.879 |
| 2013 | 0.076 | 1.000 | 0.104 | 0.862 | 0.112 | 0.745 | 0.069 | 0.804 | 0.181 | 0.644 |
| 2014 | 0.091 | 0.591 | 0.092 | 0.710 | 0.091 | 0.591 | 0.092 | 0.710 | 0.183 | 0.566 |
| 2015 | 0.076 | 0.766 | 0.234 | 0.367 | 0.185 | 0.525 | 0.125 | 0.446 | 0.309 | 0.408 |
| 2016 | 0.094 | 0.517 | 0.056 | 0.563 | 0.131 | 0.458 | 0.019 | 1.000 | 0.150 | 0.488 |
| 2017 | 0.068 | 0.773 | 0.091 | 0.503 | 0.087 | 0.637 | 0.072 | 0.589 | 0.159 | 0.456 |

Table 6: Estimated annual abundance of female PIBKC population components from the NMFS EBS trawl survey.

| year | immature females |  | mature females |  | all females |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | biomass | cv | biomass | cv | biomass | cv |
|  | 1000's t |  | 1000's t |  | 1000's t |  |
| 1975 | 1.270 | 0.730 | 11.172 | 0.691 | 12.442 | 0.636 |
| 1976 | 3.178 | 0.963 | 2.613 | 0.807 | 5.792 | 0.891 |
| 1977 | 2.313 | 0.784 | 11.259 | 0.896 | 13.572 | 0.874 |
| 1978 | 0.321 | 0.611 | 6.171 | 0.738 | 6.492 | 0.717 |
| 1979 | 0.108 | 0.634 | 1.081 | 0.805 | 1.189 | 0.760 |
| 1980 | 0.728 | 0.446 | 211.575 | 0.986 | 212.303 | 0.983 |
| 1981 | 0.687 | 0.297 | 5.797 | 0.496 | 6.484 | 0.458 |
| 1982 | 0.613 | 0.406 | 8.764 | 0.694 | 9.377 | 0.669 |
| 1983 | 0.384 | 0.722 | 9.864 | 0.784 | 10.248 | 0.781 |
| 1984 | 0.054 | 0.698 | 3.031 | 0.382 | 3.085 | 0.380 |
| 1985 | 0.005 | 0.457 | 0.520 | 0.448 | 0.525 | 0.445 |
| 1986 | 0.011 | 0.727 | 2.420 | 0.901 | 2.431 | 0.896 |
| 1987 | 0.128 | 0.866 | 0.785 | 0.590 | 0.913 | 0.526 |
| 1988 | 0.240 | 0.645 | 0.478 | 0.490 | 0.718 | 0.473 |
| 1989 | 1.032 | 0.601 | 0.714 | 0.470 | 1.746 | 0.497 |
| 1990 | 1.314 | 0.764 | 1.615 | 0.454 | 2.929 | 0.491 |
| 1991 | 0.659 | 0.493 | 2.117 | 0.397 | 2.776 | 0.376 |
| 1992 | 1.106 | 0.740 | 1.543 | 0.463 | 2.649 | 0.463 |
| 1993 | 0.455 | 0.573 | 1.636 | 0.457 | 2.092 | 0.399 |
| 1994 | 0.320 | 0.703 | 4.573 | 0.454 | 4.893 | 0.443 |
| 1995 | 0.386 | 0.764 | 3.893 | 0.518 | 4.279 | 0.496 |
| 1996 | 0.166 | 0.486 | 5.418 | 0.504 | 5.585 | 0.491 |
| 1997 | 0.189 | 0.670 | 2.839 | 0.429 | 3.028 | 0.407 |
| 1998 | 0.420 | 0.431 | 1.761 | 0.460 | 2.182 | 0.392 |
| 1999 | 0.113 | 0.797 | 2.755 | 0.459 | 2.868 | 0.467 |
| 2000 | 0.023 | 0.699 | 1.439 | 0.462 | 1.462 | 0.460 |
| 2001 | 0.000 | 1.000 | 1.816 | 0.722 | 1.817 | 0.722 |
| 2002 | 0.000 | 1.000 | 1.401 | 0.776 | 1.401 | 0.775 |
| 2003 | 0.021 | 0.667 | 1.286 | 0.745 | 1.307 | 0.734 |
| 2004 | 0.005 | 0.711 | 0.118 | 0.516 | 0.123 | 0.504 |
| 2005 | 0.477 | 1.000 | 0.370 | 0.570 | 0.847 | 0.606 |
| 2006 | 0.038 | 0.602 | 0.538 | 0.760 | 0.576 | 0.712 |
| 2007 | 0.045 | 0.995 | 0.237 | 0.826 | 0.282 | 0.707 |
| 2008 | 0.178 | 0.882 | 0.493 | 0.659 | 0.672 | 0.705 |
| 2009 | 0.030 | 0.576 | 0.595 | 0.840 | 0.625 | 0.818 |
| 2010 | 0.083 | 0.575 | 0.311 | 0.660 | 0.394 | 0.634 |
| 2011 | 0.015 | 0.836 | 0.022 | 1.000 | 0.037 | 0.674 |
| 2012 | 0.131 | 0.936 | 0.106 | 0.436 | 0.237 | 0.637 |
| 2013 | 0.035 | 0.657 | 0.131 | 0.816 | 0.166 | 0.654 |
| 2014 | 0.016 | 1.000 | 0.091 | 0.605 | 0.108 | 0.529 |
| 2015 | 0.020 | 0.708 | 0.139 | 0.687 | 0.160 | 0.662 |
| 2016 | 0.073 | 0.468 | 0.331 | 0.496 | 0.405 | 0.478 |
| 2017 | 0.108 | 0.811 | 0.153 | 0.558 | 0.262 | 0.533 |

Table 7: Estimated annual abundance of male PIBKC population components from the NMFS EBS trawl survey.

| year | immature males |  | mature males |  | sublegal males |  | legal males |  | all males |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | biomass | cV | biomass | cV | biomass | cV | biomass | cV | biomass | CV |
|  | 1000's t |  | 1000's t |  | 1000's t |  | 1000's t |  | 1000's t |  |
| 1975 | 8.341 | 0.525 | 38.054 | 0.501 | 19.378 | 0.466 | 27.016 | 0.499 | 46.395 | 0.475 |
| 1976 | 4.129 | 0.944 | 14.059 | 0.451 | 5.539 | 0.811 | 12.649 | 0.468 | 18.188 | 0.452 |
| 1977 | 3.713 | 0.443 | 42.618 | 0.768 | 5.966 | 0.463 | 40.366 | 0.784 | 46.332 | 0.729 |
| 1978 | 2.765 | 0.509 | 17.370 | 0.558 | 6.618 | 0.412 | 13.517 | 0.642 | 20.135 | 0.506 |
| 1979 | 0.061 | 0.785 | 10.959 | 0.315 | 1.981 | 0.452 | 9.040 | 0.311 | 11.021 | 0.315 |
| 1980 | 2.084 | 0.492 | 23.553 | 0.430 | 4.958 | 0.464 | 20.679 | 0.446 | 25.637 | 0.417 |
| 1981 | 1.704 | 0.299 | 11.628 | 0.174 | 2.779 | 0.297 | 10.554 | 0.175 | 13.332 | 0.175 |
| 1982 | 1.152 | 0.232 | 7.389 | 0.187 | 1.647 | 0.217 | 6.893 | 0.192 | 8.541 | 0.175 |
| 1983 | 0.962 | 0.357 | 5.409 | 0.178 | 1.897 | 0.297 | 4.474 | 0.175 | 6.371 | 0.187 |
| 1984 | 0.130 | 0.362 | 2.216 | 0.229 | 0.521 | 0.268 | 1.824 | 0.247 | 2.345 | 0.222 |
| 1985 | 0.039 | 0.733 | 1.055 | 0.267 | 0.338 | 0.374 | 0.755 | 0.283 | 1.094 | 0.263 |
| 1986 | 0.004 | 1.000 | 1.505 | 0.303 | 0.035 | 0.897 | 1.473 | 0.307 | 1.508 | 0.302 |
| 1987 | 0.191 | 0.783 | 2.923 | 0.411 | 0.334 | 0.536 | 2.781 | 0.414 | 3.115 | 0.397 |
| 1988 | 0.170 | 0.707 | 0.842 | 0.529 | 0.170 | 0.707 | 0.842 | 0.529 | 1.012 | 0.457 |
| 1989 | 1.275 | 0.620 | 0.827 | 0.637 | 1.275 | 0.620 | 0.827 | 0.637 | 2.102 | 0.551 |
| 1990 | 2.004 | 0.661 | 3.078 | 0.600 | 3.567 | 0.665 | 1.514 | 0.515 | 5.082 | 0.610 |
| 1991 | 1.377 | 0.386 | 4.690 | 0.386 | 2.741 | 0.336 | 3.326 | 0.450 | 6.067 | 0.373 |
| 1992 | 1.801 | 0.512 | 4.391 | 0.423 | 3.157 | 0.446 | 3.035 | 0.446 | 6.192 | 0.432 |
| 1993 | 1.088 | 0.545 | 4.556 | 0.307 | 2.442 | 0.409 | 3.203 | 0.301 | 5.644 | 0.305 |
| 1994 | 0.619 | 0.388 | 3.410 | 0.345 | 1.224 | 0.350 | 2.806 | 0.351 | 4.029 | 0.343 |
| 1995 | 0.968 | 0.863 | 8.360 | 0.604 | 2.541 | 0.673 | 6.787 | 0.615 | 9.328 | 0.629 |
| 1996 | 0.745 | 0.605 | 4.641 | 0.269 | 1.512 | 0.524 | 3.873 | 0.265 | 5.386 | 0.279 |
| 1997 | 0.381 | 0.545 | 3.233 | 0.276 | 0.849 | 0.451 | 2.765 | 0.271 | 3.614 | 0.294 |
| 1998 | 0.692 | 0.413 | 2.798 | 0.249 | 0.980 | 0.354 | 2.510 | 0.255 | 3.490 | 0.252 |
| 1999 | 0.161 | 0.402 | 1.729 | 0.337 | 0.464 | 0.414 | 1.426 | 0.347 | 1.890 | 0.333 |
| 2000 | 0.113 | 0.679 | 2.091 | 0.296 | 0.459 | 0.373 | 1.746 | 0.305 | 2.205 | 0.304 |
| 2001 | 0.087 | 0.764 | 1.599 | 0.735 | 0.225 | 0.628 | 1.461 | 0.759 | 1.686 | 0.733 |
| 2002 | 0.000 | 0.000 | 0.680 | 0.506 | 0.033 | 1.000 | 0.647 | 0.525 | 0.680 | 0.506 |
| 2003 | 0.019 | 0.984 | 0.702 | 0.400 | 0.050 | 0.723 | 0.671 | 0.411 | 0.721 | 0.390 |
| 2004 | 0.036 | 0.649 | 0.107 | 0.583 | 0.094 | 0.487 | 0.048 | 1.000 | 0.143 | 0.455 |
| 2005 | 0.326 | 0.942 | 0.344 | 0.710 | 0.326 | 0.942 | 0.344 | 0.710 | 0.670 | 0.589 |
| 2006 | 0.087 | 0.585 | 0.166 | 0.603 | 0.114 | 0.616 | 0.139 | 0.699 | 0.253 | 0.462 |
| 2007 | 0.197 | 0.737 | 0.306 | 0.798 | 0.298 | 0.632 | 0.206 | 0.734 | 0.503 | 0.661 |
| 2008 | 0.212 | 0.952 | 0.046 | 1.000 | 0.212 | 0.952 | 0.046 | 1.000 | 0.258 | 0.797 |
| 2009 | 0.254 | 0.680 | 0.497 | 0.713 | 0.565 | 0.740 | 0.187 | 0.604 | 0.751 | 0.698 |
| 2010 | 0.092 | 0.853 | 0.303 | 0.461 | 0.205 | 0.702 | 0.190 | 0.483 | 0.395 | 0.522 |
| 2011 | 0.000 | 0.000 | 0.461 | 0.843 | 0.062 | 0.705 | 0.399 | 0.886 | 0.461 | 0.843 |
| 2012 | 0.165 | 1.000 | 0.644 | 0.735 | 0.350 | 1.000 | 0.459 | 0.643 | 0.809 | 0.786 |
| 2013 | 0.015 | 1.000 | 0.250 | 0.797 | 0.075 | 0.824 | 0.190 | 0.752 | 0.265 | 0.754 |
| 2014 | 0.083 | 0.623 | 0.233 | 0.699 | 0.083 | 0.623 | 0.233 | 0.699 | 0.317 | 0.567 |
| 2015 | 0.082 | 0.747 | 0.622 | 0.394 | 0.275 | 0.494 | 0.428 | 0.458 | 0.703 | 0.395 |
| 2016 | 0.071 | 0.486 | 0.130 | 0.613 | 0.133 | 0.495 | 0.068 | 1.000 | 0.201 | 0.515 |
| 2017 | 0.046 | 0.767 | 0.255 | 0.514 | 0.076 | 0.599 | 0.224 | 0.573 | 0.300 | 0.470 |

## Size compositions

Annual size compositions for PIBKC in the NMFS EBS trawl survey were calculated by sex, shell condition, and 5 mm size (carapace width) bin, accumulating individuals $>200 \mathrm{~mm}$ CL in the last size bin (195-200 mm CL). There is no need here to distinguish among the population components used above to present abundance and biomass trends (e.g., immature females) in the following size compositions because those components were based on size ranges that can be extracted from the size compositions.

## By sex

Size compositions for PIBKC from the NMFS EBS trawl survey are presented here by sex for the entire survey time period (1975-present) and for 2001-present.

## By sex and shell condition

Size compositions for PIBKC from the NMFS EBS trawl survey are presented here by sex for the entire survey time period (1975-present) and for 2001-present.

## Spatial patterns



Figure 10: Basemap for future maps, with EBS bathymetry (blue lines), NMFS EBS trawl survey station grid (black) lines, and the Pribilof Islands Habitat Conservation Area (orange outline).


Figure 6: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, over the entire survey period.


Figure 7: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex, since 2001.


Figure 8: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex and shell condition, for entire survey period.


Figure 9: Annual size compositions for PIBKC in the NMFS EBS trawl survey, by sex and shell condition, since 2000.


Figure 11: Survey CPUE (biomass) for females PIBKC. Page 1 of 11


Figure 12: Survey CPUE (biomass) for females PIBKC. Page 2 of 11


Figure 13: Survey CPUE (biomass) for females PIBKC. Page 3 of 11


Figure 14: Survey CPUE (biomass) for females PIBKC. Page 4 of 11


Figure 15: Survey CPUE (biomass) for females PIBKC. Page 5 of 11


Figure 16: Survey CPUE (biomass) for females PIBKC. Page 6 of 11


Figure 17: Survey CPUE (biomass) for females PIBKC. Page 7 of 11


Figure 18: Survey CPUE (biomass) for females PIBKC. Page 8 of 11


Figure 19: Survey CPUE (biomass) for females PIBKC. Page 9 of 11


Figure 20: Survey CPUE (biomass) for females PIBKC. Page 10 of 11


Figure 21: Survey CPUE (biomass) for females PIBKC. Page 11 of 11


Figure 22: Survey CPUE (biomass) for males PIBKC. Page 1 of 11


Figure 23: Survey CPUE (biomass) for males PIBKC. Page 2 of 11


Figure 24: Survey CPUE (biomass) for males PIBKC. Page 3 of 11


Figure 25: Survey CPUE (biomass) for males PIBKC. Page 4 of 11


Figure 26: Survey CPUE (biomass) for males PIBKC. Page 5 of 11


Figure 27: Survey CPUE (biomass) for males PIBKC. Page 6 of 11


Figure 28: Survey CPUE (biomass) for males PIBKC. Page 7 of 11


Figure 29: Survey CPUE (biomass) for males PIBKC. Page 8 of 11


Figure 30: Survey CPUE (biomass) for males PIBKC. Page 9 of 11


Figure 31: Survey CPUE (biomass) for males PIBKC. Page 10 of 11


Figure 32: Survey CPUE (biomass) for males PIBKC. Page 11 of 11

# Appendix C: PIBKC 2017 Status Determination 

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11 September, 2017

## Contents

Introduction ..... 2
Status Determination and OFL calculations ..... 2
MMB-at-mating ..... 3
Data ..... 4
Survey smoothing ..... 9
Smoothing results ..... 10
Status determination ..... 12
Overfishing status ..... 12
Overfished status ..... 12
Tables ..... 15
Fishery data ..... 15
Survey data ..... 16
References ..... 21
List of Tables
1 Estimated $B_{M S Y_{p r o x y}}$ and current MMB at the time of the survey, using the raw survey data and the RE-smoothed data. ..... 14
2 Estimated values for the heta coefficient ..... 14
3 More results from the OFL determination. ..... 14
4 Annual retained catch biomass and bycatch (not mortality; in t), as available, in the directed fishery, the other crab fisheries, and the groundfish fisheries. ..... 15
5 Input ('raw') male survey abundance data (numbers of crab) ..... 16
6 Input ('raw') male survey biomass data, in $t$. ..... 17
7 Input ('raw') female survey abundance data (numbers of crab). ..... 18
8 Input ('raw') female survey biomass data, in t. ..... 19
9 A comparison of estimates for MMB (in t) at the time of the survey. ..... 20

## List of Figures

1 Time series of retained PIBKC catch in the directed fishery
2 Time series of retained PIBKC catch in the directed fishery (recent time period) ..... 5
3 Time series of PIBKC bycatch in the crab and groundfish fisheries. ..... 5
4 Time series of PIBKC bycatch in the crab and groundfish fisheries (recent time period). ..... 6
5 Time series of NMFS EBS bottom trawl survey biomass for PIBKC. Confidence intervals shown are $80 \%$ CI's, assuming lognormal error distributions. ..... 7
6 Time series of NMFS EBS bottom trawl survey biomass for PIBKC (recent time pe-riod). Confidence intervals shown are $80 \%$ CI's, assuming lognormal error distributions. 8
7 Log10-scale time series for the NMFS EBS bottom trawl survey biomass for PIBKC. Confidence intervals shown are $80 \%$ CI's, assuming lognormal error distributions. . ..... 9
8 Arithmetic-scale raw and smoothed survey MMB time series. Confidence intervals shown are $80 \%$ CIs, assuming lognormal error distributions. ..... 11
9 Arithmetic-scale raw and smoothed survey MMB time series, since 2000. Confidence intervals shown are $80 \%$ CIs, assuming lognormal error distributions. ..... 11
10 Log-scale raw and smoothed survey MMB time series. Confidence intervals shown are $80 \%$ CIs, assuming lognormalerror distributions. ..... 12
11 Estimated time series for MMB at the time of the survey (no smoothing), at the time of the fishery, and at the time of mating. ..... 13
12 Estimated time series for MMB using the RE method at the time of the survey (the random effects time series), at the time of the fishery, and at the time of mating. ..... 13

## Introduction

This is an appendix to the 2017 stock assessment chapter for the Pribilof Islands blue king crab stock (PIBKC). It presents results for status determination (is overfishing occurring?, is the stock overfished?) for the current year using the "rPIBKC"" R package developed by the assessment author. The rPIBKC package (source code and R package) is available under version control at https://github.com/wStockhausen/rPIBKC.git.

## Status Determination and OFL calculations

For all crab stocks managed by the NPFMC, overfishing is evaluated by comparing the previous year's catch mortality (retained + discard mortality) to the previous year's OFL: if the former is greater than the latter, then overfishing is occurring. Overfished status is assessed with respect to MSST, the Minimum Stock Size Threshold. If stock biomass drops below the MSST, the stock is considered to be overfished. For crab stocks, MSST is one-half $B_{M S Y}$, where $B_{M S Y}$ is the longterm spawning stock biomass when the stock is fished at maximum sustainable yield (MSY). Thus, the stock is overfished if $B / B_{M S Y}<0.5$, where $B$ is the "current"" spawning stock biomass. In general, the overfishing limit (OFL) for the subsequent year is based on $B / B_{M S Y}$ and an " $F_{O F L}$ " harvest control rule, where $F_{O F L}$ is the fishing mortality rate that yields the OFL. Furthermore, if $B / B_{M S Y}<\beta(=0.25)$, directed fishing on the stock is prohibited. For PIBKC, the OFL is based on average historic catch mortality over a specified time period (a Tier 5 approach) and is consequently fixed at 1.16 t .

PIBKC falls into Tier 4 for status determination. For Tier 4 stocks, it is not possible to determine $B_{M S Y}$ and MSST directly. Instead, average mature male biomass (MMB) at the time of mating
("MMB at mating"") is used as a proxy for $B_{M S Y}$, where the averaging is over some time period assumed to be representative of the stock being fished at an average rate near $F_{M S Y}$ and is thus fluctuating around $B_{M S Y}$. For PIBKC, the NPFMC's Science and Statistical Committee (SSC) has endorsed using the disjoint time periods [1980-84, 1990-97] to calculate $B_{M S Y_{p r o x y}}$ to avoid time periods of low abundance possibly caused by high fishing pressure. Alternative time periods (e.g., 1975 to 1979) have also been considered but rejected. Once $B_{M S Y_{p r o x y}}$ has been calculated, overfished status is then determined by the ratio $B / B_{M S Y_{\text {proxy }}}$ : the stock is overfished if the ratio is less than 0.5 , where $B$ is taken as"current" MMB-at-mating.

## MMB-at-mating

MMB-at-mating $\left(M M B_{m}\right)$ is calculated from MMB at the time of the annual NMFS EBS bottom trawl survey $\left(M M B_{s}\right)$ by accounting for natural and fishing mortality from the time of the survey to mating. MMB at the time of the survey in year $y$ is calculated from survey data using:

$$
M M B_{s_{y}}=\sum_{z} w_{z} \cdot P_{z} \cdot n_{z, y}
$$

where $w_{z}$ is male weight at size $z(\mathrm{~mm} \mathrm{CL}), P_{z}$ is the probability of maturity at size $z$, and $n_{z, y}$ is survey-estimated male abundance at size $z$ in year $y$.

For a year $y$ prior to the assessment year, $M M B_{m_{y}}$ is given by

1. $M M B_{f_{y}}=M M B_{s_{y}} \cdot e^{-M \cdot t_{s f}}$
2. $M M B_{m_{y}}=\left[M M B_{f_{y}}-R M_{y}-D M_{y}\right] \cdot e^{-M \cdot t_{f m}}$
where $M M B_{f_{y}}$ is the MMB in year $y$ just prior to the fishery, $M$ is natural mortality, $R M_{y}$ is retained mortality on MMB in the directed fishery in year $y, D M_{y}$ is discard mortality on MMB (not on all crab) in all fisheries in year $y$, $t_{s f}$ is the time between the survey and the fishery, and $t_{f m}$ is the time between the fishery and mating.

For the assessment year, the fishery has not yet occurred so $R M$ and $D M$ are unknown. The amount of fishing mortality presumably depends on the (as yet-to-be-determined) overfishing limit, so an iterative procedure is used to estimate MMB-at-mating for the fishery year. This procedure involves:

1. "guess" a value for $F_{O F L}$, the directed fishing mortality rate that yields OFL $\left(F_{O F L_{\max }}=\gamma \cdot M\right.$ is used)
2. determine the OFL corresponding to fishing at $F_{O F L}$ using the following equations:

- $M M B_{f}=M M B_{s} \cdot e^{-M \cdot t_{s f}}$
- $R M_{O F L}=\left(1-e^{-F_{O F L}}\right) \cdot M M B_{s} \cdot e^{-M \cdot t_{s f}}$
- $D M_{O F L}=\theta \cdot \frac{M M B_{f}}{p_{\text {male }}}$
- $O F L=R M_{O F L}+D M_{O F L}$

3. project MMB-at-mating from the "current" survey MMB and the OFL:

$$
\text { - } M M B_{m}=\left[M M B_{f_{y}}-\left(R M_{O F L}+p_{\text {male }} \cdot D M_{O F L}\right)\right] \cdot e^{-M \cdot t_{f m}}
$$

4. use the harvest control rule to determine the $F_{O F L}$ corresponding to the projected MMB-atmating.
5. update the "guess" in 1. for the result in 4.
6. repeat steps 2-5 until the process has converged, yielding self-consistent values for $F_{O F L}$ and MMB-at-mating.
where $p_{\text {male }}$ is the assumed fraction of discard mortality on males. Note that this procedure determines the OFL for the assessment year as well as the current MMB-at-mating. Also note that, while the retained mortality $R M_{O F L}$ is based on the $F_{O F L}$, the discard mortality $D M_{O F L}$ is assumed to be proportional to the MMB at the time of the fishery, with proportionality constant $\frac{\theta}{p_{\text {male }}}$. The constant $\theta$ is determined by the average ratio of discard mortality on MMB $\left(D M_{M M B}\right)$ to MMB at the time of the fishery $\left(M M B_{f}\right)$ over a recent time interval:

$$
\theta=\frac{1}{N} \sum_{y} \frac{D M_{M M B_{y}}}{M M B_{f_{y}}}
$$

where the sum is over the last N years. In addition, $D M_{M M B}$ is assumed to be proprtional to total discard mortality, with that proportionality given by the percenatge of males in the stock.

## Data

Data from the following files were used in this assessment:

- fishery data: ./Data2017AM.Fisheries.csv
- survey data : ./Data2017AM.Surveys.csv

The following figures illustrate the time series of retained PIBKC in the directed fishery and PIBKC incidentally taken in the crab and groundfish fisheries (i.e., bycatch):


Figure 1: Time series of retained PIBKC catch in the directed fishery.


Figure 2: Time series of retained PIBKC catch in the directed fishery (recent time period).


Figure 3: Time series of PIBKC bycatch in the crab and groundfish fisheries.


Figure 4: Time series of PIBKC bycatch in the crab and groundfish fisheries (recent time period).

The following figures illustrate the time series of PIBKC survey biomass in the NMFS EBS bottom trawl survey:


Figure 5: Time series of NMFS EBS bottom trawl survey biomass for PIBKC. Confidence intervals shown are $80 \%$ CI's, assuming lognormal error distributions.


Figure 6: Time series of NMFS EBS bottom trawl survey biomass for PIBKC (recent time period). Confidence intervals shown are $80 \%$ CI's, assuming lognormal error distributions.


Figure 7: Log10-scale time series for the NMFS EBS bottom trawl survey biomass for PIBKC. Confidence intervals shown are $80 \%$ CI's, assuming lognormal error distributions.

## Survey smoothing

For PIBKC, the variances associated with annual survey estimates of MMB are so large that, prior to estimating $B_{M S Y}$ and "current" MMB-at-mating, the survey MMB time series is first smoothed to reduce overall variability. Starting with the 2015 assessment (Stockhausen, 2015), a random
effects (RE) model based on code developed by Jim Ianelli (NOAA/NMFS/AFSC) has been used to perform the smoothing. This is a statistical approach which models annual log-scale changes in "true" survey MMB as a random walk process using

$$
<\ln \left(M M B_{s}\right)>_{y}=<\ln \left(M M B_{s}\right)>_{y-1}+\epsilon_{y}, \text { where } \epsilon_{y} \sim N\left(0, \phi^{2}\right)
$$

as the state equation and

$$
\ln \left(M M B_{s_{y}}\right)=<\ln \left(M M B_{s}\right)>_{y}+\eta_{y}, \text { where } \eta_{y} \sim N\left(0, \sigma_{s_{y}}^{2}\right)
$$

as the observation equation, where $<\ln \left(M M B_{s}\right)>_{y}$ is the estimated "true" log-scale survey MMB in year $y, \epsilon_{y}$ represents normally-distributed process error in year $y$ with standard deviation $\phi, M M B_{s_{y}}$ is the observed survey MMB in year $y, \eta_{y}$ represents normally-distributed $\ln$-scale observation error, and $\sigma_{s_{y}}$ is the log-scale survey MMB standard deviation in year $y$. The $M M B_{s}$ 's and $\sigma_{s}$ 's are observed quantities, the $<\ln \left(M M B_{s}\right)>$ 's and $\phi$ are estimated parameters, and the $\epsilon$ 's are random effects (essentially nuisance parameters) that are integrated out in the solution.

Parameter estimates are obtained by minimizing the objective function

$$
\Lambda=\sum_{y}\left[\ln (2 \pi \phi)+\left(\frac{<\ln \left(M M B_{s}\right)>_{y}-<\ln \left(M M B_{s}\right)>_{y-1}}{\phi}\right)^{2}\right]+\sum_{y}\left(\frac{\ln \left(M M B_{s_{y}}\right)-<\ln \left(M M B_{s}\right)>_{y}}{\sigma_{s_{y}}}\right)^{2}
$$

The model is coded in C ++ and uses AD Model Builder C ++ libraries (Fournier et al., 2012) to minimize the objective function.

## Smoothing results

For comparison, the raw and RE-smoothed survey MMB time series are shown below in Figures $8-10$, on both arithmetic and natural log scales:


Figure 8: Arithmetic-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80\% CIs, assuming lognormal error distributions.


Figure 9: Arithmetic-scale raw and smoothed survey MMB time series, since 2000. Confidence intervals shown are $80 \%$ CIs, assuming lognormal error distributions.


Figure 10: Log-scale raw and smoothed survey MMB time series. Confidence intervals shown are 80\% CIs, assuming lognormalerror distributions.

## Status determination

## Overfishing status

For PIBKC, the total fishing mortality in $2016 / 17$ was 0.3820875 t while the OFL was 1.16 t. Thus, overfishing did not occur in 2016/17.

## Overfished status

As discussed previously, overfished status is determined by the ratio $B / B_{M S Y_{\text {proxy }}}$ : the stock is overfished if the ratio is less than 0.5 , where $B$ is taken as "current" MMB-at-mating. For PIBKC, $B_{M S Y_{\text {proxy }}}$ is obtained by averaging estimated MMB-at-mating over the period [1980/81-1984/85,1990/91-1997/98]. Following recommendations made by the CPT and SSC in 2015 (CPT, 2015; SSC, 2015), $B$ and $B_{M S Y_{\text {proxy }}}$ are based on MMB-at-mating calculated using the RE-smoothed time series of survey biomass projected forward to mating time.

## MMB-at-mating

For comparison, time series for MMB-at-mating using both the raw (unsmoothed) survey MMB time series and the RE-smoothed survey MMB time series were calculated. The results are shown below in Figures 12 and 13:


Figure 11: Estimated time series for MMB at the time of the survey (no smoothing), at the time of the fishery, and at the time of mating.


Figure 12: Estimated time series for MMB using the RE method at the time of the survey (the random effects time series), at the time of the fishery, and at the time of mating.

Values for $B_{M S Y_{\text {proxy }}}$ and the estimated current (2017) MMB at the time of the survey from the raw survey data and the RE-smoothed results are:

Table 1: Estimated $B_{M S Y_{p r o x y}}$ and current MMB at the time of the survey, using the raw survey data and the RE-smoothed data.

| Estimation Type | Current survey MMB $(\mathrm{t})$ | $B_{M S Y_{\text {proxy }}}(\mathrm{t})$ |
| :--- | :---: | :---: |
| raw data | 253 | 5,012 |
| RE-smoothed | 256 | 4,108 |

The value above for $B_{M S Y_{\text {proxy }}}$ using the raw data is shown for illustration only. As noted previously, $B_{M S Y_{\text {proxy }}}$ for this assessment is based on averaging the MMB-at-mating calculated from the RE-smoothed survey MMB (i.e., 4107.8663144 t).

Values for $\theta$, used in the projected MMB calculations, based on averaging over the last three years, are:

Table 2: Estimated values for the heta coefficient.

|  | Estimation Type | $\$ \backslash$ theta $\$$ |
| :---: | :---: | :---: |
| 1 | raw data | 0.0007627 |
| 2 | RE-smoothed | 0.0006203 |

Results from the calculations for $B$ ("current" MMB), overfished status, and an illustrative Tier 4-based OFL for 2017/18 (not used for PIBKC) are:

Table 3: More results from the OFL determination.

|  | quantity | units | raw.data | RE.smoothed |
| :---: | :---: | :---: | :---: | :---: |
| 1 | $B$ ("current" MMB) | t | 227.41 | 230.21 |
| 2 | $B_{M S Y}$ | t | $5,012.14$ | $4,107.87$ |
| 3 | stock status | - | overfished | overfished |
| 4 | $F_{O F L}$ | year $^{-1}$ | 0.00 | 0.00 |
| 5 | $R M_{O F L}$ | t | 0.00 | 0.00 |
| 6 | $D M_{O F L}$ | t | 0.37 | 0.30 |
| 7 | $O F L$ | t | 0.37 | 0.30 |

Because $B / B_{M S Y}$ using RE-smoothed MMB-at-mating from the Table above is 0.056 , the stock is overfished. Furthermore, because $B / B_{M S Y}<\beta(=0.25)$, directed fishing on PIBKC is prohibited.

## Tables

## Fishery data

Table 4: Annual retained catch biomass and bycatch (not mortality; in $t$ ), as available, in the directed fishery, the other crab fisheries, and the groundfish fisheries.

| year | $\underset{\mathrm{t}}{\text { females }}$ | ```crab fisheries pot discard legal t``` | $\underset{\mathrm{t}}{\text { sublegal }}$ | ```directed fishery pot retained legal t``` | ```groundfi pot discard all t``` | heries trawl discard all t |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1966 | 0.0000 | $N A$ | $N A$ | 0.0000 | 0.0000 | $N A$ |
| 1967 | $N A$ | $N A$ | $N A$ | 1,097.6928 | $N A$ | $N A$ |
| 1968 | $N A$ | $N A$ | $N A$ | 725.7473 | $N A$ | $N A$ |
| 1969 | $N A$ | $N A$ | $N A$ | 2,485.6846 | $N A$ | $N A$ |
| 1970 | $N A$ | $N A$ | $N A$ | 580.5979 | $N A$ | $N A$ |
| 1971 | $N A$ | $N A$ | $N A$ | 557.9183 | $N A$ | $N A$ |
| 1972 | $N A$ | $N A$ | $N A$ | 136.0776 | $N A$ | $N A$ |
| 1973 | $N A$ | $N A$ | $N A$ | 580.5979 | $N A$ | $N A$ |
| 1974 | $N A$ | $N A$ | $N A$ | 3,225.0397 | $N A$ | $N A$ |
| 1975 | $N A$ | $N A$ | $N A$ | 1,102.2288 | $N A$ | $N A$ |
| 1976 | $N A$ | $N A$ | $N A$ | 2,998.2437 | $N A$ | $N A$ |
| 1977 | $N A$ | $N A$ | $N A$ | 2,930.2049 | $N A$ | $N A$ |
| 1978 | $N A$ | $N A$ | $N A$ | 2,902.9894 | $N A$ | $N A$ |
| 1979 | $N A$ | $N A$ | $N A$ | 2,721.5525 | $N A$ | $N A$ |
| 1980 | $N A$ | $N A$ | $N A$ | 4,975.9052 | $N A$ | $N A$ |
| 1981 | $N A$ | $N A$ | $N A$ | 4,118.6161 | $N A$ | $N A$ |
| 1982 | $N A$ | $N A$ | $N A$ | 2,000.3411 | $N A$ | $N A$ |
| 1983 | $N A$ | $N A$ | $N A$ | 993.3667 | $N A$ | $N A$ |
| 1984 | $N A$ | $N A$ | $N A$ | 140.6135 | $N A$ | $N A$ |
| 1985 | $N A$ | $N A$ | $N A$ | 240.4038 | $N A$ | $N A$ |
| 1986 | $N A$ | $N A$ | $N A$ | 117.9339 | $N A$ | $N A$ |
| 1987 | $N A$ | $N A$ | $N A$ | 317.5145 | $N A$ | $N A$ |
| 1988 | $N A$ | $N A$ | $N A$ | 0.0000 | $N A$ | $N A$ |
| 1989 | $N A$ | $N A$ | $N A$ | 0.0000 | $N A$ | $N A$ |
| 1990 | $N A$ | $N A$ | $N A$ | 0.0000 | $N A$ | $N A$ |
| 1991 | $N A$ | $N A$ | $N A$ | 0.0000 | 0.0670 | 6.1990 |
| 1992 | $N A$ | $N A$ | $N A$ | 0.0000 | 0.8790 | 60.7910 |
| 1993 | $N A$ | $N A$ | $N A$ | 0.0000 | 0.0000 | 34.2320 |
| 1994 | $N A$ | $N A$ | $N A$ | 0.0000 | 0.0350 | 6.8560 |
| 1995 | $N A$ | $N A$ | $N A$ | 625.9571 | 0.1080 | 1.2840 |
| 1996 | 0.0000 | 0.0000 | 0.8074 | 426.3766 | 0.0310 | 0.0670 |
| 1997 | 0.0000 | 0.0000 | 0.0000 | 231.3320 | 1.4620 | 0.1300 |
| 1998 | 3.7149 | 2.2952 | 0.4672 | 235.8679 | 19.8000 | 0.0790 |
| 1999 | 1.9686 | 3.4927 | 4.2910 | 0.0000 | 0.7950 | 0.0200 |
| 2000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1160 | 0.0230 |
| 2001 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.8330 | 0.0290 |
| 2002 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0710 | 0.2970 |
| 2003 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.3450 | 0.2270 |
| 2004 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.8160 | 0.0020 |
| 2005 | 0.0499 | 0.0000 | 0.0000 | 0.0000 | 0.3530 | 1.3390 |
| 2006 | 0.1043 | 0.0000 | 0.0000 | 0.0000 | 0.1380 | 0.0740 |
| 2007 | 0.1361 | 0.0000 | 0.0000 | 0.0000 | 3.9930 | 0.1320 |
| 2008 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1410 | 0.4730 |
| 2009 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2156 | 0.2068 |
| 2010 | 0.0000 | 0.0000 | 0.1860 | 0.0000 | 0.0443 | 0.0563 |
| 2011 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1117 | 0.0071 |
| 2012 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1699 | 0.6688 |
| 2013 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0646 | 0.0000 |
| 2014 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1443 | 0.0001 |
| 2015 | 0.1028 | 0.0000 | 0.2301 | 0.0000 | 0.7443 | 0.8078 |
| 2016 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0904 | 0.4550 |

## Survey data

Table 5: Input ('raw') male survey abundance data (numbers of crab).

| year | immature |  | legal |  | mature |  | total |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | value | cv | value | cv | value | cv | value | cv |
| 1975 | 8,475, 780.89 | 0.57 | 9, 051, 485.73 | 0.50 | 28, 435, 755.89 | 1.11 | 36,911,536.79 | 1.07 |
| 1976 | 12, 328, 947.42 | 1.92 | 4, 012, 289.16 | 0.47 | 5,551, 254.42 | 0.96 | 17, 880, 201.84 | 1.50 |
| 1977 | 5, 067, 465.88 | 1.28 | 11, 768, 927.37 | 0.77 | 26, 924, 033.45 | 1.60 | 31, 991, 499.33 | 1.48 |
| 1978 | 2, 482, 381.42 | 1.50 | 3, 922, 873.85 | 0.62 | 12, 067, 151.89 | 1.16 | 14, 549, 533.30 | 1.08 |
| 1979 | 221, 771.00 | 1.42 | 3, 017, 118.91 | 0.31 | 5, 276, 802.27 | 1.14 | 5, 498, 573.27 | 1.09 |
| 1980 | 3, 513, 951.44 | 1.24 | 6, 244, 057.67 | 0.42 | 190, 745, 260.90 | 1.39 | 194, 259, 212.34 | 1.38 |
| 1981 | 2, 925, 999.23 | 0.73 | 3, 245, 951.07 | 0.18 | 9, 267, 921.40 | 0.62 | 12, 193, 920.63 | 0.63 |
| 1982 | 2, 247, 538.58 | 0.80 | 2, 071, 467.90 | 0.19 | 10, 190, 817.25 | 0.83 | 12, 438, 355.84 | 0.80 |
| 1983 | 1, 494, 458.75 | 0.90 | 1, 321, 394.69 | 0.17 | 11, 159, 269.86 | 0.97 | 12, 653, 728.61 | 0.98 |
| 1984 | 983, 046.34 | 0.91 | 558, 226.46 | 0.25 | 3, 539, 833.29 | 0.60 | 4, 522, 879.63 | 0.58 |
| 1985 | 327, 846.69 | 1.14 | 270, 241.72 | 0.29 | 914, 260.33 | 0.72 | 1, 242, 107.02 | 0.63 |
| 1986 | 55, 588.48 | 1.70 | 460, 310.63 | 0.31 | 2, 582, 129.95 | 1.20 | 2, 637, 718.43 | 1.18 |
| 1987 | 1, 023, 070.70 | 1.58 | 830, 150.65 | 0.42 | 1,573, 658.67 | 1.00 | 2, 596, 729.37 | 0.91 |
| 1988 | 2, 135, 682.52 | 1.71 | 237, 867.82 | 0.51 | 703, 331.18 | 0.99 | 2, 839, 013.70 | 1.35 |
| 1989 | 6, 150, 862.84 | 1.33 | 239, 947.52 | 0.62 | 1, 381, 703.37 | 1.28 | 7, 532, 566.21 | 1.16 |
| 1990 | 4, 627, 193.67 | 1.51 | 571, 708.33 | 0.54 | 3, 516, 258.12 | 1.17 | 8,143, 451.79 | 1.13 |
| 1991 | 2, 725, 893.73 | 0.84 | 1,237, 558.37 | 0.44 | 4, 781, 533.72 | 0.78 | 7, 507, 427.45 | 0.70 |
| 1992 | 4, 233, 139.11 | 1.51 | 1, 154, 465.28 | 0.45 | 4, 084, 797.20 | 0.91 | 8,317, 936.31 | 1.00 |
| 1993 | 2, 364, 196.25 | 1.13 | 1, 114, 300.52 | 0.30 | 3, 658,157.09 | 0.76 | 6, 022, 353.33 | 0.72 |
| 1994 | 783, 283.02 | 0.95 | 935, 268.63 | 0.34 | 6, 341, 478.39 | 0.78 | 7, 124, 761.41 | 0.77 |
| 1995 | 1, 805, 281.89 | 1.81 | 2, 186, 408.91 | 0.62 | 7, 140, 267.33 | 1.12 | 8, 945, 549.23 | 1.17 |
| 1996 | 995, 165.22 | 1.04 | 1, 269, 274.66 | 0.26 | 6, 757, 837.30 | 0.77 | 7, 753, 002.53 | 0.80 |
| 1997 | 787, 577.26 | 1.19 | 932, 852.28 | 0.28 | 3, 815, 669.55 | 0.72 | 4,603, 246.80 | 0.73 |
| 1998 | 1,449, 688.57 | 0.89 | 797, 187.26 | 0.25 | 2, 796, 606.53 | 0.69 | 4, 246, 295.10 | 0.67 |
| 1999 | 159, 535.74 | 0.37 | 452, 740.30 | 0.34 | 3, 373, 234.05 | 0.82 | 3, 532, 769.79 | 0.82 |
| 2000 | 163, 834.62 | 0.56 | 527, 589.35 | 0.30 | 2, 088, 120.40 | 0.76 | 2, 251, 955.02 | 0.77 |
| 2001 | 111, 434.07 | 1.65 | 445, 863.41 | 0.74 | 2, 219, 704.16 | 1.46 | 2, 331, 138.23 | 1.43 |
| 2002 | 18,729.46 | 1.00 | 207, 145.98 | 0.49 | 1, 447, 328.02 | 1.27 | 1, 466, 057.48 | 1.25 |
| 2003 | 112, 599.69 | 1.20 | 213, 572.37 | 0.40 | 1, 349, 151.10 | 1.15 | 1, 461, 750.78 | 1.06 |
| 2004 | 185, 710.36 | 1.22 | 15,583.88 | 1.00 | 117, 939.32 | 1.17 | 303, 649.68 | 0.93 |
| 2005 | 4, 249, 450.99 | 1.96 | 91, 932.30 | 0.71 | 381, 129.58 | 1.28 | 4, 630,580.58 | 1.81 |
| 2006 | 251, 165.41 | 1.04 | 38, 242.00 | 0.70 | 485, 119.46 | 1.33 | 736, 284.87 | 1.04 |
| 2007 | 368,647.45 | 1.45 | 54, 402.91 | 0.75 | 275, 842.91 | 1.75 | 644, 490.36 | 1.23 |
| 2008 | 576, 037.92 | 1.83 | 18, 255.62 | 1.00 | 455, 624.48 | 1.66 | 1,031,662.41 | 1.61 |
| 2009 | 420, 006.90 | 1.24 | 68, 117.04 | 0.59 | 725, 721.22 | 1.55 | 1, 145, 728.13 | 1.43 |
| 2010 | 266, 783.19 | 1.40 | 64, 702.83 | 0.48 | 379, 492.70 | 1.18 | 646, 275.89 | 1.23 |
| 2011 | 18, 089.34 | 1.00 | 129, 097.71 | 0.87 | 202, 037.20 | 1.49 | 220, 126.54 | 1.36 |
| 2012 | 229, 204.82 | 2.00 | 164, 164.90 | 0.68 | 584, 327.37 | 1.56 | 813,532.19 | 1.57 |
| 2013 | 121, 694.76 | 1.70 | 68, 726.09 | 0.80 | 254, 660.86 | 1.49 | 376, 355.62 | 1.18 |
| 2014 | 118, 710.86 | 1.59 | 91, 855.85 | 0.71 | 166, 223.38 | 1.31 | 284, 934.24 | 1.07 |
| 2015 | 75, 575.44 | 0.77 | 124, 591.54 | 0.45 | 436, 094.37 | 1.02 | 511, 669.81 | 1.06 |
| 2016 | 225, 711.04 | 1.02 | 19,344.90 | 1.00 | 378, 612.24 | 1.08 | 604, 323.27 | 0.99 |
| 2017 | 256, 098.21 | 1.52 | 71, 937.24 | 0.59 | 252, 444.72 | 1.04 | 508, 542.93 | 0.99 |

Table 6: Input ('raw') male survey biomass data, in t.

|  | immature |  | legal |  | mature |  | total |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| year | value | cv | value | cv | value | cv | value | cv |
| 1975 | 8,340.95 | 0.52 | 27, 016.47 | 0.50 | 38,053.59 | 0.50 | 46, 394.54 | 0.47 |
| 1976 | 4, 128.67 | 0.94 | 12,648.94 | 0.47 | 14, 058.93 | 0.45 | 18, 187.61 | 0.45 |
| 1977 | 3, 713.34 | 0.44 | 40, 365.94 | 0.78 | 42, 618.32 | 0.77 | 46, 331.66 | 0.73 |
| 1978 | 2, 765.31 | 0.51 | 13,516.82 | 0.64 | 17, 369.71 | 0.56 | 20,135.02 | 0.51 |
| 1979 | 61.27 | 0.79 | 9, 039.95 | 0.31 | 10, 959.38 | 0.32 | 11,020.66 | 0.31 |
| 1980 | 2, 083.76 | 0.49 | 20,678.62 | 0.45 | 23,552.92 | 0.43 | 25,636.68 | 0.42 |
| 1981 | 1,704.25 | 0.30 | 10,553.54 | 0.17 | 11,628.25 | 0.17 | 13, 332.49 | 0.18 |
| 1982 | 1,151.96 | 0.23 | 6, 893.43 | 0.19 | 7, 388.96 | 0.19 | 8,540.92 | 0.17 |
| 1983 | 962.34 | 0.36 | 4, 474.40 | 0.17 | 5, 408.73 | 0.18 | 6, 371.08 | 0.19 |
| 1984 | 129.72 | 0.36 | 1, 824.02 | 0.25 | 2, 215.66 | 0.23 | 2, 345.38 | 0.22 |
| 1985 | 39.02 | 0.73 | 755.50 | 0.28 | 1, 054.79 | 0.27 | 1, 093.81 | 0.26 |
| 1986 | 3.73 | 1.00 | 1, 473.32 | 0.31 | 1,504.69 | 0.30 | 1,508.43 | 0.30 |
| 1987 | 191.45 | 0.78 | 2, 781.34 | 0.41 | 2, 923.38 | 0.41 | 3, 114.84 | 0.40 |
| 1988 | 170.05 | 0.71 | 842.43 | 0.53 | 842.43 | 0.53 | 1, 012.48 | 0.46 |
| 1989 | 1, 274.88 | 0.62 | 827.50 | 0.64 | 827.50 | 0.64 | 2, 102.37 | 0.55 |
| 1990 | 2, 004.14 | 0.66 | 1, 514.33 | 0.52 | 3, 077.51 | 0.60 | 5, 081.65 | 0.61 |
| 1991 | 1,377.43 | 0.39 | 3, 325.77 | 0.45 | 4, 689.67 | 0.39 | 6, 067.10 | 0.37 |
| 1992 | 1, 800.51 | 0.51 | 3, 034.80 | 0.45 | 4, 391.01 | 0.42 | 6, 191.52 | 0.43 |
| 1993 | 1, 088.50 | 0.54 | 3, 202.55 | 0.30 | 4,555.60 | 0.31 | 5, 644.10 | 0.30 |
| 1994 | 618.98 | 0.39 | 2, 805.73 | 0.35 | 3, 410.36 | 0.34 | 4, 029.34 | 0.34 |
| 1995 | 967.73 | 0.86 | 6, 786.93 | 0.62 | 8, 360.23 | 0.60 | 9, 327.96 | 0.63 |
| 1996 | 744.89 | 0.61 | 3, 873.06 | 0.27 | 4, 640.62 | 0.27 | 5, 385.51 | 0.28 |
| 1997 | 381.39 | 0.55 | 2, 765.39 | 0.27 | 3, 232.58 | 0.28 | 3, 613.97 | 0.29 |
| 1998 | 692.25 | 0.41 | 2, 509.92 | 0.25 | 2, 797.93 | 0.25 | 3, 490.19 | 0.25 |
| 1999 | 160.65 | 0.40 | 1, 426.16 | 0.35 | 1, 729.24 | 0.34 | 1, 889.89 | 0.33 |
| 2000 | 113.32 | 0.68 | 1, 745.75 | 0.31 | 2, 091.34 | 0.30 | 2, 204.66 | 0.30 |
| 2001 | 87.07 | 0.76 | 1, 460.92 | 0.76 | 1,598.74 | 0.73 | 1,685.81 | 0.73 |
| 2002 | 0.00 | 0.00 | 647.07 | 0.52 | 679.80 | 0.51 | 679.80 | 0.51 |
| 2003 | 19.06 | 0.98 | 671.20 | 0.41 | 702.01 | 0.40 | 721.07 | 0.39 |
| 2004 | 36.01 | 0.65 | 48.43 | 1.00 | 106.88 | 0.58 | 142.89 | 0.46 |
| 2005 | 325.78 | 0.94 | 344.06 | 0.71 | 344.06 | 0.71 | 669.84 | 0.59 |
| 2006 | 86.89 | 0.58 | 139.22 | 0.70 | 165.89 | 0.60 | 252.77 | 0.46 |
| 2007 | 196.77 | 0.74 | 205.56 | 0.73 | 306.46 | 0.80 | 503.23 | 0.66 |
| 2008 | 211.71 | 0.95 | 45.98 | 1.00 | 45.98 | 1.00 | 257.69 | 0.80 |
| 2009 | 254.30 | 0.68 | 186.51 | 0.60 | 497.11 | 0.71 | 751.41 | 0.70 |
| 2010 | 91.64 | 0.85 | 190.05 | 0.48 | 302.93 | 0.46 | 394.57 | 0.52 |
| 2011 | 0.00 | 0.00 | 398.98 | 0.89 | 461.36 | 0.84 | 461.36 | 0.84 |
| 2012 | 164.71 | 1.00 | 458.98 | 0.64 | 643.94 | 0.74 | 808.65 | 0.79 |
| 2013 | 14.53 | 1.00 | 189.92 | 0.75 | 250.14 | 0.80 | 264.66 | 0.75 |
| 2014 | 83.15 | 0.62 | 233.39 | 0.70 | 233.39 | 0.70 | 316.54 | 0.57 |
| 2015 | 81.69 | 0.75 | 428.26 | 0.46 | 621.71 | 0.39 | 703.40 | 0.39 |
| 2016 | 70.34 | 0.49 | 67.74 | 1.00 | 128.55 | 0.61 | 198.89 | 0.52 |
| 2017 | 45.20 | 0.77 | 222.52 | 0.57 | 252.78 | 0.51 | 297.98 | 0.47 |

Table 7: Input ('raw') female survey abundance data (numbers of crab).

| year | immature |  | mature |  | total |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | value | cV | value | cV | value | cV |
| 1975 | 0.00 | 0.00 | 13, 147, 586.68 | 0.61 | 13, 147, 586.68 | 0.61 |
| 1976 | 7,369,388.06 | 0.97 | 769,149.65 | 0.51 | $8,138,537.71$ | 0.91 |
| 1977 | 851,600.68 | 0.82 | 13, 880, 050.65 | 0.86 | 14,731,651.34 | 0.86 |
| 1978 | 60,923.05 | 1.00 | 5, 926, 514.32 | 0.66 | 5, 987, 437.37 | 0.66 |
| 1979 | 142, 416.25 | 0.72 | 1,168, 934.53 | 0.81 | 1,311,350.78 | 0.77 |
| 1980 | 781, 223.69 | 0.77 | 182, 902, 918.90 | 0.98 | 183, 684, 142.60 | 0.98 |
| 1981 | 826, 523.82 | 0.41 | $5,433,490.77$ | 0.44 | 6, 260, 014.59 | 0.42 |
| 1982 | 876, 255.79 | 0.51 | 7, 837, 003.99 | 0.65 | 8,713,259.78 | 0.63 |
| 1983 | 463, 726.39 | 0.54 | 9, 307, 968.75 | 0.78 | 9,771,695.14 | 0.76 |
| 1984 | 465, 472.58 | 0.52 | 2, 769,190.35 | 0.38 | 3, 234, 662.94 | 0.37 |
| 1985 | 260, 081.29 | 0.54 | 486, 184.43 | 0.44 | 746, 265.72 | 0.36 |
| 1986 | 36,684.23 | 0.70 | 2, 101,931.80 | 0.90 | 2,138, 616.03 | 0.88 |
| 1987 | 401, 529.77 | 0.74 | 670,478.72 | 0.58 | 1,072, 008.49 | 0.48 |
| 1988 | 897,629.21 | 0.87 | 465, 463.37 | 0.48 | 1,363,092.58 | 0.64 |
| 1989 | 2,636,098.81 | 0.74 | 1,141,755.85 | 0.66 | 3,777, 854.65 | 0.58 |
| 1990 | 2, 177, 329.21 | 0.91 | 2, $045,839.41$ | 0.55 | 4, 223, 168.62 | 0.56 |
| 1991 | 805, 450.59 | 0.46 | 2,767, 448.02 | 0.42 | 3, 572, 898.61 | 0.35 |
| 1992 | 1,797, 343.33 | 0.93 | 2,149,519.20 | 0.49 | 3, 946, 862.54 | 0.52 |
| 1993 | 880, 672.33 | 0.61 | 1,782, 656.74 | 0.45 | 2, 663, 329.07 | 0.38 |
| 1994 | 144, 763.08 | 0.57 | 5, 047, 215.18 | 0.44 | 5,191,978.25 | 0.44 |
| 1995 | 658, 479.28 | 0.92 | $4,038,555.59$ | 0.52 | 4, 697, 034.87 | 0.49 |
| 1996 | 275, 735.14 | 0.42 | 5, 045, 822.06 | 0.48 | $5,321,557.20$ | 0.46 |
| 1997 | 320, 343.56 | 0.67 | 2, 614, 373.74 | 0.42 | 2,934, 717.30 | 0.39 |
| 1998 | 500, 241.34 | 0.43 | 1, 829,509.02 | 0.44 | 2,329, 750.36 | 0.37 |
| 1999 | 0.00 | 0.00 | 2,755, 975.76 | 0.49 | 2,755,975.76 | 0.49 |
| 2000 | 0.00 | 0.00 | 1,363, 069.69 | 0.46 | 1,363, 069.69 | 0.46 |
| 2001 | 18,516.37 | 1.00 | 1,697,465.09 | 0.75 | 1,715,981.46 | 0.74 |
| 2002 | 18,729.46 | 1.00 | 1,221,852.43 | 0.79 | 1,240,581.89 | 0.78 |
| 2003 | 67,328.63 | 0.48 | 1,120,254.01 | 0.76 | 1,187,582.64 | 0.72 |
| 2004 | 98, 059.03 | 0.63 | 70, 034.56 | 0.60 | 168,093.59 | 0.51 |
| 2005 | 2, 268, 112.83 | 1.00 | 289, 197.28 | 0.56 | 2, 557, 310.11 | 0.89 |
| 2006 | 113, 047.12 | 0.55 | 429, 540.72 | 0.77 | 542, 587.84 | 0.62 |
| 2007 | 122, 482.70 | 0.73 | 165, 762.60 | 0.90 | 288, 245.30 | 0.59 |
| 2008 | 342, 119.25 | 0.90 | 437, 368.86 | 0.66 | 779,488.11 | 0.75 |
| 2009 | 152, 290.08 | 0.61 | 477, 095.11 | 0.82 | 629,385.19 | 0.76 |
| 2010 | 165,632.29 | 0.56 | 249, 027.32 | 0.69 | 414,659.61 | 0.62 |
| 2011 | 18, 089.34 | 1.00 | 36,511.72 | 0.70 | 54,601.06 | 0.56 |
| 2012 | 34,682.61 | 1.00 | 312,094.57 | 0.76 | 346, 777.18 | 0.70 |
| 2013 | 45, 343.64 | 0.70 | 150,299.88 | 0.63 | 195, 643.52 | 0.53 |
| 2014 | 27, 720.50 | 1.00 | 74, 367.54 | 0.60 | 102, 088.04 | 0.51 |
| 2015 | 0.00 | 0.00 | 202, 464.39 | 0.65 | 202, 464.39 | 0.65 |
| 2016 | 131,689.04 | 0.50 | 322, 760.45 | 0.52 | 454, 449.50 | 0.50 |
| 2017 | 187, 859.97 | 0.75 | 161, 799.38 | 0.53 | 349, 659.35 | 0.54 |

Table 8: Input ('raw') female survey biomass data, in $t$.

| year | immature |  | mature |  | total |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | value | cv | value | cv | value | cv |
| 1975 | 0.00 | 0.00 | 12, 442.27 | 0.64 | 12,442.27 | 0.64 |
| 1976 | 4, 967.70 | 0.97 | 823.80 | 0.53 | 5,791.50 | 0.89 |
| 1977 | 418.58 | 0.83 | $13,153.87$ | 0.88 | 13,572.45 | 0.87 |
| 1978 | 76.40 | 1.00 | 6, 415.74 | 0.72 | 6,492.14 | 0.72 |
| 1979 | 91.67 | 0.73 | 1,097.29 | 0.79 | 1,188.96 | 0.76 |
| 1980 | 699.46 | 0.86 | 211, 603.71 | 0.98 | 212, 303.16 | 0.98 |
| 1981 | 497.16 | 0.41 | 5,986.82 | 0.47 | 6,483.97 | 0.46 |
| 1982 | 553.17 | 0.57 | 8, 823.72 | 0.68 | 9, 376.89 | 0.67 |
| 1983 | 258.05 | 0.61 | 9, 989.87 | 0.79 | 10,247.93 | 0.78 |
| 1984 | 15.35 | 0.69 | 3, 069.56 | 0.38 | 3, 084.90 | 0.38 |
| 1985 | 4.87 | 0.46 | 519.81 | 0.45 | 524.67 | 0.44 |
| 1986 | 11.02 | 0.73 | 2, 419.78 | 0.90 | 2,430.80 | 0.90 |
| 1987 | 118.72 | 0.86 | 794.61 | 0.58 | 913.33 | 0.53 |
| 1988 | 190.14 | 0.79 | 527.64 | 0.49 | 717.78 | 0.47 |
| 1989 | 800.78 | 0.67 | 944.75 | 0.58 | 1,745.53 | 0.50 |
| 1990 | 1,118.45 | 0.93 | 1, 810.45 | 0.51 | 2,928.89 | 0.49 |
| 1991 | 342.70 | 0.48 | 2, 433.24 | 0.41 | 2,775.93 | 0.38 |
| 1992 | 801.57 | 0.96 | 1,847.65 | 0.48 | 2,649.23 | 0.46 |
| 1993 | 444.39 | 0.62 | 1,647.13 | 0.46 | 2,091.51 | 0.40 |
| 1994 | 87.01 | 0.57 | 4, 805.95 | 0.45 | 4, 892.96 | 0.44 |
| 1995 | 331.03 | 0.90 | 3, 947.94 | 0.52 | 4, 278.97 | 0.50 |
| 1996 | 176.52 | 0.42 | 5,408.25 | 0.50 | 5,584.77 | 0.49 |
| 1997 | 193.64 | 0.66 | 2, 834.78 | 0.43 | 3, 028.42 | 0.41 |
| 1998 | 267.35 | 0.42 | 1,914.46 | 0.44 | 2,181.81 | 0.39 |
| 1999 | 0.00 | 0.00 | 2, 868.27 | 0.47 | 2, 868.27 | 0.47 |
| 2000 | 0.00 | 0.00 | 1,461.82 | 0.46 | 1,461.82 | 0.46 |
| 2001 | 0.34 | 1.00 | 1,816.35 | 0.72 | 1,816.69 | 0.72 |
| 2002 | 0.24 | 1.00 | 1,400.74 | 0.78 | 1,400.98 | 0.78 |
| 2003 | 20.94 | 0.67 | 1,286.42 | 0.75 | 1,307.36 | 0.73 |
| 2004 | 25.20 | 0.82 | 97.71 | 0.60 | 122.91 | 0.50 |
| 2005 | 477.27 | 1.00 | 369.83 | 0.57 | 847.10 | 0.61 |
| 2006 | 38.16 | 0.60 | 537.85 | 0.76 | 576.01 | 0.71 |
| 2007 | 58.77 | 0.79 | 223.43 | 0.88 | 282.19 | 0.71 |
| 2008 | 222.03 | 0.90 | 449.54 | 0.64 | 671.57 | 0.70 |
| 2009 | 80.22 | 0.66 | 544.69 | 0.85 | 624.91 | 0.82 |
| 2010 | 84.08 | 0.58 | 310.16 | 0.66 | 394.24 | 0.63 |
| 2011 | 2.69 | 1.00 | 34.14 | 0.73 | 36.83 | 0.67 |
| 2012 | 8.70 | 1.00 | 228.76 | 0.66 | 237.46 | 0.64 |
| 2013 | 12.06 | 0.72 | 153.85 | 0.70 | 165.91 | 0.65 |
| 2014 | 16.43 | 1.00 | 91.11 | 0.60 | 107.54 | 0.53 |
| 2015 | 0.00 | 0.00 | 159.65 | 0.66 | 159.65 | 0.66 |
| 2016 | 72.47 | 0.47 | 328.67 | 0.50 | 401.14 | 0.48 |
| 2017 | 106.89 | 0.81 | 152.11 | 0.56 | 259.01 | 0.53 |

Table 9: A comparison of estimates for MMB (in $t$ ) at the time of the survey.

| year | raw |  |  | RE |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | value | lci | uci | value | lci | uci |
| 1975 | 38, 053.59 | 20,759.61 | 69,754.48 | 26,901.00 | 16,825.61 | 43,009.66 |
| 1976 | 14, 058.93 | 8,103.53 | 24,391.05 | 19, 926.60 | 13, 388.82 | 29,656.78 |
| 1977 | 42, 618.32 | 17,814.39 | 101, 958.08 | 21,264.90 | 13,591.30 | 33, 270.99 |
| 1978 | 17,369.71 | 8, 912.49 | 33, 852.16 | 16,974.60 | 11,333.27 | 25, 424.00 |
| 1979 | 10,959.38 | 7,385.67 | 16, 262.32 | 13,329.30 | 9, 743.03 | 18,235.63 |
| 1980 | 23,552.92 | 13,894.39 | 39, 925.46 | 15,605.10 | 11, 032.07 | 22,073.75 |
| 1981 | 11,628.25 | 9, 320.75 | 14,507.00 | 11,423.00 | 9,355.46 | 13, 947.47 |
| 1982 | 7,388.96 | 5,824.58 | 9, 373.50 | 7,448.55 | 6, 051.74 | 9, 167.76 |
| 1983 | 5, 408.73 | 4,315.80 | 6,778.45 | 5,081.02 | 4,155.14 | 6, 213.21 |
| 1984 | 2, 215.66 | 1,659.01 | 2,959.08 | 2, 347.24 | 1,840.91 | 2, 992.84 |
| 1985 | 1,054.79 | 753.94 | 1,475.68 | 1,349.79 | 1, 020.02 | 1,786.18 |
| 1986 | 1,504.69 | 1,029.62 | 2,198.96 | 1,555.26 | 1,156.67 | 2,091.20 |
| 1987 | 2, 923.38 | 1,761.10 | 4,852.75 | 1,927.64 | 1,351.62 | 2,749.15 |
| 1988 | 842.43 | 445.93 | 1,591.49 | 1,427.29 | 946.09 | 2,153.24 |
| 1989 | 827.50 | 391.56 | 1,748.76 | 1,598.80 | 1, 027.48 | 2, 487.79 |
| 1990 | 3, 077.51 | 1,512.59 | 6,261.49 | 2,602.58 | 1,717.52 | 3, 943.72 |
| 1991 | 4,689.67 | 2,910.49 | 7,556.46 | 3, 812.12 | 2, 677.47 | 5,427.61 |
| 1992 | 4,391.01 | 2,612.05 | 7,381.55 | 4,181.16 | 2, 939.68 | 5, 946.94 |
| 1993 | 4,555.60 | 3,100.43 | 6,693.73 | 4, 328.92 | 3, 200.20 | 5,855.75 |
| 1994 | 3,410.36 | 2, 219.61 | 5, 239.91 | 4, 017.00 | 2, 906.92 | 5,551.00 |
| 1995 | 8,360.23 | 4,090.73 | 17, 085.84 | 4,941.99 | 3, 335.75 | 7,321.67 |
| 1996 | 4, 640.62 | 3, 308.54 | 6, 509.03 | 4,384.30 | 3, 316.32 | 5,796.22 |
| 1997 | 3, 232.58 | 2, 284.30 | 4,574.53 | 3, 322.05 | 2, 523.45 | 4, 373.38 |
| 1998 | 2,797.93 | 2,042.57 | 3, 832.65 | 2,704.95 | 2, 085.48 | 3, 508.43 |
| 1999 | 1,729.24 | 1,136.48 | 2, 631.17 | 1,976.11 | 1,450.90 | 2,691.44 |
| 2000 | 2,091.34 | 1,442.89 | 3,031.19 | 1,836.48 | 1,358.21 | 2,483.16 |
| 2001 | 1,598.74 | 688.93 | 3, 710.05 | 1,264.67 | 829.84 | 1,927.36 |
| 2002 | 679.80 | 368.60 | 1,253.75 | 784.02 | 528.41 | 1,163.28 |
| 2003 | 702.01 | 428.47 | 1,150.19 | 548.55 | 381.89 | 787.92 |
| 2004 | 106.88 | 53.46 | 213.67 | 278.26 | 179.24 | 432.00 |
| 2005 | 344.06 | 151.76 | 780.00 | 265.97 | 168.64 | 419.46 |
| 2006 | 165.89 | 81.25 | 338.67 | 224.99 | 142.84 | 354.39 |
| 2007 | 306.46 | 124.64 | 753.49 | 230.18 | 141.64 | 374.08 |
| 2008 | 45.98 | 15.82 | 133.66 | 210.46 | 126.20 | 350.98 |
| 2009 | 497.11 | 218.63 | 1,130.34 | 294.20 | 185.57 | 466.43 |
| 2010 | 302.93 | 172.57 | 531.78 | 321.26 | 214.21 | 481.79 |
| 2011 | 461.36 | 180.34 | 1,180.27 | 372.10 | 232.13 | 596.46 |
| 2012 | 643.94 | 277.26 | 1,495.58 | 398.87 | 247.63 | 642.49 |
| 2013 | 250.14 | 101.79 | 614.66 | 345.09 | 214.61 | 554.90 |
| 2014 | 233.39 | 103.97 | 523.89 | 338.82 | 217.04 | 528.91 |
| 2015 | 621.71 | 382.23 | 1,011.25 | 398.72 | 274.64 | 578.88 |
| 2016 | 128.55 | 62.34 | 265.09 | 258.43 | 166.93 | 400.10 |
| 2017 | 252.78 | 135.99 | 469.85 | 255.86 | 158.16 | 413.90 |

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# Saint Matthew Island Blue King Crab Stock Assessment 2017 

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## Executive Summary

1. Stock: Blue king crab, Paralithodes platypus, Saint Matthew Island (SMBKC), Alaska.
2. Catches: Peak historical harvest was 4288 t ( 9.454 million pounds) in $1983 / 84^{1}$. The fishery was closed for 10 years after the stock was declared overfished in 1999. Fishing resumed in 2009/10 with a fishery-reported retained catch of 209 t ( 0.461 million pounds), less than half the 529.3 t ( 1.167 million pound) TAC. Following three more years of modest harvests supported by a fishery catch per unit effort (CPUE) of around 10 crab per pot lift, the fishery was again closed in 2013/14 due to declining trawl-survey estimates of abundance and concerns about the health of the stock. The directed fishery resumed again in $2014 / 15$ with a TAC of 300 t ( 0.655 million pounds), but the fishery performance was relatively poor with a retained catch of 140 t ( 0.309 million pounds). The retained catch in 2015/16 was even lower at 48 t ( 0.105 million pounds) and in 2016/2017 the fishery was closed.
3. Stock biomass: The 1978-2017 NMFS trawl survey mean biomass is $5,762 \mathrm{t}$ with the 8 th lowest value occurring in 2017 (the fourth lowest since 2000) with a biomass of $\geq 90 \mathrm{~mm}$ carapace length (CL) and larger male crab of just under $1,800 \mathrm{t}(\sim 31 \%$ of the long term mean; 6.12 million lbs with a CV of $60 \%$ ). The most recent 3 -year average of the NMFS survey is $65 \%$ of the mean value, suggesting a general decline in biomass compared to the survey estimates in 2010 and 2011 that were nearly twice the current average. The assessment model estimates dampen the interannual variability observed in the survey biomass and suggest that the stock (in survey biomass units) is presently at about $45 \%$ of the long term model-predicted survey biomass average. The trend from these values suggests a slight decline.
4. Recruitment: Recruitment is based on estimated number of male crab within the 90-104 mm CL size class in each year. The 2017 trawl-survey area-swept estimate of 0.073 million male SMBKC in this size class is the lowest in the 40 years since 1978 and caps a six-year (2012-2017) average recruitment that is only $54 \%$ of this mean. In the pot-survey, the abundance of this size group in 2017 was also the second-lowest in the time series ( $22 \%$ of the mean for the available pot-survey data).
5. Management performance: In this assessment estimated total male catch is the sum of fisheryreported retained catch, estimated male discard mortality in the directed fishery, and estimated male bycatch mortality in the groundfish fisheries. Based on the reference model for SMBKC, the stock was above the minimum stock-size threshold (MSST) in 2016/17 and is hence not overfished. Overfishing did not occur in this year as the directed fishery was closed (Tables 1 and 2). Nonetheless, the low survey values and paucity of crabs in the region, as indicated by the surveys, remains a concern.
[^6]Table 1: Status and catch specifications (1000 t) for the reference model. Notes: A - calculated from the assessment reviewed by the Crab Plan Team in September 2013, B - calculated from the assessment reviewed by the Crab Plan Team in September 2014, C - calculated from the assessment reviewed by the Crab Plan Team in September 2015, D - calculated from the assessment reviewed by the Crab Plan Team in September 2016, E - calculated from the assessment reviewed by the Crab Plan Team in September 2017.

| Year | MSST | Biomass <br> $\left(M M B_{\text {mating }}\right)$ | TAC | Retained <br> catch | Total <br> male catch | OFL | ABC |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2012 / 13$ | $1.80^{A}$ | $2.85^{A}$ | 0.74 | 0.73 | 0.82 | 1.02 | 0.92 |
| $2013 / 14$ | $1.50^{B}$ | $3.01^{B}$ | 0.00 | 0.00 | 0.00 | 0.56 | 0.45 |
| $2014 / 15$ | $1.86^{C}$ | $2.48^{C}$ | 0.30 | 0.14 | 0.15 | 0.43 | 0.34 |
| $2015 / 16$ | $1.84^{D}$ | $2.11^{D}$ | 0.19 | 0.05 | 0.05 | 0.28 | 0.22 |
| $2016 / 17$ | $1.97^{E}$ | $2.12^{E}$ | 0.00 | 0.00 | 0.05 | 0.28 | 0.22 |
| $2017 / 18$ |  | $2.18^{E}$ |  |  |  | 0.12 | 0.1 |

Table 2: Status and catch specifications (million pounds) for the reference model.

| Year | MSST | Biomass <br> $\left(M M B_{\text {mating }}\right)$ | TAC | Retained <br> catch | Total <br> male catch | OFL | ABC |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2012 / 13$ | $4.0^{A}$ | $6.29^{A}$ | 1.630 | 1.616 | 1.81 | 2.24 | 2.02 |
| $2013 / 14$ | $3.4^{B}$ | $6.64^{B}$ | 0.000 | 0.000 | 0.0006 | 1.24 | 0.99 |
| $2014 / 15$ | $4.1^{C}$ | $5.47^{C}$ | 0.655 | 0.309 | 0.329 | 0.94 | 0.75 |
| $2015 / 16$ | $4.1^{D}$ | $4.65^{D}$ | 0.419 | 0.110 | 0.110 | 0.62 | 0.49 |
| $2016 / 17$ | $4.3^{E}$ | $4.68^{E}$ | 0.41 | 0.000 | 0.000 | 0.62 | 0.49 |
| $2017 / 18$ |  | $4.81^{E}$ |  |  |  | 0.27 | 0.22 |

6. Basis for the OFL: Estimated mature-male biomass (MMB) on 15 February is used as the measure of biomass for this Tier 4 stock, with males measuring 105 mm CL or more considered mature. The $B_{M S Y}$ proxy is obtained by averaging estimated MMB over a specific reference time period, and current CPT/SSC guidance recommends using the full assessment time frame as the default reference period (Table 3).

Table 3: Basis for the OFL (1000 t) from the reference model.

| Year | Tier | $B_{M S Y}$ | Biomass <br> $\left(M M B_{\text {mating }}\right)$ | $B / B_{M S Y}$ | $F_{O F L}$ | $\gamma$ | Basis for $B_{M S Y}$ | Natural <br> mortality |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2012 / 13$ | 4 a | 3.56 | 5.63 | 1.56 | 0.18 | 1 | $1978-2012$ | 0.18 |
| $2013 / 14$ | 4 b | 3.06 | 3.01 | 0.98 | 0.18 | 1 | $1978-2013$ | 0.18 |
| $2014 / 15$ | 4 b | 3.28 | 2.71 | 0.82 | 0.14 | 1 | $1978-2014$ | 0.18 |
| $2015 / 16$ | 4 b | 3.71 | 2.45 | 0.66 | 0.11 | 1 | $1978-2015$ | 0.18 |
| $2016 / 17$ | 4 b | 3.67 | 2.23 | 0.61 | 0.09 | 1 | $1978-2016$ | 0.18 |
| $2017 / 18$ | 4b | 3.93 | 2.18 | 0.55 | 0.09 | 1 | $1978-2016$ | 0.18 |

## A. Summary of Major Changes

## Changes in Management of the Fishery

There are no new changes in management of the fishery.

## Changes to the Input Data

Data used in this assessment have been updated to include the most recently available fishery and survey numbers. This assessment makes use of two new survey data points including the 2017 NMFS trawl-survey estimate of abudance, and the 2017 ADF\&G pot survey CPUE. Both of these surveys have associated size compositon data. The assessment also uses updated 2010-2016 groundfish and fixed gear bycatch estimates based on NMFS Alaska Regional Office (AKRO) data. There was no directed fishery data due to the 2016/17 closure.

## Changes in Assessment Methodology

As with 2016, this assessment is done using the General model for Alasks crab stocks (Gmacs) framework. The model is configured to track three stages of length categories and was first presented in May 2011 by Bill Gaeuman and accepted by the CPT in May 2012. A difference from the original approach and that used here is that natural and fishing mortality are continuous within 5 discrete seasons (using the appropriate catch equation rather than assuming an applied pulse removal). Season length in Gmacs is controlled by changing the proportion of natural mortality that is applied each season. An added diagnostic output is provided to include estimates of the "dynamic $B_{0}$." This simply computes the ratio of the spawning biomass as estimated relative to the spawning biomass that would have occurred had there been no historical fishing mortality. Details of this implementation are provided in Appendix A.

## Changes in Assessment Results

Both surveys indicate a decline over the past few years. The "reference" model is that selected for use in 2016. The addition of new data introduced this year area are presented sequentially. Two alternative models are presented for sensitivity. One involves a re-analysis of the NMFS trawl survey data using a spatio-temporal Delta-GLMM approach (VAST model, Thorson and Barnett 2017) and the other configuration (named "Fit survey") simply adds emphasis on the survey data (assumes a lower input variance). In all cases, the model tends to moderate the declines observed in the surveys.

## B. Responses to SSC and CPT Comments

## CPT and SSC Comments on Assessments in General

Comment: Regarding general code development, the CPT had the following requests:

1. specify priors (e.g., gamma) using mean and variance/standard deviation for all parameters to ease specifying priors
This was completed.
2. include an option to calculate dynamic $B_{M S Y}$

This was completed.
3. add the ability to "jitter" initial parameter values

The framework for conducting this research has been added but has yet to be fully tested.
4. add the ability to conduct retrospective analyses

Incomplete.
5. add ability to estimate bycatch fishing mortality rates when observer data are missing but effort data is available

This was completed.
6. Continued exploration of data weighting (Francis and other approaches) and evaluation of models with and without the 1998 natural mortality spike. The authors are encouraged to bring other models forward for CPT and SSC consideration

We introduced an alternative time-series estimated from the NMFS trawl survey using the VAST spatio-temporal Delta GLMM model and continued with the iterative re-weighting for composition data.

## C. Introduction

## Scientific Name

The blue king crab is a lithodid crab, Paralithodes platypus (Brant 1850).

## Distribution

Blue king crab are sporadically distributed throughout the North Pacific Ocean from Hokkaido, Japan, to southeastern Alaska (Figure 1). In the eastern Bering Sea small populations are distributed around St. Matthew Island, the Pribilof Islands, St. Lawrence Island, and Nunivak Island. Isolated populations also exist in some other cold water areas of the Gulf of Alaska (NPFMC 1998). The St. Matthew Island Section for blue king crab is within Area Q2 (Figure 2), which is the Northern District of the Bering Sea king crab registration area and includes the waters north of Cape Newenham ( $58^{\circ} 39^{\prime} \mathrm{N}$. lat.) and south of Cape Romanzof ( $61^{\circ} 49^{\prime}$ N. lat.).

## Stock Structure

The Alaska Department of Fish and Game (ADF\&G) Gene Conservation Laboratory division, has detected regional population differences between blue king crab collected from St. Matthew Island and the Pribilof Islands ${ }^{2}$. NMFS tag-return data from studies on blue king crab in the Pribilof Islands and St. Matthew Island support the idea that legal-sized males do not migrate between the two areas (Otto and Cummiskey 1990). St. Matthew Island blue king crab tend to be smaller than their Pribilof conspecifics, and the two stocks are managed separately.

## Life History

Like the red king crab, Paralithodes camtshaticus, the blue king crab is considered a shallow water species by comparison with other lithodids such as golden king crab, Lithodes aequispinus, and the scarlet king crab, Lithodes couesi (Donaldson and Byersdorfer 2005). Adult male blue king crab are found at an average depth of 70 m (NPFMC 1998). The reproductive cycle appears to be annual for the first two reproductive cycles and biennial thereafter (Jensen and Armstrong 1989) and mature crab seasonally migrate inshore where they molt and mate. Unlike red king crab, juvenile blue king crab do not form pods, but instead rely on cryptic coloration for protection from predators and require suitable habitat such as cobble and shell hash. Somerton and MacIntosh (1983) estimated SMBKC male size at sexual maturity to be 77 mm carapace length (CL). Paul et al. (1991) found that spermatophores were present in the vas deferens of $50 \%$ of the St. Matthew Island blue king crab males examined with sizes of $40-49 \mathrm{~mm}$ CL and in $100 \%$ of the males at least 100 mm

[^7]CL. Spermataphore diameter also increased with increasing CL with an asymptote at $\sim 100 \mathrm{~mm}$ CL. They noted, however, that although spermataphore presence indicates physiological sexual maturity, it may not be an indicator of functional sexual maturity. For purposes of management of the St. Matthew Island blue king crab fishery, the State of Alaska uses 105 mm CL to define the lower size bound of functionally mature males (Pengilly and Schmidt 1995). Otto and Cummiskey (1990) report an average growth increment of 14.1 mm CL for adult SMBKC males.

## Management History

The SMBKC fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990). Ten U.S. vessels harvested 545 t ( 1.202 million pounds) in 1977, and harvests peaked in 1983 when 164 vessels landed 4288 t ( 9.454 million pounds) (Fitch et al. 2012; Table 7).

The fishing seasons were generally short, often lasting only a few days. The fishery was declared overfished and closed in 1999 when the stock biomass estimate was below the minimum stock-size threshold (MSST) of $4,990 \mathrm{t}$ ( 11.0 million pounds) as defined by the Fishery Management Plan (FMP) for the Bering Sea/Aleutian Islands King and Tanner crabs (NPFMC 1999). Zheng and Kruse (2002) hypothesized a high level of SMBKC natural mortality from 1998 to 1999 as an explanation for the low catch per unit effort (CPUE) in the 1998/99 commercial fishery and the low numbers across all male crab size groups caught in the annual NMFS eastern Bering Sea trawl survey from 1999 to 2005 (see survey data in next section). In November 2000, Amendment 15 to the FMP for Bering Sea/Aleutian Islands king and Tanner crabs was approved to implement a rebuilding plan for the SMBKC stock (NPFMC 2000). The rebuilding plan included a State of Alaska regulatory harvest strategy ( 5 AAC 34.917 ), area closures, and gear modifications. In addition, commercial crab fisheries near St. Matthew Island were scheduled in fall and early winter to reduce the potential for bycatch mortality of vulnerable molting and mating crab.

NMFS declared the stock rebuilt on 21 September 2009, and the fishery was reopened after a 10-year closure on 15 October 2009 with a TAC of 529 t ( 1.167 million pounds), closing again by regulation on 1 February 2010. Seven participating vessels landed a catch of 209 t ( 460,859 pounds) with a reported effort of 10,697 pot lifts and an estimated CPUE of 9.9 retained individual crab per pot lift. The fishery remained open the next three years with modest harvests and similar CPUE, but large declines in the NMFS trawl-survey estimate of stock abundance raised concerns about the health of the stock. This prompted ADF\&G to close the fishery again for the $2013 / 14$ season. The fishery was reopened for the $2014 / 15$ season with a low TAC of 297 t ( 0.655 million pounds) and in $2015 / 16$ the TAC was further reduced to 186 t ( 0.411 million pounds) then completely closed during the 2016/17 season.
Although historical observer data are limited due to low sampling effort, bycatch of female and sublegal male crab from the directed blue king crab fishery off St. Matthew Island was relatively high historically, with estimated total bycatch in terms of number of crab captured sometimes more than twice as high as the catch of legal crab (Moore et al. 2000; ADF\&G Crab Observer Database). Pot-lift sampling by ADF\&G crab observers (Gaeuman 2013; ADF\&G Crab Observer Database) indicates similar bycatch rates of discarded male crab since the reopening of the fishery (Table 5), with total male discard mortality in the 2012/13 directed fishery estimated at about $12 \%$ ( 88 t or 0.193 million pounds) of the reported retained catch weight, assuming $20 \%$ handling mortality.

These data suggest a reduction in the bycatch of females, which may be attributable to the later timing of the contemporary fishery and the more offshore distribution of fishery effort since reopening in $2009 / 10^{3}$. Some bycatch of discarded blue king crab has also been observed historically in the eastern Bering Sea snow crab fishery, but in recent years it has generally been negligible. The St. Matthew Island golden king crab fishery, the third commercial crab fishery to have taken place in the area, typically occurred in areas with depths exceeding blue king crab distribution. NMFS observer data suggest that variable but mostly limited SMBKC bycatch has also occurred in the eastern Bering Sea groundfish fisheries (Table 6).

[^8]
## D. Data

## Summary of New Information

Data used in this assessment were updated to include the most recently available fishery and survey numbers. This assessment makes use of two new survey data points including the 2017 NMFS trawl-survey estimate of abudance, and the 2017 ADF\&G pot survey CPUE. Both of these surveys have associated size compositon data. The assessment also uses updated 1993-2016 groundfish and fixed gear bycatch estimates based on AKRO data. The fishery was closed in $2016 / 17$ so no directed fishery catch data were available. The data used in each of the new models is shown in Figure 3.

## Major Data Sources

Major data sources used in this assessment include annual directed-fishery retained-catch statistics from fish tickets (1978/79-1998/99, 2009/10-2012/13, and 2014/15-2015/16; Table 7); results from the annual NMFS eastern Bering Sea trawl survey (1978-2017; Table 8); results from the ADF\&G SMBKC pot survey (every third year during 1995-2013, then 2015-2017; Table 9); mean somatic mass given length category by year (Table 10); size-frequency information from ADF\&G crab-observer pot-lift sampling (1990/91-1998/99, 2009/10-2012/13, and 2014/15-2016/17; Table 5); and NMFS groundfish-observer bycatch biomass estimates (1992/93-2016/17; Table 6).

Figure 4 maps stations from which SMBKC trawl-survey and pot-survey data were obtained. Further information concerning the NMFS trawl survey as it relates to commercial crab species is available in Daly et al. (2014); see Gish et al. (2012) for a description of ADF\&G SMBKC pot-survey methods. It should be noted that the two surveys cover different geographic regions and that each has in some years encountered proportionally large numbers of male blue king crab in areas not covered by the other survey (Figure 5). Crab-observer sampling protocols are detailed in the crab-observer training manual (ADF\&G 2013). Groundfish SMBKC bycatch data come from NMFS Bering Sea reporting areas 521 and 524 (Figure $6)$.

## Other Data Sources

The growth transition matrix used is based on Otto and Cummiskey (1990), as in the past. Other relevant data sources, including assumed population and fishery parameters, are presented in Appendix A, which also provides a detailed description of the model configuration used for this assessment.

## E. Analytic Approach

## History of Modeling Approaches for this Stock

A four-stage catch-survey-analysis (CSA) assessment model was used before 2011 to estimate abundance and biomass and prescribe fishery quotas for the SMBKC stock (Zheng et al. 1997). The four-stage CSA is similar to a full length-based analysis, the major difference being coarser length groups, which are more suited to a small stock with consistently low survey catches. In this approach, the abundance of male crab with a CL $\geq 90 \mathrm{~mm}$ is modeled in terms of four crab stages: stage 1: 90-104 mm CL; stage 2: 105-119 mm CL; stage 3: newshell $120-133 \mathrm{~mm}$ CL; and stage 4 : oldshell $\geq 120 \mathrm{~mm}$ CL and newshell $\geq 134 \mathrm{~mm}$ CL. Motivation for these stage definitions comes from the fact that for management of the SMBKC stock, male crab measuring $\geq 105 \mathrm{~mm}$ CL are considered mature, whereas 120 mm CL is considered a proxy for the legal size of 5.5 in carapace width, including spines. Additional motivation for these stage definitions comes from an estimated average growth increment of about 14 mm per molt for SMBKC (Otto and Cummiskey 1990).

Concerns about the pre-2011 assessment model led to the CPT and SSC recommendations that included development of an alternative model with provisional assessment based on survey biomass or some other index of abundance. An alternative 3-stage model was proposed to the CPT in May 2011, but a survey-based approach was requested for the Fall 2011 assessment. In May 2012 the CPT approved a slightly revised and better documented version of the alternative model for assessment. Subsequently the model developed and used since 2012, was a variant of the previous four-stage SMBKC CSA model and similar in complexity to that described by Collie et al. (2005). Like the earlier model, it considered only male crab $\geq 90 \mathrm{~mm}$ in CL, but combined stages 3 and 4 of the earlier model resulting in just three stages (male size classes) determined by CL measurements of (1) 90-104 mm, (2) 105-119 mm, and (3) $120 \mathrm{~mm}+$ (i.e., 120 mm and above). This consolidation was driven by concern about the accuracy and consistency of shell-condition information, which had been used in distinguishing stages 3 and 4 of the earlier model.

In 2016 the accepted SMBKC assessment model made use of the modeling framework Gmacs (Webber et al. 2016). In that assessment, an effort was made to match the 2015 SMBKC stock assessment model to bridge a framework which provided greater flexibility and opportunity to evaluate model assumptions more fully.

## Assessment Methodology

This assessment model again uses the modeling framework Gmacs and is detailed in Appendix A.

## Model Selection and Evaluation

Five models were presented in the previous assessment. This year, four models are presented with the reference model being the same configuration as last year, three sensitivities are considered, one with a different treatment of NMFS bottom trawl survey (BTS) data using a geo-spatial model (VAST; Thorson and Barnett 2017), another which weights the survey data more heavily, and a third which weights the size composition data according to Francis' (2011) approach. In addition to these sensitivities, we also evaluated the impact of adding new data to the reference model. In summary, the following lists the models presented and the naming convention used:

1. 2016 Model: the 2016 recommended model without any new data
2. BTS: adds in the 2017 bottom trawl survey (BTS) data
3. BTS and pot: as with previous but including the 2017 ADFG pot survey data (Model 16.0 or "reference case")
4. VAST: applies a geo-spatial delta-GLMM model (Thorson and Barnett 2017) to the BTS data which provides a different BTS index. See appendix B for details and diagnostics. This is a preliminary examination as more work is needed to ensure options for the BTS CPUE data were specified appropriately.
5. Fit survey: an exploratory scenario that's the same as the reference model except the NMFS trawl survey is up-weighted by $\lambda^{\mathrm{NMFS}}=1.5$ and the $\mathrm{ADF} \& \mathrm{G}$ pot survey is up-weighted by $\lambda^{\mathrm{ADFG}}=2$.
6. Francis weights: is similar to the reference model except that it also uses the Francis iterative re-weighting method (Francis 2011), to re-weight the size-composition data relative to the abundance indices. The trawl survey and pot survey weights were unchanged. In this scenario the multinomial distribution was used instead as the theory underpinning the Francis weighting method is based on this distribution.

Note that SSC convention would label these (item 3 above) as model 16.0 (the model used last year). Since so few models are presented here, for simplicity model 16.0 is labeled "reference" and for the others, the naming convention above was used to make it easier to remember the main characteristic of the model configuration.

## Results

## a. Sensitivity to new data

Results for scenarios are provided with comparisons to the 2016 model and sensitivity new data are shown in Figures 7 and 8 with recruitment and spawning biomass shown in Figures 9 and 10, respectively. The fits to survey CPUEs and spawning biomass show that the addition of new data results in more of a decline than in the 2016 assessment, especially with the addition of the pot survey. The model with all new data is henceforth referred to as the "reference model."

## b. Alternative NMFS bottom-trawl survey index

Results comparing model fits between the "VAST" spatio-temporal index and the reference case show different time-series of data and a different model fit (Figure 11). The effect on spawning biomass suggests estimates were consistently higher since 1990 compared to the reference model (Figure 12).

## c. Effective sample sizes and weighting factors

Observed and estimated effective sample sizes are compared in Table 11. Data weighting factors, standard deviation of normalized residuals (SDNRs), and mean absolute residual (MAR) are presented in Table 17. The SDNR for the trawl survey is acceptable at 1.45 in the reference model, and improves to 1.36 in the Francis weight model (since size composition data are re-weighted). The SDNRs for the pot surveys show much the same pattern between each of the scenarios, but are much higher values (ranging from 3.72 to 5.45). These values are very high, and whilst they can be improved by down-weighting the pot survey, we chose to retain the values as the pot survey considered important to include (down-weighting the data further would effectively exclude the signal from this series). The MAR for the trawl and pot surveys shows the same pattern among each of the scenarios as the SDNR. The SDNR (and MAR) values for the trawl survey and pot survey size compositions were excellent, ranging from 0.49 to 0.78 . The SDNRs for the directed pot fishery and other size compositions were all accepatable.

## d. Parameter estimates

Model parameter estimates for each of the Gmacs scenarios are summarized in Tables $12,13,15$, and 16. These parameter estimates are compared in Table 16. Negative log-likelihood values and management measures for each of the model configurations are compared in Tables 4 through 18.

There are some differences in parameter estimates among models as reflected in the log-likelihood components and the management quantities. The parameter estimates in the "fit survey" scenario differ the most, as expected, particularly the estimate of the ADF\&G pot survey catchability (q) (see Table 16).

## c. Graphs of estimates.

Selectivity estimates show some variability between models (Figure 13). Estimated recruitment is variable over time for all models and in recent years is well below average (Figure 14). Estimated mature male biomass on 15 February also fluctuates considerably (Figure 15). Estimated natural mortality each year $\left(M_{t}\right)$ is presented in Figure 16.

## d. Evaluation of the fit to the data.

The model fits to total male ( $\geq 90 \mathrm{~mm} C L$ ) trawl survey biomass tend to miss the recent peak around 2010 and is slightly above the 2017 value for the key sensitivities (Figures 17). All of the models fit the pot survey

CPUE poorly (Figure 18. For both surveys the standardized residuals tend to have similar patterns with some improvement (generally) for the VAST model (Figures 19 and 20).

Fits to the size compositions for trawl survey, pot survey, and commercial observer data are reasonable but miss the largest size category in some years (Figures 21, 22, and 23) for all scenarios. Representative residual plots of the composition data fits are generally poor (Figures 24 and 25). The model fits to different types of retained and discarded catch values performed as expected given the assumed levels of uncertainty on the input data (Figure 26 ).

The contrast between the reference model and the "Francis weighted" model show minor differences (Figures 17 and 18). Unsurprisingly, the fit surveys model configuration fits the the NMFS survey biomass and ADF\&G pot survey CPUE data better but still has a similar residual pattern (note that that this scenario was only included for exploratory purposes and forcing these weights resulted in worse SDNR and MAR values for the two abundance indices).

## e. Retrospective and historic analyses.

The ability to conduct retrospective analyses with this software remains under development.

## f. Uncertainty and sensitivity analyses.

Estimated standard deviations of parameters and selected management measures for the four models are summarized in Tables $12,13,14$, and 15 (and compiled together in Table 16. Probabilities for mature male biomass and OFL in 2017 are presented in Section F.

## g. Comparison of alternative model scenarios.

The estimates of mature male biomass (Figure 15), for the fit surveys sensitivity stands out as being quite different from the other models due to a low value for pot survey catchability being estimated (which tends to scale the population). This scenario results in a lower MMB from the mid-1980s through to the late-1990s, and is again lower in the most recent 5 years. This scenario upweights both the trawl survey and the pot survey abundance indices (it upweights the pot survey more than the trawl survey) and represents a model run that places greater trust in the abundance indices, particularly the pot survey, than other data sources.

In summary, the use of the reference model for management purposes is preferred since it provides the best fit to the data and is consistent with previous model specifications. Research on alternative model specifications (e.g., natural mortality variability) was limited this year. The model using the "VAST" time series may take better account of spatial processes but requires more research to ensure it has been appropriately applied and the assumptions are reasonable. Consequently, the reference model appears reasonable and appropriate for ACL and OFL determinations for this stock in 2017. Nonetheless, the Fit surveys model, while difficult to statistically justify, portends a more dire stock status (see below) and should highlight the caution needed in managing this resource.

## F. Calculation of the OFL and ABC

The overfishing level (OFL) is the fishery-related mortality biomass associated with fishing mortality $F_{O F L}$. The SMBKC stock is currently managed as Tier 4 (2013 SAFE), and only a Tier 4 analysis is presented here. Thus given stock estimates or suitable proxy values of $B_{M S Y}$ and $F_{M S Y}$, along with two additional parameters $\alpha$ and $\beta, F_{O F L}$ is determined by the control rule

$$
\begin{align*}
& F_{O F L}= \begin{cases}F_{M S Y}, & \text { when } B / B_{M S Y}>1 \\
F_{M S Y} \frac{\left(B / B_{M S Y}-\alpha\right)}{(1-\alpha)}, & \text { when } \beta<B / B_{M S Y} \leq 1\end{cases}  \tag{1}\\
& F_{O F L}<F_{M S Y} \text { with directed fishery } F=0 \text { when } B / B_{M S Y} \leq \beta
\end{align*}
$$

where $B$ is quantified as mature-male biomass (MMB) at mating with time of mating assigned a nominal date of 15 February. Note that as $B$ itself is a function of the fishing mortality $F_{O F L}$ (therefore numerical approximation of $F_{O F L}$ is required). As implemented for this assessment, all calculations proceed according to the model equations given in Appendix A. $F_{O F L}$ is taken to be full-selection fishing mortality in the directed pot fishery and groundfish trawl and fixed-gear fishing mortalities set at their model geometric mean values over years for which there are data-based estimates of bycatch-mortality biomass.

The currently recommended Tier 4 convention is to use the full assessment period, currently 1978-2016, to define a $B_{M S Y}$ proxy in terms of average estimated MMB and to set $\gamma=1.0$ with assumed stock natural mortality $M=0.18 \mathrm{yr}^{-1}$ in setting the $F_{M S Y}$ proxy value $\gamma M$. The parameters $\alpha$ and $\beta$ are assigned their default values $\alpha=0.10$ and $\beta=0.25$. The $F_{O F L}, \mathrm{OFL}, \mathrm{ABC}$, and MMB in 2017 for all scenarios are summarized in Table 4. ABC is $80 \%$ of the OFL.

Table 4: Comparisons of management measures for the four model scenarios. Biomass and OFL are in tons.

| Component | Reference | VAST | Fit surveys | Francis weights |
| :--- | ---: | ---: | ---: | ---: |
| $\mathrm{MMB}_{2017}$ | 2179.720 | 3010.644 | 5674.035 | 2085.382 |
| $B_{\mathrm{MSY}}$ | 3930.576 | 4360.343 | 9828.733 | 3861.300 |
| $F_{\text {OFL }}$ | 0.079 | 0.103 | 0.083 | 0.076 |
| OFL $_{2017}$ | 123.613 | 220.403 | 367.946 | 117.651 |
| $\mathrm{ABC}_{2017}$ | 98.891 | 176.323 | 294.357 | 94.121 |

## G. Rebuilding Analysis

This stock is not currently subject to a rebuilding plan.

## H. Data Gaps and Research Priorities

The following topics have been listed as areas where more research on SMBKC is needed:

1. Growth increments and molting probabilities as a function of size.
2. Trawl survey catchability and selectivities.
3. Temporal changes in spatial distributions near the island.
4. Natural mortality.

## I. Projections and Future Outlook

The outlook for recruitment looks relatively pessimistic. The dynamic- $B_{0}$ analysis, which removes historical fishing and projects the population based on estimated recruitments, indicates that the effect of fishing has reduced the stock to about $68 \%$. The other aspects of depletion (ignoring stock-recruit relationship) may reflect variable survival rates due to environmental conditions and range shifts.

## J. Acknowledgements

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## Tables

Table 5: Observed proportion of crab by size class during the ADF\&G crab observer pot-lift sampling. Source:
ADF\&G Crab Observer Database.

| Year | Total pot lifts | Pot lifts sampled | Number of crab (90 mm+ CL) | Stage 1 | Stage 2 | Stage 3 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| $1990 / 91$ | 26,264 | 10 | 150 | 0.113 | 0.393 | 0.493 |
| $1991 / 92$ | 37,104 | 125 | 3,393 | 0.133 | 0.177 | 0.690 |
| $1992 / 93$ | 56,630 | 71 | 1,606 | 0.191 | 0.268 | 0.542 |
| $1993 / 94$ | 58,647 | 84 | 2,241 | 0.281 | 0.210 | 0.510 |
| $1994 / 95$ | 60,860 | 48,560 | 403 | 4,735 | 0.294 | 0.271 |
| $1995 / 96$ | 91,085 | 96 | 663 | 0.148 | 0.212 | 0.640 |
| $1996 / 97$ | 81,117 | 133 | 489 | 0.160 | 0.223 | 0.618 |
| $1997 / 98$ | 91,826 | 135 | 3,195 | 0.182 | 0.205 | 0.613 |
| $1998 / 99$ |  |  | 1.322 | 0.193 | 0.216 | 0.591 |
| $1999 / 00-2008 / 09$ | 989 | FISHERY CLOSED |  |  |  |  |
| $2009 / 10$ | 10,484 | 2,419 | 19,802 | 0.141 | 0.324 | 0.535 |
| $2010 / 11$ | 29,356 | 3,359 | 45,466 | 0.131 | 0.315 | 0.553 |
| $2011 / 12$ | 48,554 | 2,841 | 58,666 | 0.131 | 0.305 | 0.564 |
| $2012 / 13$ | 37,065 |  | 57,298 | 0.141 | 0.318 | 0.541 |
| $2013 / 14$ |  | 895 | FISHERY CLOSED |  |  |  |
| $2014 / 15$ | 10,133 |  | 919 | 3,906 | 0.094 | 0.228 |
| $2015 / 16$ | 5,475 |  | FISHERY CLOSED | 0.115 | 0.252 | 0.679 |
| $2016 / 17$ |  |  |  |  |  |  |

Table 6: Groundfish SMBKC male bycatch biomass ( t ) estimates. Trawl includes pelagic trawl and non-pelagic trawl types. Source: J. Zheng, ADF\&G, and author estimates based on data from R. Foy, NMFS. Estimates used after 2008/09 are from NMFS Alaska Regional Office.

| Year | Trawl bycatch | Fixed gear bycatch |
| ---: | ---: | ---: |
| 1978 | 0.000 | 0.000 |
| 1979 | 0.000 | 0.000 |
| 1980 | 0.000 | 0.000 |
| 1981 | 0.000 | 0.000 |
| 1982 | 0.000 | 0.000 |
| 1983 | 0.000 | 0.000 |
| 1984 | 0.000 | 0.000 |
| 1985 | 0.000 | 0.000 |
| 1986 | 0.000 | 0.000 |
| 1987 | 0.000 | 0.000 |
| 1988 | 0.000 | 0.000 |
| 1989 | 0.000 | 0.000 |
| 1990 | 0.000 | 0.000 |
| 1991 | 3.538 | 0.045 |
| 1992 | 1.996 | 2.268 |
| 1993 | 1.542 | 0.500 |
| 1994 | 0.318 | 0.091 |
| 1995 | 0.635 | 0.136 |
| 1996 | 0.500 | 0.045 |
| 1997 | 0.500 | 0.181 |
| 1998 | 0.500 | 0.907 |
| 1999 | 0.500 | 1.361 |
| 2000 | 0.500 | 0.500 |
| 2001 | 0.500 | 0.862 |
| 2002 | 0.726 | 0.408 |
| 2003 | 0.998 | 1.134 |
| 2004 | 0.091 | 0.635 |
| 2005 | 0.500 | 0.590 |
| 2006 | 2.812 | 1.451 |
| 2007 | 0.045 | 69.717 |
| 2008 | 0.272 | 6.622 |
| 2009 | 0.635 | 7.530 |
| 2010 | 0.363 | 9.571 |
| 2011 | 0.181 | 1.800 |
| 2012 | 0.100 | 1.600 |
| 2013 | 0.400 | 0.800 |
| 2014 | 0.100 | 1.100 |
| 2015 | 0.100 | 1.600 |
| 2016 | 0.500 | 3.600 |
|  |  |  |

Table 7: The 1978/79 to 2015/16 directed St. Matthew Island blue king crab pot fishery. The Guideline Harvest Level (GHL) and Total Allowable Catch (TAC) are in millions of pounds. Harvest includes deadloss. Catch per unit effort (CPUE) in this table is simply the harvest number / pot lifts. The average weight is the harvest weight / harvest number in pounds. The average CL is the average of retained crab in mm from dockside sampling of delivered crab. Source: Fitch et al 2012; ADF\&G Dutch Harbor staff, pers. comm. Note that management (GHL) units are in pounds, for conserving space, convertion to tons is ommitted.

|  |  |  | Harvest |  |  |  |  |  |  |  |  |  |  |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | :---: | :---: | :---: | :---: |
| Year | Dates | GHL/TAC | Crab | Pounds | Pot lifts | CPUE | avg wt | avg CL |  |  |  |  |  |
| $1978 / 79$ | $07 / 15-09 / 03$ |  | 436,126 | $1,984,251$ | 43,754 | 10 | 4.5 | 132.2 |  |  |  |  |  |
| $1979 / 80$ | $07 / 15-08 / 24$ |  | 52,966 | 210,819 | 9,877 | 5 | 4.0 | 128.8 |  |  |  |  |  |
| $1980 / 81$ | $07 / 15-09 / 03$ |  |  | CONFIDENTIAL |  |  |  |  |  |  |  |  |  |
| $1981 / 82$ | $07 / 15-08 / 21$ |  | $1,045,619$ | $4,627,761$ | 58,550 | 18 | 4.4 | NA |  |  |  |  |  |
| $1982 / 83$ | $08 / 01-08 / 16$ |  | $1,935,886$ | $8,844,789$ | 165,618 | 12 | 4.6 | 135.1 |  |  |  |  |  |
| $1983 / 84$ | $08 / 20-09 / 06$ | 8.0 | $1,931,990$ | $9,454,323$ | 133,944 | 14 | 4.9 | 137.2 |  |  |  |  |  |
| $1984 / 85$ | $09 / 01-09 / 08$ | $2.0-4.0$ | 841,017 | $3,764,592$ | 73,320 | 11 | 4.5 | 135.5 |  |  |  |  |  |
| $1985 / 86$ | $09 / 01-09 / 06$ | $0.9-1.9$ | 436,021 | $2,175,087$ | 46,988 | 9 | 5.0 | 139.0 |  |  |  |  |  |
| $1986 / 87$ | $09 / 01-09 / 06$ | $0.2-0.5$ | 219,548 | $1,003,162$ | 22,073 | 10 | 4.6 | 134.3 |  |  |  |  |  |
| $1987 / 88$ | $09 / 01-09 / 05$ | $0.6-1.3$ | 227,447 | $1,039,779$ | 28,230 | 8 | 4.6 | 134.1 |  |  |  |  |  |
| $1988 / 89$ | $09 / 01-09 / 05$ | $0.7-1.5$ | 280,401 | $1,236,462$ | 21,678 | 13 | 4.4 | 133.3 |  |  |  |  |  |
| $1989 / 90$ | $09 / 01-09 / 04$ | 1.7 | 247,641 | $1,166,258$ | 30,803 | 8 | 4.7 | 134.6 |  |  |  |  |  |
| $1990 / 91$ | $09 / 01-09 / 07$ | 1.9 | 391,405 | $1,725,349$ | 26,264 | 15 | 4.4 | 134.3 |  |  |  |  |  |
| $1991 / 92$ | $09 / 16-09 / 20$ | 3.2 | 726,519 | $3,372,066$ | 37,104 | 20 | 4.6 | 134.1 |  |  |  |  |  |
| $1992 / 93$ | $09 / 04-09 / 07$ | 3.1 | 545,222 | $2,475,916$ | 56,630 | 10 | 4.5 | 134.1 |  |  |  |  |  |
| $1993 / 94$ | $09 / 15-09 / 21$ | 4.4 | 630,353 | $3,003,089$ | 58,647 | 11 | 4.8 | 135.4 |  |  |  |  |  |
| $1994 / 95$ | $09 / 15-09 / 22$ | 3.0 | 827,015 | $3,764,262$ | 60,860 | 14 | 4.9 | 133.3 |  |  |  |  |  |
| $1995 / 96$ | $09 / 15-09 / 20$ | 2.4 | 666,905 | $3,166,093$ | 48,560 | 14 | 4.7 | 135.0 |  |  |  |  |  |
| $1996 / 97$ | $09 / 15-09 / 23$ | 4.3 | 660,665 | $3,078,959$ | 91,085 | 7 | 4.7 | 134.6 |  |  |  |  |  |
| $1997 / 98$ | $09 / 15-09 / 22$ | 5.0 | 939,822 | $4,649,660$ | 81,117 | 12 | 4.9 | 139.5 |  |  |  |  |  |
| $1998 / 99$ | $09 / 15-09 / 26$ | 4.0 | 635,370 | $2,968,573$ | 91,826 | 7 | 4.7 | 135.8 |  |  |  |  |  |
| $1999 / 00-2008 / 09$ |  |  | FISHERY CLOSED |  |  |  |  |  |  |  |  |  |  |
| $2009 / 10$ | $10 / 15-02 / 01$ | 1.17 | 103,376 | 460,859 | 10,697 | 10 | 4.5 | 134.9 |  |  |  |  |  |
| $2010 / 11$ | $10 / 15-02 / 01$ | 1.60 | 298,669 | $1,263,982$ | 29,344 | 10 | 4.2 | 129.3 |  |  |  |  |  |
| $2011 / 12$ | $10 / 15-02 / 01$ | 2.54 | 437,862 | $1,881,322$ | 48,554 | 9 | 4.3 | 130.0 |  |  |  |  |  |
| $2012 / 13$ | $10 / 15-02 / 01$ | 1.63 | 379,386 | $1,616,054$ | 37,065 | 10 | 4.3 | 129.8 |  |  |  |  |  |
| $2013 / 14$ |  |  |  | FISHERY CLOSED |  |  |  |  |  |  |  |  |  |
| $2014 / 15$ | $10 / 15-02 / 05$ | 0.66 | 69,109 | 308,582 | 10,133 | 7 | 4.5 | 132.3 |  |  |  |  |  |
| $2015 / 16$ | $10 / 19-11 / 28$ | 0.41 | 24,076 | 105,010 | 5,475 | 4 | 4.4 | 132.6 |  |  |  |  |  |
| $2016 / 17$ |  |  |  | FISHERY CLOSED |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |

Table 8: NMFS EBS trawl-survey area-swept estimates of male crab abundance ( $10^{6}$ crab) and male ( $\geq 90$ mm CL ) biomass ( $10^{6} \mathrm{lbs}$ ). Total number of captured male crab $\geq 90 \mathrm{~mm}$ CL is also given. Source: R. Foy, NMFS. The " + " refer to plus group.

| Year | Abundance |  |  |  |  | Biomass |  | Number of crabs |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Stage-1 | Stage-2 | Stage-3 |  |  | Total |  |  |
|  | (90-104 mm) | (105-119 mm) | $(120+\mathrm{mm})$ | Total | CV | (90+ mm CL) | CV |  |
| 1978 | 2.213 | 1.991 | 1.521 | 5.726 | 0.411 | 15.064 | 0.394 | 157 |
| 1979 | 3.061 | 2.281 | 1.808 | 7.150 | 0.472 | 17.615 | 0.463 | 178 |
| 1980 | 2.856 | 2.563 | 2.541 | 7.959 | 0.572 | 22.017 | 0.507 | 185 |
| 1981 | 0.483 | 1.213 | 2.263 | 3.960 | 0.368 | 14.443 | 0.402 | 140 |
| 1982 | 1.669 | 2.431 | 5.884 | 9.984 | 0.401 | 35.763 | 0.344 | 271 |
| 1983 | 1.061 | 1.651 | 3.345 | 6.057 | 0.332 | 21.240 | 0.298 | 231 |
| 1984 | 0.435 | 0.497 | 1.452 | 2.383 | 0.175 | 8.976 | 0.179 | 105 |
| 1985 | 0.379 | 0.376 | 1.117 | 1.872 | 0.216 | 6.858 | 0.210 | 93 |
| 1986 | 0.203 | 0.447 | 0.374 | 1.025 | 0.428 | 3.124 | 0.388 | 46 |
| 1987 | 0.325 | 0.631 | 0.715 | 1.671 | 0.302 | 5.024 | 0.291 | 71 |
| 1988 | 0.410 | 0.816 | 0.957 | 2.183 | 0.285 | 6.963 | 0.252 | 81 |
| 1989 | 2.169 | 1.154 | 1.786 | 5.109 | 0.314 | 13.974 | 0.271 | 208 |
| 1990 | 1.053 | 1.031 | 2.338 | 4.422 | 0.302 | 14.837 | 0.274 | 170 |
| 1991 | 1.147 | 1.665 | 2.233 | 5.046 | 0.259 | 15.318 | 0.248 | 197 |
| 1992 | 1.074 | 1.382 | 2.291 | 4.746 | 0.206 | 15.638 | 0.201 | 220 |
| 1993 | 1.521 | 1.828 | 3.276 | 6.626 | 0.185 | 21.051 | 0.169 | 324 |
| 1994 | 0.883 | 1.298 | 2.257 | 4.438 | 0.187 | 14.416 | 0.176 | 211 |
| 1995 | 1.025 | 1.188 | 1.741 | 3.953 | 0.187 | 12.574 | 0.178 | 178 |
| 1996 | 1.238 | 1.891 | 3.064 | 6.193 | 0.263 | 20.746 | 0.241 | 285 |
| 1997 | 1.165 | 2.228 | 3.789 | 7.182 | 0.367 | 24.084 | 0.337 | 296 |
| 1998 | 0.660 | 1.661 | 2.849 | 5.170 | 0.373 | 17.586 | 0.355 | 243 |
| 1998 | 0.223 | 0.222 | 0.558 | 1.003 | 0.192 | 3.515 | 0.182 | 52 |
| 2000 | 0.282 | 0.285 | 0.740 | 1.307 | 0.303 | 4.623 | 0.310 | 61 |
| 2001 | 0.419 | 0.502 | 0.938 | 1.859 | 0.243 | 6.242 | 0.245 | 91 |
| 2002 | 0.111 | 0.230 | 0.640 | 0.981 | 0.311 | 3.820 | 0.320 | 38 |
| 2003 | 0.449 | 0.280 | 0.465 | 1.194 | 0.399 | 3.454 | 0.336 | 65 |
| 2004 | 0.247 | 0.184 | 0.562 | 0.993 | 0.369 | 3.360 | 0.305 | 48 |
| 2005 | 0.319 | 0.310 | 0.501 | 1.130 | 0.403 | 3.620 | 0.371 | 42 |
| 2006 | 0.917 | 0.642 | 1.240 | 2.798 | 0.339 | 8.585 | 0.334 | 126 |
| 2007 | 2.518 | 2.020 | 1.193 | 5.730 | 0.420 | 14.266 | 0.385 | 250 |
| 2008 | 1.352 | 0.801 | 1.457 | 3.609 | 0.289 | 10.261 | 0.284 | 167 |
| 2009 | 1.573 | 2.161 | 1.410 | 5.144 | 0.263 | 13.892 | 0.256 | 251 |
| 2010 | 3.937 | 3.253 | 2.458 | 9.648 | 0.544 | 24.539 | 0.466 | 388 |
| 2011 | 1.800 | 3.255 | 3.207 | 8.263 | 0.587 | 24.099 | 0.558 | 318 |
| 2012 | 0.705 | 1.970 | 1.808 | 4.483 | 0.361 | 13.669 | 0.339 | 193 |
| 2013 | 0.335 | 0.452 | 0.807 | 1.593 | 0.215 | 5.043 | 0.217 | 74 |
| 2014 | 0.723 | 1.627 | 1.809 | 4.160 | 0.503 | 13.292 | 0.449 | 181 |
| 2015 | 0.992 | 1.269 | 1.979 | 4.240 | 0.774 | 12.958 | 0.770 | 153 |
| 2016 | 0.535 | 0.660 | 1.178 | 2.373 | 0.447 | 7.685 | 0.393 | 108 |
| 2017 | 0.091 | 0.323 | 0.663 | 1.077 | 0.657 | 3.955 | 0.600 | 42 |

Table 9: Size-class and total CPUE ( $90+\mathrm{mm}$ CL) with estimated CV and total number of captured crab (90+ mm CL) from the 96 common stations surveyed during the ADF\&G SMBKC pot surveys. Source: ADF\&G.

| Year | Stage-1 <br> $(90-104 \mathrm{~mm})$ | Stage-2 <br> $(105-119 \mathrm{~mm})$ | Stage-3 <br> $(120+\mathrm{mm})$ | Total CPUE | CV | Number of crabs |
| ---: | :---: | :---: | :---: | ---: | ---: | ---: |
| 1995 | 1.919 | 3.198 | 6.922 | 12.042 | 0.13 | 4624 |
| 1998 | 0.964 | 2.763 | 8.804 | 12.531 | 0.06 | 4812 |
| 2001 | 1.266 | 1.737 | 5.487 | 8.477 | 0.08 | 3255 |
| 2004 | 0.112 | 0.414 | 1.141 | 1.667 | 0.15 | 640 |
| 2007 | 1.086 | 2.721 | 4.836 | 8.643 | 0.09 | 3319 |
| 2010 | 1.326 | 3.276 | 5.607 | 10.209 | 0.13 | 3920 |
| 2013 | 0.878 | 1.398 | 3.367 | 5.643 | 0.19 | 2167 |
| 2015 | 0.198 | 0.682 | 1.924 | 2.805 | 0.18 | 1077 |
| 2016 | 0.198 | 0.456 | 1.724 | 2.378 | 0.19 | 777 |
| 2017 | 0.177 | 0.429 | 1.083 | 1.689 | 0.25 | 643 |

Table 10: Mean weight (kg) by stage in used in all of the models (provided as a vector of weights at length each year to Gmacs).

| Year | Stage-1 | Stage-2 | Stage-3 |
| ---: | ---: | ---: | ---: |
| 1978 | 0.7 | 1.2 | 1.9 |
| 1979 | 0.7 | 1.2 | 1.7 |
| 1980 | 0.7 | 1.2 | 1.9 |
| 1981 | 0.7 | 1.2 | 1.9 |
| 1982 | 0.7 | 1.2 | 1.9 |
| 1983 | 0.7 | 1.2 | 2.1 |
| 1984 | 0.7 | 1.2 | 1.9 |
| 1985 | 0.7 | 1.2 | 2.1 |
| 1986 | 0.7 | 1.2 | 1.9 |
| 1987 | 0.7 | 1.2 | 1.9 |
| 1988 | 0.7 | 1.2 | 1.9 |
| 1989 | 0.7 | 1.2 | 2.0 |
| 1990 | 0.7 | 1.2 | 1.9 |
| 1991 | 0.7 | 1.2 | 2.0 |
| 1992 | 0.7 | 1.2 | 1.9 |
| 1993 | 0.7 | 1.2 | 2.0 |
| 1994 | 0.7 | 1.2 | 1.9 |
| 1995 | 0.7 | 1.2 | 2.0 |
| 1996 | 0.7 | 1.2 | 2.0 |
| 1997 | 0.7 | 1.2 | 2.1 |
| 1998 | 0.7 | 1.2 | 2.0 |
| 1999 | 0.7 | 1.2 | 1.9 |
| 2000 | 0.7 | 1.2 | 1.9 |
| 2001 | 0.7 | 1.2 | 1.9 |
| 2002 | 0.7 | 1.2 | 1.9 |
| 2003 | 0.7 | 1.2 | 1.9 |
| 2004 | 0.7 | 1.2 | 1.9 |
| 2005 | 0.7 | 1.2 | 1.9 |
| 2006 | 0.7 | 1.2 | 1.9 |
| 2007 | 0.7 | 1.2 | 1.9 |
| 2008 | 0.7 | 1.2 | 1.9 |
| 2009 | 0.7 | 1.2 | 1.9 |
| 2010 | 0.7 | 1.2 | 1.8 |
| 2011 | 0.7 | 1.2 | 1.8 |
| 2012 | 0.7 | 1.2 | 1.8 |
| 2013 | 0.7 | 1.2 | 1.9 |
| 2014 | 0.7 | 1.2 | 1.9 |
| 2015 | 0.7 | 1.2 | 1.9 |
| 2016 | 0.7 | 1.2 | 1.9 |
| 2017 | 0.7 | 1.2 | 1.9 |
|  |  |  |  |

Table 11: Observed and input sample sizes for observer data from the directed pot fishery, the NMFS trawl survey, and the ADF\&G pot survey.

| Year | Number measured |  |  | Input sample sizes |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Observer pot | NMFS trawl | ADF\&G pot | Observer pot | NMFS trawl | ADF\&G pot |
| 1978 |  | 157 |  |  | 50 |  |
| 1979 |  | 178 |  |  | 50 |  |
| 1980 |  | 185 |  |  | 50 |  |
| 1981 |  | 140 |  |  | 50 |  |
| 1982 |  | 271 |  |  | 50 |  |
| 1983 |  | 231 |  |  | 50 |  |
| 1984 |  | 105 |  |  | 50 |  |
| 1985 |  | 93 |  |  | 46.5 |  |
| 1986 |  | 46 |  |  | 23 |  |
| 1987 |  | 71 |  |  | 35.5 |  |
| 1988 |  | 81 |  |  | 40.5 |  |
| 1989 |  | 208 |  |  | 50 |  |
| 1990 | 150 | 170 |  | 15 | 50 |  |
| 1991 | 3393 | 197 |  | 25 | 50 |  |
| 1992 | 1606 | 220 |  | 25 | 50 |  |
| 1993 | 2241 | 324 |  | 25 | 50 |  |
| 1994 | 4735 | 211 |  | 25 | 50 |  |
| 1995 | 663 | 178 | 4624 | 25 | 50 | 100 |
| 1996 | 489 | 285 |  | 25 | 50 |  |
| 1997 | 3195 | 296 |  | 25 | 50 |  |
| 1998 | 1323 | 243 | 4812 | 25 | 50 | 100 |
| 1999 |  | 52 |  |  | 26 |  |
| 2000 |  | 61 |  |  | 30.5 |  |
| 2001 |  | 91 | 3255 |  | 45.5 | 100 |
| 2002 |  | 38 |  |  | 19 |  |
| 2003 |  | 65 |  |  | 32.5 |  |
| 2004 |  | 48 | 640 |  | 24 | 100 |
| 2005 |  | 42 |  |  | 21 |  |
| 2006 |  | 126 |  |  | 50 |  |
| 2007 |  | 250 | 3319 |  | 50 | 100 |
| 2008 |  | 167 |  |  | 50 |  |
| 2009 | 19802 | 251 |  | 50 | 50 |  |
| 2010 | 45466 | 388 | 3920 | 50 | 50 | 100 |
| 2011 | 58667 | 318 |  | 50 | 50 |  |
| 2012 | 57282 | 193 |  | 50 | 50 |  |
| 2013 |  | 74 | 2167 |  | 37 | 100 |
| 2014 | 9906 | 181 |  | 50 | 50 |  |
| 2015 | 3248 | 153 | 1077 | 50 | 50 | 100 |
| 2016 |  | 108 | 777 |  | 50 | 100 |
| 2017 |  | 42 | 643 |  | 50 | 100 |

Table 12: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the reference model.

| Parameter | Estimate | SD |
| :--- | ---: | ---: |
| Natural mortality deviation in 1998/99 $\left(\delta_{1998}^{M}\right)$ | 1.652 | 0.127 |
| $\log (\bar{R})$ | 14.064 | 0.060 |
| $\log \left(n_{1}^{0}\right)$ | 14.922 | 0.171 |
| $\log \left(n_{2}^{0}\right)$ | 14.551 | 0.201 |
| $\log \left(n_{3}^{0}\right)$ | 14.360 | 0.206 |
| $q_{p o t}$ | 3.644 | 0.280 |
| $\log \left(\bar{F}^{\mathrm{df}}\right)$ | -1.923 | 0.053 |
| $\log \left(\bar{F}^{\mathrm{tb}}\right)$ | -9.019 | 0.082 |
| $\log \left(\bar{F}^{\mathrm{fb}}\right)$ | -8.217 | 0.082 |
| $\log$ Stage-1 directed pot selectivity 1978-2008 | -0.654 | 0.174 |
| $\log$ Stage-2 directed pot selectivity 1978-2008 | -0.315 | 0.126 |
| $\log$ Stage-1 directed pot selectivity $2009-2017$ | -0.463 | 0.154 |
| $\log$ Stage-2 directed pot selectivity $2009-2017$ | -0.000 | 0.000 |
| $\log$ Stage-1 NMFS trawl selectivity | -0.243 | 0.066 |
| $\log$ Stage-2 NMFS trawl selectivity | -0.000 | 0.000 |
| $\log$ Stage-1 ADF\&G pot selectivity | -0.852 | 0.127 |
| $\log$ Stage-2 ADF\&G pot selectivity | -0.026 | 0.078 |
| $F_{\text {OFL }}$ | 0.079 | 0.010 |
| OFL | 123.610 | 28.638 |

Table 13: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the VAST model.

| Parameter | Estimate | SD |
| :--- | ---: | ---: |
| Natural mortality deviation in $1998 / 99\left(\delta_{1998}^{M}\right)$ | 1.710 | 0.108 |
| $\log (\bar{R})$ | 14.205 | 0.050 |
| $\log \left(n_{1}^{0}\right)$ | 14.952 | 0.168 |
| $\log \left(n_{2}^{0}\right)$ | 14.592 | 0.193 |
| $\log \left(n_{3}^{0}\right)$ | 14.424 | 0.192 |
| $q_{p o t}$ | 2.926 | 0.166 |
| $\log \left(\bar{F}^{\text {df }}\right)$ | -2.037 | 0.042 |
| $\log \left(\bar{F}^{\text {tb }}\right)$ | -9.220 | 0.070 |
| $\log \left(\bar{F}^{\text {fb }}\right)$ | -8.419 | 0.070 |
| $\log$ Stage-1 directed pot selectivity $1978-2008$ | -0.701 | 0.171 |
| $\log$ Stage-2 directed pot selectivity $1978-2008$ | -0.331 | 0.124 |
| $\log$ Stage-1 directed pot selectivity $2009-2017$ | -0.319 | 0.145 |
| $\log$ Stage-2 directed pot selectivity $2009-2017$ | -0.000 | 0.000 |
| $\log$ Stage-1 NMFS trawl selectivity | -0.241 | 0.062 |
| $\log$ Stage-2 NMFS trawl selectivity | -0.000 | 0.000 |
| $\log$ Stage-1 ADF\&G pot selectivity | -0.798 | 0.123 |
| $\log$ Stage-2 ADF\&G pot selectivity | -0.000 | 0.000 |
| $F_{\text {OFL }}$ | 0.103 | 0.009 |
| OFL | 220.400 | 32.463 |

Table 14: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the "Fit survey" model.

| Parameter | Estimate | SD |
| :--- | ---: | ---: |
| Natural mortality deviation in 1998/99 $\left(\delta_{1998}^{M}\right)$ | 2.160 | 0.107 |
| $\log (\bar{R})$ | 14.583 | 0.065 |
| $\log \left(n_{1}^{0}\right)$ | 15.456 | 0.417 |
| $\log \left(n_{2}^{0}\right)$ | 15.288 | 0.438 |
| $\log \left(n_{3}^{0}\right)$ | 15.120 | 0.418 |
| $q_{p o t}$ | 1.010 | 0.052 |
| $\log \left(\bar{F}^{\text {df }}\right)$ | -2.901 | 0.045 |
| $\log \left(\bar{F}^{\text {tb }}\right)$ | -10.043 | 0.071 |
| $\log \left(\bar{F}^{\text {fb }}\right)$ | -9.243 | 0.071 |
| $\log$ Stage-1 directed pot selectivity 1978-2008 | -0.343 | 0.141 |
| $\log$ Stage-2 directed pot selectivity 1978-2008 | -0.082 | 0.119 |
| $\log$ Stage-1 directed pot selectivity $2009-2017$ | -0.000 | 0.000 |
| $\log$ Stage-2 directed pot selectivity $2009-2017$ | -0.000 | 0.000 |
| $\log$ Stage-1 NMFS trawl selectivity | -0.000 | 0.000 |
| $\log$ Stage-2 NMFS trawl selectivity | -0.000 | 0.000 |
| $\log$ Stage-1 ADF\&G pot selectivity | -0.000 | 0.000 |
| $\log$ Stage-2 ADF\&G pot selectivity | -0.000 | 0.000 |
| $F_{\text {OFL }}$ | 0.083 | 0.006 |
| OFL | 367.950 | 44.694 |

Table 15: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the "Francis weights" model.

| Parameter | Estimate | SD |
| :--- | ---: | ---: |
| Natural mortality deviation in 1998/99 $\left(\delta_{1998}^{M}\right)$ | 1.634 | 0.136 |
| $\log (\bar{R})$ | 14.033 | 0.064 |
| $\log \left(n_{1}^{0}\right)$ | 14.885 | 0.285 |
| $\log \left(n_{2}^{0}\right)$ | 14.561 | 0.318 |
| $\log \left(n_{3}^{0}\right)$ | 14.361 | 0.317 |
| $q_{p o t}$ | 3.526 | 0.248 |
| $\log \left(\bar{F}^{\text {df }}\right)$ | -1.884 | 0.060 |
| $\log \left(\bar{F}^{\text {tb }}\right)$ | -9.044 | 0.081 |
| $\log \left(\bar{F}^{\mathrm{fb}}\right)$ | -8.243 | 0.081 |
| $\log$ Stage-1 directed pot selectivity $1978-2008$ | -0.514 | 0.157 |
| $\log$ Stage-2 directed pot selectivity $1978-2008$ | -0.319 | 0.128 |
| $\log$ Stage-1 directed pot selectivity $2009-2017$ | -0.420 | 0.141 |
| $\log$ Stage-2 directed pot selectivity $2009-2017$ | -0.000 | 0.000 |
| $\log$ Stage-1 NMFS trawl selectivity | -0.181 | 0.083 |
| $\log$ Stage-2 NMFS trawl selectivity | -0.000 | 0.000 |
| $\log$ Stage-1 ADF\&G pot selectivity | -0.799 | 0.092 |
| $\log$ Stage-2 ADF\&G pot selectivity | -0.000 | 0.000 |
| $F_{\text {OFL }}$ | 0.076 | 0.010 |
| OFL | 117.650 | 26.963 |

Table 16: Comparisons of parameter estimates for the four model scenarios.

| Parameter | Ref | VAST | FitSurvey | Francis |
| :--- | ---: | ---: | ---: | ---: |
| $\log \left(\bar{F}^{\text {df }}\right)$ | -1.923 | -2.037 | -2.901 | -1.884 |
| $\log \left(\bar{F}^{\mathrm{fb}}\right)$ | -8.217 | -8.419 | -9.243 | -8.243 |
| $\log \left(\bar{F}^{\mathrm{tb}}\right)$ | -9.019 | -9.220 | -10.043 | -9.044 |
| $\log (\bar{R})$ | 14.064 | 14.205 | 14.583 | 14.033 |
| $\log \left(n_{1}^{0}\right)$ | 14.922 | 14.952 | 15.456 | 14.885 |
| $\log \left(n_{2}^{0}\right)$ | 14.551 | 14.592 | 15.288 | 14.561 |
| $\log \left(n_{3}^{0}\right)$ | 14.360 | 14.424 | 15.120 | 14.361 |
| $F_{\text {OFL }}$ | 0.079 | 0.103 | 0.083 | 0.076 |
| $q_{\text {pot }}$ | 0.004 | 0.003 | 0.001 | 0.004 |
| $\log$ Stage-1 ADF\&G pot selectivity | -0.852 | -0.798 | -0.000 | -0.799 |
| $\log$ Stage-1 directed pot selectivity 1978-2008 | -0.654 | -0.701 | -0.343 | -0.514 |
| $\log$ Stage-1 directed pot selectivity 2009-2017 | -0.463 | -0.319 | -0.000 | -0.420 |
| $\log$ Stage-1 NMFS trawl selectivity | -0.243 | -0.241 | -0.000 | -0.181 |
| $\log$ Stage-2 ADF\&G pot selectivity | -0.026 | -0.000 | -0.000 | -0.000 |
| $\log$ Stage-2 directed pot selectivity 1978-2008 | -0.315 | -0.331 | -0.082 | -0.319 |
| $\log$ Stage-2 directed pot selectivity $2009-2017$ | -0.000 | -0.000 | -0.000 | -0.000 |
| $\log$ Stage-2 NMFS trawl selectivity | -0.000 | -0.000 | -0.000 | -0.000 |
| Natural mortality deviation in 1998/99 $\left(\delta_{1998}^{M}\right)$ | 1.652 | 1.710 | 2.160 | 1.634 |
| OFL | 123.610 | 220.400 | 367.950 | 117.650 |

Table 17: Comparisons of data weights, Francis LF weights (i.e. the new weights that should be applied to the LFs), SDNR values, and MAR values for the four model scenarios.

| Component | Reference | VAST | Fit survey | Francis |
| :--- | ---: | ---: | ---: | ---: |
| NMFS trawl survey weight | 1.00 | 1.00 | 1.50 | 1.00 |
| ADF\&G pot survey weight | 1.00 | 1.00 | 2.00 | 1.00 |
| Directed pot LF weight | 1.00 | 1.00 | 1.95 | 1.61 |
| NMFS trawl survey LF weight | 1.00 | 1.00 | 0.22 | 0.50 |
| ADF\&G pot survey LF weight | 1.00 | 1.00 | 0.10 | 3.72 |
| Francis weight for directed pot LF | 1.69 | 1.57 | 1.96 | 1.55 |
| Francis weight for NMFS trawl survey LF | 0.57 | 0.53 | 0.22 | 0.50 |
| Francis weight for ADF\&G pot survey LF | 2.08 | 1.20 | 0.10 | 4.13 |
| SDNR NMFS trawl survey | 1.45 | 1.85 | 1.83 | 1.36 |
| SDNR ADF\&G pot survey | 3.78 | 3.88 | 5.45 | 3.72 |
| SDNR directed pot LF | 0.71 | 0.78 | 1.39 | 0.91 |
| SDNR NMFS trawl survey LF | 1.23 | 1.28 | 1.06 | 0.94 |
| SDNR ADF\&G pot survey LF | 0.80 | 0.92 | 0.96 | 1.01 |
| MAR NMFS trawl survey | 1.18 | 1.13 | 1.52 | 1.12 |
| MAR ADF\&G pot survey | 2.96 | 2.63 | 4.57 | 2.97 |
| MAR directed pot LF | 0.59 | 0.66 | 0.66 | 0.76 |
| MAR NMFS trawl survey LF | 0.52 | 0.62 | 0.69 | 0.53 |
| MAR ADF\&G pot survey LF | 0.49 | 0.78 | 0.55 | 0.59 |

Table 18: Comparisons of negative log-likelihood values for the four model scenarios. It is important to note that some of these models cannot be compared since the input sample size (or variances) are modified by re-weighting (e.g., Francis model).

| Component | Ref | VAST | FitSurvey | Francis |
| :--- | ---: | ---: | ---: | ---: |
| Pot Retained Catch | -71.53 | -71.15 | -70.53 | -71.50 |
| Pot Discarded Catch | 8.98 | 11.73 | 43.00 | 12.74 |
| Trawl bycatch Discarded Catch | -7.16 | -7.16 | -7.16 | -7.16 |
| Fixed bycatch Discarded Catch | -7.13 | -7.14 | -7.15 | -7.14 |
| NMFS Trawl Survey | -3.93 | 2.28 | 6.96 | -8.93 |
| ADF\&G Pot Survey CPUE | 57.07 | 62.32 | 130.07 | 54.50 |
| Directed Pot LF | -11.31 | -9.15 | 22.78 | 9.96 |
| NMFS Trawl LF | 18.24 | 26.27 | 92.24 | 55.53 |
| ADF\&G Pot LF | -7.40 | -4.61 | 32.83 | -6.46 |
| Recruitment deviations | 52.94 | 51.61 | 59.96 | 53.48 |
| F penalty | 14.49 | 14.49 | 14.49 | 14.49 |
| M penalty | 6.47 | 6.47 | 6.49 | 6.47 |
| Prior | 12.66 | 12.62 | 13.61 | 12.66 |
| Total | 62.39 | 88.59 | 337.59 | 118.65 |
| Total estimated parameters | 138.00 | 138.00 | 138.00 | 138.00 |

Table 19: Population abundances ( $\boldsymbol{n}$ ) by crab stage in numbers of crab at the time of the survey and mature male biomass (MMB) in tons on 15 February for the 2016 model.

| Year | $n_{1}$ | $n_{2}$ | $n_{3}$ | MMB |
| ---: | ---: | ---: | ---: | ---: |
| 1978 | 2816497 | 1960202 | 1444270 | 4173 |
| 1979 | 4054755 | 2248354 | 2097572 | 6008 |
| 1980 | 3581771 | 3047062 | 3228875 | 9573 |
| 1981 | 1366446 | 3042808 | 4547965 | 10026 |
| 1982 | 1495157 | 1783152 | 4587146 | 7110 |
| 1983 | 767497 | 1439252 | 3248511 | 4291 |
| 1984 | 639352 | 912111 | 1887891 | 2987 |
| 1985 | 880391 | 664957 | 1390828 | 2716 |
| 1986 | 1321656 | 720083 | 1212765 | 2692 |
| 1987 | 1279302 | 988951 | 1316950 | 3180 |
| 1988 | 1176369 | 1053889 | 1528925 | 3471 |
| 1989 | 2659962 | 1016938 | 1684431 | 3951 |
| 1990 | 1669442 | 1847273 | 1965108 | 4964 |
| 1991 | 1760684 | 1559550 | 2402885 | 4938 |
| 1992 | 1877628 | 1515489 | 2346712 | 5093 |
| 1993 | 2138081 | 1567357 | 2441780 | 5294 |
| 1994 | 1523681 | 1732752 | 2499174 | 5062 |
| 1995 | 1713019 | 1438756 | 2407204 | 5007 |
| 1996 | 1594900 | 1448944 | 2338286 | 4834 |
| 1997 | 890940 | 1385339 | 2278762 | 4267 |
| 1998 | 638656 | 964438 | 1894686 | 2951 |
| 1999 | 384630 | 309673 | 705797 | 1668 |
| 2000 | 423856 | 320841 | 782180 | 1824 |
| 2001 | 387023 | 346925 | 855630 | 1991 |
| 2002 | 136630 | 334576 | 926440 | 2109 |
| 2003 | 323258 | 188283 | 955265 | 1997 |
| 2004 | 215940 | 245764 | 923187 | 2003 |
| 2005 | 507624 | 203958 | 915516 | 1941 |
| 2006 | 763229 | 355768 | 915955 | 2111 |
| 2007 | 485177 | 550620 | 1016300 | 2489 |
| 2008 | 938121 | 451958 | 1157900 | 2672 |
| 2009 | 785462 | 681685 | 1283392 | 2784 |
| 2010 | 753813 | 670916 | 1398376 | 2516 |
| 2011 | 648139 | 649192 | 1313310 | 2130 |
| 2012 | 376523 | 582847 | 1099116 | 1794 |
| 2013 | 469549 | 406668 | 913357 | 2067 |
| 2014 | 426762 | 401241 | 1012730 | 2079 |
| 2015 | 356241 | 375162 | 1028792 | 2119 |
| 2016 | 355336 | 326462 | 1061000 | 2244 |
|  |  |  |  |  |

Table 20: Population abundances ( $\boldsymbol{n}$ ) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tons on 15 February for the reference model.

| Year | $n_{1}$ | $n_{2}$ | $n_{3}$ | MMB |
| ---: | ---: | ---: | ---: | ---: |
| 1978 | 3024941 | 2086744 | 1724025 | 4852 |
| 1979 | 4239965 | 2408632 | 2414987 | 6724 |
| 1980 | 3596344 | 3205302 | 3592526 | 10446 |
| 1981 | 1349025 | 3103464 | 4932899 | 10813 |
| 1982 | 1475780 | 1793338 | 4937657 | 7792 |
| 1983 | 781016 | 1431623 | 3544534 | 4882 |
| 1984 | 666738 | 917278 | 2131823 | 3448 |
| 1985 | 933667 | 682228 | 1599710 | 3167 |
| 1986 | 1410067 | 756061 | 1401082 | 3088 |
| 1987 | 1349409 | 1051073 | 1500841 | 3599 |
| 1988 | 1231932 | 1114269 | 1720553 | 3889 |
| 1989 | 2800176 | 1068482 | 1880245 | 4391 |
| 1990 | 1751534 | 1943967 | 2168052 | 5444 |
| 1991 | 1814448 | 1638180 | 2629043 | 5458 |
| 1992 | 1939805 | 1572076 | 2580522 | 5597 |
| 1993 | 2184235 | 1621426 | 2671609 | 5805 |
| 1994 | 1553370 | 1776820 | 2722837 | 5530 |
| 1995 | 1770998 | 1470210 | 2619081 | 5455 |
| 1996 | 1600408 | 1492289 | 2536543 | 5262 |
| 1997 | 912973 | 1402738 | 2466495 | 4667 |
| 1998 | 660074 | 982653 | 2061868 | 3267 |
| 1999 | 394430 | 327571 | 798265 | 1861 |
| 2000 | 442239 | 332277 | 869216 | 1999 |
| 2001 | 405731 | 361052 | 935595 | 2156 |
| 2002 | 144740 | 349823 | 1001982 | 2267 |
| 2003 | 341000 | 197937 | 1026826 | 2142 |
| 2004 | 227177 | 259039 | 989524 | 2142 |
| 2005 | 505715 | 214734 | 978693 | 2071 |
| 2006 | 763531 | 358196 | 973818 | 2222 |
| 2007 | 521970 | 551619 | 1065877 | 2583 |
| 2008 | 935990 | 473156 | 1203369 | 2781 |
| 2009 | 760273 | 687508 | 1331849 | 2875 |
| 2010 | 729826 | 658570 | 1439363 | 2570 |
| 2011 | 600893 | 631520 | 1338699 | 2152 |
| 2012 | 345261 | 550063 | 1105742 | 1768 |
| 2013 | 442426 | 377975 | 898271 | 2009 |
| 2014 | 367920 | 376271 | 982889 | 1999 |
| 2015 | 352930 | 333413 | 985388 | 1999 |
| 2016 | 379414 | 310688 | 1003127 | 2122 |
| 2017 | 186468 | 318041 | 1029878 | 2180 |
|  |  |  |  |  |

Table 21: Population abundances ( $\boldsymbol{n}$ ) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tons on 15 February for the Francis weights model.

| Year | $n_{1}$ | $n_{2}$ | $n_{3}$ | MMB |
| ---: | ---: | ---: | ---: | ---: |
| 1978 | 2914158 | 2107534 | 1724626 | 4878 |
| 1979 | 4110549 | 2352595 | 2415404 | 6660 |
| 1980 | 3272000 | 3113252 | 3552247 | 10263 |
| 1981 | 1255767 | 2888789 | 4821836 | 10358 |
| 1982 | 1252747 | 1669317 | 4727728 | 7247 |
| 1983 | 752019 | 1263907 | 3284909 | 4156 |
| 1984 | 589896 | 845294 | 1824879 | 2791 |
| 1985 | 797309 | 614749 | 1298973 | 2469 |
| 1986 | 1195843 | 656276 | 1102745 | 2411 |
| 1987 | 1416960 | 896378 | 1180842 | 2818 |
| 1988 | 1481565 | 1101427 | 1381697 | 3256 |
| 1989 | 3404588 | 1206002 | 1614487 | 4029 |
| 1990 | 1438930 | 2332738 | 2073038 | 5713 |
| 1991 | 1815552 | 1589318 | 2715817 | 5567 |
| 1992 | 2022514 | 1556550 | 2627746 | 5667 |
| 1993 | 2472885 | 1663260 | 2710930 | 5929 |
| 1994 | 1478514 | 1954580 | 2804465 | 5885 |
| 1995 | 1775538 | 1486535 | 2770349 | 5768 |
| 1996 | 1693651 | 1500281 | 2671388 | 5530 |
| 1997 | 769965 | 1458341 | 2592267 | 4987 |
| 1998 | 664628 | 919851 | 2182322 | 3417 |
| 1999 | 413378 | 324515 | 845070 | 1945 |
| 2000 | 389302 | 342029 | 908581 | 2084 |
| 2001 | 464065 | 334225 | 968329 | 2187 |
| 2002 | 151330 | 374068 | 1021377 | 2331 |
| 2003 | 403096 | 209704 | 1055881 | 2209 |
| 2004 | 204945 | 298185 | 1025667 | 2254 |
| 2005 | 428497 | 215067 | 1026496 | 2161 |
| 2006 | 847860 | 314466 | 1006528 | 2234 |
| 2007 | 564417 | 585018 | 1079224 | 2646 |
| 2008 | 889231 | 508147 | 1235657 | 2881 |
| 2009 | 860820 | 672564 | 1371981 | 2929 |
| 2010 | 707726 | 710694 | 1475014 | 2687 |
| 2011 | 538185 | 636243 | 1393311 | 2249 |
| 2012 | 344859 | 516030 | 1147911 | 1801 |
| 2013 | 471797 | 366494 | 915902 | 2028 |
| 2014 | 369039 | 389149 | 994635 | 2033 |
| 2015 | 286665 | 338310 | 1001843 | 2033 |
| 2016 | 297822 | 274688 | 1012976 | 2101 |
| 2017 | 175628 | 259829 | 1012138 | 2085 |
|  |  |  |  |  |

Table 22: Population abundances ( $\boldsymbol{n}$ ) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tons on 15 February for the model that uses the VAST BTS index.

| Year | $n_{1}$ | $n_{2}$ | $n_{3}$ | MMB |
| ---: | ---: | ---: | ---: | ---: |
| 1978 | 3115215 | 2172899 | 1838086 | 5169 |
| 1979 | 4165349 | 2488423 | 2562202 | 7061 |
| 1980 | 3502187 | 3189337 | 3748592 | 10724 |
| 1981 | 1366561 | 3044705 | 5046205 | 10957 |
| 1982 | 1475664 | 1783853 | 5004687 | 7901 |
| 1983 | 742837 | 1428422 | 3591786 | 4964 |
| 1984 | 631179 | 894542 | 2161933 | 3474 |
| 1985 | 858312 | 654510 | 1608409 | 3152 |
| 1986 | 1248013 | 704090 | 1386589 | 3002 |
| 1987 | 1360239 | 941837 | 1447079 | 3373 |
| 1988 | 1246057 | 1084264 | 1621642 | 3675 |
| 1989 | 2985149 | 1066574 | 1783972 | 4201 |
| 1990 | 1870987 | 2048386 | 2104422 | 5447 |
| 1991 | 1939133 | 1740581 | 2640145 | 5596 |
| 1992 | 2122333 | 1676762 | 2653809 | 5854 |
| 1993 | 2412369 | 1759724 | 2803232 | 6218 |
| 1994 | 1718543 | 1952155 | 2924306 | 6104 |
| 1995 | 1977307 | 1622056 | 2891334 | 6157 |
| 1996 | 1908447 | 1659726 | 2859846 | 6069 |
| 1997 | 1131105 | 1633109 | 2850023 | 5704 |
| 1998 | 803062 | 1182797 | 2518291 | 4178 |
| 1999 | 464910 | 375024 | 972746 | 2241 |
| 2000 | 511519 | 388018 | 1045620 | 2392 |
| 2001 | 473002 | 418852 | 1117669 | 2561 |
| 2002 | 165752 | 407162 | 1189639 | 2683 |
| 2003 | 401411 | 228852 | 1214492 | 2527 |
| 2004 | 269011 | 303583 | 1167639 | 2525 |
| 2005 | 715254 | 253240 | 1153927 | 2442 |
| 2006 | 979145 | 489934 | 1159636 | 2718 |
| 2007 | 703674 | 717650 | 1308132 | 3224 |
| 2008 | 1182362 | 631080 | 1507167 | 3527 |
| 2009 | 919542 | 879699 | 1688787 | 3706 |
| 2010 | 874752 | 812665 | 1849739 | 3416 |
| 2011 | 738581 | 764892 | 1772676 | 3022 |
| 2012 | 445923 | 672431 | 1546550 | 2629 |
| 2013 | 551092 | 475675 | 1334636 | 2893 |
| 2014 | 473134 | 470339 | 1407020 | 2842 |
| 2015 | 447580 | 424314 | 1396981 | 2801 |
| 2016 | 547678 | 394543 | 1401765 | 2924 |
| 2017 | 311774 | 441360 | 1421219 | 3011 |
|  |  |  |  |  |

Table 23: Population abundances ( $\boldsymbol{n}$ ) by crab) stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tons on 15 February for the fit surveys model.

| Year | $n_{1}$ | $n_{2}$ | $n_{3}$ | MMB |
| ---: | ---: | ---: | ---: | ---: |
| 1978 | 5159537 | 4361084 | 3687283 | 11213 |
| 1979 | 6210267 | 4373769 | 5405672 | 13986 |
| 1980 | 3673747 | 4974775 | 7269812 | 19463 |
| 1981 | 1540288 | 3733146 | 8904090 | 18930 |
| 1982 | 1435675 | 2110417 | 8589692 | 15134 |
| 1983 | 924987 | 1513838 | 6744725 | 11444 |
| 1984 | 759383 | 1026332 | 4845730 | 8627 |
| 1985 | 888512 | 770974 | 3926869 | 8069 |
| 1986 | 1169500 | 759806 | 3384557 | 6842 |
| 1987 | 2073978 | 915706 | 3136254 | 6538 |
| 1988 | 3432758 | 1480998 | 3087326 | 6799 |
| 1989 | 7016427 | 2439826 | 3416727 | 8943 |
| 1990 | 2176388 | 4792406 | 4545548 | 13018 |
| 1991 | 3012152 | 2822327 | 6091388 | 13390 |
| 1992 | 3410492 | 2644416 | 6181631 | 13578 |
| 1993 | 4658345 | 2811786 | 6359402 | 14361 |
| 1994 | 3595317 | 3576027 | 6638067 | 14873 |
| 1995 | 2415186 | 3225465 | 6988280 | 15949 |
| 1996 | 3767773 | 2439220 | 7129303 | 15116 |
| 1997 | 3507563 | 2947152 | 6984231 | 15576 |
| 1998 | 2577269 | 2967449 | 6856068 | 11783 |
| 1999 | 935872 | 614530 | 1723836 | 3915 |
| 2000 | 1680050 | 734770 | 1838776 | 4266 |
| 2001 | 2898966 | 1197252 | 2066729 | 5214 |
| 2002 | 560274 | 2042480 | 2606795 | 7177 |
| 2003 | 183891 | 994184 | 3260530 | 7216 |
| 2004 | 104651 | 433447 | 3241730 | 6549 |
| 2005 | 981856 | 202910 | 2936121 | 5717 |
| 2006 | 1923313 | 624740 | 2648339 | 5653 |
| 2007 | 3575445 | 1298593 | 2709815 | 6506 |
| 2008 | 1607754 | 2450926 | 3247373 | 8834 |
| 2009 | 1497545 | 1723791 | 4100573 | 8829 |
| 2010 | 1772043 | 1420514 | 4344790 | 8209 |
| 2011 | 1093878 | 1475839 | 4248690 | 7957 |
| 2012 | 687238 | 1109613 | 4006465 | 7204 |
| 2013 | 763979 | 757501 | 3630856 | 7292 |
| 2014 | 799080 | 684574 | 3487434 | 6713 |
| 2015 | 589916 | 680368 | 3273389 | 6284 |
| 2016 | 429463 | 560172 | 3111618 | 6152 |
| 2017 | 190561 | 429189 | 2921581 | 5674 |
|  |  |  |  |  |

## Figures



Figure 1: Distribution of blue king crab (Paralithodes platypus) in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters (shown in blue).


Figure 2: King crab Registration Area Q (Bering Sea).

Data by type and year


Figure 3: Data extent for the SMBKC assessment (with the 2017 Pot survey included).


Figure 4: Trawl and pot-survey stations used in the SMBKC stock assessment.


Figure 5: Catches (in numbers) of male blue king crab measuring 90 mm CL from the 2012-2017 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock. Note that the area north of St. Matthew Island, which often shows large catches of crab at station R-24 is not covered in the ADF\&G pot-survey data used in the assessment.


Figure 6: NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521 .


Figure 7: Fits to NMFS area-swept trawl estimates of total $(>90 \mathrm{~mm})$ male survey biomass with the addition of new data. Error bars are plus and minus 2 standard deviations.


Figure 8: Comparisons of fits to CPUE from the ADF\&G pot surveys with the addition of new data. Error bars are plus and minus 2 standard deviations.


Figure 9: Sensitivity of new data in 2017 on estimated recruitment ; 1978-2017.


Figure 10: Sensitivity of new data in 2017 on estimated mature male biomass (MMB); 1978-2017.


Figure 11: Comparisons of fits to area-swept estimates of total ( $>90 \mathrm{~mm}$ ) male survey biomass ( t ) for the standard design-based estimate and for estimates derived from the VAST spatio-temporal model of Thorson and Barnett (2017). Error bars are plus and minus 2 standard deviations.


Figure 12: Sensitivity of new data in 2017 on estimated mature male biomass (MMB); 1978-2017 comparing the reference model with that fitted to the VAST BTS estimates.


Figure 13: Comparisons of the estimated stage-1 and stage-2 selectivities for the different model scenarios (the stage-3 selectivities are all fixed at 1). Estimated selectivities are shown for the directed pot fishery, the trawl bycatch fishery, the fixed bycatch fishery, the NMFS trawl survey, and the ADF\&G pot survey. Two selectivity periods are estimated in the directed pot fishery, from 1978-2008 and 2009-2017.


Figure 14: Estimated recruitment 1979-2017 comparing model alternatives. The solid horizontal lines in the background represent the estimate of the average recruitment parameter ( $\bar{R}$ ) in each model scenario.


Figure 15: Comparisons of estimated mature male biomass (MMB) time series on 15 February during 1978-2017 for each of the model scenarios.


Figure 16: Time-varying natural mortality $\left(M_{t}\right)$. Estimated pulse period occurs in 1998/99 (i.e. $M_{1998}$ ).


Figure 17: Comparisons of area-swept estimates of total ( $90+\mathrm{mm}$ CL) male survey biomass (tons) and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.


Figure 18: Comparisons of total ( $90+\mathrm{mm}$ CL) male pot survey CPUEs and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.


Figure 19: Standardized residuals for area-swept estimates of total male survey biomass for the model scenarios.


Figure 20: Standardized residuals for total male pot survey CPUEs for each of the Gmacs model scenarios.


Figure 21: Observed and model estimated size-frequencies of SMBKC by year retained in the directed pot fishery for the model scenarios.


Figure 22: Observed and model estimated size-frequencies of discarded male SMBKC by year in the NMFS trawl survey for the model scenarios.


Figure 23: Observed and model estimated size-frequencies of discarded SMBKC by year in the ADF\&G pot survey for the model scenarios.


Figure 24: Bubble plots of residuals by stage and year for the directed pot fishery size composition data for SMBKC in the reference model.


Figure 25: Bubble plots of residuals by stage and year for the ADF\&G pot survey size composition data for SMBKC in the fit surveys model.


Figure 26: Comparison of observed and model predicted retained catch and bycatches in each of the Gmacs models. Note that difference in units between each of the panels, some panels are expressed in numbers of crab, some as biomass (tons).


Figure 27: Comparisons of mature male biomass relative to the dynamic $B_{0}$ value, ( 15 February, 1978-2017) for each of the model scenarios.

## Appendix A: SMBKC Model Description

## 1. Introduction

The Gmacs model has been specified to account only for male crab $\geq 90 \mathrm{~mm}$ in carapace length (CL). These are partitioned into three stages (size- classes) determined by CL measurements of (1) 90-104 mm, (2) 105-119 mm , and (3) $120+\mathrm{mm}$. For management of the St. Matthew Island blue king crab (SMBKC) fishery, 120 mm CL is used as the proxy value for the legal measurement of 5.5 in carapace width ( CW ), whereas 105 mm CL is the management proxy for mature-male size ( 5 AAC 34.917 (d)). Accordingly, within the model only stage-3 crab are retained in the directed fishery, and stage- 2 and stage- 3 crab together comprise the collection of mature males. Some justification for the 105 mm value is presented in Pengilly and Schmidt (1995), who used it in developing the current regulatory SMBKC harvest strategy. The term "recruit" here designates recruits to the model, i.e., annual new stage-1 crab, rather than recruits to the fishery. The following description of model structure reflects the Gmacs base model configuration.

## 2. Model Population Dynamics

Within the model, the beginning of the crab year is assumed contemporaneous with the NMFS trawl survey, nominally assigned a date of 1 July. Although the timing of the fishery is different each year, MMB is 15 February, which is the reference date for calculation of federal management biomass quantities. To accommodate this, each model year is split into 5 seasons $(t)$ and a proportion of the natural mortality $\left(\tau_{t}\right)$, scaled relative to the portions of the year, is applied in each of these seasons where $\sum_{t=1}^{t=5} \tau_{t}=1$. Each model year consists of the following processes with time-breaks denoted here by "Seasons." However, it is important to note that actual seasons are survey-to-fishery, fishery-to Feb 15, and Feb 15 to July 1. The following breakdown accounts for events and fishing mortality treatments:

1. Season 1 (survey period)

- Beginning of the SMBKC fishing year (1 July)
- $\tau_{1}=0$
- Surveys

2. Season 2 (natural mortality until pulse fishery)

- $\tau_{2}$ ranges from 0.05 to 0.44 depending on the time of year the fishery begins each year (i.e., a higher value indicates the fishery begins later in the year; see Table 7)

3. Season 3 (pulse fishery)

- $\tau_{3}=0$
- fishing mortality applied

4. Season 4 (natural mortality until spawning)

- $\tau_{4}=0.63-\sum_{i=1}^{i=4} \tau_{i}$
- Calculate MMB (15 February)

5. Season 5 (natural mortality and somatic growth through to June 30th)

- $\tau_{5}=0.37$
- Growth and molting
- Recruitment (all to stage-1)

The proportion of natural mortality $\left(\tau_{t}\right)$ applied during each season in the model is provided in Table 24. The beginning of the year (1 July) to the date that MMB is measured ( 15 February) is $63 \%$ of the year. Therefore $63 \%$ of the natural mortality must be applied before the MMB is calculated. Because the timing of the fishery is different each year, $\tau_{2}$ varies and thus $\tau_{4}$ varies also.
With boldface lower-case letters indicating vector quantities we designate the vector of stage abundances during season $t$ and year $y$ as

$$
\begin{equation*}
\boldsymbol{n}_{t, y}=n_{l, t, y}=\left[n_{1, t, y}, n_{2, t, y}, n_{3, t, y}\right]^{\top} \tag{2}
\end{equation*}
$$

The number of new crab, or recruits, of each stage entering the model each season $t$ and year $y$ is represented as the vector $\boldsymbol{r}_{t, y}$. The SMBKC formulation of Gmacs specifies recruitment to stage-1 only during season $t=5$, thus the recruitment size distribution is

$$
\begin{equation*}
\phi_{l}=[1,0,0]^{\top} \tag{3}
\end{equation*}
$$

and the recruitment is

$$
\boldsymbol{r}_{t, y}= \begin{cases}0 & \text { for } \quad t<5  \tag{4}\\ \bar{R} \phi_{l} \delta_{y}^{R} & \text { for } \quad t=5\end{cases}
$$

where $\bar{R}$ is the average annual recruitment and $\delta_{y}^{R}$ are the recruitment deviations each year $y$

$$
\begin{equation*}
\delta_{y}^{R} \sim \mathcal{N}\left(0, \sigma_{R}^{2}\right) \tag{5}
\end{equation*}
$$

Using boldface upper-case letters to indicate a matrix, we describe the size transition matrix $\boldsymbol{G}$ as

$$
\boldsymbol{G}=\left[\begin{array}{ccc}
1-\pi_{12}-\pi_{13} & \pi_{12} & \pi_{13}  \tag{6}\\
0 & 1-\pi_{23} & \pi_{23} \\
0 & 0 & 1
\end{array}\right]
$$

with $\pi_{j k}$ equal to the proportion of stage- $j$ crab that molt and grow into stage- $k$ within a season or year. The natural mortality each season $t$ and year $y$ is

$$
\begin{equation*}
M_{t, y}=\bar{M} \tau_{t}+\delta_{y}^{M} \text { where } \delta_{y}^{M} \sim \mathcal{N}\left(0, \sigma_{M}^{2}\right) \tag{7}
\end{equation*}
$$

Fishing mortality by year $y$ and season $t$ is denoted $F_{t, y}$ and calculated as

$$
\begin{equation*}
F_{t, y}=F_{t, y}^{\mathrm{df}}+F_{t, y}^{\mathrm{tb}}+F_{t, y}^{\mathrm{fb}} \tag{8}
\end{equation*}
$$

where $F_{t, y}^{\mathrm{df}}$ is the fishing mortality associated with the directed fishery, $F_{t, y}^{\mathrm{tb}}$ is the fishing mortality associated with the trawl bycatch fishery, $F_{t, y}^{\mathrm{fb}}$ is the fishing mortality associated with the fixed bycatch fishery. Each of these are derived as

$$
\begin{array}{lll}
F_{t, y}^{\mathrm{df}}=\bar{F}^{\mathrm{df}}+\delta_{t, y}^{\mathrm{df}} & \text { where } & \delta_{t, y}^{\mathrm{df}} \sim \mathcal{N}\left(0, \sigma_{\mathrm{df}}^{2}\right), \\
F_{t, y}^{\mathrm{tb}}=\bar{F}^{\mathrm{tb}}+\delta_{t, y}^{\mathrm{tb}} & \text { where } & \delta_{t, y}^{\mathrm{df}} \sim \mathcal{N}\left(0, \sigma_{\mathrm{tb}}^{2}\right), \\
F_{t, y}^{\mathrm{fb}}=\bar{F}^{\mathrm{fb}}+\delta_{t, y}^{\mathrm{fb}} & \text { where } & \delta_{t, y}^{\mathrm{df}} \sim \mathcal{N}\left(0, \sigma_{\mathrm{fb}}^{2}\right), \tag{9}
\end{array}
$$

where $\delta_{t, y}^{\mathrm{df}}, \delta_{t, y}^{\mathrm{tb}}$, and $\delta_{t, y}^{\mathrm{fb}}$ are the fishing mortality deviations for each of the fisheries, each season $t$ during each year $y, \bar{F}^{\text {df }}, \bar{F}^{\text {tb }}$, and $\bar{F}^{\mathrm{fb}}$ are the average fishing mortalities for each fishery. The total mortality $Z_{l, t, y}$ represents the combination of natural mortality $M_{t, y}$ and fishing mortality $F_{t, y}$ during season $t$ and year $y$

$$
\begin{equation*}
Z_{t, y}=Z_{l, t, y}=M_{t, y}+F_{t, y} \tag{10}
\end{equation*}
$$

The survival matrix $\boldsymbol{S}_{t, y}$ during season $t$ and year $y$ is

$$
\boldsymbol{S}_{t, y}=\left[\begin{array}{ccc}
1-e^{-Z_{1, t, y}} & 0 & 0  \tag{11}\\
0 & 1-e^{-Z_{2, t, y}} & 0 \\
0 & 0 & 1-e^{-Z_{3, t, y}}
\end{array}\right]
$$

The basic population dynamics underlying Gmacs can thus be described as

$$
\begin{array}{lc}
\boldsymbol{n}_{t+1, y}=\boldsymbol{S}_{t, y} \boldsymbol{n}_{t, y}, & \text { if } t<5 \\
\boldsymbol{n}_{t, y+1}=\boldsymbol{G} \boldsymbol{S}_{t, y} \boldsymbol{n}_{t, y}+\boldsymbol{r}_{t, y} & \text { if } t=5 .
\end{array}
$$

## 3. Model Data

Data inputs used in model estimation are listed in Table 25.

## 4. Model Parameters

Table 26 lists fixed (externally determined) parameters used in model computations. In all scenarios, the stage-transition matrix is

$$
\boldsymbol{G}=\left[\begin{array}{ccc}
0.2 & 0.7 & 0.1  \tag{13}\\
0 & 0.4 & 0.6 \\
0 & 0 & 1
\end{array}\right]
$$

which is the combination of the growth matrix and molting probabilities.
Estimated parameters are listed in Table 27 and include an estimated natural mortality deviation parameter in 1998/99 ( $\delta_{1998}^{M}$ ) assuming an anomalous mortality event in that year, as hypothesized by Zheng and Kruse (2002), with natural mortality otherwise fixed at $0.18 \mathrm{yr}^{-1}$.

## 5. Model Objective Function and Weighting Scheme

The objective function consists of the sum of several "negative log-likelihood" terms characterizing the hypothesized error structure of the principal data inputs (Table 18). A lognormal distribution is assumed to characterize the catch data and is modelled as

$$
\begin{align*}
\sigma_{t, y}^{\mathrm{catch}} & =\sqrt{\log \left(1+\left(C V_{t, y}^{\mathrm{catch}}\right)^{2}\right)}  \tag{14}\\
\delta_{t, y}^{\mathrm{catch}} & =\mathcal{N}\left(0,\left(\sigma_{t, y}^{\mathrm{catch}}\right)^{2}\right) \tag{15}
\end{align*}
$$

where $\delta_{t, y}^{c a t c h}$ is the residual catch. The relative abudance data is also assumed to be lognormally distributed

$$
\begin{align*}
\sigma_{t, y}^{\mathrm{I}} & =\frac{1}{\lambda} \sqrt{\log \left(1+\left(C V_{t, y}^{\mathrm{I}}\right)^{2}\right)}  \tag{16}\\
\delta_{t, y}^{\mathrm{I}} & =\log \left(I^{\mathrm{obs}} / I^{\mathrm{pred}}\right) / \sigma_{t, y}^{\mathrm{I}}+0.5 \sigma_{t, y}^{\mathrm{I}} \tag{17}
\end{align*}
$$

and the likelihood is

$$
\begin{equation*}
\sum \log \left(\delta_{t, y}^{\mathrm{I}}\right)+\sum 0.5\left(\sigma_{t, y}^{\mathrm{I}}\right)^{2} \tag{18}
\end{equation*}
$$

Gmacs calculates standard deviation of the normalised residual (SDNR) values and median of the absolute residual (MAR) values for all abundance indices and size compositions to help the user come up with resonable likelihood weights. For an abundance data set to be well fitted, the SDNR should not be much greater than 1 (a value much less than 1, which means that the data set is fitted better than was expected, is not a cause for concern). What is meant by "much greater than 1 " depends on $m$ (the number of years in the data set). Francis (2011) suggests upper limits of $1.54,1.37$, and 1.26 for $m=5,10$, and 20 , respectively. Although an SDNR not much greater than 1 is a necessary condition for a good fit, it is not sufficient. It is important to plot the observed and expected abundances to ensure that the fit is good.

Gmacs also calculates Francis weights for each of the size composition data sets supplied (Francis 2011). If the user wishes to use the Francis iterative re-weighting method, first the weights applied to the abundance indices should be adjusted by trial and error until the SDNR (and/or MAR) are adequte. Then the Francis weights supplied by Gmacs should be used as the new likelihood weights for each of the size composition data sets the next time the model is run. The user can then iteratively adjust the abudance index and size composition weights until adequate SDNR (and/or MAR) values are achieved, given the Francis weights.

## 6. Estimation

The model was implemented using the software AD Model Builder (Fournier et al. 2012), with parameter estimation by minimization of the model objective function using automatic differentiation. Parameter estimates and standard deviations provided in this document are AD Model Builder reported values assuming maximum likelihood theory asymptotics.

Table 24: Proportion of the natural mortality $\left(\tau_{t}\right)$ that is applied during each season $(t)$ in the model.

| Year | Season 1 | Season 2 | Season 3 | Season 4 | Season 5 |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1978 | 0.00 | 0.07 | 0.00 | 0.56 | 0.37 |
| 1979 | 0.00 | 0.06 | 0.00 | 0.57 | 0.37 |
| 1980 | 0.00 | 0.07 | 0.00 | 0.56 | 0.37 |
| 1981 | 0.00 | 0.05 | 0.00 | 0.58 | 0.37 |
| 1982 | 0.00 | 0.07 | 0.00 | 0.56 | 0.37 |
| 1983 | 0.00 | 0.12 | 0.00 | 0.51 | 0.37 |
| 1984 | 0.00 | 0.10 | 0.00 | 0.53 | 0.37 |
| 1985 | 0.00 | 0.14 | 0.00 | 0.49 | 0.37 |
| 1986 | 0.00 | 0.14 | 0.00 | 0.49 | 0.37 |
| 1987 | 0.00 | 0.14 | 0.00 | 0.49 | 0.37 |
| 1988 | 0.00 | 0.14 | 0.00 | 0.49 | 0.37 |
| 1989 | 0.00 | 0.14 | 0.00 | 0.49 | 0.37 |
| 1990 | 0.00 | 0.14 | 0.00 | 0.49 | 0.37 |
| 1991 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 1992 | 0.00 | 0.14 | 0.00 | 0.49 | 0.37 |
| 1993 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 1994 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 1995 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 1996 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 1997 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 1998 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 1999 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 2000 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 2001 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 2002 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 2003 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 2004 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 2005 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 2006 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 2007 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 2008 | 0.00 | 0.18 | 0.00 | 0.45 | 0.37 |
| 2009 | 0.00 | 0.44 | 0.00 | 0.19 | 0.37 |
| 2010 | 0.00 | 0.44 | 0.00 | 0.19 | 0.37 |
| 2011 | 0.00 | 0.44 | 0.00 | 0.19 | 0.37 |
| 2012 | 0.00 | 0.44 | 0.00 | 0.19 | 0.37 |
| 2013 | 0.00 | 0.44 | 0.00 | 0.19 | 0.37 |
| 2014 | 0.00 | 0.44 | 0.00 | 0.19 | 0.37 |
| 2015 | 0.00 | 0.44 | 0.00 | 0.19 | 0.37 |
| 2016 | 0.00 | 0.44 | 0.00 | 0.19 | 0.37 |
| 2017 | 0.00 | 0.44 | 0.00 | 0.19 | 0.37 |

Table 25: Data inputs used in model estimation.

| Data | Years | Source |
| :--- | :--- | :--- |
| Directed pot-fishery retained-catch number <br> (not biomass) | $1978 / 79-1998 / 99$ <br> $2009 / 10-2015 / 16$ | Fish tickets <br> (fishery closed 1999/00-2008/09 and 2016/17) |
| Groundfish trawl bycatch biomass | $1992 / 93-2016 / 17$ | NMFS groundfish observer program |
| Groundfish fixed-gear bycatch biomass | $1992 / 93-2016 / 17$ | NMFS groundfish observer program |
| NMFS trawl-survey biomass index <br> (area-swept estimate) and CV | $1978-2017$ | NMFS EBS trawl survey |
| ADF\&G pot-survey abundance index <br> (CPUE) and CV | ADF\&G SMBKC pot survey |  |
| NMFS trawl-survey stage proportions <br> and total number of measured crab | $1995-2017$ | NMFS EBS trawl survey |
| ADF\&G pot-survey stage proportions <br> and total number of measured crab | $1995-2017$ | ADF\&G SMBKC pot survey |
| Directed pot-fishery stage proportions <br> and total number of measured crab | $1990 / 91-1998 / 99$ | ADF\&G crab observer program |

Table 26: Fixed model parameters for all scenarios.

| Parameter | Symbol | Value | Source/rationale |
| :---: | :---: | :---: | :---: |
| Trawl-survey catchability | $q$ | 1.0 | Default |
| Natural mortality | $M$ | $0.18 \mathrm{yr}^{-1}$ | NPFMC (2007) |
| Size transition matrix | G | Equation 13 | Otto and Cummiskey (1990) |
| Stage-1 and stage-2 mean weights | $w_{1}, w_{2}$ | $0.7,1.2 \mathrm{~kg}$ | Length-weight equation (B. Foy, NMFS) applied to stage midpoints |
| Stage-3 mean weight | $w_{3, y}$ | Depends on year Table 10 | Fishery reported average retained weight from fish tickets, or its average, and mean weights of legal males |
| Recruitment SD | $\sigma_{R}$ | 1.2 | High value |
| Natural mortality SD | $\sigma_{M}$ | 10.0 | High value (basically free parameter) |
| Directed fishery <br> handling mortality |  | 0.2 | 2010 Crab SAFE |
| Groundfish trawl handling mortality |  | 0.8 | 2010 Crab SAFE |
| Groundfish fixed-gear handling mortality |  | 0.5 | 2010 Crab SAFE |

Table 27: The lower bound (LB), upper bound (UB), initial value, prior, and estimation phase for each estimated model parameter.

| Parameter | LB | Initial value | UB | Prior | Phase |
| :--- | ---: | ---: | ---: | :--- | ---: |
| Average recruitment $\log (R)$ | -7 | 10.0 | 20 | Uniform $(-7,20)$ | 1 |
| Stage-1 initial numbers $\log \left(n_{1}^{0}\right)$ | 5 | 14.5 | 20 | Uniform $(5,20)$ | 1 |
| Stage-2 initial numbers $\log \left(n_{2}^{0}\right)$ | 5 | 14.0 | 20 | Uniform $(5,20)$ | 1 |
| Stage-3 initial numbers $\log \left(n_{3}^{0}\right)$ | 5 | 13.5 | 20 | Uniform $(5,20)$ | 1 |
| ADF\&G pot survey catchability $q$ | 0 | 4.0 | 5 | Uniform $(0,5)$ | 1 |
| Stage-1 directed fishery selectivity 1978-2008 | 0 | 0.4 | 1 | Uniform $(0,1)$ | 3 |
| Stage-2 directed fishery selectivity 1978-2008 | 0 | 0.7 | 1 | Uniform $(0,1)$ | 3 |
| Stage-1 directed fishery selectivity 2009-2017 | 0 | 0.4 | 1 | Uniform $(0,1)$ | 3 |
| Stage-2 directed fishery selectivity 2009-2017 | 0 | 0.7 | 1 | Uniform $(0,1)$ | 3 |
| Stage-1 NMFS trawl survey selectivity | 0 | 0.4 | 1 | Uniform $(0,1)$ | 4 |
| Stage-2 NMFS trawl survey selectivity | 0 | 0.7 | 1 | Uniform $(0,1)$ | 4 |
| Stage-1 ADF\&G pot survey selectivity | 0 | 0.4 | 1 | Uniform $(0,1)$ | 4 |
| Stage-2 ADF\&G pot survey selectivity | 0 | 0.7 | 1 | Uniform $(0,1)$ | 4 |
| Natural mortality deviation during 1998 $\delta_{1998}^{M}$ | -3 | 0.0 | 3 | Normal $\left(0, \sigma_{M}^{2}\right)$ | 4 |
| Recruitment deviations $\delta_{y}^{R}$ | -7 | 0.0 | 7 | Normal $\left(0, \sigma_{R}^{2}\right)$ | 3 |
| Average directed fishery fishing mortality $\bar{F}^{\text {df }}$ | - | 0.2 | - | - | 1 |
| Average trawl bycatch fishing mortality $\bar{F}^{\text {tb }}$ | - | 0.001 | - | - | 1 |
| Average fixed gear bycatch fishing mortality $\bar{F}^{\mathrm{fb}}$ | - | 0.001 | - | - | 1 |

# Appendix B: SMBKC Stock Assessment Input Files 

## The data file used for the reference model (16.0) control file:

| \# Gmacs Main <br> \# GEAR_INDEX | Data File V DESCRIPTION | on 1.1: SM17 |
| :---: | :---: | :---: |
| \# 1 | : Pot fishery | ined catch. |
| \# 1 | : Pot fishery | discarded ca |
| \# 2 | : Trawl bycat |  |
| \# 3 | : Fixed bycat |  |
| \# 4 | : Trawl survey |  |
| \# 5 | : Pot survey |  |
| \# Fisheries: 1 Pot Fishery, 2 Pot Discard, 3 Trawl by-catch, 3 Fixed by-catch \# Surveys: 4 NMFS Trawl Survey, 5 Pot Survey |  |  |
| 1978 \# Start year |  |  |
| 2017 \# End year |  |  |
| 2018 \# Projection year |  |  |
| 5 \# Number of seasons |  |  |
| 5 \# Numb | of distinct | groups (among |
| 1 \# Numb | of sexes |  |
| 1 \# Numb | of shell cond | n types |
| 1 \# Numb | of maturity |  |
| 3 \# Numb | of size-class | n the model |
| 5 \# Seas | recruitment |  |
| 5 \# Seas | molting and g | h occurs |
| 4 \# Seas | to calculate |  |
| 1 \# Seas | for N output |  |
| \# size_breaks (a vector giving the break points between size intervals with dimension nclass +1 ) |  |  |
| $\begin{array}{lllll}90 & 105 & 120 & 135\end{array}$ |  |  |
| \# weight-at-length input method (1 = allometry i.e. w_l = a*l^b, $2=$ vector by sex, 3 = matrix by sex) |  |  |
| \# weight-at- | ngth allometry | $=a * l^{\sim} \mathrm{b}$ |
| 4.03E-07 |  |  |
| \# b (male, female) |  |  |
| 3.141334 |  |  |
| \# Male weight-at-length |  |  |
| 0.000748427 | 0.001165731 | 0.001930510 |
| 0.000748427 | 0.001165731 | 0.001688886 |
| 0.000748427 | 0.001165731 | 0.001922246 |
| 0.000748427 | 0.001165731 | 0.001877957 |
| 0.000748427 | 0.001165731 | 0.001938634 |
| 0.000748427 | 0.001165731 | 0.002076413 |
| 0.000748427 | 0.001165731 | 0.001899330 |
| 0.000748427 | 0.001165731 | 0.002116687 |
| 0.000748427 | 0.001165731 | 0.001938784 |
| 0.000748427 | 0.001165731 | 0.001939764 |
| 0.000748427 | 0.001165731 | 0.001871067 |
| 0.000748427 | 0.001165731 | 0.001998295 |
| 0.000748427 | 0.001165731 | 0.001870418 |
| 0.000748427 | 0.001165731 | 0.001969415 |



| 0.0000 | 0.4400 | 0.0000 | 0.1900 | 0.3700 |
| :--- | :--- | :--- | :--- | :--- |
| 0.0000 | 0.4400 | 0.0000 | 0.1900 | 0.3700 |
| 0.0000 | 0.4400 | 0.0000 | 0.1900 | 0.3700 |
| 0.0000 | 0.4400 | 0.0000 | 0.1900 | 0.3700 |
| 0.0000 | 0.4400 | 0.0000 | 0.1900 | 0.3700 |
| 0.0000 | 0.4400 | 0.0000 | 0.1900 | 0.3700 |
| 0.0000 | 0.4400 | 0.0000 | 0.1900 | 0.3700 |
| 0.0000 | 0.4400 | 0.0000 | 0.1900 | 0.3700 |
| 0.0000 | 0.4400 | 0.0000 | 0.1900 | 0.3700 |

\# Fishing fleet names (delimited with : no spaces in names)
Pot_Fishery:Trawl_Bycatch:Fixed_bycatch
\# Survey names (delimited with : no spaces in names)
NMFS_Trawl:ADFG_Pot
\# Number of catch data frames
4
\# Number of rows in each data frame
$\begin{array}{llll}28 & 16 & 26 & 26\end{array}$
\#\# CATCH DATA
\#\# Type of catch: 1 = retained, 2 = discard
\#\# Units of catch: 1 = biomass, 2 = numbers
\#\# for SMBKC Units are in number of crab for landed \& 1000 kg for discards.
\#\# Male Retained

| \# year | seas | fleet | sex | obs | cv | type | units | mult |  | effort | discard_mortality |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1978 | 2 | 1 | 1 | 436126 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1979 | 2 | 1 | 1 | 52966 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1980 | 2 | 1 | 1 | 33162 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1981 | 2 | 1 | 1 | 1045619 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1982 | 2 | 1 | 1 | 1935886 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1983 | 2 | 1 | 1 | 1931990 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1984 | 2 | 1 | 1 | 841017 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1985 | 2 | 1 | 1 | 436021 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1986 | 2 | 1 | 1 | 219548 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1987 | 2 | 1 | 1 | 227447 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1988 | 2 | 1 | 1 | 280401 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1989 | 2 | 1 | 1 | 247641 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1990 | 2 | 1 | 1 | 391405 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1991 | 2 | 1 | 1 | 726519 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1992 | 2 | 1 | 1 | 545222 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1993 | 2 | 1 | 1 | 630353 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1994 | 2 | 1 | 1 | 827015 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1995 | 2 | 1 | 1 | 666905 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1996 | 2 | 1 | 1 | 660665 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1997 | 2 | 1 | 1 | 939822 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 1998 | 2 | 1 | 1 | 635370 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 2009 | 2 | 1 | 1 | 103376 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 2010 | 2 | 1 | 1 | 298669 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 2011 | 2 | 1 | 1 | 437862 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 2012 | 2 | 1 | 1 | 379386 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 2014 | 2 | 1 | 1 | 69109 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 2015 | 2 | 1 | 1 | 24407 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| 2016 | 2 | 1 | 1 | 24.407 | 0.03 | 1 | 2 | 1 |  | 0 | 0 |
| \# Male | disca | Pot | fishery |  |  |  |  |  |  |  |  |
| 1990 | 2 | 1 | 1 | 254.9787861 |  | 0.6 | 2 | 1 | 1 | 0 | 0.2 |
| 1991 | 2 | 1 | 1 | 531.4483252 |  | 0.6 | 2 | 1 | 1 | 0 | 0.2 |
| 1992 | 2 | 1 | 1 | 1050.387026 |  | 0.6 | 2 | 1 | 1 | 0 | 0.2 |
| 1993 | 2 | 1 | 1 | 951.4626128 |  | 0.6 | 2 | 1 | 1 | 0 | 0.2 |
| 1994 | 2 | 1 | 1 | 1210.764588 |  | 0.6 | 2 | 1 | 1 | 0 | 0.2 |
| 1995 | 2 | 1 | 1 | 363.112032 |  | 0.6 | 2 | 1 | 1 | 0 | 0.2 |
| 1996 | 2 | 1 | 1 | 528.5244687 |  | 0.6 | 2 | 1 | 1 | 0 | 0.2 |
| 1997 | 2 | 1 | 1 | 1382.825328 |  | 0.6 | 2 | 1 | 1 | 0 | 0.2 |
| 1998 | 2 | 1 | 1 | 781.1032977 |  | 0.6 | 2 | 1 | 1 | 0 | 0.2 |
| 2009 | 2 | 1 | 1 | 123.3712279 |  | 0.2 | 2 | 1 | 1 | 0 | 0.2 |
| 2010 | 2 | 1 | 1 | 304.6562225 |  | 0.2 | 2 | 1 | 1 | 0 | 0.2 |
| 2011 | 2 | 1 | 1 | 481.3572126 |  | 0.2 | 2 | 1 | 1 | 0 | 0.2 |
| 2012 | 2 | 1 | 1 | 437.3360731 |  | 0.2 | 2 | 1 | 1 | 0 | 0.2 |


| 2014 | 2 | 1 | 1 | 45.483974 |  | 0.2 | 2 | 1 | 1 | 0 | 0.2 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2015 | 2 | 1 | 1 | 21.193785 |  | 0.2 | 2 | 1 | 1 | 0 | 0.2 |
| 2016 | 2 | 1 | 1 | 0.0211937 |  | 0.2 | 2 | 1 | 1 | 0 | 0.2 |
| \# Tra | f | di |  |  |  |  |  |  |  |  |  |
| 1991 | 2 | 2 | 1 | 3.538 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 1992 | 2 | 2 | 1 | 1.996 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 1993 | 2 | 2 | 1 | 1.542 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 1994 | 2 | 2 | 1 | 0.318 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 1995 | 2 | 2 | 1 | 0.635 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 1996 | 2 | 2 | 1 | 0.500 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 1997 | 2 | 2 | 1 | 0.500 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 1998 | 2 | 2 | 1 | 0.500 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 1999 | 2 | 2 | 1 | 0.500 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2000 | 2 | 2 | 1 | 0.500 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2001 | 2 | 2 | 1 | 0.500 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2002 | 2 | 2 | 1 | 0.726 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2003 | 2 | 2 | 1 | 0.998 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2004 | 2 | 2 | 1 | 0.091 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2005 | 2 | 2 | 1 | 0.500 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2006 | 2 | 2 | 1 | 2.812 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2007 | 2 | 2 | 1 | 0.045 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2008 | 2 | 2 | 1 | 0.272 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2009 | 2 | 2 | 1 | 0.635 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2010 | 2 | 2 | 1 | 0.363 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2011 | 2 | 2 | 1 | 0.181 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2012 | 2 | 2 | 1 | 0.100 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2013 | 2 | 2 | 1 | 0.400 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2014 | 2 | 2 | 1 | 0.100 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2015 | 2 | 2 | 1 | 0.100 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| 2016 | 2 | 2 | 1 | 0.500 | 0.31 | 2 | 1 | 1 | 0 | 0.8 |  |
| \# Fix |  | di |  |  |  |  |  |  |  |  |  |
| 1991 | 2 | 3 | 1 | 0.045 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 1992 | 2 | 3 | 1 | 2.268 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 1993 | 2 | 3 | 1 | 0.500 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 1994 | 2 | 3 | 1 | 0.091 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 1995 | 2 | 3 | 1 | 0.136 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 1996 | 2 | 3 | 1 | 0.045 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 1997 | 2 | 3 | 1 | 0.181 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 1998 | 2 | 3 | 1 | 0.907 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 1999 | 2 | 3 | 1 | 1.361 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2000 | 2 | 3 | 1 | 0.500 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2001 | 2 | 3 | 1 | 0.862 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2002 | 2 | 3 | 1 | 0.408 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2003 | 2 | 3 | 1 | 1.134 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2004 | 2 | 3 | 1 | 0.635 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2005 | 2 | 3 | 1 | 0.590 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2006 | 2 | 3 | 1 | 1.451 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2007 | 2 | 3 | 1 | 69.717 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2008 | 2 | 3 | 1 | 6.622 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2009 | 2 | 3 | 1 | 7.530 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2010 | 2 | 3 | 1 | 9.571 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2011 | 2 | 3 | 1 | 1.800 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2012 | 2 | 3 | 1 | 1.600 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2013 | 2 | 3 | 1 | 0.8 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2014 | 2 | 3 | 1 | 1.1 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2015 | 2 | 3 | 1 | 1.600 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| 2016 | 2 | 3 | 1 | 3.600 | 0.31 | 2 | 1 | 1 | 0 | 0.5 |  |
| \#\# RELATIVE ABUNDANCE DATA |  |  |  |  |  |  |  |  |  |  |  |
| \#\# Units of abundance: 1 = biomass, 2 = numbers <br> \#\# for SMBKC Units are in crabs for Abundance. <br> \#\# Number of relative abundance indicies |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| 2 |  |  |  |  |  |  |  |  |  |  |  |
| \#\# Number of rows in each index$40 \quad 9$ |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |
| \# Survey data (abundance indices, units are mt for trawl survey and crab/potlift for pot survey) |  |  |  |  |  |  |  |  |  |  |  |

```
# Year, Seas, Fleet, Sex, Abundance, CV units
1978 14 1 6832.819 0.394 1
1979 14417989.881 0.463 1
1980 1 4 1 9986.830 0.507 1
1981 14 4 6551.132 0.402 1
1982 144116221.933 0.344 1
1983 14 1 9634.250 0.298 1
1984 14414071.218 0.179 1
1985 1 4 1 3110.541 0.210 1
1986 14411416.849 0.388 1
1987 14 4 2278.917 0.291 1
1988 1 4 1 3158.169 0.252 1
1989 14416338.622 0.271 1
1990 14 1 6730.130 0.274 1
1991 14 1 6948.184 0.248 1
1992 14 1 7093.272 0.201 1
1993 14 1 9548.459 0.169 1
1994 14416539.133 0.176 1
1995 1 4 1 5703.591 0.178 1
1996 1 4 1 9410.403 0.241 1
1997 14 1 10924.107 0.337 1
1998 1 4 1 7976.839 0.355 1
1999 14 4 1594.546 0.182 1
2000 1 4 1 2096.795 0.310 1
2001 14 1 2831.440 0.245 1
2002 1 4 1 1732.599 0.320 1
2003 14 1 1566.675 0.336 1
2004 14411523.869 0.305 1
2005 1 4 1 1642.017 0.371 1
2006 14 1 3893.875 0.334 1
2007 14 1 6470.773 0.385 1
2008 1 4 1 4654.473 0.284 1
2009 14 1 6301.470 0.256 1
2010 1 4 1 11130.898 0.466 1
2011 1 4 1 10931.232 0.558 1
2012 1 4 1 6200.219 0.339 1
2013 14412287.557 0.217 1
2014 14 1 6029.220 0.449 1
2015 1 4 1 5877.433 0.770 1
2016 1 4 1 3485.909 0.393 1
2017 1 4 1 1793.760 0.599 1
1995 1 5 1 12042.000 0.130 2
1998 1 5 1 12531.000 0.060 2
2001 1 5 1 8477.000 0.080 2
2004 1 5 1 1667.000 0.150 2
2007 1 5 1 8643.000 0.090 2
2010 1 5 1 10209.000 0.130 2
2013 1 5 1 5643.000 0.190 2
2015 1 5 1 2805.000 0.180 2
2016 1 5 1 2378.000 0.186 2
## Number of length frequency matrices
3
## Number of rows in each matrix
15 40 9
## Number of bins in each matrix (columns of size data)
3 3 3
## SIZE COMPOSITION DATA FOR ALL FLEETS
## SIZE COMP LEGEND
## Sex: 1 = male, 2 = female, 0 = both sexes combined
## Type of composition: 1 = retained, 2 = discard, 0 = total composition
## Maturity state: 1 = immature, 2 = mature, 0 = both states combined
## Shell condition: 1 = new shell, 2 = old shell, 0 = both shell types combined
##length proportions of pot discarded males
##Year, Seas, Fleet, Sex, Type, Shell, Maturity, Nsamp, DataVec
    1990 2 1 1 0 0 0 15 0.1133 0.3933 0.4933
```



```
    2015 1 5 1 0 0 0 100 0.0706 0.2431 0.6859
    2016 1 5 1 0 0 0 100 0.0832 0.1917 0.7251
## Growth data (increment)
# nobs_growth
3
# MidPoint Sex Increment CV
97.5 1 14.1 0.2197
112.5
127.5 1 14.1 0.2197
# 97.5 1 13.8 0.2197
# 112.5 1 14.1 0.2197
# 127.5 1 14.4 0.2197
# Use custom transition matrix ( 0=no, 1=growth matrix, 2=transition matrix, i.e. growth and molting)
O
# The custom growth matrix (if not using just fill with zeros)
# Alternative TM (loosely) based on Otto and Cummiskey (1990)
0.2 0.7 0.1
0.0}00.4\quad0.
0.0 0.0 1.0
# Use custom natural mortality ( }0=n0,1=yes, by sex and year
0
0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.1,
## eof
9999
```

The reference model (16.0) control file:




```
## 3 = Blocked changes (deviates constrained by variance at specific knots)
## 4 = Time blocks
## ------------------------------------------------------------------------------------------------------
## Sex-specific? (0=no, 1=yes)
0
## Type
3
## Phase of estimation
4
## STDEV in m_dev for Random walk
10.0
## Number of nodes for cubic spline or number of step-changes for option 3
2
O # Females (ignored if single sex...)
## Year position of the knots (vector must be equal to the number of nodes)
19981999
# 1976 1980 1985 1994 # Females (ignored if single sex...)
```



```
## ------------------------------------------------------------------------------------------------------
## OTHER CONTROLS
## ---------------------------------------------------------------------------------------------------
    # Estimated rec_dev phase
    # # Estimated rec_ini phase
    # # VERBOSE FLAG (0 = off, 1 = on, 2 = objective func)
    2 # Initial conditions (0 = Unfished, 1 = Steady-state fished, 2 = Free parameters)
    1978 # First year for average recruitment for Bspr calculation
    2016 # Last year for average recruitment for Bspr calculation
    0.35 # Target SPR ratio for Bmsy proxy
    1 # Gear index for SPR calculations (i.e. directed fishery)
    1 # Lambda (proportion of mature male biomass for SPR reference points)
    # Use empirical molt increment data (0 = FALSE, 1 = TRUE)
    0 # Stock-Recruit-Relationship (0 = None, 1 = Beverton-Holt)
## EOF
9999
```


# Appendix C. Test of VAST spatio-temporal analysis of SMBKC from NMFS bottom-trawl survey data 

## Overview

This is an example application of VAST for estimating single-species abundance indices specifically applied to a subset of NMFS/AFSC bottom trawl survey data. Further details can be found at the GitHub repo mainpage, wiki, and glossary. The R help files, e.g., ?Data_Fn for explanation of data inputs, or ?Param_Fn for explanation of parameters. VAST has involved many publications for developing individual features (see references section below).
The following loads in the main libraries.

```
library(TMB)
library(VAST)
Version <- "VAST_v2_0_0"
```


## Spatial settings and model configuration

The following settings define the spatial resolution for the model, and whether to use a grid or mesh approximation as well as specific model settings.

```
Method <- "Mesh"
grid_size_km <- 25
n_x <- 50 # Number of stations
Kmeans_Config <- list(randomseed = 1, nstart = 100,
    iter.max = 1000)
FieldConfig <- c(Omega1 = 1, Epsilon1 = 1, Omega2 = 1,
    Epsilon2 = 1)
RhoConfig <- c(Beta1 = 0, Beta2 = 0, Epsilon1 = 0,
    Epsilon2 = 0)
OverdispersionConfig <- c(Vessel = 0, VesselYear = 0)
ObsModel <- c(2, 0)
Options <- c(SD_site_density = 0, SD_site_logdensity = 0,
    Calculate_Range = 1, Calculate_evenness = 0, Calculate_effective_area = 1,
    Calculate_Cov_SE = 0, Calculate_Synchrony = 0,
    Calculate_Coherence = 0)
strata.limits <- data.frame(STRATA = "All_areas")
VesselConfig <- c(Vessel = 0, VesselYear = 1)
```


## Data preparation

## Data-frame for catch-rate data

The following extracts a subset of the data file downloaded from AKFIN.

```
# Read in header names
m.df <- data.frame(read.csv("male_ge90.csv", header = T,
    as.is = T))
hnames <- read.csv("hdr.csv", header = T)
names(m.df) <- names(hnames)
# Get into format for VASt
p.df <- transmute(m.df, yr = as.numeric(SURVEY_YEAR),
    loc = STRATUM_NAME, lat = as.numeric(MID_LATITUDE),
    long = as.numeric(MID_LONGITUDE), CrabN = as.numeric(CRAB_NUM),
    cpueN = as.numeric(CRAB_CPUENUM), cpueKG = as.numeric(CRAB_CPUEWGT_MT)/1000)
Data_Geostat <- p.df %>% mutate(Catch_KG = cpueKG,
    Year = yr, Vessel = "missing", AreaSwept_km2 = 1,
    Lat = lat, Lon = long, Pass = 0)
# Create a coverage of this specific are (St.
# Matthews Island)
posLL <- p.df %>% select(Lat = lat, Lon = long)
# Apply to create the extrapolation grid
Extrapolation_List <- SpatialDeltaGLMM::Prepare_Extrapolation_Data_Fn(Region = "Other",
    observations_LL = posLL, strata.limits = strata.limits)
## Derived objects for spatio-temporal estimation
Spatial_List <- SpatialDeltaGLMM::Spatial_Information_Fn(grid_size_km = grid_size_km,
    n_x = n_x, Method = Method, Lon = Data_Geostat[,
            "Lon"], Lat = Data_Geostat[, "Lat"], Extrapolation_List = Extrapolation_List,
    randomseed = Kmeans_Config[["randomseed"]], nstart = Kmeans_Config[["nstart"]],
    iter.max = Kmeans_Config[["iter.max"]], DirPath = DateFile,
    Save_Results = FALSE)
# Add knots to Data_Geostat
Data_Geostat <- cbind(Data_Geostat, knot_i = Spatial_List$knot_i)
```


## Build and run model

To estimate parameters, first create a list of data-inputs used for parameter estimation. Data_Fn has some simple checks for buggy inputs, but also please read the help file ?Data_Fn.
library (VAST)
TmbData <- Data_Fn(Version = Version, FieldConfig = FieldConfig,
OverdispersionConfig = OverdispersionConfig, RhoConfig = RhoConfig,
ObsModel = ObsModel, c_i = rep(0, nrow(Data_Geostat)),
b_i = Data_Geostat[, "Catch_KG"], a_i = Data_Geostat[,
"AreaSwept_km2"], v_i = as.numeric(Data_Geostat[,
"Vessel"]) - 1, s_i = Data_Geostat[, "knot_i"] -
1, t_i = Data_Geostat[, "Year"], a_xl = Spatial_List\$a_xl,
MeshList = Spatial_List\$MeshList, GridList = Spatial_List\$GridList,

```
    Method = Spatial_List$Method, Options = Options)
# We then build the TMB object.
TmbList <- Build_TMB_Fn(TmbData = TmbData, RunDir = DateFile,
    Version = Version, RhoConfig = RhoConfig, loc_x = Spatial_List$loc_x,
    Method = Method)
Obj <- TmbList[["Obj"]]
## Estimate fixed effects and predict random effects
## Next, we use a gradient-based nonlinear minimizer
## to identify maximum likelihood estimates for
## fixed-effects
Opt <- TMBhelper::Optimize(obj = Obj, lower = TmbList[["Lower"]],
    upper = TmbList[["Upper"]], getsd = TRUE, savedir = DateFile,
    bias.correct = FALSE)
# Store output
Report <- Obj$report()
```


## Diagnostic plots

```
SpatialDeltaGLMM::Plot_data_and_knots(Extrapolation_List = Extrapolation_List,
    Spatial_List = Spatial_List, Data_Geostat = Data_Geostat,
    PlotDir = DateFile)
Region = "Other"
MapDetails_List <- SpatialDeltaGLMM::MapDetails_Fn(Region = Region,
    NN_Extrap = Spatial_List$PolygonList$NN_Extrap,
    Extrapolation_List = Extrapolation_List)
# Decide which years to plot
Year_Set <- seq(min(Data_Geostat[, "Year"]), max(Data_Geostat[,
    "Year"]))
Years2Include <- which(Year_Set %in% sort(unique(Data_Geostat[,
    "Year"])))
```


## Convergence

Diagnostics generated during parameter estimation can confirm that parameter estimates are away from upper or lower bounds and that the final gradient for each fixed-effect is close to zero. For explanation of parameters, please see references (and specifically ?Data_Fn in R).
[1] ""

## Encounter-probability component

One can check to ensure that observed encounter frequencies for either low or high probability samples are within the $95 \%$ predictive interval for predicted encounter probability (Figure . Diagnostics for positive-catchrate component was evaluated using a standard Q-Q plot. Qualitatively, the fits to SMBKC are reasonable but could stand some more evaluation for improvement as only one configuration was tested here (Figures and .

```
Enc_prob <- SpatialDeltaGLMM::Check_encounter_prob(Report = Report,
    Data_Geostat = Data_Geostat, DirName = DateFile)
```



Figure 1: Observed encounter rates and predicted probabilities for SMBKC.

```
Q <- SpatialDeltaGLMM::QQ_Fn(TmbData = TmbData, Report = Report,
    FileName_PP = paste0(DateFile, "Posterior_Predictive.jpg"),
    FileName_Phist = paste0(DateFile, "Posterior_Predictive-Histogram.jpg"),
    FileName_QQ = paste0(DateFile, "Q-Q_plot.jpg"),
    FileName_Qhist = paste0(DateFile, "Q-Q_hist.jpg"))
```


## Pearson residuals

Spatially the residual pattern can be evaluated over time. Results for SMBKC shows that consistent positive or negative residuals accross or within years is limited for the encounter probability component of the model and for the positive catch rate component (Figures 4 and 5 , respectively). Some VAST plots for visualizing results can be seen by examining the direction of faster or slower spatial decorrelation (termed "geometric anisotropy"; Figure 6).

```
SpatialDeltaGLMM:::plot_residuals(Lat_i = Data_Geostat[,
    "Lat"], Lon_i = Data_Geostat[, "Lon"], TmbData = TmbData,
    Report = Report, Q = Q, savedir = DateFile, MappingDetails = MapDetails_List[["MappingDetail
    PlotDF = MapDetails_List[["PlotDF"]], MapSizeRatio = MapDetails_List[["MapSizeRatio"]],
    Xlim = MapDetails_List[["Xlim"]], Ylim = MapDetails_List[["Ylim"]],
    FileName = DateFile, Year_Set = Year_Set, Years2Include = Years2Include,
    Rotate = MapDetails_List[["Rotate"]], Cex = MapDetails_List[["Cex"]],
    Legend = MapDetails_List[["Legend"]], zone = MapDetails_List[["Zone"]],
    mar = c(0, 0, 2, 0), oma = c(3.5, 3.5, 0, 0), cex = 1.8)
```

SpatialDeltaGLMM: :PlotAniso_Fn(FileName = paste0(DateFile,
"Aniso.png"), Report = Report, TmbData = TmbData)

## Quantile_histogram



Figure 2: Plot indicating distribution of quantiles for "positive catch rate" component.


Figure 3: Quantile-quantile plot of residuals for "positive catch rate" component.


Figure 4: Pearson residuals of the encounter probability component at SMBKC stations, 1976-2017.


Figure 5: Pearson residuals of the positive catch rate component for SMBKC stations, 1976-2017.

## Distance at 10\% correlation



Figure 6: Directional decorrelation for SMBKC stations, 1978-2017.

```
SpatialDeltaGLMM: :PlotResultsOnMap_Fn(plot_set = c(3),
    MappingDetails = MapDetails_List[["MappingDetails"]],
    Report = Report, Sdreport = Opt\$SD, PlotDF = MapDetails_List[["PlotDF"]],
    MapSizeRatio = MapDetails_List[["MapSizeRatio"]],
    Xlim = MapDetails_List[["X̄lim"]], Ylim = MapDetails_List[["Ylim"]],
    FileName = DateFile, Year Set = Year Set, Years2Include = Years2Include,
    Rotate = MapDetails_List[["Rotate"]], Cex = MapDetails_List[["Cex"]],
    Legend = MapDetails_List[["Legend"]], zone = MapDetails_List[["Zone"]],
    \(\operatorname{mar}=c(0,0,2,0), \quad\) ma \(=c(3.5,3.5,0,0), ~ c e x=1.8\),
    plot_legend_fig = FALSE)
```


## Densities and biomass estimates A heatmap of the relative densities over

time shows a consistent pattern in the relative biomass of males $>89 \mathrm{~mm}$ (Figure 7 ). For the application to SMBKC, the biomass index was scaled to have the same mean as that from the design-based estimate (5,763 t) of abundance is generally most useful for stock assessment models (Table 2).

## References

Please cite 2016 (ICES J. Mar. Sci. J. Cons.) if using the package; 2016 (Glob. Ecol. Biogeogr) if exploring factor decomposition of spatio-temporal variation; 2015 (ICES J. Mar. Sci. J. Cons.) if calculating an index of abundance; 2016 (Methods Ecol. Evol.) if using the center-of-gravity metric; 2016 (Fish. Res.) if using the bias-correction feature; 2016 (Proc R Soc B) if using the effective-area-occupied metric.

Thorson, J.T., and Barnett, L.A.K. In press. Comparing estimates of abundance trends and distribution shifts using single- and multispecies models of fishes and biogenic habitat. ICES J. Mar. Sci. J. Cons

Thorson, J.T., Ianelli, J.N., Larsen, E., Ries, L., Scheuerell, M.D., Szuwalski, C., and Zipkin, E. 2016. Joint dynamic species distribution models: a tool for community ordination and spatiotemporal monitoring. Glob. Ecol. Biogeogr. 25(9): 1144-1158. doi:10.1111/geb.12464. url: http://onlinelibrary.wiley.com/doi/10.1111/geb.12464/abstract

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Thorson, J.T., and Kristensen, K. 2016. Implementing a generic method for bias correction in statistical models using random effects, with spatial and population dynamics examples. Fish. Res. 175: 66-74. doi:10.1016/j.fishres.2015.11.016. url: http://www.sciencedirect.com/science/article/pii/S0165783615301399

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Thorson, J.T., Rindorf, A., Gao, J., Hanselman, D.H., and Winker, H. 2016. Density-dependent changes in effective area occupied for sea-bottom-associated marine fishes. Proc R Soc B 283(1840): 20161853. doi:10.1098/rspb.2016.1853. URL: http://rspb.royalsocietypublishing.org/content/283/1840/20161853.

To see these entries in BibTeX format, use 'print(, bibtex=TRUE)', 'toBibtex(.)', or set 'options(citation.bibtex. $\max =999$ ).


Figure 7: St. Matthews Island blue king crab (males $>89 \mathrm{~mm}$ ) density maps as predicted using the VAST model approach, 1976-2017.


Figure 8: St. Matthews Island blue king crab (males $>89 \mathrm{~mm}$ ) relative abundance as predicted using the VAST model approach.

Table 1: SMBKC parameter estimates, bounds, and final gradients as derived from the VAST modeling framework.


Table 2: SMBKC male $>89 \mathrm{~mm}$ biomass ( t ) estimates as derived from the VAST modeling framework.

| Year | Estimate | CV |
| ---: | ---: | ---: |
| 1977 | 3654.3 | 0.801 |
| 1978 | 9467.9 | 0.234 |
| 1979 | 10354.7 | 0.276 |
| 1980 | 10318.3 | 0.187 |
| 1981 | 9142.0 | 0.192 |
| 1982 | 21625.3 | 0.196 |
| 1983 | 9004.3 | 0.152 |
| 1984 | 4873.7 | 0.162 |
| 1985 | 3708.6 | 0.183 |
| 1986 | 1401.1 | 0.238 |
| 1987 | 2942.9 | 0.226 |
| 1988 | 3020.4 | 0.212 |
| 1989 | 6377.5 | 0.185 |
| 1990 | 7102.0 | 0.192 |
| 1991 | 7111.8 | 0.168 |
| 1992 | 7721.3 | 0.157 |
| 1993 | 10730.5 | 0.155 |
| 1994 | 7291.9 | 0.163 |
| 1995 | 6164.3 | 0.141 |
| 1996 | 9530.6 | 0.162 |
| 1997 | 9144.6 | 0.164 |
| 1998 | 6919.4 | 0.165 |
| 1999 | 2316.9 | 0.196 |
| 2000 | 2110.6 | 0.213 |
| 2001 | 3105.0 | 0.242 |
| 2002 | 1656.7 | 0.250 |
| 2003 | 1639.7 | 0.234 |
| 2004 | 1457.0 | 0.216 |
| 2005 | 1856.6 | 0.300 |
| 2006 | 3894.4 | 0.176 |
| 2007 | 5595.6 | 0.158 |
| 2008 | 4569.5 | 0.176 |
| 2009 | 6480.5 | 0.145 |
| 2010 | 7723.8 | 0.144 |
| 2011 | 7102.5 | 0.178 |
| 2012 | 5725.3 | 0.147 |
| 2013 | 2603.0 | 0.170 |
| 2014 | 4517.7 | 0.199 |
| 2015 | 2330.7 | 0.235 |
| 2016 | 2797.0 | 0.230 |
| 2017 | 1192.9 | 0.293 |
|  |  |  |

# Norton Sound Red King Crab Stock Assessment for the fishing year 2016 

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## Executive Summary

1. Stock. Red king crab, Paralithodes camtschaticus, in Norton Sound, Alaska.
2. Catches. This stock supports three main fisheries: summer commercial, winter commercial, and winter subsistence fisheries. Of those, the summer commercial fishery accounts for more than $90 \%$ of total harvest. The summer commercial fishery started in 1977, and catch peaked in the late 1970s with retained catch of over 2.9 million pounds. Since 1982, retained catches have been below 0.5 million pounds, averaging 0.275 million pounds, including several low years in the 1990s. Retained catches have increased to about 0.4 million pounds in recent years coincident with increases in estimated abundance.
3. Stock Biomass. Following a peak in 1977, abundance or the stock collapsed to a historic low in 1982. Estimated mature male biomass (MMB) has shown an increasing trend since 1997. However, uncertainty in historical biomass is high due in part to infrequent trawl surveys (every 3 to 5 years) and limited winter pot surveys.
4. Recruitment. Model estimated recruitment was weak during the late 1970s and high during the early 1980s, with a slight downward trend from 1983 to 1993. Estimated recruitment has been highly variable but on an increasing trend in recent years.
5. Management performance.

Status and catch specifications (million lb.)

| Year | MSST | Biomass <br> (MMB) | GHL | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2012 / 13$ | $1.76^{\mathrm{A}}$ | 4.59 | 0.47 | 0.47 | 0.47 | $0.53^{\mathrm{A}}$ | 0.48 |
| $2013 / 14$ | $2.06^{\mathrm{B}}$ | 5.00 | 0.50 | 0.35 | 0.35 | $0.58^{\mathrm{B}}$ | 0.52 |
| $2014 / 15$ | $2.11^{\mathrm{C}}$ | 3.71 | 0.38 | 0.39 | 0.39 | $0.46^{\mathrm{C}}$ | 0.42 |
| 2015 | $2.41^{\mathrm{D}}$ | 5.13 | 0.39 | 0.40 | 0.52 | $0.72^{\mathrm{D}}$ | 0.58 |
| 2016 | $2.26^{\mathrm{E}}$ | 5.87 | TBD | TBD | TBD | $0.71^{\mathrm{E}}$ | 0.57 |

Status and catch specifications (1000t)

| Year | MSST | Biomass <br> (MMB) | GHL | Retained <br> Catch | Total Catch | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2012 / 13$ | $0.80^{\mathrm{A}}$ | 1.93 | 0.21 | 0.21 | 0.21 | $0.24^{\mathrm{A}}$ | 0.22 |
| $2013 / 14$ | $0.93^{\mathrm{B}}$ | 2.27 | 0.23 | 0.16 | 0.16 | $0.26^{\mathrm{B}}$ | 0.24 |
| $2014 / 15$ | $0.96^{\mathrm{C}}$ | 1.68 | 0.17 | 0.18 | 0.18 | $0.21^{\mathrm{C}}$ | 0.19 |
| 2015 | $1.09^{\mathrm{D}}$ | 2.33 | 0.18 | 0.18 | 0.24 | $0.33^{\mathrm{D}}$ | 0.26 |
| 2016 | 1.03 | 2.66 | TBD | TBD | TBD | $0.32^{\mathrm{E}}$ | 0.26 |

Notes:
MSST was calculated as $\mathrm{B}_{\mathrm{MSY}} / 2$
A-Calculated from the assessment reviewed by the Crab Plan Team in May 2012
B-Calculated from the assessment reviewed by the Crab Plan Team in May 2013
C-Calculated from the assessment reviewed by the Crab Plan Team in May 2014
D-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2015
E-Calculated from the assessment reviewed by the Crab Plan Team in Jan 2016
Conversion to Metric ton: 1 Metric ton $=2.2046 \times 1000 \mathrm{lb}$

Biomass in millions of pounds

| Year | Tier | BMSY | Current <br> MMB | B/BMSY <br> (MMB) | FofL | Years to <br> define <br> $\mathbf{B}_{\text {MSY }}$ | M | 1-Buffer | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2012 / 13$ | 4 a | 3.51 | 4.59 | 1.2 | 0.18 | $1980-2012$ | 0.18 | 0.9 | 0.48 |
| $2013 / 14$ | 4 b | 4.12 | 5.00 | 1.2 | 0.18 | $1980-2013$ | 0.18 | 0.9 | 0.52 |
| $2014 / 15$ | 4 b | 4.19 | 3.71 | 0.9 | 0.16 | $1980-2014$ | 0.18 | 0.9 | 0.42 |
| 2015 | 4 a | 4.81 | 5.13 | 1.1 | 0.18 | $1980-2015$ | 0.18 | 0.8 | 0.58 |
| 2016 | 4 a | 4.53 | 5.87 | 1.3 | 0.18 | $1980-2016$ | 0.18 | 0.8 | 0.57 |

Biomass in 1000t

| Year | Tier | BMSY | Current <br> MMB | B/BMSY <br> $(\mathbf{M M B})$ | Fofl | Years to <br> define <br> BMSY | M | 1-Buffer | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2012 / 13$ | 4 a | 1.59 | 1.93 | 1.2 | 0.18 | $1980-2012$ | 0.18 | 0.9 | 0.22 |
| $2013 / 14$ | 4 a | 1.86 | 2.27 | 1.2 | 0.18 | $1980-2013$ | 0.18 | 0.9 | 0.24 |
| $2014 / 15$ | 4 b | 1.90 | 1.68 | 0.9 | 0.16 | $1980-2014$ | 0.18 | 0.9 | 0.19 |
| 2015 | 4 a | 2.18 | 2.33 | 1.1 | 0.18 | $1980-2015$ | 0.18 | 0.8 | 0.26 |
| 2016 | 4 a | 2.06 | 2.66 | 1.3 | 0.18 | $1980-2016$ | 0.18 | 0.8 | 0.26 |

6. Probability Density Function of the OFL, OFL profile, and mcmc estimates.

7. The basis for the ABC recommendation

For Tier 4 stocks, the default maximum ABC is based on $\mathrm{P}^{*}=49 \%$ that is essentially identical to the OFL. Accounting for uncertainties in assessment and model results, the SSC chose to use $90 \%$ OFL ( $10 \%$ Buffer) for the Norton Sound red king crab stock from 2011 to 2014. In 2015, the buffer was increased to $20 \%$ ( $\mathrm{ABC}=80 \% \mathrm{OFL}$ ).
8. A summary of the results of any rebuilding analyses.

N/A

## A. Summary of Major Changes in 2015

1. Changes to the management of the fishery:

None
2. Changes to the input data
a. Data update: 2015 summer commercial fishery (total catch, catch length comp, discards length comp), 2014/2015 winter commercial and subsistence catch
b. Data update: 1977-2015 standardized commercial catch CPUE and CV. No changes in standardization methodology (SAFE 2013).
3. Changes to the assessment methodology:

None
4. Changes to the assessment results.

None

## B. Response to SSC and CPT Comments

Crab Plan Team - Jan 162015

- Provide trawl survey documentation

Trawl survey report is published as ADFG report. The report is available at http://www.adfg.alaska.gov/FedAidPDFs/FDS15-40.pdf

- Provide an explanation and legend for figures comparing input sample sizes with effective sample.

Done

- Provide the documentation on the survey CPUE standardization as an Appendix

Included in the Appendix B.

- Fix trawl survey selectivity parameter to 1.0 (i.e., do not estimate)

Not conducted because selectivity was not always 1.0.

- Provide stock-specific maturity information for possible move to Tier 3.

Author's reply:
Assumed male size at (functional) maturity of the NSRKC (CL 94 mm ) was determined by adjusting that of Tier 3 BBRKC (CL 120mm) reflecting their slower growth and smaller size. However, male size at (functional) maturity of Tier 3 BBRKC is also assumed (Zheng et al. 2014). For BBRKC male size at maturity is 103 mm CL by chelae allometry (Somerton 1980), 50-59 mm CL by spermatophore presence (Paul et al. 1991). Functional size-at-functional maturity is likely greater than physiological or morphological maturity based on in situ grasping pair morphometry was estimated at 120 to 130 mm CL for Kodiak Island red king crab (Powell et al. 2002, Webb 2014).

- Include a discussion of the relative uncertainty in model parameters and data employed in the model as well as relative weightings in model configuration for use in best approximating the uncertainty in the OFL.

Author's reply:
Tagging data weighting issue has been discussed in SAFE 2015 and effects of input sample size for length composition have been discussed at modeling workshop in 2013
and 2014. We would gladly examine if there is a request for examining effects of specific data set.

SSC Feb 2-4 2015

- The SSC identified the fate of large males as the major uncertainty and hopes that this can be resolved through further research. The competing hypotheses of localized depletion, high natural mortality, or migration to a refuge from fishing have very different implications for OFL and ABC. Until this is resolved, the SSC felt that moving this stock to Tier 3 status would be problematic.

Author's reply:
The CPT (Sept 17 2015) commented that the fate of large males is not really a tier 3 question, although does need more investigation.

Regarding the SSC's hypotheses of localized depletion, high natural mortality, or migration to a refuge from fishing; we examined the available data and suggest the following:

Trawl survey did not show any pattern that higher number of larger crab being caught at edge of survey boundaries. Spring survey 2012-2015 also did not see higher proportion of large crabs along the coastal area. On the other hand, fall surveys in 2013-2014 consistently showed higher proportion ( $17 \%$ in 2013 , $23 \%$ in 2014) of the largest size class (> 123 mm CL) crab. Those larger crabs were absent in spring survey conducted 8 months later ( $5 \%$ in $2014,3.5 \%$ in 2015). Winter commercial catch length composition did not show high large crab proportion (11 \% in Jan-May 2015). These results do not seem to support the hypotheses of localized depletion or migration to a refuge from fishing.

Regarding the high natural mortality, see section 3.c: Model selection and evaluation search for balance.

- The SSC prefers that OFL and ABC be consistently presented in units of tons.

Author's reply:
We agree to SSC about using of tons as standard metric, international standard. Unfortunately, however, pounds is the customary unit of the US public. We prefer our report to be easily readable to the US public, including crab fishermen, by using the US customary units.

- Explore iterative data reweighting after guidance from the data weighting workshop.

Author's reply:
As of preparation of this report (Nov. 2015), no specific recommendations of exploring iterative re-weighting procedures have been provided by the time of NSRKC assessment. We look forward implementing the recommendations for January 2017 assessment.

- Maturity data on males is needed before moving NSRKC to tier 3.

Author's reply:
Assumed male size at (functional) maturity of the NSRKC (CL 94 mm ) was determined by adjusting that of Tire 3 BBRKC (CL 120mm) reflecting their slower growth and smaller size. However, male size at (functional) maturity of Tire 3 BBRKC is also assumed (Zheng et al. 2014). For BBRKC male size at maturity is CL 103 mm by chelae allometry (Somerton 1980), $50-59 \mathrm{~mm}$ CL by spermatophore presence (Paul et al. 1991). Estimated size at functional maturity is only available for one red king crab stock in Alaska (Webb 2014) in which the $5^{\text {th }}$ percentile of the size frequency distribution of males observed in grasping pairs near Kodiak Island was $\sim 120 \mathrm{~mm}$ CL (Powell et al. 2002).

## SSC Oct 5-7 2015

- The SSC supports the plan team's recommendations of exploring iterative re-weighting procedures after the Center for the Advancement of Population Assessment Methodology (CAPAM) data-weighting workshop in late October 2015.

Author's reply:
As of preparation of this report (Nov. 2015), no specific recommendations of exploring iterative re-weighting procedures have been provided by the time of NSRKC assessment. We look forward implementing the recommendations for January 2017 assessment.

- The SSC also recommends that the author follow the terms of reference and provide retrospective estimates of spawning stock biomass and the appropriate statistics (e.g., Mohns' rho).

Author's reply:
Mohns' rho (Mohn 1999) was calculated, as $\rho=\sum\left(B_{(1976 y), y+1}-B_{(19762015), y+1}\right) / B_{(1976 y), y+1}$,
only for the author preferred model. Mohns' rho has NO statistical range criteria of whether an assessment model is deemed acceptable/ unacceptable. We appreciate SSC providing a list of appropriate statistics to be reported for assessment model evaluations, and guidance how each statistics are weighed for selecting the best assessment model.

## C. Introduction

1. Species: red king crab (Paralithodes camtschaticus) in Norton Sound, Alaska.
2. General Distribution: Norton Sound red king crab is one of the northernmost red king crab populations that can support a commercial fishery (Powell et al. 1983). It is distributed throughout Norton Sound with a westward limit of $167-168^{\circ} \mathrm{W}$. longitude, depths less than 30 m , and summer bottom temperatures above $4^{\circ} \mathrm{C}$. The Norton Sound red king crab management area consists of two units: Norton Sound Section (Q3) and Kotzebue Section (Q4) (Menard et al. 2011). The Norton Sound Section (Q3) consists of all waters in Registration Area Q north of the latitude of Cape Romanzof, east of the International Dateline, and south of $66^{\circ} \mathrm{N}$ latitude (Figure 1). The Kotzebue Section (Q4) lies immediately north of the Norton Sound Section and includes Kotzebue Sound. Commercial fisheries have not occurred regularly in the Kotzebue Section. This report deals with the Norton Sound Section of the Norton Sound red king crab management area.
3. Evidence of stock structure: Thus far, no studies have been made on possible stock separation within the putative stock known as Norton Sound red king crab.
4. Life history characteristics relevant to management: One of the unique life-history traits of Norton Sound red king crab is that they spend their entire lives in shallow water since Norton Sound is generally less than 40 m in depth. Distribution and migration patterns of Norton Sound red king crab have not been well studied. Based on the 1976-2006 trawl surveys, red king crab in Norton Sound are found in areas with a mean depth range of $19 \pm 6$ (SD) m and bottom temperatures of $7.4 \pm 2.5(\mathrm{SD})^{\circ} \mathrm{C}$ during summer. Norton Sound red king crab are consistently abundant offshore of Nome.

Norton Sound red king crab migrate between deeper offshore and inshore shallow waters. . Timing of the inshore mating migration is unknown, but is assumed to be during late fall to winter (Powell et al. 1983). Offshore migration occurs in late May - July (Jennifer Bell, ADF\&G, personal communication). The results from a study funded by North Pacific Research Board (NPRB) during 2012-2014 suggest that older/large crab (> 104mm CL) stay offshore in winter, based on findings that large crab are not found nearshore during spring offshore migration periods (Jennifer Bell, ADF\&G, personal communication). Timing of molting is unknown but is considered to occur in late August - September, based on increase catches of fresh-molted crab later in the fishing season (August- September) (Joyce Soong, ADF\&G personal communication); however, blood hormonal studies suggested an AprilMay molting season (Jennifer Bell, ADF\&G, personal communication), which is consistent with Powell et al. (1983). Recent observations indicate biennial mating (Robert Foy, NOAA, personal communication). Trawl surveys show that crab distribution is dynamic. Recent surveys show high abundance on the southeast side of the sound, offshore of Stebbins and Saint Michael.
5. Brief management history: Norton Sound red king crab fisheries consist of commercial and subsistence fisheries. The commercial red king crab fishery started in 1977 and occurs in summer (June - August) and winter (December - May). The majority of red king crab is harvested offshore during the summer commercial fishery, whereas most of the winter subsistence fishery harvest occurs nearshore.

## Summer Commercial Fishery

A large-vessel summer commercial crab fishery started in 1977 in the Norton Sound Section (Table 1) and continued from 1977 through 1990. No summer commercial fishery occurred in 1991 because there was no staff to manage the fishery. In March 1993, the Alaska Board of Fisheries (BOF) limited participation in the fishery to small boats. Then on June 27, 1994, a super-exclusive designation went into effect for the fishery. This designation stated that a vessel registered for the Norton Sound crab fishery may not be used to take king crabs in any other registration areas during that registration year. A vessel moratorium was put into place before the 1996 season. This was intended to precede a license limitation program. In 1998, Community Development Quota (CDQ) groups were allocated a portion of the summer harvest; however, no CDQ harvest occurred until the 2000 season. On January 1, 2000 the North Pacific License Limitation Program (LLP) went into effect for the Norton Sound crab fishery. The program dictates that a vessel which exceeds 32 feet in length overall must hold a valid crab license issued under the LLP by the National Marine Fisheries Service. Regulation changes and location of buyers resulted in harvest distribution moving eastward in Norton Sound in the mid-1990s.In Norton Sound, a legal crab is defined as $\geq 4-3 / 4$ inch carapace width (CW, Menard et al. 2011), which is approximately equivalent to $\geq 104 \mathrm{~mm}$ carapace length mm CL. Since 2005, commercial buyers started accepting only legal crab of $\geq 5$ inch CW.

Not all Norton Sound area is open for commercial fisheries. Since the beginning of the commercial fisheries in 1977, approximately 5-10 miles off the shore of southern Seward Peninsula from Port Clarence to St. Michael have been closed to protect crab nursery grounds during the summer commercial crab fishery (Figure 2). The spatial extent of closed waters has varied historically.

## CDQ Fishery

The Norton Sound and Lower Yukon CDQ groups divide the CDQ allocation. Only fishers designated by the Norton Sound and Lower Yukon CDQ groups are allowed to participate in this portion of the king crab fishery. Fishers are required to have a CDQ fishing permit from the Commercial Fisheries Entry Commission (CFEC) and register their vessel with the Alaska Department of Fish and Game (ADF\&G) before begin fishing. Fishers operate under the authority of each CDQ group who decides how their crab quota is to be harvested. During the March 2002 BOF meeting, new regulations for the CDQ crab fishery were adopted that affected; closed-water boundaries were relaxed in eastern Norton Sound and waters west of Sledge Island. In March 2008, the BOF changed the start date of the Norton Sound open-access portion of the fishery to be opened by emergency order as early as June 15. The CDQ fishery may open at any time (as soon as ice is out), by emergency order.

## Winter Commercial Fishery

The winter commercial crab fishery is a small fishery using hand lines and pots through the nearshore ice. On average 10 permit holders harvested 2,500 crabs during 1978-2009. From 2007 to 2015 the winter commercial catch increased from 3,000 crabs to over 40,000 (Table 2). In 2015 winter commercial catch reached $20 \%$ of total crab catch. The BOF responded in May 2015 by amending regulations to allocate $8 \%$ of the total commercial guideline harvest level (GHL) to the winter commercial fishery. The winter red king crab commercial fishing
season was also set from January 15 to April 30, unless changed by emergency order. The new regulation will be in effect for the 2016 season.

## Subsistence Fishery

While the subsistence fishery has a long history, harvest information is available only since the 1977/78 season. The majority of the subsistence crab fishery harvest occurs during winter using hand lines and pots through nearshore ice. Average annual winter subsistence harvest was 5,400 crab (1977-2010). Subsistence harvesters need to obtain a permit before fishing and record daily effort and catch. Subsistence fishery has no size or sex limit; however, the majority of retained catches are males of near legal crab size. The subsistence fishery catch is influenced not only by crab abundance, but also by changes in distribution, changes in gear (e.g., more use of pots instead of hand lines since 1980s), and ice conditions (e.g., reduced catch due to unstable ice conditions: 1987-88, 1988-89, 1992-93, 2000-01, 2003-04, 2004-05, and 2006-07).

The summer subsistence crab fishery harvest has been monitored since 2004 with an average harvest of 712 crab per year. Since this harvest is very small, the summer subsistence fishery was not included in the assessment model.
6. Brief description of the annual ADF\&G harvest strategy

Since 1997 Norton Sound red king crab have been managed based on a guideline harvest level (GHL). From 1999 to 2011 the GHL for the summer commercial fishery was determined by a prediction model and the model estimated predicted biomass: (1) $0 \%$ harvest rate of legal crab when estimated legal biomass $<1.5$ million lb ; $(2) \leq 5 \%$ of legal male abundance when the estimated legal biomass falls within the range $1.5-2.5$ million lb ; and (3) $\leq 10 \%$ of legal male when estimated legal biomass $>2.5$ million lb.
In 2012 a revised GHL for the summer commercial fishery was implemented: (1) $0 \%$ harvest rate of legal crab when estimated legal biomass < 1.25 million lb ; $(2) \leq 7 \%$ of legal male abundance when the estimated legal biomass falls within the range $1.25-2.0$ million lb ; $(3) \leq$ $13 \%$ of legal male abundance when the estimated legal biomass falls within the range 2.0-3.0 million lb ; and $(3) \leq 15 \%$ of legal male biomass when estimated legal biomass $>3.0$ million lb.

In 2015 the Alaska Board of Fisheries passed the following regulations regarding winter commercial fisheries:

1. Revised GHL to include all fisheries (winter, summer, commercial, and subsistence).
2. Set guideline harvest level for winter commercial fishery $\left(\mathrm{GHL}_{\mathrm{w}}\right)$ at $8 \%$ of the total GHL (i.e., $\mathrm{GHL}_{\mathrm{w}}=0.08 \times \mathrm{GHL}$ ), and summer commercial guideline harvest level $\left(\mathrm{GHL}_{\mathrm{s}}\right)$ be remainder of total GHL (i.e., $\mathrm{GHL}_{\mathrm{s}}=\mathrm{GHL}-$ winter comm. harvest winter subsistence harvest).
3. Date of the winter red king crab commercial fishing season is from January 15 to April 30.

| Year | Notable historical management changes |
| :--- | :--- |
| 1976 | The abundance survey started |
| 1977 | Large vessel commercial fisheries began |


| 1991 | Fishery closed due to staff constraints |
| :--- | :--- |
| 1994 | Super exclusive designation went into effect. The end of large vessel commercial fishery <br> operation. The majority of commercial fishery subsequently shifted to east of $164^{\circ} \mathrm{W}$ longitude. |
| 1998 | Community Development Quota (CDQ) allocation went into effect |
| 1999 | Guideline Harvest Level (GHL) went into effect |
| 2000 | North Pacific License Limitation Program (LLP) went into effect. |
| 2002 | Change in closed water boundaries (Figure 2) |
| 2005 | Commercially accepted legal crab size changed from $\geq 4-3 / 4$ inch CW to $\geq 5$ inch CW |
| 2006 | The Statistical area Q3 section expanded (Figure 1 ) |

7. Summary of the history of the $B_{\mathrm{MSY}}$.

NSRKC is a Tier 4 crab stock. Direct estimation of the $B_{\text {MSY }}$ is not possible. The $B_{\text {MSY }}$ proxy is calculated as mean model estimated mature male biomass (MMB) from 1980 to present. Choice of this period was based on a hypothesized shift in stock productivity a due to a climatic regime shift indexed by the Pacific Decadal Oscillation (PDO) in 1976-77. Stock status of the NSRKC was Tier 4a until 2013. In 2014 the stock fell to Tier 4b, but came back to Tire 4 a in 2015.

## D. Data

1. Summary of new information:

Trawl survey:
Trawl survey report is published as ADFG report. The report is available at http://www.adfg.alaska.gov/FedAidPDFs/FDS15-40.pdf

Winter commercial and subsistence fishery:
Winter commercial fishery catch in 2015 was 41,046 crabs ( $98,750 \mathrm{lb}$.), which was the highest harvest record since development of its fishery. Subsistence crab catch was $7,651(15,302 \mathrm{lb}$., Table 2).

Summer commercial fishery:
The summer commercial fishery opened on June 29 and closed on July 24 due to meeting the GHL. This was the shortest fishery in the history. A total of 144,255 crabs ( $401,115 \mathrm{lb}$.) were harvested (Table 1).

Total harvest for 2015 season was 192,952 crabs ( $515,167 \mathrm{lb}$.) and did not exceed the 2015 ABC of 0.58 million lb.
2. Available survey, catch, and tagging data

|  | Years | Data Types | Tables |
| :--- | :--- | :--- | :--- |
| Summer trawl survey | $76,79,82,85,88,91,96,99$, | Abundance | 3 |
|  | $02,06,08,10,11,14$ | Length proportion | 5 , Figure 3 |
| Winter pot survey | $81-87,89-91,93,95-00,02-12$ | Length proportion | 6, Figure 3 |
| Summer commercial | $76-90,92-15$ | Retained catch | 1 |
| fishery |  | Standardized CPUE, | 1 |
|  |  | Length proportion | 4, Figure 3 |
| Summer commercial | $87-90,92,94,2012-2014$ | Length proportion | 7, Figure 3 |
| Discards | (sublegal only) |  |  |
| Winter subsistence fishery | $76-15$ | Total catch | 2 |
|  |  | Retained catch | 2 |
| Winter commercial fishery | $78-15$ | Retained catch | 2 |
| Tag recovery | $80-15$ | Recovered tagged crab | 8 |

Data available but not used for assessment

| Data | Years | Data Types | Reason for not used |
| :---: | :---: | :---: | :---: |
| Summer pot survey | 80-82,85 | Abundance <br> Length proportion | Uncertainties on how estimates were made. |
| Summer preseason survey | 95 | Length proportion | Just one year of data |
| Summer subsistence fishery | 2005-2013 | retained catch | Too few catches compared to commercial |
| Winter Pot survey | $\begin{aligned} & -87,89-91,93,95- \\ & 00,02-12 \end{aligned}$ | CPUE, <br> Length | Not reliable due to ice conditions |
| Winter Commercial | 2015 | Length proportion | Years of data too short |
| Preseason Spring pot survey | 2011-15 | CPUE, <br> Length proportion | Years of data too short |
| Postseason Fall pot survey | 2013-15 | CPUE, <br> Length proportion | Years of data too short |



Catches in other fisheries
In Norton Sound, no other crab, groundfish, or shellfish fisheries exist.

|  | Fishery | Data availability |
| :--- | :--- | :---: |
| Bycatch in other crab <br> fisheries | Does not exist | NA |
| Bycatch in groundfish pot | Does not exist | NA |
| Bycatch in groundfish trawl | Does not exist | NA |
| Bycatch in the scallop fishery | Does not exist | NA |

3. Other miscellaneous data:

Spring offshore migration distance and direction (2013-2015)
Monthly blood hormone level (indication of molting timing) (2014-2015)
Data aggregated:
Proportion of legal size crab, estimated from trawl survey and observer data. (Table 11)
Data estimated outside the model:
Summer commercial catch standardized CPUE (Table 1)

## E. Analytic Approach

## 1. History of the modeling approach.

The Norton Sound red king crab stock was assessed using a length-based synthesis model (Zheng et al. 1998). Since adoption of the model, the major challenge is a conflict between model projection and data, specifically the model projects higher abundanceproportion of the largest size class of crab than in seen in data. This problem was further exasperated when natural mortality $M$ was set as 0.18 from previous $M=0.3$ in 2011 (SAFE 2011). This problem was examined and resolved by increasing $M$ of the largest length crabs to $3.6 \times M$ or $M=0.648$ (SAFE 2012). Profile likelihood analyses have been conducted several times, which resulted in the lowest likelihood at $\boldsymbol{M}=\mathbf{0 . 3 4}$ (SAFE 2012, 2013). However, even at this higher $M$, the model was not able to resolve poor fits to the commercial catch. Profile likelihood of commercial catch was lowest around $\mathrm{M}=$ 0.5 or greater.

From 2013 to 2014, the NSRKC model was thoroughly examined by the CPT during the modeling workshop. The workshop improved the model fit thorough excluding some data (summer pot survey), revising the trawl survey abundance estimates, standardizing commercial catch CPUE, including tag recovery data to estimate the growth transition matrix within the model, and changing weights in the likelihood. However, the issue of $M$
was not addressed in this workshop. For the 2016 assessment we again examined the influence of $M$ on model performance.

Historical Model configuration progression:
2011 (SAFE 2011)

1. $M=0.18$
2. $M$ of the last length class $=0.288$
3. Include summer commercial discards mortality $=0.2$
4. Weight of fishing effort $=20$,
5. The maximum effective sample size for commercial catch and winter surveys $=100$,

2012 (SAFE 2012)

1. $M$ of the last length class $=3.6 \times M$
2. The maximum effective sample size for commercial catch and winter surveys $=50$,
3. Weight of fishing effort $=50$.

2013 (SAFE 2013)

1. Standardize commercial catch cpue and replace likelihood of commercial catch efforts to standardized commercial catch cpue with weight $=1.0$
2. Eliminate summer pot survey data from likelihood
3. Estimate survey $q$ of 1976-1991 NMFS survey with maximum of 1.0
4. The maximum effective sample size for commercial catch and winter surveys $=20$.

2014 (SAFE 2014)

1. Modify functional form of selectivity and molting probability to improve parameter estimates ( 2 parameter logistic to 1 parameter logistic)
2. Include additional variance for the standardized cpue.
3. Include winter pot survey cpue (But was removed from the final model due to lack of fit)
4. Estimate growth transition matrix from tagged recovery data.

2015 (SAFE 2015)

1. Winter pot survey selectivity is an inverse logistic, estimating selectivity of the smallest length group independently
2. Reduce Weight of tag-recovery: $\mathrm{W}=0.5$
3. Model parsimony: one trawl survey selectivity and one commercial pot selectivity

## 2. Model Description

a. Description of overall modeling approach:

The model is a male-only size structured model that combines multiple sources of survey, catch, and mark-recovery data using a maximum likelihood approach to estimate abundance, recruitment, catchability of the commercial pot gear, and parameters for selectivity and molting probabilities (See Appendix A for full model description).

## b-f. See Appendix A.

g. Critical assumptions of the model:
i. Male crab mature at CL length 94 mm .

Size at maturity of the NSRKC (CL 94 mm ) was determined by adjusting that of BBRKC (CL 120 mm ) reflecting their slower growth and smaller size.
ii. Molting events in fall after the fishery
iii. Instantaneous natural mortality $M$ is 0.18 for all length classes, except for the last length group (> 123 mm ) where $M$ is 3.6 times higher ( 0.648 ). $M$ is constant over time.
iv. Trawl survey selectivity is a logistic function with 1.0 for length classes 5-6. . Selectivity is constant over time.
v. Winter pot survey selectivity is a dome shaped function: Reverse logistic function of 1.0 for length class CL 84 mm , and model estimate for CL < 84mm length classes. Selectivity is constant over time.
This assumption is based on the fact that low proportion of large crabs caught in nearshore area where the winter surveys occur. Causes of this have been argued: (1) large crab do not migrate into nearshore in winter, or (2) large crab are fished out by winter fisheries where the survey occurs (i.e., local depletion). Recent studies suggest that the former was more likely the cause (Jennifer Bell, ADFG, personal communication).
vi. Summer commercial fisheries selectivity is an asymptotic logistic function of 1.0 at the length class CL 124 mm . While fishery changed greatly between the periods of 1977-1992 and 1993-present in terms of fishing vessel composition and pot configuration, the selectivity of each period was assumed to be identical. Model fits of separating and combining two periods were examined in 2015, which showed no difference between the two models (SAFE 2015). For model parsimony, the two were combined.
vii. Summer trawl survey selectivity is an asymptotic logistic function of 1.0 at the length of CL 124 mm . While the survey changed greatly between NOAA (19761991) and ADF\&G (1996-present) in terms of survey vessel and trawl net structure, selectivity of both periods was assumed to be identical. Model fits separating and combining the two surveys were examined in 2015. No differences between the two model were observed (SAFE 2015) and for model parsimony the two were combined.
viii. Winter commercial and subsistence fishery selectivity and length-shell conditions are the same as those of the winter pot survey. All winter commercial and subsistence harvests occur February $1^{\text {st }}$.
Winter commercial king crab pots can be any dimension (5AAC 34.925(d)). No length composition data exists for crab harvested in the winter commercial or subsistence fisheries. However, because commercial fishers are also subsistence fishers, it is reasonable to assume that the commercial fishers used crab pots that they use for subsistence harvest, and hence both fisheries have the same selectivity.
ix. Growth increments are a function of length, are constant over time, estimated from tag recovery data.
x. Molting probability is an inverse logistic function of length for males.
xi. A summer fishing season for the directed fishery is short. All summer commercial harvests occur July $1^{\text {st. }}$.
xii. Discards handling mortality for all fisheries is $20 \%$. No empirical estimate is available.
xiii. Annual retained catch is measured without error.
xiv. All legal size crab ( $\geq 4-3 / 4$ inch $C W$ ) are retained.

Since 2005, buyers announced that only legal crab with $\geq 5$ inch CW are acceptable for purchase. Since samples are taken at a commercial dock, it was anticipated that this change would lower the proportion of legal crab for length class 4 . However, the model was not sensitive to this change (SAFE 2013).
xv. All sublegal size crab or commercially unacceptable size crab (<5 inch CW, since 2005) are discarded.
xvi. Length compositions have a multinomial error structure and abundance has a lognormal error structure.
h. Changes of assumptions since last assessment:

None.
i. Code validation

The model code was reviewed at the CPT modeling workshop in 2013 and 2014. It is available from the authors.

## 3. Model Selection and Evaluation

a. Description of alternative model configurations.

CPT did not recommend any future model modifications in Jan 2015, except for fixing the trawl survey selectivity parameter. Here, we examined 3 major model scenarios: (1) estimate multiplier of the last length class natural mortality multiplier ( $m s$ ) from the model, (2) estimate $M$ equal for all length classes from the model, and (3) estimate $M$ and $m s$ from the model. For data input, we examined 3 scenarios: (1) expand length classes (2) change growth increment interval from 10 mm to 5 mm , and (3) both (1) and (2). Increasing length ranges or reducing growth increment interval increases use of data. This may increase the number of parameters to be estimated, but may also improve model fit.

List of model scenarios considered.

| Scenario | Length <br> Range | Length <br> Interval | M | ms <br> $(>123 \mathrm{~mm})$ |
| :---: | :---: | :---: | :---: | :---: |
| 0 (Default) | $74-124$ | 10 | 0.18 | 3.6 |
| 1 |  |  | 0.18 | Est |
| 2 |  |  | Est | 1.0 |
| 3 |  |  | Est | Est |
| 4 | $64-134$ | 10 | 0.18 | 3.6 |
| 5 |  |  | 0.18 | Est |
| 6 |  |  | Est | 1.0 |
| 7 |  |  | Est | Est |
| 8 | $74-124$ | 5 | 0.18 | 3.6 |
| 9 |  |  | 0.18 | Est |
| 10 |  |  | Est | 1.0 |
| 11 |  |  | Est | Est |
| 12 | $64-134$ | 5 | 0.18 | 3.6 |
| 13 |  |  | 0.18 | Est |
| 14 |  |  | Est | 1.0 |
| 15 |  |  | Est | Est |

Est: model estimated.
b. Evaluation of alternative models results:

For model 1 to 15

| Model | Number of <br> Parameters | Total | TSA | St. <br> CPUE | TLP | WLP | CLP | OBS | REC | TAG |
| ---: | ---: | ---: | ---: | ---: | :--- | :--- | ---: | ---: | ---: | ---: |
| 0 | 59 | 310.9 | 9.7 | -21.7 | 124.5 | 44.6 | 59.7 | 33.5 | 12.0 | 48.6 |
| 1 | 60 | 310.8 | 9.6 | -21.7 | 124.2 | 44.6 | 60.1 | 33.5 | 12.1 | 48.4 |
| 2 | 60 | 324.2 | 9.3 | -21.2 | 120.1 | 44.8 | 72.1 | 34.4 | 11.2 | 53.4 |
| 3 | 61 | 310.7 | 9.6 | -21.6 | 123.6 | 44.3 | 60.5 | 33.5 | 11.9 | 48.8 |
| 4 | 61 | 292.9 | 10.0 | -21.1 | 102.0 | 42.3 | 58.0 | 29.8 | 12.3 | 59.5 |
| 5 | 62 | 293.0 | 10.0 | -21.0 | 102.0 | 42.3 | 58.2 | 29.8 | 12.3 | 59.5 |
| 6 | 62 | 314.0 | 9.9 | -20.9 | 103.3 | 45.1 | 69.7 | 31.4 | 11.4 | 64.1 |
| 7 | 63 | 292.6 | 9.9 | -21.1 | 102.6 | 42.2 | 57.9 | 29.5 | 12.4 | 59.2 |
| 8 | 60 | 353.2 | 9.8 | -22.1 | 119.4 | 43.7 | 63.4 | 30.5 | 11.6 | 96.8 |
| 9 | 61 | 353.1 | 9.8 | -22.1 | 119.1 | 43.6 | 63.8 | 30.4 | 11.6 | 96.8 |
| 10 | 61 | 366.3 | 9.5 | -21.7 | 116.7 | 46.3 | 71.2 | 32.1 | 11.0 | 101.2 |
| 11 | 62 | 352.8 | 9.8 | -22.1 | 118.3 | 43.8 | 63.7 | 30.7 | 11.5 | 97.0 |
| 12 | 64 | 354.8 | 10.3 | -21.3 | 101.9 | 44.7 | 62.5 | 28.0 | 12.3 | 116.3 |
| 13 | 65 | 354.8 | 10.3 | -21.3 | 101.9 | 44.7 | 62.5 | 28.0 | 12.3 | 116.3 |
| 14 | 65 | 378.4 | 10.2 | -21.2 | 104.6 | 49.0 | 73.3 | 29.8 | 11.6 | 121.0 |
| 15 | 66 | 354.3 | 10.2 | -21.3 | 102.1 | 44.3 | 62.9 | 27.6 | 12.4 | 116.1 |

TSA: Trawl survey abundance
St. CPUE: Summer commercial catch standardized cpue
TLP: Trawl survey length composition:
WLP: Winter pot survey length composition
CLP: Summer commercial catch length composition
REC: Recruitment deviation

OBS: Summer Commercial catch Observer discards length composition
TAG: Tagging recovery data composition

Estimated $M, m s$, MMB (2016) and OFL. Bold fonts are model estimate.

| Model | $M$ | $m s$ | MMB(2016) | OFL |
| ---: | ---: | ---: | :---: | :---: |
| 0 | 0.18 | 3.6 | 5.99 | 0.85 |
| 1 | 0.18 | $\mathbf{3 . 4 2}$ | 5.78 | 0.82 |
| 2 | $\mathbf{0 . 4 2}$ | 1 | 6.15 | 1.74 |
| 3 | $\mathbf{0 . 2 1}$ | $\mathbf{2 . 9 6}$ | 6.03 | 0.78 |
| 4 | 0.18 | 3.6 | 5.88 | 0.77 |
| 5 | 0.18 | $\mathbf{3 . 5 6}$ | 5.87 | 0.77 |
| 6 | $\mathbf{0 . 4}$ | 1 | 5.81 | 1.42 |
| 7 | $\mathbf{0 . 1 4}$ | $\mathbf{4 . 6 1}$ | 6.54 | 0.81 |
| 8 | 0.18 | 3.6 | 6.50 | 0.86 |
| 9 | 0.18 | $\mathbf{3 . 4 5}$ | 6.46 | 0.85 |
| 10 | $\mathbf{0 . 4 1}$ | 1 | 6.63 | 1.64 |
| 11 | $\mathbf{0 . 2 2}$ | $\mathbf{2 . 7 8}$ | 6.54 | 1.02 |
| 12 | 0.18 | 3.6 | 6.17 | 0.76 |
| 13 | 0.18 | $\mathbf{3 . 6 0}$ | 6.17 | 0.76 |
| 14 | $\mathbf{0 . 3 9}$ | 1 | 6.16 | 1.33 |
| 15 | $\mathbf{0 . 1 4}$ | $\mathbf{4 . 8 2}$ | 6.05 | 0.59 |

c. Search for balance:

Diagnostics and output from alternative models are detailed in Appendices C1 (model 0) to C16 (model 15) Among all alternative models, major differences are: estimate $M$ of the largest length class, estimate M for all lengths equal, estimate $M$ and the largest length class, increase range of length classes, and decrease increments length class. Estimating $M$ multiplier of the largest length class ( $m s$ ) did not change model fit (Model 0 vs. Model 1), indicating that $m s=3.6$ is still a valid assumption. Estimating $M$ (Model 0 vs. Model 2) improved fits of trawl survey length composition, but worsened fit of commercial fishery length composition and tag recovery. The model tends to overestimate commercial catch proportion of largest length class or underestimate that of middle length crabs. We also attempted to estimate selectivity of the largest length class as separate parameter, which allows model to choose dome shaped selectivity. However, the estimate was 1.0. Estimate of $M$ was 0.42 that was more than twice higher than the default assumption of $M=0.18$. Profile analyses showed that each likelihood components had different information about $M$ (Appendix B1); however, except for winter pot and observer length comp, all other likelihood components were minimized at $M$ ranging 0.3 to 0.6 . This suggests that under the assumption of constant natural mortality across length classes and current model configurations, the data do not support the assumption of $M=0.18$. Estimating both $M$ and that of the largest length class (Model 0 vs. Model 3) did not change model fit. Estimated $M$ was 0.21 for all and $0.617(m s=2.96)$ for the largest length class, similar to model assumption. This suggests that given available data and model configuration, assuming
higher mortality for the largest length classes is the best option. This also suggests that if $M=$ 0.18 across all length classes is true then model structure may need to be re-examined. Increasing the length classes (Model 0 vs. Model 4) or decreasing length category interval from 10 mm to 5 mm (Model 0 vs. Model 8) can increase use of more data and thus may yield better estimates for selectivities and molting probability. Regardless, all models had similar fit to trawl survey abundance and standardized CPUE.

Projected MMB for 2016 was similar across models ranging from 5.8 to 6.6 million lb . On the other hand, estimates of OFL differed greatly across the models because of differences in $M$. Considering all factors, we initially considered alternative models $0,1,5$, and 13 for the 2016 assessment. Among the 4 models, Model 5 had the lowest Mohn's rho (Model 0: 0.482 , Model 1: -0.556 , Model 5: 0.115 , Model 13: 0.924 ). While Mohn's rho has no cutoff criteria to which a model is deemed unacceptable, a model with Mohn's roh closer to 0 is generally considered a better model. Thus, we recommend the Model 5 for the 2016 assessment model.

## 4. Results

1. List of effective sample sizes and weighting factors (Figure 4)
"Implied" effective sample sizes were calculated as

$$
n=\sum_{l} \hat{P}_{y, l}\left(1-\hat{P}_{y, l}\right) / \sum_{l}\left(P_{y, l}-\hat{P}_{y, l}\right)^{2}
$$

Where $P_{y, l}$ and $\hat{P}_{y, l}$ are observed and estimated length compositions in year $y$ and length group $l$, respectively. Estimated effective sample sizes vary greatly over time.

Maximum sample size for length proportion:

| Survey data | Sample size |
| :--- | :---: |
| Summer commercial, winter pot, <br> and summer observer | minimum of $0.1 \times$ actual sample size or 10 |
| Summer trawl and pot survey | minimum of $0.5 \times$ actual sample size or 20 |

2. Tables of estimates.
a. Model parameter estimates (Tables 10, 11, 12, 13).
b. Abundance and biomass time series (Table 14)
c. Recruitment time series (Table 14).
d. Time series of catch/biomass (Tables 14 and 15)
3. Graphs of estimates.
a. Molting probability and trawl/pot selectivity (Figure 5)
b. Trawl survey and model estimated trawl survey abundance (Figure 6)
c. Estimated male abundances (recruits, legal, and total) (Figure 7)
d. Estimated mature male biomass (Figure 8)
e. Time series of standardized cpue for the summer commercial fishery (Figure 9).
f. Time series of catch and estimated harvest rate (Figure 10).
4. Evaluation of the fit to the data.
a. Fits to observed and model predicted catches.

Not applicable. Catch is assumed to be measured without error; however fits of cpue are available (Figures 9, 11).
b. Model fits to survey numbers (Figures 6, 11).

All model estimated abundances of total crab were within the $95 \%$ confidence interval of the survey observed abundance, except for 1976 and 1979, where model estimates were higher than the observed abundances.
c. Fits of catch proportions by lengths (Figures 12, 13).
d. Model fits to catch and survey proportions by length (Figures 12, 14, 15, 16).
e. Marginal distribution for the fits to the composition data
f. Plots of implied versus input effective sample sizes and time-series of implied effective sample size (Figure 4).
g. Tables of RMSEs for the indices:

Trawl survey: 0.36
Summer commercial standardized CPUE: 0.5.
h. QQ plots and histograms of residuals (Figure 11).
5. Retrospective and prospective analyses (Figure 17,18).
6. Uncertainty and sensitivity analyses.

See Sections 2 and 5.

## F. Calculation of the OFL

1. Specification of the Tier level and stock status.

The Norton Sound red king crab stock is placed in Tier 4. It is not possible to estimate the spawner-recruit relationship, but some abundance and harvest estimates are available to build a computer simulation model that captures the essential population dynamics. Tier 4 stocks are assumed to have reliable estimates of current survey biomass and instantaneous $M$; however, the estimates for the Norton Sound red king crab stock are uncertain. Survey biomass is based on triennial trawl surveys with CVs ranging from 15-42\% (Table 4).

Tire 4 level and the OFL are determined by the $F_{M S Y}$ proxy, $B_{M S Y}$ proxy, and estimated legal male abundance and biomass:

| level | Criteria | $F_{\text {OFL }}$ |
| :---: | :---: | :---: |
| a | $B / B_{M S Y^{\text {max }}}>1$ | $F_{\text {OFL }}=\gamma M$ |
| b |  | $F_{O F L}=\gamma M\left(B / B_{M S Y}{ }^{\text {mox }}-\alpha\right) /(1-\alpha)$ |
| c | $B / B_{M S Y \text { prx }} \leq \beta$ | $F_{\text {OFL }}=$ bycatch mortality \& directed fishery $F=0$ |

where $B$ is a mature male biomass (MMB), $B_{M S Y}$ proxy is average mature male biomass over a specified time period, $M=0.18, \gamma=1, \alpha=0.1$, and $\beta=0.25$

For Norton Sound red king crab, MMB is defined as the biomass of males > 94 mm CL on February 01 (Appendix A). $B_{M S Y}$ proxy is
$B_{M S Y}$ proxy $=$ average model estimated MMB from 1980-2016

Predicted mature male biomass in 2016 in February 01 is:

Mature male biomass : 5.87 (SD 1.12) million lb.

Estimated $B_{M S Y}$ proxy is:
4.53 million lb.

Since projected MMB is greater than $B_{M S Y}$ proxy, Norton Sound red king crab stock status is Tire 4 a.
2. Calculation of OFL.

The OFL was calculated for retained, unretained, and total male catch, in which OFL is calculated by applying Fofl control rule to crab abundance estimates.

$$
O F L=\left(1-\exp \left(-F_{O F L}\right)\right) L e g a l_{-} B
$$

Legal_B, biomass of legal crab subject to fisheries is calculated as : Projected abundance by length crab $\times$ fishing selectivity by length crab $\times$ Proportion of legal crab per length class $\times$ Average lb per length class (Appendix A)

The Norton Sound red king crab fishery consists of a small (1-17\% of total catch biomass) winter subsistence and commercial fishery from January to May and summer commercial fishery (83-99\% of total catch biomass) from mid-June to September. The two fisheries use different fishing gears and thus have different catch selectivities (Figure 5, Table 11).

In determination of OFL, Legal_B should be biomass right before the majority of fisheries occur that is July 01 , which is calculated as: (Feb $1^{\text {st }}$ abundance - winter fishery harvests - winter fishery discards $\times$ handling mortality) $\times$ natural mortality from Feb $1^{\text {st }}$ to June $30^{\text {th }}$. However, because model assessment is based on February 01 population, and winter fishery is yet to occur, predicted July 01 population cannot be calculated directly.
Hence, under the direction of the CPT (Jan 12, 2016), the crab abundance (Legal_B) used for calculation of the OFL the July 01 Legal_B was calculated as: Projected legal abundance (Feb 1st) $\times$ Commercial pot selectivity $\times$ Proportion of legal crab per length class $\times$ average lb per length class $\times$ natural mortality from February $1^{\text {st }}$ to July $1^{\text {st }}$.

$$
\begin{aligned}
& \text { Legal_ }_{-} B=\left(\sum_{l}\left(N_{w, l}+O_{w, l}\right) S_{s, l} L_{l} w m_{l}\right) e^{-0.42 M} \\
& O F L_{r}=\left(1-\exp \left(-F_{O F L}\right)\right) L_{\text {egal }}^{-} \text {B }
\end{aligned}
$$

For next year (2017) calculation of (Legal_B) will be updated to incorporate projected winter fishery removal.

The unretained OFL is a sub-legal crab biomass catchable to summer commercial pot fisheries calculated as: Projected legal abundance (Feb 1st) $\times$ Commercial pot selectivity $\times$ Proportion of sub-legal crab per length class $\times$ Average lb per length class $\times$ handling mortality.

$$
O F L_{n r}=\left(1-\exp \left(-F_{O F L}\right)\right) \sum_{l}\left(N_{s, l,}+O_{s, l}\right) S_{s, l}\left(1-L_{l}\right) w m_{l} h m
$$

where $N_{s, l}$ and $O_{s, l}$ are summer abundances of newshell and oldshell crab in length class $l$ in the terminal year, $L_{l}$ is the proportion of legal males in length class $l, S_{s, l}$ is summer commercial catch selectivity, $w m_{l}$ is average weight in length class $l$ and $h m$ is handling mortality rate. .

The total male OFL is

$$
O F L_{T}=O F L_{r}+O F L_{n r}
$$

For calculation of the OFL 2016

Legal male biomass (July 01): 4.31 (SD 0.89) million lb
$\mathrm{OFL}_{\mathrm{r}}=0.710$ million lb .
$\mathrm{OFL}_{\mathrm{nr}}=0.180$ million lb.
$\mathrm{OFL}_{\mathrm{T}}=0.890$ million lb .

## G. Calculation of the ABC

1. Specification of the probability distribution of the OFL.

Probability distribution of the OFL was determined based on the CPT recommendation in January 2015 of 20\% buffer:

Retained ABC for legal male crab is $80 \%$ of OFL
$\mathrm{ABC}=0.710 \times 0.8=0.568$ million lb.

## H. Rebuilding Analyses

Not applicable

## I. Data Gaps and Research Priorities

The major data gap is the fate of crab greater than 123 mm .

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Figure 1. King crab fishing districts and sections of Statistical Area Q.


Figure 2. Closed water regulations in effect for the Norton Sound commercial crab fishery.





$$
\square 64 \quad \square 74 \quad \square 84 \quad \square 94 \quad \square 104 \square 114 \quad \square 124 \quad \square 134
$$

Figure 3. Observed length compositions 1976-2015.


Figure 4. Effective sample size vs. implied sample size. Figures in the first column show effective sample size (x-axis) vs. frequency (y-axis). Vertical solid line is the implied sample size. Figures in the second column show implied sample size ( x -axis) vs. effective sample size ( y -axis). Dashed line indicates linear regression slope, and solid line is 1:1 line. Figures in the third column show year (xaxis) vs. effective sample size (y-axis).


Figure 5. Molting probability and trawl/pot selectivities.

## Trawl survey crab abundance



Figure 6. Estimated trawl survey male abundance with $95 \%$ lognormal Confidence Interval (crab $\geq 74$ mm CL).

## Modeled crab abundance Feb 01



Figure 7. Estimated abundances of legal and recruits males from 1976-2015.

MMB Feb 01


Figure 8. Estimated MMB from 1976-2015. Dash line shows Bmsy (Average MMB of 1980-2016). Black points indicate projected MMB of 2016.

## Summer commercial standardized cpue



Figure 9. Summer commercial standardized cpue. Black line is input SD and red line is input and estimated additional SD.

Total catch \& Harvest rate


Figure 10. Commercial Catch and estimated harvest rate of legal male.


Figure 11. Residual and QQ plot.


Figure 12. Bubble plot of predicted and observed length proportion (Alternative model 0). Black circle indicates model estimates lower than observed, white circle indicates model estimates higher than observed. Size of circle indicate degree of deviance (larger circle = larger deviance).


Figure 13. Predicted (dashed line) vs. observed (black dots) length class proportion for the summer commercial catch.

Winter pot length: observed vs predicted


Figure 14. Predicted vs. observed length class proportion for winter pot survey.

Trawl length: observed vs predicted


Discards length: observed vs predicted


Figure 15. Predicted vs. observed length class proportion for trawl survey and commercial observer.


Figure 16. Predicted vs. observed length class proportion for tag recovery data 1980-1992, and 1993-2014.

## Retrospective Analysis



Figure 17. Retrospective analyses. Each line shows retrospective MMB. Model 5

## Retrospective Analysis



Figure 18. Retrospective analyses. Each line shows retrospective MMB. Model 13

Table 1. Historical summer commercial red king crab fishery economic performance, Norton Sound Section, eastern Bering Sea, 1977-2014. Bold type shows data that are used for the assessment model.

| Year | Guideline Harvest Level (lb) ${ }^{\text {b }}$ | Commercial <br> Harvest (lb) ${ }^{\text {a,b }}$ |  | Total Number (Open Access) |  |  |  | Total Pots |  | ST CPUE |  | Season Length |  | Midday from July 1 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Open |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | Access | CDQ | Harvest | Vessels | Permits | Landings | Registered | Pulls | CPUE | SD | Days | Dates |  |
| 1977 | c | 0.52 |  | 195,877 | 7 | 7 | 13 |  | 5,457 | 4.18 | 0.34 | 60 | c | 0.03 |
| 1978 | 3.00 | 2.09 |  | 660,829 | 8 | 8 | 54 |  | 10,817 | 2.21 | 0.23 | 60 | 6/07-8/15 | 0.03 |
| 1979 | 3.00 | 2.93 |  | 970,962 | 34 | 34 | 76 |  | 34,773 | 3.09 | 0.18 | 16 | 7/15-7/31 | 0.063 |
| 1980 | 1.00 | 1.19 |  | 329,778 | 9 | 9 | 50 |  | 11,199 | 3.03 | 0.26 | 16 | 7/15-7/31 | 0.063 |
| 1981 | 2.50 | 1.38 |  | 376,313 | 36 | 36 | 108 |  | 33,745 | 0.89 | 0.19 | 38 | 7/15-8/22 | 0.093 |
| 1982 | 0.50 | 0.23 |  | 63,949 | 11 | 11 | 33 |  | 11,230 | 0.11 | 0.25 | 23 | 8/09-9/01 | 0.14 |
| 1983 | 0.30 | 0.37 |  | 132,205 | 23 | 23 | 26 | 3,583 | 11,195 | 1.00 | 0.22 | 3.8 | 8/01-8/05 | 0.093 |
| 1984 | 0.40 | 0.39 |  | 139,759 | 8 | 8 | 21 | 1,245 | 9,706 | 0.94 | 0.23 | 13.6 | 8/01-8/15 | 0.107 |
| 1985 | 0.45 | 0.43 |  | 146,669 | 6 | 6 | 72 | 1,116 | 13,209 | 0.34 | 0.20 | 21.7 | 8/01-8/23 | 0.132 |
| 1986 | 0.42 | 0.48 |  | 162,438 | 3 | 3 |  | 578 | 4,284 | 0.76 | 0.41 | 13 | 8/01-8/25 | 0.153 |
| 1987 | 0.40 | 0.33 |  | 103,338 | 9 | 9 |  | 1,430 | 10,258 | 0.57 | 0.32 | 11 | 8/01-8/12 | 0.118 |
| 1988 | 0.20 | 0.24 |  | 76,148 | 2 | 2 |  | 360 | 2,350 | 1.44 | 0.67 | 9.9 | 8/01-8/11 | 0.115 |
| 1989 | 0.20 | 0.25 |  | 79,116 | 10 | 10 |  | 2,555 | 5,149 | 1.80 | 0.32 | 3 | 8/01-8/04 | 0.096 |
| 1990 | 0.20 | 0.19 |  | 59,132 | 4 | 4 |  | 1,388 | 3,172 | 1.13 | 0.40 | 4 | 8/01-8/05 | 0.099 |
| 1991 | 0.34 |  |  | 0 |  | Summer F | shery |  |  |  |  |  |  |  |
| 1992 | 0.34 | 0.07 |  | 24,902 | 27 | 27 |  | 2,635 | 5,746 | 0.30 | 0.31 | 2 | 8/01-8/03 | 0.093 |
| 1993 | 0.34 | 0.33 |  | 115,913 | 14 | 20 | 208 | 560 | 7,063 | 0.91 | 0.10 | 52 | 7/01-8/28 | 0.09 |
| 1994 | 0.34 | 0.32 |  | 108,824 | 34 | 52 | 407 | 1,360 | 11,729 | 0.81 | 0.06 | 31 | 7/01-7/31 | 0.044 |
| 1995 | 0.34 | 0.32 |  | 105,967 | 48 | 81 | 665 | 1,900 | 18,782 | 0.43 | 0.05 | 67 | 7/01-9/05 | 0.066 |
| 1996 | 0.34 | 0.22 |  | 74,752 | 41 | 50 | 264 | 1,640 | 10,453 | 0.51 | 0.08 | 57 | 7/01-9/03 | 0.096 |
| 1997 | 0.08 | 0.09 |  | 32,606 | 13 | 15 | 100 | 520 | 2,982 | 0.85 | 0.10 | 44 | 7/01-8/13 | 0.101 |
| 1998 | 0.08 | 0.03 | 0.00 | 10,661 | 8 | 11 | 50 | 360 | 1,639 | 0.80 | 0.13 | 65 | 7/01-9/03 | 0.088 |
| 1999 | 0.08 | 0.02 | 0.00 | 8,734 | 10 | 9 | 53 | 360 | 1,630 | 0.93 | 0.13 | 66 | 7/01-9/04 | 0.101 |
| 2000 | 0.33 | 0.29 | 0.01 | 111,728 | 15 | 22 | 201 | 560 | 6,345 | 1.26 | 0.06 | 91 | 7/01-9/29 | 0.11 |
| 2001 | 0.30 | 0.28 | 0.00 | 98,321 | 30 | 37 | 319 | 1,200 | 11,918 | 0.66 | 0.05 | 97 | 7/01-9/09 | 0.085 |
| 2002 | 0.24 | 0.24 | 0.01 | 86,666 | 32 | 49 | 201 | 1,120 | 6,491 | 1.25 | 0.06 | 77 | 6/15-9/03 | 0.074 |
| 2003 | 0.25 | 0.25 | 0.01 | 93,638 | 25 | 43 | 236 | 960 | 8,494 | 0.88 | 0.05 | 68 | 6/15-8/24 | 0.079 |
| 2004 | 0.35 | 0.31 | 0.03 | 120,289 | 26 | 39 | 227 | 1,120 | 8,066 | 1.37 | 0.05 | 51 | 6/15-8/08 | 0.063 |
| 2005 | 0.37 | 0.37 | 0.03 | 138,926 | 31 | 42 | 255 | 1,320 | 8,867 | 1.26 | 0.05 | 73 | 6/15-8/27 | 0.071 |
| 2006 | 0.45 | 0.42 | 0.03 | 150,358 | 28 | 40 | 249 | 1,120 | 8,867 | 1.38 | 0.05 | 68 | 6/15-8/22 | 0.09 |
| 2007 | 0.32 | 0.29 | 0.02 | 110,344 | 38 | 30 | 251 | 1,200 | 9,118 | 1.07 | 0.05 | 52 | 6/15-8/17 | 0.063 |
| 2008 | 0.41 | 0.36 | 0.03 | 143,337 | 23 | 30 | 248 | 920 | 8,721 | 1.42 | 0.05 | 73 | 6/23-9/03 | 0.063 |
| 2009 | 0.38 | 0.37 | 0.03 | 143,485 | 22 | 27 | 359 | 920 | 11,934 | 0.89 | 0.04 | 98 | 6/15-9/20 | 0.1 |
| 2010 | 0.40 | 0.39 | 0.03 | 149,822 | 23 | 32 | 286 | 1,040 | 9,698 | 1.27 | 0.04 | 58 | 6/28-8/24 | 0.096 |
| 2011 | 0.36 | 0.37 | 0.03 | 141,626 | 24 | 25 | 173 | 1,040 | 6,808 | 1.62 | 0.05 | 33 | 6/28-7/30 | 0.038 |
| 2012 | 0.47 | 0.44 | 0.03 | 161,113 | 40 | 29 | 312 | 1,200 | 10,041 | 1.34 | 0.04 | 72 | 6/29-9/08 | 0.077 |
| 2013 | 0.50 | 0.37 | 0.02 | 130,603 | 37 | 33 | 460 | 1,420 | 15,058 | 0.69 | 0.04 | 74 | 7/3-9/14 | 0.107 |
| 2014 | 0.38 | 0.36 | 0.03 | 129,657 | 52 | 33 | 309 | 1,560 | 10,127 | 1.16 | 0.05 | 52 | 6/25-8/15 | 0.052 |
| 2015 | 0.39 | 0.37 | 0.03 | 144,255 | 42 | 36 | 251 | 1,480 | 8,356 | 1.53 | 0.05 | 26 | 6/29-7/24 | 0.030 |

${ }^{\text {a }}$ Deadloss included in total. ${ }^{\mathrm{b}}$ Millions of pounds. ${ }^{\mathrm{c}}$ Information not available.

Table 2. Historical winter commercial and subsistence red king crab fisheries, Norton Sound Section, eastern Bering Sea, 1977-2015. Bold typed data are used for the assessment model.

| Model Year | Year ${ }^{\text {a }}$ | Commercial |  | Winter ${ }^{\text {b }}$ | Subsistence |  |  | Total Crab |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | \# of | \# of Crab |  |  | Permits |  |  |  |
|  |  | Fish ers | Harvested |  | Issued | Returned | Fished | Caught ${ }^{\text {c }}$ | Retained ${ }^{\text {d }}$ |
| 1978 | 1978 | 37 | 9,625 | 1977/78 | 290 | 206 | 149 | NA | 12,506 |
| 1979 | 1979 | $1{ }^{\text {f }}$ | $221{ }^{\text {f }}$ | 1978/79 | 48 | 43 | 38 | NA | 224 |
| 1980 | 1980 | $1{ }^{\text {f }}$ | $22^{\text {f }}$ | 1979/80 | 22 | 14 | 9 | NA | 213 |
| 1981 | 1981 | 0 | 0 | 1980/81 | 51 | 39 | 23 | NA | 360 |
| 1982 | 1982 | $1{ }^{\text {f }}$ | $17^{\text {f }}$ | 1981/82 | 101 | 76 | 54 | NA | 1,288 |
| 1983 | 1983 | 5 | 549 | 1982/83 | 172 | 106 | 85 | NA | 10,432 |
| 1984 | 1984 | 8 | 856 | 1983/84 | 222 | 183 | 143 | 15,923 | 11,220 |
| 1985 | 1985 | 9 | 1,168 | 1984/85 | 203 | 166 | 132 | 10,757 | 8,377 |
| 1986 | 1985/86 | 5 | 2,168 | 1985/86 | 136 | 133 | 107 | 10,751 | 7,052 |
| 1987 | 1986/87 | 7 | 1,040 | 1986/87 | 138 | 134 | 98 | 7,406 | 5,772 |
| 1988 | 1987/88 | 10 | 425 | 1987/88 | 71 | 58 | 40 | 3,573 | 2,724 |
| 1989 | 1988/89 | 5 | 403 | 1988/89 | 139 | 115 | 94 | 7,945 | 6,126 |
| 1990 | 1989/90 | 13 | 3,626 | 1989/90 | 136 | 118 | 107 | 16,635 | 12,152 |
| 1991 | 1990/91 | 11 | 3,800 | 1990/91 | 119 | 104 | 79 | 9,295 | 7,366 |
| 1992 | 1991/92 | 13 | 7,478 | 1991/92 | 158 | 105 | 105 | 15,051 | 11,736 |
| 1993 | 1992/93 | 8 | 1,788 | 1992/93 | 88 | 79 | 37 | 1,193 | 1,097 |
| 1994 | 1993/94 | 25 | 5,753 | 1993/94 | 118 | 95 | 71 | 4,894 | 4,113 |
| 1995 | 1994/95 | 42 | 7,538 | 1994/95 | 166 | 131 | 97 | 7,777 | 5,426 |
| 1996 | 1995/96 | 9 | 1,778 | 1995/96 | 84 | 44 | 35 | 2,936 | 1,679 |
| 1997 | 1996/97 | $2^{\text {f }}$ | $83^{\text {f }}$ | 1996/97 | 38 | 22 | 13 | 1,617 | 745 |
| 1998 | 1997/98 | 5 | 984 | 1997/98 | 94 | 73 | 64 | 20,327 | 8,622 |
| 1999 | 1998/99 | 5 | 2,714 | 1998/99 | 95 | 80 | 71 | 10,651 | 7,533 |
| 2000 | 1999/00 | 10 | 3,045 | 1999/00 | 98 | 64 | 52 | 9,816 | 5,723 |
| 2001 | 2000/01 | 3 | 1,098 | 2000/01 | 50 | 27 | 12 | 366 | 256 |
| 2002 | 2001/02 | 11 | 2,591 | 2001/02 | 114 | 61 | 45 | 5,119 | 2,177 |
| 2003 | 2002/03 | 13 | 6,853 | 2002/03 | 107 | 70 | 61 | 9,052 | 4,140 |
| 2004 | 2003/04 | $2^{\text {f }}$ | $522{ }^{\text {f }}$ | 2003/04 ${ }^{\text {g }}$ | 96 | 77 | 41 | 1,775 | 1,181 |
| 2005 | 2004/05 | 4 | 2,091 | 2004/05 | 170 | 98 | 58 | 6,484 | 3,973 |
| 2006 | 2005/06 | $1{ }^{\text {f }}$ | $75^{\text {f }}$ | 2005/06 | 98 | 97 | 67 | 2,083 | 1,239 |
| 2007 | 2006/07 | 8 | 3,313 | 2006/07 | 129 | 127 | 116 | 21,444 | 10,690 |
| 2008 | 2007/08 | 9 | 5,796 | 2007/08 | 139 | 137 | 108 | 18,621 | 9,485 |
| 2009 | 2008/09 | 7 | 4,951 | 2008/09 | 105 | 105 | 70 | 6,971 | 4,752 |
| 2010 | 2009/10 | 10 | 4,834 | 2009/10 | 125 | 123 | 85 | 9,004 | 7,044 |
| 2011 | 2010/11 | 5 | 3,365 | 2010/11 | 148 | 148 | 95 | 9,183 | 6,640 |
| 2012 | 2011/12 | 35 | 9,157 | 2011/12 | 204 | 204 | 138 | 11,341 | 7,311 |
| 2013 | 2012/13 | 26 | 22,639 | 2012/13 | 149 | 148 | 104 | 21,524 | 7,622 |
| 2014 | 2013/14 | 21 | 14,986 | 2013/14 | 103 | 103 | 75 | 5,421 | 3,252 |
| 2015 | 2014/15 | 44 | 41,046 | 2014/15 | 155 | 153 | 107 | 9,840 | 7,651 |

a Prior to 1985 the winter commercial fishery occurred from January 1 - April 30. As of March 1985, fishing may occur from November 15 - May 15.
b The winter subsistence fishery occurs during months of two calendar years (as early as December, through May).
c The number of crab actually caught; some may have been returned.
d The number of crab Retained is the number of crab caught and kept.
f Confidentiality was waived by the fishers.
h Prior to 2005, permits were only given out of the Nome ADF\&G office. Starting with the 2004-5 season, permits were given out in
Elim, Golovin, Shaktoolik, and White Mountain.

Table 3. Summary of triennial trawl survey Norton Sound male red king crab abundance estimates. Trawl survey abundance estimate is based on $10 \times 10 \mathrm{nmil}^{2}$ grid, except for $2010\left(20 \times 20 \mathrm{nmil}^{2}\right)$.

| Year | Dates | Survey <br> Agency | Survey method | Survey coverage |  |  | Abundance $\geq 74 \mathrm{~mm}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | surveyed stations | Stations w/ NSRKC | n mile $^{2}$ <br> covered |  | CV |
| 1976 | 9/02-9/05 | NMFS | Trawl | 103 | 62 | 10260 | 4247.5 | 0.31 |
| 1979 | 7/26-8/05 | NMFS | Trawl | 85 | 22 | 8421 | 1417.2 | 0.20 |
| 1980 | 7/04-7/14 | ADFG | Pots |  |  |  | 2092.3 | N/A |
| 1981 | 6/28-7/14 | ADFG | Pots |  |  |  | 2153.4 | N/A |
| 1982 | 7/06-7/20 | ADFG | Pots |  |  |  | 1140.5 | N/A |
| 1982 | 9/05-9/11 | NMFS | Trawl | 58 | 37 | 5721 | 2791.7 | 0.29 |
| 1985 | 7/01-7/14 | ADFG | Pots |  |  |  | 2320.4 | 0.083 |
| 1985 | 9/16-10/01 | NMFS | Trawl | 78 | 49 | 7688 | 2306.3 | 0.25 |
| 1988 | 8/16-8/30 | NMFS | Trawl | 78 | 41 | 7721 | 2263.4 | 0.29 |
| 1991 | 8/22-8/30 | NMFS | Trawl | 52 | 38 | 5183 | 3132.5 | 0.43 |
| 1996 | 8/07-8/18 | ADFG | Trawl | 50 | 30 | 4938 | 1264.7 | 0.317 |
| 1999 | 7/28-8/07 | ADFG | Trawl | 53 | 31 | 5221 | 2276.1 | 0.194 |
| 2002 | 7/27-8/06 | ADFG | Trawl | 57 | 37 | 5621 | 1747.6 | 0.125 |
| 2006 | 7/25-8/08 | ADFG | Trawl | 101 | 45 | 10008 | 2549.7 | 0.288 |
| 2008 | 7/24-8/11 | ADFG | Trawl | 74 | 44 | 7330 | 2707.1 | 0.164 |
| $2010^{\text {a }}$ | 7/27-8/09 | NMFS | Trawl | 35 | 15 | 13749 | 2041.0 | 0.455 |
| 2011 | 7/18-8/15 | ADFG | Trawl | 65 | 34 | 6447 | 2701.7 | 0.133 |
| 2014 | 7/18-7/30 | ADFG | Trawl | 47 | 34 | 4700 | 5481.5 | 0.486 |

Table 4. Summer commercial catch size/shell compositions. Sizes in this and Tables 5-10 and 12 are mm carapace length. Legal size ( 4.75 inch carapace width is approximately equal to 124 mm carapace length.
Model 5 data

|  |  | New Shell |  |  |  |  |  |  |  | Old Shell |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year | Sample | $\begin{aligned} & \hline 64- \\ & 73 \end{aligned}$ | $74-83$ | 84-93 | $\begin{aligned} & \hline 94- \\ & 103 \end{aligned}$ | $\begin{aligned} & \hline 104- \\ & 113 \end{aligned}$ | $\begin{aligned} & \hline 114- \\ & 123 \end{aligned}$ | $\begin{aligned} & \hline 124- \\ & 133 \end{aligned}$ | 134+ |  | $\begin{aligned} & 4-74- \\ & 388 \end{aligned}$ | $\begin{array}{cc} \hline 84- & 94- \\ 93 & 103 \end{array}$ | $\begin{aligned} & \hline 104- \\ & 113 \end{aligned}$ | $\begin{aligned} & \hline 114- \\ & 123 \end{aligned}$ | $\begin{aligned} & \hline 124- \\ & 133 \end{aligned}$ | 134+ |
| 1977 | 1549 | 0 | 0 | 0 | 0.00 | 0.42 | 0.34 | 0.08 | 0.05 | - | 0 | 00.00 | 0.06 | 0.04 | 0.01 | 0.00 |
| 1978 | 389 | 0 | 0 | 0 | 0.01 | 0.19 | 0.47 | 0.26 | 0.04 | 0 | 0 | 00.00 | 0.01 | 0.01 | 0.01 | 0.00 |
| 1979 | 1660 | 0 | 0 | 0 | 0.03 | 0.23 | 0.38 | 0.26 | 0.07 | 0 | ) 0 | 00.00 | 0.03 | 0.00 | 0.00 | 0.01 |
| 1980 | 1068 | 0 | 0 | 0 | 0.00 | 0.10 | 0.31 | 0.37 | 0.18 | 0 | 0 | 00.00 | 0.00 | 0.01 | 0.02 | 0.01 |
| 1981 | 1784 | 0 | 0 | 0 | 0.00 | 0.07 | 0.15 | 0.28 | 0.23 | 0 | 0 | 00.00 | 0.00 | 0.05 | 0.12 | 0.09 |
| 1982 | 1093 | 0 | 0 | 0 | 0.04 | 0.19 | 0.16 | 0.22 | 0.29 | 0 | 0 | 00.00 | 0.01 | 0.02 | 0.03 | 0.03 |
| 1983 | 802 | 0 | 0 | 0 | 0.04 | 0.41 | 0.36 | 0.06 | 0.03 | 0 | ) 0 | 00.00 | 0.04 | 0.01 | 0.02 | 0.02 |
| 1984 | 963 | 0 | 0 | 0 | 0.10 | 0.42 | 0.28 | 0.06 | 0.01 | 0 | 0 | 00.01 | 0.07 | 0.05 | 0.01 | 0.00 |
| 1985 | 2691 | 0 | 0 | 0.00 | 0.06 | 0.31 | 0.37 | 0.15 | 0.02 | 0 |  | 00.00 | 0.03 | 0.03 | 0.01 | 0.00 |
| 1986 | 1138 | 0 | 0 | 0 | 0.03 | 0.36 | 0.39 | 0.12 | 0.02 | 0 | 0 | 00.00 | 0.02 | 0.04 | 0.02 | 0.00 |
| 1987 | 1985 | 0 | 0 | 0 | 0.02 | 0.18 | 0.29 | 0.27 | 0.11 | 0 | 0 | 00.00 | 0.03 | 0.06 | 0.03 | 0.01 |
| 1988 | 1522 | 0 | 0.00 | 0 | 0.02 | 0.20 | 0.30 | 0.18 | 0.04 | 0 | ) | 00.01 | 0.06 | 0.10 | 0.07 | 0.02 |
| 1989 | 2595 | 0 | 0 | 0 | 0.01 | 0.16 | 0.32 | 0.17 | 0.05 | 0 | 0 | 00.00 | 0.06 | 0.12 | 0.09 | 0.02 |
| 1990 | 1289 | 0 | 0 | 0 | 0.01 | 0.14 | 0.35 | 0.26 | 0.07 | 0 | 0 | 00.00 | 0.04 | 0.07 | 0.05 | 0.01 |
| 1991 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1992 | 2566 | 0 | 0 | 0 | 0.02 | 0.20 | 0.27 | 0.14 | 0.09 | 0 | 0 | 00.00 | 0.08 | 0.13 | 0.06 | 0.02 |
| 1993 | 17804 | 0 | 0 | 0 | 0.01 | 0.23 | 0.39 | 0.23 | 0.03 | 0 |  | 00.00 | 0.02 | 0.04 | 0.03 | 0.01 |
| 1994 | 404 | 0 | 0 | 0 | 0.02 | 0.09 | 0.08 | 0.07 | 0.02 | 0 | 0 | 00.02 | 0.19 | 0.25 | 0.20 | 0.05 |
| 1995 | 1167 | 0 | 0 | 0 | 0.04 | 0.26 | 0.29 | 0.15 | 0.05 | 0 |  | 00.01 | 0.05 | 0.07 | 0.06 | 0.01 |
| 1996 | 787 | 0 | 0 | 0 | 0.03 | 0.22 | 0.24 | 0.09 | 0.05 | 0 |  | 00.01 | 0.12 | 0.14 | 0.08 | 0.02 |
| 19 | 1198 | 0 | 0 | 0 | 0.03 | 0.37 | 0.34 | 0.10 | 0.03 | 0 | ) | 00.00 | 0.06 | 0.04 | 0.03 | 0.01 |
| 1998 | 1055 | 0 | 0 | 0 | 0.03 | 0.23 | 0.24 | 0.08 | 0.03 | 0 |  | 00.02 | 0.11 | 0.14 | 0.08 | 0.03 |
| 199 | 562 | 0 | 0 | 0 | 0.06 | 0.29 | 0.24 | 0.18 | 0.09 | 0 |  | 00.00 | 0.02 | 0.05 | 0.04 | 0.00 |
| 2000 | 17213 | 0 | 0 | 0 | 0.02 | 0.30 | 0.39 | 0.11 | 0.02 | 0 | 0 | 00.00 | 0.05 | 0.07 | 0.04 | 0.01 |
| 2001 | 20030 | 0 | 0 | 0 | 0.02 | 0.22 | 0.37 | 0.21 | 0.07 | 0 |  | 00.00 | 0.02 | 0.05 | 0.02 | 0.01 |
| 2002 | 5219 | 0 | 0 | 0 | 0.04 | 0.23 | 0.28 | 0.25 | 0.07 | 0 | 0 | 00.00 | 0.03 | 0.04 | 0.03 | 0.01 |
| 2003 | 5226 | 0 | 0 | 0 | 0.02 | 0.37 | 0.32 | 0.12 | 0.03 | 0 |  | 00.00 | 0.02 | 0.05 | 0.05 | 0.01 |
| 2004 | 9606 | 0 | 0 | 0 | 0.01 | 0.38 | 0.39 | 0.11 | 0.03 | 0 | 0 | 00.00 | 0.03 | 0.03 | 0.01 | 0.01 |
| 2005 | 5360 | 0 |  | 0 | 0.00 | 0.25 | 0.47 | 0.16 | 0.02 | 0 | 0 | 00.00 | 0.02 | 0.05 | 0.02 | 0.01 |
| 2006 | 6707 | 0 | 0 | 0 | 0.00 | 0.18 | 0.35 | 0.17 | 0.02 | 0 | 0 | 00.00 | 0.05 | 0.14 | 0.07 | 0.01 |
| 2007 | 6125 | 0 | 0 | 0 | 0.01 | 0.36 | 0.34 | 0.14 | 0.03 | 0 | 0 | 00.00 | 0.02 | 0.06 | 0.03 | 0.01 |
| 2008 | 5766 | 0 | 0 | 0 | 0.00 | 0.35 | 0.35 | 0.06 | 0.01 | 0 |  | 00.00 | 0.09 | 0.09 | 0.04 | 0.01 |
| 2009 | 6026 | 0 | 0 | 0 | 0.01 | 0.34 | 0.33 | 0.11 | 0.02 | 0 | 0 | 00.00 | 0.08 | 0.08 | 0.02 | 0.01 |
| 2010 | 5902 | 0 |  | 0 | 0.01 | 0.39 | 0.36 | 0.10 | 0.01 | 0 |  | 00.00 | 0.05 | 0.05 | 0.02 | 0.00 |
| 2011 | 2552 | 0 | 0 | 0 | 0.00 | 0.32 | 0.40 | 0.12 | 0.02 | 0 | 0 | 00.00 | 0.06 | 0.06 | 0.02 | 0.00 |
| 2012 | 5056 | 0 | 0 | 0 | 0.00 | 0.24 | 0.46 | 0.18 | 0.02 | 0 | 0 | 00.00 | 0.03 | 0.04 | 0.02 | 0.00 |
| 2013 | 6072 | 0 | 0 | 0 | 0.00 | 0.24 | 0.37 | 0.24 | 0.06 | 0 | 0 | 00.00 | 0.01 | 0.04 | 0.02 | 0.00 |
| 2014 | 4682 | 0 | 0 | 0 | 0.01 | 0.28 | 0.24 | 0.18 | 0.07 | 0 | 0 | 00.00 | 0.04 | 0.09 | 0.07 | 0.02 |
| 2015 | 4173 | 0 | 0 | 0 | 0.01 | 0.48 | 0.28 | 0.10 | 0.03 | 0 | 0 | 00.00 | 0.02 | 0.03 | 0.03 | 0.01 |

## Model 13 data

| New Shell |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year | Sample | $\begin{gathered} 64- \\ 68 \end{gathered}$ | $\begin{aligned} & \text { 79- } \\ & 73 \end{aligned}$ | $\begin{gathered} 74- \\ 78 \end{gathered}$ | $\begin{aligned} & 79- \\ & 83 \end{aligned}$ | 84-88 | 89-93 | $\begin{aligned} & 94- \\ & 98 \end{aligned}$ | $\begin{aligned} & 99- \\ & 103 \end{aligned}$ | $\begin{aligned} & 104- \\ & 108 \end{aligned}$ |  | $\begin{gathered} 114- \\ 118 \end{gathered}$ |  | $\begin{gathered} 124- \\ 128 \end{gathered}$ | $\begin{gathered} 129- \\ 133 \end{gathered}$ | 134+ |
| 1977 | 1549 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.15 | 0.27 | 0.22 | 0.12 | 0.05 | 0.02 | 0.05 |
| 1978 | 389 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.01 | 0.04 | 0.14 | 0.23 | 0.24 | 0.17 | 0.10 | 0.04 |
| 197 | 1660 | 0 | 0 | 0 |  | 0.00 | 0.00 | 0.00 | 0.03 | 0.09 | 0.1 | 0.20 | 0.19 | 0.16 | 0.10 | 0.07 |
| 1980 | 1068 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.05 | 0.12 | 0.18 | 0.19 | 0.18 | 0.18 |
| 198 | 1784 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.05 | 0.06 | 0.09 | 0.13 | 0.15 | 0.23 |
| 1982 | 1093 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.04 | 0.09 | 0.10 | 0.07 | 0.09 | 0.10 | 0.12 | 0.29 |
| 1983 | 802 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.04 | 0.16 | 0.25 | 0.23 | 0.13 | 0.04 | 0.02 | 0.03 |
| 198 | 963 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.01 | 0.09 | 0.21 | 0.21 | 0.16 | 0.12 | 0.04 | 0.02 | 0.01 |
| 1985 | 2691 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.06 | 0.14 | 0.17 | 0.19 | 0.19 | 0.11 | 0.05 | 0.02 |
| 198 | 1138 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.03 | 0.14 | 0.22 | 0.23 | 0.16 | 0.08 | 0.04 | 0.02 |
| 1987 | 1985 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.02 | 0.05 | 0.13 | 0.14 | 0.15 | 0.14 | 0.13 | 0.11 |
| 198 | 1522 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.02 | 0.06 | 0.14 | 0.16 | 0.15 | 0.10 | 0.08 | 0.04 |
| 198 | 2595 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.01 | 0.07 | 0.10 | 0.15 | 0.16 | 0.11 | 0.06 | 0.05 |
| 199 | 1289 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.01 | 0.05 | 0.09 | 0.17 | 0.18 | 0.16 | 0.10 | 0.07 |
| 1991 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 19 | 2566 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.02 | 0.08 | 0.12 | . 1 | 0.12 | 0.0 | 0.05 | 0.09 |
| 1993 | 17804 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.01 | 0.09 | 0.14 | 0.19 | 0.20 | 0.15 | 0.08 | 0.03 |
| 1994 | 404 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.02 | 0.04 | 0.05 | 0.03 | 0.05 | 0.04 | 0.03 | 0.02 |
| 1995 | 1167 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.04 | 0.10 | 0.17 | 0.15 | 0.14 | 0.09 | 0.06 | 0.05 |
| 1996 | 787 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.03 | 0.10 | 0.12 | 0.13 | 0.11 | 0.05 | 0.04 | 0.05 |
| 199 | 1198 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.03 | 0.1 |  | 0.22 | 0.13 | 0.07 | 0.03 | 0.03 |
| 1998 | 1055 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.02 | 0.08 | 0.16 | 0.14 | 0.11 | 0.05 | 0.03 | 0.03 |
| 199 | 562 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.06 | 0.13 | 0.17 | 0.12 | 0.12 | 0.11 | 0.08 | 0.09 |
| 2000 | 17213 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.02 | 0.10 | 0.19 | 0.23 | 0.16 | 0.08 | 0.03 | 0.02 |
| 2001 | 20030 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.02 | 0.09 | 0.14 | 0.21 | 0.16 | 0.13 | 0.07 | 0.07 |
| 200 | 5219 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.04 | 0.10 | 0.13 | 0.13 | 0.15 | 0.15 | 0.10 | 0.07 |
| 2003 | 5226 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.02 | 0.14 | 0.23 | 0.20 | 0.12 | 0.07 | 0.05 | 0.03 |
| 2004 | 9606 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.01 | 0.11 | 0.28 | 0.24 | 0.15 | 0.07 | 0.04 | 0.03 |
| 2005 | 5360 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.20 | 0.26 | 0.21 | 0.12 | 0.04 | 0.02 |
| 2006 | 6707 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.14 | 0.18 | 0.17 | 0.12 | 0.06 | 0.02 |
| 2007 | 6125 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.01 | 0.13 | 0.23 | 0.19 | 0.15 | 0.09 | 0.05 | 0.03 |
| 2008 | 5766 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 |  | 0.23 | 0.12 | 0.04 | 0.01 | 0.01 |
| 2009 | 6026 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.01 | 0.12 | 0.22 | 0.19 | 0.14 | 0.08 | 0.04 | 0.02 |
| 2010 | 5902 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.01 | 0.11 | 0.28 | 0.23 | 0.13 | 0.07 | 0.03 | 0.01 |
| 2011 | 2552 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 0.23 | 0.25 | 0.15 | 0.08 | 0.04 | 0.02 |
| 2012 | 5056 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.06 | 0.18 | 0.25 | 0.21 | 0.13 | 0.05 | 0.02 |
| 2013 | 6072 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 |  |  | 0.18 | 0.15 | 0.10 | 0.06 |
| 2014 | 4682 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.01 | 0.11 | 0.17 | 0.13 | 0.11 | 0.09 | 0.09 | 0.07 |
| 2015 | 4173 | 0 | 0 | 0 | 0 | 0.00 | 0.00 | 0.00 | 0.01 | 0.19 |  |  | 0.10 | 0.06 | 0.04 | 0.03 |

## Model 13 data

| Old Shell |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year | Sample | $\begin{gathered} 64- \\ 68 \end{gathered}$ | $\begin{aligned} & \hline 79- \\ & 73 \end{aligned}$ | $\begin{gathered} 74- \\ 78 \end{gathered}$ | $\begin{array}{cc} \hline 79- & 84-88 \\ 83 & 84 \end{array}$ | 89-93 | $\begin{gathered} 94- \\ 98 \end{gathered}$ | $\begin{aligned} & 99- \\ & 103 \end{aligned}$ | $\begin{array}{cc} \hline 104- & 109- \\ 108 & 113 \end{array}$ | $\begin{array}{cc} 114- & 119- \\ 118 & 123 \end{array}$ | $\begin{gathered} 124- \\ 128 \end{gathered}$ | $\begin{gathered} \hline 129- \\ 133 \end{gathered}$ | 134+ |
| 1977 | 1549 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.020 .04 | 0.030 .01 | 0.01 | 0.00 | 0.00 |
| 1978 | 389 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.000 .00 | 0.000 .01 | 0.01 | 0.00 | 0.00 |
| 19 | 1660 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.000 .03 | 0.000 .00 | 0.00 | 0.00 | 0.01 |
| 1980 | 1068 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.000 .00 | 0.000 .01 | 0.01 | 0.01 | 0.01 |
| 198 | 1784 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.000 .00 | 0.020 .03 | 0.05 | 0.07 | 0.09 |
| 1982 | 1093 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .01 | 0.010 .01 | 0.01 | 0.02 | 0.03 |
| 1983 | 802 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .02 | 0.010 .00 | 0.01 | 0.01 | 0.02 |
| 198 | 963 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.01 | 0.040 .03 | 0.030 .02 | 0.00 | 0.00 | 0.00 |
| 1985 | 2691 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .02 | 0.020 .01 | 0.01 | 0.00 | 0.00 |
| 1986 | 1138 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .01 | 0.020 .02 | 0.02 | 0.01 | 0.00 |
| 1987 | 1985 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .02 | 0.030 .03 | 0.02 | 0.01 | 0.01 |
| 1988 | 1522 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.01 | 0.030 .04 | 0.050 .05 | 0.05 | 0.02 | 0.02 |
| 1989 | 2595 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.020 .03 | 0.060 .06 | 0.06 | 0.03 | 0.02 |
| 199 | 1289 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.0 | 0.010 .03 | 0.03 | 0.03 | 0.02 | 0.01 |
| 1991 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1992 | 2566 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | , 0.05 | 0.0 | 0.03 | 0.03 | 0.02 |
| 1993 | 17804 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .01 | 0.020 .02 | 0.02 | 0.01 | 0.01 |
| 1994 | 404 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.02 | 0.090 .10 | 0.100 .15 | 0.11 | 0.09 | 0.05 |
| 1995 | 1167 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.0 | 0.020 .03 | 0.030 .04 | 0.04 | 0.03 | 0.01 |
| 1996 | 787 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.01 | 0.050 .07 | 0.080 .06 | 0.04 | 0.03 | 0.02 |
| 1997 | 1198 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.0 | 0.030 .03 | 0.020 .02 | 0.02 | 0.01 | 0.01 |
| 1998 | 1055 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.02 | 0.050 .06 | 0.080 .06 | 0.05 | 0.04 | 0.03 |
| 1999 | 562 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .01 | 0.030 .02 | 0.04 | 0.01 | 0.00 |
| 2000 | 17213 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.020 .03 | 0.030 .03 | 0.02 | 0.01 | 0.01 |
| 2001 | 20030 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .02 | 0.030 .02 | 0.02 | 0.01 | 0.01 |
| 2002 | 5219 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .02 | 0.020 .02 | 0.02 | 0.01 | 0.01 |
| 2003 | 5226 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .01 | 0.020 .02 | 0.03 | 0.02 | 0.01 |
| 2004 | 9606 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .02 | 0.020 .01 | 0.01 | 0.01 | 0.01 |
| 2005 | 5360 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.000 .02 | 0.030 .02 | 0.01 | 0.01 | 0.01 |
| 2006 | 6707 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .04 | 0.070 .07 | 0.05 | 0.02 | 0.01 |
| 2007 | 6125 |  | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .02 | 0.020 .03 | 0.02 | 0.01 | 0.01 |
| 2008 | 5766 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.030 .06 | 0.050 .04 | 0.02 | 0.01 | 0.01 |
| 2009 | 6026 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.020 .05 | 0.050 .03 | 0.01 | 0.01 | 0.01 |
| 2010 | 5902 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.020 .04 | 0.030 .02 | 0.02 | 0.01 | 0.00 |
| 2011 | 2552 | 0 | 0 |  | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.020 .04 | 0.030 .02 | 0.01 | 0.00 | 0.00 |
| 2012 | 5056 | 0 | 0 |  | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .02 | 0.020 .02 | 0.01 | 0.01 | 0.00 |
| 2013 | 6072 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.000 .01 | 0.020 .02 | 0.01 | 0.01 | 0.00 |
| 2014 | 4682 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .03 | 0.040 .05 | 0.04 | 0.03 | 0.02 |
| 2015 | 4173 | 0 | 0 | 0 | $0 \quad 0.00$ | 0.00 | 0.00 | 0.00 | 0.010 .01 | 0.010 .02 | 0.02 | 0.01 | 0.01 |

Table 5. Summer Trawl Survey size/shell compositions.
Model 5 data

|  |  |  | New Shell |  |  |  |  | Old Shell |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | mp | $64-$ | $\begin{array}{cc} \hline 74- & 84- \\ 83 & 93 \end{array}$ | $\begin{aligned} & 94- \\ & 10 \end{aligned}$ | $\begin{gathered} \hline 104- \\ 113 \end{gathered}$ | $\begin{aligned} & \hline 114- \\ & 123 \end{aligned}$ | $\begin{array}{ll} \hline 124- \\ 133 & 134+ \end{array}$ | $\begin{gathered} 64- \\ 73 \end{gathered}$ | $\begin{array}{cc} \hline 74- & 84- \\ 83 & 93 \end{array}$ | $\begin{aligned} & 94- \\ & 103 \end{aligned}$ | $\begin{gathered} \hline 104- \\ 113 \end{gathered}$ | $\begin{aligned} & \hline 114- \\ & 123 \end{aligned}$ | $24-$ |
| 1976 | 1326 |  | 0.020 .10 | 0.1 | 0. | 0. | 0.020 .00 | 0.00 | 0.00 | 0.02 | 0.03 | 0.04 | 0.010 .0 |
| 1979 | 220 |  | 0.00 | 0.02 | 0.05 | 0.0 | . 03 |  | 0.0 | 0.0 | 0.14 | 0.40 | 0.1 |
| 1982 | 327 | 0.22 | 0.070 .16 | 0.2 | 0.17 | 0.0 | . 00 | 0.0 | 0.000 .01 | 0. | 0.03 | 0.02 | 0.0 |
| 1985 | 350 |  | 0.19 | 0.17 | 0.16 | 0.06 | 0.01 | 0.00 | . 00.00 | 0.02 | 0.0 | 0.08 | 0.0 |
|  | 36 |  | 0.190 .12 | 0.13 | 0.11 | . 06 | . 03 | 0. | 0.000 .01 | 0.0 | 0.03 | 0.0 | 0.050 .03 |
|  |  |  | 0.02 | 0.03 | 0.06 | . 0 | . 01 | 0. | . 02 | 0.0 | 0.1 | 0.1 | 0.090 .02 |
| 1996 | 26 |  | 0.210 .13 | 0.09 | . 05 | 0.00 | . 00 | 0.0 | 0.03 | 0.0 | 0.0 | 0.04 | 0.0 |
|  | 283 |  | 0.010 .10 | 0.29 | 26 | 0.13 | 0.030 .01 | 0. | 0.000 .00 | 0.03 | 0.05 | 0.04 | 0.02 |
|  |  |  | 0.120 .14 | 0.11 | 02 | 0.03 | . 02 |  | 030.07 | 0.10 | 0.0 | 0.0 | 0.050 .0 |
|  |  |  | 60.21 | 0.11 | 06 | 0.04 | . 02 | 0.0 | 000.00 | 0.02 | 0.0 | 0.04 | 0.0 |
| 2008 | 27 |  |  | 0.11 | 0.10 | 0.03 | . 020.01 | 0.00 | 0. 04 | 0.06 | 0.08 | 0.01 | 0.0 |
| 2010 |  | . 01 | 0.06 | 0.17 | 0.06 | 0.03 | . 000. | 0.0 | 030.09 | 0.20 | 9 | 0.07 | 0.03 |
| 20 | 315 | 0.13 | 0.110 .09 | 0.11 | 0.18 | 0.14 | 0.030 .01 | 0.00 | 0.000 .01 | 0.02 | 0.09 | 0.04 | 0.030 .00 |
| 014 | 391 | 0.08 | 0.150 .24 | 0.18 | 0.09 | 0.02 | 0.010 .01 | 0.00 | 0.000 .03 | 0.10 | 0.05 | 0.04 | 0.010. |

Model 13 data

| New Shell |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year Sample | $64-$ | $79-$ | $74-$ | $79-$ | $84-$ | $89-$ | $94-$ | $99-$ | $104-$ | $109-$ | $114-$ | $119-$ | $124-$ | $129-$ | $134+$ |  |
| 1976 | 1326 | 0.00 | 0.01 | 78 | 83 | 88 | 93 | 98 | 103 | 108 | 113 | 118 | 123 | 128 | 133 |  |
| 1979 | 220 | 0.00 | 0.01 | 0.00 | 0.02 | 0.04 | 0.06 | 0.08 | 0.10 | 0.16 | 0.18 | 0.13 | 0.05 | 0.02 | 0.01 | 0.00 |
| 1982 | 327 | 0.14 | 0.08 | 0.04 | 0.03 | 0.06 | 0.10 | 0.09 | 0.14 | 0.10 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 |
| 1985 | 350 | 0.05 | 0.06 | 0.05 | 0.05 | 0.08 | 0.11 | 0.09 | 0.08 | 0.08 | 0.08 | 0.03 | 0.03 | 0.01 | 0.00 | 0.00 |
| 1988 | 366 | 0.09 | 0.08 | 0.10 | 0.09 | 0.06 | 0.06 | 0.07 | 0.06 | 0.06 | 0.04 | 0.03 | 0.02 | 0.02 | 0.01 | 0.00 |
| 1991 | 340 | 0.09 | 0.09 | 0.06 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.04 | 0.03 | 0.00 | 0.01 | 0.01 | 0.01 |
| 1996 | 269 | 0.09 | 0.20 | 0.10 | 0.11 | 0.07 | 0.06 | 0.06 | 0.03 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| 1999 | 283 | 0.02 | 0.01 | 0.00 | 0.01 | 0.03 | 0.07 | 0.10 | 0.19 | 0.14 | 0.12 | 0.09 | 0.04 | 0.03 | 0.00 | 0.01 |
| 2002 | 244 | 0.07 | 0.03 | 0.07 | 0.05 | 0.06 | 0.07 | 0.07 | 0.05 | 0.01 | 0.00 | 0.01 | 0.02 | 0.02 | 0.00 | 0.01 |
| 2006 | 373 | 0.08 | 0.11 | 0.12 | 0.14 | 0.11 | 0.10 | 0.06 | 0.06 | 0.04 | 0.02 | 0.01 | 0.03 | 0.01 | 0.01 | 0.00 |
| 2008 | 275 | 0.07 | 0.06 | 0.07 | 0.08 | 0.11 | 0.11 | 0.05 | 0.06 | 0.06 | 0.04 | 0.03 | 0.00 | 0.01 | 0.01 | 0.01 |
| 2010 | 69 | 0.00 | 0.01 | 0.01 | 0.03 | 0.04 | 0.01 | 0.09 | 0.09 | 0.03 | 0.03 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 |
| 2011 | 315 | 0.05 | 0.08 | 0.09 | 0.03 | 0.04 | 0.05 | 0.05 | 0.06 | 0.07 | 0.11 | 0.08 | 0.06 | 0.03 | 0.01 | 0.01 |
| 2014 | 391 | 0.04 | 0.04 | 0.06 | 0.09 | 0.10 | 0.14 | 0.11 | 0.07 | 0.06 | 0.03 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |

Model 13 data

| Old Shell |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year Sample | $64-$ | $79-$ | $74-$ | $79-$ | $84-$ | $89-$ | $94-$ | $99-$ | $104-$ | $109-$ | $114-$ | $119-$ | $124-$ | $129-$ | $134+$ |  |  |  |  |
| 1976 | 1326 | 0.00 | 0.00 | 78 | 83 | 88 | 93 | 98 | 103 | 108 | 113 | 118 | 123 | 128 | 133 |  |  |  |  |
| 1979 | 220 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.00 | 0.01 | 0.01 |  |  |  |
| 1982 | 327 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 |  |  |  |
| 1985 | 350 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.03 | 0.04 | 0.04 | 0.03 | 0.02 | 0.01 |  |  |  |
| 1988 | 366 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.03 | 0.03 | 0.04 | 0.03 | 0.02 | 0.03 |  |  |  |
| 1991 | 340 | 0.01 | 0.02 | 0.04 | 0.02 | 0.01 | 0.01 | 0.04 | 0.04 | 0.08 | 0.08 | 0.07 | 0.07 | 0.05 | 0.04 | 0.02 |  |  |  |
| 1996 | 269 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.01 | 0.02 | 0.02 | 0.03 | 0.02 | 0.02 | 0.02 | 0.02 | 0.03 |  |  |  |
| 1999 | 283 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.01 | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 | 0.00 | 0.00 |  |  |  |
| 2002 | 244 | 0.00 | 0.01 | 0.01 | 0.02 | 0.02 | 0.05 | 0.06 | 0.05 | 0.05 | 0.04 | 0.05 | 0.04 | 0.03 | 0.02 | 0.02 |  |  |  |
| 2006 | 373 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.00 | 0.00 |  |  |  |
| 2008 | 275 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.03 | 0.02 | 0.04 | 0.03 | 0.05 | 0.00 | 0.01 | 0.01 | 0.02 | 0.00 |  |  |  |
| 2010 | 69 | 0.00 | 0.00 | 0.03 | 0.00 | 0.04 | 0.04 | 0.07 | 0.13 | 0.06 | 0.13 | 0.07 | 0.00 | 0.01 | 0.01 | 0.01 |  |  |  |
| 2011 | 315 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.05 | 0.04 | 0.02 | 0.03 | 0.01 | 0.02 | 0.00 |  |  |  |
| 2014 | 391 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.05 | 0.05 | 0.02 | 0.03 | 0.03 | 0.01 | 0.01 | 0.00 | 0.00 |  |  |  |

Table 6. Winter pot survey size/shell compositions.
Model 5 data

|  |  |  |  | New Shell |  |  |  |  |  |  | Old Shell |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year | CPUE | Sample | 64-73 | 74-83 | $\begin{aligned} & \hline 84- \\ & 93 \end{aligned}$ | $\begin{aligned} & \hline 94- \\ & 103 \end{aligned}$ | $\begin{aligned} & \hline 104- \\ & 113 \end{aligned}$ | $\begin{aligned} & \hline 114- \\ & 123 \end{aligned}$ | $\begin{aligned} & \hline 124- \\ & 133 \end{aligned}$ | 134+ | $\begin{aligned} & \hline 64- \\ & 73 \end{aligned}$ | $\begin{aligned} & \hline 74- \\ & 83 \end{aligned}$ | 84-93 | $\begin{aligned} & \hline 94- \\ & 103 \end{aligned}$ | $\begin{aligned} & \hline 104- \\ & 113 \end{aligned}$ | $\begin{aligned} & 114- \\ & 123 \end{aligned}$ | $\begin{aligned} & \hline 124- \\ & 133 \end{aligned}$ | 134+ |
| 1981/82 | NA | 719 | 0.00 | 0.10 | 0.23 | 0.21 | 0.07 | 0.02 | 0.02 | 0.00 | 0.00 | 0.05 | 0.11 | 0.11 | 0.04 | 0.02 | 0.02 | 0.00 |
| 1982/83 | 24.2 | 2583 | 0.03 | 0.08 | 0.28 | 0.28 | 0.21 | 0.07 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.01 | 0.01 | 0.01 |
| 1983/8 | 24.0 | 1677 | 0.01 | 0.16 | 0.26 | 0.23 | 0.15 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.06 | 0.03 | 0.01 | . 01 |
| 1984/85 | 24. | 789 | 0.02 | 0.09 | 0.25 | 0.35 | 0.16 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.03 | 0.02 | 0.00 | 0.00 |
| 1985/86 | 19.2 | 594 | 0.04 | 0.12 | 0.17 | 0.24 | 0.19 | 0.08 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.06 | 0.04 | 0.01 | 0.00 |
| 1986/87 | 5.8 | 144 | 0.00 | 0.06 | 0.15 | 0.19 | 0.07 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.04 | 0.30 | 0.11 | 0.03 | 0.00 |
| 1987/88 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1988/89 | 13.0 | 500 | 0.02 | 0.13 | 0.15 | 0.13 | 0.19 | 0.17 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.08 | 0.03 | 0.00 |
| 1989/90 | 21.0 | 2076 | 0.00 | 0.05 | 0.21 | 0.26 | 0.18 | 0.12 | 0.06 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.06 | 0.02 | . 00 |
| 1990/91 | 22.9 | 1283 | 0.00 | 0.01 | 0.09 | 0.29 | 0.27 | 0.10 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.12 | 0.07 | . 02 |
| 1992/93 | 5.5 | 181 | 0.00 | 0.01 | 0.03 | 0.06 | 0.13 | 0.12 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.19 | 0.27 | 0.10 | 0.05 |
| 1993/94 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1994/95 | 6.2 | 858 | 0.01 | 0.0 | 0.08 | 0.10 | 0.26 | 0.23 | 0.07 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.03 | 0.07 | 0.06 | 0.02 |
| 1995/96 | 9.9 | 1580 | 0.06 | 0.14 | 0.20 | 0.19 | 0.11 | 0.07 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.06 | 0.07 | 0.03 | 0.01 |
| 1996/97 | 2.9 | 398 | 0.07 | 0.21 | 0.22 | 0.11 | 0.15 | 0.11 | 0.05 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.03 | 0.01 | 0.01 |
| 1997/98 | 10.9 | 881 | 0.00 | 0.1 | 0.41 | 0.27 | 0.05 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.03 | 0.02 | 0.02 | 0. |
| 1998/99 | 10.7 | 1307 | 0.00 | 0.02 | 0.12 | 0.36 | 0.36 | 0.08 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.01 | 0.01 | 0.00 |
| 1999/00 | 6.2 | 575 | 0.02 | 0.09 | 0.10 | 0.16 | 0.33 | 0.18 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.05 | 0.02 | 0.01 | 0.00 |
| 2000/01 | 3.1 | 44 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2001/02 | 13.0 | 828 | 0.05 | 0.29 | 0.26 | 0.17 | 0.06 | 0.06 | 0.04 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 |
| 2002/03 | 9.6 | 824 | 0.02 | 0.10 | 0.22 | 0.28 | 0.18 | 0.06 | 0.02 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.02 | 0.01 |
| 2003/04 | 3.7 | 296 | 0.00 | 0.02 | 0.16 | 0.26 | 0.32 | 0.14 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.01 |
| 2004/05 | 4.4 | 405 | 0.00 | 0.07 | 0.14 | 0.18 | 0.22 | 0.19 | 0.07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.06 | 0.01 | 0.00 |
| 2005/06 | 6.0 | 512 | 0.00 | 0.14 | 0.23 | 0.21 | 0.16 | 0.05 | 0.02 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.04 | 0.07 | 0.03 | 0.01 |
| 2006/07 | 7.3 | 159 | 0.07 | 0.14 | 0.19 | 0.35 | 0.13 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.04 | 0.00 | 0.00 |
| 2007/08 | 25.0 | 3552 | 0.01 | 0.14 | 0.25 | 0.17 | 0.14 | 0.07 | 0.01 | 0.00 | 0.01 | 0.04 | 0.07 | 0.03 | 0.03 | 0.01 | 0.01 | 0.00 |
| 2008/09 | 21.9 | 525 | 0.00 | 0.07 | 0.13 | 0.35 | 0.20 | 0.08 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.04 | 0.10 | 0.00 | 0.00 |
| 2009/10 | 25.3 | 578 | 0.01 | 0.05 | 0.13 | 0.21 | 0.24 | 0.11 | 0.02 | 0.00 | 0.00 | 0.00 | 0.01 | 0.06 | 0.10 | 0.05 | 0.01 | 0.00 |
| 2010/11 | 22.1 | 596 | 0.02 | 0.08 | 0.13 | 0.20 | 0.17 | 0.13 | 0.05 | 0.00 | 0.00 | 0.00 | 0.01 | 0.03 | 0.11 | 0.05 | 0.01 | 0.00 |
| 2011/12 | 29.4 | 675 | 0.03 | 0.11 | 0.23 | 0.19 | 0.12 | 0.13 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.05 | 0.05 | 0.03 | 0.00 |

## Model 13 data

| New Shell |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year | CPUE | Sample | 64-68 | $\begin{array}{ccc} \hline & 74- & 79- \\ 79-73 & 78 & 83 \end{array}$ | 84-88 | 89-93 | 94-98 | $\begin{array}{lcc} \hline 99- & 104-109- \\ 103 & 108 & 113 \end{array}$ | $\begin{gathered} 114- \\ 118 \end{gathered}$ | $\begin{gathered} 119- \\ 123 \end{gathered}$ | $\begin{gathered} 124- \\ 128 \end{gathered}$ | $\begin{gathered} 129- \\ 133 \end{gathered}$ | 134+ |
| 1981/82 | NA | 719 | 0.00 | 0.000 .030 .07 | 0.09 | 0.13 | 0.12 | 0.090 .040 .03 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 |
| 1982/83 | 24.2 | 2583 | 0.01 | 0.020 .030 .06 | 0.12 | 0.16 | 0.14 | 0.140 .110 .10 | 0.05 | 0.02 | 0.01 | 0.00 | 0.00 |
| 1983/84 | 24.0 | 1677 | 0.00 | 0.010 .050 .11 | 0.14 | 0.11 | 0.12 | 0.110 .090 .06 | 0.04 | 0.02 | 0.00 | 0.00 | 0.00 |
| 1984/85 | 24.5 | 789 | 0.01 | 0.010 .030 .06 | 0.09 | 0.16 | 0.21 | 0.140 .100 .05 | 0.04 | 0.02 | 0.00 | 0.00 | 0.00 |
| 1985/86 | 19.2 | 594 | 0.01 | 0.030 .060 .07 | 0.07 | 0.10 | 0.13 | 0.120 .090 .10 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 |
| 1986/87 | 5.8 | 144 | 0.00 | 0.000 .020 .03 | 0.06 | 0.10 | 0.09 | 0.100 .030 .04 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 |
| 1987/88 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1988/89 | 13.0 | 500 | 0.00 | 0.010 .050 .08 | 0.10 | 0.05 | 0.06 | 0.080 .100 .09 | 0.11 | 0.06 | 0.02 | 0.01 | 0.00 |
| 1989/90 | 21.0 | 2076 | 0.00 | 0.000 .010 .04 | 0.08 | 0.13 | 0.14 | 0.120 .090 .09 | 0.06 | 0.06 | 0.04 | 0.02 | 0.01 |
| 1990/91 | 22.9 | 1283 | 0.00 | 0.000 .010 .00 | 0.03 | 0.06 | 0.12 | 0.170 .150 .11 | 0.07 | 0.03 | 0.01 | 0.00 | 0.00 |
| 1992/93 | 5.5 | 181 | 0.00 | 0.00 | 0.01 | 0.03 | 0.03 | 0.020 .060 .07 | 0.09 | 0.03 | 0.02 | 0. | 00 |
| 1993/94 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1994/95 | 6.2 | 858 | 0.00 | 0 | 0.0 | 0.0 | 0.0 | 0.050 .110 .15 | 0.14 | 0.10 | 0.05 | 0. | 1 |
| 1995/96 | 9.9 | 1580 | 0.02 | 0.050 .060 .07 | 0.08 | 0.12 | 0.11 | 0.090 .070 .05 | 0.03 | 0.03 | 0.02 | 0.01 | 0.00 |
| 1996/97 | 2.9 | 398 | 0.01 | 0.060 .110 .11 | 0.12 | 0.10 | 0.06 | 0.050 .060 .09 | 0.06 | 0.05 | 0.02 | 0.03 | 0.01 |
| 1997/98 | 10.9 | 881 | 0.00 | 0.000 .03 | 0.19 | 0.22 | 0.16 | 0.100 .040 .02 | 0.02 | 0.01 | 0.00 | 0.0 | 0.00 |
| 1998/99 | 10.7 | 1307 | 0.00 | 0.000 .010 .01 | 0.04 | 0.08 | 0.14 | 0.220 .220 .14 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 |
| 1999/00 | 6.2 | 575 | 0.01 | 0.010 .040 .05 | 0.04 | 0.06 | 0.07 | 0.090 .150 .18 | 0.12 | 0.06 | 0.03 | 0.00 | 0.00 |
| 2000/01 | 3. | 44 |  |  |  |  |  |  |  |  |  |  |  |
| 2001/02 | 13.0 | 828 | 0.01 | 0.040 .130 .17 | 0.14 | 0.12 | 0.10 | 0.070 .040 .03 | 0.03 | 0.03 | 0.03 | 0.01 | 0.01 |
| 2002/03 | 9.6 | 824 | 0.01 | 0.010 .040 .06 | 0.09 | 0.13 | 0.16 | 0.120 .100 .08 | 0.04 | 0.02 | 0.01 | 0.01 | 0.00 |
| 2003/04 | 3.7 | 296 | 0.00 | 0.000 .000 .01 | 0.04 | 0.12 | 0.12 | 0.140 .140 .18 | 0.10 | 0.04 | 0.01 | 0.01 | 0.00 |
| 2004/05 | 4.4 | 405 | 0.00 | 0.000 .030 .04 | 0.06 | 0.08 | 0.08 | 0.100 .110 .10 | 0.11 | 0.08 | 0.04 | 0.03 | 0.00 |
| 2005/06 | 6.0 | 512 | 0.00 | 0.000 .040 .10 | 0.12 | 0.11 | 0.12 | 0.090 .090 .07 | 0.03 | 0.03 | 0.02 | 0.00 | 0.00 |
| 2006/07 | 7.3 | 159 | 0.03 | 0.040 .040 .09 | 0.03 | 0.16 | 0.19 | 0.160 .090 .04 | 0.02 | 0.03 | 0.00 | 0.00 | 0.00 |
| 2007/08 | 25.0 | 3552 | 0.00 | 0.010 .040 .11 | 0.12 | 0.13 | 0.09 | 0.080 .070 .07 | 0.04 | 0.02 | 0.00 | 0.00 | 0.00 |
| 2008/09 | 21.9 | 525 | 0.00 | 0.000 .020 .05 | 0.04 | 0.09 | 0.15 | 0.200 .130 .07 | 0.05 | 0.03 | 0.01 | 0.00 | 0.00 |
| 2009/10 | 25.3 | 578 | 0.00 | 0.010 .010 .03 | 0.04 | 0.09 | 0.09 | 0.120 .120 .12 | 0.08 | 0.03 | 0.01 | 0.01 | 0.00 |
| 2010/11 | 22.1 | 596 | 0.00 | 0.020 .020 .05 | 0.07 | 0.07 | 0.09 | 0.120 .080 .09 | 0.07 | 0.06 | 0.03 | 0.02 | 0.00 |
| 2011/12 | 29.4 | 675 | 0.00 | 0.020 .050 .06 | 0.11 | 0.12 | 0.10 | 0.090 .070 .05 | 0.06 | 0.07 | 0.03 | 0.01 | 0.00 |


| Old Shell |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year | CPUE | Sample | 64-68 | 79-73 | $\begin{array}{cc} \hline 74- & 79- \\ 78 & 83 \end{array}$ | 84-88 | 89-93 | 94-98 | $\begin{array}{lll} \hline 99- & 104-109- \\ 103 & 108 & 113 \end{array}$ | $\begin{aligned} & 114- \\ & 118 \end{aligned}$ | $\begin{gathered} \hline 119- \\ 123 \end{gathered}$ | $\begin{gathered} \hline 124- \\ 128 \end{gathered}$ | $\begin{gathered} \hline 129- \\ 133 \end{gathered}$ | 134+ |
| 1981/82 | NA | 719 | 0.00 | 0.00 | 0.020 .03 | 0.05 | 0.07 | 0.06 | 0.050 .030 .01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 |
| 1982/83 | 24. | 2583 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.000 .010 .01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 |
| 1983/84 | 24.0 | 1677 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.020 .030 .03 | 0.02 | 0.01 | 0.00 | 0.00 | 0.01 |
| 1984/85 | 24.5 | 789 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.010 .020 .01 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 |
| 1985/86 | 19.2 | 594 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.01 | 0.010 .030 .03 | 0.02 | 0.02 | 0.01 | 0.00 | 0.00 |
| 1986/87 | 5.8 | 144 | 0.00 | 0.00 | 0.000 .00 | 0.01 | 0.00 | 0.02 | 0.020 .150 .15 | 0.08 | 0.03 | 0.02 | 0.01 | 0.00 |
| 1987/88 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1988/89 | 13.0 | 500 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.000 .010 .04 | 0.05 | 0.04 | 0.02 | 0.01 | 0.00 |
| 1989/90 | 21.0 | 2076 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.000 .010 .02 | 0.03 | 0.03 | 0.01 | 0.01 | 0.00 |
| 1990/91 | 22.9 | 1283 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.000 .010 .02 | 0.05 | 0.07 | 0.04 | 0.03 | 0.02 |
| 1992/93 | 5.5 | 181 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.01 | 0.010 .060 .14 | 0.10 | 0.17 | 0.06 | 0.05 | 0.05 |
| 1993/94 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1994/95 | 6.2 | 858 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.000 .010 .02 | 0.03 | 0.04 | 0.03 | 0.03 | 0.02 |
| 1995/96 | 9.9 | 1580 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.010 .020 .04 | 0.04 | 0.03 | 0.02 | 0.01 | 0.01 |
| 1996/97 | 2.9 | 398 | 0.00 | 0.0 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.000 .020 .00 | 0.01 | 0.02 | 0.01 | 0.00 | 0.01 |
| 1997/98 | 10.9 | 881 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.01 | 0.000 .010 .02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| 1998/99 | 10.7 | 1307 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.010 .010 .02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1999/00 | 6.2 | 575 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.000 .020 .03 | 0.02 | 0.01 | 0.00 | 0.01 | 0.00 |
| 2000/01 | 3.1 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2001/02 | 13.0 | 828 | 0.00 | 0.01 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.000 .000 .00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 |
| 2002/03 | 9.6 | 824 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.01 | 0.010 .010 .01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 |
| 2003/04 | 3.7 | 296 | 0.00 | 0.00 | 0.000 .00 | 0.01 | 0.00 | 0.00 | 0.010 .000 .02 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 |
| 2004/05 | 4.4 | 405 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.000 .020 .02 | 0.04 | 0.02 | 0.01 | 0.00 | 0.00 |
| 2005/06 | 6.0 | 512 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.01 | 0.01 | 0.010 .020 .03 | 0.05 | 0.03 | 0.02 | 0.01 | 0.01 |
| 2006/07 | 7.3 | 159 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.01 | 0.00 | 0.010 .000 .02 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 |
| 2007/08 | 25.0 | 3552 | 0.00 | 0.01 | 0.010 .03 | 0.04 | 0.03 | 0.02 | 0.020 .020 .01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 |
| 2008/09 | 21.9 | 525 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.000 .010 .03 | 0.06 | 0.04 | 0.00 | 0.00 | 0.00 |
| 2009/10 | 25.3 | 578 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.01 | 0.02 | 0.040 .050 .05 | 0.03 | 0.03 | 0.01 | 0.00 | 0.00 |
| 2010/11 | 22.1 | 596 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.01 | 0.02 | 0.020 .050 .06 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 |
| 2011/12 | 29.4 | 675 | 0.00 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.010 .020 .04 | 0.03 | 0.03 | 0.02 | 0.01 | 0.00 |

Table 7. Summer commercial1987-1994, 2012-2015 observer discards size/shell compositions Model 5 data

|  |  |  |  |  |  | New Shell |  |  | Old Shell |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Y | mple | $\begin{aligned} & \hline 64- \\ & 73 \end{aligned}$ | $\begin{aligned} & \hline 74- \\ & 83 \end{aligned}$ | $\begin{gathered} \hline 84- \\ 93 \end{gathered}$ | $\begin{aligned} & \hline 94- \\ & 103 \end{aligned}$ | $\begin{aligned} & \hline 104- \\ & 113 \end{aligned}$ | $\begin{aligned} & 114- \\ & 123 \end{aligned}$ | $\begin{array}{ll}124-1 \\ 133 & 134+\end{array}$ | $\begin{gathered} \hline 64- \\ 73 \end{gathered}$ | $\begin{aligned} & \hline 74- \\ & 83 \end{aligned}$ | $\begin{aligned} & \hline 84- \\ & 93 \end{aligned}$ | $\begin{aligned} & 94- \\ & 103 \end{aligned}$ | $\begin{aligned} & \hline 104- \\ & 113 \end{aligned}$ | $\begin{aligned} & 114- \\ & 123 \end{aligned}$ | $\begin{array}{ll} \hline 124- \\ 133 & 134+ \end{array}$ |
| 1987 | 1146 | 0.0 | 0. | 0.32 | 0.33 | 0.03 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.02 | 0.04 | 0.00 | 0.00 | 0.000 .00 |
| 1988 | 722 | 0.01 | 0. | 0.15 | 0.48 | 0.14 | 0.00 | 0.000 .00 | 0.00 | 0.01 | 0.03 | 0.10 | 0.04 | 0.00 | 0.000 .00 |
| 1989 | 100 | . 0 | 0.1 | . 2 | 0.22 | 0.03 | 0.00 | 0.000 .00 | 0.02 | 0.0 | 0.07 | 0.11 | 0.03 | 0.00 | 0.000 .00 |
| 1990 | 507 | 0.08 | 0.23 | 0.27 | 0.27 | 0.04 | 0.00 | 0.000 .00 | 0.02 | 0.02 | 0.02 | 0.05 | 0.01 | 0.00 | 0.000 .00 |
| 1992 | 580 | 0.11 | 0.1 | 0.30 | 0.29 | 0.03 | 0.00 | 0.000 .00 | 0.01 | 0.02 | 0.02 | 0.04 | 0.01 | 0.00 | 0.000 .00 |
| 1994 | 850 | 0.07 | 0.0 | . 11 | 0.15 | 0.02 | 0.00 | 0.000 .00 | 0.07 | 0.07 | 0.15 | 0.24 | 0.05 | 0.00 | 0.000 .00 |
| 2012 | 939 | 0.21 | 0. | 0.19 | 0.32 | 0.10 | 0.01 | 0.000 .00 | 0.00 | 00 | 0.00 | 0.02 | 0.02 | 0.00 | 0.000 .00 |
| 2013 | 261 | 0.34 | 0. | 0.16 | 0.16 | 0.04 | 0.00 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 2014 | 1755 | 0.05 | 0.1 | 0.26 | 0.41 | 0.12 | 0.01 | 0.000 .00 | 0.00 | 0.00 | 0.01 | 0.03 | 0.01 | 0.00 | 0.000 .00 |
| 2015 | 824 | 0.01 | 0.08 | 0.18 | 0.44 | 0.23 | 0.02 | 0.000 .00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 | 0.00 | 0.000 .00 |

Model 13 data

| New Shell |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year | mple | $\begin{gathered} 64- \\ 68 \end{gathered}$ | $\begin{aligned} & 79- \\ & 73 \end{aligned}$ | $\begin{gathered} 74- \\ 78 \end{gathered}$ | $\begin{aligned} & 79- \\ & 83 \end{aligned}$ | 84- | $\begin{aligned} & 89- \\ & 93 \end{aligned}$ | $\begin{gathered} 94- \\ 98 \end{gathered}$ | $\begin{aligned} & 99- \\ & 103 \end{aligned}$ | $\begin{gathered} 104- \\ 108 \end{gathered}$ | $\begin{gathered} 109- \\ 113 \end{gathered}$ | $\begin{gathered} 114- \\ 118 \end{gathered}$ | $\begin{gathered} 119- \\ 123 \end{gathered}$ | $\begin{gathered} 124- \\ 128 \end{gathered}$ | $\begin{array}{cc} 129-134+ \\ 133 & \end{array}$ |
| 1987 | 1146 | 0.02 | 0.04 | 0.08 | 0.11 | 0.13 | 0.19 | 0.18 | 0.15 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 1988 | 722 | 0.00 | 0.01 | 0.01 | 0.03 | 0.06 | 0.09 | 0.21 | 0.26 | 0.12 | 0.02 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 1989 | 1000 | 0.02 | 0.05 | 0.10 | 0.09 | 0.10 | 0.14 | 0.13 | 0.09 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 1990 | 507 | 0.03 | 0.05 | 0.09 | 0.13 | 0.14 | 0.13 | 0.16 | 0.11 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 1992 | 580 | 0.04 | 0.07 | 0.07 | 0.10 | 0.14 | 0.15 | 0.15 | 0.14 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 1994 | 850 | 0.03 | 0.05 | 0.02 | 0.04 | 0.04 | 0.06 | 0.08 | 0.06 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 2012 | 939 | 0.11 | 0.10 | 0.06 | 0.05 | 0.09 | 0.10 | 0.15 | 0.17 | 0.09 | 0.01 | 0.01 | 0.00 | 0.00 | 0.000 .00 |
| 2013 | 2617 | 0.14 | 0.20 | 0.17 | 0.12 | 0.08 | 0.08 | 0.08 | 0.08 | 0.04 | 0.01 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 2014 | 1755 | 0.01 | 0.03 | 0.04 | 0.06 | 0.10 | 0.16 | 0.19 | 0.22 | 0.10 | 0.02 | 0.01 | 0.00 | 0.00 | 0.000 .00 |
| 2015 | 824 | 0.00 | 0.01 | 0.02 | 0.06 | 0.07 | 0.11 | 0.15 | 0.29 | 0.19 | 0.04 | 0.01 | 0.01 | 0.00 | 0.000 .00 |

Model 13 data

| Old Shell |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year | ample | $\begin{gathered} \hline 64- \\ 68 \end{gathered}$ | $\begin{gathered} 79- \\ 73 \end{gathered}$ | $\begin{gathered} 74- \\ 78 \end{gathered}$ | $\begin{gathered} \hline 79- \\ 83 \end{gathered}$ | $\begin{gathered} \hline 84- \\ 88 \end{gathered}$ | $\begin{gathered} \hline 89- \\ 93 \end{gathered}$ | $\begin{gathered} \hline 94- \\ 98 \end{gathered}$ | $\begin{aligned} & \hline 99- \\ & 103 \end{aligned}$ | $\begin{aligned} & \hline 104- \\ & 108 \end{aligned}$ | $\begin{aligned} & \hline 109- \\ & 113 \end{aligned}$ | $\begin{gathered} 114- \\ 118 \end{gathered}$ | $\begin{aligned} & \hline 119- \\ & 123 \end{aligned}$ | $\begin{gathered} 124- \\ 128 \end{gathered}$ | $\begin{array}{cc} \hline 129-134+ \\ 133 & \end{array}$ |
| 1987 | 1146 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.01 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 1988 | 722 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.04 | 0.05 | 0.04 | 0.01 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 1989 | 1000 | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 | 0.04 | 0.06 | 0.05 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 1990 | 507 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 1992 | 580 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 1994 | 850 | 0.03 | 0.04 | 0.03 | 0.04 | 0.07 | 0.08 | 0.12 | 0.12 | 0.04 | 0.01 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 2012 | 939 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2013 | 2617 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 2014 | 1755 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.000 .00 |
| 2015 | 824 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.000 .00 |

Table 8 The number of tagged data released and recovered after 1 year (Y1) - 3 year (Y3) during 1980-1992 and 1993-2015 periods.

| Model 5 data |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Release <br> Length <br> Class | Recap Length Class | 1980-1992 |  |  | 1993-2014 |  |  |
|  |  | Y1 | Y2 | Y3 | Y1 | Y2 | Y3 |
| 64-73 | 64-73 |  |  |  |  |  |  |
| 64-73 | 74-83 | 1 |  |  |  |  |  |
| 64-73 | 84-93 | 1 |  |  | 3 | 1 |  |
| 64-73 | 94-103 |  | 1 |  |  | 4 |  |
| 64-73 | 104-113 |  |  |  |  | 4 | 1 |
| 64-73 | 114-123 |  |  |  |  |  | 2 |
| 64-73 | 124-133 |  |  |  |  |  |  |
| 64-73 | 134+ |  |  |  |  |  |  |
| 74-83 | 74-83 |  |  |  |  |  |  |
| 74-83 | 84-93 |  |  |  | 21 |  |  |
| 74-83 | 94-103 |  |  |  | 22 | 10 |  |
| 74-83 | 104-113 |  | 2 |  | 4 | 68 | 3 |
| 74-83 | 114-123 |  |  | 2 |  | 3 | 2 |
| 74-83 | 124-133 |  |  |  |  |  |  |
| 74-83 | 134+ |  |  |  |  |  |  |
| 84-93 | 84-93 |  |  |  |  |  |  |
| 84-93 | 94-103 | 5 |  |  | 42 | 4 |  |
| 84-93 | 104-113 | 10 | 2 |  | 80 | 20 | 6 |
| 84-93 | 114-123 |  | 1 | 1 | 7 | 37 | 2 |
| 84-93 | 124-133 |  |  |  | 1 | 1 | 2 |
| 84-93 | 134+ |  |  |  |  |  |  |
| 94-103 | 94-103 | 3 |  |  | 6 | 1 |  |
| 94-103 | 104-113 | 31 | 1 | 1 | 144 | 19 |  |
| 94-103 | 114-123 | 26 | 1 | 3 | 71 | 7 | 10 |
| 94-103 | 124-133 | 2 |  | 1 |  | 8 | 6 |
| 94-103 | 134+ |  |  |  | 1 |  |  |
| 104-113 | $104-113$ | 16 |  |  | 44 | 2 |  |
| 104-113 | 114-123 | 34 | 13 |  | 73 | 22 | 4 |
| 104-113 | 124-133 | 7 | 6 | 3 | 12 | 4 | 7 |
| 104-113 | 134+ |  |  |  |  |  |  |
| 114-123 | $114-123$ | 16 | 2 |  | 62 | 4 |  |
| 114-123 | 124-133 | 26 | 9 | 1 | 59 | 28 | 3 |
| 114-123 | 134+ | 5 | 1 |  | 19 | 4 | 2 |
| 124-133 | $124-133$ | 15 |  |  | 36 | 6 |  |
| 124-133 | 134+ | 10 | 4 | 2 | 10 | 8 | 4 |
| 134+ | 134+ | 15 | 6 | 1 | 8 |  |  |


| Model 13 data |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Release Recap |  | 1980-1992 |  |  | 1993-2014 |  |  |
| Length <br> Class | Length Class | Y1 | Y2 | Y3 | Y1 | Y2 | Y3 |
| 64-68 | 64-68 |  |  |  |  |  |  |
| 64-68 | 69-73 |  |  |  |  |  |  |
| 64-68 | 74-78 | 1 |  |  |  |  |  |
| 64-68 | 79-83 |  |  |  |  |  |  |
| 64-68 | 84-88 |  |  |  |  |  |  |
| 64-68 | 89-93 |  |  |  |  |  |  |
| 64-68 | 94-98 |  |  |  |  |  |  |
| 64-68 | 99-103 |  |  |  |  |  |  |
| 64-68 | 104-108 |  |  |  |  | 1 |  |
| 64-68 | 109-113 |  |  |  |  |  |  |
| 64-68 | 114-118 |  |  |  |  |  |  |
| 64-68 | 119-123 |  |  |  |  |  |  |
| 64-68 | 123-128 |  |  |  |  |  |  |
| 64-68 | 129-133 |  |  |  |  |  |  |
| 64-68 | 134+ |  |  |  |  |  |  |
| 69-73 | 69-73 |  |  |  |  |  |  |
| 69-73 | 74-78 |  |  |  |  |  |  |
| 69-73 | 79-83 |  |  |  |  |  |  |
| 69-73 | 84-88 | 1 |  |  | 3 |  |  |
| 69-73 | 89-93 |  |  |  |  | 1 |  |
| 69-73 | 94-98 |  |  |  |  | 2 |  |
| 69-73 | 99-103 |  | 1 |  |  | 2 |  |
| 69-73 | 104-108 |  |  |  |  | 2 |  |
| 69-73 | 109-113 |  |  |  |  | 1 | 1 |
| 69-73 | 114-118 |  |  |  |  |  | 1 |
| 69-73 | 119-123 |  |  |  |  |  |  |
| 69-73 | 123-128 |  |  |  |  |  |  |
| 69-73 | 129-133 |  |  |  |  |  |  |
| 69-73 | 134+ |  |  |  |  |  |  |
| 74-78 | 74-78 |  |  |  |  |  |  |
| 74-78 | 79-83 |  |  |  |  |  |  |
| 74-78 | 84-88 |  |  |  | 5 |  |  |
| 74-78 | 89-93 |  |  |  | 10 |  |  |
| 74-78 | 94-98 |  |  |  | 1 | 1 |  |
| 74-78 | 99-103 |  |  |  |  | 7 |  |
| 74-78 | 104-108 |  | 1 |  |  | 10 |  |
| 74-78 | 109-113 |  |  |  |  | 3 |  |
| 74-78 | 114-118 |  |  |  |  |  | 2 |
| 74-78 | 119-123 |  |  | 2 |  |  |  |


| 74-78 | 123-128 |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 74-78 | 129-133 |  |  |  |  |  |  |
| 74-78 | 134+ |  |  |  |  |  |  |
| 79-83 | 79-83 |  |  |  |  |  |  |
| 79-83 | 84-88 |  |  |  | 1 |  |  |
| 79-83 | 89-93 |  |  |  | 5 |  |  |
| 79-83 | 94-98 |  |  |  | 17 | 1 |  |
| 79-83 | 99-103 |  |  |  | 4 | 1 |  |
| 79-83 | 104-108 |  | 1 |  | 3 | 20 | 1 |
| 79-83 | 109-113 |  |  |  | 1 | 35 | 2 |
| 79-83 | 114-118 |  |  |  |  | 3 |  |
| 79-83 | 119-123 |  |  |  |  |  |  |
| 79-83 | 123-128 |  |  |  |  |  |  |
| 79-83 | 129-133 |  |  |  |  |  |  |
| 79-83 | 134+ |  |  |  |  |  |  |
| 84-88 | 84-88 |  |  |  |  |  |  |
| 84-88 | 89-93 |  |  |  |  |  |  |
| 84-88 | 94-98 |  |  |  | 5 |  |  |
| 84-88 | 99-103 |  |  |  | 25 | 3 |  |
| 84-88 | 104-108 | 2 |  |  | 8 | 1 |  |
| 84-88 | 109-113 |  | 2 |  | 2 | 15 | 4 |
| 84-88 | 114-118 |  |  |  |  | 22 | 1 |
| 84-88 | 119-123 |  |  |  |  |  |  |
| 84-88 | 123-128 |  |  |  |  |  |  |
| 84-88 | 129-133 |  |  |  |  | 1 |  |
| 84-88 | 134+ |  |  |  |  |  |  |
| 89-93 | 89-93 |  |  |  |  |  |  |
| 89-93 | 94-98 |  |  |  |  |  |  |
| 89-93 | 99-103 | 5 |  |  | 12 | 1 |  |
| 89-93 | 104-108 | 5 |  |  | 58 |  | 1 |
| 89-93 | 109-113 | 3 |  |  | 12 | 4 | 1 |
| 89-93 | 114-118 |  | 1 | 1 |  | 7 | 1 |
| 89-93 | 119-123 |  |  |  | 5 | 6 |  |
| 89-93 | 123-128 |  |  |  | 1 |  | 1 |
| 89-93 | 129-133 |  |  |  |  |  | 1 |
| 89-93 | 134+ |  |  |  |  |  |  |
| 94-98 | 94-98 |  |  |  |  |  |  |
| 94-98 | 99-103 |  |  |  | 1 |  |  |
| 94-98 | 104-108 | 5 |  |  | 32 | 6 |  |
| 94-98 | 109-113 | 14 |  |  | 84 | 7 |  |
| 94-98 | 114-118 | 4 |  |  | 10 |  | 3 |
| 94-98 | 119-123 |  | 1 | 3 |  | 4 | 5 |
| 94-98 | 123-128 | 1 |  | 1 |  | 6 | 1 |


| 94-98 | 129-133 | 1 |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 94-98 | 134+ |  |  |  | 1 |  |  |
| 99-103 | 99-103 | 3 |  |  | 5 | 1 |  |
| 99-103 | 104-108 |  |  |  | 4 |  |  |
| 99-103 | 109-113 | 12 | 1 | 1 | 24 | 6 |  |
| 99-103 | 114-118 | 19 |  |  | 59 | 2 | 1 |
| 99-103 | 119-123 | 3 |  |  | 2 | 1 | 1 |
| 99-103 | 123-128 |  |  |  |  | 2 | 2 |
| 99-103 | 129-133 |  |  |  |  |  | 3 |
| 99-103 | 134+ |  |  |  |  |  |  |
| 104-108 | 104-108 | 10 |  |  | 7 |  |  |
| 104-108 | 109-113 | 1 |  |  | 4 | 1 |  |
| 104-108 | 114-118 | 10 | 2 |  | 21 | 6 | 1 |
| 104-108 | 119-123 | 15 | 3 |  | 20 | 4 |  |
| 104-108 | 123-128 | 3 | 1 | 2 | 2 | 2 | 1 |
| 104-108 | 129-133 |  |  | 1 |  | 1 | 3 |
| 104-108 | 134+ |  |  |  |  |  |  |
| 109-113 | 109-113 |  |  |  | 29 |  |  |
| 109-113 | 114-118 | 5 |  |  | 1 |  | 1 |
| 109-113 | 119-123 |  | 2 |  | 31 | 12 | 2 |
| 109-113 | 123-128 | 9 | 6 |  | 10 | 1 | 1 |
| 109-113 | 129-133 | 4 | 5 |  |  |  | 2 |
| 109-113 | 134+ |  |  |  |  |  |  |
| 114-118 | 114-118 |  |  |  | 24 |  |  |
| 114-118 | 119-123 | 3 |  |  | 18 | 2 |  |
| 114-118 | 123-128 |  | 2 |  | 22 | 7 | 2 |
| 114-118 | 129-133 | 10 | 4 |  | 8 | 2 | 1 |
| 114-118 | 134+ | 2 |  |  | 1 | 1 |  |
| 119-123 | 119-123 | 1 |  |  | 20 |  |  |
| 119-123 | 123-128 | 12 |  |  | 5 | 4 |  |
| 119-123 | 129-133 | 1 |  |  | 24 | 15 |  |
| 119-123 | 134+ | 13 | 5 | 1 | 18 | 3 | 2 |
| 123-128 | 123-128 | 4 | 1 |  | 19 | 1 |  |
| 123-128 | 129-133 | 3 |  |  | 6 | 1 |  |
| 123-128 | 134+ | 4 | 2 | 1 | 8 | 5 | 3 |
| 129-133 | 129-133 | 12 |  |  | 11 | 4 |  |
| 129-133 | 134+ | 6 | 2 | 1 | 2 | 3 | 1 |
| 134+ | 134+ | 15 | 6 | 1 | 8 |  |  |

Table 9. Summary of initial input parameter values and bounds for a length-based population model of Norton Sound red king crab. Parameters with "log_" indicate log scaled parameters.

| Parameter | Parameter description | Equation Number in Appendix A | Lower | Upper |
| :---: | :---: | :---: | :---: | :---: |
| $\log _{\text {_ }} \mathrm{q}_{1}$ | Commercial fishery catchability (1977-92) | (20) | -32.5 | 8.5 |
| $\log _{-} \mathrm{q}_{2}$ | Commercial fishery catchability (1993-2014) | (20) | -32.5 | 10.0 |
| $\log _{-} \mathrm{N}_{76}$ | Initial abundance | (1) | 2.0 | 15.0 |
| $\mathrm{R}_{0}$ | Mean Recruit | (13) | 2.0 | 12.0 |
| $\log _{\_} \sigma_{R}{ }^{2}$ | Recruit standard deviation | (13) | -20.0 | 20.0 |
| $\mathrm{a}_{1}$ | Parameter for intimal length proportion | (2) | -5.0 | 5.0 |
| $\mathrm{a}_{2}$ | Parameter for intimal length proportion | (2) | -5.0 | 5.0 |
| $\mathrm{a}_{3}$ | Parameter for intimal length proportion | (2) | -5.0 | 5.0 |
| $\mathrm{a}_{4}$ | Parameter for intimal length proportion | (2) | -5.0 | 5.0 |
| $\mathrm{a}_{5}$ | Parameter for intimal length proportion | (2) | -5.0 | 5.0 |
| r | Proportion of length class 1 for recruit | (14) | 0.5 | 0.9 |
| $\log _{-} \alpha$ | Inverse logistic molting parameter | (15) | -5.5 | -2.0 |
| $\log _{-} \phi_{\text {st1 }}$ | Logistic trawl selectivity parameter (NMFS) | (16) | -15.0 | -1.0 |
| $\log _{-} \phi_{\text {st2 }}$ | Logistic trawl selectivity parameter (ADF\&G) | (16) | -15.0 | -1.0 |
| $\log _{-} \phi_{w}$ | Logistic winter pot selectivity parameter Or <br> Inverse logistic winter pot selectivity parameter | $(15,16)$ | -10.0 | 10.0 |
| $\mathrm{Sw}_{6} / \mathrm{Sw}_{1}$ | Winter pot selectivity of length class 6 (logistic), length class 1 (inverse logistic) | $(15,16)$ | 0.1 | 1.0 |
| $\log _{-} \phi_{l}$ | Logistic commercial catch selectivity parameter (1977-92) | (16) | -5.0 | -1.0 |
| $\log _{-} \phi_{2}$ | Logistic commercial catch selectivity parameter (1993-2014) | (16) | $-5.0$ | -1.0 |
| $w^{2}{ }_{t}$ | Additional varince for standard CPUE | (31) | 0.0 | 6.0 |
| q | Survey q for NMFS trawl 1976-91 | (31) | 0.1 | 1.0 |
| $\sigma$ | Growth transition sigma | (17) | 0.0 | 30.0 |
| $\beta_{1}$ | Growth transition mean | (17) | 0.0 | 20.0 |
| $\beta_{2}$ | Growth transition increment | (17) | 0.0 | 20.0 |

Table 10 . Summary of parameter estimates and standard deviations of Norton Sound red king crab. Model 5

|  | Estimate | std.dev |
| :---: | :---: | :---: |
| $\log _{\text {_ }} \mathrm{q}_{1}$ | -6.9259 | 0.1906 |
| $\log _{\text {_ }} \mathrm{q}_{2}$ | -6.7761 | 0.11195 |
| $\log _{\sim} \mathrm{N}_{76}$ | 9.1231 | 0.15299 |
| $\mathrm{R}_{0}$ | 6.4911 | 0.090086 |
| $\underline{\log \sigma_{\mathrm{R}}{ }^{2}}$ | 0.027945 | 0.44393 |
| $\log _{\_} \mathrm{R}_{77}$ | -0.56982 | 0.37063 |
| $\log _{-} \mathrm{R}_{78}$ | -0.71447 | 0.35474 |
| $\log _{\_} \mathrm{R}_{79}$ | 0.24017 | 0.32398 |
| $\log _{-} \mathrm{R}_{80}$ | 0.34399 | 0.29828 |
| $\log _{\_} \mathrm{R}_{81}$ | 0.31351 | 0.27449 |
| $\log _{-} \mathrm{R}_{82}$ | 0.40028 | 0.31875 |
| $\log _{-} \mathrm{R}_{83}$ | 0.58749 | 0.28078 |
| $\log _{-} \mathrm{R}_{84}$ | 0.061908 | 0.31094 |
| $\log _{-} \mathrm{R}_{85}$ | 0.45028 | 0.28276 |
| $\log _{-} \mathrm{R}_{86}$ | -0.008591 | 0.30533 |
| $\log _{\_} \mathrm{R}_{87}$ | -0.008095 | 0.26231 |
| $\log _{-} \mathrm{R}_{88}$ | 0.010236 | 0.2729 |
| $\log _{-} \mathrm{R}_{89}$ | -0.39646 | 0.29694 |
| $\log _{-} \mathrm{R}_{90}$ | -0.28167 | 0.26238 |
| $\log _{\_} \mathrm{R}_{91}$ | -0.54566 | 0.2904 |
| $\log _{-} \mathrm{R}_{92}$ | -0.74061 | 0.31228 |
| $\log _{-} \mathrm{R}_{93}$ | -0.61466 | 0.29318 |
| $\log _{-} \mathrm{R}_{94}$ | -0.37182 | 0.26754 |
| log_R ${ }_{95}$ | -0.086911 | 0.24029 |
| $\log _{\_} \mathrm{R}_{96}$ | 0.53258 | 0.21708 |
| $\log _{-} \mathrm{R}_{97}$ | -0.20834 | 0.31568 |
| $\log _{\_} \mathrm{R}_{98}$ | -0.66352 | 0.31794 |
| $\log _{-} \mathrm{R}_{99}$ | -0.17289 | 0.31294 |
| $\log _{-} \mathrm{R}_{00}$ | 0.14649 | 0.26868 |
| $\log _{\_} \mathrm{R}_{01}$ | 0.16903 | 0.25699 |
| $\log _{-} \mathrm{R}_{02}$ | 0.006718 | 0.30956 |
| $\log _{-} \mathrm{R}_{03}$ | -0.31276 | 0.33503 |
| $\log _{-} \mathrm{R}_{04}$ | 0.28697 | 0.24744 |
| $\log _{\_} \mathrm{R}_{05}$ | 0.3216 | 0.24164 |
| $\log _{-} \mathrm{R}_{06}$ | 0.48335 | 0.24985 |
| $\log _{-} \mathrm{R}_{07}$ | 0.485 | 0.24724 |
| $\log _{-} \mathrm{R}_{08}$ | 0.11161 | 0.29966 |
| $\log _{-} \mathrm{R}_{09}$ | -0.31992 | 0.30542 |
| $\log _{-} \mathrm{R}_{10}$ | 0.050226 | 0.25402 |
| $\log _{\_} \mathrm{R}_{11}$ | 0.2479 | 0.2958 |
| $\log _{-} \mathrm{R}_{12}$ | 0.95366 | 0.26511 |


| name | Estimate | std.dev |
| :---: | ---: | ---: |
| $\log _{-} \mathrm{R}_{13}$ | -0.064742 | 0.36781 |
| $\log _{-} \mathrm{R}_{14}$ | -0.14998 | 0.44671 |
| $\mathrm{a}_{1}$ | 2.5859 | 4.3418 |
| $\mathrm{a}_{2}$ | 2.6678 | 4.2709 |
| $\mathrm{a}_{3}$ | 4.003 | 4.0705 |
| $\mathrm{a}_{4}$ | 4.2557 | 4.0567 |
| $\mathrm{a}_{5}$ | 4.4771 | 4.0493 |
| $\mathrm{a}_{6}$ | 3.6832 | 4.0742 |
| $\mathrm{a}_{7}$ | 2.0469 | 4.2894 |
| r 1 | 14.988 | 63.407 |
| r 2 | 14.626 | 63.407 |
| $\log _{-} \alpha$ | -2.0122 | 0.016911 |
| $\log _{-} \phi_{\text {st1 }}$ | -2.6268 | 0.35705 |
| $\log _{-} \phi_{w}$ | -2.0465 | 0.050315 |
| $\mathrm{Sw}_{1}$ | 0.070758 | 0.034013 |
| $\mathrm{Sw}_{2}$ | 0.44402 | 0.10674 |
| $\log _{-} \phi_{1}$ | -2.0887 | 0.057957 |
| $w_{t}$ | 0.075056 | 0.023717 |
| q | 0.74645 | 0.13422 |
| $\sigma$ | 4.3015 | 0.26533 |
| $\beta_{1}$ | 10.292 | 0.80362 |
| $\beta_{2}$ | 8.1997 | 0.20266 |
| $M$ |  |  |
| $m s$ | 3.5552 | 0.31672 |
|  |  |  |

Model 13

|  | Estimate | std.dev |
| :---: | :---: | :---: |
| $\log _{-} q_{1}$ | -6.915 | 0.1882 |
| $\log _{\text {_ }} \mathrm{q}_{2}$ | -6.7478 | 0.10959 |
| $\log _{\_} \mathrm{N}_{76}$ | 9.1446 | 0.15016 |
| $\mathrm{R}_{0}$ | 6.4965 | 0.087764 |
| $\log \sigma_{\mathrm{R}}{ }^{2}$ | -0.017897 | 0.4288 |
| $\log _{\_} \mathrm{R}_{77}$ | -0.6057 | 0.35732 |
| $\log _{\_} \mathrm{R}_{78}$ | -0.70196 | 0.34304 |
| $\log _{-} \mathrm{R}_{79}$ | 0.34168 | 0.27485 |
| $\log _{-} \mathrm{R}_{80}$ | 0.26841 | 0.27664 |
| $\log _{-} \mathrm{R}_{81}$ | 0.33319 | 0.25218 |
| $\log _{-} \mathrm{R}_{82}$ | 0.48945 | 0.27443 |
| $\log _{-} \mathrm{R}_{83}$ | 0.48783 | 0.26815 |
| $\log _{-} \mathrm{R}_{84}$ | 0.11651 | 0.28101 |
| $\log _{-} \mathrm{R}_{85}$ | 0.46689 | 0.25099 |
| $\log _{-} \mathrm{R}_{86}$ | -0.051417 | 0.27787 |
| $\log _{\_} \mathrm{R}_{87}$ | -0.007842 | 0.24367 |
| $\log _{\text {_ }} \mathrm{R}_{88}$ | 0.024252 | 0.2508 |
| $\log _{-} \mathrm{R}_{89}$ | -0.44084 | 0.27779 |
| $\log _{-} \mathrm{R}_{90}$ | -0.29302 | 0.24642 |
| $\log _{-} \mathrm{R}_{91}$ | -0.5423 | 0.27091 |
| $\log _{-} \mathrm{R}_{92}$ | -0.74135 | 0.29141 |
| $\log _{-} \mathrm{R}_{93}$ | -0.53768 | 0.2666 |
| $\log _{\text {_ } \mathrm{R}_{94}}$ | -0.4061 | 0.25618 |
| $\log _{-} \mathrm{R}_{95}$ | -0.087755 | 0.22817 |
| $\log _{-} \mathrm{R}_{96}$ | 0.54883 | 0.19138 |
| $\log _{-} \mathrm{R}_{97}$ | -0.31011 | 0.2923 |
| $\log _{-} \mathrm{R}_{98}$ | -0.62355 | 0.29992 |
| $\log _{-} \mathrm{R}_{99}$ | -0.16896 | 0.28657 |
| $\log _{-} \mathrm{R}_{00}$ | 0.18266 | 0.24043 |
| $\log _{-} \mathrm{R}_{01}$ | 0.18352 | 0.23424 |
| $\log _{\_} \mathrm{R}_{02}$ | -0.068791 | 0.29021 |
| $\log _{\_} \mathrm{R}_{03}$ | -0.2684 | 0.30106 |
| $\log _{-} \mathrm{R}_{04}$ | 0.32018 | 0.22461 |
| $\log _{\_} \mathrm{R}_{05}$ | 0.26825 | 0.23038 |
| $\log _{\_} \mathrm{R}_{06}$ | 0.53006 | 0.21792 |
| $\log _{-} \mathrm{R}_{07}$ | 0.44263 | 0.22501 |
| $\log _{\_} \mathrm{R}_{08}$ | 0.10561 | 0.26684 |
| $\log _{\_} \mathrm{R}_{09}$ | -0.27795 | 0.27491 |
| $\log _{-} \mathrm{R}_{10}$ | 0.027615 | 0.24224 |
| $\log _{\_} \mathrm{R}_{11}$ | 0.34476 | 0.27238 |
| $\log _{-} \mathrm{R}_{12}$ | 0.91115 | 0.26265 |


| name | Estimate | std.dev |
| :---: | ---: | ---: |
| $\log _{-} \mathrm{R}_{13}$ | -0.080906 | 0.35931 |
| $\log _{-} \mathrm{R}_{14}$ | -0.16095 | 0.44919 |
| $\mathrm{a}_{1}$ | 2.5616 | 4.089 |
| $\mathrm{a}_{2}$ | 1.8895 | 4.5519 |
| $\mathrm{a}_{3}$ | 1.3861 | 4.7425 |
| $\mathrm{a}_{4}$ | 2.2245 | 4.1301 |
| $\mathrm{a}_{5}$ | 2.9176 | 3.9276 |
| $\mathrm{a}_{6}$ | 3.1745 | 3.8839 |
| $\mathrm{a}_{7}$ | 3.4127 | 3.8627 |
| $\mathrm{a}_{8}$ | 3.3869 | 3.8586 |
| $\mathrm{a}_{9}$ | 3.4946 | 3.8463 |
| $\mathrm{a}_{10}$ | 3.4981 | 3.8466 |
| $\mathrm{a}_{11}$ | 3.1417 | 3.8613 |
| $\mathrm{a}_{12}$ | 2.1496 | 3.9518 |
| $\mathrm{a}_{13}$ | 1.7873 | 4.1704 |
| $\mathrm{a}_{14}$ | 0.30529 | 5.1112 |
| r 1 | 14.967 | 135.17 |
| r 2 | 14.943 | 135.17 |
| r 3 | 14.885 | 135.17 |
| r 4 | 14.347 | 135.17 |
| r 5 | -6.8084 | 17901 |
| $\log _{\_} \alpha$ | -2.0597 | 0.012815 |
| $\log _{-} \phi_{\text {st }}$ | -2.5495 | 0.27329 |
| $\log _{\_} \phi_{w}$ | -2.0929 | 0.049215 |
| $\mathrm{Sw}_{1}$ | 0.032224 | 0.034442 |
| $\mathrm{Sw}_{2}$ | 0.10802 | 0.061776 |
| $\mathrm{Sw}_{3}$ | 0.2926 | 0.11008 |
| $\mathrm{Sw}_{4}$ | 0.52251 | 0.15919 |
| $\log _{-} \phi_{1}$ | -2.0581 | 0.060299 |
| $w_{t}$ | $7.38 \mathrm{E}-02$ | 0.023578 |
| q | 0.743 | 0.13223 |
| $\sigma$ | 3.5999 | 0.31154 |
| $\beta_{l}$ | 2.7995 | 0.12141 |
| $\beta_{2}$ | 13.289 | 0.4609 |
| $M$ |  |  |
| $m s$ | 3.5999 | 0.31154 |
|  |  |  |

Table 11. Estimated selectivities, molting probabilities, and proportions of legal crab by length (mm CL) class for Norton Sound male red king crab.

Model 5

|  |  |  | Selectivity |  |  |  |
| :---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Length <br> Class | Legal <br> Proportion | Mean <br> weight (lb) | ADFG/ <br> NOAA | Winter <br> Pot | Summer <br> Fishery | Molting <br> Probability |
| $64-73$ | 0.00 | 0.434 | 0.86 | 0.07 | 0.15 | 1.00 |
| $74-83$ | 0.00 | 0.855 | 0.93 | 0.44 | 0.37 | 1.00 |
| $84-93$ | 0.00 | 1.313 | 0.96 | 0.99 | 0.67 | 0.99 |
| $94-103$ | 0.13 | 1.823 | 0.98 | 0.95 | 0.88 | 0.95 |
| $104-113$ | 0.87 | 2.387 | 0.99 | 0.85 | 0.96 | 0.83 |
| $114-123$ | 1.00 | 3.064 | 1.00 | 0.61 | 0.99 | 0.56 |
| $124-133$ | 1.00 | 3.840 | 1.00 | 0.30 | 1.00 | 0.25 |
| $134+$ | 1.00 | 4.649 | 1.00 | 0.11 | 1.00 | 0.08 |

Model 13

|  |  |  | Selectivity |  |  |  |
| :---: | ---: | ---: | ---: | ---: | ---: | ---: |
| Length <br> Class | Legal <br> Proportion | Mean <br> weight (lb) | ADFG/ <br> NOAA | Winter <br> Pot | Summer <br> Fishery | Molting <br> Probability |
| $64-68$ | 0.00 | 0.332 | 0.81 | 0.03 | 0.12 | 1.00 |
| $69-73$ | 0.00 | 0.537 | 0.86 | 0.11 | 0.20 | 1.00 |
| $74-78$ | 0.00 | 0.747 | 0.90 | 0.29 | 0.32 | 1.00 |
| $79-83$ | 0.00 | 0.965 | 0.93 | 0.52 | 0.47 | 0.99 |
| $84-88$ | 0.00 | 1.194 | 0.95 | 0.99 | 0.63 | 0.99 |
| $89-93$ | 0.00 | 1.435 | 0.97 | 0.98 | 0.76 | 0.98 |
| $94-98$ | 0.02 | 1.691 | 0.98 | 0.96 | 0.86 | 0.96 |
| $99-103$ | 0.23 | 1.958 | 0.98 | 0.93 | 0.92 | 0.92 |
| $104-108$ | 0.77 | 2.239 | 0.99 | 0.88 | 0.96 | 0.86 |
| $109-113$ | 0.97 | 2.543 | 0.99 | 0.80 | 0.98 | 0.76 |
| $114-118$ | 1.00 | 2.882 | 1.00 | 0.68 | 0.99 | 0.63 |
| $119-123$ | 1.00 | 3.252 | 1.00 | 0.53 | 0.99 | 0.47 |
| $123-128$ | 1.00 | 3.641 | 1.00 | 0.38 | 1.00 | 0.32 |
| $129-133$ | 1.00 | 4.041 | 1.00 | 0.25 | 1.00 | 0.20 |
| $134+$ | 1.00 | 4.446 | 1.00 | 0.15 | 1.00 | 0.12 |

Table 12: Estimated molting probability incorporated transition matrix.
Model 5: without molting probability

| Pre-molt | Post-molt Length Class |  |  |  |  |  |  |  |
| ---: | :--- | :---: | :---: | :---: | ---: | ---: | ---: | :---: |
| Length | $64-73$ | $74-83$ | $84-93$ | $94-103$ | $104-113$ | $114-123$ | $124-133$ | $134+$ |
| Class | 0.001 | 0.208 | 0.726 | 0.065 | 0.000 | 0.000 | 0.000 | 0.000 |
| $64-73$ | 0.003 | 0.344 | 0.626 | 0.027 | 0.000 | 0.000 | 0.000 |  |
| $74-83$ |  | 0.003 | 0.011 | 0.499 | 0.480 | 0.009 | 0.000 | 0.000 |
| $84-93$ |  |  |  | 0.030 | 0.641 | 0.326 | 0.003 | 0.000 |
| $94-103$ |  |  |  |  | 0.072 | 0.734 | 0.194 | 0.001 |
| $104-113$ |  |  |  |  |  | 0.148 | 0.752 | 0.100 |
| $114-123$ |  |  |  |  |  |  | 0.277 | 0.723 |
| $124-133$ |  |  |  |  |  |  |  | 1.000 |

Model 5: with molting probability

| Pre-molt | Post-molt Length Class |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | ---: | ---: | ---: | ---: |
| Length | $64-73$ | $74-83$ | $84-93$ | $94-103$ | $104-113$ | $114-123$ | $124-133$ | $134+$ |
| Class | 0.002 | 0.207 | 0.726 | 0.065 | 0.000 | 0.000 | 0.000 | 0.00 |
| $64-73$ | 0.007 | 0.343 | 0.624 | 0.027 | 0.000 | 0.000 | 0.00 |  |
| $74-83$ |  | 0.00 | 0.025 | 0.492 | 0.474 | 0.009 | 0.000 | 0.00 |
| $84-93$ |  |  | 0.081 | 0.608 | 0.309 | 0.003 | 0.00 |  |
| $94-103$ |  |  |  | 0.033 | 0.606 | 0.160 | 0.00 |  |
| $104-113$ |  |  |  |  | 0.233 | 0.527 | 0.418 | 0.06 |
| $114-123$ |  |  |  |  |  |  | 0.821 | 0.18 |
| $124-133$ |  |  |  |  |  |  |  | 1.00 |

Model 13: without molting probability


Model 13: with molting probability

| Premolt | Post-molt Length Class |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  | 99- | 104- | 109- | 114- | 119- | 124- | 129- | 134+ |
| Length Class | 64-68 | 79-73 | 74-78 | 79-83 | 84-88 | 89-93 | 94-98 | 103 | 108 | 113 | 118 | 123 | 128 | 133 |  |
| 64-68 | 0.001 | 0.000 | 0.034 | 0.451 | 0.474 | 0.040 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 69-73 |  | 0.002 | 0.000 | 0.057 | 0.525 | 0.393 | 0.023 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 74-78 |  |  | 0.004 | 0.001 | 0.090 | 0.582 | 0.311 | 0.012 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 79-83 |  |  |  | 0.007 | 0.002 | 0.136 | 0.615 | 0.234 | 0.006 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 84-88 |  |  |  |  | 0.013 | 0.004 | 0.194 | 0.620 | 0.167 | 0.003 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 89-93 |  |  |  |  |  | 0.024 | 0.008 | 0.261 | 0.593 | 0.113 | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 |
| 94-98 |  |  |  |  |  |  | 0.044 | 0.016 | 0.332 | 0.536 | 0.071 | 0.001 | 0.000 | 0.000 | 0.000 |
| 99-103 |  |  |  |  |  |  |  | 0.080 | 0.027 | 0.395 | 0.455 | 0.042 | 0.000 | 0.000 | 0.000 |
| $\begin{gathered} 104- \\ 108 \end{gathered}$ |  |  |  |  |  |  |  |  | 0.141 | 0.043 | 0.435 | 0.358 | 0.023 | 0.000 | 0.000 |
| 109- |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 113 |  |  |  |  |  |  |  |  |  | 0.237 | 0.061 | 0.435 | 0.255 | 0.011 | 0.000 |
| 114- |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 118 |  |  |  |  |  |  |  |  |  |  | 0.371 | 0.077 | 0.386 | 0.161 | 0.005 |
| 119- |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 123 |  |  |  |  |  |  |  |  |  |  |  | 0.528 | 0.085 | 0.299 | 0.088 |
| 123- |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 128 |  |  |  |  |  |  |  |  |  |  |  |  | 0.680 | 0.092 | 0.228 |
| 129- |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 133 |  |  |  |  |  |  |  |  |  |  |  |  |  | 0.807 | 0.193 |
| 134+ |  |  |  |  |  |  |  |  |  |  |  |  |  |  | 1.000 |

Table 13. Annual abundance estimates (million crab) and mature male biomass (MMB, million lb) for Norton Sound red king crab estimated by a length-based analysis from 1976 to 2014

Model 5.

| Year | Abundance |  |  | Legal ( $\geq 104 \mathrm{~mm}$ ) |  |  |  | MMB |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Recruits | $\begin{gathered} \text { Total } \\ (\geq 74 \mathrm{~mm}) \\ \hline \end{gathered}$ | $\begin{gathered} \text { Mature } \\ (\geq 94 \\ \mathrm{mm}) \end{gathered}$ | Abundance | S.D | Biomass | S.D | Biomass | S.D. |
| 1976 | 2.610 | 9.165 | 6.554 | 4.250 | 1.036 | 11.262 | 2.929 | 15.667 | 3.424 |
| 1977 | 1.175 | 8.041 | 6.866 | 5.580 | 0.960 | 16.221 | 2.908 | 18.739 | 3.087 |
| 1978 | 0.797 | 6.368 | 5.571 | 5.024 | 0.738 | 15.872 | 2.402 | 16.957 | 2.437 |
| 1979 | 0.566 | 4.383 | 3.817 | 3.485 | 0.505 | 11.589 | 1.723 | 12.235 | 1.751 |
| 1980 | 1.039 | 3.126 | 2.087 | 1.878 | 0.339 | 6.373 | 1.186 | 6.776 | 1.218 |
| 1981 | 1.426 | 2.929 | 1.504 | 1.216 | 0.236 | 4.109 | 0.824 | 4.650 | 0.887 |
| 1982 | 1.467 | 2.787 | 1.319 | 0.890 | 0.211 | 2.746 | 0.679 | 3.553 | 0.802 |
| 1983 | 1.544 | 3.129 | 1.585 | 1.097 | 0.225 | 3.249 | 0.688 | 4.173 | 0.825 |
| 1984 | 1.791 | 3.537 | 1.746 | 1.239 | 0.246 | 3.659 | 0.745 | 4.620 | 0.887 |
| 1985 | 1.427 | 3.375 | 1.948 | 1.376 | 0.270 | 4.078 | 0.813 | 5.161 | 0.975 |
| 1986 | 1.488 | 3.554 | 2.065 | 1.537 | 0.296 | 4.576 | 0.894 | 5.584 | 1.052 |
| 1987 | 1.280 | 3.294 | 2.013 | 1.531 | 0.299 | 4.666 | 0.924 | 5.583 | 1.050 |
| 1988 | 1.075 | 3.121 | 2.046 | 1.577 | 0.291 | 4.837 | 0.905 | 5.731 | 1.031 |
| 1989 | 1.072 | 3.006 | 1.934 | 1.551 | 0.272 | 4.840 | 0.856 | 5.573 | 0.951 |
| 1990 | 0.856 | 2.674 | 1.817 | 1.450 | 0.244 | 4.582 | 0.776 | 5.281 | 0.861 |
| 1991 | 0.782 | 2.464 | 1.682 | 1.363 | 0.217 | 4.324 | 0.692 | 4.935 | 0.762 |
| 1992 | 0.690 | 2.232 | 1.542 | 1.269 | 0.184 | 4.073 | 0.592 | 4.596 | 0.641 |
| 1993 | 0.557 | 1.956 | 1.400 | 1.150 | 0.155 | 3.712 | 0.501 | 4.189 | 0.544 |
| 1994 | 0.554 | 1.714 | 1.160 | 0.958 | 0.131 | 3.091 | 0.425 | 3.479 | 0.458 |
| 1995 | 0.673 | 1.638 | 0.965 | 0.779 | 0.110 | 2.510 | 0.357 | 2.863 | 0.388 |
| 1996 | 0.881 | 1.750 | 0.869 | 0.657 | 0.098 | 2.077 | 0.313 | 2.477 | 0.350 |
| 1997 | 1.491 | 2.418 | 0.927 | 0.655 | 0.096 | 2.004 | 0.299 | 2.517 | 0.355 |
| 1998 | 1.211 | 2.439 | 1.228 | 0.796 | 0.111 | 2.361 | 0.332 | 3.171 | 0.409 |
| 1999 | 0.696 | 2.268 | 1.571 | 1.113 | 0.141 | 3.241 | 0.407 | 4.113 | 0.497 |
| 2000 | 0.775 | 2.320 | 1.545 | 1.256 | 0.148 | 3.812 | 0.447 | 4.372 | 0.492 |
| 2001 | 1.098 | 2.448 | 1.350 | 1.100 | 0.131 | 3.471 | 0.417 | 3.949 | 0.449 |
| 2002 | 1.245 | 2.584 | 1.339 | 1.002 | 0.119 | 3.150 | 0.375 | 3.786 | 0.422 |
| 2003 | 1.146 | 2.595 | 1.449 | 1.043 | 0.120 | 3.184 | 0.367 | 3.951 | 0.424 |
| 2004 | 0.898 | 2.419 | 1.521 | 1.123 | 0.126 | 3.388 | 0.381 | 4.144 | 0.445 |
| 2005 | 1.185 | 2.651 | 1.466 | 1.136 | 0.136 | 3.457 | 0.407 | 4.089 | 0.474 |
| 2006 | 1.436 | 2.851 | 1.415 | 1.056 | 0.137 | 3.251 | 0.420 | 3.930 | 0.473 |
| 2007 | 1.629 | 3.170 | 1.541 | 1.082 | 0.140 | 3.253 | 0.425 | 4.120 | 0.499 |
| 2008 | 1.726 | 3.467 | 1.741 | 1.219 | 0.151 | 3.618 | 0.453 | 4.605 | 0.528 |
| 2009 | 1.399 | 3.339 | 1.940 | 1.371 | 0.162 | 4.049 | 0.485 | 5.128 | 0.565 |
| 2010 | 0.949 | 2.972 | 2.023 | 1.514 | 0.170 | 4.512 | 0.513 | 5.485 | 0.585 |
| 2011 | 1.001 | 2.859 | 1.858 | 1.490 | 0.165 | 4.562 | 0.509 | 5.270 | 0.568 |
| 2012 | 1.265 | 2.911 | 1.646 | 1.318 | 0.151 | 4.142 | 0.478 | 4.766 | 0.520 |
| 2013 | 2.227 | 3.801 | 1.574 | 1.177 | 0.139 | 3.670 | 0.437 | 4.422 | 0.505 |
| 2014 | 1.639 | 3.477 | 1.838 | 1.208 | 0.163 | 3.642 | 0.480 | 4.821 | 0.633 |
| 2015 | 0.994 | 3.174 | 2.179 | 1.541 | 0.253 | 4.477 | 0.702 | 5.694 | 0.933 |

Model 13.

| Year | Abundance |  |  | Legal ( $\geq 104 \mathrm{~mm}$ ) |  |  |  | MMB |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Recruits | Total $(\geq 64 \mathrm{~mm})$ | Mature $(\geq 94$ mm) | Abundance | S.D | Biomass | S.D | Biomass | S.D. |
| 1976 | 2.921 | 9.364 | 6.443 | 4.072 | 0.994 | 10.830 | 2.831 | 15.270 | 3.283 |
| 1977 | 1.440 | 8.167 | 6.727 | 5.487 | 0.950 | 15.861 | 2.855 | 18.277 | 3.015 |
| 1978 | 0.824 | 6.449 | 5.624 | 4.975 | 0.737 | 15.708 | 2.391 | 16.945 | 2.410 |
| 1979 | 0.580 | 4.432 | 3.852 | 3.509 | 0.500 | 11.646 | 1.709 | 12.305 | 1.736 |
| 1980 | 1.153 | 3.243 | 2.090 | 1.886 | 0.334 | 6.420 | 1.171 | 6.806 | 1.201 |
| 1981 | 1.474 | 2.952 | 1.479 | 1.192 | 0.228 | 4.072 | 0.803 | 4.593 | 0.861 |
| 1982 | 1.502 | 2.818 | 1.316 | 0.860 | 0.200 | 2.647 | 0.647 | 3.494 | 0.779 |
| 1983 | 1.702 | 3.254 | 1.552 | 1.068 | 0.218 | 3.151 | 0.664 | 4.054 | 0.792 |
| 1984 | 1.801 | 3.535 | 1.735 | 1.204 | 0.237 | 3.546 | 0.716 | 4.534 | 0.860 |
| 1985 | 1.470 | 3.415 | 1.945 | 1.362 | 0.264 | 4.015 | 0.791 | 5.104 | 0.957 |
| 1986 | 1.567 | 3.609 | 2.042 | 1.510 | 0.290 | 4.489 | 0.874 | 5.492 | 1.025 |
| 1987 | 1.331 | 3.314 | 1.983 | 1.503 | 0.292 | 4.584 | 0.903 | 5.477 | 1.024 |
| 1988 | 1.094 | 3.137 | 2.043 | 1.548 | 0.283 | 4.739 | 0.880 | 5.671 | 1.011 |
| 1989 | 1.122 | 3.030 | 1.909 | 1.535 | 0.268 | 4.786 | 0.842 | 5.490 | 0.931 |
| 1990 | 0.883 | 2.673 | 1.790 | 1.420 | 0.238 | 4.500 | 0.759 | 5.191 | 0.842 |
| 1991 | 0.789 | 2.457 | 1.668 | 1.337 | 0.211 | 4.238 | 0.675 | 4.864 | 0.746 |
| 1992 | 0.717 | 2.227 | 1.510 | 1.246 | 0.180 | 4.006 | 0.580 | 4.500 | 0.623 |
| 1993 | 0.579 | 1.952 | 1.373 | 1.118 | 0.149 | 3.619 | 0.486 | 4.097 | 0.527 |
| 1994 | 0.602 | 1.739 | 1.138 | 0.932 | 0.126 | 3.007 | 0.410 | 3.394 | 0.442 |
| 1995 | 0.699 | 1.645 | 0.946 | 0.756 | 0.106 | 2.437 | 0.345 | 2.790 | 0.374 |
| 1996 | 0.901 | 1.758 | 0.856 | 0.639 | 0.094 | 2.015 | 0.301 | 2.419 | 0.340 |
| 1997 | 1.550 | 2.449 | 0.899 | 0.631 | 0.093 | 1.932 | 0.288 | 2.427 | 0.339 |
| 1998 | 1.243 | 2.416 | 1.173 | 0.750 | 0.105 | 2.233 | 0.312 | 3.009 | 0.386 |
| 1999 | 0.703 | 2.266 | 1.563 | 1.070 | 0.131 | 3.085 | 0.378 | 4.018 | 0.475 |
| 2000 | 0.804 | 2.329 | 1.525 | 1.246 | 0.146 | 3.758 | 0.437 | 4.289 | 0.477 |
| 2001 | 1.166 | 2.488 | 1.322 | 1.080 | 0.128 | 3.420 | 0.409 | 3.871 | 0.437 |
| 2002 | 1.324 | 2.628 | 1.304 | 0.962 | 0.113 | 3.042 | 0.359 | 3.673 | 0.407 |
| 2003 | 1.154 | 2.584 | 1.430 | 1.005 | 0.115 | 3.058 | 0.351 | 3.851 | 0.411 |
| 2004 | 0.928 | 2.435 | 1.507 | 1.103 | 0.123 | 3.305 | 0.369 | 4.065 | 0.431 |
| 2005 | 1.257 | 2.701 | 1.444 | 1.115 | 0.130 | 3.388 | 0.391 | 4.007 | 0.453 |
| 2006 | 1.468 | 2.848 | 1.381 | 1.026 | 0.131 | 3.169 | 0.402 | 3.824 | 0.452 |
| 2007 | 1.708 | 3.221 | 1.513 | 1.041 | 0.133 | 3.127 | 0.404 | 4.005 | 0.479 |
| 2008 | 1.780 | 3.470 | 1.690 | 1.170 | 0.144 | 3.469 | 0.431 | 4.434 | 0.503 |
| 2009 | 1.432 | 3.342 | 1.910 | 1.324 | 0.154 | 3.891 | 0.460 | 4.986 | 0.543 |
| 2010 | 1.006 | 2.999 | 1.993 | 1.477 | 0.163 | 4.381 | 0.492 | 5.355 | 0.562 |
| 2011 | 1.026 | 2.870 | 1.844 | 1.467 | 0.159 | 4.476 | 0.492 | 5.191 | 0.547 |
| 2012 | 1.388 | 3.009 | 1.621 | 1.300 | 0.147 | 4.088 | 0.463 | 4.686 | 0.502 |
| 2013 | 2.269 | 3.816 | 1.547 | 1.137 | 0.132 | 3.562 | 0.419 | 4.321 | 0.482 |
| 2014 | 1.696 | 3.479 | 1.783 | 1.161 | 0.154 | 3.504 | 0.451 | 4.646 | 0.601 |
| 2015 | 1.005 | 3.172 | 2.167 | 1.484 | 0.238 | 4.274 | 0.654 | 5.568 | 0.901 |

Table 14. Summary of catch and estimated discards (million lb) for Norton Sound red king crab. Assumed average crab weight is 2.5 lb for the winter commercial catch, 2.0 lb for the subsistence catch, and 1.0 lb for Winter subsistence discards. Summer and winter commercial discards were estimated from the model.

Model 5.

| Year | Summer <br> Com | Winter <br> Com | Winter <br> Sub | Discards <br> Summer | Discards <br> Winter <br> Sub | Discards <br> Winter <br> com | Total | Catch/ <br> MMB |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1977 | 0.52 | 0.000 | 0.000 | 0.020 | 0.000 | 0.000 | 0.54 | 0.029 |
| 1978 | 2.09 | 0.024 | 0.025 | 0.038 | 0.008 | 0.000 | 2.185 | 0.129 |
| 1979 | 2.93 | 0.001 | 0.000 | 0.049 | 0.000 | 0.000 | 2.98 | 0.244 |
| 1980 | 1.19 | 0.000 | 0.000 | 0.025 | 0.000 | 0.000 | 1.215 | 0.179 |
| 1981 | 1.38 | 0.000 | 0.001 | 0.069 | 0.000 | 0.000 | 1.45 | 0.312 |
| 1982 | 0.23 | 0.000 | 0.003 | 0.020 | 0.001 | 0.000 | 0.254 | 0.071 |
| 1983 | 0.37 | 0.001 | 0.021 | 0.036 | 0.006 | 0.000 | 0.434 | 0.104 |
| 1984 | 0.39 | 0.002 | 0.022 | 0.036 | 0.005 | 0.000 | 0.455 | 0.098 |
| 1985 | 0.43 | 0.003 | 0.017 | 0.037 | 0.002 | 0.000 | 0.489 | 0.095 |
| 1986 | 0.48 | 0.005 | 0.014 | 0.031 | 0.004 | 0.000 | 0.534 | 0.096 |
| 1987 | 0.33 | 0.003 | 0.012 | 0.020 | 0.002 | 0.000 | 0.367 | 0.066 |
| 1988 | 0.24 | 0.001 | 0.005 | 0.013 | 0.001 | 0.000 | 0.26 | 0.045 |
| 1989 | 0.25 | 0.001 | 0.012 | 0.012 | 0.002 | 0.000 | 0.277 | 0.050 |
| 1990 | 0.19 | 0.009 | 0.024 | 0.009 | 0.004 | 0.000 | 0.236 | 0.045 |
| 1991 | 0 | 0.010 | 0.015 | 0.000 | 0.002 | 0.000 | 0.027 | 0.005 |
| 1992 | 0.07 | 0.019 | 0.023 | 0.003 | 0.003 | 0.001 | 0.119 | 0.026 |
| 1993 | 0.33 | 0.004 | 0.002 | 0.014 | 0.000 | 0.000 | 0.35 | 0.084 |
| 1994 | 0.32 | 0.014 | 0.008 | 0.014 | 0.001 | 0.001 | 0.358 | 0.103 |
| 1995 | 0.32 | 0.019 | 0.011 | 0.016 | 0.002 | 0.001 | 0.369 | 0.129 |
| 1996 | 0.22 | 0.004 | 0.003 | 0.016 | 0.001 | 0.000 | 0.244 | 0.099 |
| 1997 | 0.09 | 0.000 | 0.001 | 0.010 | 0.001 | 0.000 | 0.102 | 0.041 |
| 1998 | 0.03 | 0.002 | 0.017 | 0.004 | 0.012 | 0.000 | 0.065 | 0.020 |
| 1999 | 0.02 | 0.007 | 0.015 | 0.002 | 0.003 | 0.000 | 0.047 | 0.011 |
| 2000 | 0.3 | 0.008 | 0.011 | 0.014 | 0.004 | 0.000 | 0.337 | 0.077 |
| 2001 | 0.28 | 0.003 | 0.001 | 0.015 | 0.000 | 0.000 | 0.299 | 0.076 |
| 2002 | 0.25 | 0.006 | 0.004 | 0.019 | 0.003 | 0.000 | 0.282 | 0.074 |
| 2003 | 0.26 | 0.017 | 0.008 | 0.022 | 0.005 | 0.001 | 0.313 | 0.079 |
| 2004 | 0.34 | 0.001 | 0.002 | 0.024 | 0.001 | 0.000 | 0.368 | 0.089 |
| 2005 | 0.4 | 0.005 | 0.008 | 0.024 | 0.003 | 0.000 | 0.44 | 0.108 |
| 2006 | 0.45 | 0.000 | 0.002 | 0.035 | 0.001 | 0.000 | 0.488 | 0.124 |
| 2007 | 0.31 | 0.008 | 0.021 | 0.030 | 0.011 | 0.001 | 0.381 | 0.092 |
| 2008 | 0.39 | 0.014 | 0.019 | 0.039 | 0.009 | 0.001 | 0.472 | 0.102 |
| 2009 | 0.4 | 0.012 | 0.010 | 0.035 | 0.002 | 0.001 | 0.46 | 0.090 |
| 2010 | 0.42 | 0.012 | 0.014 | 0.027 | 0.002 | 0.001 | 0.476 | 0.087 |
| 2011 | 0.4 | 0.008 | 0.013 | 0.020 | 0.003 | 0.000 | 0.444 | 0.084 |
| 2012 | 0.47 | 0.023 | 0.015 | 0.027 | 0.004 | 0.001 | 0.54 | 0.113 |
| 2013 | 0.35 | 0.057 | 0.015 | 0.032 | 0.014 | 0.005 | 0.473 | 0.107 |
| 2014 | 0.39 | 0.037 | 0.007 | 0.044 | 0.002 | 0.004 | 0.484 | 0.100 |
| 2015 | 0.40 | 0.103 | 0.019 | 0.030 | 0.005 | 0.006 | 0.563 | 0.099 |
|  |  |  |  |  |  |  |  |  |

Model 13

| Year | Summer <br> Com | Winter <br> Com | Winter <br> Sub | Discards <br> Summer | Discards <br> Winter <br> Sub | Discards <br> Winter <br> com | Total | Catch/ <br> MMB |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1977 | 0.52 | 0.000 | 0.000 | 0.021 | 0.000 | 0.000 | 0.541 | 0.030 |
| 1978 | 2.09 | 0.024 | 0.025 | 0.044 | 0.008 | 0.000 | 2.191 | 0.129 |
| 1979 | 2.93 | 0.001 | 0.000 | 0.052 | 0.000 | 0.000 | 2.983 | 0.242 |
| 1980 | 1.19 | 0.000 | 0.000 | 0.026 | 0.000 | 0.000 | 1.216 | 0.179 |
| 1981 | 1.38 | 0.000 | 0.001 | 0.077 | 0.000 | 0.000 | 1.458 | 0.317 |
| 1982 | 0.23 | 0.000 | 0.003 | 0.022 | 0.001 | 0.000 | 0.256 | 0.073 |
| 1983 | 0.37 | 0.001 | 0.021 | 0.039 | 0.006 | 0.000 | 0.437 | 0.108 |
| 1984 | 0.39 | 0.002 | 0.022 | 0.040 | 0.005 | 0.000 | 0.459 | 0.101 |
| 1985 | 0.43 | 0.003 | 0.017 | 0.038 | 0.002 | 0.000 | 0.49 | 0.096 |
| 1986 | 0.48 | 0.005 | 0.014 | 0.034 | 0.004 | 0.000 | 0.537 | 0.098 |
| 1987 | 0.33 | 0.003 | 0.012 | 0.021 | 0.002 | 0.000 | 0.368 | 0.067 |
| 1988 | 0.24 | 0.001 | 0.005 | 0.014 | 0.001 | 0.000 | 0.261 | 0.046 |
| 1989 | 0.25 | 0.001 | 0.012 | 0.012 | 0.002 | 0.000 | 0.277 | 0.050 |
| 1990 | 0.19 | 0.009 | 0.024 | 0.010 | 0.004 | 0.000 | 0.237 | 0.046 |
| 1991 | 0 | 0.010 | 0.015 | 0.000 | 0.002 | 0.000 | 0.027 | 0.006 |
| 1992 | 0.07 | 0.019 | 0.023 | 0.003 | 0.003 | 0.001 | 0.119 | 0.026 |
| 1993 | 0.33 | 0.004 | 0.002 | 0.016 | 0.000 | 0.000 | 0.352 | 0.086 |
| 1994 | 0.32 | 0.014 | 0.008 | 0.015 | 0.001 | 0.001 | 0.359 | 0.106 |
| 1995 | 0.32 | 0.019 | 0.011 | 0.018 | 0.002 | 0.001 | 0.371 | 0.133 |
| 1996 | 0.22 | 0.004 | 0.003 | 0.018 | 0.001 | 0.000 | 0.246 | 0.102 |
| 1997 | 0.09 | 0.000 | 0.001 | 0.011 | 0.001 | 0.000 | 0.103 | 0.042 |
| 1998 | 0.03 | 0.002 | 0.017 | 0.004 | 0.012 | 0.000 | 0.065 | 0.022 |
| 1999 | 0.02 | 0.007 | 0.015 | 0.002 | 0.003 | 0.000 | 0.047 | 0.012 |
| 2000 | 0.3 | 0.008 | 0.011 | 0.015 | 0.004 | 0.000 | 0.338 | 0.079 |
| 2001 | 0.28 | 0.003 | 0.001 | 0.016 | 0.000 | 0.000 | 0.3 | 0.078 |
| 2002 | 0.25 | 0.006 | 0.004 | 0.022 | 0.003 | 0.001 | 0.286 | 0.078 |
| 2003 | 0.26 | 0.017 | 0.008 | 0.025 | 0.005 | 0.001 | 0.316 | 0.082 |
| 2004 | 0.34 | 0.001 | 0.002 | 0.026 | 0.001 | 0.000 | 0.37 | 0.091 |
| 2005 | 0.4 | 0.005 | 0.008 | 0.026 | 0.003 | 0.000 | 0.442 | 0.110 |
| 2006 | 0.45 | 0.000 | 0.002 | 0.038 | 0.001 | 0.000 | 0.491 | 0.128 |
| 2007 | 0.31 | 0.008 | 0.021 | 0.033 | 0.011 | 0.001 | 0.384 | 0.096 |
| 2008 | 0.39 | 0.014 | 0.019 | 0.043 | 0.009 | 0.001 | 0.476 | 0.107 |
| 2009 | 0.4 | 0.012 | 0.010 | 0.038 | 0.002 | 0.001 | 0.463 | 0.093 |
| 2010 | 0.42 | 0.012 | 0.014 | 0.029 | 0.002 | 0.001 | 0.478 | 0.089 |
| 2011 | 0.4 | 0.008 | 0.013 | 0.021 | 0.003 | 0.000 | 0.445 | 0.086 |
| 2012 | 0.47 | 0.023 | 0.015 | 0.028 | 0.004 | 0.001 | 0.541 | 0.115 |
| 2013 | 0.35 | 0.057 | 0.015 | 0.037 | 0.014 | 0.005 | 0.478 | 0.111 |
| 2014 | 0.39 | 0.037 | 0.007 | 0.048 | 0.002 | 0.004 | 0.488 | 0.105 |
| 2015 | 0.40 | 0.103 | 0.019 | 0.033 | 0.005 | 0.006 | 0.566 | 0.102 |
|  |  |  |  |  |  |  |  |  |

## Aleutian Islands Golden King Crab (Lithodes aequispinus) Model-Based Stock Assessment in Spring 2017

Draft report for the May 2017 Crab Plan Team Meeting

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## Executive Summary

## 1. Stock

Golden king crab, Lithodes aequispinus, Aleutian Islands, east of $174^{\circ} \mathrm{W}$ longitude (EAG) and west of $174^{\circ} \mathrm{W}$ longitude (WAG).

## 2. Catches

The Aleutian Islands golden king crab commercial fishery developed in the early 1980s; the harvest peaked in 1986/87 at 5.900 and 8.800 million pounds, respectively, for EAG and WAG. Catches have been steady since 1996/97 following implementation of total allowable catches (TACs) of 3.000 (EAG) and 2.700 (WAG) million pounds. The TACs were increased to 3.150 and 2.835 million pounds for the two respective regions for the 2008/09 fishing year following an Alaska Board of Fisheries (BOF) decision. These levels were below the limit TACs determined under Tier 5 criteria (considering 1991-1995 mean catch as the limit catch) under the most recent crab management plan. The TACs were further increased by another BOF decision to 3.310 million pounds for EAG and 2.980 million pounds for WAG beginning with the 2012/13 fishing year. The fishery has harvested close to TAC levels since 1996/97. Catch rates (crab / pot-pull) increased in both EAG and WAG fisheries in the mid-2000s. However, in recent years WAG catch rates have declined. The below par fishery performance in WAG lead to reduction in TAC to 2.235 million pounds for the 2016/17 fishing season.

## 3. Stock biomass

Estimated mature male biomass (MMB) for EAG under all scenarios decreased from high levels during the 1990s of the directed fishery, then systematically increased during the 2000s and 2010s. Estimated MMB for WAG decreased during the late 1980s and 1990s, systematically increased during the 2000s, and decreased during last few years since 2009. The low levels of MMB for EAG were observed in 19951997 and in 1990s for WAG. Stock trends reflected the fishery standardized CPUE trends in both regions.

## 4. Recruitment

The numbers of recruits to the model size groups under all scenarios have fluctuated in both EAG and WAG. For EAG, the model recruitment was high in 1987, 1988, 2008, and 2011 to 2014; and lowest in 1986. An increasing trend in recruitment was observed since the early-1990s in EAG. The model recruitment for WAG was high in 1985 and 1986, and lowest in 2011. After 1985 and 1986 peaks, the recruitment trend was low.

## 5. Management performance

The model was accepted at the September 2016 CPT and October 2016 SSC meetings for OFL determination for the 2017/18 fishery cycle. In addition, the CPT in January 2017 and SSC in February 2017 recommended using the Tier 3 method to compute OFL and ABC. Since it has not yet been used for making any management decision, past management performance by this model outcome cannot be assessed. However, we provide the management performance (status and catch specifications) tables with the Tier 3 assessment results for scenario 9 for individual regions (EAG and WAG) and the entire Aleutian Islands (AI). The AI results can be compared with the prior years' performance under Tier 5 assessment procedure (Pengilly 2016):

Status and catch specifications ( 1000 t) of EAG golden king crab

| Fishing <br> Year | MSST | Biomass <br> $($ MMB $)$ | TAC $^{\text {a }}$ | Retained <br> Catch | Total <br> Catch | OFL | ABC <br> $(0.75 *$ OFL $)$ | ABC <br> $(0.8 * O F L)$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2016 / 17$ | N/A | N/A | 1.501 | Fishing $^{\mathrm{b}}$ | Fishing $^{\mathrm{b}}$ |  |  |  |
| $2017 / 18^{\mathrm{c}}$ | 3.524 | 9.306 |  |  |  | 4.486 | 3.365 | 3.589 |

a. Total allowable catch, established in lb. and converted to t .
b. Fishing in progress
c. Tier 3 assessment scenario 9 results

Status and catch specifications (million lb) of EAG golden king crab

| Fishing Year | MSST | Biomass (MMB) | TAC ${ }^{\text {a }}$ | Retained Catch | Total Catch | OFL | $\begin{gathered} \text { ABC } \\ \left(0.75^{*} \text { OFL }\right) \end{gathered}$ | $\begin{gathered} \mathrm{ABC} \\ (0.8 * \mathrm{OFL}) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2016/17 | N/A | N/A | 3.310 | Fishing ${ }^{\text {b }}$ | Fishing ${ }^{\text {b }}$ |  |  |  |
| 2017/18 ${ }^{\text {c }}$ | 7.769 | 20.515 |  |  |  | 9.890 | 7.417 | 7.912 |

Status and catch specifications (1000 t) of WAG golden king crab

| Fishing <br> Year | MSST | Biomass <br> (MMB) | TAC $^{\text {a }}$ | Retained <br> Catch | Total <br> Catch | OFL | ABC <br> $(\mathbf{0 . 7 5} * \mathbf{O F L})$ | ABC <br> $(\mathbf{0 . 8} * \mathbf{O F L})$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | ---: |
| $2016 / 17$ | N/A | N/A | 1.014 | Fishing $^{\mathrm{b}}$ | Fishing $^{\mathrm{b}}$ |  |  |  |
| $2017 / 18^{\mathrm{c}}$ | 2.520 | 4.927 |  |  |  | 1.532 | 1.149 | 1.226 |

a. Total allowable catch, established in lb. and converted to t .
b. Fishing in progress
c. Tier 3 assessment scenario 9 results

Status and catch specifications (million lb) of WAG golden king crab

| Fishing <br> Year | MSST | Biomass <br> $(\mathbf{M M B})$ | TAC $^{\mathrm{a}}$ | Retained <br> Catch | Total <br> Catch | OFL | ABC <br> $(\mathbf{0 . 7 5} \boldsymbol{0 F L})$ | ABC <br> $(\mathbf{0 . 8} \boldsymbol{0} \mathbf{O F L})$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2016 / 17$ | N/A | N/A | 2.235 | Fishing $^{\mathrm{b}}$ | Fishing $^{\mathrm{b}}$ |  |  |  |
| $2017 / 18^{\mathrm{c}}$ | 5.555 | 10.863 |  |  |  | 3.378 | 2.534 | 2.702 |

a. Total allowable catch
b. Fishing in progress
c. Tier 3 assessment scenario 9 results

During the May 2017 meeting, the CPT noted that a single OFL and ABC are defined for AIGKC. However, separate models are available by area. The CPT considered two ways for computing an OFL for AIGKC.

Approach 1: Apply the OFL control rule by area and sum the OFLs by area.
Approach 2: Determine stock status for the stock by adding the estimates of current MMB and $\mathrm{B}_{\text {MSY }}$ by area. This stock status is then used to determine the ratio of $\mathrm{F}_{\text {OFL }}$ to $\mathrm{F}_{35 \%}$ by area, which is then used to calculate the OFLs by area which are then added together to calculate an OFL for the entire stock.

The CPT preferred the $2^{\text {nd }}$ approach because it relies on a single stock status determination. In contrast, use of the $1^{\text {st }}$ approach would lead to the EAG area being in Tier 3a and the WAG area being in Tier 3b, which would not lead to a unique Tier level. We computed the status and catch specifications following the two approaches:

Status and catch specifications (1000 t) of Aleutian Islands golden king crab

| Year | MSST | Biomass <br> (MMB) | TAC | Retained $_{\text {Catch }^{\text {a }}}$ | Total <br> Catch $^{\text {a }}$ | OFL | ABC $^{\text {e }}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2013 / 14$ | N/A | N/A | 2.853 | 2.894 | 3.192 | 5.69 | 5.12 |
| $2014 / 15$ | N/A | N/A | 2.853 | 2.771 | 3.079 | 5.69 | 4.26 |
| $2015 / 16$ | N/A | N/A | 2.853 | 2,729 | 3,073 | 5.69 | 4.26 |
| $2016 / 17$ | N/A | N/A | 2.515 | Fishing $^{\text {b }}$ | Fishing $^{\text {b }}$ | 5.69 | 4.26 |
| $2017 / 18^{\text {c }}$ | 6.044 | 14.233 |  |  |  | 6.018 | 4.815 |
| $2017 / 18^{\text {d }}$ | 6.044 | 14.205 |  |  |  | 6.048 | 4.838 |

a. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.
b. Fishing in progress
c. Approach 1 above
d. Approach 2 above
e. The last two ABC estimates are based on $20 \%$ buffer whereas the other estimates are based on $25 \%$ buffer

Status and catch specifications (million lb) of Aleutian Islands golden king crab

| Year | MSST | Biomass <br> (MMB) | TAC | Retained <br> Catch $^{2}$ | Total <br> Catch $^{\text {a }}$ | OFL | ABC $^{\text {e }}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2013 / 14$ | N/A | N/A | 6.290 | 6.38 | 7.04 | 12.54 | 11.28 |
| $2014 / 15$ | N/A | N/A | 6.290 | 6.11 | 6.79 | 12.53 | 9.40 |
| $2015 / 16$ | N/A | N/A | 6.290 | 6.016 | 6.775 | 12.53 | 9.40 |
| $2016 / 17$ | N/A | N/A | 5.545 | Fishing $^{\text {b }}$ | Fishing $^{\text {b }}$ | 12.53 | 9.40 |
| $2017 / 18^{\text {c }}$ | 13.325 | 31.378 |  |  |  | 13.268 | 10.614 |
| $2017 / 18^{\text {d }}$ | 13.325 | 31.315 |  |  |  | 13.333 | 10.666 |

a. Total retained catch plus estimated bycatch mortality of discarded bycatch during crab fisheries and groundfish fisheries.
b. Fishing in progress
c. Approach 1 above
d. Approach 2 above
e. The last two ABC estimates are based on $20 \%$ buffer whereas the other estimates are based on $25 \%$ buffer

## 6. Basis for the OFL

We provide the OFL estimates under the Tier 3 approach for EAG, WAG, and the two regions pooled together (i.e., for the entire Aleutian Islands, AI), respectively. The length-based model developed for the Tier 3 analysis estimated MMB on February 15 each year for the period 1986 through 2016 and projected to February 15,2017 for OFL and ABC determination. The Tier 3 approach uses the mean number of recruits for the period 1987 - 2012 for OFL and ABC calculation.

Total OFL and ABC estimates are provided for seven scenarios (1, 2, 3, 4, 9, 10, and 11) for EAG, WAG, and AI, respectively in the following six tables. Following the May 2017 CPT suggestion, we also considered a separate scenario $9^{* *}$ for WAG to calculate the OFL and ABC for the entire Aleutian Islands under approach 2. We treat scenario 1 as the base scenario for EAG and WAG. We recommend the OFL and ABC estimates for scenario 9 (knife-edge selectivity). Since the OFL and ABC have been set for the entire AI under Tier 5 procedure, we suggest implementing the combined OFL and ABC for AI.

## EAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in million pounds. Current $\mathrm{MMB}=\mathrm{MMB}$ on 15 Feb .2017.

| Scenario | Tier | B $35 \%$ | Current MMB | MMB/ <br> $B_{35 \%}$ | $F_{\text {OFL }}$ | Recruitment Years to define $B_{35 \%}$ | $F_{35 \%}$ | OFL | $\begin{gathered} \mathrm{ABC} \\ \left(\mathrm{P}^{*}=0.49\right) \end{gathered}$ | $\begin{gathered} \hline \mathrm{ABC} \\ (0.75 * \mathrm{OFL}) \end{gathered}$ | $\begin{gathered} \mathrm{ABC} \\ (0.8 * \mathrm{OFL}) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 3a | 14.177 | 18.820 | 1.33 | 0.64 | 1987-2012 | 0.64 | 8.787 | 8.753 | 6.591 | 7.030 |
| 2 | 3 a | 14.309 | 19.050 | 1.33 | 0.63 | 1987-2012 | 0.63 | 8.873 | 8.837 | 6.654 | 7.098 |
| 3 | 3 a | 14.818 | 20.203 | 1.36 | 0.61 | 1987-2012 | 0.61 | 9.641 | 9.601 | 7.231 | 7.713 |
| 4 | 3 a | 13.791 | 17.987 | 1.30 | 0.66 | 1987-2012 | 0.66 | 8.301 | 8.268 | 6.226 | 6.641 |
| 9 | 3 a | 15.539 | 20.515 | 1.32 | 0.75 | 1987-2012 | 0.75 | 9.890 | 9.852 | 7.417 | 7.912 |
| 10 | 3 a | 14.265 | 18.840 | 1.32 | 0.62 | 1987-2012 | 0.62 | 8.556 | 8.523 | 6.417 | 6.845 |
| 11 | 3 a | 15.577 | 20.507 | 1.32 | 0.73 | 1987-2012 | 0.73 | 9.672 | 9.635 | 7.254 | 7.738 |

Biomass in 1000 t ; total OFL and ABC for the next fishing season in t .

| Scenario | Tier | $B_{35 \%}$ | Current <br> MMB | MMB/ $B_{35 \%}$ | $F_{\text {OFL }}$ | Recruitment Years to Define $B_{35 \%}$ | $F_{35 \%}$ | OFL | $\begin{gathered} \mathrm{ABC} \\ \left(\mathrm{P}^{*}=0.49\right) \end{gathered}$ | $\begin{gathered} \mathrm{ABC} \\ (0.75 * \mathrm{OFL}) \end{gathered}$ | $\begin{gathered} \mathrm{ABC} \\ \left(0.8^{*} \mathrm{OFL}\right) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1 | 3a | 6.430 | 8.536 | 1.33 | 0.64 | 1987-2012 | 0.64 | 3,985.959 | 3,970.495 | 2,989.469 | 3,188.767 |
| 2 | 3a | 6.491 | 8.641 | 1.33 | 0.63 | 1987-2012 | 0.63 | 4,024.578 | 4,008.452 | 3,018.433 | 3,219.662 |
| 3 | 3a | 6.721 | 9.164 | 1.36 | 0.61 | 1987-2012 | 0.61 | 4,373.272 | 4,355.014 | 3,279.954 | 3,498.617 |
| 4 | 3a | 6.256 | 8.159 | 1.30 | 0.66 | 1987-2012 | 0.66 | 3,765.375 | 3,750.119 | 2,824.031 | 3,012.300 |
| 9 | 3 a | 7.048 | 9.306 | 1.32 | 0.75 | 1987-2012 | 0.75 | 4,486.052 | 4,468.684 | 3,364.539 | 3,588.842 |
| 10 | 3 a | 6.471 | 8.546 | 1.32 | 0.62 | 1987-2012 | 0.62 | 3,880.873 | 3,865.821 | 2,910.655 | 3,104.698 |
| 11 | 3 a | 7.066 | 9.302 | 1.32 | 0.73 | 1987-2012 | 0.73 | 4,387.350 | 4,370.392 | 3,290.512 | 3,509.880 |

## WAG (Tier 3):

Biomass, total OFL, and ABC for the next fishing season in million pounds. Current $\mathrm{MMB}=\mathrm{MMB}$ on 15 Feb .2017.

| Scenario | Tier | B35\% | Current <br> MMB | MMB/$B_{35 \%}$ | Recruitment Years to |  |  | OFL | $\begin{gathered} \mathrm{ABC} \\ \left(\mathrm{P}^{*}=0.49\right) \end{gathered}$ | $\begin{gathered} \hline \text { ABC } \\ (0.75 * \mathrm{OFL}) \end{gathered}$ | $\begin{gathered} \mathrm{ABC} \\ (0.8 * \mathrm{OFL}) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | $F_{\text {OFL }}$ | Define $B_{35 \%}$ | $F_{35 \%}$ |  |  |  |  |
| 1 | 3b | 10.214 | 9.671 | 0.95 | 0.54 | 1987-2012 | 0.57 | 2.862 | 2.842 | 2.146 | 2.289 |
| 2 | 3 b | 10.099 | 9.535 | 0.94 | 0.54 | 1987-2012 | 0.58 | 2.767 | 2.747 | 2.075 | 2.213 |
| 3 | 3 b | 10.226 | 9.680 | 0.95 | 0.54 | 1987-2012 | 0.57 | 2.861 | 2.840 | 2.145 | 2.288 |
| 4 | 3 b | 9.866 | 9.031 | 0.92 | 0.49 | 1987-2012 | 0.54 | 2.445 | 2.427 | 1.834 | 1.956 |
| 9 | 3 b | 11.111 | 10.863 | 0.98 | 0.66 | 1987-2012 | 0.68 | 3.378 | 3.355 | 2.534 | 2.702 |
| 9** | 3 a | 9.937 | 10.800 | 1.09 | 0.68 | 1993-1997 | 0.68 | 3.443 | 3.428 | 2.582 | 2.754 |
| 10 | 3 b | 10.049 | 9.704 | 0.97 | 0.59 | 1987-2012 | 0.61 | 3.115 | 3.093 | 2.336 | 2.492 |
| 11 | 3 b | 11.025 | 10.928 | 0.99 | 0.71 | 1987-2012 | 0.72 | 3.616 | 3.591 | 2.712 | 2.893 |

Biomass in 1000 t ; total OFL and ABC for the next fishing season in t .

| Scenario | Tier | B35\% | Current <br> MMB | MMB /$B_{35 \%}$ | Recruitment Years to |  |  | OFL | $\begin{gathered} \mathrm{ABC} \\ \left(\mathrm{P}^{*}=0.49\right) \end{gathered}$ | $\begin{gathered} \mathrm{ABC} \\ (0.75 * \mathrm{OFL}) \end{gathered}$ | $\begin{gathered} \mathrm{ABC} \\ (0.8 * \mathrm{OFL}) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | $F_{\text {OFL }}$ | Define $B_{35 \%}$ | $F_{35 \%}$ |  |  |  |  |
| 1 | 3b | 4.633 | 4.387 | 0.95 | 0.54 | 1987-2012 | 0.57 | 1,298.130 | 1,288.987 | 973.598 | 1,038.504 |
| 2 | 3 b | 4.581 | 4.325 | 0.94 | 0.54 | 1987-2012 | 0.58 | 1,254.898 | 1,245.940 | 941.173 | 1,003.918 |
| 3 | 3 b | 4.638 | 4.391 | 0.95 | 0.54 | 1987-2012 | 0.57 | 1,297.539 | 1,288.389 | 973.155 | 1,038.032 |
| 4 | 3 b | 4.475 | 4.097 | 0.92 | 0.49 | 1987-2012 | 0.54 | 1,108.982 | 1,100.974 | 831.737 | 887.186 |
| 9 | 3 b | 5.040 | 4.927 | 0.98 | 0.66 | 1987-2012 | 0.68 | 1,532.280 | 1,521.602 | 1,149.210 | 1,225.824 |
| 9** | 3 a | 4.507 | 4.899 | 1.09 | 0.68 | 1993-1997 | 0.68 | 1,561.668 | 1,554.794 | 1,171.251 | 1,249.334 |
| 10 | 3 b | 4.558 | 4.402 | 0.97 | 0.59 | 1987-2012 | 0.61 | 1,412.980 | 1,402.879 | 1,059.735 | 1,130.384 |
| 11 | 3 b | 5.001 | 4.957 | 0.99 | 0.71 | 1987-2012 | 0.72 | 1,640.212 | 1,628.919 | 1,230.159 | 1,312.169 |

Aleutian Islands (AI)
Total OFL and ABC for the next fishing season in million pounds.

| Scenario | OFL | ABC <br> $\left(\mathrm{P}^{*}=0.49\right)$ | ABC <br> $(0.75 * \mathrm{OFL})$ | ABC <br> $\left(0.8^{*} \mathrm{OFL}\right)$ |
| ---: | ---: | ---: | ---: | ---: |
| 1 | 11.649 | 11.595 | 8.737 | 9.319 |
| 2 | 11.64 | 11.584 | 8.729 | 9.311 |
| 3 | 12.502 | 12.441 | 9.376 | 10.001 |
| 4 | 10.746 | 10.695 | 8.06 | 8.597 |
| 9 | 13.268 | 13.207 | 9.951 | 10.614 |
| $9 * *$ | 13.333 | 13.280 | 9.999 | 10.666 |
| 10 | 11.671 | 11.616 | 8.753 | 9.337 |
| 11 | 13.288 | 13.226 | 9.966 | 10.631 |

Aleutian Islands (AI)
Total OFL and ABC for the next fishing season in $t$.

| Scenario | OFL | ABC <br> $\left(\mathrm{P}^{*}=0.49\right)$ | ABC <br> $\left(0.75^{*} \mathrm{OFL}\right)$ | ABC <br> $\left(0.8^{* O F L}\right)$ |
| ---: | ---: | ---: | ---: | ---: |
|  | $5,284.089$ | $5,259.482$ | $3,963.067$ | $4,227.271$ |
| 2 | $5,279.476$ | $5,254.392$ | $3,959.606$ | $4,223.580$ |
| 3 | $5,670.811$ | $5,643.403$ | $4,253.109$ | $4,536.649$ |
| 4 | $4,874.357$ | $4,851.093$ | $3,655.768$ | $3,899.486$ |
| 9 | $6,018.330$ | $5,990.286$ | $4,513.749$ | $4,814.666$ |
| $9 * *$ | $6,047.720$ | $6,023.478$ | $4,535.790$ | $4,838.176$ |
| 10 | $5,293.853$ | $5,268.700$ | $3,970.390$ | $4,235.082$ |
| 11 | $6,027.562$ | $5,999.311$ | $4,520.671$ | $4,822.049$ |

## 7. Probability density functions of OFL

Assuming a lognormal distribution of total OFL, we determined the cumulative distributions of OFL and selected the median as the OFL.

## 8. The basis for the $A B C$ recommendation

An $\mathrm{x} \%$ buffer on the OFL; i.e., $\mathrm{ABC}=(1.0-\mathrm{x} / 100)^{*} \mathrm{OFL}$. We considered $\mathrm{x}=20 \%$ and $25 \%$. The CPT preferred $20 \%$.
See also the section G on ABC
9. A summary of results of any rebuilding analysis:

Not applicable.

## A. Summary of Major Changes

1. Changes (if any) to management of the fishery Propose changes to OFL and ABC under model based Tier 3 assessment.
2. Changes to input data
(a) Retained catch (1981/82-2015/16), total catch (1990/91-2015/16), and groundfish bycatch (1989/90-2015/16) biomass and size compositions were the same as in the September 2016 and January 2017 assessment.
(b) Fish ticket retained CPUE were standardized by the GLM with the lognormal link function for the 1985/86-1998/98 period, which was the same as in the September 2016 and January 2017 assessment.
(c) For scenario 3, observer pot sample legal size crab CPUE data were extended back to 1991/92 and standardized by the generalized linear model (GLM) with the negative binomial link function, separately for 1991/92-2004/05 and 2005/06-2015/16 periods.
(d) Male maturity proportions by size classes were added.
3. Changes to assessment methodology
(a) The same model has been improved:
(b) The ADMB cumulative gamma function was used instead of numerical approximation for recruit distribution estimation.
(c) We removed the Tier 4 OFL fishing mortality penalty from the set of likelihood functions.
(d) The equilibrium initial population and Tier $3 \mathrm{~B}_{\text {MSY }}$ reference point estimation procedures used the mean number of recruits for 1987-2012.
(e) Francis re-weighting method was used to updating the input effective sample sizes for length composition data for all scenarios (Siddeek et al. 2016c, in press 2017).
(a) Changes to assessment results

Not applicable because the model has not been used previously.

## B. Response to September 2016 CPT comments

Comment 1: The CPT recommended bringing likelihood profile on $M$, mean MMB, and MMB depletion to the May 2017 CPT meeting.

Response:
We have provided $M$ profiles in Figures 4 to 6, mean MMB profile in Figure 7 and MMB depletion profile in Figure 8. The penalty functions for mean MMB and MMB depletion profile analysis are defined in Equations A. 33 and A. 34 respectively in Appendix A.
We used finer incremental steps in the $M$ profile calculation.
Comment 2: Tables 1 (EAG) and 15 (WAG) should be modified to provide the retained catch, pot bycatch breakdown by males and females (make clear if mortality applied) and trawl bycatch followed by total catch.

Response:
We included Table 1a that lists the retained catch, bycatch (males and females lumped together), groundfish discard catch (males and females lumped together), and the total catch with details of what rates of mortality were applied during the 1990/91-2015/16 period for the entire Aleutian Islands. Crab fishery bycatch data were recorded since 1990 after introduction of observer sampling. We will delineate the data by EAG and WAG in the near future.

Comment 3: The plots showing estimated selectivity curves should include both the estimates for pre- and post-rationalization periods.

Response:
We provided this separation in Figure 13 for EAG and Figure 32 for WAG.
Comment 4. Continue the development of a spatial model that could be used to explore the implications of changed in fishing locations

Response:
Appendix F provides a preliminary analysis to exploring the potential impact of area shrinkage on the fishery and the stock dynamics.

## Response to January 2017 CPT comments

Comment 1. While the CPT accepts the approach of using a combined EAG/WAG model to estimate natural mortality, the team would also like to see evidence that tests have been done to show that the combined model gives precisely the same results as the two individual models, since only the individual models have undergone technical review. The assessment author should confirm that the combined profile (without the prior) has a minimum at $0.225 \mathrm{yr}^{-1}$ because the step size for $M$ was fairly small.

## Response:

We have provided $M$ profiles in Figures 4 (scenario 0a considered $M$ penalty for $M$ estimation), 5 (scenario 0 b disregarded $M$ penalty for $M$ estimation), and 6 (scenario 1 b disregarded $M$ penalty for $M$ estimation using separate EAG and WAG data sets). It appears that all results were close. The $95 \%$ confidence intervals under lognormal distribution assumption (formulas are given in Table 49) indicated highly overlapping intervals, Sc0a: 0.2143-0.2310, Sc0b: 0.2157-0.2329, EAG Sc1b: 0.2107-0.2313, and WAG Sc1b: $0.2155-0.2472$. We opted to use the $M$ estimation from combined data that disregarded the $M$ penalty for most of the scenarios.

Comment 2. The likelihood profiles by data components for natural mortality showed that the WAG CPUE had a different profile than other data components, showing a strong improvement in fit at lower values of natural mortality. It would be good to confirm that this is correct.

Response: With the improvement of the model, the total likelihood fits for EAG and WAG attained minimum around $0.224 \mathrm{yr}^{-1}$. The CPUE likelihood patterns for EAG and WAG behaved similarly although they did not attain the minima at the total likelihood minimum value.

Comment 3. What the CPT actually wanted was to evaluate use of the retained catch CPUE time series for the period 1985-1998. Model scenario 4, which did include retained catch CPUE, suggested that it provided useful information in the early years of the fishery, and the CPT recommends that it be included in the base model for May. Examination of diagnostics for the observer CPUE data indicated there was justification for starting the observer CPUE time series in 1995, since the earlier data in 1991-1994 was based on fewer boats and different gear than was used subsequently. In addition, only the catcher-processor vessels carried observers prior to 1995.

Response:
(a) We considered the 1995/96-2015/16 observer CPUE time series in the base and most other scenarios.
(b) However, as per CPT suggestion, we considered one scenario (scenario 3) that included observer CPUE index from 1991-1994.

Comment 4. The CPT recommends that CVs for the recruitment estimates be examined and that only those recruitment estimates that are informed by data (i.e., recruit CVs less than sigma R) be used to obtain mean recruitment to initialize the model.

Response: We examined the recruit standard deviation pattern (Figure 9) and selected the time period 1987-2012 based on recruit standard deviation values < $70 \%$ sigma R for
mean number of recruits estimation to determining equilibrium abundance and $\mathrm{B}_{\text {MSY }}$ reference points for EAG and WAG.

Comment 5. The CPT recommends that dome-shaped selectivity models not be carried forward for the May meeting.

Response: Done.

Comment 6. The CPT agrees with the author's recommendation that the Francis method be adopted as the preferred approach for selecting weights for length-composition data for AIGKC.

Response: We used Francis re-weighting method for selecting weights for length composition data for all scenarios (Appendix D).

Comment 7. The CPT recommends that the changes in the spatial pattern of fishing be evaluated further for the May CPT meeting based on plots by year (or blocks of years).

Response: Appendix F provides the spatial pattern of observer sample, effort , catch, and productivity in core and non-core areas by year during 1990-2015. The core and noncore fishing areas were defined based on finer scaling of observer sampling locations (please see Appendix F for details). We also estimated CPUE indices, catch, fishing mortality and MMB trends using core data and compared those with the estimates from the full data set models.

Comment 8. An $\mathbf{F 3 5 \%}$ calculation requires vectors for maturity, selectivity, and natural mortality-all of which are available for AIGKC. Therefore the CPT recommends that AIGKC be placed in Tier 3. If the SSC agrees with this recommendation in February, there would be no need to develop OFL/ABC tables for Tier 4 in the May assessment document.

Response: We followed the Tier 3 approach.
Comment 9. The CPT recommends that these maturity data be re-evaluated for the May CPT meeting to determine whether a maturity curve can be estimated reliably.

Response: We used the maturity proportions by size estimated from1991 ADFG pot survey maturity data in the model. It appears that a reliable maturity curve can be fitted. The maturity analysis is detailed in Appendix C.

Comment 10. The CPT also discussed whether the primary abundance index for AIGKC as calculated from fishery data should be considered in recommending a Tier level. The CPT regards this as an important factor in assessment uncertainty, but recommends that this be considered when recommending a buffer for the ABC, not in determining the Tier level.

Response: Because of uncertainty in fisheries data, we provided the $20 \%$ and $25 \%$ buffer options for ABC calculation. The CPT in May 2017 selected the $20 \%$ buffer.

Comment 11. CPT would prefer to see similar runs grouped together for May, as it is hard to compare 15 model runs on one graph (for example, Figure 29 on p. 95).

Response: As per CPT suggestion we grouped the similar featured scenario plots as: Group 1: scenarios 1 (base), 2 (drop fishery CPUE index), 3 (extend observer CPUE index back to 1991/92), and 4 (three selectivity and catchability); group 2: scenarios 1,5 (low bracketing of $M$ ), and 6 (high bracketing of $M$ ); group3: scenarios 1 and 9 (knifeedge maturity); group 4: scenarios 1,10 (separately estimated $M$ for EAG and WAG), and 11 (separately estimated $M$ for EAG and WAG with knife-edge maturity).

We adopted the following color scheme for scenarios that have multiple outputs:
Scenarios 1: black, 2: orange, 3: red, 4: blue, 5: violet, 6: dark green, 9: green, 10: dark red, and 11: dark blue.

Specifications of all scenarios are provided in Table T1.

## Response to February 2017 SSC comments

Comment 1: The SSC recommends that, pending completion of the CPT and SSC requests, the authors bring forward a Tier 3 analysis for AIGKC for consideration at the May CPT and June SSC meetings.

Response: We did only Tier 3 analysis in this cycle.

Comment 2: The SSC strongly encourages future efforts to develop a fishery-independent survey for this resource, in addition to continuing efforts to better understand the CPUE data through investigation of the annual spatial distribution of the fishery and changes in individual vessel participation.

Response:
(a) We are making every effort to expand the fishery independent survey currently being conducted in the EAG area.
(b) Please see our response to January 2017 CPT comment 7.

Comment 3: The SSC generally supports the CPT recommendations, but recommends a slightly revised approach to the treatment of natural mortality. The SSC requests that the author prepares a likelihood profile using a finer resolution (smaller step-size). The SSC requests that the author makes a run using both EAG and WAG data sets combined that includes a prior on natural mortality (0.18) with a CV of $50 \%$.

When the final preferred model has been developed, the SSC requests one additional run that does not use this prior on natural mortality in order to evaluate its effect.

Response:
(a) We considered two options: 1 . including the $M$ prior (Equation A. 32 in Appendix A) and 2. Not including the $M$ prior. The results appear not significantly different. Improvement of the model may have produced consistent outcome, which is encouraging (Figures 4 to 6 ). So, we opted to using the $M$ estimate obtained without the $M$ prior in all scenarios.
(b) We used the finer resolution (smaller step-size of 0.025 ) to calculate the profiles.

Comment 4: Finally, the author to perform jitter runs to avoid unexpected model behavior.
Response: We conducted 100 jitter runs following stock synthesis procedure for scenarios 1 and 9 for EAG and WAG, respectively. The convergence did not deviate from the original optimized positions for most runs, thus supporting global convergence (Appendix E).

Comment 5: The SSC notes that the tuning of input-to-effective sample sizes for the McAllisterIanelli method appears to have been conducted at the level of individual year's observations. This is not consistent with general practice, or the conclusions from the 2015 CAPAM workshop, which recommended tuning the input values to the Harmonic mean effective sample size for all years by fishery or fleet. SSC supports the CPT recommendation to use the Francis method for future analyses.

Response: Our last assessment report on this topic was not clear to you. We apologize for that. Indeed, we used the harmonic mean as a single multiplier for the time series of input effective sample sizes under McAllister and Ianelli (1997) method. Anyway, in the current analysis, we used only the Francis method of iterated weighting of effective sample sizes for all scenarios including the $M$ estimation scenarios (Appendix D). So, the confusion on using McAllister and Ianelli method does not arise now.

Comment 6: Recruitments that are included in the $B_{\text {MSY }}$ calculations should have an estimated variance substantially less than sigma $R$, and should generally not include the terminal year's estimates (2016 in this draft analysis) unless specifically warranted by informative data. The SSC recommends the CPT and authors review the GPT guidance on making these calculations and strive for some consistency in their approach.

Response: We used a subset of recruitment estimates that excluded the terminal year's R for equilibrium abundance and $\mathrm{B}_{\text {MSY }}$ reference points estimation (please see our response to January 2017 CPT comment 4).

## C. Introduction

1. Scientific name: Golden king crab, Lithodes aequispinus.
2. Distribution: In Alaska, golden king crab is distributed in the Aleutian Islands, on the continental slope of the eastern Bering Sea, and around the Gulf of Alaska to southeastern Alaska.
3. Evidence of stock structure: There is no direct evidence of separate stock structure in the Aleutian Islands. But contrast between CPUE trends suggests different factors may influence stock productivity in EAG and WAG.
4. Life history characteristics relevant to management: There is a paucity of information on golden king crab life history characteristics due in part to the deep depth distribution ( $\sim 200-1000 \mathrm{~m}$ ) and the asynchronous nature of life history events (Otto and Cummiskey 1985; Somerton and Otto 1986). The reproductive cycle is thought to last approximately 24 months and at any one time, ovigerous females can be found carrying egg clutches in highly disparate developmental states (Otto and Cummiskey 1985). Females carry large, yolk-rich, eggs, which hatch into lecithotrophic (non-feeding) larvae that are negatively phototactic (Adams and Paul 1999). Molting and mating are also asynchronous and protracted (Otto and Cummiskey 1985; Shirley and Zhou 1997) with some indications of seasonality (Hiramoto 1985). Molt increment for large males (adults) in Southeast Alaska is 16.3 mm CL per molt (Koeneman and Buchanan 1985), and was
estimated at 14.4 mm CL for legal males in the EAG (Watson et al. 2002). Annual molting probability of males decreases with increasing size, which results in a protracted inter-molt period and creates difficulty in determining annual molt probability (Watson et al. 2002). Male size-at-maturity varies among stocks (Webb 2014) and declines with increasing latitude from about 130 mm CL in the Aleutian Islands to 90 mm CL in Saint Matthew Island section (Somerton and Otto 1986). Along with a lack of annual survey data, limited stock-specific life history stock information prevents development of the standard length-based assessment model.
5. Brief summary of management history and annual ADFG harvest strategy: Since 1996, the Alaska Department of Fish and Game (ADF\&G) has divided management of the Aleutian Islands golden king crab fishery at $174^{\circ} \mathrm{W}$ longitude (ADF\&G 2002). Hereafter, the east of $174^{\circ} \mathrm{W}$ longitude stock segment is referred to as EAG and the west of $174^{\circ} \mathrm{W}$ longitude stock segment is referred to as WAG. The stocks in the two areas were managed with a constant annual guideline harvest level or total allowable (retained) catch ( 3.000 million pounds for EAG and 2.700 million pounds for WAG). In 2008, however, the total allowable catch was increased by the Board of Fisheries (BOF) to 3.150 and 2.830 million pounds for EAG and WAG, respectively (an approximately 5\% increase in TAC). The TACs were further increased by another BOF decision to 3.310 million pounds for EAG and 2.980 million pounds for WAG beginning with the 2012/13 fishing year. The below par fishery performance in WAG in recent years lead to reduction in TAC to 2.235 million pounds for the 2016/17 fishing season.

Additional management measures include a male-only fishery and a minimum legal size limit ( 152.4 mm CW, or approximately 136 mm CL), which is at least one annual molt increment larger than the $50 \%$ maturity length of 120.8 mm CL for males estimated by Otto and Cummiskey (1985). We re-evaluated the male maturity size using 1991 pot survey measurements of carapace length and chela height in EAG (Appendix C). The $50 \%$ male maturity length estimates varied from 108.5 mm CL (segmented regression analysis) to 109.72 mm CL (logistic
regression model fit) to 110.6 mm CL (assessment model fit). We used the maturity curve developed from the 1991 data for all scenarios except scenarios 9 and 11 in which a knife-edge $50 \%$ maturity length of 111 mm CL was used for mature male biomass (MMB) estimation. Daily catch and catch-per-unit effort (CPUE) are determined in-season to monitor fishery performance and progress towards the respective TACs. Figures 1 to 3 provide the historical time series of catches, CPUE, and the geographic distribution of catch during the recent fishing season. Increases in CPUE were observed during the late 1990s through the early 2000s, and with the implementation of crab rationalization in 2005. This is likely due to changes in gear in the late 1990s (crab fishermen, personal communication, July 1, 2008) and, after rationalization, to increased soak time (Siddeek et al. 2015), and decreased competition owing to the reduced number of vessels fishing. Decreased competition could allow crab vessels to target only the most productive fishing areas.
6. Summary of the history of the basis and estimates of $M M B_{M S Y}$ or proxy $M M B_{M S Y}$ :

We estimated the proxy $M M B_{M S Y}$ as $B_{35 \%}$ using the Tier 3 estimation procedure, which is explained in a subsequent section.

## D. Data

1. Summary of new information:
(a) Commercial fishery retained catch by size, estimated total catch by size, groundfish male discard catch by size, observer CPUE index, commercial fishery CPUE index, and tag-recapture data were updated to include 2015/16 information in September 2016 and January 2017. The details are given in the pictorial table below.
(b) Male maturity proportion by size-class from 1991 pot survey size measurements.
2. Available catch and tagging data:

a. A time series of retained and total catch, groundfish fishery discard mortality, and pot fishery effort (Tables 1a for the entire Aleutian Islands and 1b for EAG and Table 25 for WAG). The estimation methods are described in Appendix B.
b. Time series of pot fishery and observer nominal retained and total CPUE, observer sample size, estimated observer CPUE index (Table 2 for EAG and Table 26 for WAG), and estimated commercial fishery CPUE index (Table 3 for EAG and Table 27 for WAG). The estimation methods, CPUE fits and diagnostic plots are described in Appendix B.
c. Information on length compositions (Figures 10 to 12 for length compositions for EAG; and 29 to 31 for length compositions for WAG).
d. Survey biomass estimates are not available for the area because no systematic surveys, covering the entire fishing area, have occurred.
f. Other time series data: None.
3. Length-weight relationship: $\mathrm{W}=\mathrm{al}^{\mathrm{b}}$ where $\mathrm{a}=3.725^{*} 10^{-4}, \mathrm{~b}=3.090$.
4. Information on any data sources available, but excluded from the assessment: None.

## E. Analytic Approach

## 1. History of modeling approaches for this stock

A size structured assessment model based on only fisheries data has been under development for a number of years for the EAG and WAG golden king crab stocks. The model was accepted in 2016 for OFL and ABC setting for the 2017/18 season. The CPT in January and SSC in February 2017 recommended to using the Tier 3 procedure to set the OFL and ABC. They also suggested to using the maturity data to estimate MMB. We followed these suggestions in this report.

## Model Description

a. The underlying population dynamics model is male-only and length-based (Appendix A). This model combines commercial retained catch, total catch, groundfish fishery discarded catch, standardized observer legal size catch-per-unit-effort (CPUE) indices, fishery retained catch size composition, total catch size composition, and tag recaptures by release-recapture length to estimate stock assessment parameters. The tagging data were used to calculate the size transition matrix. To estimate the male mature biomass (MMB), we used a maturity curve based on the new maturity data. To include a long time series of CPUE indices for stock abundance contrast, we also considered the 1985/86-1998/99 legal size standardized CPUE indices as a separate likelihood component in the base (scenario 1) and a number of other scenarios (see Table T1).

There were significant changes in fishing practice due to changes in management regulations (e.g., constant TAC since 1996/97 and crab rationalization since 2005/06), pot configuration (escape web on the pot door increased to 9-inch since 1999), and improved observer recording in Aleutian Islands golden king crab fisheries since 1998. These changes prompted us to consider two sets of catchability and total selectivity parameters with only one set of retention parameters for the periods 1985/86-2004/05 and 2005/062015/16.

However, in order to respond to a January 2017 CPT comment, we considered three catchabilities, three sets of total selectivity, and one set of retention curves in one scenario (scenario 4).

We fitted the observer and commercial fishery CPUE indices with GLM estimated standard errors and an additional constant variance; the latter was estimated by the model fit. The assessment model predicted total and retained CPUEs. However, we compared only the predicted retained CPUE with the observer legal size crab CPUE indices in the likelihood function because observer recordings of legal size crabs are reliable.
The data series used in the current assessment for EAG ranges from 1985/86 to $2015 / 16$ for retained catch biomass and size composition; 1995/96 to 2015/16 for standardized legal size crab observer CPUE index; 1989/90 to 2015/16 for groundfish fishery male bycatch biomass and size composition; 1985/86 to 1998/99 for standardized crab fish ticket CPUE index; 1990/91 to 2015/16 for total catch biomass and total catch length composition; 1991, 1997, 2000, 2003, and 2006 releases and up to 2012 recapture time period for tagging information, and male maturity proportion by size.

The data series used for the WAG ranges are the same as those for EAG.
b. Software: AD Model Builder (Fournier et al. 2012).
c. -f . Details are given in Appendix A.
g. Critical assumptions and consequences of assumption failures: Because of the lack of an annual stock survey we relied heavily on standardized CPUE indices (Appendix B) and catch and size composition information to determine the stock abundance trends in both regions. We assumed that the observer and fish ticket CPUE indices are linearly related to exploitable abundance. We kept $M$ constant at $0.224 \mathrm{yr}^{-1}$. The $M$ value was the combined estimates for EAG and WAG. We assumed directed pot fishery discard mortality proportion at $0.20 \mathrm{yr}^{-1}$, overall groundfish fishery mortality
proportion at $0.65 \mathrm{yr}^{-1}$ [mean of groundfish pot fishery mortality $\left(0.5 \mathrm{yr}^{-1}\right)$ and groundfish trawl fishery mortality $\left(0.8 \mathrm{yr}^{-1}\right)$ ], groundfish fishery selectivity at full selection for all length classes (selectivity =1.0). Any discard of legal size males in the directed pot fishery was not considered in this analysis. These fixed values invariably reduced the number of model parameters to be estimated and helped in convergence. We assumed different $q$ 's (scaling parameter for standardized CPUE in the model, Equation A. 14 in Appendix A) and logistic selectivity patterns (Equation A. 9 in Appendix A) for different periods for the pot fishery. We also assumed a logistic maturity pattern in the model (Equation A. 10 in Appendix A).
h. Changes to any of the above since the previous assessment: Does not apply for this assessment since the model has not been used for previous assessment.
i. Model code has been checked and validated. The code is available from the authors.

## 2. Model Selection and Evaluation

a. Description of alternative model configurations:

We considered 11 scenarios overall for EAG and WAG (Table T1). We presented OFL and ABC results for selected seven scenarios separately for EAG, WAG, and the entire AI in the executive summary tables. We considered scenario 1 as the base scenario. It considers:
i) Initial abundance by the equilibrium condition considering the mean number of recruits for 1987-2012: The equilibrium abundance was determined for 1960 , projected it forward with only $M$ and annual recruits until 1980, then retained catches removed during 1981-1984 and projected it to obtain the initial abundance in 1985 (see Equations A. 4 and A. 5 in Appendix A).
ii) Observer CPUE indices for 1995/96-2015/16.
iii) Fishery CPUE indices for 1985/86-1998/99.
iv) Initial (Stage-1) weighting of effective sample sizes: number of days for retained and total catch size compositions and number of fishing trips for
groundfish discard size composition (the groundfish size composition was not used in the model fitting); and (Stage-2) iterative re-weighting of effective sample sizes by the Francis method (Appendix D).
v) Two catchability and two sets of logistic total selectivity for the periods 1985/86-2004/05 and 2005/06-2015/16, and a single set of logistic retention curve parameters.
vi) Full selectivity (selectivity $=1.0$ ) for groundfish (trawl) bycatch.
vii) Logistic maturity curve by size.
viii) Stock dynamics $M=0.224 \mathrm{yr}^{-1}$, pot fishery handling mortality $=0.2 \mathrm{yr}^{-1}$; and mean groundfish bycatch handling mortality $=0.65 \mathrm{yr}^{-1}$.
ix) Size transition matrix using tagging data estimated by the normal probability function with the logistic molt probability sub-model. The tagrecaptures were treated as Bernoulli trials (i.e., Stage-1 weighting).
x) The time period, 1987/88-2012/13, was used to determine the mean number of recruits for $B_{35 \%}$ (a proxy for $M M B_{M S Y}$ ) estimation under Tier 3. The salient features and variations from the base scenario of all other scenarios are listed in Table T1. The list of fixed and estimable parameters are provided in Table A1 and detail weights with coefficient of variations (CVs) assigned to each type of data are listed in Table A2 of Appendix A.

As per CPT and SSC requests, jittering of initial parameter values for scenarios 1 and 9 were done to confirm model global convergence. The results indicated that global convergence was achieved for most of the runs (Appendix E).

Table T1. Features of model scenarios. Initial condition was estimated by the equilibrium condition for all scenarios. Changes from scenario 1 specifications are highlighted by the light blue shade.

| Scenario | Size- composition weighting | Catchability and logistic total selectivity sets | Maturity | CPUE data type | Treatment of $M$ and Tier $3 B_{\text {MSY }}$ reference points | $\begin{gathered} \text { Natural } \\ \text { mortality }\left(M y r^{-1}\right) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 0a | Stage1:Number of days/trips Stage-2: <br> Francis method | 2 | Logistic curve | Observer from 1995/962015/16 \& Fish Ticket from 1985/86-1998/99 | Estimate a common $M$ using the combined EAG and WAG data with an $M$ prior | 0.223 |
| 0b | Stage1:Number of days/trips Stage-2: <br> Francis method | 2 | Logistic curve | Observer from 1995/962015/16 \& Fish Ticket from 1985/86-1998/99 | Estimate a common $M$ using the combined EAG and WAG data without an $M$ prior | 0.224 |
| 1b | Stage1:Number of days/trips Stage-2: <br> Francis method | 2 | Logistic curve | Observer from 1995/962015/16 \& Fish Ticket from 1985/86-1998/99 | Estimate separate $M$ for each area using individual EAG or WAG data without an $M$ prior | $\begin{aligned} & \text { EAG: } 0.221 \\ & \text { WAG: } 0.231 \end{aligned}$ |
| 1 | Stage1 :Number of days/trips Stage-2: <br> Francis method | 2 | Logistic curve | Observer from 1995/962015/16 \& Fish Ticket from 1985/86-1998/99 | Single $M$ from combined EAG and WAG data; Tier $3 \mathrm{~B}_{\mathrm{MSY}}$ reference points based on average recruitment from 1987-2012 | 0.224 |
| 2 | Stage1:Number of days/trips Stage-2: <br> Francis method | 2 | Logistic curve | Omit Fish Ticket CPUE likelihood | Single $M$ from combined EAG and WAG data; Tier $3 \mathrm{~B}_{\mathrm{MSY}}$ reference points based on average recruitment from 1987-2012 | 0.224 |
| 3 | Stage1:Number of days/trips Stage-2: <br> Francis method | 2 | Logistic curve | Observer CPUE from 1991/92-2015/16 \& Fish Ticket | Single $M$ from combined EAG and WAG data; Tier $3 \mathrm{~B}_{\mathrm{MSY}}$ reference points based on average recruitment from 1987-2012 | 0.224 |

Stage-
1:Number of days/trips Stage-2:
Francis method Stage-
1:Number of days/trips Stage-2:
Francis method Stage-
1:Number of days/trips Stage-2:
Francis method

## Stage-

1:Number of days/trips Stage-2
Francis method

## Stage-

1:Number of days/trips Stage-2:
Francis method
Stage-

1:Number of days/trips Stage-2:
Francis method

> Stage-

1:Number of
days/trips
Stage-2:
Francis method
2

Logistic curve
Observer \& Fish Ticket
Obser \& Fish Ticket

Observer \& Fish ticket
Logistic curve

Logistic curve

Logistic curve

Logistic curve

## Knife-edge <br> 111 mmCL

Knife-edge
111 mmCL
Observer \& Fish Ticket

Single $M$ from combined EAG and WAG data; Tier $3 \mathrm{~B}_{\mathrm{MSY}}$ reference points based on average recruitment from 1987-2012

Low bracketing value of $M$; Tier $3 \mathrm{~B}_{\text {MSY }}$ reference points based on average recruitment from 1987-2012

High bracketing value of $M$; Tier $3 \mathrm{~B}_{\text {MSY }}$ reference points based on average recruitment from 1987-2012

Single $M$ from combined EAG and WAG data; Tier $3 \mathrm{~B}_{\mathrm{MSY}}$ reference points based on average recruitment from 1982-2016

Single $M$ from combined EAG and WAG data; Tier $3 \mathrm{~B}_{\text {MSY }}$ reference points based on average recruitment from 1996-2016

Single $M$ from combined EAG and WAG
data; Tier $3 \mathrm{~B}_{\mathrm{MSY}}$ reference points based on
average recruitment from 1987-2012

Considered only for WAG for Approach 2

OFL and ABC calculation; Single $M$ from combined EAG and WAG data; Tier 3
$\mathrm{B}_{\text {MSY }}$ reference points based on average recruitment from 1993-1997

1:Number of days/trips Stage-2:
Francis method

## Stage-

1:Number of days/trips Stage-2:
Francis method

Logistic curve Observer \& Fish Ticket Separate $M$ from EAG and WAG data; Tier $3 \mathrm{~B}_{\text {MSY }}$ reference points based on average recruitment from 1987-2012

## Knife-edg

 111 mmCLObserver \& Fish Ticket
Separate $M$ from EAG and WAG data; Tier $3 \mathrm{~B}_{\mathrm{MSY}}$ reference points based on average recruitment from 1987-2012

EAG: 0.221
WAG: 0.231

EAG: 0.221
WAG: 0.231
b. Progression of results: Model was previously not used, so, not applicable.
c. Model was previously not used. So labeling the previous year approved model as model 0 is not applicable.
d. Evidence of search for balance between realistic and simpler models: Unlike annually surveyed stocks, Aleutian Islands golden king crab stock biomass is difficult to track and several biological parameters are assumed based on knowledge from red king crab (e.g., handling mortality rate of $0.2 \mathrm{yr}^{-1}$ ) due to a lack of species/stock specific information. We fixed a number of model parameters after initially running the model with free parameters to reduce the number of parameters to be estimated (e.g., groundfish bycatch selectivity parameters were fixed). The 11 scenarios also considered different configuration of parameters to select parsimonious models. The detailed results of the selected seven scenarios are provided in tables and figures. The total catch OFLs and the reduction in terminal (2015) MMB from the initial condition (i.e., virgin MMB in 1960) for the entire 11 scenarios for EAG and WAG are provided in Table 49. The reduction in terminal MMB from the initial condition is higher for WAG than EAG.
e. Convergence status and criteria: ADMB default convergence criteria were used.
f. Table of the sample sizes assumed for the size compositional data:

We estimated the initial input effective sample sizes (i.e., Stage-1) either as number of fishing days for retained and total catch compositions and number of fishing trips for groundfish size composition (Note: we did not use the groundfish size composition in the model fit) for all scenarios. Then we estimated the Stage-2 effective sample sizes iteratively from Stage-1 input effective sample sizes using the Francis' $(2011,2016)$ mean length based method (Appendix D).

We provide the initial input sample sizes (Stage-1) and Stage-2 effective sample sizes for scenarios 1 to 6 and 9 to 11 in Tables 4 to 12 for EAG and Tables 28 to 36 for WAG.
g. Provide the basis for data weighting, including whether the input effective sample sizes are tuned and the survey CV adjusted: Described previously (f) and details are in Appendix D.
h. Do parameter estimates make sense? The estimated parameter values are within the bounds and various plots suggest that the parameter values are reasonable for a fixed $M$ value for these stocks.
i. Model selection criteria: We used a number of diagnostic criteria to select the appropriate models for our recommendation: CPUE fits, observed vs. predicted tag recapture numbers by time at large and release size, retained and total catch, and groundfish bycatch fits. Figures are provided for the preferred scenarios in the Results section.
j. Residual analysis: We illustrated residual fits by bubble plots for size composition predictions in various figures in the Results section.
k. Model evaluation: Only one model with a number of scenarios is presented and the evaluations are presented in the Results section below.

## 3. Results

1. List of effective sample sizes and weighting factors:

The Stage-1 and Stage-2 effective sample sizes are listed for various scenarios in Tables 4 to 12 for EAG and Tables 28 to 36 for WAG. The weights for different data sets are provided in Table A2 for various scenarios, respectively, for EAG and WAG (Appendix A). These weights (with the corresponding coefficient of variations) adequately fitted the length compositions and no further changes were examined.

We used weighting factors for catch biomass, recruitment deviation, pot fishery F , and groundfish fishery F . We set the retained catch biomass to a large value (500.0) because retained catches are more reliable than any other data sets. We scaled the total catch biomass in accordance with the observer annual sample sizes with a maximum of 250.0 . The total catches were derived from observer nominal total CPUE and effort. In some years, observer sample sizes were low (Tables 2 and 26). We chose a small groundfish bycatch weight (0.2) based on the

September 2015 CPT suggestion to lower its weight. We used the best fit criteria to choose the lower weight for the groundfish bycatch. Groundfish bycatch of Aleutian Islands golden king crab is very low. We set the CPUE weights to 1.0 for all scenarios. We included a constant (model estimated) variance in addition to input CPUE variance for the CPUE fit. We used the Burnham et al. (1987) suggested formula for $\ln$ (CPUE) [and $\ln (\mathrm{MMB})$ ] variance estimation (Equation A. 15 of Appendix A). However, the estimated additional variance values were small for both observer and fish ticket CPUE indices for the two regions. Nevertheless, the CPUE index variances estimated from the negative binomial and lognormal GLMs were adequate to fit the model, as confirmed by the fit diagnostics (Fox and Weisberg 2011). Parameter estimates are provided in Tables 13 and 14 for EAG and 37 and 38 for WAG for a subset (nine) of scenarios. The numbers of estimable parameters are listed in Table A1 of Appendix A. The weights with the corresponding coefficient of variations specifications are detailed in Tables A2 of Appendix A for EAG and WAG.
2. Include tables showing differences in likelihood: Tables 24 and 48 list the total and component negative log likelihood values and their differences between scenarios of similar sample sizes and free parameters for EAG and WAG, respectively.
3. Tables of estimates:
a. The parameter estimates with coefficient of variation for nine scenarios which are a subset of eleven scenarios are summarized respectively in Tables 13 and 14 for EAG and 37 and 38 for WAG. We have also provided the boundaries for parameter searches in those tables. All parameter estimates were within the bounds.
b. All scenarios considered molt probability parameters in addition to the linear growth increment and normally distributed growth variability parameters to determine the size transition matrix.
c. The mature male and legal male abundance time series for representative nine scenarios among the eleven scenarios are summarized in Tables 15 to

23 (scenarios 1, 2, 3, 4, 5, 6, 9, 10, and 11) for EAG and Tables 39 to 47 for WAG.
d. The recruitment estimates for those nine scenarios are summarized in Tables 15 to 23 for EAG and Tables 39 to 47 for WAG.
e. The likelihood component values and the total likelihood values for nine scenarios are summarized in Table 24 for EAG and Table 48 for WAG. Scenarios 3 (observer CPUE time series extended back to 1991/92) has the minimum among the total negative log likelihoods for models with base data and equal number of free parameters for EAG and WAG, respectively.
4. Graphs of estimates:
a. Total selectivity and retention curves of the pre- and post-rationalization periods for nine of the eleven scenarios are illustrated in Figure 13 for EAG and Figure 32 for WAG. Total selectivity for the pre-rationalization period was used in the tagging model. The groundfish bycatch selectivity appeared flat in the preliminary analysis, indicating that all size groups were vulnerable to the gear. This is also shown in the size compositions of groundfish bycatch (Figures 12 and 31 for EAG and WAG, respectively). Thus, we set the groundfish bycatch selectivity to 1.0 for all length-classes in the subsequent analysis.
b. The mature male biomass time series for nine (a subset of eleven) scenarios are depicted in Figures 28 and 47 for EAG and WAG, respectively. Mature male biomass tracked the CPUE trends well for all scenarios for EAG and WAG. The biomass variance was estimated using Burnham et al. (1987) suggested formula (Equation A. 15 in Appendix A). We determined the mature male biomass values on 15 February each year and considered the 1986-2016 time series of recruits for estimating mean number of recruits for $B_{35 \%}$ calculation under Tier 3 approach.
c. The full selection pot fishery F over time for nine scenarios is shown in Figures 27 and 46 for EAG and WAG, respectively. The F peaked in late 1980s and early to mid-1990s and systematically declined in the EAG. On
the other hand, the F peaked in late 1980s, 1990s and early 2000s, then declined in late 2000s and slightly increased since 2010 in the WAG. The increase in F in recent years may be due to a decline in abundance under constant high harvest allocation to WAG.
d. F vs. MMB: We provide these plots for scenarios 1 and 9 for EAG and WAG in Figure 48.
e. Stock-Recruitment relationship: None.
f. The temporal changes in total number of recruits to the modeled population for nine scenarios are illustrated in Figure 15 for EAG and in Figure 34 for WAG. The recruitment distribution to the model size group (101-185 mm CL) is shown in Figures 16 and 35 for EAG and WAG, respectively for the nine scenarios.
5. Evaluation of the fit to the data:
g. Fits to catches: The fishery retained, total, and groundfish bycatch (observed vs. estimated) plots for nine scenarios are illustrated in Figures 19 and 38 for EAG and WAG, respectively. The 1981/82-1984//85 retained catch plots for nine scenarios are depicted in Figures 20 and 39 for EAG and WAG, respectively. All predicted fits were very close to observed values, especially for retained catch and groundfish bycatch mortality. However, pre 1995 total catch data did not fit well.
h. Survey data plot: We did not consider the pot survey data for the analysis.
i. CPUE index data: The predicted vs. input CPUE indices for nine scenarios are shown in Figure 26 for EAG and Figure 45 for WAG. All scenarios appear to fit the CPUE indices satisfactorily for EAG. However, the scenario 3 fit (extended observer CPUE indices) overestimated the CPUE trend in late years of the pre-rationalization period for EAG. The CPUE variance was estimated using Burnham et al. (1987) suggested formula (Equation A. 15 in Appendix A).
j. Tagging data: The predicted vs. observed tag recaptures by length-class for years 1 to 6 recaptures are depicted in Figure 14 for EAG and Figure 33 for WAG. The predictions appear reasonable. Note that we used the

EAG tagging information for size transition matrix estimation for both stocks (EAG and WAG). The size transition matrices estimated using EAG tagging data in the EAG and WAG models were similar.
k. Molt probability: The predicted molt probabilities vs. CL for the nine scenarios are depicted in Figures 17 and 36 for EAG and WAG, respectively. The fits appear to be satisfactory.

1. Maturity curve: The observed and predicted maturity probability vs. CL for the nine scenarios are depicted in Figures 18 and 37 for EAG and WAG, respectively. The fits appear to be satisfactory. We show the knifeedge selection curve in the same figures as well. The model estimated $50 \%$ maturity length under scenario 1 was 110.62 mm CL.
m . Fit to catch size compositions: Retained, total, and groundfish discard length compositions are shown in Figures 10 to 12 for EAG and 29 to 31 for WAG. The retained and total catch size composition fits appear satisfactory. But, the fits to groundfish bycatch size compositions are bad. Note that we did not use the groundfish size composition in any of the model scenario fits.

We illustrate the standardized residual plots as bubble plots of size composition over time for retained catch (Figures 21, 23, 49, 51, 53, and 55 for EAG, and 40, 42, 57, 59, 61, and 63 for WAG) and for total catch (Figures 22, 24, 50, 52, 54, and 56 for EAG, and 41, 43, 58, 60, 62, and 64 for WAG) for selected scenarios (1, 9, 2, 3, 4, and 11). The retained catch bubble plots appear random for the selected scenarios.
n. Marginal distributions for the fits to the composition data: We did not provide this plot in this report.
o. Plots of implied versus input effective sample sizes and time series of implied effective sample sizes: We did not provide the plots, but provided the estimated values in Tables 4 to 12 for EAG and in Tables 28 to 36 for WAG, respectively.
p. Tables of RMSEs for the indices: We did not provide this table in this report.
q. Quantile-quantile (Q-Q) plots: We did not provide this plot for model fits in this report. However, we provided this plot for the CPUE standardization fits in Appendix B.
6. Retrospective and historical analysis: The retrospective fits for five scenarios (a subset of eleven scenarios) are shown in Figure 25 for EAG and in Figure 44 for WAG. The retrospective fits were prepared for the whole time series 1961 to 2016. The retrospective patterns did not show severe departure when five terminal year's data were removed systematically and hence the current formulation of the model appears stable. A severe drop in modeled biomass from the initial MMB occurred when the fishery time series started in 1981.
7. Uncertainty and sensitivity analysis:
a. The main task was to determine a plausible size transition matrix to project the population over time. In a previous study, we investigated the sensitivity of the model to determining the size transition matrix by using or not using a molt probability function (Siddeek et al. 2016a). The model fit is better when the molt probability model is included. Therefore, we included a molt probability sub-model for the size transition matrix calculation in all scenarios.
b. We also determined likelihood values at different $M$, mean MMB, and MMB depletion values and plotted component negative likelihood against $M$, mean MMB, and MMB depletion (Figures 4 to 8 ). We discussed the merit of $M$ estimation within the model in the CPT and SSC comments section.
c. Conduct 'jitter analysis': We conducted the (random) jitter analysis on scenarios 1 and 9 model fitted parameters (details in Appendix E).

## F. Calculation of the OFL

Specification of the Tier level:
The Aleutian Islands golden king crab stocks are currently managed under a Tier 5 (average catch OFL) control rule. Following January 2017 CPT and February

2017 SSC recommendations we proceeded to compute OFL and ABC under Tier 3 estimation procedure.

The critical assumptions for $\mathrm{B}_{\mathrm{MSY}}$ reference point estimation are:
a. Natural mortality is constant.
b. Growth transition matrix is fixed and estimated using tagging data with the molt probability sub-model.
c. Total fishery selectivity and retention curves are length dependent and the 2005/06-2015/16 period selectivity estimates are used.
d. Groundfish bycatch fishery selectivity is kept constant at 1.0 for all length groups.
e. Model estimated recruits (in millions of crab) are averaged for the time period 1987-2012.
f. Model estimated groundfish bycatch mortality values are averaged for the period 2005 to 2014 (10 years).
g. A size dependent maturity proportion is used for MMB estimation.

Method: We simulated the population abundance starting from the model estimated terminal year stock size by length, model estimated parameter values, a fishing mortality value ( F ), and adding a constant number of annual recruits. Once the stock dynamics were stabilized (we used the $99^{\text {th }}$ year estimates) for an $F$, we calculated the MMB/R for that F . We computed the relative $M M B / R$ in percentage, $\left(\frac{M M B}{R}\right)_{x \%}\left(\right.$ where $\mathrm{x} \%=\frac{\frac{M M B_{F}}{R}}{\frac{M M B_{0}}{R}} \times$ 100 and $M M B_{0} / R$ is the virgin $M M B / R$ ) for different F values.
$F_{35 \%}$ is the F value that produces the $\mathrm{MMB} / \mathrm{R}$ value equal to $35 \%$ of $M M B_{0} / R$. $B_{35 \%}$ is estimated using the following formula:
$B_{35 \%}=\left(\frac{M M B}{R}\right)_{35} \times \bar{R}$, where $\bar{R}$ is the mean number of model estimated recruits for a selected period.
$F_{O F L}$ is determined using Equation A. 31 in Appendix A. The OFL is estimated by an iterative procedure accounting for intervening total removals (see Appendix A for the formulas).

The $F_{\text {OFL }}$, total catch OFL, and the retained catch portion of the OFL for coming year for scenarios 1 and 9 are:

Scenario 1:
EAG: $F_{\text {OFL }}=0.64$; OFL total catch $=3.986$ thousand metric tons, retained catch portion of the $\mathrm{OFL}=3.858$ thousand metric tons.

WAG: $F_{O F L}=0.54$; OFL total catch $=1.298$ thousand metric tons; retained catch portion of the $\mathrm{OFL}=1.213$ thousand metric tons.

AI: OFL total catch $=5.284$ thousand metric tons.

Scenario 9:
EAG: $F_{O F L}=0.75$; OFL total catch $=4.486$ thousand metric tons, retained catch portion of the OFL $=4.337$ thousand metric tons.

WAG: $F_{O F L}=0.66 ;$ OFL total catch $=1.532$ thousand metric tons; retained catch portion of the $\mathrm{OFL}=1.429$ thousand metric tons.

AI: OFL total catch $=6.018$ thousand metric tons.

## G. Calculation of the ABC

We estimated the cumulative probability distribution of OFL assuming a $\log$ normal distribution of OFL. We calculated the OFL at the 0.5 probability and the ABC at the 0.49 probability and considered an additional buffers by setting $\mathrm{ABC}=0.75^{*} \mathrm{OFL}$ and $\mathrm{ABC}=0.8 * \mathrm{OFL}$. The ABC estimates with the $20 \%$ buffer for scenarios 1 and 9 are:

Scenario 1:
EAG: $\mathrm{ABC}=3.189$ thousand metric tons.
WAG: $\mathrm{ABC}=1.039$ thousand metric tons.
$\mathrm{AI}: \mathrm{ABC}=4.227$ thousand metric tons.

Scenario 9:
EAG: $\mathrm{ABC}=3.589$ thousand metric tons.
WAG: $\mathrm{ABC}=1.226$ thousand metric tons.
$\mathrm{AI}: \mathrm{ABC}=4.815$ thousand metric tons.

## H. Rebuilding Analysis

Not applicable.

## I. Data Gaps and Research Priorities

1. The recruit abundances were estimated from commercial catch sampling data. The implicit assumption in the analysis was that the estimated recruits come solely from the same exploited stock through growth and mortality. The current analysis did not consider the possibility that additional recruitment may occur through immigration from neighboring areas and possibly separate sub-stocks. Extensive tagging experiments or resource surveys are needed to investigate stock distributions.
2. We estimated $M$ in the model. However, an independent estimate of $M$ is needed for comparison. Tagging is one possibility.
3. An extensive tagging study will also provide independent estimates of molting probability and growth. We used the historical tagging data to determine the size transition matrix.
4. An arbitrary $20 \%$ handling mortality rate on discarded males was used, which was obtained from the red king crab literature (Kruse et al. 2000; Siddeek 2002). An experimentally-based independent estimate of handling mortality is needed for golden king crab.
5. The Aleutian king crab research foundation has recently initiated crab survey programs in the Aleutian Islands. This program needs to be strengthened and continued for golden king crab research to address some of the data gaps and establish a fishery independent data source.
6. We have been using the length-weight relationship established based on late 1990s data for golden king crab. The Aleutian king crab research foundation program can help us to update this relationship by collecting new length weight information.
7. We have recently included the male maturity data in the model. The maturity data available to us were collected in 1984 and 1991. The foundation can help us to update the maturity information by collecting new data on size, chela height, and egg and clutch conditions.

## J. Acknowledgments

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Table 1a. Estimated annual total catch (t) of Aleutian Islands golden king crab during 1990-2015, partitioned by source of mortality: retained catch, estimated bycatch of males and females during crab fisheries, and estimated bycatch of males and females during groundfish fisheries. The crab fishery bycatch mortality rate of 0.2 and the groundfish fisheries (in federal reporting areas 541, 542 , and 543) bycatch mortality rates of 0.5 for fixed gear and 0.8 for trawl gear were applied. 1990 refers to 1990/91 fishery.

| Year | Retained Catch | Bycatch by Fishery Type |  | Total <br> Catch |
| :---: | :---: | :---: | :---: | :---: |
|  |  | Crab | Groundfish |  |
| 1990 | 3,161 | 1,254 | - | - |
| 1991 | 3,494 | 1,021 | - | - |
| 1992 | 2,854 | 1,187 | - | - |
| 1993 | 2,518 | - | 3.9 | - |
| 1994 | 3,687 | - | 1.3 | - |
| 1995 | 3,157 | 1,093 | 2.0 | 4,252 |
| 1996 | 2,638 | 823 | 5.0 | 3,466 |
| 1997 | 2,697 | 789 | 0.5 | 3,486 |
| 1998 | 2,242 | 670 | 1.4 | 2,913 |
| 1999 | 2,648 | 685 | 2.9 | 3,337 |
| 2000 | 2,730 | 807 | 1.9 | 3,539 |
| 2001 | 2,685 | 625 | 0.5 | 3,310 |
| 2002 | 2,478 | 514 | 17.5 | 3,010 |
| 2003 | 2,570 | 451 | 20.1 | 3,041 |
| 2004 | 2,529 | 392 | 1.4 | 2,922 |
| 2005 | 2,504 | 229 | 1.8 | 2,735 |
| 2006 | 2,380 | 234 | 17.5 | 2,638 |
| 2007 | 2,498 | 275 | 59.0 | 2,833 |
| 2008 | 2,576 | 251 | 32.9 | 2,860 |
| 2009 | 2,682 | 253 | 16.6 | 2,951 |
| 2010 | 2,707 | 247 | 19.8 | 2,975 |
| 2011 | 2,705 | 230 | 15.5 | 2,951 |
| 2012 | 2,843 | 263 | 9.2 | 3,115 |
| 2013 | 2,894 | 287 | 10.7 | 3,192 |
| 2014 | 2,771 | 303 | 4.9 | 3,079 |
| 2015 | 2,729 | 312 | 32.0 | 3,073 |

Table 1b. Time series of annual retained catch (1981-1984 values are in number of crabs and the rest in $t$ ), estimated total male catch (weight of crabs on the deck without applying any handling mortality), estimated groundfish fishery discard mortality of males (handling mortality rates of 0.5 for pot gear and 0.8 for trawl gear were applied), and pot fishery effort (number of pot lifts) for the EAG golden king crab stock. The crab weights are for the size range $\geq 101 \mathrm{~mm}$ CL. NA: no observer sampling to compute catch. The directed fishery data included cost-recovery beginning in 2013. 1981 refers to 1981/82 fishery.

| Year | Retained Catch Biomass | Total Catch Biomass (t) | Groundfish Discard Mortality (t) | Pot Fishery Effort (no. pot lifts) |
| :---: | :---: | :---: | :---: | :---: |
| 1981 | 203,968 |  |  |  |
| 1982 | 529,787 |  |  |  |
| 1983 | 662,280 |  |  |  |
| 1984 | 801,100 |  |  |  |
| 1985 | 2,677 |  |  | 117,718 |
| 1986 | 2,798 |  |  | 155,240 |
| 1987 | 1,882 |  |  | 146,501 |
| 1988 | 2,382 |  |  | 155,518 |
| 1989 | 2,738 |  | 0.61 | 155,262 |
| 1990 | 1,623 | 1,881 | 1.97 | 106,281 |
| 1991 | 2,006 | 5,899 | 0.00 | 133,428 |
| 1992 | 2,102 | 5,580 | 1.01 | 133,778 |
| 1993 | 1,407 | NA | 0.95 | 106,890 |
| 1994 | 2,017 | 2,266 | 0.29 | 191,455 |
| 1995 | 2,197 | 3,734 | 0.78 | 177,773 |
| 1996 | 1,605 | 2,059 | 0.04 | 113,460 |
| 1997 | 1,464 | 2,548 | 0.10 | 106,403 |
| 1998 | 1,398 | 2,797 | 0.76 | 83,378 |
| 1999 | 1,321 | 2,280 | 0.35 | 79,129 |
| 2000 | 1,343 | 2,555 | 0.47 | 71,551 |
| 2001 | 1,385 | 2,097 | 1.46 | 62,639 |
| 2002 | 1,228 | 1,800 | 0.68 | 52,042 |
| 2003 | 1,278 | 1,816 | 0.43 | 58,883 |
| 2004 | 1,252 | 1,619 | 0.12 | 34,848 |
| 2005 | 1,253 | 1,713 | 0.28 | 24,569 |
| 2006 | 1,365 | 1,621 | 0.70 | 26,195 |
| 2007 | 1,307 | 1,790 | 0.69 | 22,653 |
| 2008 | 1,396 | 1,787 | 0.86 | 24,466 |
| 2009 | 1,423 | 1,750 | 1.14 | 26,298 |
| 2010 | 1,388 | 1,719 | 2.41 | 25,851 |
| 2011 | 1,418 | 1,736 | 1.15 | 17,915 |
| 2012 | 1,470 | 1,927 | 3.60 | 20,827 |
| 2013 | 1,518 | 1,818 | 2.02 | 21,388 |
| 2014 | 1,524 | 1,939 | 2.30 | 17,002 |
| 2015 | 1,658 | 2,102 | 0.19 | 19,376 |

Table 2. Time series of nominal annual pot fishery retained, observer retained, and observer total catch-per-unit-effort (CPUE, number of crabs per pot lift), observer sample size (number of sampled pots), and GLM estimated observer CPUE Index for the EAG golden king crab stock. Observer retained CPUE includes retained and non-retained legal size crabs.

|  | Pot <br> Fishery <br> Nominal <br> Retained <br> CPUE | Obs. <br> Nominal <br> Retained <br> CPUE | Obs. <br> Nominal <br> Total <br> CPUE | Obs. <br> Sample <br> Size <br> (no.pot <br> lifts) | Obs. <br> CPUE <br> Index |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1990 | 8.90 | 2.17 | 13.00 | 138 |  |
| 1991 | 8.20 | 17.36 | 36.91 | 377 |  |
| 1992 | 8.36 | 10.43 | 38.52 | 199 |  |
| 1993 | 7.79 | 5.07 | 20.82 | 31 |  |
| 1994 | 5.89 | 2.54 | 12.91 | 127 |  |
| 1995 | 5.89 | 5.06 | 16.98 | 6,388 | 0.73 |
| 1996 | 6.45 | 5.17 | 13.81 | 8,360 | 0.76 |
| 1997 | 7.34 | 7.13 | 18.25 | 4,670 | 0.79 |
| 1998 | 8.88 | 9.17 | 25.77 | 3,616 | 0.95 |
| 1999 | 8.96 | 9.25 | 20.77 | 3,851 | 0.88 |
| 2000 | 9.85 | 9.92 | 25.39 | 5,043 | 0.91 |
| 2001 | 11.66 | 11.14 | 22.48 | 4,626 | 1.18 |
| 2002 | 12.37 | 11.99 | 22.59 | 3,980 | 1.26 |
| 2003 | 10.92 | 11.02 | 19.43 | 3,960 | 1.11 |
| 2004 | 18.30 | 17.73 | 28.48 | 2,206 | 1.80 |
| 2005 | 25.40 | 29.44 | 38.48 | 1,193 | 1.02 |
| 2006 | 24.84 | 25.20 | 33.52 | 1,098 | 0.82 |
| 2007 | 27.95 | 31.09 | 40.37 | 998 | 0.96 |
| 2008 | 27.26 | 29.73 | 38.18 | 613 | 0.93 |
| 2009 | 25.85 | 26.64 | 35.89 | 408 | 0.76 |
| 2010 | 25.96 | 26.05 | 36.76 | 436 | 0.77 |
| 2011 | 37.33 | 38.79 | 51.69 | 361 | 1.13 |
| 2012 | 33.02 | 38.00 | 47.74 | 438 | 1.09 |
| 2013 | 33.67 | 35.83 | 46.16 | 499 | 1.05 |
| 2014 | 42.29 | 46.96 | 60.00 | 376 | 1.37 |
| 2015 | 39.18 | 43.08 | 58.75 | 478 | 1.31 |
|  |  |  |  |  |  |

Table 3. Time series of GLM estimated CPUE indices and coefficient of variations (CV) for the fish ticket based retained catch-per-pot lift for the EAG golden king crab stock. The GLM was fitted to the 1985/86 to 1998/99 time series of data and used in scenario 4.

| Year | CPUE <br> Index | CV |
| :---: | :---: | :---: |
| $1985 / 86$ | 1.67 | 0.05 |
| $1986 / 87$ | 1.22 | 0.05 |
| $1987 / 88$ | 0.96 | 0.06 |
| $1988 / 89$ | 1.03 | 0.05 |
| $1989 / 90$ | 1.04 | 0.04 |
| $1990 / 91$ | 0.83 | 0.06 |
| $1991 / 92$ | 0.84 | 0.06 |
| $1992 / 93$ | 0.93 | 0.06 |
| $1993 / 94$ | 0.90 | 0.06 |
| $1994 / 95$ | 0.80 | 0.07 |
| $1995 / 96$ | 0.77 | 0.07 |
| $1996 / 97$ | 0.83 | 0.07 |
| $1997 / 98$ | 1.20 | 0.05 |
| $1998 / 99$ | 1.36 | 0.05 |

Table 4. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 1 model fit to EAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input <br> Groundfish <br> Trip | Sample <br> Size (no) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sroundfish <br> Effective |  |  |  |  |  |  |
| Sample <br> Size (no) |  |  |  |  |  |  |
| 1985 | 57 | 51 |  |  |  |  |
| 1986 | 11 | 10 |  |  |  |  |
| 1987 | 61 | 54 |  |  |  |  |
| 1988 | 352 | 314 |  |  |  |  |
| 1989 | 792 | 706 |  |  | 9 | 4 |
| 1990 | 163 | 145 | 22 | 11 | 13 | 6 |
| 1991 | 140 | 125 | 48 | 24 | NA | NA |
| 1992 | 49 | 44 | 41 | 20 | 2 | 1 |
| 1993 | 340 | 303 | NA | NA | 2 | 1 |
| 1994 | 319 | 285 | 34 | 17 | 4 | 2 |
| 1995 | 879 | 784 | 1,117 | 558 | 5 | 2 |
| 1996 | 547 | 488 | 509 | 254 | 4 | 2 |
| 1997 | 538 | 480 | 711 | 355 | 8 | 4 |
| 1998 | 541 | 483 | 574 | 287 | 15 | 7 |
| 1999 | 463 | 413 | 607 | 303 | 14 | 6 |
| 2000 | 436 | 389 | 495 | 247 | 16 | 7 |
| 2001 | 488 | 435 | 510 | 255 | 13 | 6 |
| 2002 | 406 | 362 | 438 | 219 | 15 | 7 |
| 2003 | 405 | 361 | 416 | 208 | 17 | 8 |
| 2004 | 280 | 250 | 299 | 149 | 10 | 4 |
| 2005 | 266 | 237 | 232 | 116 | 12 | 5 |
| 2006 | 234 | 209 | 143 | 71 | 14 | 6 |
| 2007 | 199 | 178 | 134 | 67 | 17 | 8 |
| 2008 | 197 | 176 | 113 | 56 | 15 | 7 |
| 2009 | 170 | 152 | 95 | 47 | 16 | 7 |
| 2010 | 183 | 163 | 108 | 54 | 26 | 12 |
| 2011 | 160 | 143 | 107 | 53 | 13 | 6 |
| 2012 | 187 | 167 | 99 | 49 | 18 | 8 |
| 2013 | 193 | 172 | 122 | 61 | 17 | 8 |
| 2014 | 168 | 150 | 99 | 49 | 16 | 7 |
| 2015 | 190 | 169 | 125 | 62 | 9 | 4 |
|  |  |  |  |  |  | 4 |

Table 5. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 2 model fit to EAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input <br> Groundfish <br> Trip | Sample <br> Size (no) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sroundfish <br> Effective |  |  |  |  |  |  |
| Sample <br> Size (no) |  |  |  |  |  |  |
| 1985 | 57 | 50 |  |  |  |  |
| 1986 | 11 | 10 |  |  |  |  |
| 1987 | 61 | 54 |  |  |  |  |
| 1988 | 352 | 311 |  |  |  |  |
| 1989 | 792 | 701 |  |  | 9 | 4 |
| 1990 | 163 | 144 | 22 | 11 | 13 | 6 |
| 1991 | 140 | 124 | 48 | 24 | NA | NA |
| 1992 | 49 | 43 | 41 | 20 | 2 | 1 |
| 1993 | 340 | 301 | NA | NA | 2 | 1 |
| 1994 | 319 | 282 | 34 | 17 | 4 | 2 |
| 1995 | 879 | 778 | 1,117 | 553 | 5 | 2 |
| 1996 | 547 | 484 | 509 | 252 | 4 | 2 |
| 1997 | 538 | 476 | 711 | 352 | 8 | 4 |
| 1998 | 541 | 479 | 574 | 284 | 15 | 7 |
| 1999 | 463 | 410 | 607 | 300 | 14 | 6 |
| 2000 | 436 | 386 | 495 | 245 | 16 | 7 |
| 2001 | 488 | 432 | 510 | 252 | 13 | 6 |
| 2002 | 406 | 359 | 438 | 217 | 15 | 7 |
| 2003 | 405 | 358 | 416 | 206 | 17 | 8 |
| 2004 | 280 | 248 | 299 | 148 | 10 | 4 |
| 2005 | 266 | 235 | 232 | 115 | 12 | 5 |
| 2006 | 234 | 207 | 143 | 71 | 14 | 6 |
| 2007 | 199 | 176 | 134 | 66 | 17 | 8 |
| 2008 | 197 | 174 | 113 | 56 | 15 | 7 |
| 2009 | 170 | 150 | 95 | 47 | 16 | 7 |
| 2010 | 183 | 162 | 108 | 53 | 26 | 12 |
| 2011 | 160 | 142 | 107 | 53 | 13 | 6 |
| 2012 | 187 | 165 | 99 | 49 | 18 | 8 |
| 2013 | 193 | 171 | 122 | 60 | 17 | 8 |
| 2014 | 168 | 149 | 99 | 49 | 16 | 7 |
| 2015 | 190 | 168 | 125 | 62 | 9 | 4 |
|  |  |  |  |  |  |  |

Table 6. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 3 model fit to EAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input <br> Groundfish <br> Trip | Sample <br> Size (no) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sroundfish <br> Effective |  |  |  |  |  |  |
| Sample <br> Size (no) |  |  |  |  |  |  |
| 1985 | 57 | 51 |  |  |  |  |
| 1986 | 11 | 10 |  |  |  |  |
| 1987 | 61 | 54 |  |  |  |  |
| 1988 | 352 | 313 |  |  |  |  |
| 1989 | 792 | 704 |  |  | 9 | 4 |
| 1990 | 163 | 145 | 22 | 12 | 13 | 6 |
| 1991 | 140 | 124 | 48 | 25 | NA | NA |
| 1992 | 49 | 44 | 41 | 22 | 2 | 1 |
| 1993 | 340 | 302 | NA | NA | 2 | 1 |
| 1994 | 319 | 284 | 34 | 18 | 4 | 2 |
| 1995 | 879 | 782 | 1,117 | 592 | 5 | 2 |
| 1996 | 547 | 486 | 509 | 270 | 4 | 2 |
| 1997 | 538 | 478 | 711 | 377 | 8 | 4 |
| 1998 | 541 | 481 | 574 | 304 | 15 | 7 |
| 1999 | 463 | 412 | 607 | 321 | 14 | 6 |
| 2000 | 436 | 388 | 495 | 262 | 16 | 7 |
| 2001 | 488 | 434 | 510 | 270 | 13 | 6 |
| 2002 | 406 | 361 | 438 | 232 | 15 | 7 |
| 2003 | 405 | 360 | 416 | 220 | 17 | 8 |
| 2004 | 280 | 249 | 299 | 158 | 10 | 5 |
| 2005 | 266 | 237 | 232 | 123 | 12 | 5 |
| 2006 | 234 | 208 | 143 | 76 | 14 | 6 |
| 2007 | 199 | 177 | 134 | 71 | 17 | 8 |
| 2008 | 197 | 175 | 113 | 60 | 15 | 7 |
| 2009 | 170 | 151 | 95 | 50 | 16 | 7 |
| 2010 | 183 | 163 | 108 | 57 | 26 | 12 |
| 2011 | 160 | 142 | 107 | 57 | 13 | 6 |
| 2012 | 187 | 166 | 99 | 52 | 18 | 8 |
| 2013 | 193 | 172 | 122 | 65 | 17 | 8 |
| 2014 | 168 | 149 | 99 | 52 | 16 | 7 |
| 2015 | 190 | 169 | 125 | 66 | 9 | 5 |
|  |  |  |  |  |  |  |

Table 7. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 4 model fit to EAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input <br> Groundfish <br> Trip | Sample <br> Size (no) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sroundfish <br> Effective |  |  |  |  |  |  |
| Sample <br> Size (no) |  |  |  |  |  |  |
| 1985 | 57 | 54 |  |  |  |  |
| 1986 | 11 | 10 |  |  |  |  |
| 1987 | 61 | 58 |  |  |  |  |
| 1988 | 352 | 335 |  |  |  |  |
| 1989 | 792 | 754 |  |  | 9 | 4 |
| 1990 | 163 | 155 | 22 | 11 | 13 | 6 |
| 1991 | 140 | 133 | 48 | 23 | NA | NA |
| 1992 | 49 | 47 | 41 | 20 | 2 | 1 |
| 1993 | 340 | 324 | NA | NA | 2 | 1 |
| 1994 | 319 | 304 | 34 | 16 | 4 | 2 |
| 1995 | 879 | 837 | 1,117 | 539 | 5 | 2 |
| 1996 | 547 | 521 | 509 | 246 | 4 | 2 |
| 1997 | 538 | 512 | 711 | 343 | 8 | 4 |
| 1998 | 541 | 515 | 574 | 277 | 15 | 7 |
| 1999 | 463 | 441 | 607 | 293 | 14 | 6 |
| 2000 | 436 | 415 | 495 | 239 | 16 | 7 |
| 2001 | 488 | 465 | 510 | 246 | 13 | 6 |
| 2002 | 406 | 387 | 438 | 211 | 15 | 7 |
| 2003 | 405 | 386 | 416 | 201 | 17 | 8 |
| 2004 | 280 | 267 | 299 | 144 | 10 | 4 |
| 2005 | 266 | 253 | 232 | 112 | 12 | 5 |
| 2006 | 234 | 223 | 143 | 69 | 14 | 6 |
| 2007 | 199 | 190 | 134 | 65 | 17 | 8 |
| 2008 | 197 | 188 | 113 | 55 | 15 | 7 |
| 2009 | 170 | 162 | 95 | 46 | 16 | 7 |
| 2010 | 183 | 174 | 108 | 52 | 26 | 12 |
| 2011 | 160 | 152 | 107 | 52 | 13 | 6 |
| 2012 | 187 | 178 | 99 | 48 | 18 | 8 |
| 2013 | 193 | 184 | 122 | 59 | 17 | 8 |
| 2014 | 168 | 160 | 99 | 48 | 16 | 7 |
| 2015 | 190 | 181 | 125 | 60 | 9 | 4 |
|  |  |  |  |  |  |  |

Table 8. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 5 model fit to EAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input <br> Groundfish <br> Trip | Sample <br> Size (no) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sroundfish <br> Effective |  |  |  |  |  |  |
| Sample <br> Size (no) |  |  |  |  |  |  |
| 1985 | 57 | 50 |  |  |  |  |
| 1986 | 11 | 10 |  |  |  |  |
| 1987 | 61 | 53 |  |  |  |  |
| 1988 | 352 | 308 |  |  |  |  |
| 1989 | 792 | 692 |  |  | 9 | 4 |
| 1990 | 163 | 143 | 22 | 11 | 13 | 6 |
| 1991 | 140 | 122 | 48 | 24 | NA | NA |
| 1992 | 49 | 43 | 41 | 21 | 2 | 1 |
| 1993 | 340 | 297 | NA | NA | 2 | 1 |
| 1994 | 319 | 279 | 34 | 17 | 4 | 2 |
| 1995 | 879 | 769 | 1,117 | 567 | 5 | 2 |
| 1996 | 547 | 478 | 509 | 258 | 4 | 2 |
| 1997 | 538 | 470 | 711 | 361 | 8 | 4 |
| 1998 | 541 | 473 | 574 | 291 | 15 | 7 |
| 1999 | 463 | 405 | 607 | 308 | 14 | 6 |
| 2000 | 436 | 381 | 495 | 251 | 16 | 7 |
| 2001 | 488 | 427 | 510 | 259 | 13 | 6 |
| 2002 | 406 | 355 | 438 | 222 | 15 | 7 |
| 2003 | 405 | 354 | 416 | 211 | 17 | 8 |
| 2004 | 280 | 245 | 299 | 152 | 10 | 4 |
| 2005 | 266 | 233 | 232 | 118 | 12 | 5 |
| 2006 | 234 | 205 | 143 | 73 | 14 | 6 |
| 2007 | 199 | 174 | 134 | 68 | 17 | 8 |
| 2008 | 197 | 172 | 113 | 57 | 15 | 7 |
| 2009 | 170 | 149 | 95 | 48 | 16 | 7 |
| 2010 | 183 | 160 | 108 | 55 | 26 | 12 |
| 2011 | 160 | 140 | 107 | 54 | 13 | 6 |
| 2012 | 187 | 164 | 99 | 50 | 18 | 8 |
| 2013 | 193 | 169 | 122 | 62 | 17 | 8 |
| 2014 | 168 | 147 | 99 | 50 | 16 | 7 |
| 2015 | 190 | 166 | 125 | 63 | 9 | 4 |
|  |  |  |  |  |  |  |

Table 9. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 6 model fit to EAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input <br> Groundfish <br> Trip | Sample <br> Size (no) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Sroundfish <br> Effective |  |  |  |  |  |  |
| Sample <br> Size (no) |  |  |  |  |  |  |
| 1985 | 57 | 51 |  |  |  |  |
| 1986 | 11 | 10 |  |  |  |  |
| 1987 | 61 | 55 |  |  |  |  |
| 1988 | 352 | 315 |  |  |  |  |
| 1989 | 792 | 708 |  |  | 9 | 4 |
| 1990 | 163 | 146 | 22 | 11 | 13 | 6 |
| 1991 | 140 | 125 | 48 | 24 | NA | NA |
| 1992 | 49 | 44 | 41 | 20 | 2 | 1 |
| 1993 | 340 | 304 | NA | NA | 2 | 1 |
| 1994 | 319 | 285 | 34 | 17 | 4 | 2 |
| 1995 | 879 | 786 | 1,117 | 550 | 5 | 2 |
| 1996 | 547 | 489 | 509 | 251 | 4 | 2 |
| 1997 | 538 | 481 | 711 | 350 | 8 | 4 |
| 1998 | 541 | 484 | 574 | 283 | 15 | 7 |
| 1999 | 463 | 414 | 607 | 299 | 14 | 6 |
| 2000 | 436 | 390 | 495 | 244 | 16 | 7 |
| 2001 | 488 | 437 | 510 | 251 | 13 | 6 |
| 2002 | 406 | 363 | 438 | 216 | 15 | 7 |
| 2003 | 405 | 362 | 416 | 205 | 17 | 8 |
| 2004 | 280 | 250 | 299 | 147 | 10 | 4 |
| 2005 | 266 | 238 | 232 | 114 | 12 | 5 |
| 2006 | 234 | 209 | 143 | 70 | 14 | 6 |
| 2007 | 199 | 178 | 134 | 66 | 17 | 8 |
| 2008 | 197 | 176 | 113 | 56 | 15 | 7 |
| 2009 | 170 | 152 | 95 | 47 | 16 | 7 |
| 2010 | 183 | 164 | 108 | 53 | 26 | 12 |
| 2011 | 160 | 143 | 107 | 53 | 13 | 6 |
| 2012 | 187 | 167 | 99 | 49 | 18 | 8 |
| 2013 | 193 | 173 | 122 | 60 | 17 | 8 |
| 2014 | 168 | 150 | 99 | 49 | 16 | 7 |
| 2015 | 190 | 170 | 125 | 62 | 9 | 4 |
|  |  |  |  |  |  |  |

Table 10. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 9 model fit to EAG data. NA: not available.

| Year | Initial <br> Input Retained Days Sample Size (no) | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Total Effective Sample Size (no) | Initial Input Groundfish Trip Sample Size (no) | Stage-2 <br> Groundfish Effective Sample Size (no) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1985 | 57 | 51 |  |  |  |  |
| 1986 | 11 | 10 |  |  |  |  |
| 1987 | 61 | 54 |  |  |  |  |
| 1988 | 352 | 314 |  |  |  |  |
| 1989 | 792 | 706 |  |  | 9 | 4 |
| 1990 | 163 | 145 | 22 | 11 | 13 | 6 |
| 1991 | 140 | 125 | 48 | 24 | NA | NA |
| 1992 | 49 | 44 | 41 | 20 | 2 | 1 |
| 1993 | 340 | 303 | NA | NA | 2 | 1 |
| 1994 | 319 | 285 | 34 | 17 | 4 | 2 |
| 1995 | 879 | 784 | 1,117 | 558 | 5 | 2 |
| 1996 | 547 | 488 | 509 | 254 | 4 | 2 |
| 1997 | 538 | 480 | 711 | 355 | 8 | 4 |
| 1998 | 541 | 483 | 574 | 287 | 15 | 7 |
| 1999 | 463 | 413 | 607 | 303 | 14 | 6 |
| 2000 | 436 | 389 | 495 | 247 | 16 | 7 |
| 2001 | 488 | 435 | 510 | 255 | 13 | 6 |
| 2002 | 406 | 362 | 438 | 219 | 15 | 7 |
| 2003 | 405 | 361 | 416 | 208 | 17 | 8 |
| 2004 | 280 | 250 | 299 | 149 | 10 | 4 |
| 2005 | 266 | 237 | 232 | 116 | 12 | 5 |
| 2006 | 234 | 209 | 143 | 71 | 14 | 6 |
| 2007 | 199 | 178 | 134 | 67 | 17 | 8 |
| 2008 | 197 | 176 | 113 | 56 | 15 | 7 |
| 2009 | 170 | 152 | 95 | 47 | 16 | 7 |
| 2010 | 183 | 163 | 108 | 54 | 26 | 12 |
| 2011 | 160 | 143 | 107 | 53 | 13 | 6 |
| 2012 | 187 | 167 | 99 | 49 | 18 | 8 |
| 2013 | 193 | 172 | 122 | 61 | 17 | 8 |
| 2014 | 168 | 150 | 99 | 49 | 16 | 7 |
| 2015 | 190 | 169 | 125 | 62 | 9 | 4 |

Table 11. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 10 model fit to EAG data. NA: not available.

| Year | Initial <br> Input <br> Retained Days <br> Sample <br> Size (no) | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input Groundfish Trip Sample Size (no) | Stage-2 <br> Groundfish Effective Sample Size (no) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1985 | 57 | 51 |  |  |  |  |
| 1986 | 11 | 10 |  |  |  |  |
| 1987 | 61 | 54 |  |  |  |  |
| 1988 | 352 | 314 |  |  |  |  |
| 1989 | 792 | 706 |  |  | 9 | 4 |
| 1990 | 163 | 145 | 22 | 11 | 13 | 6 |
| 1991 | 140 | 125 | 48 | 24 | NA | NA |
| 1992 | 49 | 44 | 41 | 20 | 2 | 1 |
| 1993 | 340 | 303 | NA | NA | 2 | 1 |
| 1994 | 319 | 284 | 34 | 17 | 4 | 2 |
| 1995 | 879 | 783 | 1,117 | 558 | 5 | 2 |
| 1996 | 547 | 487 | 509 | 254 | 4 | 2 |
| 1997 | 538 | 479 | 711 | 355 | 8 | 4 |
| 1998 | 541 | 482 | 574 | 287 | 15 | 7 |
| 1999 | 463 | 413 | 607 | 303 | 14 | 6 |
| 2000 | 436 | 389 | 495 | 247 | 16 | 7 |
| 2001 | 488 | 435 | 510 | 255 | 13 | 6 |
| 2002 | 406 | 362 | 438 | 219 | 15 | 7 |
| 2003 | 405 | 361 | 416 | 208 | 17 | 8 |
| 2004 | 280 | 250 | 299 | 149 | 10 | 4 |
| 2005 | 266 | 237 | 232 | 116 | 12 | 5 |
| 2006 | 234 | 209 | 143 | 71 | 14 | 6 |
| 2007 | 199 | 177 | 134 | 67 | 17 | 8 |
| 2008 | 197 | 176 | 113 | 56 | 15 | 7 |
| 2009 | 170 | 152 | 95 | 47 | 16 | 7 |
| 2010 | 183 | 163 | 108 | 54 | 26 | 12 |
| 2011 | 160 | 143 | 107 | 53 | 13 | 6 |
| 2012 | 187 | 167 | 99 | 49 | 18 | 8 |
| 2013 | 193 | 172 | 122 | 61 | 17 | 8 |
| 2014 | 168 | 150 | 99 | 49 | 16 | 7 |
| 2015 | 190 | 169 | 125 | 62 | 9 | 4 |

Table 12. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 11 model fit to EAG data. NA: not available.

| Year | Initial <br> Input Retained Days Sample Size (no) | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Total Effective Sample Size (no) | Initial Input Groundfish Trip Sample Size (no) | Stage-2 <br> Groundfish Effective Sample Size (no) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1985 | 57 | 51 |  |  |  |  |
| 1986 | 11 | 10 |  |  |  |  |
| 1987 | 61 | 54 |  |  |  |  |
| 1988 | 352 | 314 |  |  |  |  |
| 1989 | 792 | 706 |  |  | 9 | 4 |
| 1990 | 163 | 145 | 22 | 11 | 13 | 6 |
| 1991 | 140 | 125 | 48 | 24 | NA | NA |
| 1992 | 49 | 44 | 41 | 20 | 2 | 1 |
| 1993 | 340 | 303 | NA | NA | 2 | 1 |
| 1994 | 319 | 284 | 34 | 17 | 4 | 2 |
| 1995 | 879 | 783 | 1,117 | 558 | 5 | 2 |
| 1996 | 547 | 487 | 509 | 254 | 4 | 2 |
| 1997 | 538 | 479 | 711 | 355 | 8 | 4 |
| 1998 | 541 | 482 | 574 | 287 | 15 | 7 |
| 1999 | 463 | 413 | 607 | 303 | 14 | 6 |
| 2000 | 436 | 389 | 495 | 247 | 16 | 7 |
| 2001 | 488 | 435 | 510 | 255 | 13 | 6 |
| 2002 | 406 | 362 | 438 | 219 | 15 | 7 |
| 2003 | 405 | 361 | 416 | 208 | 17 | 8 |
| 2004 | 280 | 250 | 299 | 149 | 10 | 4 |
| 2005 | 266 | 237 | 232 | 116 | 12 | 5 |
| 2006 | 234 | 209 | 143 | 71 | 14 | 6 |
| 2007 | 199 | 177 | 134 | 67 | 17 | 8 |
| 2008 | 197 | 176 | 113 | 56 | 15 | 7 |
| 2009 | 170 | 152 | 95 | 47 | 16 | 7 |
| 2010 | 183 | 163 | 108 | 54 | 26 | 12 |
| 2011 | 160 | 143 | 107 | 53 | 13 | 6 |
| 2012 | 187 | 167 | 99 | 49 | 18 | 8 |
| 2013 | 193 | 172 | 122 | 61 | 17 | 8 |
| 2014 | 168 | 150 | 99 | 49 | 16 | 7 |
| 2015 | 190 | 169 | 125 | 62 | 9 | 4 |

Table 13. Parameter estimates and coefficient of variations (CV) with the 2015 MMB (MMB on 15 Feb 2016) for scenarios 1 , 2 , 3 , and 4 for the golden king crab data from the EAG, 1985/86-2015/16. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

|  | Scenario 1 |  | Scenario 2 |  | Scenario 3 |  | Scenario 4 |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Parameter | Estimate | CV | Estimate | CV | Estimate | CV | Estimate | CV | Limits |
| $\log _{-} \omega_{1}$ ( growth incr. intercept) | 2.54 | 0.01 | 2.54 | 0.01 | 2.54 | 0.01 | 2.54 | 0.01 | 1.0, 4.5 |
| $\omega_{2}$ (growth incr. slope) | -8.24 | 0.21 | -8.24 | 0.21 | 8.37 | 0.21 | -7.65 | 0.23 | -12.0,-5.0 |
| $\log _{\_} \mathrm{a}$ (molt prob. slope) | -2.52 | 0.02 | -2.52 | 0.02 | 2.49 | 0.02 | -2.56 | 0.03 | -4.61,-1.39 |
| $\log _{\text {_ }} \mathrm{b}$ (molt prob. L50) | 4.95 | 0.001 | 4.95 | 0.001 | 4.95 | 0.001 | 4.95 | 0.001 | 3.869,5.05 |
| $\sigma$ (growth variability std) | 3.68 | 0.03 | 3.68 | 0.03 | 3.68 | 0.03 | 3.69 | 0.03 | 0.1,12.0 |
| log_total sel delta0, 1985-94 |  |  |  |  |  |  | 2.98 | 0.05 | 0,4.4 |
| log_total sel delta日, 1985-04 or 1995-04 | 3.36 | 0.02 | 3.37 | 0.02 | 3.35 | 0.02 | 3.48 | 0.02 | 0.,4.4 |
| log_total sel delta $\theta$, 2005-15 | 2.99 | 0.03 | 2.98 | 0.03 | 2.94 | 0.03 | 3.01 | 0.03 | 0.,4.4 |
| $\log _{-}$ret. sel delta $\theta$, 1985-15 | 1.85 | 0.02 | 1.85 | 0.02 | 1.85 | 0.02 | 1.86 | 0.02 | 0.,4.4 |
| log_maturity delta_mat | 3.80 | 0.48 | 3.80 | 0.48 | 3.80 | 0.48 | 3.80 | 0.48 | 0,4.4 |
| $\log _{-}$maturity mat ${ }_{50}$ | 4.71 | 0.04 | 4.71 | 0.04 | 4.71 | 0.04 | 4.71 | 0.04 | 4.4,4.85 |
| log_tot sel $\theta_{50}, 1985-94$ |  |  |  |  |  |  | 4.85 | 0.004 | 4.0,5.0 |
| log_tot sel $\theta_{50}, 1985-04$ or 1995-04 | 4.84 | 0.002 | 4.84 | 0.003 | 4.84 | 0.002 | 4.87 | 0.004 | 4.0,5.0 |
| log_tot sel $\theta_{50}, 2005-15$ | 4.92 | 0.002 | 4.92 | 0.002 | 4.91 | 0.002 | 4.93 | 0.002 | 4.0,5.0 |
| $\log _{-}$ret. sel $\theta_{50}, 1985-15$ | 4.91 | 0.0003 | 4.91 | 0.0003 | 4.91 | 0.0003 | 4.91 | 0.0003 | 4.0,5.0 |
| $\log _{\_} \beta_{\mathrm{r}}$ (rec.distribution par.) | -1.08 | 0.18 | -1.06 | 0.19 | 1.06 | 0.18 | -1.05 | 0.20 | -12.0, 12.0 |
| Logq1 (catchability 1985-94) |  |  |  |  |  |  | -0.68 | 0.13 | -9.0, 2.25 |
| $\operatorname{logq2}$ (catchability 1995-04) | -0.63 | 0.12 | -0.66 | 0.14 | -0.59 | 0.13 | -0.46 | 0.26 | -9.0, 2.25 |
| $\operatorname{logq} 3$ (catchability 2005-15) | -1.07 | 0.12 | -1.09 | 0.13 | -1.25 | 0.11 | -0.97 | 0.15 | -9.0, 2.25 |
| $\mathrm{log}_{\text {_ }}$ mean_rec (mean rec.) | 0.96 | 0.05 | 0.96 | 0.05 | 1.00 | 0.05 | 0.93 | 0.05 | 0.01, 5.0 |
| log_mean_Fpot (Pot fishery F) | -1.11 | 0.06 | -1.12 | 0.07 | 1.21 | 0.06 | -1.04 | 0.08 | -15.0, -0.01 |
| log_mean_Fground (GF byc. F) | -9.35 | 0.10 | -9.35 | 0.10 | 9.43 | 0.10 | -9.30 | 0.10 | -15.0, -1.6 |
| $\sigma_{e}^{2}$ (observer CPUE additional var) | 0.018 | 0.38 | 0.02 | 0.37 | 0.024 | 0.39 | 0.018 | 0.38 | 0.0, 0.15 |
| $\sigma_{e}^{2}$ (fishery CPUE additional var) | 0.052 | 0.42 |  |  | 0.038 | 0.43 | 0.051 | 0.43 | 0.0,1.0 |
| 2015 MMB | 10,597 | 0.32 | 10,749 | 0.32 | 11,605 | 0.32 | 10,036 | 0.32 |  |

Table 14. Parameter estimates and coefficient of variations (CV) with the 2015 MMB (MMB on 15 Feb 2016) for scenarios 5 , 6 , 9 , 10, and 11 for the golden king crab data from the EAG, 1985/86-2015/16. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

|  | Scenario 5 |  | Scenario 6 |  | Scenario 9 |  | Scenario 10 |  | Scenario 11 |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Parameter | Estimate | CV | Estimate | CV | Estimate | CV | Estimate | CV | Estimate | CV | Limits |
| $\log _{-} \omega_{1}$ ( growth incr. intercept) | 2.54 | 0.01 | 2.54 | 0.01 | 2.54 | 0.01 | 2.54 | 0.01 | 2.54 | 0.01 | 1.0, 4.5 |
| $\omega_{2}$ ( growth incr. slope) | -8.31 | 0.21 | -8.12 | 0.21 | -8.24 | 0.21 | -8.25 | 0.21 | -8.25 | -0.21 | -12.0,-5.0 |
| $\log _{-} \mathrm{a}$ (molt prob. slope) | -2.48 | 0.02 | -2.55 | 0.02 | -2.52 | 0.02 | -2.52 | 0.02 | -2.52 | -0.02 | -4.61,-1.39 |
| $\log _{-} \mathrm{b}$ (molt prob. L50) | 4.95 | 0.001 | 4.95 | 0.001 | 4.95 | 0.001 | 4.95 | 0.001 | 4.95 | 0.001 | 3.869,5.05 |
| $\sigma$ (growth variability std) | 3.68 | 0.03 | 3.68 | 0.03 | 3.68 | 0.03 | 3.68 | 0.03 | 3.68 | 0.03 | 0.1,12.0 |
| log_total sel delta 0 , 1985-04 | 3.38 | 0.02 | 3.34 | 0.02 | 3.36 | 0.02 | 3.37 | 0.02 | 3.37 | 0.02 | 0.,4.4 |
| $\log _{-}$total sel delta $\theta, 2005-15$ | 2.98 | 0.03 | 3.00 | 0.03 | 2.99 | 0.03 | 2.99 | 0.03 | 2.99 | 0.03 | 0.,4.4 |
| $\log _{-}$ret. sel delta $\theta$, 1985-15 | 1.85 | 0.02 | 1.86 | 0.02 | 1.85 | 0.02 | 1.85 | 0.02 | 1.85 | 0.02 | 0.,4.4 |
| log_maturity delta_mat | 3.80 | 0.48 | 3.80 | 0.48 |  |  | 3.80 | 0.48 |  |  | 0,4.4 |
| $\log _{\text {_ }}$ maturity mat ${ }_{50}$ | 4.71 | 0.04 | 4.71 | 0.04 |  |  | 4.71 | 0.04 |  |  | 4.4,4.85 |
| log_tot sel $\theta_{50}$, 1985-04 | 4.83 | 0.002 | 4.85 | 0.002 | 4.84 | 0.002 | 4.84 | 0.002 | 4.84 | 0.002 | 4.0,5.0 |
| log_tot sel $\theta_{50}, 2005-15$ | 4.92 | 0.002 | 4.93 | 0.002 | 4.92 | 0.002 | 4.92 | 0.002 | 4.92 | 0.002 | 4.0,5.0 |
| log_ret. sel $\theta_{50}, 1985-15$ | 4.91 | 0.0003 | 4.91 | 0.0003 | 4.91 | 0.0003 | 4.91 | 0.0003 | 4.91 | 0.0003 | 4.0,5.0 |
| $\log _{\_} \beta_{\mathrm{r}}$ (rec.distribution par.) | -1.07 | 0.19 | -1.09 | 0.18 | -1.08 | 0.18 | -1.08 | 0.19 | -1.08 | -0.19 | -12.0, 12.0 |
| logq2 (catchability 1985-04) | -0.56 | 0.13 | -0.71 | 0.11 | -0.63 | 0.12 | -0.62 | 0.12 | -0.62 | -0.12 | -9.0, 2.25 |
| logq3 (catchability 2005-15) | -1.02 | 0.12 | -1.11 | 0.12 | -1.07 | 0.12 | -1.06 | 0.12 | -1.06 | -0.12 | -9.0, 2.25 |
| log_mean_rec (mean rec.) | 0.72 | 0.06 | 1.22 | 0.04 | 0.96 | 0.05 | 0.94 | 0.05 | 0.94 | 0.05 | 0.01, 5.0 |
| log_mean_Fpot (Pot fishery F) | -1.06 | 0.06 | -1.17 | 0.06 | -1.11 | 0.06 | -1.11 | 0.06 | -1.11 | -0.06 | -15.0, -0.01 |
| log_mean_Fground (GF byc. F) | -9.24 | 0.10 | -9.48 | 0.10 | -9.35 | 0.10 | -9.34 | 0.10 | -9.34 | -0.10 | -15.0, -1.6 |
| $\sigma_{e}^{2}$ (observer CPUE additional var) | 0.017 | 0.37 | 0.020 | 0.40 | 0.018 | 0.38 | 0.018 | 0.38 | 0.018 | 0.38 | 0.0, 0.15 |
| $\sigma_{e}^{2}$ (fishery CPUE additional var) | 0.051 | 0.42 | 0.052 | 0.43 | 0.052 | 0.42 | 0.052 | 0.42 | 0.052 | 0.42 | 0.0,1.0 |
| 2015 MMB | 9,676 | 0.31 | 11,711 | 0.32 | 12,051 | 0.15 | 10,518 | 0.32 | 11,959 | 0.15 |  |

Table 15. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 1 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year $y$. Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year $y$ fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\text {eq }}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | Recruits to the Model ( $\geq \mathbf{1 0 1}$ mm CL) | $\begin{gathered} \text { Mature Male } \\ \text { Biomass } \\ (\geq 121 \mathrm{~mm} \mathrm{CL}) \end{gathered}$ | CV | $\begin{gathered} \text { Legal Male } \\ \text { Biomass }(\geq 136 \\ \text { mm CL }) \end{gathered}$ | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \mathrm{MMB}_{\mathrm{eq}}=18,488 \\ \mathrm{MMB}_{35}=6,276 \end{gathered}$ |  |  |  |
| 1985 | 1.77 |  |  | 9,843 | 0.06 |
| 1986 | 1.06 | 6,617 | 0.28 | 8,359 | 0.04 |
| 1987 | 4.45 | 6,412 | 0.26 | 6,535 | 0.04 |
| 1988 | 4.08 | 6,102 | 0.31 | 5,424 | 0.05 |
| 1989 | 1.91 | 5,118 | 0.34 | 4,880 | 0.07 |
| 1990 | 2.95 | 5,376 | 0.32 | 4,537 | 0.06 |
| 1991 | 3.94 | 5,515 | 0.32 | 4,785 | 0.06 |
| 1992 | 2.34 | 5,275 | 0.33 | 4,533 | 0.05 |
| 1993 | 2.10 | 5,444 | 0.32 | 4,627 | 0.05 |
| 1994 | 2.63 | 5,087 | 0.31 | 5,065 | 0.04 |
| 1995 | 2.49 | 4,536 | 0.32 | 4,546 | 0.04 |
| 1996 | 2.40 | 4,645 | 0.32 | 3,919 | 0.04 |
| 1997 | 3.29 | 5,006 | 0.32 | 4,075 | 0.05 |
| 1998 | 3.03 | 5,475 | 0.32 | 4,213 | 0.05 |
| 1999 | 3.27 | 6,176 | 0.32 | 4,703 | 0.06 |
| 2000 | 3.09 | 6,809 | 0.32 | 5,419 | 0.06 |
| 2001 | 2.34 | 7,183 | 0.31 | 6,139 | 0.06 |
| 2002 | 3.07 | 7,711 | 0.30 | 6,783 | 0.07 |
| 2003 | 2.62 | 8,037 | 0.30 | 7,203 | 0.07 |
| 2004 | 2.22 | 8,186 | 0.30 | 7,578 | 0.08 |
| 2005 | 3.38 | 8,470 | 0.29 | 7,881 | 0.08 |
| 2006 | 2.60 | 8,602 | 0.29 | 7,867 | 0.08 |
| 2007 | 2.46 | 8,689 | 0.30 | 8,103 | 0.09 |
| 2008 | 4.19 | 9,164 | 0.29 | 8,324 | 0.09 |
| 2009 | 2.81 | 9,473 | 0.30 | 8,337 | 0.10 |
| 2010 | 2.66 | 9,698 | 0.30 | 8,887 | 0.10 |
| 2011 | 3.56 | 10,031 | 0.29 | 9,338 | 0.10 |
| 2012 | 3.50 | 10,362 | 0.30 | 9,448 | 0.10 |
| 2013 | 2.91 | 10,530 | 0.30 | 9,699 | 0.10 |
| 2014 | 3.25 | 10,697 | 0.31 | 10,057 | 0.11 |
| 2015 | 2.84 | 10,597 | 0.32 | 10,205 | 0.13 |
| 2016 | 2.61 | 10,533 | 0.32 |  |  |

Table 16. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 2 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y . Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\text {eq }}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | Recruits to the Model ( $\geq \mathbf{1 0 1} \mathbf{~ m m}$ CL) | $\begin{gathered} \text { Mature Male } \\ \text { Biomass } \\ (\geq 121 \mathrm{~mm} \mathrm{CL}) \end{gathered}$ | CV | Legal Male Biomass ( $\geq \mathbf{1 3 6}$ mm CL) | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{aligned} \mathrm{MMB}_{\mathrm{eq}} & =18,610 \\ \mathrm{MMB}_{35} & =6,329 \end{aligned}$ |  |  |  |
| 1985 | 1.69 |  |  | 9,908 | 0.06 |
| 1986 | 1.03 | 6,590 | 0.28 | 8,403 | 0.04 |
| 1987 | 4.29 | 6,315 | 0.26 | 6,523 | 0.04 |
| 1988 | 4.30 | 6,034 | 0.31 | 5,368 | 0.05 |
| 1989 | 1.87 | 5,056 | 0.34 | 4,759 | 0.07 |
| 1990 | 2.92 | 5,323 | 0.32 | 4,461 | 0.07 |
| 1991 | 3.99 | 5,481 | 0.32 | 4,741 | 0.06 |
| 1992 | 2.34 | 5,255 | 0.33 | 4,490 | 0.05 |
| 1993 | 2.07 | 5,427 | 0.33 | 4,602 | 0.05 |
| 1994 | 2.61 | 5,065 | 0.31 | 5,055 | 0.04 |
| 1995 | 2.46 | 4,502 | 0.32 | 4,534 | 0.04 |
| 1996 | 2.40 | 4,605 | 0.32 | 3,894 | 0.05 |
| 1997 | 3.34 | 4,980 | 0.32 | 4,036 | 0.05 |
| 1998 | 3.06 | 5,472 | 0.32 | 4,173 | 0.06 |
| 1999 | 3.31 | 6,202 | 0.32 | 4,689 | 0.06 |
| 2000 | 3.13 | 6,868 | 0.32 | 5,437 | 0.07 |
| 2001 | 2.37 | 7,270 | 0.32 | 6,189 | 0.07 |
| 2002 | 3.12 | 7,827 | 0.30 | 6,866 | 0.08 |
| 2003 | 2.64 | 8,171 | 0.30 | 7,313 | 0.08 |
| 2004 | 2.24 | 8,330 | 0.30 | 7,715 | 0.08 |
| 2005 | 3.40 | 8,618 | 0.29 | 8,031 | 0.09 |
| 2006 | 2.62 | 8,750 | 0.30 | 8,019 | 0.09 |
| 2007 | 2.49 | 8,836 | 0.30 | 8,252 | 0.10 |
| 2008 | 4.22 | 9,315 | 0.29 | 8,472 | 0.10 |
| 2009 | 2.84 | 9,630 | 0.30 | 8,485 | 0.10 |
| 2010 | 2.69 | 9,857 | 0.30 | 9,040 | 0.10 |
| 2011 | 3.59 | 10,194 | 0.29 | 9,496 | 0.10 |
| 2012 | 3.54 | 10,533 | 0.30 | 9,610 | 0.11 |
| 2013 | 2.93 | 10,702 | 0.31 | 9,866 | 0.11 |
| 2014 | 3.25 | 10,862 | 0.31 | 10,230 | 0.12 |
| 2015 | 2.84 | 10,749 | 0.32 | 10,378 | 0.13 |
| 2016 | 2.61 | 10,639 | 0.32 |  |  |

Table 17. Annual abundance estimates of model recruits (millions of crabs), legal male biomass $(\mathrm{t})$ with coefficient of variations $(\mathrm{CV})$, and mature male biomass ( t ) with CV for scenario 3 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\text {eq }}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | Recruits to the Model ( $\mathbf{~} \mathbf{1 0 1} \mathbf{~ m m}$ CL) | $\begin{gathered} \text { Mature Male } \\ \text { Biomass } \\ (\geq 121 \mathrm{~mm} \mathrm{CL}) \end{gathered}$ | CV | $\begin{gathered} \text { Legal Male } \\ \text { Biomass }(\geq 136 \\ \text { mm CL) } \end{gathered}$ | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \text { MMBeq }=19,355 \\ \text { MMB35 }=6,546 \end{gathered}$ |  |  |  |
| 1985 | 1.80 |  |  | 9,911 | 0.06 |
| 1986 | 1.07 | 6,628 | 0.28 | 8,375 | 0.04 |
| 1987 | 4.41 | 6,403 | 0.26 | 6,536 | 0.04 |
| 1988 | 4.08 | 6,088 | 0.31 | 5,423 | 0.05 |
| 1989 | 1.89 | 5,094 | 0.34 | 4,875 | 0.07 |
| 1990 | 3.00 | 5,362 | 0.32 | 4,527 | 0.06 |
| 1991 | 3.92 | 5,499 | 0.32 | 4,759 | 0.06 |
| 1992 | 2.45 | 5,295 | 0.33 | 4,522 | 0.05 |
| 1993 | 2.17 | 5,505 | 0.32 | 4,628 | 0.05 |
| 1994 | 2.71 | 5,202 | 0.31 | 5,104 | 0.04 |
| 1995 | 2.61 | 4,722 | 0.32 | 4,643 | 0.04 |
| 1996 | 2.54 | 4,905 | 0.32 | 4,081 | 0.05 |
| 1997 | 3.53 | 5,374 | 0.32 | 4,309 | 0.05 |
| 1998 | 3.29 | 5,979 | 0.32 | 4,533 | 0.06 |
| 1999 | 3.56 | 6,835 | 0.32 | 5,151 | 0.06 |
| 2000 | 3.39 | 7,632 | 0.32 | 6,026 | 0.07 |
| 2001 | 2.58 | 8,143 | 0.31 | 6,914 | 0.07 |
| 2002 | 3.33 | 8,786 | 0.30 | 7,720 | 0.07 |
| 2003 | 2.80 | 9,179 | 0.30 | 8,260 | 0.08 |
| 2004 | 2.37 | 9,356 | 0.30 | 8,725 | 0.08 |
| 2005 | 3.61 | 9,664 | 0.29 | 9,064 | 0.09 |
| 2006 | 2.81 | 9,812 | 0.29 | 9,045 | 0.09 |
| 2007 | 2.68 | 9,916 | 0.30 | 9,290 | 0.10 |
| 2008 | 4.43 | 10,415 | 0.28 | 9,526 | 0.10 |
| 2009 | 2.95 | 10,721 | 0.30 | 9,555 | 0.10 |
| 2010 | 2.81 | 10,924 | 0.30 | 10,132 | 0.10 |
| 2011 | 3.75 | 11,233 | 0.29 | 10,565 | 0.11 |
| 2012 | 3.63 | 11,530 | 0.30 | 10,634 | 0.11 |
| 2013 | 3.00 | 11,644 | 0.31 | 10,858 | 0.12 |
| 2014 | 3.38 | 11,759 | 0.31 | 11,178 | 0.13 |
| 2015 | 2.95 | 11,605 | 0.32 | 11,260 | 0.15 |
| 2016 | 2.70 | 11,291 | 0.32 |  |  |

Table 18. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass ( t ) with coefficient of variation (CV) for scenario 4 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y . Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\mathrm{eq}}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | Recruits to the Model ( $\geq \mathbf{1 0 1} \mathbf{~ m m}$ CL) | $\begin{aligned} & \text { Mature Male } \\ & \text { Biomass } \\ & (\geq 121 \mathrm{~mm} \mathrm{CL}) \end{aligned}$ | CV | Legal Male Biomass ( $\geq \mathbf{1 3 6}$ mm CL ) | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \mathrm{MMB}_{\mathrm{eq}}=17,962 \\ \mathrm{MMB}_{35}=6,106 \end{gathered}$ |  |  |  |
| 1985 | 1.70 |  |  | 9,775 | 0.06 |
| 1986 | 1.01 | 8,751 | 0.26 | 8,377 | 0.04 |
| 1987 | 4.39 | 6,674 | 0.28 | 6,586 | 0.04 |
| 1988 | 3.80 | 6,464 | 0.26 | 5,472 | 0.05 |
| 1989 | 1.82 | 6,082 | 0.31 | 4,879 | 0.07 |
| 1990 | 3.17 | 5,051 | 0.34 | 4,442 | 0.07 |
| 1991 | 3.60 | 5,360 | 0.32 | 4,655 | 0.06 |
| 1992 | 2.15 | 5,449 | 0.32 | 4,479 | 0.05 |
| 1993 | 2.14 | 5,146 | 0.33 | 4,517 | 0.05 |
| 1994 | 2.53 | 5,291 | 0.32 | 4,861 | 0.04 |
| 1995 | 2.41 | 4,908 | 0.31 | 4,330 | 0.04 |
| 1996 | 2.31 | 4,330 | 0.32 | 3,700 | 0.05 |
| 1997 | 3.14 | 4,401 | 0.33 | 3,822 | 0.06 |
| 1998 | 2.90 | 4,701 | 0.32 | 3,912 | 0.06 |
| 1999 | 3.11 | 5,098 | 0.33 | 4,320 | 0.07 |
| 2000 | 3.01 | 5,717 | 0.33 | 4,954 | 0.07 |
| 2001 | 2.26 | 6,294 | 0.32 | 5,591 | 0.08 |
| 2002 | 3.03 | 6,633 | 0.32 | 6,191 | 0.08 |
| 2003 | 2.55 | 7,162 | 0.31 | 6,610 | 0.08 |
| 2004 | 2.10 | 7,497 | 0.30 | 7,003 | 0.08 |
| 2005 | 3.32 | 7,646 | 0.30 | 7,328 | 0.09 |
| 2006 | 2.52 | 7,940 | 0.29 | 7,320 | 0.09 |
| 2007 | 2.37 | 8,076 | 0.30 | 7,550 | 0.09 |
| 2008 | 4.12 | 8,160 | 0.30 | 7,776 | 0.10 |
| 2009 | 2.69 | 8,642 | 0.29 | 7,794 | 0.10 |
| 2010 | 2.59 | 8,936 | 0.30 | 8,329 | 0.10 |
| 2011 | 3.48 | 9,155 | 0.31 | 8,767 | 0.10 |
| 2012 | 3.40 | 9,489 | 0.30 | 8,882 | 0.10 |
| 2013 | 2.83 | 9,817 | 0.30 | 9,132 | 0.11 |
| 2014 | 3.13 | 9,983 | 0.31 | 9,481 | 0.12 |
| 2015 | 2.75 | 10,141 | 0.31 | 9,634 | 0.13 |
| 2016 | 2.54 | 10,036 | 0.32 |  |  |

Table 19. Annual abundance estimates of model recruits (millions of crabs), legal male biomass ( t$)$ with coefficient of variations (CV), and mature male biomass ( t ) with CV for scenario 5 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\mathrm{eq}}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | Recruits to the Model ( $\geq \mathbf{1 0 1} \mathbf{~ m m}$ CL) | Mature Male Biomass $(\geq 121 \mathrm{~mm} \mathrm{CL})$ | CV | Legal Male Biomass ( $\geq \mathbf{1 3 6}$ mm CL ) | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \mathrm{MMB}_{\mathrm{eq}}=20,065 \\ \mathrm{MMB}_{35}=6,783 \end{gathered}$ |  |  |  |
| 1985 | 1.52 |  |  | 9,377 | 0.05 |
| 1986 | 0.90 | 6,213 | 0.28 | 7,976 | 0.04 |
| 1987 | 3.94 | 6,019 | 0.26 | 6,242 | 0.04 |
| 1988 | 3.56 | 5,694 | 0.30 | 5,211 | 0.05 |
| 1989 | 1.64 | 4,737 | 0.34 | 4,686 | 0.07 |
| 1990 | 2.57 | 4,993 | 0.32 | 4,315 | 0.06 |
| 1991 | 3.42 | 5,093 | 0.32 | 4,566 | 0.06 |
| 1992 | 2.02 | 4,851 | 0.33 | 4,313 | 0.05 |
| 1993 | 1.82 | 5,053 | 0.32 | 4,370 | 0.04 |
| 1994 | 2.26 | 4,707 | 0.31 | 4,818 | 0.03 |
| 1995 | 2.13 | 4,145 | 0.32 | 4,321 | 0.04 |
| 1996 | 2.04 | 4,229 | 0.32 | 3,683 | 0.04 |
| 1997 | 2.76 | 4,516 | 0.32 | 3,815 | 0.04 |
| 1998 | 2.52 | 4,901 | 0.32 | 3,920 | 0.05 |
| 1999 | 2.71 | 5,506 | 0.32 | 4,336 | 0.05 |
| 2000 | 2.53 | 6,054 | 0.31 | 4,974 | 0.05 |
| 2001 | 1.93 | 6,400 | 0.31 | 5,612 | 0.06 |
| 2002 | 2.52 | 6,897 | 0.30 | 6,192 | 0.06 |
| 2003 | 2.11 | 7,207 | 0.30 | 6,605 | 0.07 |
| 2004 | 1.78 | 7,368 | 0.30 | 6,975 | 0.07 |
| 2005 | 2.72 | 7,625 | 0.28 | 7,272 | 0.07 |
| 2006 | 2.08 | 7,738 | 0.29 | 7,277 | 0.08 |
| 2007 | 1.99 | 7,829 | 0.29 | 7,480 | 0.08 |
| 2008 | 3.38 | 8,228 | 0.28 | 7,682 | 0.09 |
| 2009 | 2.27 | 8,510 | 0.30 | 7,694 | 0.09 |
| 2010 | 2.15 | 8,741 | 0.30 | 8,183 | 0.09 |
| 2011 | 2.90 | 9,064 | 0.29 | 8,615 | 0.09 |
| 2012 | 2.86 | 9,391 | 0.29 | 8,749 | 0.09 |
| 2013 | 2.36 | 9,585 | 0.30 | 9,007 | 0.10 |
| 2014 | 2.61 | 9,764 | 0.30 | 9,374 | 0.11 |
| 2015 | 2.24 | 9,676 | 0.31 | 9,555 | 0.13 |
| 2016 | 2.06 | 9,857 | 0.31 |  |  |

Table 20. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 6 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\text {eq }}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | Recruits to the Model ( $\geq \mathbf{1 0 1} \mathbf{~ m m}$ CL) | Mature Male Biomass ( $\geq 121 \mathrm{~mm} \mathrm{CL}$ ) | CV | $\begin{gathered} \text { Legal Male } \\ \text { Biomass }(\geq 136 \\ \text { mm CL) } \end{gathered}$ | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \mathrm{MMB}_{\mathrm{eq}}=17,523 \\ \mathrm{MMB}_{35}=5,996 \end{gathered}$ |  |  |  |
| 1985 | 2.14 |  |  | 10,515 | 0.06 |
| 1986 | 1.28 | 7,188 | 0.28 | 8,905 | 0.05 |
| 1987 | 5.17 | 6,962 | 0.27 | 6,949 | 0.05 |
| 1988 | 4.82 | 6,676 | 0.31 | 5,723 | 0.05 |
| 1989 | 2.29 | 5,654 | 0.34 | 5,156 | 0.07 |
| 1990 | 3.49 | 5,911 | 0.32 | 4,855 | 0.07 |
| 1991 | 4.70 | 6,105 | 0.32 | 5,094 | 0.06 |
| 1992 | 2.80 | 5,866 | 0.33 | 4,840 | 0.05 |
| 1993 | 2.50 | 5,990 | 0.32 | 4,984 | 0.05 |
| 1994 | 3.18 | 5,624 | 0.31 | 5,407 | 0.04 |
| 1995 | 3.04 | 5,099 | 0.32 | 4,860 | 0.04 |
| 1996 | 2.95 | 5,250 | 0.32 | 4,255 | 0.05 |
| 1997 | 4.11 | 5,728 | 0.32 | 4,449 | 0.05 |
| 1998 | 3.81 | 6,322 | 0.32 | 4,640 | 0.06 |
| 1999 | 4.15 | 7,162 | 0.32 | 5,239 | 0.06 |
| 2000 | 3.93 | 7,909 | 0.32 | 6,068 | 0.07 |
| 2001 | 2.96 | 8,306 | 0.32 | 6,899 | 0.07 |
| 2002 | 3.88 | 8,855 | 0.30 | 7,618 | 0.08 |
| 2003 | 3.40 | 9,184 | 0.30 | 8,027 | 0.08 |
| 2004 | 2.89 | 9,300 | 0.30 | 8,388 | 0.08 |
| 2005 | 4.37 | 9,617 | 0.29 | 8,680 | 0.09 |
| 2006 | 3.39 | 9,765 | 0.30 | 8,630 | 0.09 |
| 2007 | 3.19 | 9,836 | 0.30 | 8,903 | 0.10 |
| 2008 | 5.39 | 10,411 | 0.29 | 9,142 | 0.10 |
| 2009 | 3.63 | 10,748 | 0.30 | 9,147 | 0.10 |
| 2010 | 3.43 | 10,949 | 0.31 | 9,769 | 0.10 |
| 2011 | 4.51 | 11,277 | 0.30 | 10,235 | 0.10 |
| 2012 | 4.41 | 11,594 | 0.30 | 10,304 | 0.10 |
| 2013 | 3.72 | 11,710 | 0.31 | 10,528 | 0.11 |
| 2014 | 4.18 | 11,844 | 0.31 | 10,852 | 0.12 |
| 2015 | 3.70 | 11,711 | 0.32 | 10,944 | 0.13 |
| 2016 | 3.39 | 11,359 | 0.33 |  |  |

Table 21. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 9 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y . Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\text {eq }}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | Recruits to the Model ( $\geq \mathbf{1 0 1} \mathbf{~ m m}$ CL) | Mature Male Biomass ( $\geq 121 \mathrm{~mm} \mathrm{CL})$ | CV | Legal Male Biomass ( $\geq \mathbf{1 3 6}$ mm CL) | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{aligned} \mathrm{MMB}_{\mathrm{eq}} & =20,164 \\ \mathrm{MMB}_{35} & =6,879 \end{aligned}$ |  |  |  |
| 1985 | 1.77 |  |  | 9,843 | 0.06 |
| 1986 | 1.06 | 7,556 | 0.04 | 8,359 | 0.04 |
| 1987 | 4.45 | 6,924 | 0.05 | 6,535 | 0.04 |
| 1988 | 4.08 | 7,067 | 0.05 | 5,424 | 0.05 |
| 1989 | 1.91 | 6,288 | 0.06 | 4,880 | 0.07 |
| 1990 | 2.95 | 6,251 | 0.05 | 4,537 | 0.06 |
| 1991 | 3.94 | 6,349 | 0.04 | 4,785 | 0.06 |
| 1992 | 2.34 | 6,373 | 0.04 | 4,533 | 0.05 |
| 1993 | 2.10 | 6,439 | 0.03 | 4,627 | 0.05 |
| 1994 | 2.63 | 5,884 | 0.04 | 5,065 | 0.04 |
| 1995 | 2.49 | 5,317 | 0.04 | 4,546 | 0.04 |
| 1996 | 2.40 | 5,457 | 0.04 | 3,919 | 0.04 |
| 1997 | 3.29 | 5,774 | 0.05 | 4,075 | 0.05 |
| 1998 | 3.03 | 6,436 | 0.05 | 4,213 | 0.05 |
| 1999 | 3.27 | 7,208 | 0.06 | 4,703 | 0.06 |
| 2000 | 3.09 | 7,955 | 0.06 | 5,419 | 0.06 |
| 2001 | 2.34 | 8,408 | 0.07 | 6,139 | 0.06 |
| 2002 | 3.07 | 8,800 | 0.07 | 6,783 | 0.07 |
| 2003 | 2.62 | 9,232 | 0.07 | 7,203 | 0.07 |
| 2004 | 2.22 | 9,379 | 0.08 | 7,578 | 0.08 |
| 2005 | 3.38 | 9,520 | 0.08 | 7,881 | 0.08 |
| 2006 | 2.60 | 9,870 | 0.08 | 7,867 | 0.08 |
| 2007 | 2.46 | 9,927 | 0.09 | 8,103 | 0.09 |
| 2008 | 4.19 | 10,257 | 0.09 | 8,324 | 0.09 |
| 2009 | 2.81 | 10,946 | 0.09 | 8,337 | 0.10 |
| 2010 | 2.66 | 11,107 | 0.09 | 8,887 | 0.10 |
| 2011 | 3.56 | 11,310 | 0.10 | 9,338 | 0.10 |
| 2012 | 3.50 | 11,773 | 0.10 | 9,448 | 0.10 |
| 2013 | 2.91 | 12,044 | 0.11 | 9,699 | 0.10 |
| 2014 | 3.25 | 12,119 | 0.13 | 10,057 | 0.11 |
| 2015 | 2.84 | 12,051 | 0.15 | 10,205 | 0.13 |
| 2016 | 2.61 | 11,910 | 0.17 |  |  |

Table 22. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass ( t ) with CV for scenario 10 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y . Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\text {eq }}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | Recruits to the Model ( $\geq \mathbf{1 0 1} \mathbf{~ m m}$ CL) | Mature Male Biomass ( $\geq 121 \mathrm{~mm} \mathrm{CL})$ | CV | Legal Male Biomass ( $\geq \mathbf{1 3 6}$ mm CL) | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \mathrm{MMB}_{\mathrm{eq}}=18,591 \\ \mathrm{MMB}_{35}=6,313 \end{gathered}$ |  |  |  |
| 1985 | 1.75 |  |  | 9,800 | 0.06 |
| 1986 | 1.04 | 6,580 | 0.28 | 8,323 | 0.04 |
| 1987 | 4.40 | 6,376 | 0.26 | 6,508 | 0.04 |
| 1988 | 4.03 | 6,065 | 0.31 | 5,404 | 0.05 |
| 1989 | 1.88 | 5,083 | 0.34 | 4,862 | 0.07 |
| 1990 | 2.91 | 5,341 | 0.32 | 4,517 | 0.06 |
| 1991 | 3.89 | 5,477 | 0.32 | 4,765 | 0.06 |
| 1992 | 2.31 | 5,237 | 0.33 | 4,513 | 0.05 |
| 1993 | 2.07 | 5,409 | 0.32 | 4,604 | 0.05 |
| 1994 | 2.59 | 5,052 | 0.31 | 5,043 | 0.04 |
| 1995 | 2.46 | 4,500 | 0.32 | 4,525 | 0.04 |
| 1996 | 2.36 | 4,607 | 0.32 | 3,897 | 0.04 |
| 1997 | 3.24 | 4,961 | 0.32 | 4,051 | 0.05 |
| 1998 | 2.98 | 5,421 | 0.32 | 4,186 | 0.05 |
| 1999 | 3.22 | 6,113 | 0.32 | 4,669 | 0.06 |
| 2000 | 3.03 | 6,739 | 0.32 | 5,378 | 0.06 |
| 2001 | 2.30 | 7,111 | 0.31 | 6,091 | 0.06 |
| 2002 | 3.02 | 7,637 | 0.30 | 6,729 | 0.07 |
| 2003 | 2.57 | 7,961 | 0.30 | 7,149 | 0.07 |
| 2004 | 2.18 | 8,112 | 0.30 | 7,524 | 0.08 |
| 2005 | 3.32 | 8,394 | 0.29 | 7,827 | 0.08 |
| 2006 | 2.55 | 8,525 | 0.29 | 7,815 | 0.08 |
| 2007 | 2.42 | 8,612 | 0.30 | 8,048 | 0.09 |
| 2008 | 4.11 | 9,080 | 0.29 | 8,268 | 0.09 |
| 2009 | 2.76 | 9,387 | 0.30 | 8,281 | 0.10 |
| 2010 | 2.62 | 9,614 | 0.30 | 8,825 | 0.10 |
| 2011 | 3.50 | 9,945 | 0.29 | 9,275 | 0.10 |
| 2012 | 3.44 | 10,278 | 0.29 | 9,388 | 0.10 |
| 2013 | 2.86 | 10,448 | 0.30 | 9,640 | 0.10 |
| 2014 | 3.19 | 10,617 | 0.31 | 9,999 | 0.11 |
| 2015 | 2.78 | 10,518 | 0.32 | 10,151 | 0.13 |
| 2016 | 2.56 | 10,475 | 0.32 |  |  |

Table 23. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass ( t ) with CV for scenario 11 for golden king crab in the EAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y . Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\text {eq }}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | Recruits to the Model ( $\mathbf{Z 1 0 1 ~ m m}$ CL) | Mature Male Biomass $(\geq 121 \mathrm{~mm} \mathrm{CL})$ | CV | $\begin{gathered} \text { Legal Male } \\ \text { Biomass }(\geq 136 \\ \text { mm CL) } \end{gathered}$ | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \mathrm{MMB}_{\mathrm{eq}}=20,262 \\ \mathrm{MMB}_{35}=6,894 \end{gathered}$ |  |  |  |
| 1985 | 1.75 |  |  | 9,800 | 0.06 |
| 1986 | 1.04 | 7,512 | 0.04 | 8,323 | 0.04 |
| 1987 | 4.40 | 6,885 | 0.05 | 6,508 | 0.04 |
| 1988 | 4.03 | 7,025 | 0.05 | 5,404 | 0.05 |
| 1989 | 1.88 | 6,246 | 0.06 | 4,862 | 0.07 |
| 1990 | 2.91 | 6,211 | 0.05 | 4,517 | 0.06 |
| 1991 | 3.89 | 6,306 | 0.04 | 4,765 | 0.06 |
| 1992 | 2.31 | 6,327 | 0.04 | 4,513 | 0.05 |
| 1993 | 2.07 | 6,397 | 0.03 | 4,604 | 0.05 |
| 1994 | 2.59 | 5,845 | 0.04 | 5,043 | 0.04 |
| 1995 | 2.46 | 5,276 | 0.04 | 4,525 | 0.04 |
| 1996 | 2.36 | 5,413 | 0.04 | 3,897 | 0.04 |
| 1997 | 3.24 | 5,722 | 0.05 | 4,051 | 0.05 |
| 1998 | 2.98 | 6,374 | 0.05 | 4,186 | 0.05 |
| 1999 | 3.22 | 7,136 | 0.06 | 4,669 | 0.06 |
| 2000 | 3.03 | 7,874 | 0.06 | 5,378 | 0.06 |
| 2001 | 2.30 | 8,323 | 0.07 | 6,091 | 0.06 |
| 2002 | 3.02 | 8,715 | 0.07 | 6,729 | 0.07 |
| 2003 | 2.57 | 9,145 | 0.07 | 7,149 | 0.07 |
| 2004 | 2.18 | 9,293 | 0.08 | 7,524 | 0.08 |
| 2005 | 3.32 | 9,434 | 0.08 | 7,827 | 0.08 |
| 2006 | 2.55 | 9,780 | 0.08 | 7,815 | 0.08 |
| 2007 | 2.42 | 9,837 | 0.09 | 8,048 | 0.09 |
| 2008 | 4.11 | 10,162 | 0.09 | 8,268 | 0.09 |
| 2009 | 2.76 | 10,844 | 0.09 | 8,281 | 0.10 |
| 2010 | 2.62 | 11,008 | 0.09 | 8,825 | 0.10 |
| 2011 | 3.50 | 11,212 | 0.10 | 9,275 | 0.10 |
| 2012 | 3.44 | 11,675 | 0.10 | 9,388 | 0.10 |
| 2013 | 2.86 | 11,948 | 0.11 | 9,640 | 0.10 |
| 2014 | 3.19 | 12,026 | 0.13 | 9,999 | 0.11 |
| 2015 | 2.78 | 11,959 | 0.15 | 10,151 | 0.13 |
| 2016 | 2.56 | 11,840 | 0.17 |  |  |

Table 24. Negative log-likelihood values of the fits for scenarios (Sc) 1 (base), 2 (drops retained catch CPUE), 3 (includes 1991-1994 observer CPUE), 4 (three catchability and total selectivity parameter sets), 5 (low bracketing value of $M$ ), 6 (high bracketing value of $M$ ), 9 (knife-edge maturity), 10 (EAG only data based $M$ ), and 11 (EAG only data based $M$ with knife-edge maturity) for golden king crab in the EAG. Differences in likelihood values are given for scenarios with the same number of data points (base) and free parameters. Likelihood components with zero entry in the entire rows are omitted. RetdcatchB= retained catch biomass.

| Likelihood Component | Sc 1 | Sc 2 | Sc 3 | Sc 4 | Sc 5 | Sc 6 | Sc 9 | Sc 10 | Sc11 | $\begin{aligned} & \hline \text { Sc3- } \\ & \text { Sc } 1 \end{aligned}$ | $\begin{gathered} \hline \text { Sc 5- } \\ \text { Sc } 1 \end{gathered}$ | $\begin{gathered} \text { Sc } 6- \\ \text { Sc } 1 \end{gathered}$ | $\begin{gathered} \text { Sc } 10- \\ \text { Sc } 1 \end{gathered}$ | $\begin{gathered} \hline \text { Sc } 11- \\ \text { Sc } 9 \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Number of free parameters | 139 | 138 | 139 | 142 | 139 | 139 | 137 | 139 | 137 |  |  |  |  |  |
| Data | base | base | base | base | base | base | base | base | base |  |  |  |  |  |
| Retlencomp | -1152.09 | -1151.47 | -1150.71 | -1164.02 | -1148.80 | -1152.06 | -1152.09 | -1151.96 | -1151.96 | 1.38 | 3.29 | 0.03 | 0.13 | 0.13 |
| Totallencomp | -1201.41 | -1199.97 | -1213.01 | -1194.82 | -1204.80 | -1198.51 | -1201.41 | -1201.65 | -1201.65 | -11.6 | -3.39 | 2.9 | -0.24 | -0.24 |
| Observer cpue | -11.92 | -11.86 | -5.96 | -12.21 | -12.62 | -10.93 | -11.92 | -11.99 | -11.99 | 5.96 | -0.7 | 0.99 | -0.07 | -0.07 |
| RetdcatchB | 7.08 | 6.85 | 7.46 | 7.14 | 7.22 | 6.94 | 7.08 | 7.09 | 7.09 | 0.38 | 0.14 | -0.14 | 0.01 | 0.01 |
| TotalcatchB | 20.12 | 19.99 | 20.30 | 20.47 | 20.14 | 20.14 | 20.12 | 20.12 | 20.12 | 0.18 | 0.02 | 0.02 | 0.00 | 0.00 |
| GdiscdcatchB | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Rec_dev | 5.77 | 6.10 | 6.13 | 5.83 | 7.50 | 5.20 | 5.77 | 5.86 | 5.86 | 0.36 | 1.73 | -0.57 | 0.09 | 0.09 |
| Pot F_dev | 0.01 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| Gbyc_F_dev | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tag | 2690.70 | 2690.59 | 2690.35 | 2688.91 | 2690.67 | 2690.72 | 2690.70 | 2690.70 | 2690.70 | -0.35 | -0.03 | 0.02 | 0.00 | 0.00 |
| Fishery cpue | -0.52 | - | -2.54 | -0.68 | -0.57 | -0.45 | -0.52 | -0.52 | -0.52 | -2.02 | -0.05 | 0.07 | 0.00 | 0.00 |
| Maturity | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | - | 0.17 | - | 0.00 | 0.00 | 0.00 | 0.00 | - |
| Total | 357.95 | 360.43 | 352.23 | 350.83 | 358.96 | 361.25 | 357.78 | 357.87 | 357.70 | -5.72 | 1.01 | 3.3 | -0.08 | -0.08 |

Table 25. Time series of annual retained catch (1981-1984 values are in number of crabs and the rest in t ), estimated total male catch (weight of crabs on the deck without applying any handling mortality), estimated groundfish fishery discard mortality of males (handling mortality rates of 0.5 for pot gear and 0.8 for trawl gear were applied), and pot fishery effort (number of pot lifts) for the WAG golden king crab stock. The crab weights are for the size range $\geq 101 \mathrm{~mm}$ CL. NA: no observer sampling to compute catch.

| Year | Retained Catch Biomass | Total Catch Biomass (t) | Ground-fish <br> Discard <br> Mortality (t) | Pot Fishery Effort (no. pot lifts) |
| :---: | :---: | :---: | :---: | :---: |
| 1981 | 38,436 |  |  |  |
| 1982 | 1,114,351 |  |  |  |
| 1983 | 1,288,357 |  |  |  |
| 1984 | 188,782 |  |  |  |
| 1985 | 1,996 |  |  | 118,563 |
| 1986 | 4,200 |  |  | 277,780 |
| 1987 | 2,496 |  |  | 160,229 |
| 1988 | 2,441 |  |  | 166,409 |
| 1989 | 3,028 |  | 0.08 | 202,541 |
| 1990 | 1,621 | 3,684 | 0.57 | 108,533 |
| 1991 | 1,347 | 2,565 | 0.03 | 101,429 |
| 1992 | 1,019 | 1,517 | 0.43 | 69,443 |
| 1993 | 661 | 2,814 | 0.00 | 127,764 |
| 1994 | 1,606 | 4,942 | 0.12 | 195,138 |
| 1995 | 1,178 | 2,128 | 0.71 | 115,248 |
| 1996 | 1,223 | 1,763 | 1.03 | 99,267 |
| 1997 | 1,055 | 1,793 | 0.37 | 86,811 |
| 1998 | 926 | 1,085 | 1.85 | 35,975 |
| 1999 | 1,227 | 2,087 | 1.42 | 107,040 |
| 2000 | 1,369 | 2,228 | 0.80 | 101,239 |
| 2001 | 1,275 | 2,133 | 0.43 | 105,512 |
| 2002 | 1,207 | 1,889 | 0.92 | 78,979 |
| 2003 | 1,238 | 1,855 | 0.31 | 66,236 |
| 2004 | 1,254 | 1,874 | 0.95 | 56,846 |
| 2005 | 1,223 | 1,772 | 3.43 | 30,116 |
| 2006 | 1,041 | 1,539 | 2.27 | 26,870 |
| 2007 | 1,222 | 1,602 | 1.50 | 29,950 |
| 2008 | 1,199 | 1,721 | 6.43 | 26,200 |
| 2009 | 1,324 | 1,666 | 4.30 | 26,489 |
| 2010 | 1,328 | 1,579 | 2.47 | 29,994 |
| 2011 | 1,323 | 1,506 | 2.24 | 26,326 |
| 2012 | 1,395 | 1,812 | 3.73 | 32,716 |
| 2013 | 1,431 | 1,891 | 3.85 | 41,835 |
| 2014 | 1,248 | 1,583 | 2.45 | 41,548 |
| 2015 | 1,166 | 1,548 | 1.43 | 41,108 |

Table 26. Time series of nominal annual pot fishery retained, observer retained, and observer total catch-per-unit-effort (CPUE, number of crabs per pot lift), observer sample size (number of sampled pots), and GLM estimated observer CPUE Index for the WAG golden king crab stock. Observer retained CPUE includes retained and non-retained legal size crabs.

|  | Pot Fishery <br> Nominal <br> Retained <br> CPUE | Obs. <br> Nominal <br> Retained <br> CPUE | Obs. <br> Nominal <br> Total <br> CPUE | Obs. <br> Sample Size <br> (no.pot lifts) | Obs. CPUE <br> Index |
| :--- | :---: | :---: | :---: | :---: | :---: |
| 1990 | 6.98 | 11.83 | 26.67 | 340 |  |
| 1991 | 7.43 | 7.78 | 19.17 | 857 |  |
| 1992 | 5.90 | 6.39 | 16.83 | 690 |  |
| 1993 | 4.43 | 6.54 | 17.23 | 174 |  |
| 1994 | 4.08 | 6.71 | 19.23 | 1,270 |  |
| 1995 | 4.65 | 4.96 | 14.28 | 5,598 | 1.17 |
| 1996 | 6.07 | 5.42 | 13.54 | 7,194 | 0.95 |
| 1997 | 6.56 | 6.52 | 15.03 | 3,985 | 0.96 |
| 1998 | 11.40 | 9.41 | 23.09 | 1,876 | 1.07 |
| 1999 | 6.32 | 5.93 | 14.49 | 4,523 | 0.91 |
| 2000 | 6.97 | 6.40 | 16.64 | 4,740 | 0.85 |
| 2001 | 6.51 | 5.99 | 14.66 | 4,454 | 0.83 |
| 2002 | 8.42 | 7.47 | 17.37 | 2,509 | 0.92 |
| 2003 | 10.22 | 9.29 | 18.17 | 3,334 | 1.16 |
| 2004 | 12.06 | 11.14 | 22.45 | 2,619 | 1.27 |
| 2005 | 21.23 | 23.89 | 36.23 | 1,365 | 1.18 |
| 2006 | 19.64 | 24.01 | 33.47 | 1,183 | 1.10 |
| 2007 | 20.05 | 21.04 | 32.46 | 1,082 | 1.00 |
| 2008 | 22.43 | 24.57 | 38.16 | 979 | 1.15 |
| 2009 | 23.72 | 26.55 | 34.08 | 892 | 1.23 |
| 2010 | 20.88 | 22.35 | 29.05 | 867 | 1.08 |
| 2011 | 23.40 | 23.79 | 31.13 | 837 | 1.11 |
| 2012 | 20.57 | 22.82 | 30.76 | 1,109 | 1.07 |
| 2013 | 16.42 | 16.96 | 25.01 | 1,223 | 0.81 |
| 2014 | 15.29 | 15.28 | 22.67 | 1,137 | 0.72 |
| 2015 | 14.71 | 15.74 | 22.14 | 1,296 | 0.74 |
|  |  |  |  |  |  |

Table 27. Time series of GLM estimated CPUE indices and coefficient of variations (CV) for the fish ticket based retained catch-per-pot lift for the WAG golden king crab stock. The GLM was fitted to the 1985/86 to 1998/99 time series of data.

|  | CPUE <br> Index | CV |
| :---: | :---: | :---: |
| 1985 | 2.02 | 0.03 |
| 1986 | 1.72 | 0.03 |
| 1987 | 1.21 | 0.04 |
| 1988 | 1.35 | 0.03 |
| 1989 | 1.14 | 0.03 |
| 1990 | 0.87 | 0.04 |
| 1991 | 0.72 | 0.06 |
| 1992 | 0.72 | 0.06 |
| 1993 | 0.68 | 0.08 |
| 1994 | 0.82 | 0.05 |
| 1995 | 0.88 | 0.05 |
| 1996 | 0.84 | 0.04 |
| 1997 | 0.77 | 0.04 |
| 1998 | 1.05 | 0.04 |

Table 28. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 1 model fit to WAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days <br> Sample | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input <br> Groundfish <br> Trip Sample <br> Size (no) | Stage-2 <br> Groundfish <br> Effective <br> Sample Size |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | (no) |  |

Table 29. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 2 model fit to WAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days <br> Sample | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input <br> Groundfish <br> Trip Sample <br> Size (no) | Stage-2 <br> Groundfish <br> Effective <br> Sample Size |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Size (no) |  |  |  | (no) |  |

Table 30. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 3 model fit to WAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days <br> Sample | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size <br> (no) | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input <br> Groundfish <br> Trip Sample <br> Size (no) | Stage-2 <br> Groundfish <br> Effective <br> Sample Size |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | (no) |  |

Table 31. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 4 model fit to WAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days <br> Sample | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input <br> Groundfish <br> Trip Sample <br> Size (no) | Stage-2 <br> Groundfish <br> Effective <br> Sample Size |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Size (no) |  |  |  | (no) |  |

Table 32. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 5 model fit to WAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days <br> Sample | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input <br> Groundfish <br> Trip Sample <br> Size (no) | Stage-2 <br> Groundfish <br> Effective <br> Sample Size |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | (no) |  |

Table 33. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 6 model fit to WAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days | Stage-2 <br> Retained <br> Effective <br> Sample | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size (no) | Stage-2 <br> Total <br> Effective <br> Sample <br> Size | Initial Input <br> Groundfish <br> Trip Sample <br> Size (no) | Stage-2 <br> Groundfish <br> Effective <br> Sample Size |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | (no) |  |

Table 34. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 9 model fit to WAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days <br> Sample | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input <br> Groundfish <br> Trip Sample <br> Size (no) | Stage-2 <br> Groundfish <br> Effective <br> Sample Size |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | (no) |  |

Table 35. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 10 model fit to WAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days <br> Sample | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input <br> Groundfish <br> Trip Sample <br> Size (no) | Stage-2 <br> Groundfish <br> Effective <br> Sample Size |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Size (no) |  |  |  | (no) |  |

Table 36. The initial input number of days/trips and stage-2 effective sample sizes iteratively estimated by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 11 model fit to WAG data. NA: not available.

| Year | Initial <br> Input <br> Retained <br> Days <br> Sample | Stage-2 <br> Retained <br> Effective <br> Sample <br> Size (no) | Initial <br> Input <br> Total <br> Days <br> Sample <br> Size | Stage-2 <br> Total <br> Effective <br> Sample <br> Size (no) | Initial Input <br> Groundfish <br> Trip Sample <br> Size (no) | Stage-2 <br> Groundfish <br> Effective <br> Sample Size |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  | (no) |  |

Table 37. Parameter estimates and coefficient of variations (CV) with the 2015 MMB (MMB on 15 Feb 2016) for scenarios 1 , 2 , 3 , and 4 for the golden king crab data from the WAG, 1985/86-2015/16. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

|  | Scenario 1 |  | Scenario 2 |  | Scenario 3 |  | Scenario 4 |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Parameter | Estimate | CV | Estimate | CV | Estimate | CV | Estimate | CV | Limits |
| $\log _{-} \omega_{1}$ ( growth incr. intercept) | 2.54 | 0.01 | 2.54 | 0.01 | 2.54 | 0.01 | 2.55 | 0.01 | 1.0, 4.5 |
| $\omega_{2}$ (growth incr. slope) | -7.82 | 0.22 | -7.68 | 0.22 | -7.81 | 0.22 | -8.17 | 0.21 | -12.0,-5.0 |
| $\log _{\text {_ }} \mathrm{a}$ (molt prob. slope) | -2.62 | 0.03 | -2.64 | 0.03 | -2.62 | 0.03 | -2.54 | 0.03 | -4.61,-1.39 |
| $\log _{-} \mathrm{b}$ (molt prob. L50) | 4.95 | 0.001 | 4.95 | 0.001 | 4.95 | 0.001 | 4.96 | 0.001 | 3.869,5.05 |
| $\sigma$ (growth variability std) | 3.69 | 0.03 | 3.69 | 0.03 | 3.69 | 0.03 | 3.68 | 0.03 | 0.1,12.0 |
| log_total sel deltae, 1985-94 |  |  |  |  |  |  | 3.34 | 0.05 | 0,4.4 |
| log_total sel delta日, 1985-04 or 1995-04 | 3.39 | 0.01 | 3.40 | 0.01 | 3.39 | 0.01 | 3.42 | 0.02 | 0.,4.4 |
| $\log _{-}$total sel delta $\theta$, 2005-15 | 2.88 | 0.03 | 2.91 | 0.03 | 2.89 | 0.03 | 2.89 | 0.03 | 0.,4.4 |
| $\log _{-}$ret. sel delta $\theta$, 1985-15 | 1.78 | 0.02 | 1.78 | 0.02 | 1.78 | 0.02 | 1.77 | 0.02 | 0.,4.4 |
| log_maturity delta_mat | 3.80 | 0.48 | 3.80 | 0.48 | 3.80 | 0.48 | 3.80 | 0.48 | 0,4.4 |
| $\log _{-}$maturity mat ${ }_{50}$ | 4.71 | 0.04 | 4.71 | 0.04 | 4.71 | 0.04 | 4.71 | 0.04 | 4.4,4.85 |
| log_tot sel $\theta_{50}$, 1985-94 |  |  |  |  |  |  | 4.77 | 0.01 | 4.0,5.0 |
| log_tot sel $\theta_{50}, 1985-04$ or 1995-04 | 4.87 | 0.002 | 4.87 | 0.002 | 4.87 | 0.002 | 4.88 | 0.003 | 4.0,5.0 |
| log_tot sel $\theta_{50}, 2005-15$ | 4.90 | 0.002 | 4.90 | 0.002 | 4.90 | 0.002 | 4.90 | 0.002 | 4.0,5.0 |
| $\log _{-}$ret. sel $\theta_{50}, 1985-15$ | 4.92 | 0.0002 | 4.92 | 0.0002 | 4.92 | 0.0002 | 4.92 | 0.0002 | 4.0,5.0 |
| $\log \_\beta_{\mathrm{r}}$ (rec.distribution par.) | -1.03 | 0.16 | -1.03 | 0.17 | -1.03 | 0.16 | -0.97 | 0.18 | -12.0, 12.0 |
| Logq1 (catchability 1985-94) |  |  |  |  |  |  | -0.37 | 0.15 | -9.0, 2.25 |
| $\operatorname{logq} 2$ (catchability 1995-04) | -0.09 | 0.76 | 0.04 | 2.15 | -0.06 | 1.22 | 0.20 | 0.42 | -9.0, 2.25 |
| $\operatorname{logq} 3$ (catchability 2005-15) | -0.48 | 0.21 | -0.43 | 0.24 | -0.48 | 0.21 | -0.38 | 0.26 | -9.0, 2.25 |
| log_mean_rec (mean rec.) | 0.79 | 0.06 | 0.80 | 0.06 | 0.79 | 0.06 | 0.75 | 0.06 | 0.01, 5.0 |
| log_mean_Fpot (Pot fishery F) | -0.73 | 0.09 | -0.72 | 0.09 | -0.73 | 0.09 | -0.71 | 0.09 | -15.0, -0.01 |
| log_mean_Fground (GF byc. F) | -8.44 | 0.11 | -8.42 | 0.11 | -8.44 | 0.11 | -8.33 | 0.11 | -15.0, -1.6 |
| $\sigma_{e}^{2}$ (observer CPUE additional var) | 0.021 | 0.37 | 0.018 | 0.38 | 0.021 | 0.36 | 0.016 | 0.38 | 0.0, 0.15 |
| $\sigma_{e}^{2}$ (fishery CPUE additional var) | 0.016 | 0.65 |  |  | 0.021 | 0.70 | 0.002 | 0.91 | 0.0,1.0 |
| 2015 MMB | 4,332 | 0.35 | 4,228 | 0.35 | 4,334 | 0.35 | 3,865 | 0.35 |  |

Table 38. Parameter estimates and coefficient of variations (CV) with the 2015 MMB (MMB on 15 Feb 2016 ) for scenarios 5, 6, 9, 10, and 11 for the golden king crab data from the WAG, 1985/86-2015/16. Recruitment and fishing mortality deviations and initial size frequency determination parameters were omitted from this list.

|  | Scenario 5 |  | Scenario 6 |  | Scenario 9 |  | Scenario 10 |  | Scenario 11 |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Parameter | Estimate | CV | Estimate | CV | Estimate | CV | Estimate | CV | Estimate | CV | Limits |
| $\log _{-} \omega_{1}$ ( growth incr. intercept) | 2.54 | 0.01 | 2.54 | 0.01 | 2.54 | 0.01 | 2.54 | 0.01 | 2.54 | 0.01 | 1.0, 4.5 |
| $\omega_{2}$ ( growth incr. slope) | -7.90 | 0.21 | -7.71 | 0.22 | -7.82 | 0.22 | -7.80 | 0.22 | -7.80 | 0.22 | -12.0,-5.0 |
| $\log _{-} \mathrm{a}$ (molt prob. slope) | -2.59 | 0.03 | -2.64 | 0.03 | -2.62 | 0.03 | -2.62 | 0.03 | -2.62 | 0.03 | -4.61,-1.39 |
| $\log _{-} \mathrm{b}$ (molt prob. L50) | 4.95 | 0.001 | 4.95 | 0.001 | 4.95 | 0.001 | 4.95 | 0.001 | 4.95 | 0.001 | 3.869,5.05 |
| $\sigma$ (growth variability std) | 3.69 | 0.03 | 3.69 | 0.03 | 3.69 | 0.03 | 3.69 | 0.03 | 3.69 | 0.03 | 0.1,12.0 |
| log_total sel delta 0 , 1985-04 | 3.42 | 0.01 | 3.37 | 0.01 | 3.39 | 0.01 | 3.39 | 0.01 | 3.39 | 0.01 | 0.,4.4 |
| $\log _{-}$total sel delta $\theta, 2005-15$ | 2.89 | 0.03 | 2.88 | 0.03 | 2.88 | 0.03 | 2.88 | 0.03 | 2.88 | 0.03 | 0.,4.4 |
| $\log _{-}$ret. sel delta $\theta$, 1985-15 | 1.77 | 0.02 | 1.78 | 0.02 | 1.78 | 0.02 | 1.78 | 0.02 | 1.78 | 0.02 | 0.,4.4 |
| log_maturity delta_mat | 3.80 | 0.48 | 3.80 | 0.48 |  |  | 3.80 | 0.48 |  |  | 0,4.4 |
| $\log _{\text {_ }}$ maturity mat ${ }_{50}$ | 4.71 | 0.04 | 4.71 | 0.04 |  |  | 4.71 | 0.04 |  |  | 4.4,4.85 |
| log_tot sel $\theta_{50}$, 1985-04 | 4.86 | 0.002 | 4.87 | 0.002 | 4.87 | 0.002 | 4.87 | 0.002 | 4.87 | 0.002 | 4.0,5.0 |
| log_tot sel $\theta_{50}, 2005-15$ | 4.89 | 0.002 | 4.90 | 0.002 | 4.90 | 0.002 | 4.90 | 0.002 | 4.90 | 0.002 | 4.0,5.0 |
| log_ret. sel $\theta_{50}, 1985-15$ | 4.91 | 0.0002 | 4.92 | 0.0002 | 4.92 | 0.0002 | 4.92 | 0.0002 | 4.92 | 0.0002 | 4.0,5.0 |
| $\log _{\_} \beta_{\mathrm{r}}$ (rec.distribution par.) | -1.02 | 0.17 | -1.03 | 0.16 | -1.03 | 0.16 | -1.03 | 0.16 | -1.03 | 0.16 | -12.0, 12.0 |
| logq2 (catchability 1985-04) | -0.04 | 1.82 | -0.15 | 0.45 | -0.09 | 0.76 | -0.10 | 0.68 | -0.10 | 0.68 | -9.0, 2.25 |
| logq3 (catchability 2005-15) | -0.42 | 0.23 | -0.55 | 0.20 | -0.48 | 0.21 | -0.49 | 0.21 | -0.49 | 0.21 | -9.0, 2.25 |
| log_mean_rec (mean rec.) | 0.58 | 0.07 | 1.03 | 0.05 | 0.79 | 0.06 | 0.83 | 0.05 | 0.83 | 0.05 | 0.01, 5.0 |
| log_mean_Fpot (Pot fishery F) | -0.69 | 0.09 | -0.79 | 0.09 | -0.73 | 0.09 | -0.74 | 0.09 | -0.74 | 0.09 | -15.0, -0.01 |
| log_mean_Fground (GF byc. F) | -8.34 | 0.11 | -8.56 | 0.11 | -8.44 | 0.11 | -8.46 | 0.11 | -8.46 | 0.11 | -15.0, -1.6 |
| $\sigma_{e}^{2}$ (observer CPUE additional var) | 0.020 | 0.37 | 0.023 | 0.37 | 0.021 | 0.37 | 0.021 | 0.37 | 0.021 | 0.37 | 0.0, 0.15 |
| $\sigma_{e}^{2}$ (fishery CPUE additional var) | 0.020 | 0.65 | 0.013 | 0.64 | 0.016 | 0.65 | 0.016 | 0.65 | 0.016 | 0.65 | 0.0,1.0 |
| 2015 MMB | 3,824 | 0.35 | 4,999 | 0.35 | 5,005 | 0.17 | 4,438 | 0.35 | 5,128 | 0.17 |  |

Table 39. Annual abundance estimates of model recruits (millions of crabs), legal male biomass $(\mathrm{t})$ with coefficient of variations $(\mathrm{CV})$, and mature male biomass ( t ) with CV for scenario 1 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\text {eq }}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | Recruits to the Model ( $\geq \mathbf{1 0 1} \mathbf{~ m m}$ CL) | $\begin{gathered} \text { Mature Male } \\ \text { Biomass } \\ (\geq 121 \mathrm{~mm} \mathrm{CL}) \end{gathered}$ | CV | Legal Male Biomass $(\geq 136 \mathrm{~mm} \mathrm{CL})$ | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \mathrm{MMB}_{\mathrm{eq}}=13,306 \\ \mathrm{MMB}_{35}=4,722 \end{gathered}$ |  |  |  |
| 1985 | 4.14 |  |  | 8,743 | 0.10 |
| 1986 | 3.74 | 7,099 | 0.31 | 8,312 | 0.08 |
| 1987 | 2.86 | 6,462 | 0.33 | 5,949 | 0.07 |
| 1988 | 1.98 | 5,518 | 0.33 | 5,614 | 0.05 |
| 1989 | 2.64 | 3,914 | 0.34 | 4,990 | 0.04 |
| 1990 | 2.06 | 3,580 | 0.34 | 3,181 | 0.06 |
| 1991 | 1.65 | 3,364 | 0.34 | 2,923 | 0.05 |
| 1992 | 2.19 | 3,571 | 0.33 | 2,873 | 0.05 |
| 1993 | 1.71 | 4,022 | 0.32 | 2,999 | 0.05 |
| 1994 | 2.07 | 3,467 | 0.32 | 3,566 | 0.03 |
| 1995 | 2.01 | 3,439 | 0.33 | 2,901 | 0.04 |
| 1996 | 1.84 | 3,434 | 0.33 | 2,852 | 0.04 |
| 1997 | 1.97 | 3,531 | 0.33 | 2,901 | 0.04 |
| 1998 | 2.02 | 3,817 | 0.32 | 2,989 | 0.04 |
| 1999 | 2.40 | 3,880 | 0.32 | 3,271 | 0.04 |
| 2000 | 2.70 | 4,034 | 0.33 | 3,213 | 0.04 |
| 2001 | 2.77 | 4,428 | 0.33 | 3,243 | 0.04 |
| 2002 | 2.72 | 4,943 | 0.33 | 3,609 | 0.05 |
| 2003 | 1.92 | 5,204 | 0.33 | 4,172 | 0.05 |
| 2004 | 2.48 | 5,455 | 0.31 | 4,703 | 0.06 |
| 2005 | 2.50 | 5,710 | 0.31 | 4,908 | 0.07 |
| 2006 | 2.70 | 6,200 | 0.30 | 5,094 | 0.07 |
| 2007 | 1.88 | 6,288 | 0.31 | 5,537 | 0.07 |
| 2008 | 1.62 | 6,162 | 0.30 | 5,849 | 0.06 |
| 2009 | 2.07 | 5,903 | 0.29 | 5,896 | 0.06 |
| 2010 | 1.75 | 5,580 | 0.29 | 5,512 | 0.06 |
| 2011 | 1.27 | 5,089 | 0.30 | 5,191 | 0.06 |
| 2012 | 2.06 | 4,667 | 0.29 | 4,838 | 0.06 |
| 2013 | 2.26 | 4,392 | 0.31 | 4,215 | 0.07 |
| 2014 | 1.54 | 4,230 | 0.34 | 3,764 | 0.09 |
| 2015 | 2.27 | 4,332 | 0.35 | 3,781 | 0.13 |
| 2016 | 2.21 | 4,990 | 0.36 |  |  |

Table 40. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) CV for scenario 2 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year $y$. Mature male biomass for fishing year $y$ was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\mathrm{eq}}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | Recruits to the Model ( $\geq 101$ mm CL) | $\begin{aligned} & \text { Mature Male } \\ & \text { Biomass } \\ & (\geq 121 \mathrm{~mm} \mathrm{CL}) \end{aligned}$ | CV | $\begin{gathered} \text { Legal Male } \\ \text { Biomass }(\geq 136 \\ \text { mm CL) } \end{gathered}$ | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \text { MMBeq }=13,158 \\ \text { MMB35 }=4,685 \end{gathered}$ |  |  |  |
| 1985 | 3.19 |  |  | 10,255 | 0.09 |
| 1986 | 3.83 | 7,527 | 0.29 | 9,478 | 0.06 |
| 1987 | 2.68 | 6,632 | 0.31 | 6,477 | 0.06 |
| 1988 | 1.94 | 5,548 | 0.32 | 5,814 | 0.05 |
| 1989 | 2.80 | 3,929 | 0.33 | 5,030 | 0.05 |
| 1990 | 2.09 | 3,615 | 0.34 | 3,147 | 0.06 |
| 1991 | 1.66 | 3,423 | 0.34 | 2,927 | 0.06 |
| 1992 | 2.02 | 3,590 | 0.33 | 2,921 | 0.06 |
| 1993 | 1.69 | 4,007 | 0.32 | 3,064 | 0.05 |
| 1994 | 2.05 | 3,412 | 0.32 | 3,574 | 0.04 |
| 1995 | 1.97 | 3,356 | 0.33 | 2,846 | 0.04 |
| 1996 | 1.81 | 3,335 | 0.33 | 2,770 | 0.04 |
| 1997 | 1.95 | 3,421 | 0.33 | 2,800 | 0.04 |
| 1998 | 1.98 | 3,696 | 0.32 | 2,875 | 0.04 |
| 1999 | 2.35 | 3,744 | 0.32 | 3,149 | 0.04 |
| 2000 | 2.63 | 3,873 | 0.33 | 3,084 | 0.04 |
| 2001 | 2.70 | 4,237 | 0.33 | 3,092 | 0.05 |
| 2002 | 2.68 | 4,728 | 0.33 | 3,424 | 0.05 |
| 2003 | 1.93 | 4,988 | 0.33 | 3,952 | 0.06 |
| 2004 | 2.46 | 5,246 | 0.32 | 4,465 | 0.06 |
| 2005 | 2.48 | 5,511 | 0.31 | 4,682 | 0.07 |
| 2006 | 2.68 | 6,009 | 0.31 | 4,885 | 0.07 |
| 2007 | 1.88 | 6,111 | 0.31 | 5,340 | 0.07 |
| 2008 | 1.61 | 6,003 | 0.31 | 5,662 | 0.06 |
| 2009 | 2.06 | 5,761 | 0.29 | 5,726 | 0.06 |
| 2010 | 1.73 | 5,452 | 0.29 | 5,365 | 0.06 |
| 2011 | 1.25 | 4,971 | 0.30 | 5,060 | 0.06 |
| 2012 | 2.03 | 4,553 | 0.29 | 4,719 | 0.06 |
| 2013 | 2.24 | 4,279 | 0.31 | 4,104 | 0.07 |
| 2014 | 1.54 | 4,124 | 0.34 | 3,651 | 0.09 |
| 2015 | 2.25 | 4,228 | 0.35 | 3,664 | 0.12 |
| 2016 | 2.22 | 4,914 | 0.36 |  |  |

Table 41. Annual abundance estimates of model recruits (millions of crabs), legal male biomass $(\mathrm{t})$ with coefficient of variations $(\mathrm{CV})$, and mature male biomass ( t ) with CV for scenario 3 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\text {eq }}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | $\begin{aligned} & \text { Recruits to the } \\ & \text { Model ( } \geq 101 \\ & \text { mm CL) } \end{aligned}$ | $\begin{gathered} \text { Mature Male } \\ \text { Biomass } \\ (\geq 121 \mathrm{~mm} \mathrm{CL}) \end{gathered}$ | CV | Legal Male Biomass ( $\geq 136$ mm CL) | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \hline \text { MMBeq }=13,317 \\ \text { MMB35 }=4,724 \end{gathered}$ |  |  |  |
| 1985 | 4.10 |  |  | 8,799 | 0.11 |
| 1986 | 3.69 | 7,104 | 0.31 | 8,359 | 0.08 |
| 1987 | 2.86 | 6,448 | 0.32 | 5,972 | 0.07 |
| 1988 | 1.99 | 5,497 | 0.33 | 5,605 | 0.05 |
| 1989 | 2.72 | 3,915 | 0.34 | 4,964 | 0.04 |
| 1990 | 2.10 | 3,603 | 0.34 | 3,156 | 0.06 |
| 1991 | 1.63 | 3,398 | 0.34 | 2,928 | 0.05 |
| 1992 | 2.15 | 3,600 | 0.33 | 2,909 | 0.05 |
| 1993 | 1.69 | 4,038 | 0.32 | 3,042 | 0.05 |
| 1994 | 2.07 | 3,470 | 0.32 | 3,594 | 0.03 |
| 1995 | 2.00 | 3,433 | 0.33 | 2,905 | 0.04 |
| 1996 | 1.84 | 3,425 | 0.33 | 2,846 | 0.04 |
| 1997 | 1.97 | 3,520 | 0.33 | 2,890 | 0.04 |
| 1998 | 2.02 | 3,807 | 0.32 | 2,977 | 0.04 |
| 1999 | 2.40 | 3,870 | 0.32 | 3,259 | 0.04 |
| 2000 | 2.70 | 4,023 | 0.33 | 3,203 | 0.04 |
| 2001 | 2.77 | 4,417 | 0.33 | 3,231 | 0.05 |
| 2002 | 2.73 | 4,933 | 0.33 | 3,595 | 0.05 |
| 2003 | 1.93 | 5,199 | 0.33 | 4,159 | 0.06 |
| 2004 | 2.48 | 5,454 | 0.31 | 4,693 | 0.06 |
| 2005 | 2.50 | 5,711 | 0.31 | 4,903 | 0.07 |
| 2006 | 2.70 | 6,200 | 0.31 | 5,094 | 0.07 |
| 2007 | 1.88 | 6,287 | 0.31 | 5,539 | 0.07 |
| 2008 | 1.61 | 6,160 | 0.30 | 5,849 | 0.06 |
| 2009 | 2.07 | 5,900 | 0.29 | 5,894 | 0.06 |
| 2010 | 1.75 | 5,577 | 0.29 | 5,509 | 0.06 |
| 2011 | 1.26 | 5,085 | 0.30 | 5,187 | 0.06 |
| 2012 | 2.06 | 4,664 | 0.29 | 4,834 | 0.06 |
| 2013 | 2.27 | 4,391 | 0.31 | 4,211 | 0.07 |
| 2014 | 1.54 | 4,232 | 0.34 | 3,761 | 0.09 |
| 2015 | 2.27 | 4,334 | 0.35 | 3,780 | 0.13 |
| 2016 | 2.21 | 4,993 | 0.36 |  |  |

Table 42. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) CV for scenario 4 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y . Mature male biomass for fishing year y was estimated on February 15 of year $\mathrm{y}+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\mathrm{eq}}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | Recruits to the Model ( $\geq 101$ mm CL) | $\begin{aligned} & \text { Mature Male } \\ & \text { Biomass } \\ & (\geq 121 \mathrm{~mm} \mathrm{CL}) \end{aligned}$ | CV | $\begin{gathered} \text { Legal Male } \\ \text { Biomass }(\geq 136 \\ \text { mm CL) } \end{gathered}$ | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \mathrm{MMB}_{\text {eq }}=12,936 \\ \mathrm{MMB}_{35}=4,659 \end{gathered}$ |  |  |  |
| 1985 | 3.66 |  |  | 9,110 | 0.06 |
| 1986 | 4.83 | 7,086 | 0.30 | 8,597 | 0.05 |
| 1987 | 3.02 | 6,534 | 0.32 | 5,980 | 0.06 |
| 1988 | 2.31 | 5,748 | 0.32 | 5,855 | 0.04 |
| 1989 | 2.36 | 4,079 | 0.32 | 5,401 | 0.04 |
| 1990 | 1.85 | 3,623 | 0.33 | 3,631 | 0.05 |
| 1991 | 1.60 | 3,304 | 0.32 | 3,262 | 0.05 |
| 1992 | 1.90 | 3,357 | 0.31 | 3,022 | 0.05 |
| 1993 | 1.74 | 3,740 | 0.31 | 3,007 | 0.04 |
| 1994 | 1.92 | 3,075 | 0.32 | 3,433 | 0.03 |
| 1995 | 1.81 | 2,958 | 0.33 | 2,675 | 0.04 |
| 1996 | 1.83 | 2,947 | 0.33 | 2,551 | 0.04 |
| 1997 | 1.75 | 3,017 | 0.33 | 2,547 | 0.04 |
| 1998 | 1.85 | 3,274 | 0.32 | 2,650 | 0.04 |
| 1999 | 2.13 | 3,274 | 0.33 | 2,914 | 0.04 |
| 2000 | 2.37 | 3,334 | 0.34 | 2,814 | 0.04 |
| 2001 | 2.51 | 3,639 | 0.34 | 2,783 | 0.05 |
| 2002 | 2.59 | 4,115 | 0.33 | 3,058 | 0.05 |
| 2003 | 1.96 | 4,428 | 0.33 | 3,551 | 0.05 |
| 2004 | 2.31 | 4,721 | 0.32 | 4,082 | 0.06 |
| 2005 | 2.24 | 4,980 | 0.31 | 4,358 | 0.06 |
| 2006 | 2.53 | 5,468 | 0.31 | 4,607 | 0.07 |
| 2007 | 1.85 | 5,600 | 0.31 | 5,048 | 0.06 |
| 2008 | 1.55 | 5,530 | 0.30 | 5,363 | 0.06 |
| 2009 | 1.93 | 5,307 | 0.29 | 5,441 | 0.06 |
| 2010 | 1.73 | 5,042 | 0.29 | 5,091 | 0.06 |
| 2011 | 1.19 | 4,600 | 0.30 | 4,806 | 0.06 |
| 2012 | 1.86 | 4,179 | 0.29 | 4,506 | 0.06 |
| 2013 | 2.15 | 3,902 | 0.31 | 3,901 | 0.06 |
| 2014 | 1.47 | 3,758 | 0.34 | 3,447 | 0.08 |
| 2015 | 2.13 | 3,865 | 0.35 | 3,478 | 0.11 |
| 2016 | 2.12 | 4,576 | 0.35 |  |  |

Table 43. Annual abundance estimates of model recruits (millions of crabs), legal male biomass $(\mathrm{t})$ with coefficient of variations $(\mathrm{CV})$, and mature male biomass ( t ) with CV for scenario 5 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year $\mathrm{y}+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\text {eq }}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | Recruits to the Model ( $\geq 101$ mm CL) | $\begin{aligned} & \text { Mature Male } \\ & \text { Biomass } \\ & (\geq 121 \mathrm{~mm} \mathrm{CL}) \end{aligned}$ | CV | Legal Male Biomass ( $\geq \mathbf{1 3 6}$ mm CL) | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \text { MMBeq }=14,656 \\ \text { MMB35 }=5,146 \end{gathered}$ |  |  |  |
| 1985 | 3.49 |  |  | 8,621 | 0.10 |
| 1986 | 3.28 | 6,634 | 0.30 | 8,131 | 0.08 |
| 1987 | 2.48 | 6,020 | 0.32 | 5,714 | 0.06 |
| 1988 | 1.71 | 5,147 | 0.33 | 5,364 | 0.05 |
| 1989 | 2.32 | 3,602 | 0.33 | 4,774 | 0.04 |
| 1990 | 1.76 | 3,272 | 0.34 | 3,006 | 0.05 |
| 1991 | 1.40 | 3,064 | 0.34 | 2,749 | 0.05 |
| 1992 | 1.87 | 3,255 | 0.33 | 2,690 | 0.05 |
| 1993 | 1.46 | 3,709 | 0.32 | 2,813 | 0.05 |
| 1994 | 1.78 | 3,172 | 0.32 | 3,378 | 0.03 |
| 1995 | 1.72 | 3,137 | 0.33 | 2,728 | 0.03 |
| 1996 | 1.57 | 3,125 | 0.33 | 2,676 | 0.04 |
| 1997 | 1.70 | 3,213 | 0.33 | 2,714 | 0.04 |
| 1998 | 1.74 | 3,495 | 0.32 | 2,792 | 0.04 |
| 1999 | 2.05 | 3,545 | 0.32 | 3,073 | 0.03 |
| 2000 | 2.29 | 3,657 | 0.33 | 3,021 | 0.04 |
| 2001 | 2.33 | 3,988 | 0.33 | 3,029 | 0.04 |
| 2002 | 2.27 | 4,438 | 0.33 | 3,349 | 0.05 |
| 2003 | 1.59 | 4,673 | 0.33 | 3,856 | 0.05 |
| 2004 | 2.03 | 4,884 | 0.31 | 4,337 | 0.05 |
| 2005 | 2.04 | 5,097 | 0.31 | 4,520 | 0.06 |
| 2006 | 2.22 | 5,544 | 0.30 | 4,677 | 0.06 |
| 2007 | 1.54 | 5,642 | 0.31 | 5,087 | 0.06 |
| 2008 | 1.34 | 5,562 | 0.30 | 5,376 | 0.06 |
| 2009 | 1.73 | 5,347 | 0.29 | 5,442 | 0.05 |
| 2010 | 1.45 | 5,070 | 0.29 | 5,108 | 0.05 |
| 2011 | 1.06 | 4,642 | 0.30 | 4,826 | 0.05 |
| 2012 | 1.72 | 4,248 | 0.29 | 4,512 | 0.05 |
| 2013 | 1.85 | 3,952 | 0.31 | 3,934 | 0.06 |
| 2014 | 1.24 | 3,774 | 0.34 | 3,490 | 0.08 |
| 2015 | 1.86 | 3,824 | 0.35 | 3,468 | 0.12 |
| 2016 | 1.79 | 4,547 | 0.35 |  |  |

Table 44. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass (t) with CV for scenario 6 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y . Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\text {eq }}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | Recruits to the Model ( $\geq 101$ mm CL) | $\begin{aligned} & \text { Mature Male } \\ & \text { Biomass } \\ & (\geq 121 \mathrm{~mm} \mathrm{CL}) \end{aligned}$ | CV | Legal Male Biomass ( $\geq \mathbf{1 3 6}$ mm CL) | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \text { MMBeq }=12,419 \\ \text { MMB35 }=4,421 \end{gathered}$ |  |  |  |
| 1985 | 5.01 |  |  | 9,039 | 0.10 |
| 1986 | 4.46 | 7,762 | 0.32 | 8,635 | 0.08 |
| 1987 | 3.40 | 7,075 | 0.33 | 6,284 | 0.07 |
| 1988 | 2.37 | 6,026 | 0.33 | 5,960 | 0.05 |
| 1989 | 3.11 | 4,343 | 0.34 | 5,289 | 0.04 |
| 1990 | 2.51 | 4,002 | 0.34 | 3,422 | 0.06 |
| 1991 | 2.00 | 3,775 | 0.34 | 3,160 | 0.06 |
| 1992 | 2.65 | 4,003 | 0.33 | 3,119 | 0.05 |
| 1993 | 2.07 | 4,448 | 0.32 | 3,248 | 0.05 |
| 1994 | 2.50 | 3,874 | 0.32 | 3,818 | 0.04 |
| 1995 | 2.44 | 3,858 | 0.33 | 3,136 | 0.04 |
| 1996 | 2.24 | 3,866 | 0.33 | 3,093 | 0.04 |
| 1997 | 2.38 | 3,974 | 0.33 | 3,159 | 0.04 |
| 1998 | 2.44 | 4,268 | 0.32 | 3,261 | 0.04 |
| 1999 | 2.92 | 4,354 | 0.32 | 3,544 | 0.04 |
| 2000 | 3.31 | 4,572 | 0.33 | 3,483 | 0.04 |
| 2001 | 3.42 | 5,056 | 0.33 | 3,545 | 0.05 |
| 2002 | 3.39 | 5,659 | 0.33 | 3,977 | 0.06 |
| 2003 | 2.43 | 5,948 | 0.33 | 4,615 | 0.06 |
| 2004 | 3.16 | 6,251 | 0.31 | 5,208 | 0.07 |
| 2005 | 3.20 | 6,562 | 0.31 | 5,432 | 0.07 |
| 2006 | 3.44 | 7,111 | 0.31 | 5,652 | 0.08 |
| 2007 | 2.40 | 7,185 | 0.31 | 6,140 | 0.07 |
| 2008 | 2.04 | 6,990 | 0.31 | 6,486 | 0.07 |
| 2009 | 2.58 | 6,668 | 0.29 | 6,508 | 0.06 |
| 2010 | 2.18 | 6,280 | 0.29 | 6,053 | 0.06 |
| 2011 | 1.58 | 5,698 | 0.30 | 5,679 | 0.06 |
| 2012 | 2.54 | 5,238 | 0.29 | 5,274 | 0.07 |
| 2013 | 2.87 | 4,993 | 0.31 | 4,590 | 0.08 |
| 2014 | 1.96 | 4,846 | 0.34 | 4,127 | 0.10 |
| 2015 | 2.85 | 4,999 | 0.35 | 4,190 | 0.13 |
| 2016 | 2.80 | 5,558 | 0.36 |  |  |

Table 45. Annual abundance estimates of model recruits (millions of crabs), legal male biomass $(\mathrm{t})$ with coefficient of variations $(\mathrm{CV})$, and mature male biomass ( t ) with CV for scenario 9 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\text {eq }}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | $\begin{aligned} & \text { Recruits to the } \\ & \text { Model ( } \geq 101 \\ & \text { mm CL) } \end{aligned}$ | Mature Male Biomass ( $\geq 121 \mathrm{~mm} \mathrm{CL})$ | CV | $\begin{gathered} \text { Legal Male } \\ \text { Biomass }(\geq 136 \\ \text { mm CL) } \end{gathered}$ | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \text { MMBeq }=14,528 \\ \text { MMB35 }=5,137 \end{gathered}$ |  |  |  |
| 1985 | 4.14 |  |  | 8,743 | 0.10 |
| 1986 | 3.74 | 8,346 | 0.05 | 8,312 | 0.08 |
| 1987 | 2.86 | 7,724 | 0.04 | 5,949 | 0.07 |
| 1988 | 1.98 | 6,628 | 0.04 | 5,614 | 0.05 |
| 1989 | 2.64 | 4,607 | 0.05 | 4,990 | 0.04 |
| 1990 | 2.06 | 4,312 | 0.05 | 3,181 | 0.06 |
| 1991 | 1.65 | 4,060 | 0.05 | 2,923 | 0.05 |
| 1992 | 2.19 | 4,177 | 0.04 | 2,873 | 0.05 |
| 1993 | 1.71 | 4,763 | 0.03 | 2,999 | 0.05 |
| 1994 | 2.07 | 4,064 | 0.04 | 3,566 | 0.03 |
| 1995 | 2.01 | 4,067 | 0.04 | 2,901 | 0.04 |
| 1996 | 1.84 | 4,085 | 0.04 | 2,852 | 0.04 |
| 1997 | 1.97 | 4,162 | 0.04 | 2,901 | 0.04 |
| 1998 | 2.02 | 4,487 | 0.04 | 2,989 | 0.04 |
| 1999 | 2.40 | 4,534 | 0.04 | 3,271 | 0.04 |
| 2000 | 2.70 | 4,734 | 0.04 | 3,213 | 0.04 |
| 2001 | 2.77 | 5,233 | 0.05 | 3,243 | 0.04 |
| 2002 | 2.72 | 5,848 | 0.05 | 3,609 | 0.05 |
| 2003 | 1.92 | 6,206 | 0.06 | 4,172 | 0.05 |
| 2004 | 2.48 | 6,323 | 0.06 | 4,703 | 0.06 |
| 2005 | 2.50 | 6,630 | 0.06 | 4,908 | 0.07 |
| 2006 | 2.70 | 7,175 | 0.06 | 5,094 | 0.07 |
| 2007 | 1.88 | 7,370 | 0.06 | 5,537 | 0.07 |
| 2008 | 1.62 | 7,141 | 0.05 | 5,849 | 0.06 |
| 2009 | 2.07 | 6,723 | 0.05 | 5,896 | 0.06 |
| 2010 | 1.75 | 6,420 | 0.05 | 5,512 | 0.06 |
| 2011 | 1.27 | 5,893 | 0.06 | 5,191 | 0.06 |
| 2012 | 2.06 | 5,292 | 0.07 | 4,838 | 0.06 |
| 2013 | 2.26 | 5,061 | 0.09 | 4,215 | 0.07 |
| 2014 | 1.54 | 5,021 | 0.13 | 3,764 | 0.09 |
| 2015 | 2.27 | 5,005 | 0.17 | 3,781 | 0.13 |
| 2016 | 2.21 | 5,814 | 0.19 |  |  |

Table 46. Annual abundance estimates of model recruits (millions of crabs), legal male biomass (t) with coefficient of variations (CV), and mature male biomass ( t ) with CV for scenario 10 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y . Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\text {eq }}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | $\begin{aligned} & \hline \text { Recruits to the } \\ & \text { Model ( } \geq 101 \\ & \text { mm CL) } \end{aligned}$ | $\begin{gathered} \text { Mature Male } \\ \text { Biomass } \\ (\geq 121 \mathrm{~mm} \mathrm{CL}) \end{gathered}$ | CV | Legal Male Biomass ( $\geq 136$ mm CL) | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \text { MMBeq }=13,112 \\ \text { MMB35 }=4.647 \end{gathered}$ |  |  |  |
| 1985 | 4.28 |  |  | 8,780 | 0.10 |
| 1986 | 3.85 | 7,201 | 0.31 | 8,357 | 0.08 |
| 1987 | 2.95 | 6,558 | 0.33 | 6,000 | 0.07 |
| 1988 | 2.04 | 5,598 | 0.33 | 5,668 | 0.05 |
| 1989 | 2.71 | 3,981 | 0.34 | 5,037 | 0.04 |
| 1990 | 2.13 | 3,646 | 0.34 | 3,218 | 0.06 |
| 1991 | 1.70 | 3,428 | 0.34 | 2,960 | 0.05 |
| 1992 | 2.26 | 3,638 | 0.33 | 2,912 | 0.05 |
| 1993 | 1.76 | 4,089 | 0.32 | 3,039 | 0.05 |
| 1994 | 2.14 | 3,531 | 0.32 | 3,606 | 0.03 |
| 1995 | 2.08 | 3,505 | 0.33 | 2,938 | 0.04 |
| 1996 | 1.90 | 3,501 | 0.33 | 2,890 | 0.04 |
| 1997 | 2.03 | 3,600 | 0.33 | 2,941 | 0.04 |
| 1998 | 2.08 | 3,887 | 0.32 | 3,032 | 0.04 |
| 1999 | 2.48 | 3,953 | 0.32 | 3,313 | 0.04 |
| 2000 | 2.79 | 4,117 | 0.33 | 3,255 | 0.04 |
| 2001 | 2.87 | 4,525 | 0.33 | 3,289 | 0.05 |
| 2002 | 2.82 | 5,054 | 0.33 | 3,665 | 0.05 |
| 2003 | 2.00 | 5,320 | 0.33 | 4,241 | 0.06 |
| 2004 | 2.58 | 5,579 | 0.31 | 4,782 | 0.06 |
| 2005 | 2.60 | 5,843 | 0.31 | 4,991 | 0.07 |
| 2006 | 2.81 | 6,342 | 0.31 | 5,182 | 0.07 |
| 2007 | 1.96 | 6,428 | 0.31 | 5,633 | 0.07 |
| 2008 | 1.68 | 6,292 | 0.31 | 5,950 | 0.06 |
| 2009 | 2.15 | 6,022 | 0.29 | 5,993 | 0.06 |
| 2010 | 1.81 | 5,690 | 0.29 | 5,598 | 0.06 |
| 2011 | 1.32 | 5,184 | 0.30 | 5,268 | 0.06 |
| 2012 | 2.13 | 4,756 | 0.29 | 4,907 | 0.06 |
| 2013 | 2.36 | 4,487 | 0.31 | 4,275 | 0.07 |
| 2014 | 1.60 | 4,328 | 0.34 | 3,822 | 0.09 |
| 2015 | 2.36 | 4,438 | 0.35 | 3,847 | 0.13 |
| 2016 | 2.30 | 5,081 | 0.36 |  |  |

Table 47. Annual abundance estimates of model recruits (millions of crabs), legal male biomass $(\mathrm{t})$ with coefficient of variations ( CV ), and mature male biomass ( t ) with CV for scenario 11 for golden king crab in the WAG. Legal male biomass was estimated on July 1 (start of fishing year) of fishing year y. Mature male biomass for fishing year y was estimated on February 15 of year $y+1$, after the year y fishery total catch removal. Recruits estimates for 1961 to 2016 are restricted to 1985-2016. Equilibrium $\mathrm{MMB}_{\text {eq }}$ and $\mathrm{MMB}_{35}$ are also listed.

| Year | $\begin{aligned} & \hline \text { Recruits to the } \\ & \text { Model ( } \geq 101 \\ & \text { mm CL) } \end{aligned}$ | $\begin{gathered} \text { Mature Male } \\ \text { Biomass } \\ (\geq 121 \mathrm{~mm} \mathrm{CL}) \end{gathered}$ | CV | Legal Male Biomass ( $\geq 136$ mm CL) | CV |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | $\begin{gathered} \text { MMBeq }=14,340 \\ \text { MMB35 }=5,099 \end{gathered}$ |  |  |  |
| 1985 | 4.28 |  |  | 8,780 | 0.10 |
| 1986 | 3.85 | 8,472 | 0.05 | 8,357 | 0.08 |
| 1987 | 2.95 | 7,840 | 0.04 | 6,000 | 0.07 |
| 1988 | 2.04 | 6,724 | 0.04 | 5,668 | 0.05 |
| 1989 | 2.71 | 4,685 | 0.05 | 5,037 | 0.04 |
| 1990 | 2.13 | 4,389 | 0.05 | 3,218 | 0.06 |
| 1991 | 1.70 | 4,136 | 0.05 | 2,960 | 0.05 |
| 1992 | 2.26 | 4,255 | 0.04 | 2,912 | 0.05 |
| 1993 | 1.76 | 4,842 | 0.03 | 3,039 | 0.05 |
| 1994 | 2.14 | 4,138 | 0.04 | 3,606 | 0.03 |
| 1995 | 2.08 | 4,143 | 0.04 | 2,938 | 0.04 |
| 1996 | 1.90 | 4,163 | 0.04 | 2,890 | 0.04 |
| 1997 | 2.03 | 4,242 | 0.04 | 2,941 | 0.04 |
| 1998 | 2.08 | 4,568 | 0.04 | 3,032 | 0.04 |
| 1999 | 2.48 | 4,617 | 0.04 | 3,313 | 0.04 |
| 2000 | 2.79 | 4,829 | 0.05 | 3,255 | 0.04 |
| 2001 | 2.87 | 5,345 | 0.05 | 3,289 | 0.05 |
| 2002 | 2.82 | 5,976 | 0.05 | 3,665 | 0.05 |
| 2003 | 2.00 | 6,343 | 0.06 | 4,241 | 0.06 |
| 2004 | 2.58 | 6,465 | 0.06 | 4,782 | 0.06 |
| 2005 | 2.60 | 6,783 | 0.06 | 4,991 | 0.07 |
| 2006 | 2.81 | 7,340 | 0.06 | 5,182 | 0.07 |
| 2007 | 1.96 | 7,535 | 0.06 | 5,633 | 0.07 |
| 2008 | 1.68 | 7,293 | 0.06 | 5,950 | 0.06 |
| 2009 | 2.15 | 6,860 | 0.05 | 5,993 | 0.06 |
| 2010 | 1.81 | 6,547 | 0.06 | 5,598 | 0.06 |
| 2011 | 1.32 | 6,005 | 0.06 | 5,268 | 0.06 |
| 2012 | 2.13 | 5,393 | 0.07 | 4,907 | 0.06 |
| 2013 | 2.36 | 5,168 | 0.10 | 4,275 | 0.07 |
| 2014 | 1.60 | 5,136 | 0.13 | 3,822 | 0.09 |
| 2015 | 2.36 | 5,128 | 0.17 | 3,847 | 0.13 |
| 2016 | 2.30 | 5,922 | 0.20 |  |  |

Table 48. Negative log-likelihood values of the fits for scenarios (Sc) 1 (base), 2 (drops retained catch CPUE), 3 (includes 1991-1994 observer CPUE), 4 (three catchability and total selectivity parameter sets), 5 (low bracketing value of $M$ ), 6 (high bracketing value of $M$ ), 9 (knife-edge maturity), 10 (WAG only data based $M$ ), and 11 (WAG only data based $M$ with knife-edge maturity) for golden king crab in the WAG. Differences in likelihood values are given for scenarios with the same number of data points (base) and free parameters. Likelihood components with zero entry in the entire rows are omitted. Retdcatch $B=$ retained catch biomass.

| Likelihood Component | Sc 1 | Sc 2 | Sc 3 | Sc 4 | Sc 5 | Sc 6 | Sc 9 | Sc 10 | Sc11 | $\begin{aligned} & \hline \text { Sc3- } \\ & \text { Sc } 1 \end{aligned}$ | $\begin{gathered} \hline \text { Sc } 5- \\ \text { Sc } 1 \end{gathered}$ | $\begin{gathered} \hline \text { Sc } 6- \\ \text { Sc } 1 \end{gathered}$ | $\begin{gathered} \text { Sc } 10- \\ \text { Sc } 1 \end{gathered}$ | $\begin{gathered} \text { Sc } 11- \\ \text { Sc } 9 \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Number of free parameters | 139 | 138 | 139 | 142 | 139 | 139 | 137 | 139 | 137 |  |  |  |  |  |
| Data | base | base | base | base | base | base | base | base | base |  |  |  |  |  |
| Retlencomp | -1103.6 | -1106.21 | -1106.66 | -1113.50 | -1102.73 | -1101.23 | -1103.60 | -1103.42 | -1103.42 | -3.06 | 0.87 | 2.37 | 0.18 | 0.18 |
| Totallencomp | -1347.65 | -1342.09 | -1345.97 | -1333.15 | -1349.49 | -1346.04 | -1347.65 | -1347.34 | -1347.34 | 1.68 | -1.84 | 1.61 | 0.31 | 0.31 |
| Observer cpue | -10.48 | -12.22 | -12.22 | -13.04 | -11.09 | -9.71 | -10.48 | -10.36 | -10.36 | -1.74 | -0.61 | 0.77 | 0.12 | 0.12 |
| RetdcatchB | 4.76 | 5.47 | 4.92 | 4.86 | 4.79 | 4.74 | 4.76 | 4.75 | 4.75 | 0.16 | 0.03 | -0.02 | -0.01 | -0.01 |
| TotalcatchB | 43.03 | 43.59 | 43.24 | 34.40 | 43.18 | 42.71 | 43.03 | 42.99 | 42.99 | 0.21 | 0.15 | -0.32 | -0.04 | -0.04 |
| GdiscdcatchB | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Rec_dev | 4.59 | 4.25 | 4.57 | 5.22 | 5.13 | 4.48 | 4.59 | 4.54 | 4.54 | -0.02 | 0.54 | -0.11 | -0.05 | -0.05 |
| Pot F_dev | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Gbyc_F_dev | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tag | 2692.35 | 2692.91 | 2692.40 | 2698.88 | 2692.25 | 2692.23 | 2692.35 | 2692.34 | 2692.34 | 0.05 | -0.1 | -0.12 | -0.01 | -0.01 |
| Fishery cpue | -7.96 | - | -6.43 | -18.11 | -6.63 | -9.29 | -7.96 | -8.20 | -8.20 | 1.53 | 1.33 | -1.33 | -0.24 | -0.24 |
| Maturity | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 | - | 0.17 | - | 0.00 | 0.00 | 0.00 | 0.00 | - |
| Total | 275.26 | 285.93 | 274.08 | 265.78 | 275.65 | 278.13 | 275.10 | 275.54 | 275.37 | -1.18 | 0.39 | 2.87 | 0.28 | 0.27 |

Table 49. Predicted total catch OFL ( t ), $\mathrm{B}_{35 \%}$, and terminal MMB ratio for various scenarios for EAG and WAG, respectively. Sc $=\mathrm{scenario}$; $\mathrm{MMB}_{2015} / \mathrm{MMB}_{\text {initial }}=$ ratio of terminal MMB relative to initial MMB $\left(=\mathrm{MMB}_{1960}\right)$.



Figure 1. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the EAG, 1985/86-2015/16 fisheries (note: 1985 refers to the 1985/86 fishing year).


Figure 2. Historical commercial harvest (from fish tickets; metric tons) and catch-per-unit effort (CPUE, number of crabs per pot lift) of golden king crab in the WAG, 1985/86-2015/16 fisheries (note: 1985 refers to the 1985/86 fishing year).


Figure 3. Catch distribution by statistical area.in 2015/16.


Figure 4. Total and components negative log-likelihoods vs. $M$ for scenario 0a model fit for EAG and WAG combined data. The $M$ estimate was obtained using an $M$ penalty. The $M$ estimate was $0.2225 \mathrm{yr}^{-1}\left( \pm 0.0191 \mathrm{yr}^{-1}\right)$. The negative $\log$ likelihood values were estimated for fixed proportions of estimated $M$ without using an $M$ penalty and they were zero adjusted.


Figure 5. Total and components negative log-likelihoods vs. $M$ for scenario $\mathbf{0 b}$ model fit for EAG and WAG combined data. The $M$ estimate was obtained without using an $M$ penalty. The $M$ estimate was $0.2242 \mathrm{yr}^{-1}\left( \pm 0.0196 \mathrm{yr}^{-1}\right)$. The negative $\log$ likelihood values were estimated for fixed proportions of estimated $M$ without using an $M$ penalty and they were zero adjusted.


Figure 6. Total and components negative log-likelihoods vs. $M$ for scenario 1b model separate fit to EAG data and WAG data. The $M$ estimate was obtained without using an $M$ penalty. The $M$ estimate for EAG was $0.2208 \mathrm{yr}^{-1}\left( \pm 0.0238 \mathrm{yr}^{-1}\right)$ and that for WAG was $0.2308 \mathrm{yr}^{-1}(土$ $0.0350 \mathrm{yr}^{-1}$ ). The negative log likelihood values were estimated for fixed proportions of estimated $M$ without using an $M$ penalty and they were zero adjusted.





Figure 7. Total and components negative log-likelihoods vs. mean $M M B$ for scenario 1 model fit to EAG and WAG data, respectively. The negative log likelihood values were estimated for fixed proportions of the scenario 1 estimate of mean MMB and they were zero adjusted.


Figure 8. Total and components negative log-likelihoods vs. MMB depletion (i.e., $\mathrm{MMB}_{2015} / \mathrm{MMB}_{1960}$ ) for scenario 1 model fit to EAG and WAG data, respectively. The negative log likelihood values were estimated for fixed proportions of the scenario 1 estimate of MMB depletion and they were zero adjusted.


Figure 9. Standard deviation of recruit_dev plot for EAG and WAG. The mean recruit for years with standard deviation less than 0.7 sigma R was used to initialize model. We selected the 1987-2012 period for mean recruit estimation.


Figure 10. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions under scenarios 1 (black line), 2 (orange line), 3 (red line), 4 (blue line), 5 (violet line), 6 (dark green line), 9 (green line), 10 (dark red line), and 11 (dark blue line) for golden king crab in the EAG, 1985/86 to 2015/16. This color scheme is used in all other graphs.


Figure 11. Predicted (line) vs. observed (bar) total catch relative length frequency distributions under scenarios 1 to 11 for golden king crab in the EAG, 1990/91 to 2015/16.


Figure 12. Predicted (line) vs. observed (bar) groundfish (or trawl) discarded bycatch relative length frequency distributions under scenarios 1 to 11 for golden king crab in the EAG, 1989/90 to $2015 / 16$. Note that this data set was not used in the model fitting.


Figure 13. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios 1 to 11 fits to golden king crab data in the EAG.


Figure 14. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 recaptures under scenario 1 for EAG golden king crab.


Figure 15. Estimated number of male recruits (crab size $\geq 101 \mathrm{~mm} \mathrm{CL}$ ) to the assessment model under scenarios (Sc) 1 to 11 for EAG golden king crab data, 1961-2016. Top left: scenarios 1 to 4; top right: scenarios 1,5 , and 6 ; bottom left: scenarios 1 and 9 ; and bottom right: scenarios 1 , 10 , and 11. This grouping scheme was used in a number of subsequent figures. The number of recruits are centralized using (R-mean $R$ )/mean $R$ for comparing different scenarios' results.


Figure 16. Recruit size distribution to the assessment model under scenarios (Sc) 1 to 11 for EAG golden king crab.


Figure 17. Estimated molt probability vs. carapace length of golden king crab for scenarios (Sc) 1 to 11 in the EAG.


Figure 18. Estimated maturity probability vs. carapace length of golden king crab for scenarios (Sc) 1 to 11 in the EAG.



Figure 19. Observed (open circle) vs. predicted (solid line) retained catch (top left in each scenario set), total catch (top right in each scenario set), and groundfish bycatch (bottom left in each scenario set) of golden king crab for scenarios (Sc) 1 to 11, in EAG, 1985-2015.


Figure 20. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios (Sc) 1 to 11 fits in the EAG, 1981-1984. Note: Input retained catches to the model during pre-1985 fishery period were in number of crabs.

EAG Retained Catch Size Composition Standardized Residuals


Figure 21. Bubble plot of standardized residuals of retained catch length composition for scenario 1 fit for EAG golden king crab, 1985/86-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 22 Bubble plot of standardized residuals of total catch length composition for scenario 1 fit for EAG golden king crab, 1990/91-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 23. Bubble plot of standardized residuals of retained catch length composition for scenario 9 fit for EAG golden king crab, 1985/86-2015/16. Blue circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 24. Bubble plot of standardized residuals of total catch length composition for scenario 9 fit for EAG golden king crab, 1990/91-2015/16. Blue circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 25. Retrospective fits of MMB by the model following removal of terminal year data under scenarios (Sc) 1 to 9 for golden king crab in the EAG, 1960-2015.


Figure 26. Comparison of input CPUE indices (open circles with $+/-2$ SE) with predicted CPUE indices (colored solid lines) under scenarios (Sc) 1 to 11 for EAG golden king crab data, 1985/86-2015/16. Model estimated additional standard error was added to each input standard error.


Figure 27. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 1 to 11 model fits in the EAG, 1981-2015.


Figure 28. Trends in golden king crab mature male biomass for scenarios (Sc) 1 to 11 fits in the EAG, 1960/61-2015/16. Scenario 1 estimates have two standard errors confidence limits.


Figure 29. Predicted (line) vs. observed (bar) retained catch relative length frequency distributions under scenarios 1 (black line), 2 (orange line), 3 (red line), 4 (blue line), 5 (violet line), 6 (dark green line), 9 (green line), 10 (dark red line), and 11 (dark blue line) for golden king crab in the WAG, 1985/86 to 2015/16. This color scheme is used in all other graphs.


Figure 30. Predicted (line) vs. observed (bar) total catch relative length frequency distributions under scenarios 1 to 11 for golden king crab in the WAG, 1990/91 to 2015/16.


Figure 31. Predicted (line) vs. observed (bar) groundfish (or trawl) discarded bycatch relative length frequency distributions under scenarios 1 to 11 for golden king crab in the WAG, 1989/90 to $2015 / 16$. Note that this data set was not used in the model fitting.


Figure 32. Estimated total (black solid line) and retained selectivity (red dotted line) for pre- and post- rationalization periods under scenarios 1 to 11 fits to golden king crab data in the WAG.


Figure 33. Observed (open circles) vs. predicted (solid line) tag recaptures by size bin for years 1 to 6 recaptures under scenario 1 for WAG golden king crab.


Figure 34. Estimated number of male recruits (crab size $\geq 101 \mathrm{~mm} \mathrm{CL}$ ) to the assessment model under scenarios (Sc) 1 to 11 for WAG golden king crab data, 1961-2016. Top left: scenarios 1 to 4; top right: scenarios 1,5 , and 6 ; bottom left: scenarios 1 and 9 ; and bottom right: scenarios 1 , 10, and 11.The number of recruits are centralized using ( $\mathrm{R}-$ mean R )/mean R for comparing different scenarios' results.


Figure 35. Recruit size distribution to the assessment model under scenarios (Sc) 1 to 11 for WAG golden king crab.


Figure 36. Estimated molt probability vs. carapace length of golden king crab for scenarios (Sc) 1 to 11 in the WAG.


Figure 37. Estimated maturity probability vs. carapace length of golden king crab for scenarios (Sc) 1 to 11 in the WAG.



Figure 38. Observed (open circle) vs. predicted (solid line) retained catch (top left in each scenario set), total catch (top right in each scenario set), and groundfish bycatch (bottom left in each scenario set) of golden king crab for scenarios (Sc) 1 to 11, in WAG, 1985-2015.


Figure 39. Observed (open circle) vs. predicted (solid line) retained catch of golden king crab for scenarios (Sc) 1 to 11 fits in the WAG, 1981-1984. Note: Input retained catches to the model during pre-1985 fishery period were in number of crabs.


Figure 40. Bubble plot of standardized residuals of retained catch length composition for scenario 1 fit for WAG golden king crab, 1985/86-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 41. Bubble plot of standardized residuals of total catch length composition for scenario 1 fit for WAG golden king crab, 1990/91-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 42. Bubble plot of standardized residuals of retained catch length composition for scenario 9 fit for WAG golden king crab, 1985/86-2015/16. Blue circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the
residual.


Figure 43. Bubble plot of standardized residuals of total catch length composition for scenario 9 fit for WAG golden king crab, 1990/91-2015/16. Blue circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 44. Retrospective fits of MMB by the model following removal of terminal year data under scenarios (Sc) 1 to 9 for golden king crab in the WAG, 1960-2015.


Figure 45. Comparison of input CPUE indices (open circles with $+/-2$ SE) with predicted CPUE indices (colored solid lines) under scenarios (Sc) 1 to 11 for WAG golden king crab data, 1985/86-2015/16. Model estimated additional standard error was added to each input standard error.


Figure 46. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 1 to 11 model fits in the WAG, 1981-2015.


Figure 47. Trends in golden king crab mature male biomass for scenarios (Sc) 1 to 11 fits in the WAG, 1960/61-2015/16. Scenario 1 estimates have two standard errors confidence limits.


Figure 48. Relationships between full fishing mortalities for the directed pot fishery and mature male biomass on Feb. 15 during 1985-2015 under scenarios 1 and 9 for EAG and WAG. Average of recruitment from 1987 to 2012 was used to estimate $\mathrm{B}_{35 \%}$. Pot and groundfish handling mortality rates were assumed to be 0.2 and 0.65 , respectively.

EAG Retained Catch Size Composition Standardized Residuals


Figure 49. Bubble plot of standardized residuals of retained catch length composition for scenario 2 fit for EAG golden king crab, 1985/86-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 50. Bubble plot of standardized residuals of total catch length composition for scenario 2 fit for EAG golden king crab, 1990/91-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

EAG Retained Catch Size Composition Standardized Residuals


Figure 51. Bubble plot of standardized residuals of retained catch length composition for scenario 3 fit for EAG golden king crab, 1985/86-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 52. Bubble plot of standardized residuals of total catch length composition for scenario 3 fit for EAG golden king crab, 1990/91-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

EAG Retained Catch Size Composition Standardized Residuals


Figure 53. Bubble plot of standardized residuals of retained catch length composition for scenario 4 fit for EAG golden king crab, 1985/86-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 54. Bubble plot of standardized residuals of total catch length composition for scenario 4 fit for EAG golden king crab, 1990/91-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

EAG Retained Catch Size Composition Standardized Residuals


Figure 55. Bubble plot of standardized residuals of retained catch length composition for scenario 11 fit for EAG golden king crab, 1985/86-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 56. Bubble plot of standardized residuals of total catch length composition for scenario 11 fit for EAG golden king crab, 1990/91-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

WAG Retained Catch Size Composition Standardized Residuals


Figure 57. Bubble plot of standardized residuals of retained catch length composition for scenario 2 fit for WAG golden king crab, 1985/86-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 58. Bubble plot of standardized residuals of total catch length composition for scenario 2 fit for WAG golden king crab, 1990/91-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

WAG Retained Catch Size Composition Standardized Residuals


Figure 59. Bubble plot of standardized residuals of retained catch length composition for scenario 3 fit for WAG golden king crab, 1985/86-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 60. Bubble plot of standardized residuals of total catch length composition for scenario 3 fit for WAG golden king crab, 1990/91-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

WAG Retained Catch Size Composition Standardized Residuals


Figure 61. Bubble plot of standardized residuals of retained catch length composition for scenario 4 fit for WAG golden king crab, 1985/86-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 62. Bubble plot of standardized residuals of total catch length composition for scenario 4 fit for WAG golden king crab, 1990/91-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

WAG Retained Catch Size Composition Standardized Residuals


Figure 63. Bubble plot of standardized residuals of retained catch length composition for scenario 11 fit for WAG golden king crab, 1985/86-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.


Figure 64. Bubble plot of standardized residuals of total catch length composition for scenario 11 fit for WAG golden king crab, 1990/91-2015/16. Green circles are the positive and pink circles are the negative standardized residuals. The area of the circle is the relative magnitude of the residual.

## Appendix A: Integrated model

Aleutian Islands Golden King Crab (Lithodes aequispinus) Stock Assessment Model
Development- East of $174^{\circ} \mathrm{W}$ (EAG) and west of $174^{\circ} \mathrm{W}$ (WAG) Aleutian Island stocks

## Basic population dynamics

The annual [male] abundances by size are modeled using the equation:

$$
\begin{equation*}
N_{t+1, j}=\sum_{i=1}^{j}\left[N_{t, i} e^{-M}-\left(\hat{C}_{t, i}+\widehat{D}_{t, i}+\widehat{\operatorname{Tr}}_{t, i}\right) e^{\left(y_{t}-1\right) M}\right] X_{i, j}+R_{t+1, j} \tag{A.1}
\end{equation*}
$$

where $N_{t, i}$ is the number of [male] crab in length class $i$ on 1 July (start of fishing year) of year $t ; \hat{C}_{t, i}, \hat{D}_{t, i}$, and $\widehat{T} r_{t, i}$ are respectively the predicted fishery retained, pot fishery discard dead, and groundfish fishery discard dead catches in length class $i$ during year $t$; $\widehat{D}_{t, i}$ is estimated from the intermediate total ( $\widehat{T}_{t, i}$ temp $)$ catch and the retained ( $\hat{C}_{t, i}$ ) catch by Equation A.2c. $X_{i, j}$ is the probability of length-class $i$ growing into length-class $j$ during the year; $y_{t}$ is elapsed time period from 1 July to the mid -point of fishing period in year $t ; M$ is instantaneous rate of natural mortality; and $R_{t+1, j}$ recruitment to length class $j$ in year $t+1$.

The catches are predicted using the equations

$$
\begin{align*}
& \widehat{T}_{t, j, t e m p}=\frac{F_{t} s_{t, j}^{T}}{z_{t, j}} N_{t, j} e^{-y_{t} M}\left(1-e^{-Z_{t, j}}\right)  \tag{A.2a}\\
& \hat{C}_{t, j}=\frac{F_{t} s_{t, j}^{T} s_{t, j}^{r}}{z_{t, j}} N_{t, j} e^{-y_{t} M}\left(1-e^{-Z_{t, j}}\right)  \tag{A.2b}\\
& \widehat{D}_{t, j}=0.2\left(\hat{T}_{t, j, t e m p}-\hat{C}_{t, j}\right)  \tag{A.2c}\\
& \widehat{\operatorname{Tr}}_{t, j}=0.65 \frac{F_{t}^{T r} s_{j}^{T r}}{z_{t, j}} N_{t, j} e^{-y_{t} M}\left(1-e^{-Z_{t, j}}\right)  \tag{A.2d}\\
& \widehat{T}_{t, j}=\hat{C}_{t, j}+\widehat{D}_{t, j} \tag{A.2e}
\end{align*}
$$

where $Z_{t, j}$ is total fishery-related mortality on animals in length-class $j$ during year $t$ :

$$
\begin{equation*}
Z_{t, j}=F_{t} s_{t, j}^{T} s_{t, j}^{r}+0.2 F_{t} s_{t, j}^{T}\left(1-s_{t, j}^{r}\right)+0.65 F_{t}^{T r} s_{j}^{T r} \tag{A.3}
\end{equation*}
$$

$F_{t}$ is the full selection fishing mortality in the pot fishery, $F_{t}^{T r}$ is the full selection fishing mortality in the trawl fishery, $s_{t, j}^{T}$ is the total selectivity for animals in length-class $j$ by the pot fishery during year $t, s_{j}^{T r}$ is the selectivity for animals in length-class $j$ by the trawl
fishery, $s_{t, j}^{r}$ is the probability of retention for animals in length-class $j$ by the pot fishery during year t . Pot bycatch mortality of 0.2 and groundfish bycatch mortality of 0.65 (average of trawl ( 0.8 ) and fish pot ( 0.5 ) mortality) were assumed.

The initial conditions are computed as the equilibrium initial condition using the following relations:

The equilibrium stock abundance is
$\underline{\mathrm{N}}=\mathbf{X} . \mathbf{S} \cdot \underline{\mathrm{N}}+\underline{\mathrm{R}}$
The equilibrium abundance in $1960, \underline{\mathbf{N}}_{1960}$, is
$\underline{N}_{1960}=(\mathbf{I}-\mathbf{X S})^{-1} \underline{R}$
where $\mathbf{X}$ is the growth matrix, $\mathbf{S}$ is a matrix with diagonal elements given by $e^{-M}, \mathbf{I}$ is the identity matrix, and $\underline{R}$ is the product of average recruitment and relative proportion of total recruitment to each size-class.

We used the mean number of recruits from 1987 to 2012 in equation (A.5) to obtain the equilibrium solution under only natural mortality in year 1960, and then projected the equilibrium abundance under natural mortality with recruitment estimated for each year after 1960 up to 1985 with removal of retained catches during 1981/82 to 1984/85.

## Growth Matrix

The growth matrix $\mathbf{X}$ is modeled as follows:

$$
X_{i, j}= \begin{cases}0 & \text { if } j<i  \tag{A.6}\\ P_{i, j}+\left(1-m_{i}\right) & \text { if } j=i \\ P_{i, j} & \text { if } j>i\end{cases}
$$

where:

$$
P_{i, j}=m_{i}\left\{\begin{array}{lr}
\int_{-\infty}^{j_{2}-L_{i}} N\left(x \mid \mu_{i}, \sigma^{2}\right) d x & \text { if } j=i \\
\int_{j_{1}-L_{i}}^{j_{2}-L_{i}} N\left(x \mid \mu_{i}, \sigma^{2}\right) d x & \text { if } i<j<n, \\
\int_{j_{1}-L_{i}}^{\infty} N\left(x \mid \mu_{i}, \sigma^{2}\right) d x & \text { if } i=n
\end{array}\right.
$$

$$
N\left(x \mid \mu_{i}, \sigma^{2}\right)=\frac{1}{\sqrt{2 \pi \sigma^{2}}} e^{-\left(\frac{x-\mu_{i}}{\sqrt{2} \sigma}\right)^{2}}, \text { and }
$$

$\mu_{\mathrm{i}}$ is the mean growth increment for crabs in size-class $i$ :
$\mu_{\mathrm{i}}=\omega_{1}+\omega_{2} * \bar{L}_{\mathrm{i}}$.
$\omega_{1} \quad, \omega_{2}, \quad$ and $\sigma$ are estimable parameters, and $j_{1}$ and $j_{2}$ are the lower and upper limits of the receiving length-class $j$ (in mm CL ), and $\bar{L}_{\mathrm{i}}$ is the mid-point of the contributing length interval $i$. The quantity $m_{i}$ is the molt probability for size-class $i$ :
$\mathrm{m}_{\mathrm{i}}=\frac{1}{1+\mathrm{e}^{\mathrm{c}\left(\tau_{\mathrm{i}}-\mathrm{d}\right)}}$
where $c$ and $d$ are parameters.

## Selectivity and retention

a) Selectivity and retention are both assumed to be logistic functions of length. Selectivity depends on the fishing period for the pot fishery:
$S_{i}=\frac{1}{1+e^{\left[-\ln (19) \frac{\tau_{i}-\theta_{50}}{\theta_{95}-\theta_{50}}\right]}}$
where $\theta_{95}$ and $\theta_{50}$ are the parameters of the selectivity/ retention pattern (Mark Maunder, unpublished generic crab model). In the program, we re-parameterized the denominator $\left(\theta_{95}-\theta_{50}\right)$ to $\log ($ delta $\theta)$ so that the difference is always positive.

## Maturity

Maturity is assumed to be a logistic function of length formulated similar to Eq (A.9),

$$
\begin{equation*}
M a t_{i}=\frac{1}{1+e^{\left[-\ln (19) \frac{\tau_{i}-m a t_{50}}{\text { mat }_{95}-\text { mat }_{50}}\right]}} \tag{A.10}
\end{equation*}
$$

where $\operatorname{mat}_{95}$ and mat $_{50}$ are the parameters of the maturity curve. In the program, we reparameterized the denominator $\left(\operatorname{mat}_{95}-\operatorname{mat}_{50}\right)$ to $\log ($ delta_mat ) so that the difference is always positive.

## Recruitment

Recruitment to length-class $i$ during year $t$ is modeled as $R_{t, i}=\bar{R} e^{\epsilon_{i}} \Omega_{i}$ where $\Omega_{i}$ is a normalized gamma function
$\operatorname{gamma}\left(x \mid \alpha_{r}, \beta_{r}\right)=\frac{x^{\alpha_{r}-1} e^{\frac{x}{\beta_{r}}}}{\beta_{r}^{\alpha_{r}} \Gamma_{\left(\alpha_{r}\right)}}$
with $\alpha_{r}$ and $\beta_{r}$ (restricted to the first six length classes).

## Parameter estimation

Table A1 lists the parameters of the model indicating which are estimated and which are pre-specified. The objective function includes contributions related to the fit of the model to the available data and penalties (priors on the various parameters).

Tables A2 lists parameter values (with the corresponding coefficient of variations in parentheses) used to weight the components of the objective functions for EAG and WAG.

## Likelihood components

## Catches

The contribution of the catch data (retained, total, and groundfish discarded) to the objective function is given by:

$$
\begin{align*}
& L L_{r}^{\text {catch }}=\lambda_{r} \sum_{t}\left\{\ell \operatorname{n}\left(\sum_{j} \hat{C}_{t, j} w_{j}+c\right)-\ln \left(\sum_{j} C_{t, j} w_{j}+c\right)\right\}^{2}  \tag{A.12a}\\
& L L_{T}^{\text {catch }}=\lambda_{T} \sum_{t}\left\{\ln \left(\sum_{j} \hat{T}_{t, j} w_{j}+c\right)-\ln \left(\sum_{j} T_{t, j} w_{j}+c\right)\right\}^{2}  \tag{A.12b}\\
& L L_{G D}^{\text {catch }}=\lambda_{G D} \sum_{t}\left\{\ln \left(\sum_{j} \widehat{T r}_{t, j} w_{j}+c\right)-\ln \left(\sum_{j} T r_{t, j} w_{j}+c\right)\right\}^{2} \tag{A.12c}
\end{align*}
$$

where $\lambda_{r}, \lambda_{T}$, and $\lambda_{G D}$ are weights assigned to likelihood components for the retained, pot total, and groundfish discard catches; $w_{j}$ is the average mass of a crab is length-class $j$; $C_{t, j}, T_{t, j}$, and $T r_{t, j}$ are, respectively, the observed numbers of crab in size class $j$ for retained, pot total, and groundfish fishery discarded crab during year $t$, and $c$ is a small constant value. We assumed $c=0.001$.
An additional retained catch likelihood (using Equation A.12a without w) for the retained catch in number of crabs during 1981/82 to 1984/85 was also considered in all scenarios.

## Catch-rate indices

The catch-rate indices are assumed to be lognormally distributed about the model prediction. Account is taken of variation in addition to that related to sampling variation:

$$
\begin{equation*}
L L_{r}^{C P U E}=\lambda_{r, C P U E}\left\{0.5 \sum_{t} \ln \left[2 \pi\left(\sigma_{r, t}^{2}+\sigma_{e}^{2}\right)\right]+\sum_{t} \frac{\left(\ln \left(C P U E_{t}^{r}+c\right)-\ln \left(C \widehat{P U E}_{t}^{r}+c\right)\right)^{2}}{2\left(\sigma_{r, t}^{2}+\sigma_{e}^{2}\right)}\right\} \tag{A.13}
\end{equation*}
$$

where $C P U E_{t}^{r}$ is the standardized retain catch-rate index for year $t, \sigma_{r, t}$ is standard error of the logarithm of $C P U E_{t}^{r}$, and $C \widehat{P U E}_{t}^{r}$ is the model-estimate of $C P U E_{t}^{r}$ :

$$
\begin{equation*}
\widehat{C P U E}{ }_{t}^{r}=q_{k} \sum_{j} S_{j}^{T} S_{j}^{r}\left(N_{t, j}-0.5\left[\widehat{C_{t, j}}+\widehat{D_{t, j}}+\widehat{T r_{t, j}}\right]\right) e^{-y_{t} M} \tag{A.14}
\end{equation*}
$$

in which $q_{k}$ is the catchability coefficient during the $k$-th time period (e.g., pre- and postrationalization time periods), $\sigma_{e}$ is the extent of over-dispersion, $c$ is a small constant to prevent zero values (we assumed $\mathrm{c}=0.001$ ), and $\lambda_{r, C P U E}$ is the weight assigned to the catch-rate data. We used the same likelihood formula (A.14) for fish ticket retained catch rate indices for scenario 3 model.

Following Burnham et al. (1987), we computed the $\ln (C P U E)$ variance by:
$\sigma_{r, t}^{2}=\ln \left(1+C V_{r, t}^{2}\right)$

## Length-composition data

The length-composition data are included in the likelihood function using the robust normal for proportions likelihood, i.e., generically:
$L L_{r}^{L F}=0.5 \sum_{t} \sum_{j} \ln \left(2 \pi \sigma_{t, j}^{2}\right)-\sum_{t} \sum_{j} \ln \left[\exp \left(-\frac{\left(P_{t, j}-\hat{P}_{t, j}\right)^{2}}{2 \sigma_{t, j}^{2}}\right)+0.01\right]$
where $P_{t, j}$ is the observed proportion of crabs in length-class $j$ in the catch during year $t$, $\hat{P}_{t, j}$ is the model-estimate corresponding to $P_{t, j}$, i.e.:

$$
\begin{gather*}
\hat{L}_{t, j}^{r}=\frac{\hat{C}_{t, j}}{\sum_{j}^{n} \hat{C}_{t, j}} \\
\hat{L}_{t, j}^{T}=\frac{\widehat{T}_{t, j}}{\sum_{j}^{n} \hat{T}_{t, j}} \\
\hat{L}_{t, j}^{G F}=\frac{\widehat{T r}_{t, j}}{\sum_{j}^{n} \widehat{T r}_{t, j}} \tag{A.17}
\end{gather*}
$$

$\sigma_{t, j}^{2}$ is the variance of $P_{t, j}$ :

$$
\begin{equation*}
\sigma_{t, j}^{2}=\left[\left(1-P_{t, j}\right) P_{t, j}+\frac{0.1}{n}\right] / S_{t} \tag{A.18}
\end{equation*}
$$

and $S_{t}$ is the effective sample size for year $t$ and $n$ is the number of size classes.

Note: The likelihood calculation for retained length composition starts from length-class 6 (mid length 128 mm CL ) because the length-classes 1 to 5 mostly contain zero data.

## Tagging data

Let $V_{j, t, y}$ be the number of males that were released in year $t$ that were in length-class $j$ when they were released and were recaptured after $y$ years, and $\underline{\tilde{V}}_{j, t, y}$ be the vector of recaptures by length-class from the males that were released in year $t$ that were in lengthclass $j$ when they were released and were recaptured after $y$ years. The multinomial likelihood of the tagging data is then:

$$
\begin{equation*}
\ln L=\lambda_{y, t a g} \sum_{j} \sum_{t} \sum_{y} \sum_{i} \rho_{j, t, y, i} \ln \hat{\rho}_{j, t, y, i} \tag{A.19}
\end{equation*}
$$

where $\lambda_{y, \operatorname{tag}}$ is the weight assigned to the tagging data for recapture year $y, \hat{\rho}_{j, t, y, i}$ is the proportion in length-class $i$ of the recaptures of males which were released during year $t$ that were in length-class $j$ when they were released and were recaptured after $y$ years:

$$
\begin{equation*}
\underline{\hat{p}}_{j, t, y} \propto \underline{s}^{T}[\mathbf{X}]^{y} \underline{\Omega}^{(j)} \tag{A.20}
\end{equation*}
$$

where $\underline{\Omega}^{(j)}$ is a vector with $V_{j, t, y}$ at element $j$ and 0 otherwise, $\mathbf{X}$ is the growth matrix, and $s^{T}$ is the total selectivity vector (Punt et al. 1997).

This likelihood function is predicted on the assumption that all recaptures are in the pot fishery and the reporting rate is independent of the size of crab. The expected number of recaptures in length-class $l$ is given by:

$$
\begin{equation*}
r_{l}=\sum_{t} \sum_{j} \frac{s_{l}\left[\mathbf{X}^{t}\right]_{j, l}}{\sum_{l^{\prime}} s_{l}\left[\mathbf{X}^{t}\right]_{j, l^{\prime}}} \sum_{k} V_{j, k, t} \tag{A.21}
\end{equation*}
$$

The last term, $\sum_{k} V_{j, k, t}$, is the number of recaptured male crab that were released in
length-class $j$ after t time-steps. The term $\sum_{j} \frac{s_{l}\left[\mathbf{X}^{t}\right]_{j, l}}{\sum_{l^{\prime}} s_{l^{\prime}}\left[\mathbf{X}^{t}\right]_{j, l^{\prime}}} \sum_{k} V_{j, k, t}$ is the predicted number of animals recaptured in length-class $l$ that were at liberty for t time-steps.

Maturity proportion likelihood
$L L_{\text {maturity }}=\lambda_{\text {maturity }} \sum_{j}\left(\hat{P}_{j}-P_{j}\right)^{2}$
where $\lambda_{\text {msturity }}$ is the weight assigned to the maturity likelihood component; $P_{j}$ and $\hat{P}_{j}$ are the observed and expected maturity proportions respectively of male crab in size class $j$. We assumed $\lambda_{\text {maturity }}=1.0$.

## Penalties

Penalties are imposed on the deviations of annual pot fishing mortality about mean pot fishing mortality, annual trawl fishing mortality about mean trawl fishing mortality, recruitment about mean recruitment, and the posfunction (fpen):

$$
\begin{align*}
P_{1} & =\lambda_{F} \sum_{t}\left(\ell \mathrm{n} F_{t}-\ell \mathrm{n} \bar{F}\right)^{2}  \tag{A.23}\\
P_{2} & =\lambda_{F^{T r}} \sum_{t}\left(\ell \mathrm{n} F_{t}^{T r}-\ell \mathrm{n} \bar{F}^{T r}\right)^{2}  \tag{A.24}\\
P_{3} & =\lambda_{R} \sum_{t}\left(\ell \mathrm{n} \varepsilon_{t}\right)^{2}  \tag{A.25}\\
P_{5} & =\lambda_{\text {posfn }} * \text { fpen } \tag{A.26}
\end{align*}
$$

## Standardized Residual of Length Composition

$$
\begin{equation*}
\text { Std. } \text { Res }_{t, j}=\frac{P_{t, j}-\stackrel{-\mathscr{P}_{t, j}}{ }}{\sqrt{2 \sigma_{t, j}^{2}}} \tag{A.27}
\end{equation*}
$$

## Output Quantities

Harvest rate

Total pot fishery harvest rate:

$$
\begin{equation*}
\mathrm{E}_{\mathrm{t}}=\frac{\sum_{\mathrm{j}=1}^{\mathrm{n}}\left(\widehat{\mathrm{C}}_{\mathrm{j}, \mathrm{t}}+\widehat{\mathrm{D}}_{\mathrm{j}, \mathrm{t}}\right)}{\sum_{\mathrm{j}=1} \mathrm{~N}_{\mathrm{j}, \mathrm{t}}} \tag{A.28}
\end{equation*}
$$

Exploited legal male biomass at the start of year t :
$L M B_{t}=\sum_{j=\text { legal size }}^{n} s_{j}^{T} s_{j}^{r} N_{j, t} w_{j}$
where $w_{j}$ is the weight of an animal in length-class j .
Mature male biomass on 15 February spawning time (NPFMC 2007) in the following year:

MMB $_{\mathrm{t}}=\sum_{\mathrm{j}=\text { mature size }}^{\mathrm{n}}\left\{\mathrm{N}_{\mathrm{j}, \mathrm{t}} \mathrm{e}^{-\mathrm{y}^{\prime} \mathrm{M}}-\left(\widehat{\mathrm{C}}_{\mathrm{j}, \mathrm{t}}+\widehat{\mathrm{D}}_{\mathrm{j}, \mathrm{t}}+\widehat{\operatorname{Tr}}_{\mathrm{j}, \mathrm{t}}\right) \mathrm{e}^{\left(\mathrm{yt}_{\mathrm{t}}-\mathrm{y}\right) \mathrm{M}}\right\} \mathrm{w}_{\mathrm{j}}$
where $y^{\prime}$ is the elapsed time from 1 July to 15 February in the following year.
For estimating the next year limit harvest levels from current year stock abundances, a $\mathrm{F}_{\text {OFL }}$ value is needed. Current crab management plan specifies five different Tier formulas for different stocks depending on the strength of information available for a stock, for computing $\mathrm{F}_{\mathrm{OFL}}$ (NPFMC 2007). For the golden king crab, the following Tier 3 formula is applied to compute $\mathrm{F}_{\mathrm{OFL}}$ :

If,
$\mathrm{MMB}_{\text {current }}>\mathrm{B}_{35 \%}, \mathrm{~F}_{\text {OFL }}=\mathrm{F}_{35 \%}$

$$
\begin{aligned}
& \text { If, } \\
& \mathrm{MMB}_{\text {current }} \leq \mathrm{B}_{35 \%} \text { and } \mathrm{MMB}_{\text {current }}>0.25 \mathrm{~B}_{35 \%}, \\
& \mathrm{~F}_{\mathrm{OFL}}=\mathrm{F}_{35 \%} \frac{\left(\frac{\mathrm{MMB}_{\text {current }}}{\mathrm{B}_{35 \%}}=\alpha\right)}{(1-\alpha)} \\
& \text { If, } \\
& \mathrm{MMB}_{\text {current }} \leq 0.25 \mathrm{~B}_{35 \%} \\
& \mathrm{~F}_{\mathrm{OFL}}=0
\end{aligned}
$$

where $\alpha$ is a parameter, $\mathrm{MMB}_{\text {current }}$ is the mature male biomass in the current year and $\mathrm{B}_{35 \%}$ is the proxy $\mathrm{MMB}_{\mathrm{MSY}}$ for Tier 3 stocks. We assumed $\alpha=0.1$.

Because projected $\mathrm{MMB}_{\mathrm{t}}$ (i.e., $\mathrm{MMB}_{\text {current }}$ ) depends on the intervening retained and discard catch (i.e., $M M B_{t}$ is estimated after the fishery), an iterative procedure is applied using Equations A. 30 and A. 31 with retained and discard catch predicted from Equations A.2b-d. The next year limit harvest catch is estimated using Equations A.2b-d with the estimated $\mathrm{F}_{\mathrm{OFL}}$ value.

## Additional Penalty Functions for Profiles

$M$ estimation:

We used the following penalty function (P6) to estimate $M$ for scenario 0a :
$\mathrm{P}_{6}=\frac{0.5}{\ln \left(1+\mathrm{CV}^{2}\right)}\left[(\ln (\mathrm{M})-\ln (0.18))^{2}\right]$
where a CV of $50 \%$ is assigned to the penalty and $0.18 \mathrm{yr}^{-1}$ is the $M$ value used for king crab stock assessments.
For $M$ profile investigation, we disregarded the $M$ penalty and estimated total and component negative log likelihood values at fixed input $M$ values varied by $\pm 0.30$ proportion of the base scenario estimate.

Mean MMB profile:
If the current_phase $=1$,

$$
P_{7}=a 1\left(\text { meanMMB }- \text { meanMMB }^{\text {input }}\right)^{2}
$$

If the current_phase > 1 and the current_phase <= selectivity_phase,

$$
\begin{equation*}
P_{7}=\mathrm{a} 2\left(\text { meanMMB }- \text { meanMMB }^{\text {input }}\right)^{2} \tag{A.33}
\end{equation*}
$$

If the current_phase > selectivity_phase,

$$
P_{7}=\mathrm{a} 3\left(\text { meanMMB }- \text { meanMMB }^{\text {input }}\right)^{2}
$$

where a1, a2, and a3 are weights 0.05 (for EAG) or 0.01 (for WAG), 0.25 (for EAG) or 0.02 (for WAG), and 1.5 (for EAG) or 0.025 (for WAG), respectively. The superscript 'input" refers to a fixed input value. The fixed input values were varied by $\pm 0.25$ proportion of the scenario 1 estimate.

MMB depletion rate profile:
If the current_phase $=1$,

$$
\mathrm{P}_{8}=\mathrm{b} 1\left(\mathrm{MMB}_{\text {depletion }}-\mathrm{MMB}_{\text {depletion }}^{\text {input }}\right)^{2}
$$

If the current_phase > 1 and the current_phase <= selectivity_phase,

$$
\begin{equation*}
\mathrm{P}_{8}=\mathrm{b} 2\left(\mathrm{MMB}_{\text {depletion }}-\mathrm{MMB}_{\text {depletion }}^{\text {input }}\right)^{2} \tag{A.34}
\end{equation*}
$$

If the current_phase > selectivity_phase,

$$
\mathrm{P}_{8}=\mathrm{b} 3\left(\mathrm{MMB}_{\text {depletion }}-\mathrm{MMB}_{\text {depletion }}^{\text {input }}\right)^{2}
$$

Where b1, b2, and b3 are weights $0.05,0.25$, and 15,000 , respectively. The superscript 'input" refers to a fixed input value. $\mathrm{MMB}_{\text {depletion }}=\frac{\mathrm{MMB}_{2015}}{\mathrm{MMB}_{1960}}$. The fixed input values were varied by $\pm 0.25$ proportion of the scenario 1 estimate.

Table A1. Pre-specified and estimated parameters of the population dynamics model

| Parameter | Number of parameters |
| :---: | :---: |
| Initial conditions: |  |
| Length specific equilibrium abundance, $N_{1960, l}$ | 17 (estimated) |
| Fishing mortalities: |  |
| Pot fishery, $F_{t}$ | 1985-2015 (estimated) |
| Mean pot fishery fishing mortality, $\bar{F}$ | 1 (estimated) |
| Groundfish fishery, $F_{t}{ }^{T r}$ | 1989-2015 (the mean F for 1989 to 1994 was used to estimate trawl discards back to 1985 (estimated) |
| Mean groundfish fishery fishing mortality, $\bar{F}^{T r}$ | 1 (estimated) |
| Selectivity and retention: |  |
| Pot fishery total selectivity, $\theta_{50}^{T}$ | 2 or 3 (1985-2004; 2005+) (estimated) |
| Pot fishery total selectivity difference, delta $\theta^{T}$ | 2 or 3 (1985-2004; 2005+) (estimated) |
| Pot fishery retention, $\theta_{50}^{r}$ | 1 (1985+) (estimated) |
| Pot fishery retention selectivity difference, delta $\theta^{r}$ | 1 (1985+) (estimated) |
| Groundfish fishery selectivity | fixed at 1 for all size-classes |
| Maturity: |  |
| maturity, mat ${ }_{50}$ | 1 (estimated) |
| maturity difference, delta_mat | 1 (estimated) |
| Growth: |  |
| Expected growth increment, $\omega_{1}, \omega_{2}$ | 2 (estimated) |
| Variability in growth increment, $\sigma$ | 1 (estimated) |
| Molt probability (size transition matrix with tag data), $a$ | 1 (estimated) |
| Molt probability (size transition matrix with tag data), $b$ | 1 (estimated) |
| Natural mortality, M | 1 (pre-specified, $0.224 \mathrm{yr}^{-1}$ ) |
| Recruitment: |  |
| Number of recruiting length-classes | 5 (pre-specified) |
| Mean recruit length | 1 (pre-specified, 110 mmCL ) |
| Distribution to length-class, $\beta_{r}$ | 1 (estimated) |
| Median recruitment, $\bar{R}$ | 1 (estimated) |
| Recruitment deviations, $\varepsilon_{t}$ | 56 (1961-2016) (estimated) |
| Fishery catchability, $q$ | 2 (1985-2004; 2005+) or 3 (19851994; 1995-2004; 2005+) (estimated) |
| Additional CPUE indices standard deviation, $\sigma_{e}$ | 1 (estimated) |
| Likelihood weights (coefficient of variation) | Pre-specified, varies by scenario |

Table A2. Specifications for the weights with corresponding coefficient of variations* in parentheses for each scenario for EAG and WAG. select. phase $=$ selectivity phase.

| Weight | Value |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 | Scenario 7 |
| Catch: |  |  |  |  |  |  |  |
| Retained catch for | 500 (0.032) | 500 | 500 | 500 | 500 | 500 | 500 |
| 1981-1984 and/or |  |  |  |  |  |  |  |
| 1985-2015, $\lambda_{r}$ |  |  |  |  |  |  |  |
| Total catch for $1990-$ $2015, \lambda_{T}$ | Number of sampled pots scaled to a $\max 250$ | Number of sampled pots scaled to a $\max 250$ | Number of sampled pots scaled to a $\max 250$ | Number of sampled pots scaled to a $\max 250$ | Number of sampled pots scaled to a $\max 250$ | Number of sampled pots scaled to a $\max 250$ | Number of sampled pots scaled to a $\max 250$ |
| Groundfish bycatch for 1989-2015, $\lambda_{G D}$ | 0.2 (3.344) | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| Observer legal size crab catch-rate for |  |  |  |  |  |  |  |
| 1995-2015, $\lambda_{r, \text { CPUE }}$ | 1 (0.805) | 1 | $\begin{aligned} & (1991- \\ & 2015) 1 \end{aligned}$ | 1 | 1 | 1 | 1 |
| Fish ticket retained crab catch-rate for 1985-1998, $\lambda_{r, \text { CPUE }}$ | 1(0.805) |  | 1 | 1 | 1 | 1 | 1 |
| Penalty weights: |  |  |  |  |  |  |  |
| Pot fishing mortality $\operatorname{dev}, \lambda_{F}$ | Initially 1000, | Initially 1000, | Initially | Initially | Initially | Initially | Initially |
|  | relaxed to | relaxed to | 1000, relaxed | 1000, relaxed | 1000, relaxed | 1000, relaxed | 1000, relaxed |
|  | 0.001 at | 0.001 at | to 0.001 at | to 0.001 at | to 0.001 at | to 0.001 at | to 0.001 at |
|  | phases $\geq$ | phases $\geq$ | phases $\geq$ | phases $\geq$ | phases $\geq$ | phases $\geq$ | phases $\geq$ |
|  | select. phase | select. phase | select. phase | select. phase | select. phase | select. phase | select. phase |


| Table A2 Scenarios 1 to 7 continued. |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Groundfish fishing mortality dev, $\lambda_{F^{T r}}$ | Initially 1000 , relaxed to 0.001 at phases $\geq$ select. phase | Initially 1000 , relaxed to 0.001 at phases $\geq$ select. phase | Initially 1000, relaxed to 0.001 at phases $\geq$ select. phase | Initially 1000, relaxed to 0.001 at phases $\geq$ select. phase | Initially 1000, relaxed to 0.001 at phases $\geq$ select. phase | Initially 1000, relaxed to 0.001 at phases $\geq$ select. phase | Initially 1000, relaxed to 0.001 at phases $\geq$ select. phase |
| Recruitment, $\lambda_{R}$ | 2 (0.533) | 2 | 2 | 2 | 2 | 2 | 2 |
| Posfunction (to keep abundance estimates always positive), | 1000 (0.022) | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 |
| $\lambda_{\text {posfn }}$ |  |  |  |  |  |  |  |
| Maturity | 1(0.805) | 1 | 1 | 1 | 1 | 1 | 1 |
| Tagging likelihood | EAG individual tag returns | EAG tag data | EAG tag data | EAG tag data | EAG tag data | EAG tag data | EAG tag data |

* Coefficient of Variation, $C V=\sqrt{\exp \left[\frac{1}{2 W}\right]-1}, \quad$ w =weight

Table A2 continued.

| Weight | Value |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  | Scenario 8 | Scenario 9 | Scenario 10 | Scenario 11 |
| Catch: |  |  |  |  |
| Retained catch. $\lambda_{r}$ | 500 (0.032) | 500 | 500 | 500 |
| Total catch, $\lambda_{T}$ | Number of sampled pots scaled to a max $250$ | Number of sampled pots scaled to a max | Number of sampled pots scaled to a max | Number of sampled pots scaled to a max |
|  |  | 250 | 250 | 250 |
| Groundfish bycatch, $\lambda_{G D}$ | 0.2 (3.344) | 0.2 | 0.2 | 0.2 |
| Catch-rate: |  |  |  |  |
| Observer legal size crab catchrate, $\lambda_{r, \text { CPUE }}$ | 1(0.805) | 1 | 1 | 1 |
| Fish ticket retained crab catchrate, $\lambda_{\text {r,CPUE }}$ | 1(0.805) | 1 | 1 | 1 |
| Penalty weights: |  |  |  |  |
| Pot fishing mortality dev, $\lambda_{F}$ | Initially 1000 , relaxed to 0.001 at phases $\geq$ select. phase | Initially 1000, relaxed to 0.001 at phases $\geq$ select.phase | Initially 1000 , relaxed to 0.001 at phases $\geq$ select. phase | Initially 1000 , relaxed to 0.001 at phases $\geq$ select. phase |
| Trawl fishing mortality dev, $\lambda_{F^{T r}}$ | Initially 1000 , relaxed to 0.001 at phases $\geq$ select. phase | Initially 1000, relaxed to 0.001 at phases $\geq$ select. phase | Initially 1000 , relaxed to 0.001 at phases $\geq$ select. phase | Initially 1000 , relaxed to 0.001 at phases $\geq$ select. phase |
| Recruitment, $\lambda_{R}$ | 2(0.533) | 2 | 2 | 2 |
| Posfunction (to keep abundance estimates always positive), $\lambda_{\text {posfn }}$ | 1000 (0.022) | 1000 | 1000 | 1000 |


| Table A2 Scenarios 8 to 11 continued. |  |  |  |  |
| :--- | :--- | :--- | :--- | :--- |
| Maturity | $1(0.805)$ | fixed | 1 | fixed |
| Tagging likelihood | EAG tag data | EAG tag data | EAG tag data | EAG tag data |

## Appendix B: Catch and CPUE data

The commercial catch and length frequency distribution were estimated from ADF\&G landing records and dockside sampling (Bowers et al. 2008, 2011). The annual retained catch, total catch, and groundfish (or trawl) discarded mortality are provided in Table 1 for EAG and Table 15 for WAG. The weighted length frequency data were used to distribute the catch into $5-\mathrm{mm}$ size intervals. The length frequency data for a year were weighted by each sampled vessel's catch as follows. The $i$-th length-class frequency was estimated as:

$$
\begin{equation*}
\sum_{j=1}^{k} C_{j} \frac{L F_{j, i}}{\sum_{i=1}^{n} L F_{j, i}} \tag{B.1}
\end{equation*}
$$

where $k=$ number of sampled vessels in a year, $L F_{j, i}=$ number of crabs in the $i$-th length-class in the sample from $j$-th vessel, $\mathrm{n}=$ number of size classes, $C_{j}=$ number of crabs caught by $j$-th vessel. Then the relative frequency for the year was calculated and applied to the annual retained catch (in number of crabs) to obtain retained catch by length-class.

The annual total catch (in number of crabs) was estimated by the observer nominal (unstandardized) total CPUE considering all vessels multiplied by the total fishing effort (number of pot lifts). The weighted length frequency of the observer samples across the fleet was estimated using Equation B.1. Observer measurement of crab ranged from 20 to 220 mm CL. To restrict the total number of crabs to the model assumed size range (101-185+ mm CL), the proportion of observer total relative length frequency corresponding to this size range was multiplied by the total catch (number of crabs). This total number of crabs was distributed into length-classes using the weighted relative length frequency. Thus, crab sizes < 101 mm CL were excluded from the model. In addition, all crab $>185 \mathrm{~mm}$ CL were pooled into a plus length class. Note that the total crab catch by size that went into the model did not consider retained and discard components separately. However, once the model estimated the annual total catch, then retained catch was deducted from this total and
multiplied by handling mortality [we used a $20 \%$ handling mortality (Siddeek et al. 2005) to obtain the directed fishery discarded (dead) catch].

Observer data have been collected since 1988 (Moore et al. 2000; Barnard et al. 2001; Barnard and Burt 2004; Gaeuman 2011), but data were not comprehensive in the initial years, so a shorter time series of data for the period 1990/91-2014/15 was selected for this analysis. During 1990/91-1994/95, observers were only deployed on catcherprocessor vessels. During 1995/96-2004/05, observers were deployed on all fishing vessels during fishing activity. Observers have been deployed on all fishing vessels since 2005/06, but catcher-only vessels are only required to carry observers for a minimum of $50 \%$ of their fishing activity during a season; catcher-processor vessels are still required to carry observers during all fishing activity. Onboard observers count and measure all crabs caught and categorize catch as females, sublegal males, retained legal males, and non-retained legal males in a sampled pot. Prior to the 2009/10 season, depending on season, area, and type of fishing vessel, observers were also instructed to sample additional pots in which all crab were only counted and categorized as females, sublegal males, retained legal males, and non-retained legal males, but were not measured. Annual mean nominal CPUEs of retained and total crabs were estimated considering all sampled pots within each season (Tables 2 and 26). For model-fitting following a September 2016 CPT meeting suggestion, the CPUE time series was restricted to 1991/92-2015/16. Length-specific CPUE data collected by observers provides information on a wider size range of the stock than did the commercial catch length frequency data obtained from mostly legal-sized landed males.

There were significant changes in fishing practice due to changes in management regulations (e.g., since 1996/97 constant TAC and since 2005/06 crab rationalization), pot configuration (escape web on the pot door increased to 9 " since 1999), and improved observer recording in Aleutian Islands golden king crab fisheries since 1998. These changes prompted us to consider two separate observer CPUE time
series, 1995/96-2004/05 and 2005/06-2015/16, to estimate CPUE indices for model input. For scenario 3 model, we extended the observer time series to 1991/92.

To include a long time series of CPUE indices for stock abundance contrast, we also considered the 1985/86-1998/99 legal size standardized CPUE as a separate likelihood component in a number of scenarios. Because of the lack of soak time data previous to 1990, we estimated the CPUE index considering a limited set of explanatory variables (e.g., vessel, captain, area, month) and fitting the lognormal GLM to fish ticket data (Tables 3 and 27).

When using CPUE indices in the model fit, we compared the predicted with the observed legal male CPUE in the observer CPUE likelihoods because legal male (retained plus non-retained) data are more reliable than total in the observer samples.

## Observer CPUE index:

The CPUE standardization followed the GLM fitting procedure (Maunder and Punt 2004; Starr 2012; Siddeek et al. 2016b). We considered the negative binomial GLM on positive and zero catches to select the explanatory variables. The response variable CPUE is the observer sample catch record for a pot haul. The negative binomial model uses the log link function for the GLM fit. Therefore, we assumed the null model to be

$$
\begin{equation*}
\ln \left(\text { CPUE }_{\mathrm{i}}\right)=\text { Year }_{\mathrm{y}_{\mathrm{i}}} \tag{B.2}
\end{equation*}
$$

where Year is a factorial variable.
The maximum set of model terms offered to the stepwise selection procedure was:
$\ln \left(\right.$ CPUE $\left._{\mathrm{I}}\right)=$ Year $_{\mathrm{y}_{\mathrm{i}}}+\mathrm{ns}\left(\right.$ Soak $_{\mathrm{si}}$, df $)+$ Month $_{\mathrm{m}_{\mathrm{i}}}+$ Area $_{\mathrm{ai}}+$ Vessel $_{\mathrm{vi}}+$
Captain $_{\text {ci }}+$ Gear $_{\text {gi }}+n s\left(\right.$ Depth $_{\text {di }}$, df $)+n s\left(\operatorname{VesSoak~}_{\text {vsi }}\right.$, df $)$,
where Soak is in unit of days and is numeric; Month, Area code, Vessel code, Captain code, and Gear code are factorial variables; Depth in fathom is a numeric variable;

VesSoak is a numeric variable computed as annual number of vessels times annual mean soak days (to account for other vessels' effect on CPUE); ns=cubic spline, and $\mathrm{df}=$ degree of freedom.

We used a log link function and a dispersion parameter $(\theta)$ in the GLM fitting process. We used the $\mathrm{R}^{2}$ criterion for predictor variable selection (Siddeek et al. 2016b).

The $\mathrm{R}^{2}$ formula for explanatory variable selection is as follows:
$R^{2}=\frac{(\text { null model deviance-added parameter model deviance })}{\text { null model deviance }}$

An arbitrary $R^{2}$ minimum increment of 0.01 was set to select the model terms.

First we determined the dispersion parameter ( $\theta$ ) by a grid search method (Fox and Weisberg, 2011). The best $\theta$ value was obtained at the minimum AIC:

Table B.1. Dispersion parameter search.

|  | Time Period | $\theta$ | AIC |
| :--- | :--- | :--- | :--- |
| EAG | $1991 / 92-2004 / 05$ | 1.33 | 202,505 |
|  | $1995 / 96-2004 / 05$ | 1.33 | 198,234 |
|  | $2005 / 06-2015 / 16$ | 2.29 | 53,444 |
|  |  |  |  |
|  | $1991 / 92-2004 / 05$ | 0.96 | 201,561 |
|  | $1995 / 96-2004 / 05$ | 0.98 | 189,242 |
|  | $2005 / 06-2015 / 16$ | 1.13 | 86,201 |

Then we used the optimized dispersion parameter value in the GLM model for individual predictor variable fit to determine appropriate df value based on the minimum AIC:

Table B.2. Predictor variable degree of freedom search.

|  | Time Period | Predictor <br> Variable |  | AIC |
| :---: | :---: | :---: | :---: | :---: |
| EAG | 1991/92-2004/05 | Soak | 3 | 212,364 |
|  |  | Depth | 16 | 213,899 |
|  |  | VesSoak | 9 | 209,795 |
|  | 1995/96-2004/05 | Soak | 3 | 207,312 |
|  |  | Depth | 16 | 208,794 |
|  |  | VesSoak | 9 | 204,269 |
|  | 2005/06-2015/16 | Soak | 16 | 54,093 |
|  |  | Depth | 11 | 54,334 |
|  |  | VesSoak | 6 | 54,102 |
| WAG | 1991/92-2004/05 | Soak | 8 | 205,932 |
|  |  | Depth | 39 | 209,130 |
|  |  | VesSoak | 9 | 208,622 |
|  | 1995/96-2004/05 | Soak | 8 | 193,547 |
|  |  | Depth | 38 | 196,717 |
|  |  | VesSoak | 8 | 196,063 |
|  | 2005/06-2015/16 | Soak | 17 | 86,648 |
|  |  | Depth | 10 | 86,685 |
|  |  | VesSoak | 8 | 86,416 |

The final models for EAG were:
For scenario 3:
$\ln ($ CPUE $)=$ Year + Gear + Captain + ns $($ Soak, 3$)$
for the $1991 / 92-2004 / 05$ period $\left[\theta=1.33, \mathrm{R}^{2}=0.2328\right.$ with $\mathrm{ns}($ Soak, 3 ) forced in]

For other scenarios:
$\ln ($ CPUE $)=$ Year + Gear + Captain + ns (Soak, 3$)$
for the 1995/96-2004/05 period $\left[\theta=1.33, R^{2}=0.2417\right.$ with $n s(S o a k, 3)$ forced in]
$\ln ($ CPUE $)=$ Year + Captain $+\mathrm{ns}($ Soak, 16$)+$ Gear
for the $2005 / 06-2015 / 16$ period $\left(\theta=2.29, R^{2}=0.1237\right)$.

The final models for WAG were:
For scenario 3:
$\ln ($ CPUE $)=$ Year + Captain + ns $($ Soak, 8$)+$ Gear
for the 1991/92-2004/05 period $\left[\theta=0.96, \mathrm{R}^{2}=0.1721\right]$

For other scenarios:
$\ln ($ CPUE $)=$ Year + Captain + Gear $+\mathrm{ns}($ Soak, 8$)$
for the 1995/96-2004/05 period $\left[\theta=0.98, \mathrm{R}^{2}=0.1783\right]$
$\ln ($ CPUE $)=$ Year + Gear + ns(Soak, 17)
for the 2005/06-2015/16 period $\left[\theta=1.13, R^{2}=0.0562\right.$ with ns (Soak, 17) forced in]

Figures B. 1 and B. 15 depict the trends in nominal and standardized CPUE indices for the two CPUE time series for EAG and WAG, respectively. Figures B.2-B. 5 and B.16-B. 19 show the diagnostic plots for the fits for EAG and WAG, respectively. The deviance and QQ plots support good fits to EAG and WAG data by GLM using the negative binomial error distribution. Figures B.6-B. 14 and B.20-B. 27 depict CDI plots of the predictor variables for EAG and WAG, respectively.

Fish Ticket CPUE index:

We also fitted the lognormal GLM for the fish ticket retained CPUE time series 1985/86-1998/99 offering Year, Month, Vessel, Captain, and Area as explanatory variables. The final model for EAG was:
$\ln ($ CPUE $)=$ Year + Captain + Vessel + Month,$R^{2}=0.4541$
and those for WAG was:
$\ln ($ CPUE $)=$ Year + Captain + Vessel, $R^{2}=0.4561$

The $\mathrm{R}^{2}$ values for the fish ticket data fits are much higher compared to that for observer data fits.

Figures B. 28 and B. 30 depict the trends in nominal and standardized CPUE indices for the fish ticket CPUE time series for EAG and WAG, respectively. Figures B. 29 and B. 31 show the Q-Q plots for the fits for EAG and WAG, respectively. The Q-Q plots support reasonable fits to EAG and WAG data by GLM using the lognormal error distribution.


Figure B.1. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from EAG (east of $174^{\circ}$ W longitude). Top panel: 1991/92-2004/05, middle panel: 1995/962004/05, and bottom panel: 2005/06-2015/16. Standardized indices: black line and nonstandardized indices: red line.


Figure B.2. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x -axis for soak time variable. Observer data from EAG for 1991/92-2004/05 (top) and 1995/96-2004/05 (bottom) periods were used. The solid green lines are the loess smoother through the plotted values.


Figure B.3. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x -axis for soak time variable. Observer data from EAG for 2005/06-2015/16 period were used. The solid green lines are the loess smoother through the plotted values.

## Negative Binomial Fit, EAG 1991/96-2004/05



Negative Binomial Fit, EAG 1995/96-2004/05


Figure B.4. Studentized residual plots for negative binomial GLM fit to EAG golden king crab observer CPUE data for legal size male crab. Top panel is for 1991/92-2004/05 and bottom panel is for 1995/96-2004/05.

Negative Binomial Fit, EAG 2005/06-2015/16


Figure B.5. Studentized residual plots for negative binomial GLM fit to EAG golden king crab observer CPUE data for legal size male crab in 2005/06-2015/16.


Figure B.6. CDI plot for Captain for the negative binomial fit to 1991/92-2004/05 data for EAG.


Figure B.7. CDI plot for Gear for the negative binomial fit to 1991/92-2004/05 data for EAG.


Figure B.8. CDI plot for Soak for the negative binomial fit to 1991/92-2004/05 data for EAG.


Figure B.9. CDI plot for Captain for the negative binomial fit to 1995/96-2004/05 data for EAG.


Figure B.10. CDI plot for Gear for the negative binomial fit to 1995/96-2004/05 data for EAG.


Figure B.11. CDI plot for Soak for the negative binomial fit to 1995/96-2004/05 data for EAG.


Figure B.12. CDI plot for Captain for the negative binomial fit to 2005/06-2015/16 data for EAG.


Figure B.13. CDI plot for Gear for the negative binomial fit to 2005/06-2015/16 data for EAG.


Figure B.14. CDI plot for Soak for the negative binomial fit to 2005/06-2015/16 data for EAG.


Figure B.15. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer data from WAG (east of $174^{\circ}$ W longitude). Top panel: 1991/92-2004/05, middle panel: 1995/962004/05, and bottom panel: 2005/06-2015/16. Standardized indices: black line and nonstandardized indices: red line.


Figure B.16. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x -axis for soak time variable. Observer data from WAG for 1991/92-2004/05 (top) and 1995/96-2005/05 (bottom) periods were used. The solid lines are the loess smoother through the plotted values.


Figure B.17. Deviance residuals vs. explanatory and response variables of the best negative binomial fit model for legal male crab CPUE. Deviance residuals for factor variables are shown as box plots and only the linear part of the cubic splines are specified on the x -axis for soak time variable. Observer data from WAG for 2005/06-2015/16 (bottom) periods were used. The solid lines are the loess smoother through the plotted values.

## Negative Binomial Fit, WAG 1991/92-2004/05



Negative Binomial Fit, WAG 1995/96-2004/05


Figure B.18. Studentized residual plots for negative binomial GLM fit to WAG golden king crab observer CPUE data for legal size male crab. Top panel is for 1991/92-2004/05 and bottom panel is for 1995/96-2004/05.

Negative Binomial Fit, WAG 2005/06-2015/16


Figure B.19. Studentized residual plots for negative binomial GLM fit to WAG golden king crab observer CPUE data for legal size male crab in 2005/06-2015/16.


Figure B.20. CDI plot for Captain for the negative binomial fit to 1991/92-2004/05 data for WAG.


Figure B.21. CDI plot for Gear for the negative binomial fit to 1991/92-2004/05 data for WAG.


Figure B.22. CDI plot for Soak for the negative binomial fit to 1991/92-2004/05 data for WAG.


Figure B.23. CDI plot for Captain for the negative binomial fit to 1995/96-2004/05 data for WAG.


Figure B.24. CDI plot for Gear for the negative binomial fit to 1995/96-2004/05 data for WAG.


Figure B.25. CDI plot for Soak for the negative binomial fit to 1995/96-2004/05 data for WAG.


Figure B.26. CDI plot for Gear for the negative binomial fit to 2005/06-2005/15 data for WAG.


Figure B.27. CDI plot for Soak for the negative binomial fit to 2005/06-2005/15 data for WAG.


Figure B.28. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from EAG. The 1985/86-1998/99 fish ticket data set was used. Standardized indices: black line and nonstandardized indices: red line.

Log Normal Fit, EAG 1985/86-1998/99


Figure B.29. Studentized residual plots for lognormal GLM fit to EAG golden king crab fish ticket CPUE data, 1985/86-1998/99.


Figure B.30. Trends in non-standardized [arithmetic (nominal)] and standardized (lognormal GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab from WAG; 1985/86-1998/99 fish ticket data. Standardized indices: black line and non-standardized indices: red line.

## Log Normal Fit, WAG 1985/86-1998/99



Figure B.31. Studentized residual plots for lognormal GLM fit for WAG golden king crab fish ticket CPUE data, 1985/86-1998/99.

## Appendix C: Male maturity

## Male maturity:

We used the 1991 EAG pot survey collected 2457 carapace length and chela height measurements (carapace length (CL) in mm and chela height (CH) up to one-tenth of a mm ) for male maturity curve fitting and $50 \%$ maturity length determination. We determined the $50 \%$ maturity length and maturity proportion by size outside the assessment model using the 'segmented regression' package available in $R$ ( $R$ Core Team 2016). We used the estimated maturity proportion by size in the assessment model to re-evaluate the $50 \%$ maturity length and fit a smooth maturity curve.

First we fitted a linear regression model to the data pair using the $R$ package as follows:
$\ln (C H)=\beta_{0}+\beta_{1} \ln (C L)$
where $\beta_{0}$ and $\beta_{1}$ are regression parameters
The procedure of 'segmented regression' uses maximum likelihood to fit a somewhat different parameterization of the linear model. It can be approximated as
$\ln (C H)=\beta_{0}+\beta_{1} \ln (C L)+\beta_{2}[\ln (C L)-c]+\gamma I[\ln (C L)>c]$
where $\beta_{2}$ is a regression parameter and c is the break point. $\gamma I[\ln (C L)>c]$ is a dummy variable. When $\ln (\mathrm{CL})<c$, the model reduces to,
$\ln (C H)=\beta_{0}+\beta_{1} \ln (C L)+\beta_{2}[\ln (C L)-c]$
The $\gamma$ term is a measure of the distance between the end of the first segment and the beginning of the next. The model converges when $\gamma$ is minimized, thus this method constrains the segments to be (nearly) continuous.

Breakpoint analysis results:

| Estimated breakpoint, $\ln (\mathrm{CL})$ | Standard error |
| :---: | :--- |
| 4.687 | 0.012 |

Coefficients of the linear terms:

|  | Estimate | Std. Error | t value | $\operatorname{Pr}(>\|\mathrm{t}\|)$ |
| :--- | :--- | :--- | :--- | :--- |
| (Intercept) | -1.74836 | 0.08487 | -20.60 | $<2 \mathrm{e}-16^{* * *}$ |
| $\operatorname{logCL}$ | 1.04673 | 0.01899 | 55.13 | $<2 \mathrm{e}-16^{* * *}$ |
| U1.logCL | 0.61540 | 0.02727 | 22.57 | NA |


Adjusted R-squared: 0.908, AIC: 2358.9
Thus, the break point estimate of male CL (i.e., $50 \%$ maturity length) $=\exp (4.687)=108.53 \mathrm{~mm} \mathrm{CL}$.
Figure C. 1 provides the segment regression fit to the $\log (\mathrm{CL})$ and $\log (\mathrm{CH})$ data pair:


Figure C.1. Segmented linear regression fit to $\ln (\mathrm{CH})$ vs. $\operatorname{In}(\mathrm{CL})$ data of male golden king crab in EAG.

Using the two segments of the estimated linear lines, we allocated each data point to be mature or immature, considering whether the vertical height of the data point $[\mathrm{In}(\mathrm{CH})$ ] to the extended upper segment line is smaller or larger than the vertical height to the lower segment line (Figure C.2).


Figure C.2. Segmented linear regression fit to $\ln (\mathrm{CH})$ vs. $\ln (\mathrm{CL})$ data of male golden king crab in EAG with classification of mature (code 1, darkgreen) and immature (code 0, red) data points.

The estimated mature and immature proportions for each size bin are listed in Table C.1.

Table C.1. Mature and immature proportions by mid carapace length. This set of values is treated as observed maturity proportions for inputting to the population model.

| Mid CL <br> $(\mathrm{mm})$ | Mature <br> Frequency | Immature <br> Frequency | Mature <br> Proportion |
| ---: | ---: | ---: | :--- |
| 103 | 0 | 0 |  |
| 108 | 74.0 | 314 | 0.1514 |
| 113 | 124.0 | 74 | 0.5000 |
| 118 | 118.0 | 59 | 0.6776 |
| 123 | 139.0 | 63 | 0.6519 |
| 128 | 164.0 | 43 | 0.7637 |
| 133 | 197.0 | 49 | 0.7700 |
| 138 | 233.0 | 47 | 0.8074 |
| 143 | 188.0 | 47 | 0.8321 |
| 148 | 178.0 | 29 | 0.8664 |
| 153 | 105.0 | 22 | 0.8900 |
| 158 | 58.0 | 8 | 0.9292 |
| 163 | 26.0 | 7 | 0.8923 |
| 168 | 21.0 | 1 | 0.9630 |
| 173 | 2.0 | 1 | 0.9545 |
| 178 | 3.0 | 0 | 1.0000 |
| 183 | 5.0 | 1 | 0.7500 |
|  |  | 1 | 0.8333 |

Then we fitted the proportion mature vs. mid CL by the logistic regression using GLM. The results are as follows:

Model: glm(formula $=$ Maturity State $\sim$ CL, family $=$ binomial(link $=$ logit $), \quad$ data $=$ Maturity $)$
Deviance Residuals:

| Min | 1Q | Median | 3Q | Max |
| :---: | :---: | :---: | :---: | :---: |
| -3.0188 | -0.6310 | 0.4811 | 0.7320 | 2.6239 |

Coefficients:

|  | Estimate | Std. Error | z value | $\operatorname{Pr}(>\|\mathrm{z}\|)$ |
| :--- | :--- | :--- | :--- | :--- |
| (Intercept) | -6.71466 | 0.36124 | -18.59 | $<2 \mathrm{e}-16^{* * *}$ |
| CL | 0.06120 | 0.00294 | 20.82 | $<2 \mathrm{e}-16^{* * *}$ |

Signif. codes: $0{ }^{\prime * * * \prime} 0.001^{* * *} 0.01^{* * \prime} 0.05^{\prime \prime} 0.1^{\prime \prime} 1 ;$ AIC: 2358.9

The 50\% maturity length (the carapace length at the predicted proportion of 0.5 ) was estimated as 109.72 mm CL.

When we used the mature proportions (Table C.1) in the population model, we obtained the $50 \%$ maturity length as 110.62 mm CL under base scenario (Sc1). Thus, for the knife-edge maturity selection scenario models ( 9 and 11), we considered all sizes above 111 mmCL to be fully mature (1) and below this size immature (0).

## Essential R steps:

\# 1. Segmented regression:
\# fit a single linear regression first then apply segmented
library(segmented)
singleline. mod<- $\operatorname{Im}\left(\log \mathrm{CH}^{\sim} \log C L\right)$
segmented.mod<- segmented(singleline.mod,seg.Z=~/ogCL)
2. Logistic regression:
library(MASS)
best.glm<- glm(MaturityState~CL,family=binomial(link=logit),data=Maturity)

## Appendix D: Francis re-weighting method

We considered number of fishing days as the initial input effective sample sizes (i.e., Stage-1) for retained and total size compositions and number of trips for groundfish discard catch size composition without enforcing any upper limit. Please note that we did not use the groundfish discard size compositions in any of the scenarios optimization although the predicted effective sample sizes were produced as a byproduct. We estimated the Stage-2 effective sample sizes iteratively from Stage-1 input effective sample sizes. We refer to the Stage-1 effective samples sizes for the size-composition of the retained catch, total catch, and the groundfish crab bycatch for year $t$ as $\tau_{1, \mathrm{t}}^{r} \tau_{1, \mathrm{t}}^{T}$, and $\tau_{1, \mathrm{t}}^{T r}$ respectively. The reiterated effective sample sizes' subscripts replace 1 by 2 .

The Francis’ (2011) mean length based method [i.e., Francis TA1.8 method, Punt (in press)] uses the following formulas:

Observed mean length for year $t$,
$\overline{l_{t}}=\sum_{i=1}^{n} l_{t, i} \times P_{t, i}$
Predicted mean length for year $t$,
$\hat{\overline{l_{t}}}=\sum_{i=1}^{n} l_{t, i} \times \hat{P}_{t, i}$
Variance of the predicted mean length in year $t$,

$$
\begin{equation*}
\operatorname{var}\left(\hat{\bar{l}}_{t}\right)=\frac{\sum_{i=1}^{n} \hat{P}_{t, i}\left(l_{t, i}-\hat{\bar{l}}_{t}\right)^{2}}{S_{t}} \tag{D.3}
\end{equation*}
$$

Francis' reweighting parameter $W$,

$$
\begin{equation*}
W=\frac{1}{\operatorname{var}\left\{\frac{\bar{l}_{t}-\hat{l}_{t}}{\left.\sqrt{\operatorname{var}\left(\hat{l}_{t}\right)}\right\}}\right\}} \tag{D.4}
\end{equation*}
$$

where $\hat{P}_{t, i}$ and $P_{t, i}$ are the estimated and observed proportions of the catch during year $t$ in length-class $i, l_{t, i}$ is the mid length of the length-class $i$ during year $t, S_{t}$ is the effective sample
size in year $t, \hat{\bar{l}}_{t}$ and $\bar{l}_{t}$ are predicted and observed mean lengths of the catch during year $t$, and $W$ is the reweighting multiplier of Stage- 1 sample sizes.

Francis (in press 2016) suggested that a good stopping criterion for the iteration process is when there are no appreciable changes in the key outputs. Hence, we considered a stopping criterion of no appreciable change $(<0.01 \%)$ in $W$ and terminal year MMB.
$S_{t}$ is related to the initial input (Stage-1) effective sample size according to:

$$
\begin{equation*}
S_{t, i}=W_{i} \tau_{1, t} \tag{D.5}
\end{equation*}
$$

where $S_{t, i}$ is the effective sample size for year $t$ in iteration $i$ and $W_{i}$ is the Francis weight calculated using Equation D. 4 during iteration $i$.

We did the reweighting for combined data (for $M$ estimation), individual scenarios, MMB profiles, mean MMB profile, and MMB rate of depletion profile. For brevity, we provide the iteration process for Francis Stage-2 weight calculation for individual scenarios for EAG and WAG respectively in Table D:

Table D. Iteration process for stage-2 effective sample size reweighting multiplier, $W$, by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for various scenarios for EAG and WAG. The effective sample sizes are numbers of days for retained and total catch, but number of trips for groundfish discarded catch size compositions. Note: Groundfish bycatch size compositions were not fitted to the models, but different predicted weights resulted as byproducts from different iterations. Sc. =scenario. Note: For certain scenarios we have done up to six iterations, but we provide only the last three iteration results.

| Area | Sc. | Iteration No. | Retained <br> Catch Size <br> Comp <br> Effective <br> Sample <br> Multiplier <br> (W) | Total Catch Size Comp Effective Sample Multiplier (W) | Groundfish <br> Discard Catch <br> Size Comp <br> Effective <br> Sample <br> Multiplier (W) | Terminal MMB (t) | $M \mathrm{yr}^{-1}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| EAGpart | 0a | 1 | 0.8792 | 0.5080 | 0.4481 | 10,555 | 0.2224 |
|  |  | 2 | 0.8874 | 0.5019 | 0.4486 | 10,556 | 0.2225 |
|  |  | 3 | 0.8904 | 0.5003 | 0.4487 | 10,558 | 0.2225 |
| WAGpart | 0a | 1 | 0.5041 | 0.4888 | 0.7658 | 4,307 | 0.2224 |
|  |  | 2 | 0.5039 | 0.4889 | 0.7657 | 4,309 | 0.2225 |
|  |  | 3 | 0.5038 | 0.4889 | 0.7657 | 4,309 | 0.2225 |
| EAGpart | 0b | 1 | 0.8909 | 0.5000 | 0.4487 | 10,603 | 0.2241 |
|  |  | 2 | 0.8918 | 0.4995 | 0.4487 | 10,601 | 0.2241 |
|  |  | 3 | 0.8921 | 0.4994 | 0.4487 | 10,601 | 0.2241 |
| WAGpart | 0b | 1 | 0.5037 | 0.4888 | 0.7651 | 4,334 | 0.2241 |
|  |  | 2 | 0.5037 | 0.4888 | 0.7651 | 4,333 | 0.2241 |
|  |  | 3 | 0.5037 | 0.4888 | 0.7651 | 4,333 | 0.2241 |
| EAG | 1 b | 1 | 0.8921 | 0.4994 | 0.4487 | 10,512 | 0.2208 |
|  |  | 2 | 0.8915 | 0.4999 | 0.4489 | 10,512 | 0.2208 |
| WAG | 1 b | 1 | 0.5037 | 0.4888 | 0.7651 | 4,434 | 0.2308 |
|  |  | 2 | 0.5034 | 0.4881 | 0.7629 | 4,435 | 0.2308 |
|  |  | 3 | 0.5034 | 0.4880 | 0.7629 | 4,435 | 0.2308 |
| EAG | 1 | 1 | 0.8917 | 0.4996 | 0.4487 | 10,597 |  |
|  |  | 2 | 0.8920 | 0.4995 | 0.4488 | 10,597 |  |
|  |  | 3 | 0.8920 | 0.4994 | 0.4488 | 10,597 |  |
| WAG | 1 | 1 | 0.5037 | 0.4888 | 0.7651 | 4,332 |  |
|  |  | 2 | 0.5037 | 0.4888 | 0.7652 | 4,332 |  |
|  |  | 3 | 0.5038 | 0.4888 | 0.7652 | 4,332 |  |
| EAG | 2 | 1 | 0.8854 | 0.4955 | 0.4480 | 10,749 |  |
|  |  | 2 | 0.8848 | 0.4951 | 0.4479 | 10,749 |  |
|  |  | 3 | 0.8848 | 0.4950 | 0.4479 | 10,749 |  |
| WAG | 2 | 1 | 0.5012 | 0.4647 | 0.7534 | 4,227 |  |
|  |  | 2 | 0.5017 | 0.4643 | 0.7535 | 4,228 |  |
|  |  | 3 | 0.5020 | 0.4642 | 0.7536 | 4,228 |  |


| EAG | 3 | 1 | 0.8914 | 0.5285 | 0.4514 | 11,605 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | 2 | 0.8897 | 0.5294 | 0.4513 | 11,605 |
|  |  | 3 | 0.8892 | 0.5296 | 0.4513 | 11,605 |
| WAG | 3 | 1 | 0.5103 | 0.4841 | 0.7639 | 4,333 |
|  |  | 2 | 0.5110 | 0.4836 | 0.7641 | 4,334 |
|  |  | 3 | 0.5113 | 0.4834 | 0.7642 | 4,334 |
| EAG | 4 | 1 | 0.9512 | 0.4832 | 0.4466 | 10,036 |
|  |  | 2 | 0.9522 | 0.4828 | 0.4467 | 10,036 |
|  |  | 3 | 0.9525 | 0.4826 | 0.4467 | 10,036 |
| WAG | 4 | 1 | 0.5227 | 0.4235 | 0.7562 | 3,864 |
|  |  | 2 | 0.5231 | 0.4232 | 0.7563 | 3,865 |
|  |  | 3 | 0.5232 | 0.4232 | 0.7564 | 3,865 |
| EAG | 5 | 1 | 0.8758 | 0.5070 | 0.4497 | 9,676 |
|  |  | 2 | 0.8747 | 0.5075 | 0.4497 | 9,676 |
|  |  | 3 | 0.8744 | 0.5076 | 0.4496 | 9,676 |
| WAG | 5 | 1 | 0.5026 | 0.4923 | 0.7760 | 3,826 |
|  |  | 2 | 0.5018 | 0.4931 | 0.7755 | 3,825 |
|  |  | 3 | 0.5014 | 0.4934 | 0.7754 | 3,824 |
| EAG | 6 | 1 | 0.8923 | 0.4937 | 0.4460 | 11,711 |
|  |  | 2 | 0.8940 | 0.4929 | 0.4461 | 11,711 |
|  |  | 3 | 0.8945 | 0.4927 | 0.4461 | 11,711 |
| WAG | 6 | 1 | 0.4983 | 0.4859 | 0.7498 | 4,998 |
|  |  | 2 | 0.4982 | 0.4848 | 0.7496 | 4,999 |
|  |  | 3 | 0.4983 | 0.4846 | 0.7497 | 4,999 |
| EAG | 7 | 1 | 0.8920 | 0.4994 | 0.4488 | 10,597 |
| WAG | 7 | 1 | 0.5038 | 0.4888 | 0.7652 | 4,332 |
| EAG | 8 | 1 | 0.8920 | 0.4994 | 0.4488 | 10,597 |
| WAG | 8 | 1 | 0.5038 | 0.4888 | 0.7652 | 4,332 |
| EAG | 9 | 1 | 0.8920 | 0.4994 | 0.4488 | 12,051 |
| WAG | 9 | 1 | 0.5038 | 0.4888 | 0.7652 | 5,005 |
| EAG | 10 | 1 | 0.8920 | 0.4994 | 0.4488 | 10,519 |
|  |  | 2 | 0.8915 | 0.4999 | 0.4489 | 10,518 |
|  |  | 3 | 0.8912 | 0.5000 | 0.4489 | 10,518 |
| WAG | 10 | 1 | 0.5038 | 0.4888 | 0.7652 | 4,438 |
|  |  | 2 | 0.5034 | 0.4881 | 0.7628 | 4,438 |


|  |  | 3 | 0.5034 | 0.4880 | 0.7628 | 4,438 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| EAG | 11 | 1 | 0.8912 | 0.5000 | 0.4489 | 11,959 |
| WAG | 11 | 1 | 0.5034 | 0.4880 | 0.7628 | 5,128 |

## Appendix E. Jittering

Jittering of scenarios 1 and 9 parameter estimates:
We followed the Stock Synthesis approach to do 100 jittering of scenarios 1 and 9 parameter estimates to use as initial parameter values to assess model stability and to determine whether a global as opposed to local minima has been found by the search algorithm:

The Jitter factor of 0.1 was multiplied by a random normal deviation $r d e v=N(0,1)$, to a transformed parameter value based upon the predefined parameter:

$$
\begin{equation*}
\text { temp }=0.5 * \text { rdev }^{*} \text { Jitterfact or } * \ln \left(\frac{P_{\max }-P_{\min }+0.0000002}{P_{v a l}-P_{\min }+0.0000001}-1\right), \tag{E.1}
\end{equation*}
$$

with the final jittered initial parameter value back transformed as:

$$
\begin{equation*}
P_{\text {new }}=P_{\min }+\frac{P_{\max }-P_{\min }}{1.0+\exp (-2.0 \text { temp })}, \tag{E.2}
\end{equation*}
$$

where $P_{\max }$ and $P_{\min }$ are upper and lower bounds of parameter search space and $P_{\text {val }}$ is the estimated parameter value before the jittering.

Examples of jittered parameter values for the $1^{\text {st }}$ and $100^{\text {th }}$ jitter for scenario 1 for EAG and WAG are listed in Tables E. 1 and E.2. There were significant differences in the initial input parameter values at each jitter. The model results are summarized for scenarios 1 and 9 respectively in Tables E. 3 and E. 4 for EAG and Tables E. 5 and E. 6 for WAG. Almost all runs converged to the highest $\log$ likelihood values.

Table E.1. An example of the first and $100^{\text {th }}$ jittered parameter values for scenario 1 compared to the original estimates for EAG.

| Parameter | Original <br> Parameter <br> Value | Lower Bound | Upper <br> Bound | Phase | Jitter\#1 | Jitter\#100 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| rec_dev | -0.007621209 | -5 | 5 | 2 | -0.00074 | -0.00003 |
| rec_dev | -0.00983545 | -5 | 5 | 2 | -0.00113 | 0.001764 |
| rec_dev | -0.012666822 | -5 | 5 | 2 | 0.000609 | 0.002454 |
| rec_dev | -0.016270708 | -5 | 5 | 2 | 0.001421 | -0.00013 |
| rec_dev | -0.020830832 | -5 | 5 | 2 | -0.0007 | 0.002063 |
| rec_dev | -0.02656543 | -5 | 5 | 2 | 0.002309 | -0.00314 |
| rec_dev | -0.033718004 | -5 | 5 | 2 | 0.002944 | 0.005426 |
| rec_dev | -0.042549431 | -5 | 5 | 2 | -0.00144 | -0.00361 |
| rec_dev | -0.053324882 | -5 | 5 | 2 | 0.00127 | -0.01131 |
| rec_dev | -0.066278019 | -5 | 5 | 2 | -0.004 | 0.006071 |
| rec_dev | -0.081570571 | -5 | 5 | 2 | -0.00056 | -0.00713 |
| rec_dev | -0.099226953 | -5 | 5 | 2 | 0.010832 | 0.013719 |
| rec_dev | -0.119047323 | -5 | 5 | 2 | -0.02062 | 0.000781 |
| rec_dev | -0.140503671 | -5 | 5 | 2 | -0.0355 | 0.001759 |
| rec_dev | -0.162598904 | -5 | 5 | 2 | 0.012222 | 0.00039 |
| rec_dev | -0.183698125 | -5 | 5 | 2 | -0.00834 | 0.001598 |


| rec_dev | -0.201256782 | -5 | 5 | 2 | 0.006619 | 0.021168 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| rec_dev | -0.211319519 | -5 | 5 | 2 | 0.000672 | -0.03371 |
| rec_dev | -0.207502036 | -5 | 5 | 2 | -0.00411 | -0.0309 |
| rec_dev | -0.180503692 | -5 | 5 | 2 | 0.012694 | -0.01542 |
| rec_dev | -0.123342735 | -5 | 5 | 2 | 0.001442 | 0.005442 |
| rec_dev | -0.045201645 | -5 | 5 | 2 | 0.00158 | 0.006621 |
| rec_dev | 0.029136582 | -5 | 5 | 2 | 0.001061 | 0.001725 |
| rec_dev | 0.089402495 | -5 | 5 | 2 | 0.007221 | -0.0029 |
| rec_dev | -0.384889343 | -5 | 5 | 2 | 0.073548 | 0.047674 |
| rec_dev | -0.902906835 | -5 | 5 | 2 | -0.0292 | -0.08789 |
| rec_dev | 0.533564639 | -5 | 5 | 2 | 0.037675 | 0.032778 |
| rec_dev | 0.44687304 | -5 | 5 | 2 | -0.01543 | 0.061101 |
| rec_dev | -0.314047153 | -5 | 5 | 2 | 0.023384 | -0.01654 |
| rec_dev | 0.122576429 | -5 | 5 | 2 | -0.0039 | -0.01561 |
| rec_dev | 0.412310368 | -5 | 5 | 2 | -0.02322 | 0.053463 |
| rec_dev | -0.110123222 | -5 | 5 | 2 | -0.01218 | -0.01082 |
| rec_dev | -0.218632463 | -5 | 5 | 2 | 0.025955 | 0.001872 |
| rec_dev | 0.006943443 | -5 | 5 | 2 | -0.00051 | -9.2E-05 |
| rec_dev | -0.046282794 | -5 | 5 | 2 | 0.007969 | -0.00549 |
| rec_dev | -0.083888349 | -5 | 5 | 2 | -0.003 | -0.00738 |
| rec_dev | 0.233016956 | -5 | 5 | 2 | -0.00577 | 0.047905 |
| rec_dev | 0.148955659 | -5 | 5 | 2 | 0.017582 | -0.02326 |
| rec_dev | 0.227641561 | -5 | 5 | 2 | 0.020397 | 0.001212 |
| rec_dev | 0.168044398 | -5 | 5 | 2 | 0.001588 | 0.0343 |
| rec_dev | -0.108887188 | -5 | 5 | 2 | 0.002945 | 0.002444 |
| rec_dev | 0.162407336 | -5 | 5 | 2 | -0.0209 | 0.009928 |
| rec_dev | 0.005113551 | -5 | 5 | 2 | 0.000296 | -0.00046 |
| rec_dev | -0.160627991 | -5 | 5 | 2 | -0.0144 | -0.01982 |
| rec_dev | 0.259949544 | -5 | 5 | 2 | 0.012919 | -0.00678 |
| rec_dev | -0.00396377 | -5 | 5 | 2 | -6.1E-05 | $1.73 \mathrm{E}-05$ |
| rec_dev | -0.056389469 | -5 | 5 | 2 | 0.004747 | -0.00215 |
| rec_dev | 0.473415636 | -5 | 5 | 2 | 0.050748 | -0.02824 |
| rec_dev | 0.075169026 | -5 | 5 | 2 | -0.00795 | 0.007863 |
| rec_dev | 0.021190701 | -5 | 5 | 2 | 0.000501 | -0.00144 |
| rec_dev | 0.310880604 | -5 | 5 | 2 | -0.02787 | -0.05911 |
| rec_dev | 0.294577467 | -5 | 5 | 2 | 0.015264 | -0.01329 |
| rec_dev | 0.109759588 | -5 | 5 | 2 | -0.00244 | -0.01763 |
| rec_dev | 0.220969046 | -5 | 5 | 2 | -0.00903 | -0.02374 |
| rec_dev | 0.084173082 | -5 | 5 | 2 | -0.00864 | 0.003339 |
| rec_dev | 0.000000172 | -5 | 5 | 2 | 8.33E-09 | $1.28 \mathrm{E}-08$ |
| Fpot_dev | -2.043206656 | -5 | 5 | 2 | -0.2088 | 0.161353 |
| Fpot_dev | -1.005945946 | -5 | 5 | 2 | -0.02969 | -0.04945 |
| Fpot_dev | -0.676481111 | -5 | 5 | 2 | -0.01163 | -0.03165 |
| Fpot_dev | -0.413911035 | -5 | 5 | 2 | 0.037401 | -0.05638 |
| Fpot_dev | 0.112602025 | -5 | 5 | 2 | 0.009003 | -0.00208 |
| Fpot_dev | 0.401936857 | -5 | 5 | 2 | 0.035761 | 0.016653 |
| Fpot_dev | 0.178418014 | -5 | 5 | 2 | 0.026166 | -0.01577 |
| Fpot_dev | 0.765136564 | -5 | 5 | 2 | 0.076145 | -0.05429 |
| Fpot_dev | 1.17570096 | -5 | 5 | 2 | -0.06934 | -0.06232 |
| Fpot_dev | 0.56061169 | -5 | 5 | 2 | -0.04209 | 0.079606 |
| Fpot_dev | 0.769584182 | -5 | 5 | 2 | -0.00569 | 0.02741 |
| Fpot_dev | 0.892126133 | -5 | 5 | 2 | -0.06133 | 0.069375 |
| Fpot_dev | 0.409840495 | -5 | 5 | 2 | -0.03908 | -0.02549 |
| Fpot_dev | 0.677542871 | -5 | 5 | 2 | 0.088008 | 0.024399 |
|  |  |  | 2 |  |  |  |


| Fpot_dev | 0.914433283 | -5 | 5 | 2 | 0.045073 | 0.030075 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Fpot_dev | 0.594511978 | -5 | 5 | 2 | 0.031985 | 0.037231 |
| Fpot_dev | 0.559553031 | -5 | 5 | 2 | -0.0054 | 0.035317 |
| Fpot_dev | 0.476766604 | -5 | 5 | 2 | -0.05612 | -0.01349 |
| Fpot_dev | 0.246789033 | -5 | 5 | 2 | 0.006829 | 0.014387 |
| Fpot_dev | 0.114871314 | -5 | 5 | 2 | 0.001589 | 0.010866 |
| Fpot_dev | -0.05005792 | -5 | 5 | 2 | 0.001826 | 0.003591 |
| Fpot_dev | -0.299486201 | -5 | 5 | 2 | -0.00262 | 0.049051 |
| Fpot_dev | -0.339042566 | -5 | 5 | 2 | -0.00339 | 0.047638 |
| Fpot_dev | -0.433904962 | -5 | 5 | 2 | 0.020182 | 0.070041 |
| Fpot_dev | -0.291197186 | -5 | 5 | 2 | -0.05808 | 0.026351 |
| Fpot_dev | -0.240779046 | -5 | 5 | 2 | -0.01305 | -0.00896 |
| Fpot_dev | -0.292344124 | -5 | 5 | 2 | -0.04096 | -0.0097 |
| Fpot_dev | -0.274120848 | -5 | 5 | 2 | -0.01807 | -0.02918 |
| Fpot_dev | -0.258960118 | -5 | 5 | 2 | 0.018398 | -0.04268 |
| Fpot_dev | -0.34871274 | -5 | 5 | 2 | 0.061286 | 0.029559 |
| Fpot_dev | -0.396008834 | -5 | 5 | 2 | -0.03428 | -0.00575 |
| Fpot_dev | -0.374943981 | -5 | 5 | 2 | 0.020376 | 0.040815 |
| Fpot_dev | -0.368594822 | -5 | 5 | 2 | -0.09801 | 0.045321 |
| Fpot_dev | -0.404710921 | -5 | 5 | 2 | 0.003849 | 0.006273 |
| Fpot_dev | -0.338016015 | -5 | 5 | 2 | -0.02806 | -0.00015 |
| Fground_dev | 0.174390609 | -10 | 15 | 2 | 2.337762 | 2.581353 |
| Fground_dev | 1.35546881 | -10 | 15 | 2 | 2.388202 | 2.398121 |
| Fground_dev | 0.000000201 | -10 | 15 | 2 | 2.284926 | 2.810396 |
| Fground_dev | 0.672768389 | -10 | 15 | 2 | 2.610206 | 2.929459 |
| Fground_dev | 0.702294918 | -10 | 15 | 2 | 2.6574 | 2.732086 |
| Fground_dev | -0.515785649 | -10 | 15 | 2 | 2.7874 | 2.460403 |
| Fground_dev | 0.537155944 | -10 | 15 | 2 | 2.414025 | 2.308584 |
| Fground_dev | -2.415444682 | -10 | 15 | 2 | 2.935845 | 2.473627 |
| Fground_dev | -1.56355901 | -10 | 15 | 2 | 2.381744 | 2.802964 |
| Fground_dev | 0.388375903 | -10 | 15 | 2 | 2.271547 | 2.444883 |
| Fground_dev | -0.468543028 | -10 | 15 | 2 | 2.462521 | 2.810034 |
| Fground_dev | -0.269970599 | -10 | 15 | 2 | 2.853102 | 2.409323 |
| Fground_dev | 0.838013548 | -10 | 15 | 2 | 2.327215 | 2.555227 |
| Fground_dev | 0.016126262 | -10 | 15 | 2 | 2.177965 | 2.09686 |
| Fground_dev | -0.462605641 | -10 | 15 | 2 | 2.922303 | 2.682303 |
| Fground_dev | -1.774804578 | -10 | 15 | 2 | 2.447922 | 2.460607 |
| Fground_dev | -0.878071988 | -10 | 15 | 2 | 2.771126 | 2.617666 |
| Fground_dev | 0.004524048 | -10 | 15 | 2 | 2.867741 | 2.143513 |
| Fground_dev | -0.001948155 | -10 | 15 | 2 | 2.653258 | 2.264557 |
| Fground_dev | 0.110353853 | -10 | 15 | 2 | 2.43473 | 2.638914 |
| Fground_dev | 0.382225092 | -10 | 15 | 2 | 2.179648 | 2.714046 |
| Fground_dev | 1.110836887 | -10 | 15 | 2 | 2.72255 | 2.628658 |
| Fground_dev | 0.331671068 | -10 | 15 | 2 | 2.568864 | 2.918852 |
| Fground_dev | 1.426410285 | -10 | 15 | 2 | 2.489174 | 2.546676 |
| Fground_dev | 0.848886418 | -10 | 15 | 2 | 2.491412 | 2.522649 |
| Fground_dev | 0.963284595 | -10 | 15 | 2 | 2.349253 | 2.535847 |
| Fground_dev | -1.5120535 | -10 | 15 | 2 | 2.453916 | 2.216008 |
| log_a: | 2.537613653 | 1 | 4.5 | 2 | 2.742709 | 2.73427 |
| G_b: | -8.23950454 | -12 | -5 | 2 | -8.51024 | -8.50679 |
| log_aa: | -2.518807718 | -4.61 | -1.39 | 2 | -2.98017 | -2.96114 |
| log_b: | 4.949007858 | 3.869 | 5.05 | 2 | 4.379704 | 4.472672 |
| stdx: | 3.680207823 | 0.1 | 12 | 3 | 6.178232 | 6.300719 |
| log_T04delta: | 3.364342947 | 0 | 4.4 | 3 | 2.235199 | 2.333779 |


| log_T12delta: | 2.989201242 | 0 | 4.4 | 3 | 2.152641 | 2.157542 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| log_R04delta: | 1.852051648 | 0 | 4.4 | 3 | 2.194152 | 2.225931 |
| log_matLdelta: | 3.800662374 | 0 | 4.4 | 7 | 1.973719 | 2.427614 |
| log_matL50: | 4.706093694 | 4.4 | 4.85 | 7 | 4.630267 | 4.619203 |
| log_T04L50: | 4.841721825 | 4 | 5 | 3 | 4.539841 | 4.495495 |
| log_T12L50: | 4.922880263 | 4 | 5 | 3 | 4.456259 | 4.698603 |
| log_R04L50: | 4.914186905 | 4 | 5 | 4 | 4.544697 | 4.495618 |
| log_betar: | -1.08019942 | -12 | 12 | 3 | -0.02894 | 0.086335 |
| logq2: | -0.625086917 | -9 | 2.25 | 5 | -3.52296 | -2.80097 |
| logq3: | -1.067916742 | -9 | 2.25 | 6 | -3.35288 | -3.65839 |
| log_mean_rec: | 0.958560977 | 0.01 | 5 | 1 | 2.296695 | 2.673824 |
| log_mean_Fpot: | -1.1110088 | -15 | -0.01 | 1 | -6.85182 | -6.33306 |
| log_mean_Fground: | -9.347570915 | -15 | -1.6 | 1 | -8.3305 | -8.41907 |
| M | 0.224 | 0.224 | 0.224 | -1 | 0.224 | 0.224 |
| prelegal_var: | 0.018045511 | 0 | 0.15 | 6 | 0.077529 | 0.073004 |
| fishtick_var: | 0.051774166 | 0 | 1 | 6 | 0.509406 | 0.529959 |

Table E.2. An example of the first and $100^{\text {th }}$ jittered parameter values for scenario 1 compared to the original estimates for WAG.

| Parameter | Original <br> Parameter <br> Value | Lower Bound | Upper <br> Bound |  | Phase | Jitter \#1 | $\begin{aligned} & \text { Jitter\# } \\ & 100 \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| rec_dev | -0.008063154 | -5 |  | 5 | 2 | -0.00091 | 0.002301 |
| rec_dev | -0.00978087 | -5 |  | 5 | 2 | -0.00067 | -0.00191 |
| rec_dev | -0.011816765 | -5 |  | 5 | 2 | -0.00052 | -0.00191 |
| rec_dev | -0.014221245 | -5 |  | 5 | 2 | 0.001137 | 0.004131 |
| rec_dev | -0.017031588 | -5 |  | 5 | 2 | -0.00084 | 0.001241 |
| rec_dev | -0.020284059 | -5 |  | 5 | 2 | -0.0019 | 0.004063 |
| rec_dev | -0.02400396 | -5 |  | 5 | 2 | 0.00051 | 0.001359 |
| rec_dev | -0.028190918 | -5 |  | 5 | 2 | -0.00358 | 0.005322 |
| rec_dev | -0.032816518 | -5 |  | 5 | 2 | 0.003274 | -0.00513 |
| rec_dev | -0.037807785 | -5 |  | 5 | 2 | -0.00116 | -0.0002 |
| rec_dev | -0.043033727 | -5 |  | 5 | 2 | 0.016417 | -0.00241 |
| rec_dev | -0.048268279 | -5 |  | 5 | 2 | -0.00721 | 0.0014 |
| rec_dev | -0.053191363 | -5 |  | 5 | 2 | -0.00587 | 0.003168 |
| rec_dev | -0.057340294 | -5 |  | 5 | 2 | -0.00188 | 0.008884 |
| rec_dev | -0.060091827 | -5 |  | 5 | 2 | -0.02577 | -0.0213 |
| rec_dev | -0.060595142 | -5 |  | 5 | 2 | -0.00069 | -0.02674 |
| rec_dev | -0.057624174 | -5 |  | 5 | 2 | -0.00176 | -0.00674 |
| rec_dev | -0.049063386 | -5 |  | 5 | 2 | -0.01857 | -0.00425 |
| rec_dev | -0.030519063 | -5 |  | 5 | 2 | -0.00833 | -0.00095 |
| rec_dev | 0.007031467 | -5 |  | 5 | 2 | -0.00012 | 0.000789 |
| rec_dev | 0.072706409 | -5 |  | 5 | 2 | 0.007403 | 0.004484 |
| rec_dev | 0.156569327 | -5 |  | 5 | 2 | 0.021303 | 0.026841 |
| rec_dev | 0.28356529 | -5 |  | 5 | 2 | 0.016504 | 0.102956 |
| rec_dev | 0.534392075 | -5 |  | 5 | 2 | -0.02417 | -0.04185 |
| rec_dev | 0.629095682 | -5 |  | 5 | 2 | 0.248615 | -0.10565 |
| rec_dev | 0.5248473 | -5 |  | 5 | 2 | -0.08266 | 0.014412 |
| rec_dev | 0.259957227 | -5 |  | 5 | 2 | 0.034184 | -0.02924 |
| rec_dev | -0.109533657 | -5 |  | 5 | 2 | -0.0498 | -0.02017 |
| rec_dev | 0.17943553 | -5 |  | 5 | 2 | -8.6E-05 | 0.052807 |


| rec_dev | -0.067864791 | -5 | 5 | 2 | -0.02104 | -0.00506 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| rec_dev | -0.293657605 | -5 | 5 | 2 | 0.057997 | 0.019413 |
| rec_dev | -0.010999312 | -5 | 5 | 2 | -0.00075 | 0.001503 |
| rec_dev | -0.257019554 | -5 | 5 | 2 | -0.05485 | -0.04815 |
| rec_dev | -0.064084073 | -5 | 5 | 2 | -0.01792 | 0.008792 |
| rec_dev | -0.094375875 | -5 | 5 | 2 | -0.00966 | -0.02522 |
| rec_dev | -0.183588462 | -5 | 5 | 2 | 0.052279 | 0.051892 |
| rec_dev | -0.113411471 | -5 | 5 | 2 | -0.01331 | -0.01429 |
| rec_dev | -0.088579472 | -5 | 5 | 2 | 0.043412 | -0.02008 |
| rec_dev | 0.083702342 | -5 | 5 | 2 | -0.01975 | 0.00918 |
| rec_dev | 0.200477188 | -5 | 5 | 2 | 0.028294 | -0.01553 |
| rec_dev | 0.224821834 | -5 | 5 | 2 | 0.012402 | 0.03042 |
| rec_dev | 0.20807378 | -5 | 5 | 2 | -0.00342 | 0.038067 |
| rec_dev | -0.140016396 | -5 | 5 | 2 | -0.02333 | 0.049768 |
| rec_dev | 0.114428395 | -5 | 5 | 2 | 0.001581 | -0.00202 |
| rec_dev | 0.1226708 | -5 | 5 | 2 | -0.00893 | -0.03072 |
| rec_dev | 0.201039805 | -5 | 5 | 2 | -0.01608 | -0.04787 |
| rec_dev | -0.161709877 | -5 | 5 | 2 | -0.02013 | 0.002006 |
| rec_dev | -0.313486894 | -5 | 5 | 2 | 0.04291 | 0.1491 |
| rec_dev | -0.06409633 | -5 | 5 | 2 | -0.01388 | 0.001384 |
| rec_dev | -0.235743001 | -5 | 5 | 2 | 0.02175 | 0.030929 |
| rec_dev | -0.555435131 | -5 | 5 | 2 | -0.09766 | -0.0733 |
| rec_dev | -0.072343335 | -5 | 5 | 2 | 0.026099 | 0.01357 |
| rec_dev | 0.023564723 | -5 | 5 | 2 | 0.006199 | -0.00776 |
| rec_dev | -0.364189561 | -5 | 5 | 2 | 0.022057 | 0.047748 |
| rec_dev | 0.027498367 | -5 | 5 | 2 | 0.000164 | -0.00162 |
| rec_dev | 0.00000137 | -5 | 5 | 2 | -3.2E-07 | 3.62E-07 |
| Fpot_dev | -3.924112609 | -5 | 5 | 2 | -0.41797 | -2.60238 |
| Fpot_dev | -0.470333935 | -5 | 5 | 2 | -0.09624 | -0.07202 |
| Fpot_dev | -0.060146787 | -5 | 5 | 2 | 0.021983 | -0.00561 |
| Fpot_dev | -1.877169953 | -5 | 5 | 2 | -0.08916 | 0.056157 |
| Fpot_dev | -0.27407322 | -5 | 5 | 2 | -0.05142 | 0.084482 |
| Fpot_dev | 0.792542432 | -5 | 5 | 2 | -0.19056 | -0.02265 |
| Fpot_dev | 0.556393628 | -5 | 5 | 2 | -0.11619 | -0.01884 |
| Fpot_dev | 0.621819135 | -5 | 5 | 2 | -0.12675 | -0.03975 |
| Fpot_dev | 1.167884591 | -5 | 5 | 2 | -0.31695 | 0.082328 |
| Fpot_dev | 0.887495204 | -5 | 5 | 2 | -0.01233 | 0.087504 |
| Fpot_dev | 0.738343054 | -5 | 5 | 2 | -0.05995 | 0.025948 |
| Fpot_dev | 0.361344189 | -5 | 5 | 2 | -0.07207 | -0.03727 |
| Fpot_dev | -0.219187562 | -5 | 5 | 2 | 0.043482 | 0.001679 |
| Fpot_dev | 0.734942761 | -5 | 5 | 2 | -0.1214 | 0.000649 |
| Fpot_dev | 0.533875412 | -5 | 5 | 2 | 0.013037 | -0.06489 |
| Fpot_dev | 0.499632461 | -5 | 5 | 2 | 0.068636 | 0.118536 |
| Fpot_dev | 0.385835606 | -5 | 5 | 2 | -0.0263 | 0.082773 |
| Fpot_dev | 0.126996314 | -5 | 5 | 2 | 0.024954 | -0.01662 |
| Fpot_dev | 0.412724753 | -5 | 5 | 2 | 0.046771 | 0.121588 |
| Fpot_dev | 0.508707407 | -5 | 5 | 2 | -0.03366 | 0.172472 |
| Fpot_dev | 0.379856346 | -5 | 5 | 2 | 0.197416 | 0.014886 |
| Fpot_dev | 0.172048379 | -5 | 5 | 2 | 0.029462 | 0.015716 |
| Fpot_dev | 0.005708468 | -5 | 5 | 2 | -0.00026 | 0.001462 |
| Fpot_dev | -0.128459694 | -5 | 5 | 2 | 0.019458 | -0.00782 |
| Fpot_dev | -0.211394032 | -5 | 5 | 2 | 0.010564 | -0.09031 |
| Fpot_dev | -0.428901935 | -5 | 5 | 2 | -0.04252 | 0.087386 |
| Fpot_dev | -0.345860637 | -5 | 5 | 2 | -0.01006 | -0.06468 |


| Fpot_dev | -0.429188753 | -5 | 5 | 2 | 0.040988 | 0.148252 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| Fpot_dev | -0.338676995 | -5 | 5 | 2 | -0.00495 | 0.004081 |
| Fpot_dev | -0.2920727 | -5 | 5 | 2 | -0.09507 | -0.05632 |
| Fpot_dev | -0.214805708 | -5 | 5 | 2 | 0.016547 | -0.04179 |
| Fpot_dev | -0.042275157 | -5 | 5 | 2 | -0.01497 | -0.00178 |
| Fpot_dev | 0.163841908 | -5 | 5 | 2 | 0.020198 | 0.07839 |
| Fpot_dev | 0.143669186 | -5 | 5 | 2 | 0.012531 | -0.03948 |
| Fpot_dev | 0.062998442 | -5 | 5 | 2 | -0.0079 | 0.011719 |
| Fground_dev | -2.440488208 | -10 | 15 | 2 | 2.359756 | 3.130849 |
| Fground_dev | -0.372149119 | -10 | 15 | 2 | 2.541846 | 2.029075 |
| Fground_dev | -3.26 | -10 | 15 | 2 | 2.179811 | 0.920483 |
| Fground_dev | -0.565669617 | -10 | 15 | 2 | 2.213998 | 3.17078 |
| Fground_dev | -0.00000727 | -10 | 15 | 2 | 2.746651 | 3.199194 |
| Fground_dev | -1.908822385 | -10 | 15 | 2 | 3.209888 | 2.13417 |
| Fground_dev | -0.050231846 | -10 | 15 | 2 | 1.692876 | 3.135659 |
| Fground_dev | 0.335486336 | -10 | 15 | 2 | 2.0031 | 2.826001 |
| Fground_dev | -0.712524737 | -10 | 15 | 2 | 0.997206 | 2.70973 |
| Fground_dev | 0.863452175 | -10 | 15 | 2 | 1.785468 | 2.955309 |
| Fground_dev | 0.521163497 | -10 | 15 | 2 | 2.731771 | 3.582807 |
| Fground_dev | -0.155686865 | -10 | 15 | 2 | 1.26512 | 2.572691 |
| Fground_dev | -0.870248846 | -10 | 15 | 2 | 2.592969 | 2.19296 |
| Fground_dev | -0.197726437 | -10 | 15 | 2 | 3.177496 | 2.674357 |
| Fground_dev | -1.282915275 | -10 | 15 | 15 | 2 | 2.786811 |


| M | 0.224 | 0.224 | 0.224 | -1 | 0.224 | 0.224 |
| :--- | ---: | ---: | ---: | ---: | ---: | ---: |
| prelegal_var: | 0.020928046 | 0 | 0.15 | 6 | 0.087381 | 0.07614 |
| fishtick_var: | 0.016400027 | 0 | 1 | 6 | 0.226077 | 0.188182 |

Table E.3. Results from 100 jitter runs for scenario 1 for EAG. Jitter run 0 corresponds to the original optimized estimates. Note: $\mathrm{B}_{\text {MSY }}$ reference points were based on average recruitment for 1986-2016.

| Jitter Run | Objective Function | Maximum Gradient | $\mathrm{B}_{35 \%}(\mathrm{t})$ | OFL $(\mathrm{t})$ | Current MMB ( t$)$ |
| ---: | ---: | ---: | ---: | ---: | ---: |
| $\mathbf{0}$ | 357.95 | $\mathbf{0 . 0 0 0 0 1 6 3 1}$ | $\mathbf{6 2 7 6 . 3 0}$ | $\mathbf{3 9 8 5 . 9 3}$ | 8536.48 |
| 1 | 357.93 | 0.00000020 | 6276.36 | 3985.78 | 8536.79 |
| $\mathbf{2}$ | 357.93 | 0.00000541 | 6276.36 | 3985.78 | 8536.79 |
| 3 | 357.93 | 0.00011579 | 6276.36 | 3985.78 | 8536.79 |
| 4 | 357.93 | 0.00006966 | 6276.36 | 3985.78 | 8536.79 |
| 5 | 357.93 | 0.00003572 | 6276.36 | 3985.78 | 8536.79 |
| 6 | 357.93 | 0.00001752 | 6276.36 | 3985.78 | 8536.79 |
| 7 | 357.93 | 0.00005470 | 6276.36 | 3985.78 | 8536.79 |
| 8 | 357.93 | 0.00011744 | 6276.36 | 3985.78 | 8536.79 |
| 9 | 357.93 | 0.00005891 | 6276.36 | 3985.78 | 8536.79 |
| 10 | 357.93 | 0.00003164 | 6276.36 | 3985.78 | 8536.79 |
| 11 | 357.93 | 0.00000319 | 6276.36 | 3985.78 | 8536.79 |
| 12 | 357.93 | 0.00002234 | 6276.36 | 3985.78 | 8536.79 |
| 13 | 357.93 | 0.00001383 | 6276.36 | 3985.78 | 8536.79 |
| 14 | 357.93 | 0.00001126 | 6276.36 | 3985.78 | 8536.79 |
| 15 | 357.93 | 0.00010222 | 6276.36 | 3985.78 | 8536.79 |
| 16 | 357.93 | 0.00000291 | 6276.36 | 3985.78 | 8536.79 |
| 17 | 357.93 | 0.00002518 | 6276.36 | 3985.78 | 8536.79 |
| 18 | 357.93 | 0.00010882 | 6276.36 | 3985.78 | 8536.78 |
| 19 | 357.93 | 0.00000005 | 6276.36 | 3985.78 | 8536.79 |
| 20 | 357.93 | 0.00006426 | 6276.36 | 3985.78 | 8536.79 |
| 21 | 357.93 | 0.00000069 | 6276.36 | 3985.78 | 8536.79 |
| 22 | 357.93 | 0.00001009 | 6276.36 | 3985.78 | 8536.79 |
| 23 | 357.93 | 0.00003613 | 6276.36 | 3985.78 | 8536.79 |
| 24 | 357.93 | 0.00009340 | 6276.36 | 3985.78 | 8536.79 |
| 25 | 357.93 | 0.00026646 | 6276.35 | 3985.78 | 8536.78 |
| 26 | 357.93 | 0.00006301 | 6276.36 | 3985.78 | 8536.79 |
| 27 | 357.93 | 0.00004337 | 6276.36 | 3985.78 | 8536.79 |
| 28 | 357.93 | 0.00003351 | 6276.36 | 3985.78 | 8536.79 |
| 29 | 357.93 | 0.00003022 | 6276.36 | 3985.78 | 8536.78 |
| 30 | 357.93 | 0.00005049 | 6276.36 | 3985.78 | 8536.79 |
| 31 | 357.93 | 0.00000001 | 6276.36 | 3985.78 | 8536.79 |
| 32 | 357.93 | 0.00017354 | 6276.36 | 3985.78 | 8536.79 |
| 33 | 357.93 | 0.00010732 | 6276.36 | 3985.78 | 8536.79 |
| 2 |  |  |  |  |  |


| 34 | 357.93 | 0.00003140 | 6276.36 | 3985.78 | 8536.79 |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 35 | 357.93 | 0.00018539 | 6276.36 | 3985.78 | 8536.79 |
| 36 | 357.93 | 0.00001242 | 6276.36 | 3985.78 | 8536.79 |
| 37 | 357.93 | 0.00012196 | 6276.36 | 3985.78 | 8536.78 |
| 38 | 357.93 | 0.00000610 | 6276.36 | 3985.78 | 8536.79 |
| 39 | 357.93 | 0.00001384 | 6276.36 | 3985.78 | 8536.79 |
| 40 | 357.93 | 0.00001617 | 6276.36 | 3985.78 | 8536.79 |
| 41 | 357.93 | 0.00008444 | 6276.36 | 3985.78 | 8536.79 |
| 42 | 357.93 | 0.00011264 | 6276.36 | 3985.78 | 8536.79 |
| 43 | 357.93 | 0.00000742 | 6276.36 | 3985.78 | 8536.79 |
| 44 | 357.93 | 0.00088110 | 6276.37 | 3985.78 | 8536.80 |
| 45 | 357.93 | 0.00000432 | 6276.36 | 3985.78 | 8536.79 |
| 46 | 357.93 | 0.00004927 | 6276.36 | 3985.78 | 8536.79 |
| 47 | 357.93 | 0.00003060 | 6276.36 | 3985.78 | 8536.79 |
| 48 | 357.93 | 0.00011714 | 6276.35 | 3985.78 | 8536.79 |
| 49 | 357.93 | 0.00010607 | 6276.36 | 3985.78 | 8536.79 |
| 50 | 357.93 | 0.00001854 | 6276.36 | 3985.78 | 8536.79 |
| 51 | 357.93 | 0.00003346 | 6276.36 | 3985.78 | 8536.79 |
| 52 | 357.93 | 0.00003206 | 6276.36 | 3985.78 | 8536.79 |
| 53 | 357.93 | 0.00005319 | 6276.36 | 3985.78 | 8536.79 |
| 54 | 357.93 | 0.00002535 | 6276.36 | 3985.78 | 8536.79 |
| 55 | 357.93 | 0.00001109 | 6276.36 | 3985.78 | 8536.79 |
| 56 | 357.93 | 0.00005972 | 6276.36 | 3985.78 | 8536.79 |
| 57 | 357.93 | 0.00000006 | 6276.36 | 3985.78 | 8536.79 |
| 58 | 357.93 | 0.00060162 | 6276.36 | 3985.78 | 8536.79 |
| 59 | 357.93 | 0.00001156 | 6276.36 | 3985.78 | 8536.79 |
| 60 | 357.93 | 0.00018979 | 6276.36 | 3985.78 | 8536.79 |
| 61 | 357.93 | 0.00001340 | 6276.36 | 3985.78 | 8536.79 |
| 62 | 357.93 | 0.00000860 | 6276.36 | 3985.78 | 8536.79 |
| 63 | 357.93 | 0.00003140 | 6276.36 | 3985.78 | 8536.79 |
| 64 | 357.93 | 0.00008224 | 6276.36 | 3985.78 | 8536.79 |
| 65 | 357.93 | 0.00067994 | 6276.35 | 3985.78 | 8536.77 |
| 66 | 357.93 | 0.00015629 | 6276.36 | 3985.78 | 8536.79 |
| 67 | 357.93 | 0.00000958 | 6276.36 | 3985.78 | 8536.79 |
| 68 | 357.93 | 0.00002085 | 6276.36 | 3985.78 | 8536.79 |
| 69 | 357.93 | 0.00001779 | 6276.36 | 3985.78 | 8536.79 |
| 70 | 357.93 | 0.00013929 | 6276.36 | 3985.78 | 8536.79 |
| 71 | 357.93 | 0.00033909 | 6276.36 | 3985.78 | 8536.79 |
| 72 | 357.93 | 0.00005027 | 6276.36 | 3985.78 | 8536.79 |
| 73 | 03793 | 0.00039076 | 6276.35 | 3985.78 | 8536.78 |
| 74 | 0.00004030 | 6276.36 | 3985.78 | 8536.79 |  |
| 76 | 0.00000047 | 6691.96 | 4201.83 | 8967.41 |  |
| 5 | 0.00000065 | 6276.36 | 3985.78 | 8536.79 |  |


| 77 | 357.93 | 0.00007385 | 6276.36 | 3985.78 | 8536.79 |
| ---: | :--- | :--- | :--- | :--- | :--- |
| 78 | 357.93 | 0.00001649 | 6276.36 | 3985.78 | 8536.79 |
| 79 | 357.93 | 0.00005696 | 6276.36 | 3985.78 | 8536.79 |
| 80 | 357.93 | 0.00040599 | 6276.36 | 3985.78 | 8536.79 |
| 81 | 357.93 | 0.00004797 | 6276.36 | 3985.78 | 8536.79 |
| 82 | 357.93 | 0.00000075 | 6276.36 | 3985.78 | 8536.79 |
| 83 | 357.93 | 0.00005594 | 6276.36 | 3985.78 | 8536.79 |
| 84 | 357.93 | 0.00027085 | 6276.36 | 3985.78 | 8536.79 |
| 85 | 357.93 | 0.00006286 | 6276.36 | 3985.78 | 8536.79 |
| 86 | 357.93 | 0.00001511 | 6276.36 | 3985.78 | 8536.79 |
| 87 | 357.93 | 0.00000012 | 6276.36 | 3985.78 | 8536.79 |
| 88 | 357.93 | 0.00000239 | 6276.36 | 3985.78 | 8536.79 |
| 89 | 357.93 | 0.00003953 | 6276.36 | 3985.78 | 8536.79 |
| 90 | 357.93 | 0.00006176 | 6276.36 | 3985.78 | 8536.79 |
| 91 | 357.93 | 0.00001704 | 6276.36 | 3985.78 | 8536.79 |
| 92 | 357.93 | 0.00000050 | 6276.36 | 3985.78 | 8536.79 |
| 93 | 357.93 | 0.00013988 | 6276.36 | 3985.78 | 8536.79 |
| 94 | 357.93 | 0.00006838 | 6276.36 | 3985.78 | 8536.79 |
| 95 | 357.93 | 0.00039626 | 6276.36 | 3985.78 | 8536.79 |
| 96 | 357.93 | 0.00005871 | 6276.36 | 3985.78 | 8536.79 |
| 97 | 357.93 | 0.00001415 | 6276.36 | 3985.78 | 8536.79 |
| 98 | 357.93 | 0.00003001 | 6276.36 | 3985.78 | 8536.79 |
| 99 | 357.93 | 0.00017344 | 6276.36 | 3985.78 | 8536.79 |
| 100 | 357.93 | 0.00001320 | 6276.36 | 3985.78 | 8536.79 |

Table E.4. Results from 100 jitter runs for scenario 9 for EAG. Jitter run 0 corresponds to the original optimized estimates. Note: $\mathrm{B}_{\text {MSY }}$ reference points were based on average recruitment for 1986-2016.

| Jitter <br> Run |  |  |  |  | Current <br> Objective Function |  |  |
| :--- | ---: | ---: | ---: | :--- | :--- | :---: | :---: |
| $\mathbf{0}$ | $\mathbf{3 5 7 . 7 7 8 2}$ | $\mathbf{0 . 0 0 0 0 0 0 6 7}$ | $\mathbf{6 8 7 9 . 2 6}$ | $\mathbf{4 4 8 5 . 9 8}$ | $\mathbf{9 3 0 5 . 6 6}$ |  |  |
| $\mathbf{1}$ | 357.7782 | 0.00002027 | 6879.22 | 4485.98 | 9305.62 |  |  |
| $\mathbf{2}$ | 357.7782 | 0.00000417 | 6879.26 | 4485.98 | 9305.66 |  |  |
| $\mathbf{3}$ | 357.7782 | 0.00000452 | 6879.26 | 4485.98 | 9305.66 |  |  |
| $\mathbf{4}$ | 357.7782 | 0.00000200 | 6879.26 | 4485.98 | 9305.66 |  |  |
| $\mathbf{5}$ | 357.7782 | 0.00000957 | 6879.26 | 4485.98 | 9305.66 |  |  |
| 6 | 357.7782 | 0.00001232 | 6879.26 | 4485.98 | 9305.66 |  |  |
| $\mathbf{7}$ | 357.7782 | 0.00000591 | 6879.26 | 4485.98 | 9305.66 |  |  |
| 8 | 357.7782 | 0.00000004 | 6879.26 | 4485.98 | 9305.66 |  |  |
| $\mathbf{8}$ | 357.7782 | 0.00000329 | 6879.26 | 4485.98 | 9305.66 |  |  |


| 10 | 357.7782 | 0.00000106 | 6879.26 | 4485.98 | 9305.66 |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 11 | 357.7782 | 0.00000078 | 6879.27 | 4485.98 | 9305.66 |
| 12 | 357.7782 | 0.00001539 | 6879.26 | 4485.98 | 9305.66 |
| 13 | 357.7782 | 0.00012618 | 6879.26 | 4485.98 | 9305.66 |
| 14 | 357.7782 | 0.00000005 | 6879.26 | 4485.98 | 9305.66 |
| 15 | 357.7782 | 0.00000571 | 6879.26 | 4485.98 | 9305.66 |
| 16 | 357.7782 | 0.00000764 | 6879.26 | 4485.98 | 9305.66 |
| 17 | 357.7782 | 0.00000338 | 6879.26 | 4485.98 | 9305.66 |
| 18 | 357.7782 | 0.00000077 | 6879.26 | 4485.98 | 9305.66 |
| 19 | 357.7782 | 0.00005681 | 6879.27 | 4485.98 | 9305.66 |
| 20 | 357.7782 | 0.00000377 | 6879.26 | 4485.98 | 9305.66 |
| 21 | 357.7782 | 0.00001781 | 6879.26 | 4485.98 | 9305.66 |
| 22 | 357.7782 | 0.00000041 | 6879.26 | 4485.98 | 9305.66 |
| 23 | 357.7782 | 0.00000448 | 6879.26 | 4485.98 | 9305.66 |
| 24 | 357.7782 | 0.00000060 | 6879.26 | 4485.98 | 9305.66 |
| 25 | 357.8240 | 0.14128300 | 6879.63 | 4532.16 | 9273.56 |
| 26 | 357.7782 | 0.00000064 | 6879.26 | 4485.98 | 9305.66 |
| 27 | 357.7782 | 0.00000054 | 6879.26 | 4485.98 | 9305.66 |
| 28 | 357.7782 | 0.00000204 | 6879.26 | 4485.98 | 9305.66 |
| 29 | 357.7782 | 0.00001235 | 6879.26 | 4485.98 | 9305.66 |
| 30 | 357.7782 | 0.00000964 | 6879.26 | 4485.98 | 9305.66 |
| 31 | 365.4934 | 0.00017560 | 7296.68 | 4774.49 | 9728.41 |
| 32 | 357.7782 | 0.00000932 | 6879.26 | 4485.98 | 9305.66 |
| 33 | 357.7782 | 0.00000019 | 6879.26 | 4485.98 | 9305.66 |
| 34 | 357.7782 | 0.00000048 | 6879.26 | 4485.98 | 9305.66 |
| 35 | 357.7782 | 0.00000056 | 6879.26 | 4485.98 | 9305.66 |
| 36 | 357.7782 | 0.00000166 | 6879.26 | 4485.98 | 9305.66 |
| 37 | 357.7782 | 0.00005135 | 6879.26 | 4485.98 | 9305.66 |
| 38 | 357.7782 | 0.00001054 | 6879.26 | 4485.98 | 9305.66 |
| 39 | 357.7782 | 0.00000060 | 6879.26 | 4485.98 | 9305.66 |
| 40 | 357.7782 | 0.00000061 | 6879.26 | 4485.98 | 9305.66 |
| 41 | 357.7782 | 0.00000183 | 6879.26 | 4485.98 | 9305.66 |
| 42 | 357.7782 | 0.00000876 | 6879.26 | 4485.98 | 9305.66 |
| 43 | 357.7782 | 0.00000086 | 6879.26 | 4485.98 | 9305.66 |
| 44 | 357.7782 | 0.00001746 | 6879.26 | 4485.98 | 9305.66 |
| 45 | 357.7782 | 0.00000035 | 6879.26 | 4485.98 | 9305.66 |
| 46 | 357.7782 | 0.00000083 | 6879.26 | 4485.98 | 9305.66 |
| 47 | 357.7782 | 0.00000286 | 6879.26 | 4485.98 | 9305.66 |
| 48 | 357.7782 | 0.00000686 | 6879.26 | 4485.98 | 9305.66 |
| 49 | 357.7782 | 0.00000193 | 6879.26 | 4485.98 | 9305.66 |
| 50 | 357.7782 | 0.00000202 | 6879.26 | 4485.98 | 9305.66 |
| 51 | 357.7782 | 0.00000040 | 6879.26 | 4485.98 | 9305.66 |
| 52 | 357.7782 | 0.00000676 | 6879.26 | 4485.98 | 9305.66 |


| 53 | 357.7782 | 0.00001494 | 6879.27 | 4485.98 | 9305.66 |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 54 | 357.7782 | 0.00001841 | 6879.26 | 4485.98 | 9305.66 |
| 55 | 357.7782 | 0.00000103 | 6879.26 | 4485.98 | 9305.66 |
| 56 | 357.7782 | 0.00000528 | 6879.26 | 4485.98 | 9305.66 |
| 57 | 357.7782 | 0.00000792 | 6879.26 | 4485.98 | 9305.66 |
| 58 | 357.7782 | 0.00000052 | 6879.26 | 4485.98 | 9305.66 |
| 59 | 357.7782 | 0.00003530 | 6879.26 | 4485.98 | 9305.66 |
| 60 | 357.7782 | 0.00000137 | 6879.26 | 4485.98 | 9305.66 |
| 61 | 357.7782 | 0.00000891 | 6879.26 | 4485.98 | 9305.66 |
| 62 | 357.7782 | 0.00006055 | 6879.27 | 4485.98 | 9305.66 |
| 63 | 357.7782 | 0.00000095 | 6879.26 | 4485.98 | 9305.66 |
| 64 | 357.7782 | 0.00000438 | 6879.26 | 4485.98 | 9305.66 |
| 65 | 357.7782 | 0.00000373 | 6879.26 | 4485.98 | 9305.66 |
| 66 | 357.7782 | 0.00000581 | 6879.26 | 4485.98 | 9305.66 |
| 67 | 357.7782 | 0.00000273 | 6879.26 | 4485.98 | 9305.66 |
| 68 | 357.7782 | 0.00000145 | 6879.26 | 4485.98 | 9305.66 |
| 69 | 357.7782 | 0.00000018 | 6879.26 | 4485.98 | 9305.66 |
| 70 | 357.7782 | 0.00000925 | 6879.26 | 4485.98 | 9305.66 |
| 71 | 357.7782 | 0.00000041 | 6879.26 | 4485.98 | 9305.66 |
| 72 | 357.7782 | 0.00000031 | 6879.26 | 4485.98 | 9305.66 |
| 73 | 357.7782 | 0.00000176 | 6879.26 | 4485.98 | 9305.66 |
| 74 | 357.7782 | 0.00000060 | 6879.26 | 4485.98 | 9305.66 |
| 75 | 357.7782 | 0.00001089 | 6879.26 | 4485.98 | 9305.66 |
| 76 | 357.7782 | 0.00000229 | 6879.26 | 4485.98 | 9305.66 |
| 77 | 357.7782 | 0.00000185 | 6879.26 | 4485.98 | 9305.66 |
| 78 | 357.7782 | 0.00002407 | 6879.26 | 4485.98 | 9305.66 |
| 79 | 357.7782 | 0.00000660 | 6879.26 | 4485.98 | 9305.66 |
| 80 | 357.7782 | 0.00000035 | 6879.26 | 4485.98 | 9305.66 |
| 81 | 357.7782 | 0.00000359 | 6879.26 | 4485.98 | 9305.66 |
| 82 | 357.7782 | 0.00001785 | 6879.28 | 4485.98 | 9305.67 |
| 83 | 357.7782 | 0.00000048 | 6879.26 | 4485.98 | 9305.66 |
| 84 | 357.7782 | 0.00000043 | 6879.26 | 4485.98 | 9305.66 |
| 85 | 357.7782 | 0.00003714 | 6879.35 | 4485.98 | 9305.75 |
| 86 | 357.7782 | 0.00000420 | 6879.26 | 4485.98 | 9305.66 |
| 87 | 357.7782 | 0.00001208 | 6879.26 | 4485.98 | 9305.66 |
| 94 | 357.7782 | 0.00004316 | 6879.26 | 4485.98 | 9305.66 |
| 95 | 357.7782 | 0.00000040 | 6879.26 | 4485.98 | 9305.66 |
| 98 | 357.7782 | 0.00000110 | 6879.26 | 4485.98 | 9305.66 |
| 99 | 357.7782 | 0.00000039 | 6879.26 | 4485.98 | 9305.66 |
| 90 | 357.7782 | 0.00000028 | 6879.26 | 4485.98 | 9305.66 |
| 92 | 357.7782 | 0.00000122 | 6879.26 | 4485.98 | 9305.66 |
| 93 | 0.00001483 | 6879.27 | 4485.98 | 9305.66 |  |
| 95 | 0.00002021 | 6879.26 | 4485.98 | 9305.66 |  |


| 96 | 357.7782 | 0.00000712 | 6879.26 | 4485.98 | 9305.66 |
| ---: | ---: | ---: | ---: | ---: | ---: |
| 97 | 357.7782 | 0.00000112 | 6879.26 | 4485.98 | 9305.66 |
| 98 | 357.7782 | 0.00006316 | 6879.32 | 4485.98 | 9305.72 |
| 99 | 357.7782 | 0.00000930 | 6879.26 | 4485.98 | 9305.66 |
| 100 | 357.7782 | 0.00000044 | 6879.26 | 4485.98 | 9305.66 |

Table E.5. Results from 100 jitter runs for scenario 1for WAG. Jitter run 0 corresponds to the original optimized estimates. Note: $\mathrm{B}_{\mathrm{MSY}}$ reference points were based on average recruitment for 1986-2016.

| Jitter <br> Run | Objective Function | Maximum Gradient | $\mathrm{B}_{35 \%}(\mathrm{t})$ | OFL (t) | Current MMB <br> (t) |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 0 | 275.26 | 0.00006408 | 4722.22 | 1280.18 | 4402.63 |
| 1 | 272.08 | 0.00020991 | 5157.51 | 1256.94 | 4609.18 |
| 2 | 275.22 | 0.00000181 | 4741.02 | 1250.49 | 4395.09 |
| 3 | 275.22 | 0.00006921 | 4741.02 | 1250.49 | 4395.09 |
| 4 | 275.22 | 0.00000046 | 4741.02 | 1250.49 | 4395.09 |
| 5 | 275.22 | 0.00026624 | 4741.03 | 1250.49 | 4395.09 |
| 6 | 275.22 | 0.00002435 | 4741.02 | 1250.49 | 4395.09 |
| 7 | 275.22 | 0.00009719 | 4741.02 | 1250.49 | 4395.09 |
| 8 | 275.22 | 0.00009279 | 4741.02 | 1250.49 | 4395.09 |
| 9 | 275.22 | 0.00000384 | 4741.02 | 1250.49 | 4395.09 |
| 10 | 275.22 | 0.00000921 | 4741.02 | 1250.49 | 4395.09 |
| 11 | 275.22 | 0.00010524 | 4741.02 | 1250.49 | 4395.08 |
| 12 | 272.08 | 0.00003695 | 5157.51 | 1256.94 | 4609.18 |
| 13 | 275.22 | 0.00000345 | 4741.02 | 1250.49 | 4395.09 |
| 14 | 275.22 | 0.00002612 | 4741.02 | 1250.49 | 4395.09 |
| 15 | 275.22 | 0.00003335 | 4741.02 | 1250.49 | 4395.09 |
| 16 | 271.90 | 0.00001829 | 5186.77 | 1242.78 | 4594.43 |
| 17 | 275.22 | 0.00005598 | 4741.02 | 1250.49 | 4395.09 |
| 18 | 275.22 | 0.00000156 | 4741.02 | 1250.49 | 4395.09 |
| 19 | 275.22 | 0.00000216 | 4741.02 | 1250.49 | 4395.09 |
| 20 | 275.22 | 0.00000317 | 4741.02 | 1250.49 | 4395.09 |
| 21 | 275.22 | 0.00022139 | 4741.02 | 1250.49 | 4395.09 |
| 22 | 275.22 | 0.00004471 | 4741.02 | 1250.49 | 4395.09 |
| 23 | 275.22 | 0.00005165 | 4741.02 | 1250.49 | 4395.09 |
| 24 | 275.22 | 0.00001324 | 4741.02 | 1250.49 | 4395.09 |
| 25 | 275.22 | 0.00010225 | 4741.02 | 1250.49 | 4395.09 |
| 26 | 275.22 | 0.00011112 | 4741.02 | 1250.49 | 4395.09 |
| 27 | 275.22 | 0.00004498 | 4741.02 | 1250.49 | 4395.09 |
| 28 | 275.22 | 0.00000013 | 4741.02 | 1250.49 | 4395.09 |


| 29 | 272.08 | 0.00011043 | 5157.52 | 1256.94 | 4609.18 |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 30 | 275.22 | 0.00006034 | 4741.02 | 1250.49 | 4395.09 |
| 31 | 275.22 | 0.00000778 | 4741.02 | 1250.49 | 4395.09 |
| 32 | 275.22 | 0.00000002 | 4741.02 | 1250.49 | 4395.09 |
| 33 | 275.22 | 0.00000001 | 4741.02 | 1250.49 | 4395.09 |
| 34 | 275.22 | 0.00004915 | 4741.02 | 1250.49 | 4395.09 |
| 35 | 275.22 | 0.00014347 | 4741.02 | 1250.49 | 4395.09 |
| 36 | 275.22 | 0.00000968 | 4741.02 | 1250.49 | 4395.09 |
| 37 | 275.22 | 0.00008531 | 4741.02 | 1250.49 | 4395.09 |
| 38 | 275.22 | 0.00003593 | 4741.02 | 1250.49 | 4395.09 |
| 39 | 276.19 | 0.00000038 | 5128.26 | 1252.06 | 4580.12 |
| 40 | 272.08 | 0.00010997 | 5157.51 | 1256.94 | 4609.18 |
| 41 | 275.22 | 0.00012720 | 4741.02 | 1250.49 | 4395.09 |
| 42 | 275.22 | 0.00012620 | 4741.03 | 1250.49 | 4395.09 |
| 43 | 275.22 | 0.00003131 | 4741.02 | 1250.49 | 4395.09 |
| 44 | 275.22 | 0.00005433 | 4741.02 | 1250.49 | 4395.09 |
| 45 | 275.22 | 0.00005734 | 4741.02 | 1250.49 | 4395.08 |
| 46 | 275.22 | 0.00000293 | 4741.02 | 1250.49 | 4395.09 |
| 47 | 275.22 | 0.00016022 | 4741.02 | 1250.49 | 4395.09 |
| 48 | 275.22 | 0.00002603 | 4741.02 | 1250.49 | 4395.09 |
| 49 | 275.22 | 0.00000061 | 4741.02 | 1250.49 | 4395.09 |
| 50 | 275.22 | 0.00005500 | 4741.02 | 1250.49 | 4395.09 |
| 51 | 275.22 | 0.00000071 | 4741.02 | 1250.49 | 4395.09 |
| 52 | 275.22 | 0.00002028 | 4741.02 | 1250.49 | 4395.09 |
| 53 | 275.22 | 0.00011690 | 4741.02 | 1250.49 | 4395.09 |
| 54 | 275.22 | 0.00000509 | 4741.02 | 1250.49 | 4395.09 |
| 55 | 275.22 | 0.00005520 | 4741.02 | 1250.49 | 4395.09 |
| 56 | 275.22 | 0.00012576 | 4741.02 | 1250.49 | 4395.09 |
| 57 | 275.22 | 0.00055220 | 4741.02 | 1250.49 | 4395.08 |
| 58 | 275.22 | 0.00000021 | 4741.02 | 1250.49 | 4395.09 |
| 59 | 275.22 | 0.00008351 | 4741.02 | 1250.49 | 4395.09 |
| 60 | 275.22 | 0.00000071 | 4741.02 | 1250.49 | 4395.09 |
| 61 | 275.22 | 0.00000113 | 4741.02 | 1250.49 | 4395.09 |
| 62 | 275.22 | 0.00004604 | 4741.02 | 1250.49 | 4395.09 |
| 63 | 275.22 | 0.00020403 | 4741.02 | 1250.49 | 4395.09 |
| 64 | 275.22 | 0.00006138 | 4741.02 | 1250.49 | 4395.09 |
| 65 | 275.22 | 0.00000096 | 4741.02 | 1250.49 | 4395.09 |
| 66 | 275.22 | 0.00001358 | 4741.02 | 1250.49 | 4395.09 |
| 67 | 275.22 | 0.00002428 | 4741.02 | 1250.49 | 4395.09 |
| 68 | 275.22 | 0.00000259 | 4741.02 | 1250.49 | 4395.09 |
| 69 | 275.22 | 0.00000901 | 4741.02 | 1250.49 | 4395.09 |
| 70 | 272.08 | 0.00000705 | 5157.51 | 1256.94 | 4609.18 |
| 71 | 275.22 | 0.00000697 | 4741.02 | 1250.49 | 4395.09 |


| 72 | 272.08 | 0.00000119 | 5157.51 | 1256.94 | 4609.18 |
| ---: | ---: | ---: | ---: | ---: | ---: |
| 73 | 275.22 | 0.00017395 | 4741.03 | 1250.49 | 4395.09 |
| 74 | 275.22 | 0.00067063 | 4741.02 | 1250.49 | 4395.08 |
| 75 | 275.22 | 0.00001000 | 4741.02 | 1250.49 | 4395.09 |
| 76 | 275.22 | 0.00002803 | 4741.02 | 1250.49 | 4395.09 |
| 77 | 275.22 | 0.00002205 | 4741.02 | 1250.49 | 4395.09 |
| 78 | 275.22 | 0.00000185 | 4741.02 | 1250.49 | 4395.09 |
| 79 | 275.22 | 0.00009501 | 4741.03 | 1250.49 | 4395.09 |
| 80 | 272.08 | 0.00000206 | 5157.51 | 1256.94 | 4609.18 |
| 81 | 275.22 | 0.00002467 | 4741.02 | 1250.49 | 4395.09 |
| 82 | 275.22 | 0.00000349 | 4741.02 | 1250.49 | 4395.09 |
| 83 | 275.22 | 0.00005818 | 4741.02 | 1250.49 | 4395.09 |
| 84 | 275.22 | 0.00001808 | 4741.02 | 1250.49 | 4395.09 |
| 85 | 275.22 | 0.00000908 | 4741.02 | 1250.49 | 4395.09 |
| 86 | 275.22 | 0.00000007 | 4741.02 | 1250.49 | 4395.09 |
| 87 | 275.22 | 0.00000079 | 4741.02 | 1250.49 | 4395.09 |
| 88 | 275.22 | 0.00000072 | 4741.02 | 1250.49 | 4395.09 |
| 89 | 272.08 | 0.00000361 | 5157.51 | 1256.94 | 4609.18 |
| 90 | 275.22 | 0.00005307 | 4741.02 | 1250.49 | 4395.09 |
| 91 | 275.22 | 0.00003018 | 4741.02 | 1250.49 | 4395.09 |
| 92 | 275.22 | 0.00017475 | 4741.02 | 1250.49 | 4395.09 |
| 93 | 275.22 | 0.00000536 | 4741.02 | 1250.49 | 4395.09 |
| 94 | 275.22 | 0.00002238 | 4741.02 | 1250.49 | 4395.09 |
| 95 | 275.22 | 0.00002886 | 4741.02 | 1250.49 | 4395.09 |
| 96 | 275.22 | 0.00041212 | 4741.03 | 1250.49 | 4395.09 |
| 97 | 275.22 | 0.00008484 | 4741.02 | 1250.49 | 4395.09 |
| 98 | 275.22 | 0.00090622 | 4741.02 | 1250.49 | 4395.08 |
| 99 | 275.22 | 0.00000052 | 4741.02 | 1250.49 | 4395.09 |
| 100 | 275.22 | 0.00008280 | 4741.03 | 1250.49 | 4395.09 |
|  |  |  |  |  |  |
| 7 |  |  |  |  |  |

Table E.6. Results from 100 jitter runs for scenario 9 for WAG. Jitter run 0 corresponds to the original optimized estimates. Note: $\mathrm{B}_{\mathrm{MSY}}$ reference points were based on average recruitment for 1986-2016.

| Jitter <br> Run | Objective <br> Function |  |  |  |  | Current <br> MMB |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| $\mathbf{0}$ | $\mathbf{2 7 5 . 1 0}$ | $\mathbf{0 . 0 0 0 0 0 1 2 2}$ | $\mathbf{5 1 3 6 . 6 9}$ | $\mathbf{1 5 1 2 . 3 9}$ | $\mathbf{4 9 4 6 . 1 8}$ |  |
| $\mathbf{1}$ | 275.10 | 0.00000086 | 5136.69 | 1512.39 | 4946.18 |  |
| $\mathbf{2}$ | 271.92 | 0.00001024 | 5593.79 | 1524.07 | 5196.63 |  |
| $\mathbf{3}$ | 275.10 | 0.00000062 | 5136.69 | 1512.39 | 4946.18 |  |
| $\mathbf{4}$ | 275.10 | 0.00000066 | 5136.69 | 1512.39 | 4946.18 |  |


| 5 | 275.10 | 0.00000056 | 5136.69 | 1512.39 | 4946.18 |
| ---: | ---: | ---: | :--- | :--- | :--- |
| 6 | 275.10 | 0.00000434 | 5136.69 | 1512.39 | 4946.18 |
| 7 | 275.10 | 0.00000009 | 5136.69 | 1512.39 | 4946.18 |
| 8 | 275.10 | 0.00000150 | 5136.69 | 1512.39 | 4946.18 |
| 9 | 275.10 | 0.00001277 | 5136.69 | 1512.39 | 4946.18 |
| 10 | 275.10 | 0.00000602 | 5136.69 | 1512.39 | 4946.18 |
| 11 | 275.10 | 0.00019482 | 5136.69 | 1512.39 | 4946.18 |
| 12 | 275.10 | 0.00000832 | 5136.69 | 1512.39 | 4946.18 |
| 13 | 275.10 | 0.00002946 | 5136.69 | 1512.39 | 4946.18 |
| 14 | 275.10 | 0.00000191 | 5136.69 | 1512.39 | 4946.18 |
| 15 | 275.10 | 0.00000150 | 5136.69 | 1512.39 | 4946.18 |
| 16 | 271.92 | 0.00000079 | 5593.79 | 1524.07 | 5196.63 |
| 17 | 275.10 | 0.00002771 | 5136.69 | 1512.39 | 4946.18 |
| 18 | 275.10 | 0.00000567 | 5136.69 | 1512.39 | 4946.18 |
| 19 | 275.10 | 0.00004282 | 5136.69 | 1512.39 | 4946.18 |
| 20 | 275.10 | 0.00004036 | 5136.67 | 1512.39 | 4946.16 |
| 21 | 275.10 | 0.00000322 | 5136.69 | 1512.39 | 4946.18 |
| 22 | 275.10 | 0.00000084 | 5136.69 | 1512.39 | 4946.18 |
| 23 | 275.10 | 0.00000631 | 5136.69 | 1512.39 | 4946.18 |
| 24 | 275.10 | 0.00000067 | 5136.69 | 1512.39 | 4946.18 |
| 25 | 275.10 | 0.00000252 | 5136.69 | 1512.39 | 4946.18 |
| 26 | 275.10 | 0.00002649 | 5136.69 | 1512.39 | 4946.18 |
| 27 | 275.10 | 0.00003961 | 5136.69 | 1512.39 | 4946.18 |
| 28 | 275.10 | 0.00006224 | 5136.70 | 1512.39 | 4946.19 |
| 29 | 275.10 | 0.00000407 | 5136.69 | 1512.39 | 4946.18 |
| 30 | 275.10 | 0.00002247 | 5136.69 | 1512.39 | 4946.18 |
| 31 | 275.10 | 0.00000775 | 5136.68 | 1512.39 | 4946.18 |
| 32 | 275.10 | 0.00008106 | 5136.80 | 1512.39 | 4946.28 |
| 33 | 275.10 | 0.00000194 | 5136.69 | 1512.39 | 4946.18 |
| 34 | 275.10 | 0.00000129 | 5136.69 | 1512.39 | 4946.18 |
| 35 | 275.10 | 0.00002378 | 5136.68 | 1512.39 | 4946.18 |
| 36 | 275.10 | 0.00000064 | 5136.69 | 1512.39 | 4946.18 |
| 37 | 275.10 | 0.00000085 | 5136.69 | 1512.39 | 4946.18 |
| 38 | 275.10 | 0.00001217 | 5136.68 | 1512.39 | 4946.18 |
| 39 | 271.92 | 0.00000258 | 5593.79 | 1524.07 | 5196.63 |
| 40 | 275.10 | 0.00010939 | 5136.68 | 1512.39 | 4946.18 |
| 46 | 275.10 | 0.00000042 | 5136.69 | 1512.39 | 4946.18 |
| 47 | 275.10 | 0.00000576 | 5136.69 | 1512.39 | 4946.18 |
| 41 | 275.10 | 0.00003408 | 5136.69 | 1512.39 | 4946.18 |
| 42 | 0.00000485 | 5136.69 | 1512.39 | 4946.18 |  |
| 43 | 0.00000276 | 5136.69 | 1512.39 | 4946.18 |  |
| 44 | 0.00003539 | 5136.66 | 1512.39 | 4946.15 |  |
| 45 | 0.00000805 | 5136.69 | 1512.39 | 4946.18 |  |
| 2 | 275.10 |  |  |  |  |


| 48 | 275.10 | 0.00000289 | 5136.69 | 1512.39 | 4946.18 |
| :--- | :--- | :--- | :--- | :--- | :--- |
| 49 | 271.92 | 0.00000859 | 5593.79 | 1524.07 | 5196.63 |
| 50 | 275.10 | 0.00002747 | 5136.69 | 1512.39 | 4946.18 |
| 51 | 275.10 | 0.00000924 | 5136.69 | 1512.39 | 4946.18 |
| 52 | 275.10 | 0.00002677 | 5136.69 | 1512.39 | 4946.18 |
| 53 | 275.10 | 0.00000723 | 5136.69 | 1512.39 | 4946.18 |
| 54 | 275.10 | 0.00010187 | 5136.69 | 1512.39 | 4946.18 |
| 55 | 275.10 | 0.00000062 | 5136.69 | 1512.39 | 4946.18 |
| 56 | 275.10 | 0.00052373 | 5136.66 | 1512.39 | 4946.15 |
| 57 | 275.10 | 0.00001702 | 5136.69 | 1512.39 | 4946.18 |
| 58 | 275.10 | 0.00001190 | 5136.69 | 1512.39 | 4946.18 |
| 59 | 275.10 | 0.00003031 | 5136.69 | 1512.39 | 4946.18 |
| 60 | 275.10 | 0.00001616 | 5136.69 | 1512.39 | 4946.18 |
| 61 | 275.10 | 0.00000107 | 5136.69 | 1512.39 | 4946.18 |
| 62 | 271.92 | 0.00000451 | 5593.79 | 1524.07 | 5196.63 |
| 63 | 275.10 | 0.00000550 | 5136.69 | 1512.39 | 4946.18 |
| 64 | 275.10 | 0.00000364 | 5136.69 | 1512.39 | 4946.18 |
| 65 | 275.10 | 0.00001160 | 5136.69 | 1512.39 | 4946.18 |
| 66 | 275.10 | 0.00002502 | 5136.69 | 1512.39 | 4946.18 |
| 67 | 275.10 | 0.00000063 | 5136.69 | 1512.39 | 4946.18 |
| 68 | 275.10 | 0.00006237 | 5136.61 | 1512.39 | 4946.10 |
| 69 | 275.10 | 0.00003332 | 5136.69 | 1512.39 | 4946.18 |
| 70 | 275.10 | 0.00002605 | 5136.69 | 1512.39 | 4946.18 |
| 71 | 275.10 | 0.00003483 | 5136.69 | 1512.39 | 4946.18 |
| 72 | 271.92 | 0.00000709 | 5593.79 | 1524.07 | 5196.63 |
| 73 | 275.10 | 0.00000939 | 5136.69 | 1512.39 | 4946.18 |
| 74 | 275.10 | 0.00005860 | 5136.79 | 1512.39 | 4946.28 |
| 75 | 275.10 | 0.00007549 | 5136.69 | 1512.39 | 4946.18 |
| 76 | 275.10 | 0.00005234 | 5136.69 | 1512.39 | 4946.18 |
| 77 | 275.10 | 0.00001132 | 5136.69 | 1512.39 | 4946.18 |
| 78 | 275.10 | 0.00000234 | 5136.69 | 1512.39 | 4946.18 |
| 79 | 275.10 | 0.00004273 | 5136.69 | 1512.39 | 4946.18 |
| 80 | 275.10 | 0.00000006 | 5136.69 | 1512.39 | 4946.18 |
| 81 | 275.10 | 0.00000030 | 5136.69 | 1512.39 | 4946.18 |
| 82 | 275.10 | 0.00000206 | 5136.69 | 1512.39 | 4946.18 |
| 89 | 275.10 | 0.00002295 | 5136.69 | 1512.39 | 4946.18 |
| 83 | 275.10 | 0.00000575 | 5136.69 | 1512.39 | 4946.18 |
| 84 | 275.10 | 0.00000560 | 5136.69 | 1512.39 | 4946.18 |
| 85 | 275.10 | 0.00000295 | 5136.69 | 1512.39 | 4946.18 |
| 86 | 275.10 | 0.00007985 | 5136.69 | 1512.39 | 4946.18 |
| 87 | 0.00000062 | 5136.69 | 1512.39 | 4946.18 |  |
| 85 | 0.00001151 | 5136.69 | 1512.39 | 4946.18 |  |
| 5 | 0.00000134 | 5136.69 | 1512.39 | 4946.18 |  |


| 91 | 275.10 | 0.00000020 | 5136.69 | 1512.39 | 4946.18 |
| ---: | ---: | :--- | :--- | :--- | :--- |
| 92 | 275.10 | 0.00002228 | 5136.69 | 1512.39 | 4946.18 |
| 93 | 275.10 | 0.00000090 | 5136.69 | 1512.39 | 4946.18 |
| 94 | 275.10 | 0.00007147 | 5136.69 | 1512.39 | 4946.18 |
| 95 | 275.15 | 0.02132790 | 5159.06 | 1513.41 | 4966.70 |
| 96 | 275.10 | 0.00004049 | 5136.69 | 1512.39 | 4946.18 |
| 97 | 275.10 | 0.00000421 | 5136.69 | 1512.39 | 4946.18 |
| 98 | 275.10 | 0.00007738 | 5136.69 | 1512.39 | 4946.18 |
| 99 | 275.10 | 0.00000237 | 5136.69 | 1512.39 | 4946.18 |
| 100 | 275.10 | 0.00000092 | 5136.69 | 1512.39 | 4946.18 |

## Appendix F: Core Data Analysis

Problem statement: The spatial extent of the Aleutian Islands golden king crab (AIGKC) fishery has decreased markedly through time, but the current stock assessment model does not explicitly account for this change. The current exercise is an attempt to utilize only a subset of observer catch-per-uniteffort (CPUE) and (estimated) commercial fishery catch data that come from the same spatial extent (termed the "Core" fishing area) throughout the time series (1990-2015). Model runs were compared with Full dataset models (Scenarios 1 and 2 ) to examine the effects of decreasing fishing area over time.

## METHODS

## Creating the Core CPUE dataset (see Figs. F1, F2)

1) Reassigned all observer data currently used in AIGKC model lat/long from original dataset
a. About 100 rows of data (pots) out of over 110K could not be reconciled.
b. There are a number of pot locations (lat/long) that need to be error checked (e.g. show up on land)
2) Observer data (with lat/long) were plotted onto the GIS layer of $2 \times 2 \mathrm{~nm}$ boxes.
a. 2X2 boxes were created for Cooperative Survey design using 1990-2013 observer data
b. $2 \times 2$ boxes were limited to:
i. 100-1000m depth
ii. Not on land
iii. Only containing observer data with some catch (all size/sex classes of GKC); i.e., 2X2 boxes with observer data but no catch in any year were excluded and assumed to not be suitable GKC habitat.
c. $2 \times 2$ boxes were decided on as a reasonable tradeoff between spatial resolution and fishing practices (e.g. strings of gear are 2-4 nm long).
i. Sensitivity to box size should likely be considered (in progress).
3) $2 \times 2$ boxes were categorized as "Core" or "Non-Core" utilizing 2005-2013 observer data
a. $\quad$ Core $=$ area that had fishing effort and catch since rationalization
b. Non-core $=$ No effort in the area since rationalization.
4) Each row of observer data (1990-2015) was overlaid onto $2 \times 2$ boxes and categorized as:
a. Core $=$ Effort and Catch in the area since rationalization
b. Non-core $=$ No effort in the area since rationalization
c. Other = Effort and Catch outside the $2 \times 2$ box layer due to:
i. Errors in lat/long transcription
ii. Effort but no catch in any year (i.e., assumed not GKC habitat)
iii. Errors in bathymetry layer
iv. Effort and Catch data from 2014-present
1. Due to declining CPUE in WAG fishery started moving gear outside "Core" areas (e.g., AK Trojan to Bowers Ridge, and Early Dawn to Attu)
5) Observer data used in AIGKC model was then subset to only those data categorized as "Core"

## Creating the Core Catch dataset

6) We assumed that observer coverage was proportional to total fishing effort in every year
a. This needs to be vetted (though 100\% observer coverage 1995/96-2004/05).
7) We assumed fishermen are equally skilled, or that fishermen are fishing proportionally in Core and non-core areas.
a. If the least effective fishermen are fishing the less productive areas (i.e. Non-core) the ratio of Core:Non-core CPUE will be biased high and the estimate of catch inside the Core would be biased high (this would be more conservative).
8) For each year separately using the observer data, we calculated the ratio of Core:Non-Core CPUE and Effort
9) The product of these two ratios then let us estimate the ratio of Core Catch:Non-core Catch
10) The Catch ratio was then applied to overall Catch data used in the AIGKC model to estimate Catch within the Core area for each year (see algebra at the end).
a. Catch in the model is separated by size classes; size frequencies were assumed to be the same for Core and Non-core areas.
11) These two "new" datasets only contain information from the same spatial extent throughout the history of the data (1990-2015) and are just a subset of the Full data set used in the current model.

## Core Catch estimation:

Since total Catch $\left(C_{t}\right)$ equals the product of $C P U E$ and Effort $(E)$, then the ratio of Catch in the Core $\left(C_{c}\right)$ to Catch in the Non-Core ( $C_{n c}$ ) area is:

$$
\frac{C_{n c}}{C_{c}}=\frac{\left(\frac{C_{n c}}{E_{n c}}\right) \times E_{n c}}{\left(\frac{C_{c}}{E_{c}}\right) \times E_{c}}
$$

where $E_{n c}$ and $E_{c}$ are the Effort in Core and Non-core areas, respectively.

Next, if:

$$
\frac{C_{n c}}{C_{c}}=x
$$

then:

$$
C_{n c}=x C_{c}
$$

And since:

$$
C_{t}=C_{n c}+C_{c}
$$

Then substituting for $C_{n c}$ :

$$
C_{t}=x C_{c}+C_{c}
$$

And

$$
C_{t}=(x+1) C_{c}
$$

And finally

$$
C_{c}=\frac{C_{t}}{(x+1)}
$$

So we can estimate the catch in the Core area by having the total Catch (which is known) and the ratio of Catch in the Non-core and Core areas (which we can estimate).

## Modeling

CPUE standardization methods were described in Appendix B. We applied those methods to Core data to determine CPUE indices for the periods 1995/96-2004/05 and 2005/06-2015/16. Because only observer data have the location details to separate the fishing area into finer cells ( 2 X 2 nm ), we restricted the time series to 1995/96-2015/16 for CPUE standardization and population model fitting. Therefore, the population model fitting results were compared with those for scenario 2 that ignores the fishery CPUE likelihood in the model fitting. However, for completeness, we included the base scenario (scenario 1) results as well.

## RESULTS

## Core area, CPUE, and catch estimates

The Core area represents approximately $30 \%$ of the total GKC habitat that was historically fished based on the $2 \times 2 \mathrm{~nm}$ boxes (similar for EAG and WAG). Of the 110,313 rows of observer data, 78,299 (71\%) were categorized as Core, $28,441(26 \%)$ as Non-core, and $3,573(3 \%)$ as Other. Non-core and Other data were removed from the observer dataset and then only the Core data were used in the GLM for CPUE index determination.

Examining the observer data as a function of Core vs. Non-core areas prior to rationalization shows that on average $65 \%$ of the total effort came from Core areas (Fig. F3A, B) and the CPUE were on average 1.6 times greater in the Core than the Non-core areas (Fig. F3C, D) prior to rationalization. This suggests that approximately $74 \%$ of the total catch came from the Core areas (Fig F3E, F). Results are nearly identical for both the EAG and WAG. Total annual catch was then multiplied by the proportion of catch in the Core areas in each year to estimate Core catch and used in the population model fitting.

## CPUE standardization of core data

The final models for EAG were:
$\ln ($ CPUE $)=$ Year + Gear + Captain + ns $($ Soak, 3$)+$ Month
for the $1995 / 96-2004 / 05$ period $\left[\theta=1.34, \mathrm{R}^{2}=0.2526\right]$
$\ln ($ CPUE $)=$ Year + Captain + Gear $+\mathrm{ns}($ Soak, 11 $)$
for the $2005 / 06-2015 / 16$ period $\left(\theta=2.29, \mathrm{R}^{2}=0.1207\right)$.

The final models for WAG were:
$\ln ($ CPUE $)=$ Year + Captain $+\mathrm{ns}($ Soak, 15$)+$ Gear
for the $1995 / 96-2004 / 05$ period $\left[\theta=1.04, \mathrm{R}^{2}=0.1804\right]$
$\ln ($ CPUE $)=$ Year + Gear $+\mathrm{ns}($ Soak, 17)
for the $2005 / 06-2015 / 16$ period $\left[\theta=1.15, R^{2}=0.0509\right.$, Soak forced in $]$.

For both the EAG and the WAG, the standardized CPUE showed a general increase whereas the nonstandardized CPUE was relatively stable from 1995-2003. Post-rationalization showed almost no difference between CPUE indices (Figs. 4, 6). The (diagnostics) Q-Q plots of CPUE fitting appears satisfactory (Figs. 5, 7).

## Model fitting

The core data were used for fitting the scenario 2 model (scenario 2 model is described in the main text and Appendix A). We used the Francis reweighting method to determine the updated weights for the length composition effective sample sizes. The Francis iteration results on core data are provided in Table F.1.

We provide the model fitted values for CPUE indices, Catches, F, and MMB (Figs. 8 to 15) for EAG and WAG.

The CPUE indices for the three models (Sc1, Sc2, and Sc2Core) were nearly identical except for slight divergence from 2011-2015 in the EAG, and from 2001-2004 in the WAG (Figs. 8, 9). The Core retained catches were well fitted by scenario Sc2Core but not by Sc1 or Sc2 in early years as expected due to the reduction of catch data in Sc2Core prior to rationalization (Figs. 10, 11). In the EAG, the overall (19602015) mature male biomass estimates were on average $20 \%$ lower using only Core data and catch estimates (i.e., Sc2Core) and were 15\% lower since rationalization (2005-2015) compared with scenario

2 (full dataset) results. However, in the WAG, mature male biomass estimates were only 12\% (overall) and $2 \%$ (post-rationalization) lower.


Figure F1. Map of EAG depicting Core areas (tan boxes; difficult to see under green dots) with associated observer data (green dots) and Non-core areas (blue boxes) and associated observer data (blue dots). Of the total 2012 2X2nm boxes, 588 (29\%) are designated as Core and 1424 (71\%) as Noncore.


Figure F2. Map of WAG depicting Core areas (tan boxes; difficult to see under green dots) with associated observer data (green dots) and Non-core areas (blue boxes; difficult to see under blue dots) and associated observer data (blue dots). Of the total 2847 2X2nm boxes, 799 (28\%) are designated as Core and 2048 (72\%) as Non-core.


Figure F3. Effort (A, B), productivity (C, D), and Catch (E, F) from 1990-2015 in the EAG (A, C, E) and WAG (B, D, F). Effort is split into Core (black), Non-core (light grey), and Other (dark grey). Catch is split only into Core (black) and Non-core (light grey); Other catch could not be estimated. Green lines represent mean values for pre-rationalization time period (1990-2004).


Figure F.4. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer core data from EAG (east of $174^{\circ}$ W longitude). Top panel: 1995/96-2004/05 and bottom panel: 2005/06-2015/16. Standardized indices: black line and non-standardized indices: red line.

Negative Binomial Fit, EAG 1995/96-2004/05 Core


Negative Binomial Fit, EAG 2005/06-2015/16 Core


Figure F.5. Studentized residual plots for negative binomial GLM fit to EAG golden king crab observer core data for legal size male crab. Top panel is for 1995/96-2004/05 and bottom panel is for 2005/062015/16.


Figure F.6. Trends in non-standardized [arithmetic (nominal)] and standardized (negative binomial GLM) CPUE indices with +/- 2 SE for Aleutian Islands golden king crab observer core data from WAG (west of $174^{\circ} \mathrm{W}$ longitude). Top panel: 1995/96-2004/05 and bottom panel: 2005/06-2015/16. Standardized indices: black line and non-standardized indices: red line.

Negative Binomial Fit, WAG 1995/96-2004/05 Core


Negative Binomial Fit, WAG 2005/06-2015/16 Core


Figure F.7. Studentized residual plots for negative binomial GLM fit to WAG golden king crab observer core data for legal size male crab. Top panel is for 1995/96-2004/05 and bottom panel is for 2005/062015/16.

Table F.1. Iteration process for Stage-2 effective sample size reweighting multiplier, $W$, by Francis method for retained, total, and groundfish discard catch size compositions of golden king crab for scenario 2Core for EAG and WAG. The effective sample sizes are numbers of days for retained and total catch, but number of trips for groundfish discarded catch size compositions. Sc. =scenario. Note: For scenario 2Core, we have done more than six iterations to get the $W$ and MMB converged, but we provide only the last three iteration results.

| Area | Sc. | Iteration <br> No. | Retained <br> Catch Size <br> Comp <br> Effective <br> Sample <br> Multiplier <br> (W) | Total Catch <br> Size Comp <br> Effective <br> Sample <br> Multiplier <br> (W) | Groundfish <br> Discard Catch <br> Size Comp <br> Effective <br> Sample <br> Multiplier (W) | Terminal <br> MMB (t) | $M \mathrm{yr}^{-1}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| EAG | 2Core | 1 | 0.8744 | 0.5161 | 0.4438 | 8,203 |  |
|  |  | 2 | 0.8739 | 0.5164 | 0.4438 | 8,203 |  |
|  |  | 3 | 0.8737 | 0.5165 | 0.4437 | 8,203 |  |
| WAG | 2Core | 1 | 0.4859 | 0.4388 | 0.7619 | 4,114 |  |
|  |  | 2 | 0.4861 | 0.4387 | 0.7619 | 4,115 |  |
|  |  | 3 | 0.4861 | 0.4386 | 0.7619 | 4,115 |  |



Figure F.8. Comparison of core data input CPUE indices (open circles with $+/-2$ SE) with predicted CPUE indices (colored solid lines) under scenarios (Sc) 1, 2, and 2Core for EAG golden king crab data, 1985/862015/16. Model estimated additional standard error was added to each input standard error.

Note: low prediction of CPUE indices in recent years by scenario Sc2Core.


Figure F.9. Comparison of core data input CPUE indices (open circles with $+/-2$ SE) with predicted CPUE indices (colored solid lines) under scenarios (Sc) 1, 2, and 2Core for WAG golden king crab data, 1985/86-2015/16. Model estimated additional standard error was added to each input standard error.


Figure F.10. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and groundfish bycatch (bottom left) of golden king crab for scenarios (Sc) 1 to 2Core data sets, in EAG, 1985-2015.


Figure F.11. Observed (open circle) vs. predicted (solid line) retained catch (top left), total catch (top right), and groundfish bycatch (bottom left) of golden king crab for scenarios (Sc) 1 to 2Core data sets, in WAG, 1985-2015.


Figure F.12. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 1 to 2Core model fits in the EAG, 1981-2015.

Note: A little high prediction of F in recent years by scenario Sc2Core.


Figure F.13. Trends in pot fishery full selection total fishing mortality of golden king crab for scenarios (Sc) 1 to 2Core model fits in the WAG, 1981-2015.

Note: A little high prediction of F in recent years by scenario Sc2Core.


Figure F.14. Trends in golden king crab mature male biomass for scenarios (Sc) 1, 2, and 2Core fits in the EAG, 1960/61-2015/16.

Note: Low prediction of MMB by scenario Sc2Core throughout the time series.


Figure F.15. Trends in golden king crab mature male biomass for scenarios (Sc) 1, 2, and 2Core fits in the WAG, 1960/61-2015/16.

Note: Low prediction of MMB by scenario Sc2Core throughout the time series.

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# Pribilof Islands Golden King Crab <br> - 2017 Tier 5 Assessment <br> 2017 Crab SAFE Report Chapter (September 2017) 

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## Executive Summary

1. Stock: Pribilof Islands (Pribilof District) golden king crab Lithodes aequispinus

## 2. Catches:

Commercial fishing for golden king crab in the Pribilof District has been concentrated in the Pribilof Canyon. The domestic fishery developed in 1982/83, although some limited fishing occurred at least as early as 1981/82. Peak retained catch occurred in 1983/84 at $388 \mathrm{t}(856,475$ lb ). The fishing season for this stock has been defined as a calendar year (as opposed to 1-July-to-30-June crab fishing year) after 1983/84. Since then, participation in the fishery has been sporadic and annually retained catch has been variable: from $0 \mathrm{t}(0 \mathrm{lb})$ in the ten years that no vessels participated (1984, 1986, 1990-1992, 2006-2009, and 2015) to 155 t ( $341,908 \mathrm{lb}$ ) in 1995, when seven vessels made landings. The fishery is not rationalized. There is no state harvest strategy in regulation. A guideline harvest level (GHL) was first established for the fishery in 1999 at $91 \mathrm{t}(200,000 \mathrm{lb})$. The GHL was reduced to $68 \mathrm{t}(150,000 \mathrm{lb})$ for 2000-2014 and reduced to $59 \mathrm{t}(130,000 \mathrm{lb})$ in 2015 . No vessels participated in the directed fishery and no landings were made during 2006-2009. Catch data from 2003-2005 and 2010-2014 cannot be reported here under the confidentiality requirements of State of Alaska (SOA) statute Sec. 16.05.815. The 2003 and 2004 fisheries were closed by emergency order to manage the retained catch towards the GHL; the 2005 and 2010-2014 fisheries were not closed by emergency order. No vessels participated in the directed fishery during 2015 or 2016. Discarded (non-retained) catch has occurred in the directed golden king crab fishery, the eastern Bering Sea snow crab fishery, the Bering Sea grooved Tanner crab fishery, and in Bering Sea groundfish fisheries. Estimates of annual total fishery mortality during 2001-2016 due to crab fisheries range from 0 t to 73 t , with an average of 24 t . There was no discarded catch during crab fisheries in 2016. Estimates of annual fishery mortality during 1991/92-2016 due to groundfish fisheries range from $<1 \mathrm{t}$ to 9 t , with an average of 2 t (estimates of annually discarded catch during Bering Sea groundfish fisheries are reported for crab fishing years from 1991 to 2008, and by calendar years from 2009 to 2016). Total fishery mortality in groundfish fisheries during the 2016 crab fishing year was 0.24 t .

## 3. Stock biomass:

Stock biomass (all sizes, both sexes) of golden king crab have been estimated for the Pribilof Canyon area using the area-swept technique applied to data obtained from the biennial eastern Bering Sea upper continental slope trawl survey performed by NMFS-AFSC in 2002, 2004, 2008, 2010, 2012, and 2016 (Hoff and Britt 2003, 2005, 2009, 2011; Hoff 2013, 2016). See Appendix A1 for summaries of the slope survey as they pertain to data on and estimates of Pribilof Island golden king crab stock biomass. Complete data on size-sex composition of survey catch are available only from the 2008-2016 biennial surveys (C. Armistead, NMFS-AFSC, Kodiak). Biomass estimates by sex and size class from the 2008, 2010, and 2012 surveys were presented in a May 2013 (Gaeuman 2013a) report to the Crab Plan Team and biomass estimates of mature males from the 2008-2012 biennial surveys were presented in a September 2013 (Gaeuman 2013b) report to the Crab Plan Team. Biomass estimates from the 2016 survey have not been presented to the Crab Plan Team prior to this report.

## 4. Recruitment:

Estimated from size-sex composition data from the eastern Bering Sea upper continental slope trawl survey, mature male biomass in the entire survey area increased slightly from 812 t $(1,790,154 \mathrm{lb})$ in 2012 to $897 \mathrm{t}(1,977,546 \mathrm{lb})$ in 2016 , and from $256 \mathrm{t}(564,383 \mathrm{lb})$ in 2012 to $475 \mathrm{t}(1,047,196 \mathrm{lb})$ in 2016 in the Pribilof canyon.

## 5. Management performance:

No overfished determination (i.e., MSST) has been made for this stock, although approaches to using data from the biennial NMFS-AFSC eastern Bering Sea upper continental slope surveys have been presented to, and considered by, the Crab Plan Team (Gaeuman 2013a, 2013b; Pengilly 2015, Pengilly and Daly 2017; Appendix A1). No vessels participated in the 2015 or 2016 directed fisheries (i.e., retained catch= $0 \mathrm{t} ; 0 \mathrm{lb}$ ) and no bycatch was observed in crab fisheries in these years; 0.24 t of fishery mortality occurred during groundfish fisheries in 2016. Overfishing did not occur in 2016. The GHL for the 2018 season has yet to be established (M.Stichert, ADF\&G, Kodiak, pers. comm., 1 April 2017). The 2018 OFL and ABC in the table below are the author's recommendations, which follow previous determinations.

Management Performance Table (values in t)

| Calendar <br> Year | MSST | Biomass <br> $($ MMB $)$ | GHL $^{\mathbf{a}}$ | Retained <br> Catch | Total <br> Catch $^{\text {b }}$ | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2013 | N/A | N/A | 68 | Conf. $^{\text {c }}$ | Conf. $^{\text {c }}$ | 91 | 82 |
| 2014 | N/A | N/A | 68 | Conf. $^{\text {c }}$ | Conf. $^{\text {c }}$ | 91 | 82 |
| 2015 | N/A | N/A | 59 | 0 | 1.92 | 91 | 68 |
| 2016 | N/A | N/A | 59 | 0 | 0.24 | 91 | 68 |
| 2017 | N/A | N/A | 59 |  |  | 93 | 70 |
| 2018 | N/A | N/A |  |  |  | 93 | 70 |

a. Guideline harvest level, established in lb and converted to t .
b. Total retained catch plus estimated bycatch mortality of discarded catch during crab fisheries and bycatch mortality due to groundfish fisheries are included here, but not for 2013 and 2014 because the directed fishery is confidential.
c. Confidential under Sec. 16.05.815 (SOA statute). GHL not attained.

Management Performance Table (values in millions of lb)

| Calendar <br> Year | MSST | Biomass <br> $(M M B)$ | GHL $^{\text {a }}$ | Retained <br> Catch | Total <br> Catch $^{\text {b }}$ | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2013 | N/A | N/A | 150,000 | Conf. $^{\text {c }}$ | Conf. $^{\text {c }}$ | 0.20 | 0.18 |
| 2014 | N/A | N/A | 150,000 | Conf. $^{\text {c }}$ | Conf. $^{\text {c }}$ | 0.20 | 0.18 |
| 2015 | N/A | N/A | 130,000 | 0 | 0.004 | 0.20 | 0.15 |
| 2016 | N/A | N/A | 130,000 | 0 | $<0.001$ | 0.20 | 0.15 |
| 2017 | N/A | N/A | 130,000 |  |  | 0.20 | 0.15 |
| 2018 | N/A | N/A |  |  |  | 0.20 | 0.15 |

a. Guideline harvest level.
b. Total retained catch plus estimated bycatch mortality of discarded catch during crab fisheries and groundfish fisheries. Estimates of annual bycatch mortality during $1991 / 92-2016$ groundfish fisheries are $\leq 19,480 \mathrm{lb}$, with an average of $5,098 \mathrm{lb}$.
c. Confidential under Sec. 16.05.815 (SOA statute). GHL not attained.
6. Basis for the OFL and ABC: The values for 2018 are the author's recommendation.

| Calendar <br> Year | Tier | Years to define <br> Average catch (OFL) | Natural <br> Mortality | Buffer |
| :---: | :---: | :---: | :---: | :---: |
| 2013 | 5 | $1993-1998^{\mathrm{a}}$ | $0.18 \mathrm{yr}^{-1}$ | $10 \%$ |
| 2014 | 5 | $1993-1998^{\mathrm{a}}$ | $0.18 \mathrm{yr}^{-1}$ | $10 \%$ |
| 2015 | 5 | $1993-1998^{\mathrm{a}}$ | $0.18 \mathrm{yr}^{-1}$ | $25 \%$ |
| 2016 | 5 | $1993-1998^{\mathrm{a}}$ | $0.18 \mathrm{yr}^{-1}$ | $25 \%$ |
| 2017 | 5 | $1993-1998^{\mathrm{a}}$ | $0.18 \mathrm{yr}^{-1}$ | $25 \%$ |
| 2018 | 5 | $1993-1998^{\mathrm{a}}$ | $0.18 \mathrm{yr}^{-1}$ | $25 \%$ |

a. OFL was for total catch and was determined by the average of the annual retained catch for these years multiplied by a factor of 1.052 to account for the estimated bycatch mortality occurring in the directed fishery plus an estimate of the average annual bycatch mortality due to non-directed crab fisheries and groundfish fisheries for the period.
b. Assumed value for FMP king crab in NPFMC (2007); does not enter into OFL estimation for Tier 5 stocks.
7. PDF of the OFL: Sampling distribution of the recommended Tier 5 OFL was estimated by bootstrapping. The standard deviation of the estimated sampling distribution of the recommended OFL (Alternative 1) is $23 \mathrm{t}(\mathrm{CV}=0.25$; section G.1).
8. Basis for the ABC recommendation: A $25 \%$ buffer on the OFL, the default; i.e., $\mathrm{ABC}=(1-0.25) \cdot$ OFL. This is a data-poor stock.
9. A summary of the results of any rebuilding analyses: Not applicable; stock is not under a rebuilding plan.

## A. Summary of Major Changes

1. Changes to the management of the fishery: Fishery continues to be managed under authority of an ADF\&G commissioner's permit; guideline harvest level (GHL) was reduced from $68 \mathrm{t}(150,000 \mathrm{lb})$ to $59 \mathrm{t}(130,000 \mathrm{lb})$ in 2015 to account for bycatch mortality in the directed fishery, non-directed crab fisheries, and groundfish fisheries, and to avoid exceeding the ABC. The GHL remained at $59 \mathrm{t}(130,000 \mathrm{lb})$ in 2016 and 2017. The GHL for the 2018 has yet to be established.
2. Changes to the input data:

- Retained catch and discarded catch data have been updated with the results for the 2016 directed fishery, during which no vessels participated, and bycatch in other crab fisheries in 2016, which was zero.
- Discarded catch estimates from groundfish fisheries have been listed by calendar year from 2009 to 2016, including 0.24 t of bycatch mortality for 2016.

3. Changes to the assessment methodology: This assessment follows the methodology recommended by the CPT since May 2012 and the SSC since June 2012.
4. Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL: The computation of OFL in this assessment follows the methodology recommended by the CPT in May 2012 and the SSC in June 2012 applied to the same data and estimates with the same assumptions that were used for estimating the 2013-2017 Tier 5 OFLs; computations applied directly to data and estimates expressed in metric units resulted in minor changes in results used in previous assessments due to rounding.

## B. Responses to SSC and CPT Comments

- Responses to the most recent two sets of SSC and CPT comments on assessments in general (and relevant to this assessment):
- CPT, May 2016: None pertaining to a Tier 5 assessment.
- SSC, June 2016: None pertaining to a Tier 5 assessment.
- CPT, September 2016: None pertaining to a Tier 5 assessment.
- SSC, October 2015: None.
- Responses to the most recent two sets of SSC and CPT comments specific to the assessment:
- CPT, May 2016:
- "A Tier 4 assessment based on a random effects model was presented at the September 2015 meeting. Information on mature and legal male biomass from the slope trawl surveys was only available for three years (2008, 2010, and 2012), and the model runs did not appear to be able to estimate a process error term with the available data. A slope trawl survey is planned for the summer of 2016 and the CPT will re-evaluate the model with the new survey results in January or May 2017. $\qquad$ "
- Response: The author has conducted the preliminary model analysis with the 2016 survey included, and includes those results in an updated discussion paper.
- SSC, June 2016:
- "In June 2015, the SSC requested that the author approach the harvester about whether they would voluntarily allow confidential data to be presented in assessments. However, this was not done. The SSC reiterates this request."
- Still not done. No participation in the directed fishery since 2014. Waivers have been obtained from harvesters for the confidential seasons and discussions are in progress as to which processor waivers are needed (M. Westphal, ADF\&G, Dutch Harbor, pers. comm., 14 April 2017).
- "Finally, the SSC reiterates last year's request for NMFS to assess the feasibility to provide groundfish PSC data for PIGKC by calendar year".
- Groundfish bycatch data for PIGKC is provided by NMFS-AFSC by calendar year from 2009 to 2016, and is included in this assessment.
- "A Tier 4 assessment based on a random effects model was presented to the CPT in September 2015, but it was unable to estimate process error. That Tier 4 assessment was based on 5 years of slope trawl surveys. The plan is to reevaluate the random effects model after results from the 2016 slope trawl survey become available in 2017. The SSC looks forward to a future Tier 4 assessment."
- Not done. The author re-ran the model with 2016 slope survey data and presents results in an associated discussion paper. However, the author does not present this in relation to a Tier 4 or modified Tier 5 assessment.
- CPT, September 2015 and 2016:
- "The CPT recommends the random effects model be re-evaluated after results from the 2016 slope survey are available."
- Response: See above.
- SSC, October 2015:
- "The SSC concurs with the CPT recommendation" ["that the random effects model be re-evaluated after results from the 2016 slope survey are available"]
- Response: Okay. See above.


## C. Introduction

1. Scientific name: Lithodes aequispinus J. E. Benedict, 1895
2. Description of general distribution:

General distribution of golden king crab:

Golden king crab, also called brown king crab, range from Japan to British Columbia. In the BSAI, golden king crab are found at depths from 200 m to $1,000 \mathrm{~m}$, generally in high-relief habitat such as inter-island passes (NMFS 2004).

Golden, or brown, king crab occur from the Japan Sea to the northern Bering Sea (ca. $61^{\circ} \mathrm{N}$ latitude), around the Aleutian Islands, on various sea mounts, and as far south as northern British Columbia (Alice Arm) (Jewett et al. 1985). They are typically found on the continental slope at depths of $300-1,000 \mathrm{~m}$ on extremely rough bottom, and are frequently found on coral (NMFS 2004, pages 3-43).

The Pribilof District is part of king crab Registration Area Q (Figure 1). Leon et al. (2017) define those boundaries:

> The Bering Sea king crab Registration Area Q southern boundary is a line from $54^{\circ} 36^{\prime} \mathrm{N}$ lat, $168^{\circ} \mathrm{W}$ long, to $54^{\circ} 36^{\prime} \mathrm{N}$ lat, $171^{\circ} \mathrm{W}$ long, to $55^{\circ} 30^{\prime} \mathrm{N}$ lat, $171^{\circ} \mathrm{W}$ long, to $55^{\circ} 30^{\prime} \mathrm{N}$ lat, $173^{\circ} 30^{\prime} \mathrm{E}$ long. The northern boundary is the latitude of Point Hope ( $68^{\circ} 21^{\prime} \mathrm{N}$ lat). The eastern boundary is a line from $54^{\circ} 36^{\prime} \mathrm{N}$ lat, $168^{\circ} \mathrm{W}$ long, to $58^{\circ} 39^{\prime} \mathrm{N}$ lat, $168^{\circ} \mathrm{W}$ long, to Cape Newenham ( $58^{\circ} 39^{\prime} \mathrm{N}$ lat). The western boundary is the United States-Russia Maritime Boundary Line of 1990 (Figure 24). Area Q is divided into 2 districts: the Pribilof District, which includes waters south of Cape Newenham; and the Northern District, which includes all waters north of Cape Newenham.

The NMFS-AFSC conducted an eastern Bering Sea continental slope trawl survey on a biennial schedule during 2002-2016 (the 2014 survey was cancelled). Biomass estimates from the 2016 slope survey have not been presented to the Crab Plan Team prior to this document. Results of this survey from 2002-2016 show that the biomass, number, and density (in number per area and in weight per area) of golden king crab on the eastern Bering Sea continental slope are higher in the southern areas than in the northern areas (Gaeuman 2013a, 2013b; Haaga et al. 2009; Hoff 2013, 2016; Hoff and Britt 2003, 2005, 2009, 2011; Pengilly 2015; Pengilly and Daly 2017). Of the six survey subareas (see Figure 1 in Hoff 2016), biomass and abundance of golden king crab were estimated through 2016 to be highest in the Pribilof Canyon area (survey subarea 2), and most of the commercial fishery catches for golden king crab have occurred there (Neufeld and Barnard 2003; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006; Leon et al. 2017).

Results of the 2002-2016 biennial NMFS-AFSC eastern Bering Sea continental slope trawl surveys showed that a majority of golden king crab on the eastern Bering Sea continental slope occurred in the 200-400 m and 400-600 m depth ranges (Hoff and Britt 2003, 2005, 2009, 2011; Haaga et al. 2009; Hoff 2013, 2016). Commercial fishing for golden king crab in the Bering Sea typically occurs at depths of 100-300 fathoms (183-549 m; Barnard and Burt 2004, 2006; Burt and Barnard 2005, 2006; Gaeuman 2011, 2013c, 2014; Neufeld and Barnard 2003); average depth of pots fished in the 2002 Pribilof District golden king crab fishery (the most recently prosecuted fishery for which fishery observer data are not confidential) was 214 fathoms (391 $\mathrm{m})$.

## 3. Evidence of stock structure:

Although highest densities of golden king crab are found in the deep canyons of the eastern Bering Sea continental slope, golden king crab occur sporadically on the surveyed slope at locations between those canyons in the eastern Bering Sea (Hoff and Britt 2003, 2005, 2009, 2011; Gaeuman 2013b, 2014; Hoff 2013, 2016). Stock structure within the Pribilof District has not been evaluated. Fishery and slope survey data suggest that areas at the northern and southern border of the Pribilof District are largely devoid of golden king crab (Pengilly 2015, Pengilly and Daly 2017; Appendix A1), but the stock relationship between golden king crab within and outside of the Pribilof District has not been evaluated.
4. Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology):
The following review of molt timing and reproductive cycle of golden king crab is adapted from Watson et al. (2002):

Unlike red king crab, golden king crab may have an asynchronous molting cycle (McBride et al. 1982; Otto and Cummiskey 1985; Sloan 1985; Blau and Pengilly 1994). In a sample of male golden king crab $95-155-\mathrm{mm}$ CL and female golden king crab 104-157-mm CL collected from Prince William Sound and held in seawater tanks, Paul and Paul (2000) observed molting in every month of the year, although the highest frequency of molting occurred during May-October. Watson et al. (2002) estimated that only $50 \%$ of $139-\mathrm{mm}$ CL male golden king crab in the eastern Aleutian Islands molt annually and that the intermolt period for males $\geq 150-\mathrm{mm}$ CL averages $>1$ year.

Female lithodids molt before copulation and egg extrusion (Nyblade 1987). From observations on embryo development in golden king crab, Otto and Cummiskey (1985) suggested that time between successive ovipositions was roughly twice that of embryo development and that spawning and molting of mature females occurs approximately every two years. Sloan (1985) also suggested a reproductive cycle $>1$ year with a protracted barren phase for female golden king crab. Data from tagging studies on female golden king crab in the Aleutian Islands are generally consistent with a molt period for mature females of two years or less and that females carry embryos for less than two years with a prolonged period in which they remain in barren condition (Watson et al. 2002). From laboratory studies of golden king crab collected from Prince William Sound, Paul and Paul (2001b) estimated a 20 -month reproductive cycle with a 12 -month clutch brooding period.

Numerous observations on clutch and embryo condition of mature female golden king crab captured during surveys have been consistent with asynchronous, aseasonal reproduction (Otto and Cummiskey 1985; Hiramoto 1985; Sloan 1985; Somerton and Otto 1986; Blau and Pengilly 1994; Blau et al. 1998; Watson et al. 2002). Based on data from Japan (Hiramoto and Sato 1970), McBride et al. (1982) suggested that spawning of golden king crab in the Bering Sea and Aleutian Islands occurs predominately during the summer and fall.

The success of asynchronous and aseasonal spawning of golden king crab may be facilitated by fully lecithoatrophic larval development (i.e., the larvae can develop successfully to juvenile crab without eating; Shirley and Zhou 1997).

Current knowledge of reproductive biology and maturity of male and female golden king crab was reviewed by Webb (2014).

Note that asynchronous, aseasonal molting and the prolonged intermolt period (>1 year) of mature female and the larger mature male golden king crab likely makes scoring shell conditions very difficult and especially difficult to relate to "time post-molt," posing problems for inclusion of shell condition data into assessment models.

## 5. Brief summary of management history:

A complete summary of the management history through 2015 is provided in Leon et al. (2017).
The first domestic harvest of golden king crab in the Pribilof District was in 1981/82 when two vessels fished. Peak retained catch and participation occurred in 1983/84 at a retained catch of $388 \mathrm{t}(856,475 \mathrm{lb})$ landed by 50 vessels (Tables 1a and 1b). Since 1984; the fishery has been managed with a calendar-year fishing season under authority of a commissioner's permit and landings and participation have been low and sporadic. Retained catch since 1984 has ranged from $0 \mathrm{t}(0 \mathrm{lb})$ to $155 \mathrm{t}(341,908 \mathrm{lb})$, and the number of vessels participating annually has ranged from 0 to 8. No vessels fished in 2006-2009, 2015, and 2016, one vessel fished in each of 2010 and 2012-2014, and two vessels fished in 2011.

The fishery is not rationalized and has been managed inseason to a guideline harvest level (GHL) since 1999. The GHL for 1999 was $91 \mathrm{t}(200,000 \mathrm{lb})$, whereas the GHL for 2000-2014 was $68 \mathrm{t}(150,000 \mathrm{lb})$. Following the reduction of ABC from 82 t for 2014 to 68 t for 2015, the GHL was reduced in 2015 to $59 \mathrm{t}(130,000 \mathrm{lb})$.

Catch statistics for 2003-2005 and 2010-2014 are confidential under Sec. 16.05.815 of SOA statutes. It can be noted, however, that the 2003 and 2004 fisheries were closed by emergency order to manage the fishery retained catch towards the GHL, whereas the 2005 and 2010-2014 fisheries were not closed by emergency order. With regard to 2004, "Catch rates during the 2004 fishery were among the highest on record, and the fishery was the shortest ever at approximately three weeks in duration" (Bowers et al. 2005).

A summary of relevant fishery regulations and management actions pertaining to the Pribilof District golden king crab fishery is provided below.

Only males of a minimum legal size may be retained. By State of Alaska regulation (5 AAC 34.920 (a)), the minimum legal size limit for Pribilof District golden king crab is 5.5 -inches (140 mm ) carapace width ( CW ), including spines. A carapace length (CL) $\geq 124 \mathrm{~mm}$ is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007). Golden king crab may be commercially fished only with king crab pots (as defined in 5 AAC 34.050); pots used to take golden king crab in Registration Area Q (Bering Sea) may be longlined (5 AAC 34.925(f)). Pots used to fish for golden king crab in the Pribilof District must have at least four escape rings of no less than five and one-half inches inside diameter installed
on the vertical plane or at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized golden king crab (5 AAC 34.925 (c)). The sidewall "...must contain an opening equal to or exceeding 18 inches in length... The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread." (5 AAC 39.145(1)). There is a pot limit of 40 pots for vessels $\leq 125$-feet LOA and of 50 pots for vessels $>125$-feet LOA ( 5 AAC 34.925 (e)(1)(B)). Golden king crab can be harvested from 1 January through 31 December only under conditions of a permit issued by the commissioner of ADF\&G (5 AAC 34.910 (b)(3)). Since 2001, those conditions have included the carrying of a fisheries observer.

## D. Data

1. Summary of new information:
2. Retained catch and estimated discarded catch during the 2016 directed fishery (no effort and no catch), estimated discarded catch during other crab fisheries in 2016 (no catch), and the estimated discarded catch in groundfish fisheries during 2016 have been added.

## 2. Data presented as time series:

a. Total catch and b. Information on bycatch and discards:

- The 1981/82-1983/84, 1984-2016 time series of retained catch (number and weight of crab, including deadloss), effort (vessels and pot lifts), average weight of landed crab, average carapace length of landed crab, and CPUE (number of landed crab captured per pot lift) are presented in Tables 1a and 1b.
- The 1993-2016 time series of weight of retained catch and estimated weight of discarded catch and estimated weight of fishery mortality of Pribilof golden king crab during the directed fishery and all other crab fisheries are given in Table 2. Discarded catch of Pribilof golden king crab occurs mainly in the directed golden king crab fishery, when prosecuted, and to a lesser extent in the Bering Sea snow crab fishery and the Bering Sea grooved Tanner crab fishery when prosecuted. Because the Bering Sea snow crab fishery is largely prosecuted between January and May and the Bering Sea grooved Tanner crab fishery is prosecuted with a calendar year season, discarded catch in the crab fisheries can be estimated on a calendar year basis to align with the calendar-year season for Pribilof District golden king crab. Observer data on size distributions and estimated catch numbers of discarded catch were used to estimate the weight of discarded catch of golden king crab by applying a weight-at-length estimator (see below). Observers were first deployed to collect discarded catch data during the Pribilof District golden king crab fishery in 2001 and during the Bering Sea grooved Tanner crab fishery in 1994. Retained catch or observer data are confidential for at least one of the crab fisheries in 1999-2001, 2003-2005, and 2010-2014. Following Siddeek et al. (2014), the bycatch mortality rate of golden king crab captured and discarded during Aleutian Islands golden king crab fishery was assumed to be 0.2 . Following Foy (2013), bycatch mortality rate of king crab during the snow crab fishery was assumed to be 0.5 . The bycatch mortality rate during the grooved Tanner crab fishery was also assumed to be 0.5 .
- The groundfish fishery discarded catch data are grouped into crab fishery years from 1991/92-2008/09, and by calendar years from 2009-2016. The 1991/92-2016 time series of estimated annual weight of discarded catch and total fishery mortality of golden king
crab during federal groundfish fisheries by gear type (combining pot and hook-and-line gear as a single "fixed gear" category and combining non-pelagic and pelagic trawl gear as a single "trawl" category) is provided in Table 3. Following Foy (2013), the bycatch mortality of king crab captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crab captured by trawls during groundfish fisheries was assumed to be 0.8. Data from 1991/92-2008/09 are from federal reporting areas 513, 517, and 521, whereas the data from 2009-2016 are from the State statistical areas falling within the Pribilof District.
- Table 4 summarizes the available data on retained catch weight and the available estimates of discarded catch weight.
c. Catch-at-length: Not used in a Tier 5 assessment; none are presented.
d. Survey biomass estimates: Survey biomass estimates are not used in a Tier 5 assessment. However, see Appendix A1 for biomass estimates of mature male golden king crab using data from the 2002-2016 NMFS-AFSC eastern Bering Sea upper continental slope trawl survey.
e. Survey catch at length: Survey catch at length data are not used in a Tier 5 assessment. However, see Appendix A1 for size data composition by sex of golden king crab during the 2002-2016 Bering Sea upper continental slope trawl surveys.


## f. Other data time series: None.

3. Data which may be aggregated over time:
a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):

The author is not aware of data on growth per molt collected from golden king crab in the Pribilof District. Growth per molt of juvenile golden king crab, $2-35 \mathrm{~mm}$ CL, collected from Prince William Sound have been observed in a laboratory setting and equations describing the increase in CL and intermolt period were estimated from those observations (Paul and Paul 2001a); those results are not provided here. Growth per molt has also been estimated from golden king crab with $\mathrm{CL} \geq 90 \mathrm{~mm}$ that were tagged in the Aleutian Islands and recovered during subsequent commercial fisheries (Watson et al. 2002); those results are not presented here because growth-per-molt information does not enter into a Tier 5 assessment.

See section C. 4 for discussion of evidence that mature female and the larger male golden king crab exhibit asynchronous, aseasonal molting and a prolonged intermolt period (>1 year).

## b. Weight-at length or weight-at-age (by sex):

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female golden king crab according to the equation, Weight $=\mathrm{A}^{*} \mathrm{CL}^{\mathrm{B}}$ (from Table 3-5, NPFMC 2007) are: $\mathrm{A}=0.0002988$ and $\mathrm{B}=3.135$ for males and $\mathrm{A}=0.0014240$ and $\mathrm{B}=2.781$ for females.

## c. Natural mortality rate:

The default natural mortality rate assumed for king crab species by NPFMC (2007) is $\mathrm{M}=0.18$. Note, however, natural mortality was not used for OFL estimation because this stock belongs to Tier 5.
4. Information on any data sources that were available, but were excluded from the assessment:

- Standardized bottom trawl surveys to assess the groundfish and invertebrate resources of the eastern Bering Sea upper continental slope were performed in 2002, 2004, 2008, 2010, 2012, and 2016 (Hoff and Britt 2003, 2005, 2009, 2011; Haaga et al. 2009, Gaeuman 2013a, 2013b; Hoff 2016). Data and analysed results pertaining to golden king crab from the 2008-2016 EBS upper continental slope surveys are provided in Appendix A1, but are not used in this Tier 5 assessment.
- Data on the size and sex composition of retained catch and discarded catch of Pribilof District golden king crab during the directed fishery and other crab fisheries are available but are not presented in this Tier 5 assessment.


## E. Analytic Approach

1. History of modeling approaches for this stock:

Gaeuman (2013a, 2013b) and Pengilly (2015) presented assessment-modelling approaches for this stock to the Crab Plan Team using data from the biennial NMFS EBS continental slope survey. However, following the cancellation of the 2014 slope survey, this stock continued to be managed as a Tier 5 stock for 2017, as had been recommended by NPFMC (2007) and by the CPT and SSC in 2008-2017.
2. Model Description: Subsections a-i are not applicable to a Tier 5 sock.

Only an OFL and ABC is estimated for Tier 5 stocks, where "the OFL represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock" (NPFMC 2007). Although NPFMC (2007) defined the OFL in terms of the retained catch, total-catch OFLs may be considered for Tier 5 stocks for which non-target fishery removal data are available (Federal Register/Vol. 73, No. 116, 33926). The CPT (in May 2010) and the SSC (in June 2010) endorsed the use of a total-catch OFL to establish the OFL for this stock. This assessment recommends - and only considers - use of a total-catch OFL for 2018.

Additionally, NPFMC (2007) states that for estimating the OFL of Tier 5 stocks, "The time period selected for computing the average catch, hence the OFL, should be based on the best scientific information available and provide the required risk aversion for stock conservation and utilization goals." Given that a total-catch OFL is to be used, alternative configurations for the Tier 5 model are limited to: 1) alternative time periods for computing the average total-catch mortality; and 2) alternative approaches for estimating the discarded catch component of the total catch mortality during that period.

With regard to choosing from alternative time periods for computing average annual catch to compute the OFL, NPFMC (2007) suggested using the average retained catch over the years 1993 to 1999 as the estimated OFL for Pribilof District golden king crab. Years post-1984 were chosen based on an assumed 8-year lag between hatching and growth to legal size after the

1976/77 "regime shift". With regard to excluding data from years 1985 to 1992 and years after 1999, NPFMC (2007) states, "The excluded years are from 1985 to 1992 and from 2000 to 2005 for Pribilof Islands golden king crab when the fishing effort was less than $10 \%$ of the average or the GHL was set below the previous average catch." In 2008 the CPT and SSC endorsed the approach of estimating OFL as the average retained catch during 1993-1999 for setting a retained-catch OFL for 2009. However, in May 2009 the CPT set a retained-catch OFL for 2010, but using the average retained catch during 1993-1998; 1999 was excluded because it was the first year that a preseason GHL was established for the fishery. In May 2010, the CPT established a total-catch OFL computed as a function of the average retained catch during 19931998, a ratio-based estimate of the bycatch mortality during the directed fishery of that period, and an estimate of the "background" bycatch mortality due to other fisheries. Other time periods, extending into years post-1999, had been considered for computing the average retained catch in the establishment of the 2009, 2010, and 2011 OFLs, but those time periods were rejected by the CPT and the SSC. Hence the period for calculating the retained-catch portion of the Tier 5 totalcatch OFL for this stock has been firmly established by the CPT and SSC at 1993-1998 (the CPT said "this freezes the time frame..."). For the 2012 and the 2013 OFLs, the CPT and SSC recommended the period 2001-2010 for calculating the ratio-based estimate of the bycatch mortality during the 1993-1998 directed fishery, the period 1994-1998 for calculating the estimated bycatch mortality due to non-directed crab fisheries during 1993-1998, and the period 1992/93-1998/99 for calculating the estimated bycatch mortality due to groundfish fisheries during 1993-1998.

Two alternative approaches for determination of the 2013 OFL were presented to the CPT and SSC in May-June 2013. Alternative 1 was the status quo approach (i.e., the approach used to establish the 2012 total-catch OFL). Alternative 2 was the same as Alternative 1 except that it used updated discarded catch data from crab fisheries in 2011. Alternative 2 was presented specifically to allow the CPT and the SSC to clarify whether the 2013 and subsequent OFLs should be computed using data collected after 2010, or if the time periods for data used to calculate the 2013 and subsequent OFLs should be "frozen" at the years used to calculate the 2012 OFL. The CPT and the SSC both recommended Alternative 1, clarifying that Tier 5 OFLs for future years should be computed using only data collected through 2010. Following that recommendation from CPT and the SSC, only one alternative was presented for computing the 2014-2017 Tier 5 OFLs (i.e., the Alternative 1 that was presented in 2013). The 2018 Tier 5 OFL recommended here uses the same approach as used for the 2013-2017 Tier 5 OFLs.

## 3. Model Selection and Evaluation:

## a. Description of alternative model configurations

The recommended OFL is set as a total-catch OFL using 1993-1998 to compute average annual retained catch, an estimate of the ratio of bycatch mortality to retained catch during the directed fishery, an estimate of the average annual bycatch mortality due to the non-directed crab fisheries during 1994-1998, and an estimate of average annual bycatch mortality due to the groundfish fisheries during 1992/93-1998/99; i.e.,

$$
\mathrm{OFL}_{2018}=\left(1+\mathrm{R}_{2001-2010}\right) * \mathrm{RET}_{1993-1998}+\mathrm{BM}_{\mathrm{NC}, 1994-1998}+\mathrm{BM}_{\mathrm{GF}, 92 / 93-98 / 99}
$$

where,

- $\mathrm{R}_{2001-2010}$ is the average of the estimated annual ratio of bycatch mortality to retained catch in the directed fishery during 2001-2010
- $\mathrm{RET}_{1993-1998}$ is the average annual retained catch in the directed crab fishery during 19931998
- $\mathrm{BM}_{\mathrm{NC}, 1994-1998}$ is the estimated average annual bycatch mortality in non-directed crab fisheries during 1994-1998
- $\mathrm{BM}_{\mathrm{GF}, 92 / 93-98 / 99}$ is the estimated average annual bycatch mortality in groundfish fisheries during 1992/93-1998/99.

The average of the estimated annual ratio of bycatch mortality to retained catch in the directed fishery during 2001-2010 is used as a factor to estimate bycatch mortality in the directed fishery during 1993-1998 because, whereas there are no data on discarded catch for the directed fishery during 1993-1998, there are such data from the directed fishery during 2001-2010 (excluding 2006-2009, when there was no fishery effort).

There are no discarded catch data available for the non-directed fisheries during 1993, thus 1994-1998 is used to estimate average annual bycatch mortality in non-directed fisheries.

The estimated average annual bycatch mortality in groundfish fisheries during 1992/93-1998/99 is used to estimate the average annual bycatch mortality in groundfish fisheries during 19931998 because 1992/93-1998/99 is the shortest time period of crab fishery years that encompasses calendar years 1993-1998.

Statistics on the data and estimates used to calculate RET $_{1993-1998}, \mathrm{R}_{2001-2010}, \mathrm{BM}_{\mathrm{NC}, 1994-1998}$, and $\mathrm{BM}_{\mathrm{GF}, 93 / 94-98 / 99}$ are provided in Table 5; the column means in Table 5 are the calculated values of $\mathrm{RET}_{1993-1998}, \mathrm{R}_{2001-2010}, \mathrm{BM}_{\mathrm{NC}, 1994-1998}$, and $\mathrm{BM}_{\mathrm{GF}, 93 / 94-98 / 99 \text {. Using the calculated values of }}$ $\mathrm{RET}_{1993-1998}, \mathrm{R}_{2001-2010}, \mathrm{BM}_{\mathrm{NC}, 1994-1998}$, and $\mathrm{BM}_{\mathrm{GF}, 93 / 94-98 / 99}$, the calculated value of $\mathrm{OFL}_{2018}$ is,

$$
\mathrm{OFL}_{2018}=(1+0.052)^{*} 78.80 \mathrm{t}+6.09 \mathrm{t}+3.79 \mathrm{t}=93 \mathrm{t}(204,527 \mathrm{lbs}) .
$$

b. Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed: See the table, below.

| Model | Retained- <br> vs. <br> Total-catch | Time Period | Resulting OFL <br> $(\mathbf{t})$ |  |
| :--- | :---: | :---: | :---: | :---: |
| Recommended/status quo | Total-catch | $1993-1998$ |  | 93 |

This is recommended as being the best approach with the limited data available and follows the advice of the CPT and SSC to "freeze" the period for calculation of the OFL at the time period that was established for the 2012 OFL and uses the computations recommended by the CPT and SSC in 2013.
c. Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models: See Section E, above.
d. Convergence status and convergence criteria for the base-case model (or proposed basecase model): Not applicable.
e. Table (or plot) of the sample sizes assumed for the compositional data: Not applicable.
f. Do parameter estimates for all models make sense, are they credible?:

The time period used for determining the OFL was established by the SSC in June 2012. Retained catch data come from fish tickets and annual retained catch is considered a known (not estimated) value. Estimates of discarded catch from crab fisheries data are generally considered credible (e.g., Byrne and Pengilly 1998; Gaeuman 2011, 2013c, 2014), but may have greater uncertainty in a small, low effort fishery such as the Pribilof golden king crab fishery. Estimates of bycatch mortality are estimates of discarded catch times an assumed bycatch mortality rate. The assumed bycatch mortality rates (i.e., 0.2 for crab fisheries, 0.5 for fixed-gear groundfish fisheries, and 0.8 for trawl groundfish fisheries) have not been estimated from data.
g. Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty: See section E.3.c, above.
h. Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach): Not applicable.
i. Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented: See section E.3.c, above.
4. Results (best model(s)):
a. List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties: Not applicable.
b. Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons): See Tables 2-5.
c. Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible): Information requested for this subsection is not applicable to a Tier 5 stock.
d. Evaluation of the fit to the data: Not applicable for Tier 5 stock.
e. Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments): Not applicable for Tier 5 stock.
f. Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.): For this assessment, the major uncertainties are:

- Whether the time period is "representative of the production potential of the stock" and if it serves to "provide the required risk aversion for stock conservation and utilization goals", or whether any such time period exists.
- Only a period of 6 years is used to compute the OFL, 1993-1998. The SSC has noted its uneasiness with that situation (" 6 years of data are very few years upon which to base these catch specifications." June 2011 SSC minutes).
- No data on discarded catch due to the directed fishery are available from the period used to compute the OFL.
- Estimation of the OFL rests on the assumption that data on the ratio of discarded catch to retained catch from post- 2000 can be used to accurately estimate that ratio in 1993-1998.
- The bycatch mortality rates used in estimation of total catch.
- Bycatch mortality is unknown and no data that could be used to estimate the bycatch mortality of this stock are known to the author. Hence, only the values that are assumed for other BSAI king crab stock assessments are considered in this assessment. The estimated OFL increases (or decreases) relative to the bycatch mortality rates assumed: doubling the assumed bycatch mortality rates increases the OFL estimate by a factor of 1.15 ; halving the assumed bycatch mortality rates decreases the OFL estimate by a factor of 0.92.


## F. Calculation of the OFL

1. Specification of the Tier level and stock status level for computing the OFL:

- Recommended as Tier 5, total-catch OFL estimated by estimated average total catch over a specified period.
- Recommended time period for computing retained-catch OFL: 1993-1998.
- This is the same time period that was used to establish OFL for 2010-2017. The time period 1993-1998 provides the longest continuous time period through 2016 during which vessels participated in the fishery, retained-catch data can be retrieved that are not confidential, and the retained catch was not constrained by a GHL. Data on discarded catch contemporaneous with 1993-1998 to the extent possible are used to calculate the total-catch OFL.

2. List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan: Not applicable for Tier 5 stock.

## 3. Specification of the total-catch OFL:

a. Provide the equations (from Amendment 24) on which the OFL is to be based:

From Federal Register / Vol. 73, No. 116, page 33926, "For stocks in Tier 5, the overfishing level is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information." Additionally, "For stocks where nontarget fishery removal data are available, catch includes all fishery removals, including retained catch and discard losses. Discard losses will be determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the overfishing level is set for and compared to the retained catch" (FR/Vol. 73, No. 116, 33926). That compares with the specification of NPFMC (2007) that the OFL "represent[s] the average retained catch from a time period determined to be representative of the production potential of the stock."
b. Basis for projecting MMB to the time of mating: Not applicable for Tier 5 stock.
c. Specification of $\mathrm{FoFL}_{\mathrm{o}}$, OFL, and other applicable measures (if any) relevant to determining whether the stock is overfished or if overfishing is occurring: See table below. No vessels participated in the 2016 directed fishery and no bycatch was observed in crab fisheries in 2016; therefore total catch in 2016 was zero. Although 0.24 t of fishery mortality occurred during groundfish fisheries in 2016, this level of fishery mortality does not exceed the 2016 OFL. As such, overfishing did not occur in 2016. Values for the 2018 OFL and ABC are the author's recommendations.

Management Performance Table (values in t)

| Calendar <br> Year | MSST | Biomass <br> (MMB) | GHL $^{\text {a }}$ | Retained <br> Catch | Total <br> Catch $^{\text {b }}$ | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2013 | N/A | N/A | 68 | Conf. $^{\text {c }}$ | Conf. $^{\text {c }}$ | 91 | 82 |
| 2014 | N/A | N/A | 68 | Conf. $^{\text {c }}$ | Conf. $^{\text {c }}$ | 91 | 82 |
| 2015 | N/A | N/A | 59 | 0 | 1.92 | 91 | 68 |
| 2016 | N/A | N/A | 59 | 0 | 0.24 | 91 | 68 |
| 2017 | N/A | N/A | 59 |  |  | 93 | 70 |
| 2018 | N/A | N/A |  |  |  | 93 | 70 |

a. Guideline harvest level, established in lb and converted to t .
b. Total retained catch plus estimated bycatch mortality of discarded catch during crab and groundfish fisheries. Total reratined catch is not listed for 2013 and 2014 because the directed fishery is confidential under Sec. 16.05.815(SOA statute).
c. Confidential under Sec. 16.05.815 (SOA statute). GHL not attained.

## Management Performance Table (values in millions of lb)

| Calendar <br> Year | MSST | Biomass <br> $(M M B)$ | GHL $^{\mathbf{a}}$ | Retained <br> Catch | Total <br> Catch $^{\text {b }}$ | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 2013 | N/A | N/A | 150,000 | Conf. $^{\text {c }}$ | Conf. $^{\text {c }}$ | 0.20 | 0.18 |
| 2014 | N/A | N/A | 150,000 | Conf. $^{\text {c }}$ | Conf. $^{\text {c }}$ | 0.20 | 0.18 |
| 2015 | N/A | N/A | 130,000 | 0 | 0.004 | 0.20 | 0.15 |
| 2016 | N/A | N/A | 130,000 | 0 | $<0.001$ | 0.20 | 0.15 |
| 2017 | N/A | N/A | 130,000 |  |  | 0.20 | 0.15 |
| 2018 | N/A | N/A |  |  |  | 0.20 | 0.15 |

4. Specification of the retained-catch portion of the total-catch OFL:
a. Equation for recommended retained-portion of total-catch OFL.

Retained-catch portion = average retained catch during 1993-1998 (Table 5).
$=79 \mathrm{t}$.

Note that a retained catch of 79 t would exceed the author's recommended ABC for 2018 (70 t); see G.4, below.
5. Recommended Fofl, OFL total catch and the retained portion for the coming year:

See sections $\boldsymbol{F} .3$ and $\boldsymbol{F} .4$, above; no FofL is recommended for a Tier 5 stock.

## G. Calculation of ABC

1. PDF of OFL. A bootstrap estimates of the sampling distribution (assuming no error in estimation of discarded catch) of the status quo Alternative 1 OFL is shown in Figure 2 (1,000 samples drawn with replacement independently from each of the four columns of values in Table 5 to calculate $\mathrm{R}_{2001-2010}, \mathrm{RET}_{1993-1998}, \mathrm{BM}_{\mathrm{NC}, 1994-1998,} \mathrm{BM}_{\mathrm{GF}, 92 / 93-98 / 99}$, and $\mathrm{OFL}_{2016}$ ). The mean and CV computed from the 1,000 replicates are 92 t and 0.25 , respectively. Note that generated sampling distribution and computed standard deviation are meaningful as measures in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Sections E. 2 and E.4.f).

## 2. List of variables related to scientific uncertainty.

- Bycatch mortality rate in each fishery that discarded catch occurs. Note that for Tier 5 stocks, an increase in an assumed bycatch mortality rate will increase the OFL (and hence the ABC ), but has no effect on the retained-catch portion of the OFL or the retained-catch portion of the $A B C$.
- Estimated discarded catch and bycatch mortality for each fishery that discarded catch occurred in during 1993-1998.
- The time period to compute the average catch under the assumption of representing "a time period determined to be representative of the production potential of the stock."
- Stock size in 2018 is unknown.

3. List of additional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.
4. Author recommended ABC. $25 \%$ buffer on OFL; i.e., $\mathrm{ABC}=(1-0.25) \cdot(93 \mathrm{t})=70 \mathrm{t}$
(153,395 lb).

## H. Rebuilding Analyses

Not applicable; this stock has not been declared overfished.

## I. Data Gaps and Research Priorities

Data from the 2008-2012 biennial NMFS-AFSC eastern Bering Sea upper continental slope trawl surveys have been examined for their utility in determining overfishing levels and stock status by Gaeuman (2103a, 2013b) and Pengilly and Daly (2017). Cancellation of the survey that was scheduled for 2014 raised uncertainties on the prospects for obtaining fishery-independent survey data on this stock in the future; however, a slope survey was conducted in summer 2016. Those data are included in an updated discussion paper presented to the CPT.

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## List of Tables.

Table 1a: Commercial fishery history for the Pribilof District golden king crab fishery, 1981/82 through 2016: number of vessels, guideline harvest level (GHL; established in lb, converted to $\mathbf{t}$ ), weight of retained catch (Harvest; $\mathbf{t}$ ), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight ( $\mathbf{k g}$ ) of landed crab.

Table 1b: Commercial fishery history for the Pribilof District golden king crab fishery, 1981/82 through 2016: number of vessels, guideline harvest level (GHL; lb), weight of retained catch (Harvest; lb), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (lb) of landed crab.

Table 2: Weight $(\mathbf{t})$ of retained catch and estimated discarded catch of Pribilof golden king crab during crab fisheries, 1993-2016, with total fishery mortality ( $\mathbf{t}$ ) estimated by applying a bycatch mortality rate of 0.2 to the discarded catch in the directed fishery and a bycatch mortality rate of 0.5 to the discarded catch in the non-directed fisheries.

Table 3: Estimated annual weight (t) of discarded catch of Pribilof golden king crab (all sizes, males and females) during federal groundfish fisheries by gear type (fixed or trawl), 1991/922016, with total bycatch mortality (t) estimated by assuming bycatch mortality rate $=0.5$ for fixed-gear fisheries, and bycatch mortality rate $=0.8$ for trawl fisheries. 1991/92 to 2008/09 is listed bt crab fishing year, whereas 2009-2016 is listed by calendar year.

Table 4: Retained-catch weights (t) and estimates of discarded catch weights (t) of Pribilof Islands golden king crab available for a Tier 5 assessment; shaded, bold values are used in computation of the recommended (status quo Alternative 1) Tier 5 OFL.

Table 5: Data for calculation of $\operatorname{RET}_{1993-1998}(\mathbf{t})$ and estimates used in calculation of $\mathrm{R}_{\text {2001-2010 }}$ (ratio, t:t), $\mathrm{BM}_{\mathrm{NC}, 1994-1998}(\mathbf{t})$, and $\mathrm{BM}_{\mathrm{GF}, 92 / 93-98 / 99}(\mathbf{t})$ for calculation of the recommended (status quo Alternative 1) Pribilof Islands golden king crab Tier 52018 OFL (t); values under RET $_{1993-}$ 1998 are from Table 1, values under $\mathrm{R}_{2001-2010}$ were computed from the retained catch data and the directed fishery discarded catch estimates in Table 2 (assumed bycatch mortality rate $=0.2$ ), values under $\mathrm{BM}_{\mathrm{NC}, 1994-1998}$ were computed from the non-directed crab fishery discarded catch estimates in Table 2 (assumed bycatch mortality rate $=0.5$ ) and values under $\mathrm{BM}_{\mathrm{GF}, 92 / 93-98 / 99}$ are from Table 3.

## Table of Figures.

Figure 1: King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District (from Figure 2-4 in Leon et al. 2017).

Figure 2: Bootstrapped estimates of the sampling distribution of the 2018 Alternative 1 Tier 5 OFL (total catch, t ) for the Pribilof Islands golden king crab stock; histogram on left, quantile plot on right.

## List of Appendices.

Appendix A1: EBS slope survey data on Pribilof Islands golden king crab and draft Pribilof Island golden king crab stock structure template (from Pengilly and Daly May 2017 report to Crab Plan Team).

Table 1a. Commercial fishery history for the Pribilof District golden king crab fishery, 1981/82 through 2016: number of vessels, guideline harvest level (GHL; established in lb, converted to $\mathbf{t}$ ), weight of retained catch (Harvest; $\mathbf{t}$ ), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (kg) of landed crab.

| Fishing/Calendar |  |  |  |  |  | Average |  |  |  |  |  |
| :--- | :---: | ---: | ---: | ---: | ---: | ---: | ---: | ---: | :---: | :---: | :---: |
| Year | Vessels | GHL | Harvest $^{\text {a }}$ | Crab $^{\text {a }}$ | Pot lifts | CPUE | weight |  |  |  |  |
| $1981 / 82$ | 2 | - | CF | CF | CF | CF | CF |  |  |  |  |
| $1982 / 83$ | 10 | - | 32 | 15,330 | 5,252 | 3 | 2.1 |  |  |  |  |
| $1983 / 84$ | 50 | - | 388 | 253,162 | 26,035 | 10 | 1.5 |  |  |  |  |
| 1984 | 0 | - | 0 | 0 | 0 | - | - |  |  |  |  |
| 1985 | 1 | - | CF | CF | CF | CF | CF |  |  |  |  |
| 1986 | 0 | - | 0 | 0 | 0 | - | - |  |  |  |  |
| 1987 | 1 | - | CF | CF | CF | CF | CF |  |  |  |  |
| $1988-1989$ | 2 | - | CF | CF | CF | CF | CF |  |  |  |  |
| $1990-1992$ | 0 | - | 0 | 0 | 0 | - | - |  |  |  |  |
| 1993 | 5 | - | 31 | 17,643 | 15,395 | 1 | 1.7 |  |  |  |  |
| 1994 | 3 | - | 40 | 21,477 | 1,845 | 12 | 1.9 |  |  |  |  |
| 1995 | 7 | - | 155 | 82,489 | 9,551 | 9 | 1.9 |  |  |  |  |
| 1996 | 6 | - | 149 | 91,947 | 9,952 | 9 | 1.6 |  |  |  |  |
| 1997 | 7 | - | 81 | 43,305 | 4,673 | 9 | 1.9 |  |  |  |  |
| 1998 | 3 | - | 16 | 9,205 | 1,530 | 6 | 1.8 |  |  |  |  |
| 1999 | 3 | 91 | 80 | 44,098 | 2,995 | 15 | 1.8 |  |  |  |  |
| 2000 | 7 | 68 | 58 | 29,145 | 5,450 | 5 | 2.0 |  |  |  |  |
| 2001 | 6 | 68 | 66 | 33,723 | 4,262 | 8 | 2.0 |  |  |  |  |
| 2002 | 8 | 68 | 68 | 34,860 | 5,279 | 6 | 2.0 |  |  |  |  |
| 2003 | 3 | 68 | CF | CF | CF | CF | CF |  |  |  |  |
| 2004 | 5 | 68 | CF | CF | CF | CF | CF |  |  |  |  |
| 2005 | 4 | 68 | CF | CF | CF | CF | CF |  |  |  |  |
| $2006-2009$ | 0 | 68 | 0 | 0 | 0 | - | - |  |  |  |  |
| 2010 | 1 | 68 | CF | CF | CF | CF | CF |  |  |  |  |
| 2011 | 2 | 68 | CF | CF | CF | CF | CF |  |  |  |  |
| 2012 | 1 | 68 | CF | CF | CF | CF | CF |  |  |  |  |
| 2013 | 1 | 68 | CF | CF | CF | CF | CF |  |  |  |  |
| 2014 | 1 | 68 | CF | CF | CF | CF | CF |  |  |  |  |
| 2015 | 0 | 59 | 0 | 0 | 0 | - | - |  |  |  |  |
| 2016 | 0 | 59 | 0 | 0 | 0 | - | - |  |  |  |  |

Note: CF: confidential information due to less than three vessels or processors having participated in fishery;
CF: confidential information and fishery was closed by emergency order to manage the harvest to the preseason GHL.
a Deadloss included.

Table 1b. Commercial fishery history for the Pribilof District golden king crab fishery, 1981/82 through 2016: number of vessels, guideline harvest level (GHL; lb), weight of retained catch (Harvest; lb), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (lb) of landed crab.

| Fishing/Calendar |  |  |  |  |  |  | Average |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Year | Vessels | GHL | Harvest ${ }^{\text {a }}$ | Crab ${ }^{\text {a }}$ | Pot lifts | CPUE | weight |
| 1981/82 | 2 | - | CF | CF | CF | CF | CF |
| 1982/83 | 10 | - | 69,970 | 15,330 | 5,252 | 3 | 4.6 |
| 1983/84 | 50 | - | 856,475 | 253,162 | 26,035 | 10 | 3.4 |
| 1984 | 0 | - | 0 | 0 | 0 | - | - |
| 1985 | 1 | - | CF | CF | CF | CF | CF |
| 1986 | 0 | - | 0 | 0 | 0 | - | - |
| 1987 | 1 | - | CF | CF | CF | CF | CF |
| 1988-1989 | 2 | - | CF | CF | CF | CF | CF |
| 1990-1992 | 0 | - | 0 | 0 | 0 | - | - |
| 1993 | 5 | - | 67,458 | 17,643 | 15,395 | 1 | 3.8 |
| 1994 | 3 | - | 88,985 | 21,477 | 1,845 | 12 | 4.1 |
| 1995 | 7 | - | 341,908 | 82,489 | 9,551 | 9 | 4.1 |
| 1996 | 6 | - | 329,009 | 91,947 | 9,952 | 9 | 3.6 |
| 1997 | 7 | - | 179,249 | 43,305 | 4,673 | 9 | 4.1 |
| 1998 | 3 | - | 35,722 | 9,205 | 1,530 | 6 | 3.9 |
| 1999 | 3 | 200,000 | 177,108 | 44,098 | 2,995 | 15 | 4.0 |
| 2000 | 7 | 150,000 | 127,217 | 29,145 | 5,450 | 5 | 4.4 |
| 2001 | 6 | 150,000 | 145,876 | 33,723 | 4,262 | 8 | 4.3 |
| 2002 | 8 | 150,000 | 150,434 | 34,860 | 5,279 | 6 | 4.3 |
| 2003 | 3 | 150,000 | CF | CF | CF | CF | CF |
| 2004 | 5 | 150,000 | CF | CF | CF | CF | CF |
| 2005 | 4 | 150,000 | CF | CF | CF | CF | CF |
| 2006-2009 | 0 | 150,000 | 0 | 0 | 0 | - | - |
| 2010 | 1 | 150,000 | CF | CF | CF | CF | CF |
| 2011 | 2 | 150,000 | CF | CF | CF | CF | CF |
| 2012 | 1 | 150,000 | CF | CF | CF | CF | CF |
| 2013 | 1 | 150,000 | CF | CF | CF | CF | CF |
| 2014 | 1 | 150,000 | CF | CF | CF | CF | CF |
| 2015 | 0 | 130,000 | 0 | 0 | 0 | - | - |
| 2016 | 0 | 130,000 | 0 | 0 | 0 | - | - |
| Note: CF: conf  <br>   CF: con <br>   GHL. <br> a Deadloss included  | dential info dential info | rmation du ormation | e to less th nd fishery | an three ves was closed | ssels or pro by emerge | cessors h ncy orde | aving par to mana |
|  |  |  |  |  |  |  |  |

Table 2. Weight ( $\mathbf{t}$ ) of retained catch and estimated discarded catch of Pribilof golden king crab during crab fisheries, 1993-2016, with total fishery mortality (t) estimated by applying a bycatch mortality rate of 0.2 to the discarded catch in the directed fishery and a bycatch mortality rate of 0.5 to the discarded catch in the non-directed fisheries.

|  |  | Discarded (no mortality rate applied) |  |  |  |
| :--- | ---: | :---: | ---: | :---: | ---: |
| Calendar | Pribilof Islands |  |  |  |  |
| Year | Retained | golden <br> king crab | Bering Sea <br> snow crab <br> grooved | Total <br> Tanner crab | Mortality |
| 1993 | 30.60 | no data | 0.00 | no data | - |
| 1994 | 40.36 | no data | 3.80 | 1.15 | - |
| 1995 | 155.09 | no data | 0.63 | 15.65 | - |
| 1996 | 149.24 | no data | 0.24 | 2.34 | - |
| 1997 | 81.31 | no data | 4.05 | no fishing | - |
| 1998 | 16.20 | no data | 33.00 | no fishing | - |
| 1999 | 80.33 | no data | 0.00 | confidential | - |
| 2000 | 57.70 | no data | 0.00 | confidential | - |
| 2001 | 66.17 | 17.82 | 0.00 | confidential | confidential |
| 2002 | 68.24 | 19.00 | 1.06 | no fishing | 72.57 |
| 2003 | confidential | confidential | 0.15 | confidential | 72.20 |
| 2004 | confidential | confidential | 0.00 | confidential | 66.93 |
| 2005 | confidential | confidential | 0.00 | confidential | 29.85 |
| 2006 | no fishing | no fishing | 0.00 | 0.00 | 0.00 |
| 2007 | no fishing | no fishing | 0.00 | 0.00 | 0.00 |
| 2008 | no fishing | no fishing | 0.00 | no fishing | 0.00 |
| 2009 | no fishing | no fishing | 0.96 | no fishing | 0.48 |
| 2010 | confidential | confidential | 0.00 | no fishing | confidential |
| 2011 | confidential | confidential | 0.27 | no fishing | confidential |
| 2012 | confidential | confidential | 0.27 | no fishing | confidential |
| 2013 | confidential | confidential | 0.58 | no fishing | confidential |
| 2014 | confidential | confidential | 0.12 | no fishing | confidential |
| 2015 | no fishing | no fishing | 0.00 | no fishing | 0.00 |
| 2016 | no fishing | no fishing | 0.00 | no fishing | 0.00 |

Table 3. Estimated annual weight (t) of discarded catch of Pribilof golden king crab (all sizes, males and females) during federal groundfish fisheries by gear type (fixed or trawl) with total bycatch mortality ( $\mathbf{t}$ ) estimated by assuming bycatch mortality rate $=0.5$ for fixedgear fisheries and bycatch mortality rate $=0.8$ for trawl fisheries. 1991/92-2008/09 is listed by crab fishery year, while 2009-2016 are listed by calendar year.

| Crab fishing year (1991/92-2008/09) or Calendar year (2009-2016) | Bycatch in groundfish fisheries <br> (no mortality rate applied) |  |  | Total <br> Mortality |
| :---: | :---: | :---: | :---: | :---: |
|  | Fixed | Trawl | Total |  |
| 1991/92 | 0.05 | 6.11 | 6.16 | 4.91 |
| 1992/93 | 3.49 | 8.87 | 12.35 | 8.84 |
| 1993/94 | 0.51 | 9.64 | 10.14 | 7.96 |
| 1994/95 | 0.25 | 3.22 | 3.47 | 2.70 |
| 1995/96 | 0.41 | 1.90 | 2.31 | 1.72 |
| 1996/97 | 0.02 | 0.87 | 0.89 | 0.71 |
| 1997/98 | 1.34 | 0.49 | 1.83 | 1.06 |
| 1998/99 | 6.77 | 0.18 | 6.95 | 3.53 |
| 1999/00 | 4.79 | 0.65 | 5.43 | 2.91 |
| 2000/01 | 1.63 | 1.88 | 3.50 | 2.31 |
| 2001/02 | 1.50 | 0.36 | 1.85 | 1.03 |
| 2002/03 | 0.55 | 0.21 | 0.77 | 0.45 |
| 2003/04 | 0.23 | 0.18 | 0.41 | 0.26 |
| 2004/05 | 0.16 | 0.39 | 0.55 | 0.39 |
| 2005/06 | 0.09 | 0.06 | 0.15 | 0.09 |
| 2006/07 | 1.32 | 0.12 | 1.44 | 0.75 |
| 2007/08 | 8.47 | 0.16 | 8.63 | 4.36 |
| 2008/09 | 3.99 | 1.56 | 5.55 | 3.24 |
| 2009 | 2.67 | 2.55 | 5.22 | 3.38 |
| 2010 | 2.13 | 1.01 | 3.14 | 1.87 |
| 2011 | 0.85 | 1.33 | 2.18 | 1.49 |
| 2012 | 0.73 | 0.82 | 1.55 | 1.02 |
| 2013 | 0.50 | 2.49 | 2.99 | 2.24 |
| 2014 | 0.60 | 0.53 | 1.13 | 0.73 |
| 2015 | 0.81 | 1.89 | 2.70 | 1.92 |
| 2016 | 0.23 | 0.16 | 0.39 | 0.24 |
| Average | 1.70 | 1.83 | 3.53 | 2.31 |

Table 4. Retained-catch weights (t) and estimates of discarded catch weights (t) of Pribilof Islands golden king crab available for a Tier 5 assessment; shaded, bold values are used in computation of the recommended (status quo Alternative 1) Tier 5 OFL.

| Calendar Year ${ }^{\text {a }}$ | Crab Fishing Year ${ }^{\text {b }}$ | Retained catch weight Fish tickets Directed fishery | Discarded catch weight (estimated) |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | Observer data: lengths, catch per sampled pot |  | Blend method; Catch Accounting System |  |
|  |  |  | Directed fishery | Non-directed crab fisheries | Fixed gear, groundfish | Trawl gear, groundfish |
|  | 1981/82 | Confidential |  |  |  |  |
|  | 1982/83 | 31.74 |  |  |  |  |
|  | 1983/84 | 388.49 |  |  |  |  |
| 1984 | 1984/85 | 0.00 |  |  |  |  |
| 1985 | 1985/86 | Confidential |  |  |  |  |
| 1986 | 1986/87 | 0.00 |  |  |  |  |
| 1987 | 1987/88 | Confidential |  |  |  |  |
| 1988 | 1988/89 | Confidential |  |  |  |  |
| 1989 | 1989/90 | Confidential |  |  |  |  |
| 1990 | 1990/91 | 0.00 |  |  |  |  |
| 1991 | 1991/92 | 0.00 |  |  | 0.05 | 6.11 |
| 1992 | 1992/93 | 0.00 |  |  | 3.49 | 8.87 |
| 1993 | 1993/94 | 30.60 |  |  | 0.51 | 9.64 |
| 1994 | 1994/95 | 40.36 |  | 4.95 | 0.25 | 3.22 |
| 1995 | 1995/96 | 155.09 |  | 16.28 | 0.41 | 1.90 |
| 1996 | 1996/97 | 149.24 |  | 2.58 | 0.02 | 0.87 |
| 1997 | 1997/98 | 81.31 |  | 4.05 | 1.34 | 0.49 |
| 1998 | 1998/99 | 16.20 |  | 33.00 | 6.77 | 0.18 |
| 1999 | 1999/00 | 80.33 |  | Confidential | 4.79 | 0.65 |
| 2000 | 2000/01 | 57.70 |  | Confidential | 1.63 | 1.88 |
| 2001 | 2001/02 | 66.17 | 17.20 | Confidential | 1.50 | 0.36 |
| 2002 | 2002/03 | 68.24 | 19.00 | 1.06 | 0.55 | 0.21 |
| 2003 | 2003/04 | Confidential | Confidential | Confidential | 0.23 | 0.18 |
| 2004 | 2004/05 | Confidential | Confidential | Confidential | 0.16 | 0.39 |
| 2005 | 2005/06 | Confidential | Confidential | Confidential | 0.09 | 0.06 |
| 2006 | 2006/07 | 0.00 | 0.00 | 0.00 | 1.32 | 0.12 |
| 2007 | 2007/08 | 0.00 | 0.00 | 0.00 | 8.47 | 0.16 |
| 2008 | 2008/09 | 0.00 | 0.00 | 0.00 | 3.99 | 1.56 |
| 2009 | 2009/10 | 0.00 | 0.96 | 0.96 | 2.67 | 2.55 |
| 2010 | 2010/11 | Confidential | Confidential | 0.00 | 2.13 | 1.01 |
| 2011 | 2011/12 | Confidential | Confidential | 0.27 | 0.85 | 1.33 |
| 2012 | 2012/13 | Confidential | Confidential | 0.27 | 0.73 | 0.82 |
| 2013 | 2013/14 | Confidential | Confidential | 0.58 | 0.50 | 2.49 |
| 2014 | 2014/15 | Confidential | Confidential | 0.12 | 0.60 | 0.53 |
| 2015 | 2015/16 | 0.00 | 0.00 | 0.00 | 0.812 | 1.890 |
| 2016 | 2016/17 | 0.00 | 0.00 | 0.00 | 0.231 | 0.158 |

a. Year convention for retained weights in directed fishery, 1984-2016, estimates of discarded bycatch weights in directed, non-directed crab fisheries, and grounfish (2009-2016).
b. Year convention for retained weights in directed fishery, 1981/82-1983/84, and estimates of discarded bycatch rates in groundfish fisheries (1991/92-2008/09).

Table 5. Data for calculation of $\mathrm{RET}_{1993-1998}$ ( $\mathbf{t}$ ) and estimates used in calculation of $\mathrm{R}_{2001-2010}$ (ratio, t:t), $\mathrm{BM}_{\mathrm{NC}, 1994-1998}(\mathbf{t})$, and $\mathrm{BM}_{\mathrm{GF}, 92 / 93-98 / 99}(\mathbf{t})$ for calculation of the recommended (status quo Alternative 1) Pribilof Islands golden king crab Tier 52018 OFL (t); values under RET $_{1993-1998}$ are from Table 1, values under $\mathrm{R}_{2001-2010}$ were computed from the retained catch data and the directed fishery discarded catch estimates in Table 2 (assumed bycatch mortality rate $=0.2$ ), values under $\mathrm{BM}_{\mathrm{NC}, 1994-1998}$ were computed from the non-directed crab fishery discarded catch estimates in Table 2 (assumed bycatch mortality rate $=0.5$ ) and values under $\mathrm{BM}_{\mathrm{GF}, 92 / 93-98 / 99}$ are from Table 3.

| Calendar Year ${ }^{\text {a }}$ | Crab <br> Fishing Year ${ }^{\text {b }}$ | RET $_{1993-1998}$ | R2001-2010 | $\mathrm{BM}_{\mathrm{NC}, 1994-1998}$ | BM ${ }_{\text {GF,92/93-98/99 }}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 1993 | 1992/93 | 30.60 |  |  | 8.84 |
| 1994 | 1993/94 | 40.36 |  | 2.48 | 7.96 |
| 1995 | 1994/95 | 155.09 |  | 8.14 | 2.70 |
| 1996 | 1995/96 | 149.24 |  | 1.29 | 1.72 |
| 1997 | 1996/97 | 81.31 |  | 2.03 | 0.71 |
| 1998 | 1997/98 | 16.20 |  | 16.50 | 1.06 |
| 1999 | 1998/99 |  |  |  | 3.53 |
| 2000 | 1999/00 |  |  |  |  |
| 2001 | 2000/01 |  | 0.054 |  |  |
| 2002 | 2001/02 |  | 0.056 |  |  |
| 2003 | 2002/03 |  | conf. |  |  |
| 2004 | 2003/04 |  | conf. |  |  |
| 2005 | 2004/05 |  | conf. |  |  |
| 2006 | 2005/06 |  |  |  |  |
| 2007 | 2006/07 |  |  |  |  |
| 2008 | 2007/08 |  |  |  |  |
| 2009 | 2008/09 |  |  |  |  |
| 2010 | 2009/10 |  | conf. |  |  |
|  | N | 6 | 6 | 5 | 7 |
|  | Mean | 78.80 | 0.052 | 6.09 | 3.79 |
|  | S.E.M | 24.84 | 0.004 | 2.87 | 1.25 |
|  | CV | 0.32 | 0.07 | 0.47 | 0.33 |

${ }^{\text {a. }} \quad$ Year convention corresponding with values under $\mathrm{RET}_{1993-1998}, \mathrm{R}_{2001-2010}$, and $\mathrm{BM}_{\mathrm{NC}, 1994-1998}$.
b. Year convention corresponding with values under $\mathrm{BM}_{\mathrm{GF}, 92 / 93-98 / 99}$.


Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District (from Figure 2-4 in Leon et al. 2017).


Figure 2. Bootstrapped estimates of the sampling distribution of the 2017 Alternative 1 Tier 5 OFL (total catch, t ) for the Pribilof Islands golden king crab stock; histogram on left, quantile plot on right.

Appendix A1: EBS slope survey data on Pribilof Islands golden king crab and draft Pribilof Island golden king crab stock structure template (from Pengilly and Daly May 2017 report to Crab Plan Team).

# Updated discussion paper for May 2017 Crab Plan Team meeting: Random effects approach to modeling NMFS EBS slope survey area-swept biomass estimates for Pribilof Islands golden king crab. 

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## Introduction.

The Pribilof Islands golden king crab stock has been defined by the geographic borders of the Pribilof District (Figure 1) and has been managed as a Tier 5 stock (i.e., no reliable estimates of biomass and only historical catch data available) for determination of federal overfishing limits and annual catch limits (Pengilly 2014). Since 2011, the Council's Crab Plan Team (CPT) and the Scientific and Statistical Committee (SSC) have expressed interest in utilizing data collected during NMFS eastern Bering Sea (EBS) upper continental slope surveys (Hoff 2013) to establish an annual overfishing limit (OFL) and acceptable biological catch (ABC) on the basis of biomass estimates as an alternative to the standard Tier 5 historical-catch approach (see: reports of the June 2011, June 2012, June 2013, and October 2013 SSC meetings; reports of the May 2013 and September 2013 CPT meetings). Reviews of the EBS slope survey relative to the data collected on golden king crab, summaries of those data, and area-swept biomass estimates (Pengilly 2012, Gaeuman 2013a, 2013b), a Tier 4 approach to establishing OFL and ABC (Gaeuman 2013b), and "modified Tier 5" approach to establishing OFL and ABC (Gaeuman 2013a) have been presented to the CPT and SSC. Cancellation of the EBS biennial slope survey scheduled for 2014 precluded application of Gaeuman's (2013a) approach to establishment of OFL and ABC (see: report of the May 2015 CPT meeting; report of the June 2015 SSC meeting); however, the completion of the 2016 slope survey allows opportunity to revisit this approach.

In May 2015 the CPT recommended that, "a preliminary Tier 4 assessment be brought to the September 2015 meeting using available slope survey data and applying a Kalman filter approach (e.g., the program developed by Jim Ianelli for groundfish stock assessments)" (report of May 2015 CPT meeting). In June 2015, the SSC supported "the CPT recommendation that a preliminary Tier 4 assessment be brought to the September 2015 meeting, using existing slope data and applying a Kalman filter approach" (report of the June 2015 SSC meeting). The SSC also requested that the assessment include "a discussion ... of what stock delineation was chosen (what slope data were used) and the reason for that delineation," and that "a Stock Structure Template be completed for PI GKC" (report of the June 2015 SSC meeting). In September 2016 the CPT "recommends the random effects model be re-evaluated after results from the 2016
slope survey are available." The SSC confirmed that request:"The SSC concurs with the CPT recommendation" ["that the random effects model be re-evaluated after results from the 2016 slope survey are available"].

This report provides: results of applying the program developed for groundfish stock assessments to the slope survey area-swept biomass estimates of golden king crab; a discussion of the stock delineation chosen (what slope data were used and why); and a Stock Structure Template for Pribilof Islands golden king crab (Appendix C) that was prepared with the guidance of Spencer et al. (2010).

This report does not provide a Tier 4 assessment, however (i.e., no OFLs or ABCs are computed from the results of this exercise). Prior to computation of an OFL or ABC, the author would like to review the biomass estimates with the CPT so that the CPT can evaluate the results relative to the Tier 4 and Tier 5 criteria (i.e., Do the biomass estimates meet the "reliability" criterion for removing the stock from Tier 5? Do the results meet the Tier 4 criterion of having sufficient information for simulation modeling that captures the essential population dynamics of the stock?). Additionally, the term "Tier 4 assessment" in application to this stock since 2013 has lost its clarity, making it unclear if the requested assessment was to be made according to Tier 4 as defined in the FMP, according to the "modified Tier 5" approach of Gaeuman (2013a,b), or according to some modification to a Tier 4 assessment. Dependent on the evaluation of results and after clarification of the assessment approach, the computations of OFL and ABC can be performed with the results presented here.

## The NMFS EBS slope survey.

Only data from NMFS EBS slope trawl surveys performed in 2002 and later are used here. Although a pilot slope survey was also performed in 2000 and triennial surveys using a variety of nets, methods, vessels, and sampling locations were performed during 1979-1991, authors noted that, "Comparisons between the post-2000 surveys and those conducted from 1979-1991 remain confounded due to differences in sampling gear, survey design, sampling methodology, and species identification" (Hoff and Britt 2011). Starting in 2002, the slope survey was nominally a biennial survey, but no survey was performed in 2006 or 2014. Details on the methods and survey gear used in the 2002, 2004, 2008, 2010, 2012, and 2016 NMFS EBS slope surveys are provided in Hoff and Britt $(2003,2005,2009,2011)$ and $\operatorname{Hoff}(2013,2016)$, respectively. Those methods and the applicability of the slope survey data to golden king crab abundance and biomass estimation have also been summarized by Pengilly (2012) and Gaeuman (2013a,b).

Briefly, the survey samples from an area of $32,723 \mathrm{~km}^{2}$ in the $200-1,200 \mathrm{~m}$ depth zone. The surveyed area is divided into six subareas (Figure 2). Each subarea is divided into strata defined by 200 m depth zones and tows are performed at randomly-selected locations within each stratum, with target sampling density within strata proportional to the area in each subarea and stratum. Number of stations towed per survey ranged from 156 in 2002 to 231 in 2004; mean sampling density within strata ranged from approximately one tow per $162 \mathrm{~km}^{2}$ in 2004 to approximately one tow per $255 \mathrm{~km}^{2}$ in 2002. With regard to survey catchability of golden king crab by size and sex, the survey uses a Poly Nor'eastern high-opening bottom trawl equipped with mud-sweeper roller gear. ASFC scientists conveyed their opinion to the CPT during the May meeting that, with respect to golden king crab, "... the catchability of the slope net is less
than 1.0 and probably considerably lower than the shelf net due to the differences in the foot rope and surveyed habitat" (report of the May 2013 CPT meeting).

## Methods.

Data available by survey. Data on golden king crab that are available from the 2002, 2004, 2006, 2008, 20010, 2012 and 2016 NMFS EBS slope surveys are summarized in Table 1.

Although the CPT and SSC both suggested that NMFS would "provide the author with slope survey CPUE data based on State statistical areas or other stratification instead of the entire slope survey area because the entire survey extends beyond the Pribilof management area" (reports of the May 2015 CPT meeting and June 2015 SSC meeting), the author did not find it necessary or useful for this exercise to receive the data stratified by State statistical area or by any other stratification besides that defined by the survey design.

Data summarization: area-swept biomass estimates. Area-swept estimates of total (male and female, all sizes) biomass and variances of estimates within strata within survey subarea for 2002, 2004, 2008, 2010, and 2012 were obtained directly from the tables presented in Hoff and Britt (2003; 2005; 2009; 2011) and Hoff (2013). For area-swept biomass estimation of mature males and legal males from the 2008, 2010, 2012, and 2016 survey data, 107 mm CL was used as a proxy for size at maturity (Somerton and Otto 1986) and 124 mm CL was used as a proxy for the 5.5 in carapace width (including spines) legal size (NPFMC 2007); weight of males was estimated from the CL measured during the survey by weight $(\mathrm{g})=(0.0002988) \times(\mathrm{CL})^{3.135}$ (NPFMC 2007). An area-swept estimate of biomass and of the variance of the biomass estimate was computed for each stratum within a survey subarea and summed over strata within the subarea to obtain area-swept estimates of biomass within a subarea and of the variance of that biomass estimate; estimates of the biomass and associated variances within subareas were summed over subareas to obtain biomass estimates in aggregates of subareas and of the variances of those estimates.

Model estimates of biomass and projections to 2018. ${ }^{1}$ The program "re.exe" was used to estimate biomass from the area-swept estimates in surveyed years and to project biomass estimates for unsurveyed years into 2018 via a state-space random walk plus noise model. The state-space random walk plus noise is formulated as a random effect model. The random effects model considers the process errors as "random effects" (i.e., drawn from an underlying distribution) and integrated out of the likelihood. The method was developed by the NPFMC groundfish plan team's survey averaging working group as a smoothing technique similar to the Kalman Filter, but which provides more flexibility with non-linear processes and non-normal error structures.

Stock delineation chosen (what slope data were used). The author followed the guidance provided by the SSC in June 2013 (report of the June 2013 SSC meeting):

[^9]
#### Abstract

"Because the stock structure is unknown, the SSC recommends that the authors examine maps of catch-per-unit-effort by survey year to identify natural breaks in the spatial distribution of golden king crab along the slope. If no obvious breaks exist, the SSC recommends that the authors bring forward biomass estimates for the Pribilof canyon region and for the slope as a whole. However, we note that the Pribilof Canyon stations do not encompass the historical catches, which occurred inside and to the north of Pribilof Canyon. Therefore, the authors should consider a biomass estimate for an area that encompasses the majority of historical catches."


Figures 3-8 show CPUE ( $\mathrm{kg} \mathrm{km}^{-2}$ ) of golden king crab (males and females, all sizes) by tow and survey subarea during the 2002, 2004, 2008, 2010, 2012, and 2016 NMFS EBS slope surveys relative to the boundaries of the Pribilof District. Highest survey CPUE occurs at tows within survey subareas 2-4 (particularly in subarea 2; i.e., Pribilof Canyon). Tows performed in the portion of subarea 5 that lie within the Pribilof District have produced little or no catch of golden king crab, indicating a gap in golden king crab distribution between subarea 4 and the portion of the surveyed area north of the Pribilof District boundary (i.e., the portion of subarea 5 that is north of the Pribilof District boundary and all of subarea 6). Tows performed in subarea 1 that are within the Pribilof District have produced little or no catch of golden king crab, indicating a gap in distribution between Pribilof Canyon and the area east of the Pribilof District within subarea 1. It appears that the areas of subareas 1 and 5 that lie within the Pribilof District support limited densities of golden king crab. Subarea 3 appears to support only low-to-moderate densities of golden king crab relative to subarea 4 and - especially - subarea 2; tows with catch of golden king crab occurred sporadically within subarea 3, with highest densities occurring near the border of subarea 4 in 2010 and 2012 and near the border of subarea 2 in 2002.

Figure 9 shows the distribution of all 6,104 pot lifts sampled by observers with locations recorded during 1992-2014 Bering Sea golden king crab fisheries (including the Saint Matthew section of the Northern District, which is north of the Pribilof District) relative to the borders of the Pribilof District and of the survey subareas. Only one of those locations is within the portion of subarea 5 that is within the Pribilof District, none are within the portion of subarea 1 that is within the Pribilof District, and none are within subarea 3.

Figure 10 shows the 26 statistical areas with reported catch during the 1985-2014 Pribilof District golden king crab fisheries relative to the borders of the Pribilof District and of the survey subareas: one (accounting for $0.7 \%$ of the 1985-2014 total catch) lies largely in subarea 4, but extends into subarea 5 ; four ( $2.9 \%$ of the total catch) include portions of subarea 4 ; six ( $1.5 \%$ of total catch) include portions of subarea 3; one ( $8.9 \%$ of total catch) includes portions of subareas 3 and 2 ; four ( $83.9 \%$ of total catch) are in or extend into subarea 2 ; one ( $0.7 \%$ of total catch) includes portions of subareas 2 and 1 ; one ( $<0.1 \%$ of total catch) is largely within subarea 1 ; and eight ( $1.4 \%$ of total catch) are outside of the survey area (some of those may be errors in recording of statistical area).

This review of survey distribution and fishery catch and effort distribution shows that golden king crab in the Bering Sea and the fishery for golden king crab in the Bering Sea are concentrated in the Pribilof Canyon area (survey subarea 2). Nonetheless, golden king crab do
occur more sporadically and at lower densities in survey subareas 3 and 4 and there has been some limited catch and effort during Pribilof District fisheries within survey subareas 3 and 4. Portions of survey subareas 1 and 5 that lie within the Pribilof District appear to be largely devoid of golden king crab, have received little or no fishery effort during the Pribilof District fishy, and thus have produced little or no catch. The golden king crab that occur in survey subarea 6 are exploited by the Saint Matthew section fishery when it is prosecuted. Accordingly, the following analyses to estimate trends in the Pribilof District stock were performed using survey data from only survey subareas 2,3 , and 4 . Data summaries and analyses were also performed using data only from survey Subarea 2 due to the high concentration of fishery effort and fishery catch in Pribilof Canyon and the high CPUE of golden king crab within Pribilof Canyon during the slope surveys,.

## Results.

Size frequency distributions of golden king crab captured within subareas 2, 3, and 4 during the 2008, 2010, 2012, 2016 NMFS EBS slope surveys are shown in Figures 11-14.

Area-swept biomass estimates by survey subarea, for the total surveyed area (pooled subareas 1 6 ), and for pooled subareas 2-4 for 2002, 2004, 2008, 2010, 2012 and 2016 are in Table 2.

Estimates and projections through 2018 of total, mature male, and legal male biomass in survey subareas 2-4 and survey subarea 2 from the state-space random walk plus noise model are plotted in Figures 15 and 16, respectively. More detailed results produced by re.exe are provided in Appendices A and B.

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Table 1. Data on golden king crab recorded during the 2002, 2004, 2008, 2010, 2012, and NMFS EBS slope surveys.

| Survey | Weight <br> in tow | Count <br> in tow | Sex/CL/shell con/fem repro | Individual weights |
| :--- | :---: | :---: | :---: | :---: |
| 2002 | YES | YES | NO | NO |
| 2004 | YES | YES | NO | NO |
| 2008 | YES | YES | YES | 285 of 416 meas'd |
| 2010 | YES | YES | YES | NO |
| 2012 | YES | YES | YES | 495 of 899 meas'd |
| 2016 | YES | YES | YES $^{\text {b }}$ | NO |

a. Golden king crab $<100 \mathrm{~mm}$ CL were subsampled for data recording at one tow in subarea 4 during the 2012 survey.
b. Golden king crab were subsampled for data recording at one tow in subarea 2 during the 2016 survey.

Table 2. Area-swept biomass (t) estimates of total (sexes combined), mature-sized males, and legal male golden king crab computed from 2002, 2004, 2008, 2010, 2012, and 2016 NMFS eastern Bering Sea slope survey data, by survey subarea, and with coefficients of variation ( $\mathrm{CV}=$ standard error of estimate divided by the estimate).

| Survey Year | Subarea | Total (males and females) |  | Mature males (males $\geq 107 \mathrm{~mm} \mathrm{CL}$ ) |  | Legal males <br> (males $\geq 124 \mathrm{~mm} \mathrm{CL}$ ) |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Biomass (t) | CV | Biomass (t) | CV | Biomass (t) | CV |
| 2002 | 1 | 131 | 0.39 | - | - | - | - |
| 2002 | 2 | 682 | 0.22 | - | - | - | - |
| 2002 | 3 | 81 | 0.40 | - | - | - | - |
| 2002 | 4 | 53 | 0.40 | - | - | - | - |
| 2002 | 5 | 19 | 0.86 | - | - | - | - |
| 2002 | 6 | 44 | 0.69 | - | - | - | - |
| 2002 | 1-6 | 1,010 | 0.16 | - | - | - | - |
| 2002 | 2-4 | 816 | 0.19 | - | - | - | - |
| 2004 | 1 | 65 | 0.22 | - | - | - | - |
| 2004 | 2 | 817 | 0.38 | - | - | - | - |
| 2004 | 3 | 51 | 0.41 | - | - | - | - |
| 2004 | 4 | 121 | 0.36 | - | - | - | - |
| 2004 | 5 | 20 | 0.73 | - | - | - | - |
| 2004 | 6 | 24 | 0.73 | - | - | - | - |
| 2004 | 1-6 | 1,098 | 0.29 | - | - | - | - |
| 2004 | 2-4 | 989 | 0.32 | - | - | - | - |
| 2008 | 1 | 146 | 0.40 | 47 | 0.35 | 11 | 0.70 |
| 2008 | 2 | 920 | 0.32 | 490 | 0.36 | 294 | 0.29 |
| 2008 | 3 | 91 | 0.44 | 64 | 0.44 | 28 | 0.54 |
| 2008 | 4 | 205 | 0.46 | 85 | 0.53 | 78 | 0.52 |
| 2008 | 5 | 2 | 1.00 | 22 | 1.00 | 22 | 1.00 |
| 2008 | 6 | 66 | 0.50 | 30 | 0.63 | 19 | 0.61 |
| 2008 | 1-6 | 1,431 | 0.22 | 737 | 0.25 | 452 | 0.22 |
| 2008 | 2-4 | 1,216 | 0.26 | 638 | 0.29 | 401 | 0.24 |
| 2010 | 1 | 363 | 0.20 | 168 | 0.20 | 145 | 0.23 |
| 2010 | 2 | 1,614 | 0.31 | 440 | 0.24 | 349 | 0.25 |
| 2010 | 3 | 89 | 0.63 | 79 | 0.72 | 71 | 0.75 |
| 2010 | 4 | 72 | 0.41 | 46 | 0.47 | 44 | 0.50 |
| 2010 | 5 | 37 | 0.45 | 10 | 0.76 | 7 | 1.00 |
| 2010 | 6 | 122 | 0.43 | 25 | 0.51 | 12 | 1.00 |
| 2010 | 1-6 | 2,298 | 0.22 | 768 | 0.17 | 628 | 0.18 |
| 2010 | 2-4 | 1,776 | 0.29 | 565 | 0.22 | 464 | 0.23 |
| 2012 | 1 | 421 | 0.37 | 328 | 0.45 | 280 | 0.50 |
| 2012 | 2 | 778 | 0.45 | 256 | 0.32 | 207 | 0.34 |
| 2012 | 3 | 172 | 0.75 | 146 | 0.83 | 131 | 0.81 |
| 2012 | 4 | 494 | 0.69 | 26 | 0.48 | 8 | 1.00 |
| 2012 | 5 | 12 | 0.43 | 6 | 0.74 | 4 | 1.00 |
| 2012 | 6 | 149 | 0.40 | 49 | 0.33 | 40 | 0.38 |
| 2012 | 1-6 | 2,025 | 0.26 | 812 | 0.26 | 670 | 0.28 |
| 2012 | 2-4 | 1,444 | 0.35 | 429 | 0.34 | 346 | 0.37 |
| 2016 | 1 | 217 | 0.35 | 116 | 0.37 | 98 | 0.40 |
| 2016 | 2 | 1060 | 0.27 | 475 | 0.30 | 336 | 0.30 |
| 2016 | 3 | 100 | 0.34 | 74 | 0.42 | 65 | 0.47 |
| 2016 | 4 | 304 | 0.79 | 191 | 0.77 | 165 | 0.73 |
| 2016 | 5 | 23 | 0.48 | 10 | 0.72 | 4 | 1.00 |
| 2016 | 6 | 50 | 0.30 | 31 | 0.46 | 18 | 0.75 |
| 2016 | 1-6 | 1,754 | 0.22 | 897 | 0.24 | 685 | 0.24 |
| 2016 | 2-4 ${ }^{\text {²}}$ | 1,464 | 0.26 | 740 | 0.28 | 565 | 0.28 |



Figure 1. King crab Registration Area Q (Bering Sea), showing borders of the Pribilof District.


Figure 2. Map of standard survey area and the six subareas. Indicated are the 175 successful trawl stations (black dots) completed during the 2016 EBSS survey (taken from Hoff 2016).


Figure 3. 2002 slope survey tow locations (black circles) and golden king crab CPUE ( $\mathrm{kg} / \mathrm{sq}-\mathrm{km}$; white circles; largest circle $=510 \mathrm{~kg} / \mathrm{sq}-\mathrm{km}$ ); squares are $1^{\circ}$ longitude $\times 30^{\prime}$ latitude State statistical areas.


Figure 4. 2004 slope survey tow locations (black circles) and golden king crab CPUE ( $\mathrm{kg} / \mathrm{sq}-\mathrm{km}$; white circles; largest circle $=2,300 \mathrm{~kg} / \mathrm{sq}-\mathrm{km})$; squares are $1^{\circ}$ longitude $\times 30^{\prime}$ latitude State statistical areas.


Figure 5. 2008 slope survey tow locations (black circles) and golden king crab CPUE ( $\mathrm{kg} \mathrm{km}^{-2}$; yellow circles, green stars indicate values outside the normal range).


Figure 6. 2010 slope survey tow locations (black circles) and golden king crab CPUE $\left(\mathrm{kg} \mathrm{km}^{-2}\right.$; yellow circles, green stars indicate values outside the normal range).


Figure 7. 2012 slope survey tow locations (black circles) and golden king crab CPUE ( $\mathrm{kg} \mathrm{km}^{-2}$; yellow circles, green stars indicate values outside the normal range).


Figure 8. 2016 slope survey tow locations (black circles) and golden king crab CPUE ( $\mathrm{kg} \mathrm{km}^{-2}$; yellow circles, green stars indicate values outside the normal range).


Figure 9. Locations of all pots sampled by observers during Bering Sea golden king crab fisheries ( $n=6,104$ ), 1992-2014; pots north of the Pribilof District northern boundary were fished during the Northern District - Saint Matthew Island Section fishery; squares are $1^{\circ}$ longitude $\times 30^{\prime}$ latitude State statistical areas.


Figure 10. Statistical areas with reported catch during the 1985-2014 Pribilof District golden king crab fisheries: filled red squares denote statistical areas with reported catch; size of overlain white circles are proportional to the percentage of the total 1985-2014 catch reported from statistical area (biggest circle $=68 \%$ of total); squares are $1^{\circ}$ longitude x 30' latitude State statistical areas.


Figure 11. Size distribution of measured golden king crab during the 2008 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.


Figure 12. Size distribution of measured golden king crab during the 2010 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.


■ Male Female


■ Male Female


Figure 13. Size distribution of measured golden king crab during the 2012 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.


Figure 14. Size distribution of measured golden king crab during the 2016 NMFS EBS slope survey in survey Subareas 2, 3, and 4, by survey subarea.




Figure 15. Plots of estimated and projected (into 2018) biomass of total, mature male, and legal male golden king crab in NMFS slope survey Subareas 2-4 with $90 \%$ confidence intervals and survey area-swept estimates; red bars are survey estimates $\pm 2$ standard errors.




Figure 16. Plots of estimated and projected (into 2018) biomass of total, mature male, and legal male golden king crab in NMFS slope survey Subarea 2 with $90 \%$ confidence intervals and survey area-swept estimates; red bars are survey estimates $\pm 2$ standard errors.

Appendix A1. Input file (re.dat) for total golden king crab biomass in NMFS EBS slope survey Subareas 2-4 and results file (rwout.rep) produced by re.exe.

| re.dat file |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 2002 \#Start year of model |  |  |  |  |  |
| 2018 \#End year of model |  |  |  |  |  |
| 6 \#number of survey estimates |  |  |  |  |  |
| \#Years of survey |  |  |  |  |  |
| 2002 | 2004 | 2008 | 2010 | 2012 | 2016 |
| \#Biomass estimates |  |  |  |  |  |
| 816 | 989 | 1216 | 1776 | 1444 | 1464 |
| \#Coefficients of variation for biomass estimates |  |  |  |  |  |
| 0.19 | 0.32 | 0.26 | 0.29 | 0.35 | 0.26 |


| rwout.rep file |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| yrs_srv |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2002 | 2004 | 2008 | 2010 | 2012 | 2016 |  |  |  |  |  |  |  |  |  |  |  |
| srv_est |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 816 | 989 | 1216 | 1776 | 1444 | 1464 |  |  |  |  |  |  |  |  |  |  |  |
| srv_sd |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.188318 | 0.312233 | 0.25576 | 0.284166 | 0.339939 | 0.25576 |  |  |  |  |  |  |  |  |  |  |  |
| yrs |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
| LCI |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 645.592 | 679.925 | 725.189 | 752.615 | 790.057 | 838.815 | 901.75 | 922.256 | 952.61 | 949.698 | 960.644 | 943.422 | 937.229 | 940.902 | 954.447 | 899.215 | 853.018 |
| biomA |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 922.492 | 966.221 | 1012.02 | 1063.35 | 1117.29 | 1173.96 | 1233.5 | 1299.86 | 1369.79 | 1382.64 | 1395.6 | 1403.14 | 1410.71 | 1418.33 | 1425.99 | 1425.99 | 1425.99 |
| UCI |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1318.16 | 1373.07 | 1412.31 | 1502.39 | 1580.05 | 1643 | 1687.3 | 1832.06 | 1969.66 | 2012.94 | 2027.5 | 2086.87 | 2123.4 | 2138.02 | 2130.5 | 2261.36 | 2383.83 |
| low90th |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 683.706 | 719.43 | 765.09 | 795.604 | 835.309 | 885.377 | 948.313 | 974.552 | 1009.87 | 1008.79 | 1020.07 | 1005.57 | 1000.89 | 1005.05 | 1018.06 | 968.382 | 926.452 |
| upp90th |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1244.67 | 1297.67 | 1338.66 | 1421.21 | 1494.45 | 1556.59 | 1604.45 | 1733.75 | 1857.98 | 1895.02 | 1909.38 | 1957.89 | 1988.34 | 2001.55 | 1997.37 | 2099.84 | 2194.87 |
| biomsd |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 6.82708 | 6.87339 | 6.91971 | 6.96918 | 7.01866 | 7.06813 | 7.11761 | 7.17001 | 7.22241 | 7.23175 | 7.24108 | 7.24647 | 7.25185 | 7.25724 | 7.26262 | 7.26262 | 7.26262 |
| biomsd.sd |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 0.182097 | 0.179291 | 0.170039 | 0.176341 | 0.176813 | 0.171502 | 0.159833 | 0.175096 | 0.185309 | 0.191634 | 0.19055 | 0.202527 | 0.208635 | 0.209386 | 0.204842 | 0.235255 | 0.262163 |

Appendix A2. Input file (re.dat) for mature male golden king crab biomass in NMFS EBS slope survey Subareas 2-4 and results file (rwout.rep) produced by re.exe.

## re.dat file

2008 \#Start year of model
2018 \#End year of model
4 \#number of survey estimates
\#Years of survey
200820102012

| \#Biomass estimates |  |  |  |
| :---: | ---: | :--- | :--- |
| 638 | 565 | 429 | 740 |

\#Coefficients of variation for biomass estimates

| rwout.rep file |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| yrs_Srv |  |  |  |  |  |  |  |  |  |  |  |
|  | 2008 | 2010 | 2012 | 2016 |  |  |  |  |  |  |  |
| srv_est |  |  |  |  |  |  |  |  |  |  |  |
|  | 638 | 565 | 429 | 740 |  |  |  |  |  |  |  |
| srv_sd |  |  |  |  |  |  |  |  |  |  |  |
|  | 0.284166 | 0.217406 | 0.330745 | 0.274733 |  |  |  |  |  |  |  |
| yrs |  |  |  |  |  |  |  |  |  |  |  |
|  | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
| LCI |  |  |  |  |  |  |  |  |  |  |  |
|  | 455.113 | 455.114 | 455.115 | 455.114 | 455.114 | 455.115 | 455.113 | 455.109 | 455.103 | 455.099 | 455.095 |
| biomA |  |  |  |  |  |  |  |  |  |  |  |
|  | 591.486 | 591.485 | 591.484 | 591.484 | 591.485 | 591.486 | 591.488 | 591.49 | 591.492 | 591.492 | 591.492 |
| UCI |  |  |  |  |  |  |  |  |  |  |  |
|  | 768.721 | 768.718 | 768.715 | 768.716 | 768.718 | 768.721 | 768.728 | 768.74 | 768.756 | 768.762 | 768.768 |
| low90th |  |  |  |  |  |  |  |  |  |  |  |
|  | 474.693 | 474.694 | 474.694 | 474.694 | 474.693 | 474.694 | 474.693 | 474.69 | 474.684 | 474.681 | 474.678 |
| upp90th |  |  |  |  |  |  |  |  |  |  |  |
|  | 737.014 | 737.011 | 737.009 | 737.01 | 737.011 | 737.014 | 737.02 | 737.03 | 737.043 | 737.048 | 737.053 |
| biomsd |  |  |  |  |  |  |  |  |  |  |  |
|  | 6.38264 | 6.38264 | 6.38264 | 6.38264 | 6.38264 | 6.38264 | 6.38264 | 6.38265 | 6.38265 | 6.38265 | 6.38265 |
| biomsd.sd |  |  |  |  |  |  |  |  |  |  |  |
|  | 0.13372 | 0.133718 | 0.133717 | 0.133718 | 0.133718 | 0.133719 | 0.133722 | 0.133728 | 0.133737 | 0.133741 | 0.133745 |

Appendix A3. Input file (re.dat) for legal male golden king crab biomass in NMFS EBS slope survey Subareas 2-4 and results file (rwout.rep) produced by re.exe.

| re.dat file  <br> 2008 \#Start year of model <br> 2018 \#End year of model <br> 4 \#number of survey estimates |
| :--- | :--- | :--- | :--- |
| \#Years of survey |
| 2008 2010 2012 2016 <br> \#Biomass estimates    <br> 401 464 346 565 <br> \#Coefficients of variation for biomass estimates    <br> 0.24 0.23 0.37 0.28 |


| rwout.rep file |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| yrs_srv |  |  |  |  |  |  |  |  |  |  |  |
|  | 2008 | 2010 | 2012 | 2016 |  |  |  |  |  |  |  |
| srv_est |  |  |  |  |  |  |  |  |  |  |  |
|  | 401 | 464 | 346 | 565 |  |  |  |  |  |  |  |
| srv_sd |  |  |  |  |  |  |  |  |  |  |  |
|  | 0.236648 | 0.227042 | 0.358197 | 0.274733 |  |  |  |  |  |  |  |
| yrs |  |  |  |  |  |  |  |  |  |  |  |
|  | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
| LCI |  |  |  |  |  |  |  |  |  |  |  |
|  | 345.148 | 345.153 | 345.158 | 345.158 | 345.158 | 345.156 | 345.151 | 345.143 | 345.132 | 345.129 | 345.126 |
| biomA |  |  |  |  |  |  |  |  |  |  |  |
|  | 446.173 | 446.174 | 446.175 | 446.176 | 446.177 | 446.178 | 446.18 | 446.182 | 446.184 | 446.184 | 446.184 |
| UCI |  |  |  |  |  |  |  |  |  |  |  |
|  | 576.768 | 576.762 | 576.758 | 576.759 | 576.761 | 576.769 | 576.781 | 576.799 | 576.822 | 576.828 | 576.834 |
| low90th |  |  |  |  |  |  |  |  |  |  |  |
|  | 359.687 | 359.692 | 359.696 | 359.696 | 359.696 | 359.695 | 359.691 | 359.684 | 359.675 | 359.672 | 359.669 |
| upp90th |  |  |  |  |  |  |  |  |  |  |  |
|  | 553.454 | 553.45 | 553.446 | 553.448 | 553.449 | 553.456 | 553.467 | 553.481 | 553.5 | 553.505 | 553.509 |
| biomsd |  |  |  |  |  |  |  |  |  |  |  |
|  | 6.10071 | 6.10071 | 6.10071 | 6.10071 | 6.10071 | 6.10072 | 6.10072 | 6.10073 | 6.10073 | 6.10073 | 6.10073 |
| biomsd.sd |  |  |  |  |  |  |  |  |  |  |  |
|  | 0.130986 | 0.13098 | 0.130975 | 0.130975 | 0.130976 | 0.130981 | 0.13099 | 0.131004 | 0.131022 | 0.131027 | 0.131032 |

Appendix B1. Input file (re.dat) for total golden king crab biomass in NMFS EBS slope survey Subarea 2 and results file (rwout.rep)

| re.dat file |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 2002 \#Start year of model |  |  |  |  |  |
| 2018 \#End year of model |  |  |  |  |  |
| 6 \#number of survey estimates |  |  |  |  |  |
| \#Years of survey |  |  |  |  |  |
| 2002 | 2004 | 2008 | 2010 | 2012 | 2016 |
| \#Biomass estimates |  |  |  |  |  |
| 682 | 817 | 920 | 1614 | 778 | 1060 |
| \#Coefficients of variation for biomass estimates |  |  |  |  |  |
| 0.22 | 0.38 | 0.32 | 0.31 | 0.45 | 0.27 |


| rwout.rep file |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| yrs_srv |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 2002 | 2004 | 2008 | 2010 | 2012 | 2016 |  |  |  |  |  |  |  |  |  |  |  |
| srv_est |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 682 | 817 | 920 | 1614 | 778 | 1060 |  |  |  |  |  |  |  |  |  |  |  |
| srv_sd |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 0.217406 | 0.367261 | 0.312233 | 0.302917 | 0.429421 | 0.265265 |  |  |  |  |  |  |  |  |  |  |  |
| yrs |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
| LCI |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 521.757 | 558.084 | 595.708 | 624.797 | 650.996 | 673.321 | 691.078 | 684.518 | 671.956 | 681.957 | 691.351 | 684.38 | 680.48 | 679.379 | 680.946 | 657.937 | 637.299 |
| biomA |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 805.904 | 827.675 | 850.035 | 874.937 | 900.568 | 926.95 | 954.105 | 984.827 | 1016.54 | 1010.12 | 1003.74 | 1007.86 | 1011.99 | 1016.14 | 1020.31 | 1020.31 | 1020.31 |
| UCI |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 1244.8 | 1227.5 | 1212.94 | 1225.22 | 1245.82 | 1276.12 | 1317.24 | 1416.89 | 1537.82 | 1496.2 | 1457.29 | 1484.23 | 1505.01 | 1519.84 | 1528.81 | 1582.27 | 1633.51 |
| low90th |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 559.517 | 594.576 | 630.736 | 659.541 | 685.85 | 708.818 | 727.844 | 725.728 | 718.182 | 726.402 | 734.044 | 728.306 | 725.297 | 724.789 | 726.67 | 706.005 | 687.371 |
| upp90th |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 1160.79 | 1152.16 | 1145.58 | 1160.68 | 1182.51 | 1212.21 | 1250.7 | 1336.43 | 1438.84 | 1404.65 | 1372.53 | 1394.72 | 1412.01 | 1424.62 | 1432.61 | 1474.54 | 1514.52 |
| biomsd |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 6.69196 | 6.71862 | 6.74528 | 6.77415 | 6.80303 | 6.8319 | 6.86077 | 6.89247 | 6.92416 | 6.91782 | 6.91149 | 6.91558 | 6.91968 | 6.92377 | 6.92786 | 6.92786 | 6.92786 |
| biomsd.sd |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 0.221818 | 0.201078 | 0.181392 | 0.171798 | 0.165572 | 0.163101 | 0.164552 | 0.185587 | 0.211207 | 0.200438 | 0.190226 | 0.197485 | 0.202489 | 0.205403 | 0.206316 | 0.223854 | 0.240114 |

Appendix B2. Input file (re.dat) for mature male golden king crab biomass in NMFS EBS slope survey Subarea 2 and results file (rwout.rep) produced by re.exe.
\(\left.$$
\begin{array}{|lll|}\hline \begin{array}{l}\text { re.dat file } \\
2008\end{array}
$$ \& \#Start year of model <br>
2018 \& \#End year of model <br>

4 \#number of survey estimates\end{array}\right]\)|  |
| :--- | :--- | :--- |
| \#Years of survey |
| 2008 2010 2012 2016 |
| \#Biomass estimates    <br> 490 440 256 475 <br> \#Coefficients of variation for biomass estimates    <br> 0.36 0.24 0.32 0.3 |


| rwout.rep file |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| yrs_srv |  |  |  |  |  |  |  |  |  |  |  |
|  | 2008 | 2010 | 2012 | 2016 |  |  |  |  |  |  |  |
| srv_est |  |  |  |  |  |  |  |  |  |  |  |
|  | 490 | 440 | 256 | 475 |  |  |  |  |  |  |  |
| srv_sd |  |  |  |  |  |  |  |  |  |  |  |
|  | 0.34909 | 0.236648 | 0.312233 | 0.29356 |  |  |  |  |  |  |  |
| yrs |  |  |  |  |  |  |  |  |  |  |  |
|  | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
| LCI |  |  |  |  |  |  |  |  |  |  |  |
|  | 306.329 | 306.333 | 306.335 | 306.332 | 306.325 | 306.327 | 306.328 | 306.328 | 306.327 | 306.323 | 306.319 |
| biomA |  |  |  |  |  |  |  |  |  |  |  |
|  | 406.596 | 406.595 | 406.594 | 406.592 | 406.59 | 406.591 | 406.592 | 406.594 | 406.595 | 406.595 | 406.595 |
| UCI |  |  |  |  |  |  |  |  |  |  |  |
|  | 539.683 | 539.674 | 539.666 | 539.666 | 539.673 | 539.672 | 539.674 | 539.678 | 539.684 | 539.691 | 539.698 |
| low90th |  |  |  |  |  |  |  |  |  |  |  |
|  | 320.592 | 320.595 | 320.597 | 320.593 | 320.587 | 320.589 | 320.59 | 320.59 | 320.589 | 320.586 | 320.582 |
| upp90th |  |  |  |  |  |  |  |  |  |  |  |
|  | 515.674 | 515.666 | 515.66 | 515.659 | 515.664 | 515.664 | 515.665 | 515.669 | 515.674 | 515.68 | 515.685 |
| biomsd |  |  |  |  |  |  |  |  |  |  |  |
|  | 6.00782 | 6.00782 | 6.00782 | 6.00781 | 6.0078 | 6.00781 | 6.00781 | 6.00781 | 6.00782 | 6.00782 | 6.00782 |
| biomsd.sd |  |  |  |  |  |  |  |  |  |  |  |
|  | 0.14447 | 0.144463 | 0.144457 | 0.14446 | 0.144469 | 0.144466 | 0.144466 | 0.144468 | 0.144473 | 0.144479 | 0.144486 |

Appendix B3. Input file (re.dat) for legal male golden king crab biomass in NMFS EBS slope survey Subareas 2 and results file (rwout.rep) produced by re.exe.

| re.dat file |  |
| :--- | :--- | :--- |
| 2008 | \#Start year of model |
| 2018 | \#End year of model |
| 4 | \#number of survey estimates |
| \#Years of survey |  |
| 2008 2010 2012 2016 <br> \#Biomass estimates    <br> 294 349 207 336 <br> \#Coefficients of variation for biomass estimates    <br> 0.29 0.25 0.34 0.3 |  |


| rwout.rep file |  |  |  |  |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| yrs_srv |  |  |  |  |  |  |  |  |  |  |  |
|  | 2008 | 2010 | 2012 | 2016 |  |  |  |  |  |  |  |
| srv_est |  |  |  |  |  |  |  |  |  |  |  |
|  | 294 | 349 | 207 | 336 |  |  |  |  |  |  |  |
| srv_sd |  |  |  |  |  |  |  |  |  |  |  |
|  | 0.284166 | 0.246221 | 0.330745 | 0.29356 |  |  |  |  |  |  |  |
| yrs |  |  |  |  |  |  |  |  |  |  |  |
|  | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
| LCl |  |  |  |  |  |  |  |  |  |  |  |
|  | 227.905 | 227.906 | 227.907 | 227.906 | 227.905 | 227.905 | 227.905 | 227.904 | 227.903 | 227.902 | 227.901 |
| biomA |  |  |  |  |  |  |  |  |  |  |  |
|  | 301.019 | 301.02 | 301.02 | 301.019 | 301.018 | 301.019 | 301.019 | 301.019 | 301.02 | 301.02 | 301.02 |
| UCI |  |  |  |  |  |  |  |  |  |  |  |
|  | 397.589 | 397.588 | 397.587 | 397.587 | 397.587 | 397.588 | 397.59 | 397.592 | 397.594 | 397.596 | 397.599 |
| low90th |  |  |  |  |  |  |  |  |  |  |  |
|  | 238.328 | 238.329 | 238.33 | 238.329 | 238.328 | 238.328 | 238.327 | 238.327 | 238.326 | 238.325 | 238.324 |
| upp90th |  |  |  |  |  |  |  |  |  |  |  |
|  | 380.202 | 380.201 | 380.2 | 380.199 | 380.2 | 380.201 | 380.202 | 380.203 | 380.205 | 380.207 | 380.209 |
| biomsd |  |  |  |  |  |  |  |  |  |  |  |
|  | 5.70717 | 5.70718 | 5.70718 | 5.70717 | 5.70717 | 5.70717 | 5.70717 | 5.70718 | 5.70718 | 5.70718 | 5.70718 |
| biomsd.sd |  |  |  |  |  |  |  |  |  |  |  |
|  | 0.141961 | 0.14196 | 0.141958 | 0.141959 | 0.141961 | 0.141961 | 0.141963 | 0.141964 | 0.141966 | 0.14197 | 0.141973 |

## Appendix C. PIGKC stock structure template (adapted from Spencer et al. 2010). Page 1 of 2.

| Factor and criterion | Justification |
| :---: | :---: |
| Harvest and trends |  |
| Fishing mortality <br> (5-year average percent of $\mathrm{F}_{\text {abc }}$ or $\mathrm{Foff}_{\text {I }}$ ) | F, $\mathrm{F}_{\mathrm{ABC}}$, and FofL are not estimated for Tier 5 stock. Total catch annual catch is confidential, but has been below the OFLs and ABCs established for season. |
| Spatial concentration of fishery relative to abundance (Fishing is focused in areas << management areas) | Fishery effort and catch is concentrated in Pribilof Canyon, a very small area of the Pribilof District, but also an area of concentrated golden king crab density (see EBS slope survey data). |
| Population trends (Different areas show different trend directions) | Uncertain. Standardized trawl surveys in the Pribilof District have only been performed in 2002, 2004, 2008, 2010, 2012, and 2016. Total biomass estimates generally increased from 2002 through 2012; with no substantial increase in 2016. |
| Barriers and phenotypic characters |  |
| Generation time (e.g., >10 years) | Unknown, but likely >10 years. |
| Physical limitations (Clear physical inhibitors to movement) | Species occurs primarily in the 200-1000 m depth zone. No known physical barriers exist in the Pribilof District, although survey and fishery data suggest low densities in the 200-1000 m depth zone of the EBS slope between Pribilof Canyon and Zhemchug Canyon. |
| Growth differences (Significantly different LAA, WAA, or LW parameters) | No data for estimating size at age. Spatial differences in lengthweight relationship within Pribilof District have not been investigated. Within the Bering Sea males at higher latitudes have been estimated to be heavier than equal-sized males at lower latitudes. |
| Age/size-structure (Significantly different size/age compositions) | Age structure data is lacking. Spatial trends within Pribilof District in size structure have not been investigated, but trend of latitudinal decrease in mean size may exist over the Bering Sea due to latitudinal decrease in size at maturity. |
| Spawning time differences (Significantly different mean time of spawning) | Species is known to exhibit an asynchronous reproductive cycle lacking distinct seasonal variation; mean spawning time within Pribilof District has not been estimated. |

Appendix C. Page 2 of 2.

| Factor and criterion | Justification |
| :--- | :--- |
| Maturity-at-age/length differences <br> (Significantly different mean maturity- <br> at-age/ length) | No data for estimating maturity at age. Spatial differences in size at <br> maturity within Pribilof District have not been investigated. Within <br> Bering Sea, estimates of size at maturity decrease south-to-north. |
| Morphometrics (Field identifiable <br> characters) | Spatial trends within Pribilof District in morphometrics have not <br> been investigated. Latitudinal trends in male morphometrics (chela <br> size at length) may exist over the Bering Sea that are related to <br> latitudinal trends in size at maturity. |
| Meristics (Minimally overlapping <br> differences in counts) | N/A. |
|  |  |
| Spawning site fidelity (Spawning <br> individuals occur in same location <br> consistently) | Not likely: ovigerous females tend to occur in the shallower depth <br> zones at sites throughout the Pribilof District within the species <br> depth distribution. |
| Mark-recapture data (Tagging data may <br> show limited movement) | Mark-recapture data not available. |
| Natural tags (Acquired tags may show <br> movement smaller than management <br> areas) | Unknown. |
|  |  |
| Isolation by distance <br> (Significant regression) |  |
| Dispersal distance (<<Management <br> areas) | Unknown. |
| Pairwise genetic differences (Significant <br> differences between geographically <br> distinct collections) | Unknown. |

# Western Aleutian Islands Red King Crab <br> - 2017 Tier 5 Assessment <br> 2017 Crab SAFE Report Chapter (September 2017) 

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## Executive Summary

## 1. Stock:

Western Aleutian Islands (the Aleutian Islands, west of $171^{\circ} \mathrm{W}$ longitude) red king crab, Paralithodes camtschaticus

There are two districts for State management of commercial red king crab fisheries in waters of the Aleutian Islands west of $171^{\circ} \mathrm{W}$ longitude: the Adak District for waters east of $179^{\circ} \mathrm{W}$ longitude and the Petrel District for waters west of $179^{\circ} \mathrm{W}$ longitude. Although this stock has been referred to colloquially as the "Adak" stock, this report will refer to the stock as the "Western Aleutian Islands (WAI) red king crab" stock to avoid confusion with the Adak District.

## 2. Catches:

The domestic fishery has been prosecuted since 1960/61 and was opened every year through the 1995/96 crab fishing year. Peak retained catch occurred in 1964/65 at 9,613 t (21,193,000 lb). During the early years of the fishery through the late 1970s, most or all of the retained catch was harvested in the area between $172^{\circ} \mathrm{W}$ longitude and $179^{\circ} 15^{\prime} \mathrm{W}$ longitude. As the annual retained catch decreased into the mid-1970s and the early-1980s, the area west of $179^{\circ} 15^{\prime} \mathrm{W}$ longitude began to account for a larger portion of the retained catch. Retained catch during the 10 -year period 1985/86-1994/95 averaged $428 \mathrm{t}(942,940 \mathrm{lb})$, but the retained catch in 1995/96 was only $18 \mathrm{t}(38,941 \mathrm{lb})$. The fishery has been opened only occasionally during 1996/97 to present. There was an exploratory fishery with a low guideline harvest level (GHL) in 1998/99, three commissioner's permit fisheries in limited areas during 2000/01-2002/03 to allow for ADF\&GIndustry surveys, and two commercial fisheries with a GHL of $227 \mathrm{t}(500,000 \mathrm{lb})$ in 2002/03 and 2003/04. Most of the retained catch since 1990/91 was harvested in the Petrel Bank area (between $179^{\circ} \mathrm{W}$ longitude and $179^{\circ} \mathrm{E}$ longitude); in 2002/03 and 2003/04 the commercial fishery was opened only in the Petrel Bank area. Retained catch in the last two years with commercial fishing was $229 \mathrm{t}(505,642 \mathrm{lb})$ in 2002/03 and $217 \mathrm{t}(479,113 \mathrm{lb})$ in 2003/04. The fishery has been closed during 2004/05-2016/17. Discarded (non-retained) catch of red king crab occurs in the directed red king crab fishery (when prosecuted), in the Aleutian Islands golden king crab fishery, and in groundfish fisheries. Estimated annual weight of bycatch mortality due
to crab fisheries during 1995/96-2016/17 averaged 1 t (1,902 lb). Estimated annual weight of bycatch mortality due to groundfish fisheries during 1993/94-2016/17 averaged $7 \mathrm{t}(15,710 \mathrm{lb})$. Estimated weight of annual total fishery mortality during 1995/96-2016/17 averaged 34 t $(74,890 \mathrm{lb})$; the average annual retained catch during that period was $26 \mathrm{t}(57,278 \mathrm{lb})$. A cooperative red king crab survey was performed by the Aleutian Islands King Crab Foundation (an industry group) and ADF\&G in the Petrel Bank area in November 2016 (Hilsinger and Siddon 2016b), which resulted in an estimated bycatch mortality of $0.03 \mathrm{t}(59 \mathrm{lb})$. Estimated total fishery mortality in $2016 / 17$ resulted from groundfish fisheries ( 0.13 t ; 294 lb ), the Aleutian Islands golden king crab fishery ( $0.05 \mathrm{t} ; 100 \mathrm{lb}$ ), and the cooperative survey ( $0.03 \mathrm{t} ; 59 \mathrm{lb}$ ).
3. Stock biomass:

Estimates of past or present stock biomass are not available for this Tier 5 assessment.

## 4. Recruitment:

Estimates of recruitment trends and current levels relative to virgin or historic levels are not available for this Tier 5 assessment.

## 5. Management performance:

Overfishing did not occur during 2016/17 because the estimated total catch ( $0.2 \mathrm{t} ; 454 \mathrm{lb}$ ) did not exceed the Tier 5 OFL established for 2016/17 ( 56 t ; 123,867 lb). Additionally, the 2016/17 estimated total catch did not exceed the ABC established for 2016/17 (34 t; 74,320 lb). No determination has yet been made for a fishery opening or harvest level, if opened, for 2017/18. The OFL and ABC values for 2017/18 in the tables below are the author's status quo, Alternative 1 recommended values.

Management Performance Table (values in t)

| Fishing <br> Year | MSST | Biomass <br> (MMB) | TAC $^{\text {a }}$ | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2012 / 13$ | N/A | N/A | Closed | 0 | $<1$ | 56 | 34 |
| $2013 / 14$ | N/A | N/A | Closed | 0 | $<1$ | 56 | 34 |
| $2014 / 15$ | N/A | N/A | Closed | 0 | $<1$ | 56 | 34 |
| $2015 / 16$ | N/A | N/A | Closed | 0 | 1.3 | 56 | 34 |
| $2016 / 17$ | N/A | N/A | Closed | 0 | $<1$ | 56 | 34 |
| $2017 / 18$ | N/A | N/A |  |  |  | 56 | 14 |

a. Pre-season harvest levels are established as total allowable catch for the rationalized fishery west of $179^{\circ} \mathrm{W}$ longitude and as a guideline harvest level for the non-rationalized fishery east of $179^{\circ} \mathrm{W}$ longitude.

Management Performance Table (values in lb)

| Fishing <br> Year | MSST | Biomass <br> (MMB) | TAC $^{\text {a }}$ | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2012 / 13$ | N/A | N/A | Closed | 0 | 624 | 123,867 | 74,320 |
| $2013 / 14$ | N/A | N/A | Closed | 0 | 732 | 123,867 | 74,320 |
| $2014 / 15$ | N/A | N/A | Closed | 0 | 474 | 123,867 | 74,320 |
| $2015 / 16$ | N/A | N/A | Closed | 0 | 2,964 | 123,867 | 74,320 |
| $2016 / 17$ | N/A | N/A | Closed | 0 | 454 | 123,867 | 74,320 |
| $2017 / 18$ | N/A | N/A |  |  |  | 123,867 | 30,967 |

a. Pre-season harvest levels are established as total allowable catch for the rationalized fishery west of $179^{\circ} \mathrm{W}$ longitude and as a guideline harvest level for the non-rationalized fishery east of $179^{\circ} \mathrm{W}$ longitude.
6. Basis for the OFL and ABC: See table, below; values for $2017 / 18$ are the author's recommended values.

| $\underline{\text { Year }}$ | Tier | Years to define <br> Average catch (OFL) | Natural <br> Mortality | Buffer |
| :---: | :---: | :---: | :---: | :---: |
| $2012 / 13$ | 5 | $1995 / 96-2007 / 08^{\mathrm{a}}$ | $0.18^{\mathrm{b}}$ | $40 \%$ |
| $2013 / 14$ | 5 | $1995 / 96-2007 / 08^{\mathrm{a}}$ | $0.18^{\mathrm{b}}$ | $40 \%$ |
| $2014 / 15$ | 5 | $1995 / 96-2007 / 08^{\mathrm{a}}$ | $0.18^{\mathrm{b}}$ | $40 \%$ |
| $2015 / 16$ | 5 | $1995 / 96-2007 / 08^{\mathrm{a}}$ | $0.18^{\mathrm{b}}$ | $40 \%$ |
| $2016 / 17$ | 5 | $1995 / 96-2007 / 08^{\mathrm{a}}$ | $0.18^{\mathrm{b}}$ | $40 \%$ |
| $2017 / 18$ | 5 | $1995 / 96-2007 / 08^{\mathrm{a}}$ | $0.18^{\mathrm{b}}$ | $75 \%$ |

a. OFL is for total catch and was determined by the average of the total catch for these years.
b. Assumed value for FMP king crab in NPFMC (2007); does not enter into OFL estimation for Tier 5 stock.
7. PDF of the OFL: Sampling distribution of the recommended (status quo Alternative 1) Tier 5 OFL was estimated by bootstrapping (see section G.1). The standard deviation of the estimated sampling distribution of the recommended OFL is $56 \mathrm{t}(\mathrm{CV}=0.42)$. Note that generated sampling distribution and computed standard deviation are meaningful as measures in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Section E.4.f).
8. Basis for the $\mathbf{A B C}$ recommendation: The recommended ABC of 14 t is less than the ABC that was recommended by the SSC for 2012/13 - 2016/17. The recommended ABC is lowered because 1) the industry has not expressed interest in a small test fishery during 2017/18, and 2) because the stock is severely depressed as indicated by the 2016 Petrel survey (CPT minutes for May 2017).

At 14 t the ABC provides a $75 \%$ buffer on the OFL of 56 t ; i.e., (1.0-0.75). $56 \mathrm{t}=14 \mathrm{t}$.
9. A summary of the results of any rebuilding analyses: Not applicable; stock is not under a rebuilding plan.

## A. Summary of Major Changes

1. Changes to the management of the fishery: No changes have been made to management of the fishery (the fishery has remained closed) and no changes have been made to regulations pertaining to the fishery since those adopted by the Alaska Board of Fisheries in March 2014.
2. Changes to the input data:

- Data on retained catch, discarded catch, and estimates of bycatch mortality in crab and groundfish fisheries during 2016/17 have been added, but were not entered into the calculation of the recommended 2017/18 total-catch OFL.

3. Changes to the assessment methodology: None: the computation of OFL in this assessment follows the methodology recommended by the SSC in June 2010.
4. Changes to the assessment results, including projected biomass, TAC/GHL, total catch (including discard mortality in all fisheries and retained catch), and OFL: None: the computation of OFL in this assessment follows the methodology recommended by the SSC in June 2010 applied to the same data and estimates with the same assumptions that were used for estimating the 2010/11-2016/17 OFLs.

## B. Responses to SSC and CPT Comments

1. Responses to the most recent two sets of SSC and CPT comments on assessments in general:

- CPT, May 2016: None pertaining to a Tier 5 assessment.
- SSC, June 2016: None pertaining to a Tier 5 assessment.
- CPT, September 2016 (via September 2015 SAFE Introduction chapter): None pertaining to a Tier 5 assessment.
- SSC, October 2015: None pertaining to a Tier 5 assessment.

2. Responses to the most recent two sets of SSC and CPT comments specific to the assessment:

- CPT, May 2016: None.
- SSC, June 2015: "The industry expressed no desire to pursue a red king crab fishery in the Adak area at this time. However, the Petrel Bank region will be surveyed during September 2016."
- Response: The Petrel survey was conducted in November 2016 and showed very little RKC (ave CPUE=0.11).
- "The SSC also appreciates the addition of size frequency data in Appendices A1-A4. The SSC requests plotting these data to enable visualization of progression of size modes in next year's assessment."
- Response: Done. See appendix A5.
- CPT, September 2016: None.
- SSC, October 2016: None.


## C. Introduction

1. Scientific name: Paralithodes camtschaticus, Tilesius, 1815

## 2. Description of general distribution:

The general distribution of red king crab is summarized by NMFS (2004):
Red king crab are widely distributed throughout the BSAI, GOA, Sea of Okhotsk, and along the Kamchatka shelf up to depths of 250 m . Red king crab are found from eastern Korea around the Pacific rim to northern British Columbia and as far north as Point Barrow (page 3-27).

Most red and blue king crab fisheries occur at depths from 50-200 m, but red king crab fisheries in the Aleutian Islands sometimes extend to 300 m .

Red king crab is native to waters of 300 m or less extending from eastern Korea, the northern coast of the Japan Sea, Hokkaido, the Sea of Okhotsk, through the eastern Kamchatkan Peninsula, the Aleutian Islands, the Bering Sea, the GOA, and the Pacific Coast of North America as far south as Alice Arm in British Columbia. They are not found north of the Kamchatkan Peninsula on the Asian Pacific Coast. In North America red king crab range includes commercial fisheries in Norton Sound and sparse populations extending through the Bering Straits as far east as Barrow on the northern coast of Alaska. Red king crab have been acclimated to Atlantic Ocean waters in Russia and northern Norway. In the Bering Sea, red king crab are found near the Pribilof Islands and east through Bristol Bay; but north of Bristol Bay ( 58 degrees 39 minutes) they are associated with the mainland of Alaska and do not extend to offshore islands such as St . Matthew or St. Laurence Islands.

Commercial fishing for WAI red king crab was opened only in the Petrel Bank area (i.e., between $179^{\circ} \mathrm{W}$ longitude and $179^{\circ} \mathrm{E}$ longitude; Baechler and Cook 2014) during the most recent two years that the fishery was prosecuted (2002/03 and 2003/04). Fishery effort during those two years typically occurred at depths of $60-90$ fathoms ( $110-165 \mathrm{~m}$ ); average depth of pots fished in the Aleutian Islands area during 2002/03 was 68 fathoms ( 124 m ; Barnard and Burt 2004) and during 2003/04 was 82 fathoms ( 151 m ; Burt and Barnard 2005). Depth was recorded for 578 pots out of the 580 pot lifts sampled by observers during the 1996/97-2006/07 Aleutian Islands golden king crab fishery that contained 1 or more red king crab (ADF\&G observer database, Dutch Harbor, April 2008). Of those, the deepest recorded depth was 266 fathoms ( 486 m ) and $90 \%$ of pot lifts had recorded depths of 100-200 fathoms (183-366 m) ; no red king crab were present in any of the 6,465 pot lifts sampled during the 1996/97-2006/07 Aleutian Islands golden king crab fishery with depths >266 fathoms ( 486 m ).

In this chapter we will refer to the area west of $171^{\circ} \mathrm{W}$ longitude within the Aleutian Islands king crab Registration Area O as the "Western Aleutian Islands" (WAI). The Aleutian Islands king crab Registration Area O is described by Baechler and Cook (2014, page 7) as follows (see also Figure 1):


#### Abstract

"The Aleutian Islands king crab Registration Area O has as its eastern boundary the longitude of Scotch Cap Light ( $164^{\circ} 44^{\prime} \mathrm{W}$ longitude), its northern boundary a line from Cape Sarichef ( $54^{\circ} 36^{\prime} \mathrm{N}$ latitude) to $171^{\circ} \mathrm{W}$ longitude, north to $55^{\circ} 30^{\prime}$ N latitude, and as its western boundary the Maritime Boundary Agreement Line as that line is described in the text of and depicted in the annex to the Maritime Boundary Agreement between the United States and the Union of Soviet Socialist Republics signed in Washington, June 1, 1990. Area O encompasses both the waters of the Territorial Sea ( $0-3$ nautical miles) and waters of the Exclusive Economic Zone (3-200 nautical miles)."


From 1984/85 until the March 1996 Alaska Board of Fisheries meeting, the Aleutian Islands king crab Registration Area O as currently defined had been subdivided at $171^{\circ} \mathrm{W}$ longitude into the historic Adak Registration Area R and the Dutch Harbor Registration Area O. The geographic boundaries of the WAI red king crab stock are defined here by the boundaries of the historic Adak Registration Area R (i.e., the current Aleutian Islands king crab Registration Area O, west of $171^{\circ}$ W longitude). Note that in March 2014 the Alaska Board of Fisheries established two districts for management of commercial fisheries for red king crab in the waters of the Aleutian Islands west of $171^{\circ} \mathrm{W}$ longitude: 1) the Adak District, $171^{\circ}$ to $179^{\circ} \mathrm{W}$ longitude; and the Petrel District, west of $179^{\circ} \mathrm{W}$ longitude.

## 3. Evidence of stock structure:

Seeb and Smith (2005) analyzed microsatellite DNA variability in nearly 1,800 individual red king crab originating from the Sea of Okhotsk to Southeast Alaska, including a sample 75 specimens collected during 2002 from the vicinity of Adak Island in the Aleutian Islands (51 ${ }^{\circ} 51^{\prime}$ N latitude, $176^{\circ} 39^{\prime} \mathrm{W}$ longitude), to evaluate the degree to which the established geographic boundaries between stocks in the BSAI reflect genetic stock divisions. Seeb and Smith (2005) concluded that, "There is significant divergence of the Aleutian Islands population (Adak sample) and the Norton Sound population from the southeastern Bering Sea population (Bristol Bay, Port Moller, and Pribilof Islands samples)." Recent analysis of patterns of genetic diversity among red king crab stocks in the western north Pacific (Asia), eastern North Pacific, and Bering Sea by multiple techniques (SNPs, allozymes, and mtDNA) also showed that red king crab sampled near Adak Island had greater genetic similarity to stocks in Asia rather than other stocks in Alaskan waters including Bristol Bay and the Gulf of Alaska (reviewed in Grant et al. 2014).

To date, population genetic studies of red king crab within the WAI have only grouped samples from within this region as one site (i.e., Adak Island) (Grant et al. 2014). Given the complexity of currents throughout the WAI and that canyons deeper than the depth restrictions of red king crab ( $>1,000 \mathrm{~m}$ ) separate several islands, the possibility of fine scale genetic structuring exists, but remains uninvestigated. A summary of total retained catch by 1-degree longitude groupings during 1985/86-1995/96 (years for which state statistical area definitions allow for grouping by 1-degree longitude and for which catch distribution was not affected by area closures and openings; see Section C.5) shows that catch and, presumably, distribution of legal-sized male red king crab is not evenly distributed across the Aleutian Islands. Most catch during that period was from Petrel Bank, followed by the vicinity of Adak, Atka, and Amlia Islands (Figure 2). Note that the 1-degree longitude grouping of catch does not portray the spatial gaps in catch that are apparent upon a closer inspection of the 1985/86-1995/96 catch data by state statistical areas.

For example, no catch was reported during 1985/86-1995/96 from the two statistical areas (795102 and 795132) that include Amchitka Pass (Amchitka Pass lies between Petrel Bank and the Delarof Islands; see Figure 2).

McMullen and Yoshihara (1971) reported the following on male red king crab that were tagged in February 1970 on the Bering Sea and Pacific Ocean sides of Atka Island and recovered in the subsequent fishery:
"Fishermen landing tagged crabs were questioned carefully concerning the location of recapture. In no instance did crabs migrate through ocean passes between the Pacific Ocean and Bering Sea."

## 4. Description of life history characteristics relevant to stock assessments (e.g., special features of reproductive biology):

Red king crab eggs are fertilized externally and the clutch of fertilized eggs (embryos) are carried under the female's abdominal flap until hatching. Male king crab fertilize eggs by passing spermatophores from the fifth periopods to the gonopores and coxae of the female's third periopods; the eggs are fertilized during ovulation and attach to the female's pleopodal setae (Nyblade 1987, McMullen 1967). Females are generally mated within hours after molting (Powell and Nickerson 1965), but may mate up to 13 days after molting (McMullen 1969). Males must wait at least 10 days after completing a molt before mating (Powell et al. 1973), but, unlike females, do not need to molt prior to mating (Powell and Nickerson 1965).

Wallace et al. (1949, page 23) described the "egg laying frequency" of red king crab:
> "Egg laying normally takes place once a year and only rarely are mature females found to have missed an egg laying cycle. The eggs are laid in the spring immediately following shedding [i.e., molting] and mating and are incubated for a period of nearly a year. Hatching of the eggs does not occur until the following spring just prior to moulting [i.e., molting] season."

McMullen and Yoshihara (1971) reported that from 804 female red king crab (79-109-mm CL) collected during the 1969/70 commercial fishery in the western Aleutians, "Female king crab in the western Aleutians appeared to begin mating at 83 millimeters carapace length and virtually all females appeared to be mature at 102 millimeters length." Blau (1990) estimated size at maturity for WAI red king crab females as the estimated CL at which $50 \%$ of females are mature (SM50; as evidenced by presence of clutches of eggs or empty) according to a logistic regression: $89-\mathrm{mm}$ CL ( $\mathrm{SD}=2.6 \mathrm{~mm}$ ). Size at maturity has not been estimated for WAI male red king crab. However, because the estimated SM50 for WAI red king crab females is the same as that estimated for Bristol Bay red king crab females (Otto et al. 1990), the estimated maturity schedule used for Bristol Bay red king crab males (see SAFE chapter on Bristol Bay red king crab) could be applied to males in the WAI stock as a proxy.

Few data are available on the molting and mating period for red king crab specifically in the WAI. Among the red king crab captured by ADF\&G staff for tagging on the south side of Amlia Island ( $173^{\circ} \mathrm{W}$ longitude to $174^{\circ} \mathrm{W}$ longitude) in the first half of April 1971, males and females
were molting, females were hatching embryos, and mating was occurring (McMullen and Yoshihara 1971). The spring mating period for red king crab is known to last for several months, however. For example, although mating activity in the Kodiak area apparently peaks in April, mating pairs in the Kodiak area have been documented from January through May (Powell et al. 2002). Due to the timing of the commercial fishery within a year, little data on reproductive condition of WAI red king crab females have been collected by at-sea fishery observers that can be used for evaluating the mating period. Most recently, of the 3,211 mature females that were examined during the 2002/03 and 2003/04 red king crab fisheries in the Petrel Bank area, which were prosecuted in late October, only 10 were scored as "hatching" (ADF\&G observer database, Dutch Harbor, April 2008).

Data on mating pairs of red king crab collected from the Kodiak area during March-May of 1968 and 1969 showed that size of the females in the pairs increased from March to May, indicating that females tend to release their larvae and mate later in the mating season with increasing body size (Powell et al. 2002). Size of the males in those mating pairs did not increase with later sampling periods, but did show a decreasing trend in estimated time since last molt. In all the data on mating pairs collected from the Kodiak area during 1960-1984, the proportion of males that were estimated to have not recently molted prior to mating decreased monthly over the mating period (Powell et al. 2002). Those data also suggest that, for males, not molting early in the mating period provides the advantage of mating when primiparous and small, multiparous females tend to ovulate. Alternatively, males that do molt early in the mating period likely participate in mating later, and with larger females.

Current knowledge of red king crab reproductive biology, including male and female maturation, migration, mating dynamics, and potential effects of exploitation on reproductive potential, is summarized by Webb (2014).

## 5. Brief summary of management history:

A complete summary of the management history through 2011/12 is provided by Baechler and Cook (2014, pages 7-13). The domestic fishery for red king crab in the WAI began in 1960/61. Retained catch of red king crab in the Aleutians west of $172^{\circ} \mathrm{W}$ longitude averaged $5,259 \mathrm{t}$ $(11,595,068 \mathrm{lb})$ during $1960 / 61-1975 / 76$, with a peak retained catch of $9,613 \mathrm{t}(21,193,000 \mathrm{lb})$ in 1964/65 (Tables 1a and 1b, Figure 3). Guideline harvest levels (GHL; sometimes expressed as ranges, with an upper and lower GHL) for the fishery were established in most years since 1973/74. The fishery was closed in 1976/77 in the area west of $172^{\circ} \mathrm{W}$ longitude, but was reopened for each year during 1977/78-1995/96. Average retained catch during 1977/78$1995 / 96$ (for the area west of $172^{\circ} \mathrm{W}$ longitude prior to $1984 / 85$ and for the area west of $171^{\circ} \mathrm{W}$ longitude since $1984 / 85$ ) was $470 \mathrm{t}(1,036,659 \mathrm{lb})$; the peak retained catch during that period occurred in 1983/84 at $899 \mathrm{t}(1,981,579 \mathrm{lb})$. During the mid-to-late 1980s, significant portions of the catch during the WAI red king crab fishery occurred west of $179^{\circ} \mathrm{E}$ longitude or east of $179^{\circ}$ W longitude, whereas most of the retained catch was harvested from the Petrel Bank area ( $179^{\circ}$ W longitude to $179^{\circ}$ W longitude) during 1990/91-1994/95 (Figure 4). Retained catch and fishery CPUE (retained crab per pot lift) declined from 1993/94 to 1994/95 and 1995/96; retained catch in 1994/95 and, especially, 1995/96 was far below the lower GHL established. Due to concerns about the low stock level and poor recruitment indicated by results of the fishery in 1994/95-1995/96, the fishery was closed in 1996/97-1997/98. During 1998/99-2003/04 the
fishery was opened only in restricted areas, either as an open fishery managed under a GHL or as an ADF\&G-Industry survey conducted as a commissioner's permit fishery (Table 2); peak retained catch during that period was $229 \mathrm{t}(505,642 \mathrm{lb})$ harvested from the Petrel Bank area in 2002/03. The fishery has been closed during 2004/05-2016/17.

Only males of a minimum legal size may be retained by the commercial red king crab fishery in the WAI. By State of Alaska regulation ( $\mathbf{5}$ AAC 34.620 (a)), the minimum legal size limit is 6.5inches ( 165 mm ) carapace width ( CW ), including spines. A carapace length ( CL ) $\geq 138 \mathrm{~mm}$ is used to identify legal-size males when CW measurements are not available (Table 3-5 in NPFMC 2007). Except for the years 1968-1970, the minimum size has been 6.5 -inches CW since 1950; in 1968 there was a "first-season" minimum size of 6.5 -inches CW and a "secondseason" minimum size of 7.0 -inches and in 1969-1970 the minimum size was 7.0-inches CW (Donaldson and Donaldson 1992).

Red king crab may be commercially fished only with king crab pots (as defined in 5 AAC 34.050). Pots used to fish for red king crab in the WAI must, since 1996, have at least one-third of one vertical surface of the pot composed of not less than nine-inch stretched mesh webbing to permit escapement of undersized red king crab and may not be longlined ( $\mathbf{5}$ AAC 34.625 (e)). The sidewall of the pot "...must contain an opening equal to or exceeding 18 inches in length... The opening must be laced, sewn, or secured together by a single length of untreated, 100 percent cotton twine, no larger than 30 thread." (5 AAC 39.145(1)).

The WAI red king crab fishery west of $179^{\circ} \mathrm{W}$ longitude has been managed since 2005/06 under the Crab Rationalization program (50 CFR Parts 679 and 680). The WAI red king crab fishery in the area east of $179^{\circ} \mathrm{W}$ longitude was not included in the Crab Rationalization program (Baechler and Cook 2014). In March 2014 the Alaska Board of Fisheries established two red king crab management districts in state regulations for the Aleutian Islands west of $171^{\circ}$ W longitude (the Adak District, $171^{\circ}$ to $179^{\circ} \mathrm{W}$ longitude; and the Petrel District, west of $179^{\circ}$ W longitude) and some notable differences in regulations exist between the two districts. The red king crab commercial fishing season in the Adak District is August 1 to February 15, unless closed by emergency order ( $\mathbf{5}$ AAC 34.610 (a) (1)); the red king crab commercial fishing season in the Petrel is October 15 to February 15, unless closed by emergency order ( $\mathbf{5}$ AAC 34.610 (a) (2)). Only vessels 60 feet or less in overall length may participate in the commercial red king crab fishery within the state waters of the Adak District ( $\mathbf{5}$ AAC $\mathbf{3 4 . 6 1 0}$ (d)); no vessel size limit is established for federal waters in the Adak District or for state or federal waters in the Petrel District. Federal waters in the Adak District are opened to commercial red king crab fishing only if the season harvest level established by ADF\&G for the Adak District is $250,000 \mathrm{lb}$ or more ( $\mathbf{5}$ AAC 34.616 (a) (2)); there is no comparable regulation for the Petrel District. In the Adak District, pots commercially fished for red king crab may only be deployed and retrieved between 8:00 AM and 5:59 PM each day (5 AAC 34.625 (g) (2)) and the following pot limits pertain: 10 pots per vessel for vessels fishing within state waters ( $\mathbf{5}$ AAC $\mathbf{3 4 . 6 2 5}$ (g) (1) (A)); and 15 pots per vessel for vessels fishing in federal waters ( $\mathbf{5}$ AAC 34.625 (g) (1) (B)). In the Petrel District there is no regulation pertaining to periods for operation of gear and a pot limit of 250 pots per vessel (5 AAC 34.625 (d)). See also " 6 . Brief description of the annual ADF\&G harvest strategy," below.

## 6. Brief description of the annual ADF\&G harvest strategy:

Prior to the March 2014 Alaska Board of Fisheries meeting, when the board adopted a harvest strategy for the Adak District only, there was no harvest strategy in state regulation for WAI red king crab. Following results of the January/February and November 2001 ADF\&G-Industry pot surveys for red king crab in the Petrel Bank area, which produced high catch rates of legal males (CPUE $=28$ ), but low catches of females and sublegal males, ADF\&G opened the fishery in $2002 / 03$ and $2003 / 04$ with a GHL of $227 \mathrm{t}(500,000 \mathrm{lb})$; that GHL was established as the minimum GHL that could be managed inseason, given expected participation and effort (Baechler and Cook 2014). The fishery was closed in 2004/05 due to continued uncertainty on the status of pre-recruit legal males, a reduction in legal male CPUE from 18 in 2002/03 to 10 in 2003/04, and a strategy adopted by ADF\&G to close the fishery before the CPUE of legal crab dropped below 10 .

The harvest strategy for red king crab in the Adak District adopted by the Alaska Board of Fisheries in March 2014 is as follows:

5 AAC 34.616. Adak District red king crab harvest strategy. (a) In the Adak District, based on the best scientific information available, if the department determines that there is a harvestable surplus of
(1) red king crab available in the waters of Alaska in the Adak District, the commissioner may open, by emergency order, a commercial red king crab fishery only in the waters of Alaska in the Adak District under 5 AAC 34.610(a)(1);
(2) at least 250,000 pounds of red king crab in the Adak District, the commissioner may open, by emergency order, a commercial red king crab fishery in the entire Adak District under 5 AAC 34.610(a)(1).
(b) In the Adak District, during a season opened under 5 AAC 34.610(a)(1), the operator of a validly registered king crab fishing vessel shall
(1) report each day to the department
(A) the number of pot lifts;
(B) the number of crab retained for the 24 -hour fishing period preceding the report; and
(C) any other information the commissioner determines is necessary for the management and conservation of the fishery, as specified in the vessel registration certificate issued under 5 AAC 34.020; and
(2) complete and submit a logbook as prescribed and provided by the department.
7. Summary of the history of BMSY: Not applicable for this Tier 5 stock.

## D. Data

## 1. Summary of new information:

- Retained catch data from the 2016/17 directed fishery has been added; the fishery was closed and the retained catch was $0 \mathrm{t}(0 \mathrm{lb})$.
- Data on discarded catch in crab and groundfish fisheries has been updated with data from the 2016/17 Aleutian Islands golden king crab fishery and the 2016/17 groundfish fisheries in reporting areas 541, 542, and 543 (Figure 5).
- Discarded catch during the cooperative industry-ADF\&G survey in 2016. Data was available as number of crab caught per size/sex group (males: legal, sub-lagal, and females). Assumptions were made on the representative size (width) of each group, which were converted to length then weight. A bycatch mortality rate of 0.2 (as applied to crab fisheries) was applied to the estimated total weight caught.


## 2. Data presented as time series:

a. Total catch and b. Information on bycatch and discards:

- Annual retained catch weight for 1960/61-2016/17 (Tables 1a and 1b, Figure 3).
- Annual retained catch weight and estimated weights of discarded legal males, discarded sublegal males, and discarded females captured by commercial crab fisheries during 1995/96-2016/17 (Table 3). Observer data on size distributions and estimated catch numbers of discarded catch were used to estimate the weight of discarded catch of red king crab by applying a weight-at-length estimator (see below). Estimates of discarded catch prior to 1995/96 are not given due to non-existence of data or to limitations on sampling for discarded catch during the crab fisheries: prior to $1988 / 89$ there was no fishery observer program for Aleutian Islands crab fisheries and observers were required only on vessels processing king crab at sea (including catcher-processor vessels) during 1988/89-1994/95; observer data from the Aleutian Islands prior to 1990/91 is considered unreliable; and the observer data from the directed WAI red king crab fishery in 1990/91 and 1992/93-1994/95 and golden king crab fishery in the 1993/94-1994/95 are confidential due to the limited number of observed vessels. During 1995/96-2004/05, observers were required on all vessels fishing for king crab in the Aleutian Islands area at all times that a vessel was fishing. With the advent of the Crab Rationalization program in 2005/06, all vessels fishing for golden king crab in the Aleutian Islands area are now required to carry an observer for a period during which $50 \%$ of the vessel's retained catch was obtained during each trimester of the fishery; observers continue to be required at all times on a vessel fishing in the red king crab fishery west of $179^{\circ} \mathrm{W}$ longitude. All red king crab that were captured and discarded during the Aleutian Islands golden king crab fishery west of $174^{\circ} \mathrm{W}$ longitude by a vessel while an observer was on board during 2001/02-2002/03 and 2004/05-2016/17 were counted and recorded for capture location and biological data.
- Annual estimated weight of discarded catch and estimated bycatch mortality in the WAI (reporting areas 541, 542, and 543; i.e., Aleutian Islands west of $170^{\circ} \mathrm{W}$ longitude; Figure 5) during federal groundfish fisheries by gear type (fixed or trawl) for 1993/942016/17 (Table 4). Following Foy (2012a, 2012b), the bycatch mortality rate of king crab captured by fixed gear during groundfish fisheries was assumed to be 0.5 and of king crab captured by trawls during groundfish fisheries was assumed to be 0.8 . Estimates of discarded catch by gear type for 1992/93 are available, but appear to be suspect because
they are extremely low. Annual estimated weight of discarded catch during federal groundfish fisheries by reporting area (541, 542, and 543) for 1993/94-2016/17 is also presented in Table 5.
- Annual estimated weight of total fishery mortality for 1995/96-2016/17, partitioned into retained catch, estimated bycatch mortality during crab fisheries, and estimated bycatch mortality during federal groundfish fisheries (Table 6). Following Siddeek et al. (2011), the bycatch mortality rate of king crab captured and discarded during Aleutian Islands king crab fisheries was assumed to be 0.2 ; bycatch mortality in crab fisheries was estimated for Table 6 by applying that assumed bycatch mortality rate to the estimates of discarded catch given in Table 3. The estimates of bycatch mortality in groundfish fisheries given in Table 6 are from Table 4.
- Table 7 summarizes the available data on retained catch weight and estimates of discarded catch weight.
c. Catch-at-length: Although not used in a Tier 5 assessment, available retained-catch size frequency sample data from 1960/61-2016/17 are summarized and presented (Appendices A1-A4).
d. Survey biomass estimates: Not available; there is no program for regular performance of standardized surveys sampling from the entirety of the stock range.
e. Survey catch at length: Not used in a Tier 5 assessment; none are presented.
f. Other data time series: Although not used in a Tier 5 assessment, available data on CPUE (retained crab per pot lift) from 1972/73-2016/17 directed fisheries are presented (Table 1, Figure 6).

3. Data which may be aggregated over time:
a. Growth-per-molt; frequency of molting, etc. (by sex and perhaps maturity state):

Not used in a Tier 5 assessment. Growth per molt was estimated for WAI male red king crab by Vining et al. (2002) based on information received from recoveries during commercial fisheries of tagged red king crab released in the Adak Island to Amlia Island area during the 1970s (see Table 5 in Pengilly 2009). Vining et al. (2002) used a logit estimator to estimate the probability as a function of carapace length (CL, mm) at release that a male WAI red king tagged and released in new-shell condition would molt within 8-14 months after release (see Tables 6 and 7 in Pengilly 2009).

## b. Weight-at length or weight-at-age (by sex):

Parameters (A and B) used for estimating weight (g) from carapace length (CL, mm) of male and female red king crab according to the equation, Weight $=A * \mathrm{CL}^{\mathrm{B}}$ (from Table 3-5, NPFMC 2007) are: $\mathrm{A}=0.000361$ and $\mathrm{B}=3.16$ for males and $\mathrm{A}=0.022863$ and $\mathrm{B}=2.23382$ for females; note that although the estimated parameters, A and B , are those estimated for ovigerous females, those parameters were used to estimate the weight of all females without regard to reproductive status. Estimated weights in grams were converted to lb by dividing by 453.6.

## c. Natural mortality rate:

Not used in a Tier 5 assessment. NPFMC (2007) assumed a natural mortality rate of $\mathrm{M}=0.18$ for king crab species, but natural mortality rate has not been estimated specifically for red king crab in the WAI.
4. Information on any data sources that were available, but were excluded from the assessment:

- Distribution of effort and catch during the 2006 ADF\&G Petrel Bank red king crab pot survey (Gish 2007) and the 2009 ADF\&G Petrel Bank red king crab pot survey (Gish 2010).
- Sex-size distribution of catch and distribution of effort and catch during the January/February 2001 and November 2001 ADF\&G-Industry red king crab survey of the Petrel Bank area (Bowers et al. 2002) and ADF\&G-Industry red king crab pot survey conducted as a commissioner's permit fishery in November 2002 in the Adak Island and Atka-Amlia Islands areas (Granath 2003).
- Observer data on size distribution and geographic distribution of discarded catch of red king crab in the WAI red king crab fishery and the Aleutian Islands golden king crab fishery, 1988/89-2016/17 (ADF\&G observer database).
- Summary of data collected by ADF\&G WAI red king crab fishery observers or surveys during 1969-1987 (Blau 1993).


## E. Analytic Approach

1. History of modeling approaches for this stock: This is a Tier 5 assessment.
2. Model Description: Subsections a-i are not applicable to a Tier 5 assessment.

There is no regular survey of this stock. No assessment model for the WAI red king crab stock exists and none is in development. The SSC in June 2010 recommended that: the WAI red king crab stock be managed as a Tier 5 stock; the OFL be specified as a total-catch OFL; the totalcatch OFL be established as the estimated average annual weight of the retained catch and bycatch mortality in crab and groundfish fisheries over the period 1995/96-2007/08; and the period used for computing the Tier 5 total-catch OFL be fixed at 1995/96-2007/08.

Given the strong recommendations from the SSC in June 2010, Tier 5 total-catch OFLs would change only if retained catch data and estimates of discarded catch for the period 1995/962007/08 or assumed values of bycatch mortality rates used in the 2010 SAFE were revised. Given that no need has been shown to revise either the retained catch data or the discarded catch estimates for the period 1995/96-2007/08 or assumed values of bycatch mortality rates used in the 2010 SAFE, the recommended approach for establishing the 2017/18 OFL is the approach identified by the SSC in June 2010 and no alternative approaches are suggested by the author. Hence the recommended total-catch OFL for 2017/18 is computed according to the status quo "Alternative 1" approach as:

$$
\mathrm{OFL}_{2017 / 18}=\mathrm{RET}_{95 / 96-07 / 08}+\mathrm{BM}_{\mathrm{CF}, 95 / 96-07 / 08}+\mathrm{BM}_{\mathrm{GF}, 95 / 96-07 / 08},
$$

where,

- $\mathrm{RET}_{95 / 96-07 / 08}$ is the average annual retained catch in the directed crab fishery during 1995/96-2007/08
- $\mathrm{BM}_{\mathrm{CF}, 95 / 96-07 / 08}$ is the estimated average annual bycatch mortality in the directed and non-directed crab fisheries during 1995/96-2007/08, and
- $\mathrm{BM}_{\mathrm{GF}, 95 / 96-07 / 08}$ is the estimated average annual bycatch mortality in the groundfish fisheries during 1995/96-2007/08.

Given the June 2010 SSC recommendations, items $\boldsymbol{E} .2 \boldsymbol{a}-\boldsymbol{i}$ are not applicable.

## 3. Model Selection and Evaluation:

a. Description of alternative model configurations

Not applicable; see section E.2.
b. Show a progression of results from the previous assessment to the preferred base model by adding each new data source and each model modification in turn to enable the impacts of these changes to be assessed: None; see section A.4.
c. Evidence of search for balance between realistic (but possibly over-parameterized) and simpler (but not realistic) models: None; see the section A.4.
d. Convergence status and convergence criteria for the base-case model (or proposed basecase model): Not applicable.
e. Table (or plot) of the sample sizes assumed for the compositional data: Not applicable.
f. Do parameter estimates for all models make sense, are they credible?:

Use of the 1995/96-2007/08 time period for estimating annual total fishery mortality and computing a Tier 5 OFL was established by the SSC in 2010.
g. Description of criteria used to evaluate the model or to choose among alternative models, including the role (if any) of uncertainty: Use of the 1995/96-2007/08 time period for estimating annual total fishery mortality and computing a Tier 5 OFL was established by the SSC in 2010.
h. Residual analysis (e.g. residual plots, time series plots of observed and predicted values or other approach): Not applicable.
i. Evaluation of the model, if only one model is presented; or evaluation of alternative models and selection of final model, if more than one model is presented: The model follows the June 2010 SSC recommendations to freeze the time period for estimation of the Tier 5 OFL.

## 4. Results (best model(s)):

a. List of effective sample sizes, the weighting factors applied when fitting the indices, and the weighting factors applied to any penalties: Not applicable to a Tier 5 assessment.
b. Tables of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible; include estimates from previous SAFEs for retrospective comparisons): See Table 6.
c. Graphs of estimates (all quantities should be accompanied by confidence intervals or other statistical measures of uncertainty, unless infeasible): $\quad$ Not applicable to a Tier 5 assessment.
d. Evaluation of the fit to the data: Not applicable to a Tier 5 assessment.
e. Retrospective and historic analyses (retrospective analyses involve taking the "best" model and truncating the time-series of data on which the assessment is based; a historic analysis involves plotting the results from previous assessments): $N$ Not applicable to a Tier 5 assessment.
f. Uncertainty and sensitivity analyses (this section should highlight unresolved problems and major uncertainties, along with any special issues that complicate scientific assessment, including questions about the best model, etc.): For a Tier 5 assessment, the major uncertainties are:

- Whether the time period is "representative of the production potential of the stock" and if it serves to "provide the required risk aversion for stock conservation and utilization goals." Or whether any such time period exists.
- In this regard, the CPT (May 2011 minutes) noted that the OFL ( 56 t ; 0.12-million lb) that was established for this stock by the SSC in June 2010 "could be considered biased high because of years of high exploitation" and questioned "whether the time frame used to compute the OFL is meaningful as an estimate of the productivity potential of this stock."
- The bycatch mortality rates used in estimation of total catch. Being as most $(78 \%)$ of the estimated total mortality during 1995/96-2007/08 is due to the retained catch component, the total catch estimate is not severely sensitive to the assumed bycatch mortality rates. Doubling the assumed bycatch mortality during crab fisheries from 0.2 to 0.4 would increase the OFL by a factor of 1.02 ; halving that assumed rate from 0.2 to 0.1 would decrease the OFL by a factor of 0.99 . Increasing the assumed bycatch mortality rate for all groundfish fisheries (regardless of gear type) to 1.0 , would increase the OFL by a factor of 1.07.


## F. Calculation of the OFL

1. Specification of the Tier level and stock status level for computing the OFL:

- Recommended as Tier 5, total-catch OFL computed as the estimated average annual total catch over a specified period.
- Recommended time period for computing retained-catch portion of the OFL: 1995/962007/08.
- Recommended time period for computing bycatch mortality due to crab fisheries: 1995/96-2007/08.
- Recommended time period for computing bycatch mortality due to groundfish fisheries: 1995/96-2007/08.
- Recommended bycatch mortality rates: 0.2 for crab fisheries; 0.5 for fixed-gear groundfish fisheries; 0.8 for trawl groundfish fisheries.
- Recommended OFL for 2017/18 is estimated by,

$$
\mathrm{OFL}_{2017 / 18}=\mathrm{RET}_{95 / 96-07 / 08}+\mathrm{BM}_{\mathrm{CF}, 95 / 96-07 / 08}+\mathrm{BM}_{\mathrm{GF}, 95 / 96-07 / 08},
$$

where,

- $\mathrm{RET}_{95 / 96-07 / 08}$ is the average annual retained catch in the directed crab fishery during 1995/96-2007/08
- $\mathrm{BM}_{\mathrm{CF}, 95 / 96-07 / 08}$ is the estimated average annual bycatch mortality in the directed and non-directed crab fisheries during 1995/96-2007/08, and
- $\mathrm{BM}_{\mathrm{GF}, 95 / 96-07 / 08}$ is the estimated average annual bycatch mortality in the groundfish fisheries during 1995/96-2007/08.

Statistics on the data and estimates used to calculate $\mathrm{RET}_{95 / 96-07 / 08}, \mathrm{BM}_{\mathrm{CF}}, 95 / 96-07 / 08$, and $\mathrm{BM}_{\mathrm{GF}, 95 / 96-07 / 08}$ are provided in the "Mean, 1995/96-2007/08" row of Table 6. Using the calculated values of $\mathrm{RET}_{95 / 96-07 / 08}, \mathrm{BM}_{\mathrm{CF}, 95 / 96-07 / 08}$, and $\mathrm{BM}_{\mathrm{GF}, 95 / 96-07 / 08}$, $\mathrm{OFL}_{2016 / 17}$ is,

$$
\mathrm{OFL}_{2017 / 18}=43.97 \mathrm{t}+1.36 \mathrm{t}+10.86 \mathrm{t}=56 \mathrm{t}(123,867 \mathrm{lb})
$$

2. List of parameter and stock size estimates (or best available proxies thereof) required by limit and target control rules specified in the fishery management plan: Not applicable to Tier 5 assessment.

## 3. Specification of the OFL:

a. Provide the equations (from Amendment 24) on which the OFL is to be based:

From Federal Register / Vol. 73, No. 116, page 33926, "For stocks in Tier 5, the overfishing level is specified in terms of an average catch value over an historical time period, unless the Scientific and Statistical Committee recommends an alternative value based on the best available scientific information." Additionally, "For stocks where nontarget fishery removal data are available, catch includes all fishery removals, including retained catch and discard losses. Discard losses will be determined by multiplying the appropriate handling mortality rate by observer estimates of bycatch discards. For stocks where only retained catch information is available, the overfishing level is set for and compared to the retained catch" (FR/Vol. 73, No. 116, 33926). That compares with the specification of NPFMC (2007) that the OFL "represent[s]
the average retained catch from a time period determined to be representative of the production potential of the stock."
b. Basis for projecting MMB to the time of mating: Not applicable to Tier 5 assessment.
c. Specification of Fofl $^{\text {, OFL, and other applicable measures (if any) relevant to determining }}$ whether the stock is overfished or if overfishing is occurring: See Management Performance tables, below. No vessels participated in the 2016/17 directed fishery and but some bycatch was observed in the Aleutian Islands golden king crab fishery in 2016/17. Total catch mortality in 2016/17 consists of what occurred during the Aleutian Islands golden king crab fishery and groundfish fisheries ( 0.18 t ) and the cooperative industry-ADF\&G survey ( 0.03 t ). Overfishing did not occur in 2016/17. The OFL and ABC values for 2017/18 in the table below are the author's recommended values. The 2017/18 TAC has not yet been established.

Management Performance Table (values in t)

| Fishing <br> Year | MSST | Biomass <br> (MMB) | TAC $^{\text {a }}$ | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2012 / 13$ | N/A | N/A | Closed | 0 | $<1$ | 56 | 34 |
| $2013 / 14$ | N/A | N/A | Closed | 0 | $<1$ | 56 | 34 |
| $2014 / 15$ | N/A | N/A | Closed | 0 | $<1$ | 56 | 34 |
| $2015 / 16$ | N/A | N/A | Closed | 0 | 1.3 | 56 | 34 |
| $2016 / 17$ | N/A | N/A | Closed | 0 | $<1$ | 56 | 34 |
| $2017 / 18$ | N/A | N/A |  |  |  | 56 | 14 |

a. Pre-season harvest levels are established as total allowable catch for the rationalized fishery west of $179^{\circ} \mathrm{W}$ longitude and as a guideline harvest level for the non-rationalized fishery east of $179^{\circ} \mathrm{W}$ longitude.

Management Performance Table (values in lb)

| Fishing <br> Year | MSST | Biomass <br> (MMB) | TAC $^{\mathbf{a}}$ | Retained <br> Catch | Total <br> Catch | OFL | ABC |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $2012 / 13$ | N/A | N/A | Closed | 0 | 624 | 123,867 | 74,320 |
| $2013 / 14$ | N/A | N/A | Closed | 0 | 732 | 123,867 | 74,320 |
| $2014 / 15$ | N/A | N/A | Closed | 0 | 474 | 123,867 | 74,320 |
| $2015 / 16$ | N/A | N/A | Closed | 0 | 2,964 | 123,867 | 74,320 |
| $2016 / 17$ | N/A | N/A | Closed | 0 | 454 | 123,867 | 74,320 |
| $2017 / 18$ | N/A | N/A |  |  |  | 123,867 | 30,967 |

a. Pre-season harvest levels are established as total allowable catch for the rationalized fishery west of $179^{\circ} \mathrm{W}$ longitude and as a guideline harvest level for the non-rationalized fishery east of $179^{\circ} \mathrm{W}$ longitude.
4. Specification of the recommended retained-catch portion of the total-catch OFL:
a. Equation for recommended retained portion of the total-catch OFL,

Retained-catch portion $=$ average retained catch during 1995/96-2007/08

$$
=44 \text { t (96,932 lb). }
$$

5. Recommended Fofl, OFL total catch and the retained portion for the coming year:

See sections $\boldsymbol{F} .3$ and $\boldsymbol{F} .4$, above; no FofL is recommended for a Tier 5 assessment.

## G. Calculation of ABC

1. PDF of OFL. A bootstrap estimate of the sampling distribution (assuming no error in estimation of the discarded catch) of the OFL is shown in Figure 7 (the sample means of 1,000 samples drawn with replacement from the 1995/96-2007/08 estimates of total fishery mortality in Table 6). The mean ( 56 t ) and CV ( 0.42 ) computed from the 1,000 replicates are essentially the same as for the mean and CV of the 1995/96-2007/08 total catch estimates given in Table 6. Note that generated sampling distribution is meaningful as a measure in the uncertainty of the OFL only if assumptions on the choice of years used to compute the Tier 5 OFL are true (see Section E.4.f).

## 2. List of variables related to scientific uncertainty.

- The time period to compute the average catch relative to the assumption that it represents "a time period determined to be representative of the production potential of the stock."
- Bycatch mortality rate in each fishery that bycatch occurs. Note that for a Tier 5 assessment, an increase in an assumed bycatch mortality rate will increase the OFL (and hence the ABC ), but has no effect on the retained catch portion of the OFL or the retained catch portion of the $A B C$.
- Estimated discarded catch and bycatch mortality during each fishery that bycatch occurred in during 1995/96-2007/08.

3. List of additional uncertainties for alternative sigma-b. Not applicable to this Tier 5 assessment.
4. Author recommended ABC: $14 \mathrm{t}(30,967 \mathrm{lb})$. This is lower than the ABC that has been recommended by the author since the SSC recommended a $34 \mathrm{t}(74,320 \mathrm{lb}) \mathrm{ABC}$ for $2012 / 13$. The SSC's recommended ABC of 34 t for 2012/13 was determined as a value "sufficient to cover bycatch and the proposed test fishery catch" (June 2012 SSC meeting minutes, page 10). It provides a $40 \%$ buffer on the OFL of $56 \mathrm{t}(123,867 \mathrm{lb})$. However, the industry has not expressed interest in conducting a test fishery for 2017/18. Further, the 2016 Petrel survey indicated the stock is severely depressed. Thus, the author and CPT recommend increasing the buffer to $75 \%$.

## H. Rebuilding Analyses

Entire section is not applicable; this stock has not been declared overfished.

## I. Data Gaps and Research Priorities

This fishery has a long history, with the domestic fishery dating back to 1960/61. However, much of the data on this stock prior to the early-mid 1980s is difficult to retrieve for analysis. Fishery data summarized to the level of statistical area are presently not available prior to 1980/81. Changes in definitions of fishery statistical areas between 1984/85 and 1985/86 also make it difficult to assess geographic trends in effort and catch over much of the fishery's history. An effort to compile all fishery data and other written documentation on the stock and fishery and to enter all existing fishery, observer, survey, and tagging data into a database that
allows for analysis of all data from the fishery and stock through the history of the fishery would be time-consuming, challenging, and - perhaps - disappointing, but could provide valuable information if successful.

The SSC in October 2008, June 2011, and June 2013 noted the need for systematic surveys to obtain the data to estimate the biomass of this stock. Surveys on this stock have, however, been few and the geographic scope of the surveyed area is limited. Aside from the pot surveys performed in the Adak-Atka area during the mid-1970s (ADF\&G 1978, Blau 1993), the only standardized surveys for red king crab performed by ADF\&G were performed in November 2006 and November 2009 and those were limited to the Petrel Bank area (Gish 2007, 2010). ADF\&G-Industry surveys, conducted as limited fisheries that allowed retention of captured legal males under provisions of a commissioner's permit, have been performed in limited areas of the WAI: during January-February 2001 and November 2001 in the Petrel Bank area (Bowers et al. 2002) and during November 2002 in the Adak-Atka-Amlia area (Granath 2003). A very limited (18 pot lifts) Industry exploratory survey without any retention of crab was performed during mid-October to mid-December 2009 between $178^{\circ} 00^{\prime}$ E longitude and $175^{\circ} 30^{\prime}$ E longitude produced a catch of one red king crab, a legal-sized male (Baechler and Cook 2014). Based on requests from Industry in 2012, ADF\&G designed a state-waters red king crab pot survey for the Adak Island group. Twenty-five stations were designated with 20 pot lifts in each station. To defray cost of the survey, participants would be allowed to sell up to $14 \mathrm{t}(31,417 \mathrm{lb})$ of red king crab. In addition, bycatch mortality during the proposed survey was assumed not to exceed 9 t based on assumed maximum discarded catch weight and an assumed bycatch mortality rate of 0.2. In 2012 the CPT and SSC recommended an ABC of 34 t (0.74-million lb) for 2012/13 to accommodate total fishery mortality due the proposed red king crab survey in addition to estimated bycatch mortality due to non-directed fisheries (12 t). In late summer 2012, Industry advocates decided to forgo the fall 2012 survey.

Trawl surveys are preferable relative to pot surveys for providing density estimates, but crab pots may be the only practical gear for sampling king crab in the Aleutians. Standardized pot surveys are a prohibitively expensive approach to surveying the entire WAI. Surveys or exploratory fishing performed by industry in cooperation with ADF\&G, with or without allowing retention of captured legal males, reduce the costs to agencies. Agency-Industry cooperation can provide a means to obtain some information on distribution and density during periods of fishery closures. However, there can be difficulties in assuring standardization of procedures during ADF\&GIndustry surveys (Bowers et al. 2002). Moreover, costs of performing a survey have resulted in incompletion of ADF\&G-Industry surveys (Granath 2003). Hence surveys performed by Industry in cooperation with ADF\&G cannot be expected to provide sampling over the entire WAI during periods of limited stock distribution and overall low density, as apparently currently exists.

A cooperative survey between industry and ADF\&G was performed in the Adak area in September 2015 (Hilsinger et al. 2016a). A total of 442 red king crab ( 23 legal males, 74 pre recruit males, 140 juvenile males, and 204 females) were captured in Sitkin Sound and Expedition Harbor from 730 pots. Since RKC were highly aggregated (most were in inner Sitkin Sound) and few crab were legal males, further surveys of RKC in this area are a low priority. A cooperative survey between industry and ADF\&G was also performed in the Petrel area in

November 2016 (Hilsinger et al. 2016b). A total of 40 red king crab (39 legal males, 1 sub-legal male, and 0 females) were captured.

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## List of Tables

Table 1a: page 24. Commercial fishery history for the western Aleutian Islands red king crab commercial fishery, 1960/61-2016/17: number of vessels, guideline harvest level (GHL; established in lb, converted to t) for 1973/74-2004/05, total allowable catch (TAC; established in lb , converted to $\mathbf{t}$ ) in the area west of $179^{\circ} \mathrm{W}$ longitude combined with GHL (established in lb , converted to $\mathbf{t}$ ) in the area east of $179^{\circ} \mathrm{W}$ longitude for 2005/06-2016/17, weight of retained catch (Harvest; $\mathbf{t}$ ), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight ( $\mathbf{k g}$ ) of retained crab.

Table 1b: page 25. Commercial fishery history for the western Aleutian Islands red king crab commercial fishery, 1960/61-2016/17 number of vessels, guideline harvest level (GHL; lb) for 1973/74-2004/05, total allowable catch (TAC; lb) in the area west of $179^{\circ} \mathrm{W}$ longitude combined with GHL (lb) in the area east of $179^{\circ}$ W longitude for 2005/06-2016/17, weight of retained catch (Harvest; lb), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (lb) of retained crab.

Table 2: page 26. A summary of relevant fishery activities and management measures pertaining to the Western Aleutian Islands red king crab fishery since 1996/97.

Table 3: page 27. Annual retained catch (t) of Western Aleutian Islands red king crab, with the estimated annual discarded catch ( $\mathbf{t}$; not discounted for an assumed bycatch mortality rate) and components of discarded catch (legal males, sublegal males, and females) during commercial crab fisheries, 1995/96-2016/17.

Table 4: page 28. Estimated annual weight (t) of discarded catch of red king crab (all sizes, males and females) and estimated annual bycatch mortality ( $\mathbf{t}$ ) during federal groundfish fisheries by gear type (fixed or trawl) in reporting areas 541, 542, and 543 (Aleutian Islands west of $170^{\circ} \mathrm{W}$ longitude), 1993/94-2016/17 (assumes bycatch mortality rate of 0.5 for fixed-gear fisheries and 0.8 for trawl fisheries).

Table 5: page 29. Estimated annual weight of discarded catch ( $\mathbf{t}$; not discounted by an assumed bycatch mortality rate) of red king crab in reporting areas 541, 542, and 543 (Aleutian Islands west of $170^{\circ} \mathrm{W}$ longitude) during federal groundfish fisheries (all gear types combined) by reporting area, 1993/94-2016/17.

Table 6: page 30. Estimated annual weight (t) of total fishery mortality to Western Aleutian Islands red king crab, 1995/96-2016/17, partitioned by source of mortality: retained catch, estimated bycatch mortality during crab fisheries, and estimated bycatch mortality during groundfish fisheries.

Table 7: page 31. Annual retained catch weight (t) and estimates of annual discarded catch weight ( $\mathbf{t}$; not discounted for an assumed bycatch mortality rate) of Western Aleutian Islands red king crab available for a Tier 5 assessment; shaded, bold values are used in computation of the recommended (status quo) 2017/18 Tier 5 OFL.

## List of Figures

Figure 1: page 32. Aleutian Islands, Area O, red and golden king crab management area (from Baechler and Cook 2014, updated to show boundaries of the Adak and Petrel Districts for red king crab as established by the Alaska Board of Fisheries in March 2014).

Figure 2: page 33. Retained catch (t) in the Western Aleutian Islands red king crab fishery, 1985/86-1995/96 by 1-degree longitude grouping, summarized from fish ticket catch by state statistical area landing data.

Figure 3: page 34. Retained catch (t) in the Western Aleutian Islands red king crab fishery, 1960/61-2016/17 (catch is for the area west of $172^{\circ} \mathrm{W}$ longitude during 1960/61-1983/84 and for the area west of $171^{\circ} \mathrm{W}$ longitude during 1984/85-2016/17; see Table 1a).

Figure 4: page 34. Annual retained catch (t) in the Western Aleutian Islands red king crab fishery during 1985/86-1995/96, partitioned into three longitudinal zones: $171^{\circ} \mathrm{W}$ longitude to $179^{\circ} \mathrm{W}$ longitude (white bars); $179^{\circ} \mathrm{W}$ longitude to $179^{\circ} \mathrm{E}$ longitude (black bars); and $179^{\circ} \mathrm{E}$ longitude to $171^{\circ} \mathrm{E}$ longitude.

Figure 5: page 35. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands. Areas 541, 542, and 543 are used to obtain data on discarded catch of Western Aleutian Islands red king crab during groundfish fisheries (from http://www.alaskafisheries.noaa.gov/rr/figures/fig1.pdf).

Figure 6: page 36. Retained catch (number of crab) and CPUE (number of retained crab per pot lift) in the western Aleutian Islands red king crab fishery, 1972/73-2016/17 (from Table 1a). Data for 1972/73-1983/84 are for the area west of $172^{\circ}$ W longitude; data for 1984/85-1997/98, 1999/00, and 2004/05-2016/17 are for the area west of $171^{\circ} \mathrm{W}$ longitude; data for 1998/99 are for the area west of $174^{\circ} \mathrm{W}$ longitude; and data for 2000/01-2003/04 are for the area between $179^{\circ} \mathrm{W}$ longitude and $179^{\circ} \mathrm{E}$ longitude.

Figure 7: page 37. Bootstrapped estimate of the sampling distribution of the recommended 2017/2018 Tier 5 OFL (total-catch, t) for the Western Aleutian Islands red king crab stock; histogram in left column, cumulative distribution in right column.

## List of Appendices

Appendix A1: page 38. Summary of retained catch size frequency data available from Western Aleutian Islands directed red king crab fishery, 1960/61-2016/17.

Appendix A2: page 39 Available retained catch size frequency sample data 1961/62-1979/80 western Aleutian Islands directed red king crab fishery.

Appendix A3: page 42. Available retained catch size frequency sample data 1980/81-1989/90 Western Aleutian Islands directed red king crab fishery.

Appendix A4: page 45. Available retained catch size frequency sample data 1990/91-2003/04 Western Aleutian Islands directed red king crab fishery.

Appendix A5. Page 49. Plot of available retained catch size frequency sample data 1961/622003/04 western Aleutian Islands directed red king crab fishery (data listed in Appendices A2-A4).

Table 1a. Commercial fishery history for the western Aleutian Islands red king crab commercial fishery, 1960/61-2016/17: number of vessels, guideline harvest level (GHL; established in lb, converted to t) for 1973/74-2004/05, total allowable catch (TAC; established in lb , converted to t ) in the area west of $179^{\circ} \mathrm{W}$ longitude combined with GHL (established in lb , converted to $\mathbf{t}$ ) in the area east of $179^{\circ} \mathrm{W}$ longitude for 2005/06-2016/17, weight of retained catch (Harvest; $\mathbf{t}$ ), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight ( $\mathbf{k g}$ ) of retained crab.

| Crab fishing year | Area | Vessels | GHL/TAC | Harvest ${ }^{\text {a }}$ | $\mathrm{Crab}^{\text {a }}$ | Pots lifted | CPUE | Weight |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1960/61 | West of $172^{\circ} \mathrm{W}$ | 4 | - | 941 | NA | NA | NA | NA |
| 1961/62 | West of $172^{\circ} \mathrm{W}$ | 8 | - | 2,773 | NA | NA | NA | NA |
| 1962/63 | West of $172^{\circ} \mathrm{W}$ | 9 | - | 3,631 | NA | NA | NA | NA |
| 1963/64 | West of $172^{\circ} \mathrm{W}$ | 11 | - | 8,121 | NA | NA | NA | NA |
| 1964/65 | West of $172^{\circ} \mathrm{W}$ | 18 | - | 9,613 | NA | NA | NA | NA |
| 1965/66 | West of $172^{\circ} \mathrm{W}$ | 10 | - | 5,858 | NA | NA | NA | NA |
| 1966/67 | West of $172^{\circ} \mathrm{W}$ | 10 | - | 2,668 | NA | NA | NA | NA |
| 1967/68 | West of $172^{\circ} \mathrm{W}$ | 22 | - | 6,410 | NA | NA | NA | NA |
| 1968/69 | West of $172^{\circ} \mathrm{W}$ | 30 | - | 7,303 | NA | NA | NA | NA |
| 1969/70 | West of $172^{\circ} \mathrm{W}$ | 33 | - | 8,172 | NA | 115,929 | NA | 2.5 |
| 1970/71 | West of $172^{\circ} \mathrm{W}$ | 35 | - | 7,283 | NA | 124,235 | NA | NA |
| 1971/72 | West of $172^{\circ} \mathrm{W}$ | 40 | - | 7,020 | NA | 46,011 | NA | NA |
| 1972/73 | West of $172^{\circ} \mathrm{W}$ | 43 | - | 8,493 | 3,461,025 | 81,133 | 43 | 2.5 |
| 1973/74 | West of $172^{\circ} \mathrm{W}$ | 41 | 9,072 ${ }^{\text {b }}$ | 4,419 | 1,844,974 | 70,059 | 26 | 2.4 |
| 1974/75 | West of $172^{\circ} \mathrm{W}$ | 36 | $9,072{ }^{\text {b }}$ | 1,259 | 532,298 | 32,620 | 16 | 2.4 |
| 1975/76 | West of $172^{\circ} \mathrm{W}$ | 20 | 6,804 ${ }^{\text {b }}$ | 187 | 79,977 | 8,331 | 10 | 2.3 |
| 1976/77 | West of $172^{\circ} \mathrm{W}$ | FC | FC | FC | FC | FC | FC | FC |
| 1977/78 | West of $172^{\circ} \mathrm{W}$ | 12 | 113-1,134 | 411 | 160,343 | 7,269 | 22 | 2.6 |
| 1978/79 | West of $172^{\circ} \mathrm{W}$ | 13 | 227-1,361 | 366 | 149,491 | 13,948 | 11 | 2.4 |
| 1979/80 | West of $172^{\circ} \mathrm{W}$ | 18 | 227-1,361 | 212 | 82,250 | 9,757 | 8 | 2.6 |
| 1980/81 | West of $172^{\circ} \mathrm{W}$ | 17 | 227-1,361 | 644 | 254,390 | 20,914 | 12 | 2.5 |
| 1981/82 | West of $172^{\circ} \mathrm{W}$ | 46 | 227-1,361 | 748 | 291,311 | 40,697 | 7 | 2.6 |
| 1982/83 | West of $172^{\circ} \mathrm{W}$ | 72 | 227-1,361 | 772 | 284,787 | 66,893 | 4 | 2.7 |
| 1983/84 | West of $172^{\circ} \mathrm{W}$ | 106 | 227-1,361 | 899 | 298,958 | 60,840 | 5 | 3.0 |
| 1984/85 | West of $171^{\circ} \mathrm{W}$ | 64 | 680-1,361 | 588 | 196,276 | 48,642 | 4 | 3.0 |
| 1985/86 | West of $171^{\circ} \mathrm{W}$ | 35 | 227-907 | 394 | 156,097 | 29,095 | 5 | 2.5 |
| 1986/87 | West of $171^{\circ} \mathrm{W}$ | 33 | 227-680 | 323 | 126,204 | 29,189 | 4 | 2.6 |
| 1987/88 | West of $171^{\circ} \mathrm{W}$ | 71 | 227-680 | 551 | 211,692 | 43,433 | 5 | 2.6 |
| 1988/89 | West of $171^{\circ} \mathrm{W}$ | 73 | 454 | 711 | 266,053 | 64,334 | 4 | 2.7 |
| 1989/90 | West of $171^{\circ} \mathrm{W}$ | 56 | 771 | 502 | 193,177 | 54,213 | 4 | 2.6 |
| 1990/91 | West of $171^{\circ} \mathrm{W}$ | 7 | NA | 376 | 146,903 | 10,674 | 14 | 2.6 |
| 1991/92 | West of $171^{\circ} \mathrm{W}$ | 10 | NA | 431 | 165,356 | 16,636 | 10 | 2.6 |
| 1992/93 | West of $171^{\circ} \mathrm{W}$ | 12 | NA | 584 | 218,049 | 16,129 | 14 | 2.7 |
| 1993/94 | West of $171^{\circ} \mathrm{W}$ | 12 | NA | 317 | 119,330 | 13,575 | 9 | 2.7 |
| 1994/95 | West of $171^{\circ} \mathrm{W}$ | 20 | 454-680 | 89 | 30,337 | 18,146 | 2 | 2.9 |
| 1995/96 | West of $171^{\circ} \mathrm{W}$ | 4 | 454-680 | 18 | 6,880 | 1,986 | 3 | 2.6 |
| 1996/97-1997/98 | West of $171^{\circ} \mathrm{W}$ | FC | FC | FC | FC | FC | FC | FC |
| 1998/99 | $174^{\circ}-179^{\circ} \mathrm{W}$; west of $179^{\circ} \mathrm{E}$ | 1 | 7 | CF | CF | CF | CF | CF |
| 1999/00 | West of $171^{\circ} \mathrm{W}$ | FC | FC | FC | FC | FC | FC | FC |
| 2000/01 ${ }^{\text {c }}$ | $179^{\circ} \mathrm{W}-179^{\circ} \mathrm{E}$ | 1 | (Permit/Survey) | 35 | 11,299 | 496 | 23 | 3.1 |
| 2001/02 ${ }^{\text {d }}$ | $179^{\circ} \mathrm{W}-179^{\circ} \mathrm{E}$ | 4 | (Permit/Survey) | 70 | 22,080 | 564 | 39 | 3.2 |
| 2002/03 | $179^{\circ} \mathrm{W}-179^{\circ} \mathrm{E}$ | 33 | 227 | 229 | 68,300 | 3,786 | 18 | 3.4 |
| 2003/04 | $179^{\circ} \mathrm{W}-179^{\circ} \mathrm{E}$ | 30 | 227 | 217 | 59,828 | 5,774 | 10 | 3.6 |
| 2004/05-2016/17 | West of $171^{\circ} \mathrm{W}$ | FC | FC | FC | FC | FC | FC | FC |

Note: NA = Not available, FC = fishery closed, CF = confidential.
${ }^{\text {a }}$ Deadloss included.
${ }^{\text {b }}$ GHL includes all king crab species. Golden king crab incidental to red king crab.
c January/February 2001 Petrel Bank survey.
${ }^{\text {d }}$ November 2001 Petrel Bank survey.

Table 1b. Commercial fishery history for the western Aleutian Islands red king crab commercial fishery, 1960/612016/17 number of vessels, guideline harvest level (GHL; lb) for 1973/74-2004/05, total allowable catch (TAC; lb) in the area west of $179^{\circ} \mathrm{W}$ longitude combined with GHL ( $\mathbf{l b}$ ) in the area east of $179^{\circ} \mathrm{W}$ longitude for 2005/062016/17, weight of retained catch (Harvest; lb), number of retained crab, pot lifts, fishery catch per unit effort (CPUE; retained crab per pot lift), and average weight (lb) of retained crab.

| Crab fishing year | Area | Vessels | GHL/TAC | Harvest ${ }^{\text {a }}$ | Crab ${ }^{\text {a }}$ | Pots lifted | CPUE | Weight |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1960/61 | West of $172^{\circ} \mathrm{W}$ | 4 | - | 2,074,000 | NA | NA | NA | NA |
| 1961/62 | West of $172^{\circ} \mathrm{W}$ | 8 | - | 6,114,000 | NA | NA | NA | NA |
| 1962/63 | West of $172^{\circ} \mathrm{W}$ | 9 | - | 8,006,000 | NA | NA | NA | NA |
| 1963/64 | West of $172^{\circ} \mathrm{W}$ | 11 | - | 17,904,000 | NA | NA | NA | NA |
| 1964/65 | West of $172^{\circ} \mathrm{W}$ | 18 |  | 21,193,000 | NA | NA | NA | NA |
| 1965/66 | West of $172^{\circ} \mathrm{W}$ | 10 | - | 12,915,000 | NA | NA | NA | NA |
| 1966/67 | West of $172^{\circ} \mathrm{W}$ | 10 | - | 5,883,000 | NA | NA | NA | NA |
| 1967/68 | West of $172^{\circ} \mathrm{W}$ | 22 | - | 14,131,000 | NA | NA | NA | NA |
| 1968/69 | West of $172^{\circ} \mathrm{W}$ | 30 | - | 16,100,000 | NA | NA | NA | NA |
| 1969/70 | West of $172^{\circ} \mathrm{W}$ | 33 | - | 18,016,000 | NA | 115,929 | NA | 6.5 |
| 1970/71 | West of $172^{\circ} \mathrm{W}$ | 35 | - | 16,057,000 | NA | 124,235 | NA | NA |
| 1971/72 | West of $172^{\circ} \mathrm{W}$ | 40 | - | 15,475,940 | NA | 46,011 | NA | NA |
| 1972/73 | West of $172^{\circ} \mathrm{W}$ | 43 | - | 18,724,140 | 3,461,025 | 81,133 | 43 | 5.4 |
| 1973/74 | West of $172^{\circ} \mathrm{W}$ | 41 | 20,000,000 ${ }^{\text {b }}$ | 9,741,464 | 1,844,974 | 70,059 | 26 | 5.3 |
| 1974/75 | West of $172^{\circ} \mathrm{W}$ | 36 | $20,000,000^{\text {b }}$ | 2,774,963 | 532,298 | 32,620 | 16 | 5.2 |
| 1975/76 | West of $172^{\circ} \mathrm{W}$ | 20 | $15,000,000^{\text {b }}$ | 411,583 | 79,977 | 8,331 | 10 | 5.2 |
| 1976/77 | West of $172^{\circ} \mathrm{W}$ | FC | FC | FC | FC | FC | FC | FC |
| 1977/78 | West of $172^{\circ} \mathrm{W}$ | 12 | 0.25-2.5 million | 905,527 | 160,343 | 7,269 | 22 | 5.7 |
| 1978/79 | West of $172^{\circ} \mathrm{W}$ | 13 | 0.5-3.0 million | 807,195 | 149,491 | 13,948 | 11 | 5.4 |
| 1979/80 | West of $172^{\circ} \mathrm{W}$ | 18 | 0.5-3.0 million | 467,229 | 82,250 | 9,757 | 8 | 5.7 |
| 1980/81 | West of $172^{\circ} \mathrm{W}$ | 17 | 0.5-3.0 million | 1,419,513 | 254,390 | 20,914 | 12 | 5.6 |
| 1981/82 | West of $172^{\circ} \mathrm{W}$ | 46 | 0.5-3.0 million | 1,648,926 | 291,311 | 40,697 | 7 | 5.7 |
| 1982/83 | West of $172^{\circ} \mathrm{W}$ | 72 | 0.5-3.0 million | 1,701,818 | 284,787 | 66,893 | 4 | 6.0 |
| 1983/84 | West of $172^{\circ} \mathrm{W}$ | 106 | 0.5-3.0 million | 1,981,579 | 298,958 | 60,840 | 5 | 6.6 |
| 1984/85 | West of $171^{\circ} \mathrm{W}$ | 64 | 1.5 - 3.0 million | 1,296,385 | 196,276 | 48,642 | 4 | 6.6 |
| 1985/86 | West of $171^{\circ} \mathrm{W}$ | 35 | 0.5-2.0 million | 868,828 | 156,097 | 29,095 | 5 | 5.6 |
| 1986/87 | West of $171^{\circ} \mathrm{W}$ | 33 | 0.5-1.5 million | 712,543 | 126,204 | 29,189 | 4 | 5.7 |
| 1987/88 | West of $171^{\circ} \mathrm{W}$ | 71 | 0.5-1.5 million | 1,213,892 | 211,692 | 43,433 | 5 | 5.7 |
| 1988/89 | West of $171^{\circ} \mathrm{W}$ | 73 | 1.0 million | 1,567,314 | 266,053 | 64,334 | 4 | 5.9 |
| 1989/90 | West of $171^{\circ} \mathrm{W}$ | 56 | 1.7 million | 1,105,971 | 193,177 | 54,213 | 4 | 5.7 |
| 1990/91 | West of $171^{\circ} \mathrm{W}$ | 7 | NA | 828,105 | 146,903 | 10,674 | 14 | 5.6 |
| 1991/92 | West of $171^{\circ} \mathrm{W}$ | 10 | NA | 951,278 | 165,356 | 16,636 | 10 | 5.8 |
| 1992/93 | West of $171^{\circ} \mathrm{W}$ | 12 | NA | 1,286,424 | 218,049 | 16,129 | 14 | 6.0 |
| 1993/94 | West of $171^{\circ} \mathrm{W}$ | 12 | NA | 698,077 | 119,330 | 13,575 | 9 | 5.9 |
| 1994/95 | West of $171^{\circ} \mathrm{W}$ | 20 | 1.0-1.5 million | 196,967 | 30,337 | 18,146 | 2 | 6.5 |
| 1995/96 | West of $171^{\circ} \mathrm{W}$ | 4 | 1.0-1.5 million | 38,941 | 6,880 | 1,986 | 3 | 5.7 |
| 1996/97-1997/98 | West of $171^{\circ} \mathrm{W}$ | FC | FC | FC | FC | FC | FC | FC |
| 1998/99 | $174^{\circ}-179^{\circ} \mathrm{W}$; west of $179^{\circ} \mathrm{E}$ | 1 | 15,000 | CF | CF | CF | CF | CF |
| 1999/00 | West of $171^{\circ} \mathrm{W}$ | FC | FC | FC | FC | FC | FC | FC |
| 2000/01 ${ }^{\text {c }}$ | $179{ }^{\circ} \mathrm{W}-179^{\circ} \mathrm{E}$ | 1 | (Permit/Survey) | 76,562 | 11,299 | 496 | 23 | 6.8 |
| 2001/02 ${ }^{\text {d }}$ | $179^{\circ} \mathrm{W}-179^{\circ} \mathrm{E}$ | 4 | (Permit/Survey) | 153,961 | 22,080 | 564 | 39 | 7.0 |
| 2002/03 | $179^{\circ} \mathrm{W}-179^{\circ} \mathrm{E}$ | 33 | 500,000 | 505,642 | 68,300 | 3,786 | 18 | 7.4 |
| 2003/04 | $179^{\circ} \mathrm{W}-179^{\circ} \mathrm{E}$ | 30 | 500,000 | 479,113 | 59,828 | 5,774 | 10 | 8.0 |
| 2004/05-2016/17 | West of $171^{\circ} \mathrm{W}$ | FC | FC | FC | FC | FC | FC | FC |

[^10]Table 2. A summary of relevant fishery activities and management measures pertaining to the Western Aleutian Islands red king crab fishery since 1996/97.

| Crab <br> fishing year | Fishery Activities and Management Measures |
| :---: | :---: |
| $\begin{aligned} & \hline \text { 1996/97- } \\ & \text { 1997/98 } \\ & \hline \end{aligned}$ | - Fishery closed. |
| 1998/99 | - GHL of $7 \mathrm{t}(15,000 \mathrm{lb})$ for exploratory fishing with fishery closed in the Petrel Bank area (i.e., between $179^{\circ} \mathrm{W}$ longitude and $179^{\circ} \mathrm{E}$ longitude) - 1 vessel |
| 1999/00 | - Fishery closed |
| 2000/01 | - Fishery closed <br> - Catch retained during ADF\&G-Industry survey of Petrel Bank area (i.e., between $179^{\circ} \mathrm{W}$ longitude and $179^{\circ} \mathrm{E}$ longitude) conducted as commissioner's permit fishery, Jan-Feb 2001 1 vessel Retained catch weight $=35 \mathrm{t}(76,562 \mathrm{lb})$ CPUE $=23$ retained crab per pot lift |
| 2001/02 | - Fishery closed <br> - Catch retained ADF\&G-Industry survey of Petrel Bank area (i.e., between $179^{\circ} \mathrm{W}$ longitude and $179^{\circ} \mathrm{E}$ longitude) conducted as commissioner's permit fishery, November 2001 4 vessels Retained catch weight $=70 \mathrm{t}(153,961 \mathrm{lb})$ <br> - CPUE $=39$ retained crab per pot lift |
| 2002/03 | - Fishery opened with GHL of $227 \mathrm{t}(500,000 \mathrm{lb})$ restricted to Petrel Bank area (i.e., between $179^{\circ} \mathrm{W}$ longitude and $179^{\circ} \mathrm{E}$ longitude) 33 vessels <br> - Retained catch weight $=229 \mathrm{t}(505,642 \mathrm{lb})$ <br> - CPUE $=18$ retained crab per pot lift <br> - ADF\&G-Industry survey of the Adak, Atka, and Amlia Islands area conducted as a commissioner's permit fishery <br> - 4 legal males captured in 1,085 pot lifts |
| 2003/04 | - Fishery opened with GHL of $227 \mathrm{t}(500,000 \mathrm{lb})$ restricted to Petrel Bank area (i.e., between $179^{\circ} \mathrm{W}$ longitude and $179^{\circ} \mathrm{E}$ longitude) 30 vessels Retained catch weight $=217 \mathrm{t}(479,113) \mathrm{lb}$ 10 retained crab per pot lift |
| $\begin{aligned} & \hline \text { 2004/05- } \\ & 2016 / 17 \end{aligned}$ | - Fishery closed <br> - 2006 and 2009 ADF\&G pot surveys on Petrel Bank <br> - 2015 exploratory/reconnaissance survey in Adak Island area. <br> - 2016 exploratory/reconnaissance survey in the Petrel Bank area. |

Table 3. Annual retained catch (t) of Western Aleutian Islands red king crab, with the estimated annual discarded catch ( $\mathbf{t}$; not discounted for an assumed bycatch mortality rate) and components of discarded catch (legal males, sublegal males, and females) during commercial crab fisheries, 1995/96-2016/17.

| Crab fishing year | WAI red king crab fishery |  |  |  | AI golden king crab fishery |  |  | Total <br> Discarded |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Retained | Discarded |  |  |  |  |  |  |
|  |  | Legal male | Sublegal male | Female | Legal male | Sublegal male | Female |  |
| 1995/96 | 17.66 | 0.00 | 9.38 | 12.53 | 0.00 | 0.93 | 0.14 | 22.98 |
| 1996/97 | 0.00 | 0.00 | 0.00 | 0.00 | 1.49 | 0.92 | 0.30 | 2.71 |
| 1997/98 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.26 | 0.08 | 0.42 |
| 1998/99 ${ }^{\text {a }}$ | 2.68 | - ${ }^{\text {a }}$ | - ${ }^{\text {a }}$ | - ${ }^{\text {a }}$ | 0.34 | 0.06 | 0.08 | - ${ }^{\text {a }}$ |
| 1999/00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.07 | 0.34 | 0.04 | 0.46 |
| 2000/01 | 34.73 | 0.00 | 0.35 | 0.17 | 0.17 | 0.12 | 0.02 | 0.83 |
| 2001/02 | 69.84 | 0.08 | 2.98 | 3.80 | 9.07 | 0.00 | 0.17 | 16.09 |
| 2002/03 | 229.36 | 0.75 | 2.73 | 7.91 | 9.86 | 0.16 | 0.23 | 21.65 |
| 2003/04 | 217.32 | 0.29 | 2.99 | 3.61 | 4.28 | 2.88 | 3.03 | 17.08 |
| 2004/05 | 0.00 | 0.00 | 0.00 | 0.00 | 0.97 | 0.10 | 0.00 | 1.07 |
| 2005/06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.09 | 0.00 | 0.02 | 0.11 |
| 2006/07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.15 | 0.05 | 0.02 | 0.22 |
| 2007/08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.28 | 0.83 | 0.25 | 1.36 |
| 2008/09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.10 | 0.01 | 0.04 | 0.15 |
| 2009/10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.26 | 0.11 | 0.02 | 0.39 |
| 2010/11 | 0.00 | 0.00 | 0.00 | 0.00 | 1.96 | 0.08 | 0.04 | 2.07 |
| 2011/12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.43 | 0.01 | 0.04 | 0.49 |
| 2012/13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.40 | 0.03 | 0.02 | 0.44 |
| 2013/14 | 0.00 | 0.00 | 0.00 | 0.00 | 1.34 | 0.05 | 0.08 | 1.46 |
| 2014/15 | 0.00 | 0.00 | 0.00 | 0.00 | 0.24 | 0.01 | 0.03 | 0.28 |
| 2015/16 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2016/17 | 0.00 | 0.00 | 0.00 | 0.00 | 0.15 | 0.01 | 0.07 | 0.23 |
| Average | 25.98 | 0.05 | 0.88 | 1.33 | 1.49 | 0.33 | 0.22 | 4.31 |

a. Data on discarded catch of red king crab during the red king crab fishery not available (see Moore et al. 2000).

Table 4. Estimated annual weight (t) of discarded catch of red king crab (all sizes, males and females) and estimated annual bycatch mortality (t) during federal groundfish fisheries by gear type (fixed or trawl) in reporting areas 541, 542, and 543 (Aleutian Islands west of $170^{\circ} \mathrm{W}$ longitude), 1993/94-2016/17 (assumes bycatch mortality rate of 0.5 for fixedgear fisheries and 0.8 for trawl fisheries).

| Crab fishing <br> year | Discarded catch |  |  | Bycatch Mortality |  |  |
| :---: | ---: | ---: | ---: | ---: | ---: | ---: |
|  | Fixed Gear Trawl Gear |  | Fixed Gear Trawl Gear | Total |  |  |
| $1993 / 94$ | 0.60 | 40.09 |  | 0.30 | 32.07 | 32.37 |
| $1994 / 95$ | 1.36 | 10.34 |  | 0.68 | 8.27 | 8.95 |
| $1995 / 96$ | 2.63 | 6.93 |  | 1.32 | 5.55 | 6.86 |
| $1996 / 97$ | 1.30 | 20.26 |  | 0.65 | 16.21 | 16.86 |
| $1997 / 98$ | 1.73 | 5.31 |  | 0.87 | 4.25 | 5.12 |
| $1998 / 99$ | 4.60 | 20.65 |  | 2.30 | 16.52 | 18.82 |
| $1999 / 00$ | 17.13 | 12.69 |  | 8.57 | 10.15 | 18.72 |
| $2000 / 01$ | 1.22 | 6.30 |  | 0.61 | 5.04 | 5.65 |
| $2001 / 02$ | 2.42 | 27.01 |  | 1.21 | 21.61 | 22.82 |
| $2002 / 03$ | 5.12 | 33.12 |  | 2.56 | 26.50 | 29.06 |
| $2003 / 04$ | 1.62 | 4.15 |  | 0.81 | 3.32 | 4.13 |
| $2004 / 05$ | 0.36 | 5.86 |  | 0.18 | 4.69 | 4.87 |
| $2005 / 06$ | 1.61 | 1.07 |  | 0.80 | 0.86 | 1.66 |
| $2006 / 07$ | 3.08 | 0.28 |  | 1.54 | 0.22 | 1.76 |
| $2007 / 08$ | 7.70 | 1.19 |  | 3.85 | 0.95 | 4.80 |
| $2008 / 09$ | 4.89 | 4.67 |  | 2.44 | 3.73 | 6.18 |
| $2009 / 10$ | 0.14 | 6.40 |  | 0.07 | 5.12 | 5.19 |
| $2010 / 11$ | 0.04 | 1.99 |  | 0.02 | 1.59 | 1.61 |
| $2011 / 12$ | 1.19 | 0.82 |  | 0.60 | 0.41 | 1.01 |
| $2012 / 13$ | 0.01 | 0.24 |  | 0.00 | 0.19 | 0.19 |
| $2013 / 14$ | 0.01 | 0.04 |  | 0.01 | 0.03 | 0.04 |
| $2014 / 15$ | 0.00 | 0.11 |  | 0.00 | 0.09 | 0.09 |
| $2015 / 16$ | 0.03 | 1.46 |  | 0.02 | 1.17 | 1.19 |
| $2016 / 17$ | 0.00 | 0.17 |  | 0.00 | 0.13 | 0.13 |
| Average | 2.45 | 8.80 |  | 1.23 | 7.03 | 8.25 |

Table 5. Estimated annual weight of discarded catch ( $\mathbf{t}$; not discounted by an assumed bycatch mortality rate) of red king crab in reporting areas 541, 542, and 543 (Aleutian Islands west of $170^{\circ} \mathrm{W}$ longitude) during federal groundfish fisheries (all gear types combined) by reporting area, 1993/94-2016/17.

| Crab fishing | Reporting Area |  |  |  |
| :---: | ---: | ---: | ---: | ---: |
| year | 541 | 542 | 543 | Total |
| $1993 / 94$ | 37.9893 | 2.6590 | 0.0372 | 40.6855 |
| $1994 / 95$ | 10.7216 | 0.8718 | 0.1025 | 11.6959 |
| $1995 / 96$ | 5.9520 | 1.8398 | 1.7763 | 9.5681 |
| $1996 / 97$ | 1.9477 | 3.0890 | 16.5258 | 21.5624 |
| $1997 / 98$ | 1.0061 | 3.9639 | 2.0770 | 7.0470 |
| $1998 / 99$ | 6.7549 | 7.1659 | 11.3335 | 25.2542 |
| $1999 / 00$ | 16.3416 | 8.0535 | 5.4227 | 29.8183 |
| $2000 / 01$ | 1.7686 | 3.6541 | 2.0961 | 7.5192 |
| $2001 / 02$ | 3.4750 | 24.0341 | 1.9250 | 29.4341 |
| $2002 / 03$ | 10.9996 | 21.3098 | 5.9384 | 38.2483 |
| $2003 / 04$ | 2.2294 | 3.5280 | 0.0163 | 5.7733 |
| $2004 / 05$ | 0.5280 | 5.6803 | 0.0154 | 6.2237 |
| $2005 / 06$ | 1.6057 | 0.0395 | 1.0333 | 2.6785 |
| $2006 / 07$ | 2.9688 | 0.3869 | 0.0000 | 3.3557 |
| $2007 / 08$ | 5.1233 | 3.0427 | 0.7248 | 8.8909 |
| $2008 / 09$ | 1.1440 | 7.5455 | 0.8668 | 9.5563 |
| $2009 / 10$ | 1.6719 | 3.7548 | 1.1136 | 6.5404 |
| $2010 / 11$ | 0.2123 | 1.8162 | 0.0005 | 2.0289 |
| $2011 / 12$ | 0.8768 | 1.1335 | 0.0000 | 2.0108 |
| $2012 / 13$ | 0.1560 | 0.0903 | 0.0000 | 0.2463 |
| $2013 / 14$ | 0.0000 | 0.0435 | 0.0118 | 0.0553 |
| $2014 / 15$ | 0.0000 | 0.1148 | 0.0005 | 0.1152 |
| $2015 / 16$ | 0.0000 | 0.8864 | 0.6102 | 1.4966 |
| $2016 / 17$ | 0.0000 | 0.0718 | 0.0950 | 0.1669 |
| Average | 4.7280 | 4.3656 | 2.1551 | 11.2488 |

Table 6. Estimated annual weight (t) of total fishery mortality to Western Aleutian Islands red king crab, 1995/96-2016/17, partitioned by source of mortality: retained catch, estimated bycatch mortality during crab fisheries, and estimated bycatch mortality during groundfish fisheries.

| Crab fishing year | Bycatch Mortality by Fishery Type |  |  | Total Estimated <br> Fishery mortality |
| :---: | :---: | :---: | :---: | :---: |
|  | Retained Catch | Crab | Groundfish |  |
| 1995/96 | 17.66 | 4.60 | 6.86 | 29.12 |
| 1996/97 | 0.00 | 0.54 | 16.86 | 17.40 |
| 1997/98 | 0.00 | 0.08 | 5.12 | 5.20 |
| 1998/99 ${ }^{\text {a }}$ | 2.68 | 0.70 | 18.82 | 22.19 |
| 1999/00 | 0.00 | 0.09 | 18.72 | 18.81 |
| 2000/01 | 34.73 | 0.17 | 5.65 | 40.54 |
| 2001/02 | 69.84 | 3.22 | 22.82 | 95.88 |
| 2002/03 | 229.36 | 4.33 | 29.06 | 262.75 |
| 2003/04 | 217.32 | 3.42 | 4.13 | 224.87 |
| 2004/05 | 0.00 | 0.21 | 4.87 | 5.08 |
| 2005/06 | 0.00 | 0.02 | 1.66 | 1.68 |
| 2006/07 | 0.00 | 0.04 | 1.76 | 1.81 |
| 2007/08 | 0.00 | 0.27 | 4.80 | 5.08 |
| 2008/09 | 0.00 | 0.03 | 6.18 | 6.21 |
| 2009/10 | 0.00 | 0.08 | 5.19 | 5.27 |
| 2010/11 | 0.00 | 0.41 | 1.61 | 2.02 |
| 2011/12 | 0.00 | 0.10 | 1.01 | 1.10 |
| 2012/13 | 0.00 | 0.09 | 0.19 | 0.28 |
| 2013/14 | 0.00 | 0.29 | 0.04 | 0.33 |
| 2014/15 | 0.00 | 0.06 | 0.09 | 0.15 |
| 2015/16 | 0.00 | 0.16 | 1.19 | 1.34 |
| 2016/17 | 0.00 | 0.07 | 0.13 | 0.21 |
| Mean, 1995/96-2007/08 | 43.97 | 1.36 | 10.86 | 56.19 |
| CV of mean | 0.52 | 0.37 | 0.23 | 0.43 |
| Mean, 1995/96-2016/17 | 25.98 | 0.86 | 7.13 | 33.97 |
| CV of mean | 0.54 | 0.37 | 0.25 | 0.45 |

a. No discarded catch data was available from the 1998/99 directed fishery for red king crab (see Table 2); bycatch mortality due to the 1998/99 crab fisheries was estimated by multiplying the retained catch for the 1998/99 directed red king crab fishery by the ratio of the 1995/96 bycatch mortality in crab fisheries to the 1995/96 retained catch.

Table 7. Annual retained catch weight ( $\mathbf{t}$ ) and estimates of annual discarded catch weight ( $\mathbf{t}$; not discounted for an assumed bycatch mortality rate) of Western Aleutian Islands red king crab available for a Tier 5 assessment; shaded, bold values are used in computation of the recommended (status quo) 2017/18 Tier 5 OFL.

| Crab Fishing Year | Retained catch weight | Discarded catch weight (estimated) |  |  |
| :---: | :---: | :---: | :---: | :---: |
|  | Fish tickets | Observer data: lengths, catch per sampled pot | Blend method; Catch Accounting System |  |
|  | Directed fishery | Crab fisheries | Fixed gear, groundfish | Trawl gear, groundfish |
| 1960/61 | 940.75 | - | - | - |
| 1961/62 | 2773.27 | - | - | - |
| 1962/63 | 3631.46 | - | - | - |
| 1963/64 | 8121.13 | - | - | - |
| 1964/65 | 9612.99 | - | - | - |
| 1965/66 | 5858.15 | - | - | - |
| 1966/67 | 2668.49 | - | - | - |
| 1967/68 | 6409.72 | - | - | - |
| 1968/69 | 7302.85 | - | - | - |
| 1969/70 | 8171.93 | - | - | - |
| 1970/71 | 7283.34 | - | - | - |
| 1971/72 | 7019.78 | - | - | - |
| 1972/73 | 8493.14 | - | - | - |
| 1973/74 | 4418.66 | - | - | - |
| 1974/75 | 1258.70 | - | - | - |
| 1975/76 | 186.69 | - | - | - |
| 1976/77 | 0.00 | - | - | - |
| 1977/78 | 410.74 | - | - | - |
| 1978/79 | 366.14 | - | - | - |
| 1979/80 | 211.93 | - | - | - |
| 1980/81 | 643.88 | - | - | - |
| 1981/82 | 747.94 | - | - | - |
| 1982/83 | 771.93 | - | - | - |
| 1983/84 | 898.83 | - | - | - |
| 1984/85 | 588.03 | - | - | - |
| 1985/86 | 394.09 | - | - | - |
| 1986/87 | 323.20 | - | - | - |
| 1987/88 | 550.61 | - | - | - |
| 1988/89 | 710.92 | - | - | - |
| 1989/90 | 501.66 | - | - | - |
| 1990/91 | 375.62 | Confidential | - | - |
| 1991/92 | 431.49 | Confidential | - | - |
| 1992/93 | 583.51 | Confidential | - | - |
| 1993/94 | 316.64 | Confidential | 0.60 | 40.09 |
| 1994/95 | 89.34 | Confidential | 1.36 | 10.34 |
| 1995/96 | 17.66 | 22.98 | 2.63 | 6.93 |
| 1996/97 | 0.00 | 2.71 | 1.30 | 20.26 |
| 1997/98 | 0.00 | 0.42 | 1.73 | 5.31 |
| 1998/99 | 2.68 | 3.48 | 4.60 | 20.65 |
| 1999/00 | 0.00 | 0.46 | 17.13 | 12.69 |
| 2000/01 | 34.73 | 0.83 | 1.22 | 6.30 |
| 2001/02 | 69.84 | 16.09 | 2.42 | 27.01 |
| 2002/03 | 229.36 | 21.65 | 5.12 | 33.12 |
| 2003/04 | 217.32 | 17.08 | 1.62 | 4.15 |
| 2004/05 | 0.00 | 1.07 | 0.36 | 5.86 |
| 2005/06 | 0.00 | 0.11 | 1.61 | 1.07 |
| 2006/07 | 0.00 | 0.22 | 3.08 | 0.28 |
| 2007/08 | 0.00 | 1.36 | 7.70 | 1.19 |
| 2008/09 | 0.00 | 0.15 | 4.89 | 4.67 |
| 2009/10 | 0.00 | 0.39 | 0.14 | 6.40 |
| 2010/11 | 0.00 | 2.07 | 0.04 | 1.99 |
| 2011/12 | 0.00 | 0.49 | 1.19 | 0.82 |
| 2012/13 | 0.00 | 0.44 | 0.01 | 0.24 |
| 2013/14 | 0.00 | 1.46 | 0.01 | 0.04 |
| 2014/15 | 0.00 | 0.28 | 0.00 | 0.11 |
| 2015/16 | 0.00 | 0.00 | 0.03 | 1.46 |
| 2016/17 | 0.00 | 0.23 | 0.00 | 0.17 |



Figure 1. Aleutian Islands, Area O, red and golden king crab management area (from Baechler and Cook 2014, updated to show boundaries of the Adak and Petrel Districts for red king crab as established by the Alaska Board of Fisheries in March 2014).


Figure 2. Retained catch (t) in the Western Aleutian Islands red king crab fishery, 1985/861995/96 by 1-degree longitude grouping, summarized from fish ticket catch by state statistical area landing data.


Figure 3. Retained catch ( $\mathbf{t}$ ) in the Western Aleutian Islands red king crab fishery, 1960/612016/17 (catch is for the area west of $172^{\circ} \mathrm{W}$ longitude during 1960/61-1983/84 and for the area west of $171^{\circ} \mathrm{W}$ longitude during 1984/85-2016/17; see Table 1a).

$\square 171 \mathrm{E}-179 \mathrm{E}$-179E-179 W - 171 W -179 W
Figure 4. Annual retained catch ( $\mathbf{t}$ ) in the Western Aleutian Islands red king crab fishery during 1985/86-1995/96, partitioned into three longitudinal zones: $171^{\circ} \mathrm{W}$ longitude to $179^{\circ}$ W longitude (white bars); $179^{\circ} \mathrm{W}$ longitude to $179^{\circ} \mathrm{E}$ longitude (black bars); and $179^{\circ}$ E longitude to $171^{\circ} \mathrm{E}$ longitude.


Figure 5. Map of federal groundfish fishery reporting areas for the Bering Sea and Aleutian Islands. Areas 541, 542, and 543 are used to obtain data on discarded catch of Western Aleutian Islands red king crab during groundfish fisheries (from http://www.alaskafisheries.noaa.gov/rr/figures/fig1.pdf).


Figure 6. Retained catch (number of crab) and CPUE (number of retained crab per pot lift) in the western Aleutian Islands red king crab fishery, 1972/73-2016/17 (from Table 1a). Data for 1972/73-1983/84 are for the area west of $172^{\circ} \mathrm{W}$ longitude; data for 1984/851997/98, 1999/00, and 2004/05-2016/17 are for the area west of $171^{\circ} \mathrm{W}$ longitude; data for 1998/99 are for the area west of $174^{\circ} \mathrm{W}$ longitude; and data for 2000/01$2003 / 04$ are for the area between $179^{\circ} \mathrm{W}$ longitude and $179^{\circ} \mathrm{E}$ longitude.


Figure 7. Bootstrapped estimate of the sampling distribution of the recommended 2016/2017 Tier 5 OFL (total-catch, t) for the Western Aleutian Islands red king crab stock; histogram in left column, cumulative distribution in right column.

Appendix A1. Summary of retained catch size frequency data available from Western Aleutian Islands directed red king crab fishery, 1960/61-2015/16.

| Crab fishing year | N |
| :---: | :---: |
| 1960/61 | 0 |
| 1961/62 | 386 |
| 1962/63 | 661 |
| 1963/64 | 0 |
| 1964/65 | 1,285 |
| 1965/66 | 423 |
| 1966/67 | 0 |
| 1967/68 | 0 |
| 1968/69 | 0 |
| 1969/70 | 0 |
| 1970/71 | 0 |
| 1971/72 | 0 |
| 1972/73 | 10,043 |
| 1973/74 | 9,789 |
| 1974/75 | 2,609 |
| 1975/76 | 680 |
| 1976/77 | 0 |
| 1977/78 | 666 |
| 1978/79 | 1,485 |
| 1979/80 | 963 |
| 1980/81 | 2,537 |
| 1981/82 | 2,175 |
| 1982/83 | 6,287 |
| 1983/84 | 3,806 |
| 1984/85 | 1,805 |
| 1985/86 | 1,217 |
| 1986/87 | 422 |
| 1987/88 | 441 |
| 1988/89 | 4,860 |
| 1989/90 | 12,405 |
| 1990/91 | 9,406 |
| 1991/92 | 8,306 |
| 1992/93 | 5,195 |
| 1993/94 | 4,426 |
| 1994/95 | 1,037 |
| 1995/96 | 978 |
| 1996/97-1997/98 | Closed |
| 1998/99 | 0 |
| 1999/00 | Closed |
| 2000/01 | 460 |
| 2001/02 | 589 |
| 2002/03 | 2,056 |
| 2003/04 | 2,381 |
| 2004/05-2016/17 | Closed |

Appendix A2. Available retained catch size frequency sample data 1961/62-1979/80 western Aleutian Islands directed red king crab fishery. Page 1 of 3.

| CL (mm) | 1961/62 | 1962/63 | 1964/65 | 1965/66 | 1972/73 | 1973/74 | 1974/75 | 1975/76 | 1977/78 | 1978/79 | 1979/80 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 98 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 99 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 101 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 103 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 104 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 105 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 106 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 107 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 108 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 109 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 111 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 112 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 113 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 114 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 115 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 116 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 117 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 118 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 119 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 120 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 121 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 122 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 123 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 124 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 125 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 126 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 127 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 128 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 129 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 130 | 0 | 7 | 0 | 0 | 3 | 1 | 0 | 0 | 0 | 3 | 0 |
| 131 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| 132 | 0 | 1 | 0 | 0 | 1 | 7 | 6 | 1 | 0 | 1 | 1 |
| 133 | 0 | 3 | 0 | 0 | 13 | 15 | 9 | 1 | 0 | 7 | 4 |
| 134 | 0 | 3 | 2 | 0 | 22 | 24 | 15 | 0 | 1 | 4 | 1 |
| 135 | 0 | 5 | 0 | 0 | 52 | 58 | 31 | 7 | 0 | 12 | 9 |
| 136 | 0 | 4 | 0 | 1 | 91 | 107 | 30 | 7 | 5 | 13 | 3 |
| 137 | 0 | 3 | 2 | 0 | 179 | 174 | 52 | 17 | 11 | 37 | 8 |

Appendix A2. Page 2 of 3.

| CL (mm) | 1961/62 | 1962/63 | 1964/65 | 1965/66 | 1972/73 | 1973/74 | 1974/75 | 1975/76 | 1977/78 | 1978/79 | 1979/80 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 138 | 0 | 3 | 4 | 0 | 313 | 281 | 114 | 20 | 16 | 40 | 9 |
| 139 | 0 | 6 | 3 | 1 | 267 | 295 | 103 | 22 | 15 | 38 | 15 |
| 140 | 0 | 9 | 1 | 2 | 434 | 362 | 119 | 37 | 19 | 45 | 28 |
| 141 | 0 | 11 | 2 | 1 | 384 | 403 | 102 | 31 | 17 | 53 | 15 |
| 142 | 0 | 9 | 3 | 0 | 476 | 445 | 150 | 46 | 29 | 65 | 33 |
| 143 | 0 | 8 | 3 | 2 | 532 | 462 | 136 | 44 | 35 | 71 | 32 |
| 144 | 0 | 6 | 7 | 1 | 473 | 497 | 112 | 49 | 35 | 52 | 32 |
| 145 | 2 | 7 | 14 | 1 | 547 | 549 | 109 | 37 | 30 | 82 | 49 |
| 146 | 2 | 15 | 10 | 4 | 508 | 514 | 119 | 31 | 16 | 63 | 39 |
| 147 | 0 | 5 | 9 | 7 | 552 | 488 | 114 | 25 | 35 | 80 | 43 |
| 148 | 2 | 3 | 11 | 4 | 589 | 478 | 101 | 46 | 41 | 101 | 36 |
| 149 | 2 | 10 | 17 | 4 | 477 | 488 | 79 | 29 | 15 | 64 | 50 |
| 150 | 8 | 9 | 23 | 5 | 524 | 490 | 84 | 28 | 24 | 59 | 38 |
| 151 | 4 | 12 | 10 | 1 | 393 | 432 | 65 | 21 | 17 | 58 | 46 |
| 152 | 10 | 16 | 20 | 7 | 436 | 409 | 93 | 21 | 21 | 69 | 40 |
| 153 | 0 | 13 | 29 | 9 | 439 | 367 | 69 | 13 | 12 | 45 | 32 |
| 154 | 10 | 11 | 33 | 6 | 324 | 318 | 76 | 17 | 17 | 53 | 37 |
| 155 | 2 | 13 | 42 | 8 | 330 | 337 | 67 | 14 | 27 | 56 | 49 |
| 156 | 2 | 19 | 32 | 9 | 272 | 285 | 60 | 10 | 24 | 37 | 35 |
| 157 | 4 | 22 | 28 | 6 | 203 | 229 | 63 | 11 | 12 | 43 | 36 |
| 158 | 12 | 10 | 39 | 16 | 226 | 234 | 62 | 17 | 17 | 31 | 36 |
| 159 | 10 | 17 | 34 | 14 | 147 | 174 | 51 | 6 | 11 | 24 | 22 |
| 160 | 18 | 13 | 38 | 15 | 180 | 146 | 53 | 5 | 20 | 25 | 30 |
| 161 | 18 | 12 | 30 | 10 | 127 | 129 | 40 | 7 | 6 | 23 | 21 |
| 162 | 8 | 16 | 32 | 17 | 120 | 145 | 45 | 8 | 17 | 14 | 21 |
| 163 | 8 | 7 | 44 | 15 | 99 | 93 | 39 | 10 | 15 | 17 | 12 |
| 164 | 4 | 13 | 34 | 9 | 74 | 70 | 33 | 5 | 11 | 13 | 15 |
| 165 | 6 | 16 | 54 | 17 | 46 | 56 | 31 | 5 | 6 | 15 | 16 |
| 166 | 16 | 18 | 39 | 13 | 51 | 43 | 25 | 6 | 6 | 12 | 14 |
| 167 | 10 | 13 | 55 | 24 | 40 | 37 | 21 | 4 | 7 | 16 | 5 |
| 168 | 24 | 13 | 47 | 19 | 24 | 30 | 19 | 5 | 15 | 7 | 8 |
| 169 | 10 | 20 | 36 | 12 | 14 | 29 | 10 | 3 | 12 | 9 | 13 |
| 170 | 22 | 20 | 28 | 23 | 16 | 18 | 16 | 2 | 7 | 2 | 10 |
| 171 | 18 | 14 | 43 | 16 | 9 | 15 | 6 | 2 | 8 | 6 | 3 |
| 172 | 16 | 15 | 36 | 18 | 10 | 9 | 13 | 2 | 5 | 5 | 4 |
| 173 | 8 | 9 | 42 | 12 | 6 | 7 | 7 | 0 | 8 | 4 | 1 |
| 174 | 8 | 12 | 25 | 8 | 5 | 7 | 5 | 2 | 3 | 0 | 1 |
| 175 | 22 | 27 | 30 | 14 | 4 | 6 | 7 | 3 | 7 | 1 | 3 |
| 176 | 14 | 19 | 30 | 11 | 1 | 3 | 3 | 0 | 1 | 3 | 3 |
| 177 | 12 | 10 | 22 | 9 | 4 | 5 | 1 | 0 | 1 | 0 | 1 |
| 178 | 14 | 17 | 23 | 12 | 2 | 6 | 4 | 1 | 4 | 1 | 0 |

## Appendix A2. Page 3 of 3.

| CL (mm) | 1961/62 | 1962/63 | 1964/65 | 1965/66 | 1972/73 | 1973/74 | 1974/75 | 1975/76 | 1977/78 | 1978/79 | 1979/80 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 179 | 0 | 11 | 21 | 10 | 2 | 2 | 4 | 1 | 2 | 0 | 0 |
| 180 | 10 | 13 | 20 | 9 | 0 | 3 | 4 | 1 | 0 | 2 | 1 |
| 181 | 2 | 14 | 13 | 3 | 0 | 1 | 1 | 0 | 0 | 0 | 2 |
| 182 | 4 | 11 | 23 | 6 | 0 | 2 | 2 | 0 | 1 | 0 | 0 |
| 183 | 8 | 8 | 13 | 3 | 0 | 1 | 2 | 0 | 1 | 1 | 0 |
| 184 | 4 | 7 | 16 | 1 | 1 | 0 | 3 | 0 | 0 | 1 | 1 |
| 185 | 6 | 2 | 10 | 3 | 0 | 1 | 1 | 0 | 1 | 0 | 0 |
| 186 | 2 | 4 | 15 | 1 | 0 | 0 | 5 | 0 | 0 | 0 | 0 |
| 187 | 8 | 8 | 11 | 1 | 0 | 0 | 4 | 0 | 0 | 0 | 0 |
| 188 | 6 | 4 | 10 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| 189 | 0 | 5 | 11 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 190 | 2 | 4 | 12 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| 191 | 0 | 3 | 8 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 192 | 0 | 2 | 8 | 0 | 0 | 1 | 3 | 0 | 0 | 0 | 0 |
| 193 | 0 | 1 | 5 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 194 | 0 | 1 | 5 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| 195 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 196 | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 197 | 0 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 198 | 0 | 0 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| 199 | 2 | 1 | 3 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 |
| 200 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 201 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 202 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 203 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 204 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 205 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 206 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 207 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 208 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 209 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 210 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 386 | 661 | 1,285 | 423 | 10,043 | 9,789 | 2,609 | 680 | 666 | 1,485 | 963 |

Appendix A3. Available retained catch size frequency sample data 1980/81-1989/90 Western Aleutian Islands directed red king crab fishery. Page 1 of 3.

| CL (mm) | 1980/81 | 1981/82 | 1982/83 | 1983/84 | 1984/85 | 1985/86 | 1986/87 | 1987/88 | 1988/89 | 1989/90 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 98 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 99 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 101 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 103 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 104 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 105 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 106 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 107 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 108 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 109 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 111 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 112 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 113 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 114 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 115 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 116 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 117 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 118 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 119 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 120 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 121 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 122 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| 123 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 124 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 125 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 126 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 127 | 1 | 1 | 1 | 0 | 0 | 3 | 0 | 0 | 0 | 2 |
| 128 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 0 |
| 129 | 2 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 1 |
| 130 | 3 | 4 | 2 | 3 | 1 | 2 | 1 | 1 | 5 | 8 |
| 131 | 4 | 3 | 8 | 2 | 3 | 7 | 0 | 3 | 7 | 29 |
| 132 | 6 | 6 | 23 | 8 | 6 | 9 | 2 | 2 | 5 | 51 |
| 133 | 15 | 11 | 34 | 10 | 6 | 19 | 2 | 5 | 18 | 88 |
| 134 | 25 | 11 | 55 | 17 | 9 | 10 | 5 | 8 | 19 | 161 |
| 135 | 34 | 25 | 70 | 25 | 19 | 27 | 3 | 10 | 38 | 280 |
| 136 | 53 | 51 | 92 | 27 | 21 | 18 | 8 | 8 | 55 | 276 |
| 137 | 72 | 45 | 145 | 32 | 33 | 23 | 12 | 11 | 92 | 370 |

## Appendix A3. Page 2 of 3.

| CL (mm) | 1980/81 | 1981/82 | 1982/83 | 1983/84 | 1984/85 | 1985/86 | 1986/87 | 1987/88 | 1988/89 | 1989/90 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 138 | 89 | 76 | 187 | 49 | 39 | 29 | 10 | 10 | 108 | 497 |
| 139 | 106 | 55 | 184 | 49 | 30 | 39 | 10 | 11 | 121 | 532 |
| 140 | 119 | 76 | 221 | 74 | 30 | 48 | 16 | 17 | 134 | 631 |
| 141 | 99 | 78 | 224 | 58 | 46 | 48 | 16 | 13 | 118 | 529 |
| 142 | 128 | 104 | 256 | 97 | 41 | 59 | 16 | 20 | 157 | 562 |
| 143 | 127 | 110 | 323 | 94 | 57 | 38 | 13 | 18 | 161 | 514 |
| 144 | 96 | 100 | 226 | 73 | 39 | 33 | 14 | 21 | 139 | 494 |
| 145 | 115 | 105 | 224 | 94 | 56 | 28 | 25 | 21 | 179 | 559 |
| 146 | 95 | 112 | 208 | 107 | 49 | 21 | 14 | 25 | 164 | 460 |
| 147 | 103 | 97 | 250 | 99 | 47 | 36 | 14 | 17 | 186 | 460 |
| 148 | 98 | 93 | 269 | 128 | 55 | 36 | 11 | 10 | 158 | 483 |
| 149 | 94 | 79 | 186 | 94 | 36 | 28 | 14 | 17 | 170 | 399 |
| 150 | 85 | 100 | 249 | 122 | 61 | 42 | 16 | 21 | 177 | 451 |
| 151 | 76 | 82 | 172 | 87 | 47 | 27 | 13 | 18 | 146 | 283 |
| 152 | 59 | 98 | 215 | 121 | 48 | 24 | 13 | 5 | 191 | 371 |
| 153 | 66 | 75 | 234 | 134 | 58 | 27 | 8 | 17 | 170 | 361 |
| 154 | 59 | 72 | 184 | 104 | 40 | 30 | 14 | 16 | 152 | 292 |
| 155 | 45 | 73 | 176 | 104 | 58 | 39 | 12 | 13 | 147 | 370 |
| 156 | 53 | 63 | 152 | 99 | 44 | 24 | 15 | 12 | 129 | 265 |
| 157 | 59 | 59 | 164 | 111 | 41 | 31 | 6 | 7 | 132 | 244 |
| 158 | 32 | 54 | 162 | 117 | 42 | 35 | 10 | 17 | 132 | 256 |
| 159 | 41 | 27 | 131 | 70 | 30 | 36 | 14 | 6 | 105 | 232 |
| 160 | 40 | 34 | 126 | 100 | 62 | 31 | 7 | 5 | 128 | 233 |
| 161 | 30 | 33 | 99 | 93 | 30 | 17 | 6 | 9 | 105 | 190 |
| 162 | 42 | 37 | 89 | 83 | 53 | 34 | 6 | 7 | 98 | 178 |
| 163 | 31 | 21 | 106 | 94 | 52 | 23 | 6 | 4 | 97 | 185 |
| 164 | 40 | 24 | 87 | 77 | 26 | 34 | 7 | 9 | 108 | 134 |
| 165 | 43 | 18 | 86 | 88 | 50 | 24 | 5 | 8 | 92 | 153 |
| 166 | 27 | 7 | 69 | 161 | 38 | 18 | 5 | 5 | 72 | 92 |
| 167 | 32 | 11 | 90 | 80 | 41 | 17 | 3 | 2 | 71 | 92 |
| 168 | 29 | 5 | 86 | 73 | 45 | 19 | 2 | 3 | 70 | 76 |
| 169 | 21 | 1 | 46 | 51 | 32 | 18 | 5 | 2 | 57 | 85 |
| 170 | 20 | 11 | 45 | 69 | 39 | 12 | 5 | 2 | 65 | 85 |
| 171 | 18 | 3 | 37 | 47 | 22 | 3 | 3 | 1 | 45 | 65 |
| 172 | 19 | 9 | 42 | 59 | 30 | 12 | 1 | 1 | 50 | 51 |
| 173 | 15 | 1 | 45 | 57 | 24 | 7 | 2 | 1 | 32 | 48 |
| 174 | 13 | 3 | 41 | 44 | 30 | 10 | 3 | 0 | 48 | 32 |
| 175 | 12 | 3 | 28 | 36 | 24 | 5 | 1 | 0 | 48 | 35 |
| 176 | 7 | 1 | 20 | 40 | 17 | 7 | 3 | 0 | 28 | 23 |
| 177 | 9 | 2 | 20 | 39 | 17 | 2 | 0 | 0 | 19 | 26 |
| 178 | 6 | 0 | 19 | 34 | 18 | 7 | 1 | 0 | 21 | 18 |

## Appendix A3. Page 3 of 3.

| CL (mm) | 1980/81 | 1981/82 | 1982/83 | 1983/84 | 1984/85 | 1985/86 | 1986/87 | 1987/88 | 1988/89 | 1989/90 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 179 | 8 | 1 | 13 | 33 | 12 | 1 | 6 | 0 | 14 | 19 |
| 180 | 2 | 2 | 14 | 28 | 8 | 4 | 2 | 0 | 13 | 16 |
| 181 | 3 | 0 | 10 | 15 | 7 | 1 | 0 | 0 | 15 | 9 |
| 182 | 2 | 0 | 12 | 23 | 4 | 5 | 1 | 1 | 5 | 4 |
| 183 | 2 | 0 | 4 | 22 | 6 | 2 | 2 | 0 | 7 | 12 |
| 184 | 1 | 0 | 8 | 27 | 3 | 5 | 3 | 0 | 6 | 4 |
| 185 | 1 | 0 | 6 | 21 | 5 | 1 | 2 | 0 | 5 | 5 |
| 186 | 2 | 1 | 2 | 14 | 3 | 0 | 0 | 0 | 5 | 2 |
| 187 | 0 | 0 | 1 | 14 | 1 | 2 | 2 | 1 | 4 | 2 |
| 188 | 0 | 1 | 4 | 10 | 2 | 2 | 1 | 0 | 7 | 3 |
| 189 | 1 | 0 | 2 | 11 | 2 | 3 | 0 | 0 | 2 | 4 |
| 190 | 1 | 0 | 0 | 13 | 4 | 1 | 0 | 0 | 1 | 4 |
| 191 | 0 | 0 | 1 | 10 | 1 | 1 | 0 | 0 | 1 | 2 |
| 192 | 0 | 0 | 0 | 2 | 0 | 3 | 0 | 0 | 1 | 0 |
| 193 | 1 | 0 | 0 | 10 | 0 | 2 | 1 | 0 | 0 | 2 |
| 194 | 0 | 0 | 1 | 4 | 0 | 2 | 1 | 0 | 1 | 0 |
| 195 | 0 | 0 | 0 | 6 | 2 | 0 | 1 | 0 | 0 | 1 |
| 196 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| 197 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 198 | 0 | 0 | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 1 |
| 199 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 200 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 201 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 202 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 203 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 204 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| 205 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 206 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 207 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 208 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 209 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 210 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 2,537 | 2,175 | 6,287 | 3,806 | 1,805 | 1,217 | 422 | 441 | 4,860 | 12,405 |

Appendix A4. Available retained catch size frequency sample data 1990/91-2003/04 Western Aleutian Islands directed red king crab fishery. Page 1 of 3.

| CL (mm) | 1990/91 | 1991/92 | 1992/93 | 1993/94 | 1994/95 | 1995/96 | 2000/01 | 2001/02 | 2002/03 | 2003/04 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 98 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 99 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 101 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 102 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 103 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 104 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 105 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 106 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 107 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 108 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 109 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 111 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 112 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 113 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 114 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 115 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 116 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 117 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 118 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 119 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 120 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 121 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 122 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 123 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 124 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 125 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 126 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 127 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 128 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 129 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 130 | 4 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| 131 | 9 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 |
| 132 | 12 | 3 | 6 | 1 | 2 | 4 | 0 | 0 | 0 | 0 |
| 133 | 22 | 13 | 6 | 4 | 1 | 3 | 0 | 0 | 0 | 0 |
| 134 | 46 | 47 | 19 | 9 | 5 | 8 | 0 | 0 | 0 | 0 |
| 135 | 108 | 65 | 47 | 15 | 8 | 9 | 0 | 0 | 1 | 0 |
| 136 | 152 | 115 | 59 | 15 | 10 | 11 | 0 | 3 | 1 | 1 |
| 137 | 223 | 173 | 76 | 32 | 15 | 17 | 0 | 2 | 5 | 1 |

## Appendix A4. Page 2 of 3.

| CL (mm) | 1990/91 | 1991/92 | 1992/93 | 1993/94 | 1994/95 | 1995/96 | 2000/01 | 2001/02 | 2002/03 | 2003/04 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 138 | 310 | 211 | 118 | 35 | 11 | 27 | 0 | 3 | 6 | 1 |
| 139 | 381 | 255 | 101 | 41 | 18 | 24 | 1 | 2 | 2 | 0 |
| 140 | 391 | 289 | 186 | 63 | 12 | 24 | 0 | 4 | 7 | 3 |
| 141 | 455 | 315 | 156 | 89 | 16 | 31 | 1 | 5 | 14 | 4 |
| 142 | 467 | 341 | 184 | 92 | 24 | 32 | 1 | 9 | 10 | 3 |
| 143 | 449 | 392 | 216 | 102 | 20 | 23 | 2 | 8 | 13 | 6 |
| 144 | 521 | 342 | 206 | 114 | 23 | 32 | 2 | 11 | 15 | 5 |
| 145 | 483 | 359 | 220 | 148 | 16 | 32 | 3 | 7 | 18 | 11 |
| 146 | 456 | 356 | 229 | 162 | 27 | 38 | 4 | 7 | 30 | 8 |
| 147 | 469 | 390 | 244 | 155 | 29 | 24 | 3 | 7 | 18 | 12 |
| 148 | 408 | 304 | 221 | 183 | 31 | 27 | 6 | 16 | 18 | 9 |
| 149 | 428 | 319 | 160 | 136 | 20 | 30 | 7 | 10 | 30 | 8 |
| 150 | 386 | 364 | 251 | 177 | 39 | 24 | 12 | 13 | 26 | 19 |
| 151 | 315 | 288 | 145 | 186 | 29 | 25 | 15 | 16 | 35 | 22 |
| 152 | 333 | 344 | 233 | 169 | 31 | 29 | 19 | 25 | 43 | 17 |
| 153 | 292 | 369 | 170 | 180 | 38 | 18 | 20 | 22 | 41 | 27 |
| 154 | 288 | 320 | 145 | 180 | 19 | 33 | 12 | 28 | 63 | 36 |
| 155 | 311 | 295 | 164 | 174 | 28 | 34 | 14 | 18 | 58 | 39 |
| 156 | 223 | 280 | 165 | 182 | 30 | 18 | 22 | 14 | 74 | 46 |
| 157 | 203 | 294 | 148 | 154 | 25 | 30 | 17 | 24 | 74 | 33 |
| 158 | 169 | 211 | 158 | 167 | 30 | 37 | 12 | 23 | 81 | 52 |
| 159 | 167 | 199 | 86 | 154 | 25 | 23 | 20 | 20 | 97 | 56 |
| 160 | 136 | 149 | 142 | 154 | 43 | 23 | 26 | 19 | 81 | 78 |
| 161 | 106 | 121 | 88 | 149 | 28 | 21 | 16 | 15 | 69 | 64 |
| 162 | 103 | 115 | 92 | 114 | 33 | 27 | 22 | 25 | 84 | 72 |
| 163 | 77 | 118 | 96 | 115 | 34 | 16 | 15 | 30 | 78 | 57 |
| 164 | 78 | 80 | 76 | 117 | 30 | 23 | 26 | 25 | 100 | 98 |
| 165 | 78 | 66 | 79 | 95 | 21 | 22 | 20 | 13 | 75 | 115 |
| 166 | 48 | 51 | 52 | 85 | 33 | 17 | 22 | 17 | 91 | 95 |
| 167 | 59 | 56 | 74 | 77 | 24 | 29 | 21 | 24 | 82 | 105 |
| 168 | 34 | 47 | 69 | 68 | 24 | 33 | 13 | 18 | 80 | 99 |
| 169 | 33 | 43 | 29 | 70 | 16 | 13 | 20 | 13 | 53 | 99 |
| 170 | 25 | 33 | 52 | 39 | 22 | 15 | 9 | 13 | 71 | 126 |
| 171 | 29 | 33 | 33 | 47 | 13 | 10 | 16 | 6 | 58 | 87 |
| 172 | 24 | 20 | 37 | 30 | 14 | 16 | 12 | 13 | 60 | 119 |
| 173 | 14 | 19 | 23 | 19 | 17 | 10 | 4 | 18 | 41 | 99 |
| 174 | 17 | 15 | 20 | 27 | 13 | 6 | 7 | 5 | 44 | 86 |
| 175 | 18 | 12 | 19 | 23 | 8 | 11 | 6 | 9 | 49 | 92 |
| 176 | 11 | 11 | 19 | 12 | 13 | 4 | 3 | 4 | 35 | 62 |
| 177 | 4 | 5 | 12 | 19 | 13 | 2 | 5 | 4 | 27 | 68 |
| 178 | 6 | 3 | 12 | 7 | 4 | 5 | 0 | 2 | 20 | 50 |

## Appendix A4. Page 3 of 3.

| CL (mm) | 1990/91 | 1991/92 | 1992/93 | 1993/94 | 1994/95 | 1995/96 | 2000/01 | 2001/02 | 2002/03 | 2003/04 |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 179 | 7 | 7 | 11 | 9 | 3 | 1 | 1 | 6 | 20 | 53 |
| 180 | 1 | 8 | 9 | 5 | 6 | 1 | 2 | 2 | 20 | 45 |
| 181 | 1 | 13 | 6 | 5 | 7 | 1 | 0 | 2 | 9 | 44 |
| 182 | 2 | 5 | 5 | 6 | 3 | 1 | 0 | 3 | 12 | 37 |
| 183 | 0 | 8 | 3 | 2 | 3 | 1 | 0 | 2 | 3 | 22 |
| 184 | 2 | 2 | 2 | 4 | 4 | 0 | 1 | 1 | 2 | 26 |
| 185 | 1 | 1 | 3 | 0 | 6 | 0 | 0 | 0 | 0 | 11 |
| 186 | 2 | 0 | 3 | 2 | 2 | 0 | 0 | 0 | 7 | 14 |
| 187 | 1 | 2 | 0 | 1 | 4 | 1 | 0 | 1 | 1 | 13 |
| 188 | 0 | 3 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 |
| 189 | 1 | 1 | 1 | 1 | 5 | 0 | 0 | 0 | 0 | 6 |
| 190 | 0 | 1 | 1 | 1 | 3 | 0 | 0 | 0 | 3 | 6 |
| 191 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 2 |
| 192 | 0 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 4 |
| 193 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 194 | 0 | 1 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 3 |
| 195 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 196 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 197 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 198 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 199 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 200 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 201 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 202 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 203 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 204 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 205 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 206 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 207 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 208 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 209 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 210 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 9,406 | 8,306 | 5,195 | 4,426 | 1,037 | 978 | 460 | 589 | 2,056 | 2,381 |

Appendix A5. Page 1 of 1. Plot of available retained catch size frequency sample data 1961/622003/04 western Aleutian Islands directed red king crab fishery (data listed in Appendices A2-A4).

Western Aleutian Islands Red King Crab


Carapace length (mm)

# ECONOMIC STATUS REPORT SUMMARY: 

BSAI CRAB FISHERIES, 2017

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## ECONOMIC STATUS REPORT SUMMARY: BSAI CRAB FISHERIES, 2017

The Bering Sea/Aleutian Islands (BSAI) crab fisheries managed under the North Pacific Fishery Management Council's Fishery Management Plan (FMP) are currently (as of calendar year 2016) prosecuted by an active fleet of 116 catcher vessels and two catcher processors, and landed and processed at 12 processing facilities throughout the region. Of the 10 crab stocks and 11 fisheries managed under the FMP ${ }^{1}$, seven fisheries were open to targeted fishing in 2016. After closure for the 2010/11 through 2012/13 seasons, the Bering Sea Tanner (BST) crab fisheries opened for targeted fishing for 2013/14 through 2015/16 seasons, but were subsequently closed for the 2016/17 season. ${ }^{2}$ Pribilof Islands red and blue king, and Western Aleutian red king crab stocks are currently designated overfished, as detailed in the assessments for these stocks. The Saint Matthew blue king (SMB) crab fishery was closed for the 2013/14 season under the State of Alaska's management strategy, reopened for the 2014/15 and 2015/16 seasons, and closed again for 2016/17.

This report provides a brief summary of key indicators of economic status and performance of BSAI crab fisheries for the 2012 through 2016 calendar year operations. The full Economic Status Report for BSAI Crab Fisheries, 2017 (Crab Economic SAFE, currently being updated for annual release in February, 2018) provides detailed information regarding production, sales, revenue, and price indices in the harvesting and processing sectors, income, employment, and demographics of labor in both sectors, capital and operating expenditures in the fishery, quota share lease and sale market activity, changes in distribution of quota holdings, productivity in the harvesting sector, U.S. imports and exports of king and Tanner crab, price forecasts, performance metrics for catch share programs, and other information regarding data collection and ongoing economic and social science research related the BSAI crab fisheries and related communities. The following document summarizes three sets of primary indicators describing aggregate changes in gross volume and value of production, labor earnings and employment in the crab processing and harvesting sectors, and crab harvest quota leasing activity. Note that results presented below for 2016 calendar year fisheries are preliminary pending completion of data validation and additional analyses, and may be revised in the final update of the full Economic Status Report.

[^11]
## Fishery production and economic value

Harvest and processing sector production statistics by crab fishery, including ex-vessel and first wholesale output, estimated revenue, and average prices are shown in Table 1 for calendar years 2012 through 2016 and summarized in Figure 1. Across all fisheries managed under the BSAI Crab FMP, the total volume of ex-vessel landings commercially sold to processors during 2016 was 64 million pounds ( 29 thousand metric tons), a 30 percent decrease from the previous year. Processing sector finished production volume during 2016 was 42.3 million pounds ( 19.2 thousand metric tons) aggregated over all BSAI crab species and product forms, also declining 30 percent from the previous year. The effect of fishery closures and reduced production over all fisheries combined with offsetting price increases produced an aggregate 3.6 percent decrease in total ex-vessel revenues over all fisheries in 2016, totaling $\$ 259.3^{3}$ million for the year, and with aggregate first wholesale revenues declining by 3.9 percent to $\$ 349$ million.

As of 2016, allowable catch quantities in all BSAI crab fisheries currently open to targeted fishing are fully exploited ( $>98 \%$ of total allocation landed), and recent inter-annual variation in commercial landings largely reflects the results of stock assessments and the State of Alaska's specified catch limits rather than changes in fishing capacity or exploitation rate. The decrease in aggregate production during 2016 reflected declines across nearly all fisheries compared to 2015, with the total catch of 39.6 million pounds ( 17.6 thousand mt ) landed in the Bering Sea snow crab (BSS) fishery representing the largest decline in both absolute and proportional (-35\%) terms. Landings in the BST fisheries decreased 30 percent from 2015 levels, to 10.6 million pounds ( 4.7 thousand mt ), and landings of 8.4 million pounds ( 3.8 metric tons) in the Bristol Bay red king crab (BBR) fishery declined 14 percent. The 5.6 million pounds ( 2.5 metic tons) landed in the Aleutian Islands golden king crab (AIG) fisheries during 2016 represented a relatively modest reduction of 3.4 percent from 2015.

[^12]

Source: ADFEG fish tickets, eLandings, CFEC pricing, ADFEG Commercial Operator's Annual Report, NMFS AFSC BSAI Crab Economic Data Report (EDR) database. See Table 1 footnotes for details.
(a) Revenue, (b) Volume, and (c) Weighted Average Price, 2011-2015; gross revenue and production volume by sector are presented in the upper pair of panels by individual crab fishery for comparison of within-fishery variation over time, and summarized over all fisheries in the lower panels to illustrate the variation in aggregate values and relative contribution of each fishery over time. Figure does not display information for PIG fishery due to confidentiality. See Table 1 footnotes for data sources and details.

Similar to ex-vessel production, the 30 percent decrease in processing sector output aggregated over all active crab fisheries was driven in the largest part by the 35 percent decline to 25.9 million pounds ( 11.8 thousand mt ) of finished production in the BSS fishery, and a 30 percent decline in finished volume in the BST fisheries to 7.2 million pounds ( 3.2 thousand mt ).

Increases in average prices reported for both sectors continued for a second year across all crab fisheries during 2016, substantially offsetting production declines in the respective fisheries, resulting in increased ex-vessel and wholesale revenues in both AIG and BBR fisheries and partially mitigating production effects in BSS and BST fisheries (Table 1). Average BBR ex-vessel price increased $32 \%$ per landed pound to $\$ 10.67$, and average first wholesale price increased 26 percent to $\$ 18.27$ per finished pound, while AIG prices increased to o $\$ 5.38$ per-pound ( $+23 \%$ ) ex-vessel and to $\$ 9.38$ $(+28 \%)$ first wholesale. Prices in the BST fishery increased to $\$ 3.02$ ex-vessel $(+15 \%)$ and $\$ 6.31$ $(+17 \%)$ at first wholesale, and to $\$ 2.73$ average ex-vessel $(+33 \%)$, and $\$ 5.97$ average first wholesale $(+36 \%)$ per-pound.

The combined effect of declining production levels due to catch allocations and fishery closures with market-driven price increases across crab fisheries produced an overall 3.6 percent decrease in gross ex-vessel revenues and 3.9 percent revenue decline in the processing sector for 2016, with aggregate gross ex-vessel revenues of $\$ 259$ million and first wholesale revenues of $\$ 349$ million. The relatively large proportional price increases and production declines in both sectors of the BSS fishery produced gross revenue of $\$ 108$ million in the harvest sector ( $-14 \%$ ) compared to 2015 , and $\$ 155$ million in the processing sector $(-11 \%)$. The BST fishery produced gross revenue of $\$ 31.6$ million ex-vessel and $\$ 45$ million in the processing sector, both declining by 19 percent from the previous year. In contrast, gross ex-vessel earnings increased by 13 percent to $\$ 89.6$ million in the BBR fishery, and by 8 percent to $\$ 103.7$ million first wholesale, while ex-vessel revenues in the AIG fisheries increased by 19 percent to $\$ 30.1$ million and by 24 percent in the processing sector to $\$ 45.4$ million. The proportional variation in aggregate gross revenue across crab fisheries from 2015 to 2016 was unexceptional relative to inter-annual variation over the last 15 years in the historically volatile crab fisheries; longer time series for these and other measures of production and earnings performance in crab fisheries are presented and more fully examined in the BSAI Crab Economic Status Report currently being updated for 2017 (to be released in February, 2018).

## Employment and Income

A summary of selected indicators from the most recent employment data available for Crab Rationalization (CR) program fisheries is provided in Table $2^{4}$ and depicted graphically in Figure 2. Crab EDR data for calendar year 2016 are reported where available, but note that results are preliminary pending completion of data validation and additional analyses.

The number of vessels operating in one or more of the CR fisheries in 2016 declined from 82 to 80 . The active fleet in the BBR and BSS fisheries were similarly reduced, to 63 and 68 , respectively, while 46 vessels participated in the BST fishery, 11 fewer compared to 2015 . Based on the number of crew onboard reported by participating vessels during each fishery (averaged over crew size values reported in eLandings catch accounting records for crab vessels), there were an estimated 1,218 crew

[^13]positions in aggregate across all 80 vessels in CR fisheries in 2016, 114 fewer than the previous year, of which 69 were due to the smaller fleet in the BST fishery. ${ }^{5}$

[^14]Figure 2: Harvest and Processing Employment and Compensation, Selected Crab Fisheries, 2012-2016


Source: NMFS AFSC BSAI Crab Economic Data Report (EDR) database; ADFGG Shellfish Observer Program, Confidential Interview Form (CIF) database. See Table 2 footnotes for details.

Revenue-share payments to crab vessel crew members as a group totaled approximately $\$ 36$ million in 2016, with an additional $\$ 16$ million paid to vessel captains, both declining by approximately $5 \%$. ${ }^{6}$ Aggregate crew and captain earnings in the BSS fishery declined by 19 percent to $\$ 15.1$ million and decreased by 14 percent to $\$ 6.7$ million, respectively. Aggregate crew and captain earnings in the BBR fisheries increased Sexpryr-1, to $\$ 11.2$ million ( $+17 \%$ ) and $\$ 5$ million ( $+11 \%$ ), respectively. Crew and captain earnings in the BST fishery totaled $\$ 5.9$ million and $\$ 2.86$ million, respectively, nearly doubling the level of earnings in 2014.

Crab processing labor input at processing plants that received IFQ and CDQ crab landings in 2016 is estimated at 788 thousand labor hours, declining 33 percent from 2015, with the number of plants active over all CR fisheries reduced from 9 to 8 . Aggregate processing labor income generated across all CR fisheries during 2016 was $\$ 9.6$ million, 29 percent less than the previous year. Processing labor pay statistics reflect increasing hourly processing wage rates across all fisheries beginning in 2014 associated with annual incremental increases in Alaska state minimum wage. Median plant-level hourly wage rate increased by 11 percent from 2015, to $\$ 11.93$ over all CR fisheries.

## IFQ Leasing

This report provides results from the BSAI Crab Rationalization Economic Data Report (EDR) program collection of crab harvest quota allocation lease data associated with 2012 through 2016 calendar year crab fishing activity. Table 3 and Figure 3 shows aggregated results for crab fishing quota lease volume (in pounds) and cost reported for crab vessels active during the most recent five calendar years for CR fisheries, by fishing quota type category, including total quantities summed over all reporting vessels, and average values (both median and mean) for volume and cost of leased quota per vessel, and average lease price paid (\$US per pound) and average lease rate (lease price as percentage of ex-vessel price) per vessel. Both median and arithmetic mean average value metrics are presented to provide information on the variation in reported values within each stratum, with the higher mean values shown indicating the presence of a subset of high-value data points in these data. Harvest quota types are categorized as the following: catcher vessel owner (CVO) Class A IFQ; catcher vessel owner Class B IFQ and catcher/processor owner (CPO) IFQ; catcher vessel crew IFQ and catcher/processor crew IFQ, and community development quota (CDQ).

The number of vessels reporting quota leases in the 2016 BBR fishery range from 50 vessels leasing CVO Class A shares to 5 vessels leasing CDQ shares (out of 63 crab vessels active during the 2016/17 BBR fishery), and from 54 vessels leasing CVO Class A BSS IFQ allocation to 7 vessels leasing CDQ allocation (out of 67 active vessels) in the BSS fishery. Total volume and cost over all vessels leasing the respective quota types during 2016 range from 4.43 million pounds and $\$ 29.7$ million for BBR CVO Class A IFQ, to 201 thousand pounds and $\$ 1.4$ million for BBR CVO and CPC crew IFQ allocation; BSS lease volume and cost ranged from 19.6 million pounds and $\$ 26$ million for CVO Class A IFQ to 925 thousand pounds and $\$ 1.3$ million for crew share IFQ allocation.

[^15]Figure 3: Crab Harvest Quota Lease Activity; Lease Volume, Price, and Rate, Selected Crab Fisheries, 2012-2016


Source: NMFS AFSC BSAI Crab Economic Data Report (EDR) database; ADFBG Shellfish Observer Program, Confidential Interview Form (CIF) database. See Table 3 footnotes for details.

Median vessel-level values ${ }^{7}$ for 2016 BBR quota leased volume and cost ranged from 121 thousand pounds and $\$ 846$ thousand per vessel for the five vessels leasing BBR CDQ allocation, 75 thousand

[^16]pounds and $\$ 494$ thousand for BBR CVO-A shares, and 4.0 thousand pounds and $\$ 34$ thousand for BBR CVO and CPO crew IFQ. BSS per-vessel averages ranged from 337 thousand pounds and $\$ 404$ thousand per vessel for BSS CVO- Class A allocation to 22 thousand pounds and $\$ 31$ thousand for BSS crew share allocation.

Average (median) lease prices and lease rates in the BBR fishery shown in Table 3 have remained quite stable over the three years for which data are available, varying slightly year-to-year and by quota type within fishery, and with inter-annual variation in price per pound corresponding to changes in ex-vessel prices. In the 2016 BBR fishery, median lease price ranged from $\$ 6.66$ per pound for BBR CVO Class A allocation ( $62 \%$ of ex-vessel value) to $\$ 7.02$ per pound (median $63 \%$ of ex-vessel value) for CDQ allocation. Median lease price and rate in the 2016 BSS fishery were least for CVO Class A IFQ at $\$ 1.32$ (median $46 \%$ of ex-vessel value), and $\$ 1.37-\$ 1.43$ for other allocation types (ranging from median $46 \%$ to $51 \%$ of ex-vessel price).

Table 1: BSAI Crab Harvesting and Processing Sector Output - Production Volume, Gross Revenue, and Average Price ${ }^{a}$


Continued on next page.

Table 1: Continued

|  | Harvesting Sector: Ex-Vessel Statistics ${ }^{a}$ |  |  |  |  |  |  |  | Processing Sector: First Wholesale Statistics ${ }^{b}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Year | Vessels | CFEC permits | Landed volume 1000t | Landed volume million lbs | Buyers | Gross <br> revenue <br> \$million | Average price \$/lb | Plants | Finished volume, $1000 t$ | Finished volume, million lbs | Gross <br> revenue <br> \$million | Average price \$/lb |
| PIG | 2012 | 1 | 1 | * | * | 1 | * | * | 1 | * | * | * | * |
|  | 2013 | 1 | 1 | * | * | 1 | * | * | 1 | * | * | * | * |
|  | 2014 | 1 | 1 | * | * | 1 | * | * | 1 | * | * | * | * |
| SMB | 2012 | 17 | 22 | 0.72 | 1.59 | 11 | \$7.11 | \$4.46 | 6 | 0.53 | 1.18 | \$14.63 | \$12.45 |
|  | 2014 | 4 | 5 | 0.14 | 0.30 | 6 | * | * | 1 | , | * | * | * |
|  | 2015 | 3 | 3 | * | * | 4 | * | * | 1 | 0.04 | 0.08 | \$0.83 | \$10.77 |

Notes: Data shown for all BSAI crab fisheries by calendar year. All dollar values are adjusted for inflation to 2016-equivalent value. Information suppressed for confidentiality where indicated by "*", and data not available where indicated by "-".
${ }^{a}$ Except where noted, ex-vessel results reflect total commercial sales volume and value across all management programs (LLP/open access, IFQ, CDQ, ACA), inclusive of all harvesting sector production (CV, CP, and catcher-sellers); ex-vessel average price results are sourced from CV sector EDR data where available ( 2012 to 2015 for CR program fisheries) and secondarily from CFEC gross earnings estimates (2016 for CR fisheries and all years for non-CR fisheries); ex-vessel value of CP and catcher-seller landings are incorporated in revenue total using average CV ex-vessel price as a proxy per-pound value, multiplied by pounds of live catch
${ }^{b}$ Counts of buyers include CPs landing and processing their own crab, but exclude catcher sellers (NSR fishery only); processing sector results inclusive of all CP and shoreside processor output; finished volume is sourced from crab processor EDR production reports where available (2012to2015), or eLandings ex-vessel sales volume adjusted by average product recovery rate (PRR) by fishery (2016). Wholesale price results are sourced from crab processor EDR gross earnings reports where available (2012 to 2015) and secondarily from COAR gross earnings estimates (2016); gross wholesale revenue estimates are derived from price and volume sourced or estimated as described.
${ }^{c}$ Statistics reported for "All BSAI Fisheries" reflect information aggregated over all FMP crab fisheries, excluding fishery-level confidential information suppressed where indicated by "*".
${ }^{d}$ Landings and ex-vessel revenue suppressed in years where CDQ fishery landings are confidential.
${ }^{e}$ Data for Norton Sound red king crab are aggregated over the summer and winter commercial fisheries.
Source: ADF\&G fish ticket data; eLandings; CFEC ex-vessel pricing; ADF\&G Commercial Operator's Annual Report (COAR) data; NMFS AFSC BSAI Crab Economic Data Report (EDR) database.

Table 2: CR Program Fisheries Crew and Processing Sector Employment and Earnings

|  |  | Crew positions ${ }^{a}$ |  |  | Crew share ${ }^{b}$ |  | Captain share |  | Processing labor hours ${ }^{c}$ |  |  | Processing labor payment ${ }^{d}$ |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Year | Vessels | Total | Vessel median | Total \$million | Vessel median \$1,000 | Total \$million | Vessel median \$1,000 | Plants | $\begin{array}{r} \text { Total } \\ 1,000 \\ \text { hrs } \end{array}$ | $\begin{array}{r} \text { Plant } \\ \text { median } \\ 1,000 \\ \text { hrs } \end{array}$ | Median \$/hour | Total \$million | $\begin{array}{r} \text { Plant } \\ \text { me- } \\ \text { dian, } \\ \$ 1,000 \end{array}$ |
|  | 2012 | 83 | 1,081 | - | \$40.68 | - | \$18.64 | - | 13 | 1,261.90 | 71.66 | \$10.79 | \$15.05 | \$628.68 |
|  | 2013 | 81 | 1,099 | - | \$34.46 | - | \$15.85 | - | 12 | 955.77 | 53.70 | \$10.52 | \$10.30 | \$579.70 |
|  | 2014 | 76 | 1,216 | - | \$32.49 | - | \$14.85 | - | 9 | 905.08 | 103.11 | \$10.24 | \$9.78 | \$619.16 |
| Fisheries | 2015 | 82 | 1,332 | - | \$38.32 | - | \$16.83 | - | 9 | 1,179.34 | 112.90 | \$10.76 | \$13.59 | \$1,087.08 |
|  | 2016 | 80 | 1,218 | - | \$36.33 | - | \$16.00 | - | 8 | 788.23 | 95.46 | \$11.93 | \$9.66 | \$723.10 |
|  | 2012 | 6 | 46 | 7.67 | \$3.61 | \$657.98 | \$1.86 | \$329.64 | 7 | 53.16 | 2.60 | \$10.60 | \$1.15 | \$61.69 |
|  | 2013 | 6 | 44 | 7.33 | \$3.45 | \$555.20 | \$1.56 | \$283.36 | 6 | 61.09 | 5.96 | \$10.32 | \$0.63 | \$63.73 |
| AIG | 2014 | 5 | 35 | 7.00 | \$3.32 | \$717.60 | \$1.44 | \$298.53 | 4 |  |  |  | * | * |
|  | 2015 | 5 | 35 | 7.00 | \$4.11 | \$725.17 | \$1.68 | \$350.45 | 3 | * | * | * | * | * |
|  | 2016 | 5 | 36 | 7.20 | \$4.48 | \$988.90 | \$2.05 | \$361.71 | 4 | * | * | * | * | * |
|  | 2012 | 64 | 428 | 6.68 | \$8.30 | \$105.54 | \$3.74 | \$56.17 | 10 | 100.36 | 6.51 | \$11.23 | \$1.22 | \$70.20 |
|  | 2013 | 63 | 418 | 6.63 | \$7.76 | \$97.12 | \$3.69 | \$54.68 | 8 | 103.96 | 10.00 | \$10.37 | \$1.23 | \$96.98 |
| BBR | 2014 | 63 | 422 | 6.70 | \$7.90 | \$108.64 | \$3.82 | \$54.00 | 7 | 129.98 | 21.07 | \$9.68 | \$1.44 | \$77.83 |
|  | 2015 | 64 | 441 | 6.89 | \$9.60 | \$138.42 | \$4.46 | \$63.83 | 8 | 127.01 | 14.80 | \$10.79 | \$1.61 | \$120.51 |
|  | 2016 | 63 | 423 | 6.71 | \$11.20 | \$157.67 | \$4.95 | \$70.09 | 8 | 129.78 | 8.93 | \$11.91 | \$1.69 | \$87.49 |
|  | 2012 | 72 | 502 | 6.97 | \$27.88 | \$386.58 | \$12.65 | \$181.51 | 11 | 1,087.26 | 77.94 | \$10.78 | \$12.43 | \$633.98 |
|  | 2013 | 71 | 481 | 6.77 | \$22.80 | \$293.40 | \$10.38 | \$146.39 | 10 | 774.12 | 63.55 | \$10.40 | \$8.27 | \$498.94 |
| BSS | 2014 | 70 | 480 | 6.86 | \$18.12 | \$242.13 | \$8.13 | \$112.22 | 8 | 590.39 | 76.01 | \$10.87 | \$6.49 | \$468.98 |
|  | 2015 | 70 | 491 | 7.01 | \$18.62 | \$243.44 | \$7.80 | \$113.85 | 8 | 747.40 | 95.42 | \$10.94 | \$8.72 | \$811.52 |
|  | 2016 | 68 | 463 | 6.81 | \$15.11 | \$193.75 | \$6.67 | \$95.05 | 6 | 447.00 | 69.40 | \$11.74 | \$5.49 | \$537.12 |

[^17]Table 2: Continued

|  |  | Crew positions ${ }^{a}$ |  |  | Crew share ${ }^{b}$ |  | Captain share |  | Processing labor hours ${ }^{c}$ |  |  | Processing labor payment ${ }^{d}$ |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Year | Vessels | Total | Vessel median | Total \$million | Vessel median \$1,000 | Total <br> \$million | Vessel median \$1,000 | Plants | $\begin{array}{r} \text { Total } \\ 1,000 \\ \text { hrs } \end{array}$ | Plant median 1,000 hrs | Median \$/hour | Total \$million | $\begin{array}{r} \text { Plant } \\ \text { me- } \\ \text { dian, } \\ \$ 1,000 \end{array}$ |
|  | 2013 | 22 | 156 | 7.09 | \$0.46 | \$15.02 | \$0.21 | \$7.72 | 6 | 16.58 | 1.86 | \$9.97 | \$0.17 | \$16.13 |
| BST | 2014 | 41 | 279 | 6.80 | \$3.16 | \$70.83 | \$1.47 | \$31.74 | 7 | 122.27 | 8.51 | \$9.85 | \$1.26 | \$81.23 |
| BSI | 2015 | 55 | 365 | 6.63 | \$5.99 | \$114.43 | \$2.89 | \$46.74 | 7 | 230.41 | 21.84 | \$10.59 | \$2.50 | \$210.24 |
|  | 2016 | 46 | 296 | 6.42 | \$5.53 | \$80.15 | \$2.33 | \$39.20 | 6 | 144.87 | 18.44 | \$11.79 | \$1.71 | \$199.52 |
|  | 2012 | 17 | 106 | 6.24 | \$0.88 | \$45.56 | \$0.40 | \$23.22 | 6 | 21.12 | 0.76 | \$10.13 | \$0.25 | \$7.57 |
| SMB | 2014 | 4 | * | * | * | * | * | * | 1 | * | * | * | * | * |
|  | 2015 | 3 | * | * | * | * | * | * | 1 | * | * | * | * | * |

Notes: Data shown for all BSAI crab fisheries by calendar year. All dollar values are adjusted for inflation to 2016-equivalent value. Information suppressed for confidentiality where indicated by "*", and data not available where indicated by "-".
${ }^{a}$ For catcher/processors, EDR reporting may be used to adjust eLandings crew size reporting in order to estimate the number of fishing crew positions.
${ }^{b}$ Crew and captain payments reflect amounts paid for labor during the crab fishery and include all post-season adjustments, bonuses, and deductions for shared expenses such as fuel, bait, and food and provisions; payments for IFQ royalties, labor outside of crab fishery, health/retirement or other benefits are excluded.
${ }^{c}$ Processing labor hours reflect hours worked by processing-line employees working at shoreside and floating processor sectors only, excluding processing employees on catcher/processors and salaried workers employed in the processing sectors. //// ${ }^{d}$ Pay per hour statistics reflect only the shoreside and floating processing sectors; all other processing labor pay statistics are reported inclusive of catcher/processors
Source: NMFS AFSC BSAI Crab Economic Data Report (EDR) database, and Crew positions from eLandings.

Table 3: Crab Harvest Quota Lease Activity, Volume, Cost, and Average Lease Prices and Rates, CR Program Fisheries

|  |  |  | Vessels ${ }^{a}$ | Pounds L | ased (100 |  | Cost | (\$1000) |  | Lease (\$/pol |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  | Year |  | Total | Median | Mean | Total | Median | Mean | Median | Wtd mean | Median | Wtd mean |
|  |  | 2012 | 4 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2013 | 5 | 2,026.23 | 327.87 | 405.25 | \$3,730.16 | \$596.00 | \$746.03 | \$1.56 | \$1.84 | $35 \%$ | 43\% |
|  | CVO A | 2014 | 4 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2015 | 5 | 2,252.00 | 351.05 | 450.40 | \$5,262.67 | \$934.37 | \$1,052.53 | \$2.32 | \$2.34 | 49\% | 49\% |
|  |  | 2016 | 3 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2012 | 4 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2013 | 6 | 1,284.80 | 83.15 | 142.76 | \$1,904.95 | \$239.64 | \$211.66 | \$1.54 | \$1.48 | $36 \%$ | $37 \%$ |
|  | CVO B + CPO | 2014 | 4 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2015 | 5 | 1,375.30 | 24.30 | 196.47 | \$2,043.77 | \$73.56 | \$291.97 | \$1.35 | \$1.49 | $37 \%$ | $36 \%$ |
| AIG |  | 2016 | 4 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2012 | 4 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2013 | 5 | 151.06 | 27.36 | 25.18 | \$318.68 | \$46.51 | \$53.11 | \$1.94 | \$2.11 | 41\% | 49\% |
|  | $\mathrm{CVC}+\mathrm{CPC}$ | 2014 | 4 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2015 | 4 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2016 | 3 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2012 | 4 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2013 | 2 | * | * | * | * | * | * | * | * | * | * |
|  | $\mathrm{CDQ}+\mathrm{ACA}$ | 2014 | 3 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2015 | 3 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2016 | 3 | * | * | * | * | * | * | * | * | * | * |

Continued on next page.

Table 3: Continued

|  |  | Year | Vessels ${ }^{a}$ | Pounds Leased (10001bs) |  |  | Cost (\$1000) |  |  | Lease Price (\$/pound) ${ }^{b}$ |  | Lease Rate (percent of ex-vessel price) ${ }^{c}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Total | Median | Mean | Total | Median | Mean | Median | $\mathrm{Wtd}$ mean | Median | Wtd mean |
| BBR |  | 2012 | 50 | 3,618.97 | 65.48 | 72.38 | \$18,818.95 | \$322.68 | \$376.38 | \$5.46 | \$5.20 | 65\% | 62\% |
|  |  | 2013 | 51 | 4,425.47 | 78.75 | 86.77 | \$21,072.63 | \$357.10 | \$413.19 | \$4.67 | \$4.76 | 64\% | 65\% |
|  | CVO A | 2014 | 50 | 5,229.07 | 88.41 | 104.58 | \$22,743.48 | \$381.64 | \$454.87 | \$4.31 | \$4.35 | 62\% | 64\% |
|  |  | 2015 | 49 | 5,128.51 | 90.14 | 104.66 | \$26,265.72 | \$441.47 | \$536.04 | \$5.00 | \$5.12 | 63\% | 64\% |
|  |  | 2016 | 50 | 4,433.41 | 75.26 | 88.67 | \$29,676.52 | \$493.65 | \$593.53 | \$6.66 | \$6.69 | $62 \%$ | 62\% |
|  |  | 2012 | 42 | 539.10 | 7.60 | 11.72 | \$3,077.73 | \$43.96 | \$68.39 | \$5.64 | \$5.78 | 65\% | 67\% |
|  |  | 2013 | 45 | 777.86 | 10.07 | 15.56 | \$3,848.12 | \$49.12 | \$76.96 | \$4.93 | \$4.95 | 65\% | 64\% |
|  | CVO B +CPO | 2014 | 43 | 853.62 | 11.77 | 17.42 | \$3,811.95 | \$55.74 | \$77.80 | \$4.46 | \$4.47 | 64\% | 63\% |
|  |  | 2015 | 42 | 696.51 | 10.89 | 14.82 | \$3,858.85 | \$59.98 | \$82.10 | \$5.30 | \$5.54 | 63\% | 66\% |
|  |  | 2016 | 43 | 609.89 | 9.68 | 12.45 | \$4,371.69 | \$67.25 | \$89.22 | \$7.03 | \$7.17 | 64\% | $64 \%$ |
|  |  | 2012 | 36 | 171.60 | 4.24 | 4.52 | \$947.71 | \$22.41 | \$24.94 | \$5.51 | \$5.52 | 63\% | 64\% |
|  |  | 2013 | 37 | 198.96 | 4.52 | 4.85 | \$1,012.31 | \$22.48 | \$24.69 | \$4.96 | \$5.09 | 66\% | 66\% |
|  | $\mathrm{CVC}+\mathrm{CPC}$ | 2014 | 34 | 212.79 | 5.98 | 5.91 | \$947.86 | \$24.22 | \$26.33 | \$4.45 | \$4.45 | 65\% | 66\% |
|  |  | 2015 | 40 | 222.10 | 5.04 | 5.29 | \$1,222.23 | \$29.17 | \$29.10 | \$5.38 | \$5.50 | 63\% | 65\% |
|  |  | 2016 | 37 | 200.51 | 4.04 | 5.14 | \$1,395.88 | \$34.48 | \$35.79 | \$6.98 | \$6.96 | 64\% | 69\% |
|  |  | 2012 | 5 | 368.62 | 70.68 | 73.72 | \$2,304.14 | \$457.11 | \$460.83 | \$5.70 | \$6.25 | 64\% | $72 \%$ |
|  |  | 2013 | 8 | 713.42 | 77.40 | 89.18 | \$3,598.69 | \$389.18 | \$449.84 | \$5.05 | \$5.04 | 67\% | 66\% |
|  | $\mathrm{CDQ}+\mathrm{ACA}$ | 2014 | 7 | 826.41 | 117.86 | 118.06 | \$3,780.14 | \$514.32 | \$540.02 | \$4.56 | \$4.57 | 63\% | 66\% |
|  |  | 2015 | 5 | 467.90 | 99.74 | 93.58 | \$2,633.12 | \$549.12 | \$526.62 | \$5.51 | \$5.63 | 67\% | 68\% |
|  |  | 2016 | 5 | 550.41 | 120.52 | 110.08 | \$4,005.38 | \$846.14 | \$801.08 | \$7.02 | \$7.28 | 63\% | 67\% |

Continued on next page.

Table 3: Continued


Continued on next page.

Table 3: Continued


Continued on next page.

Table 3: Continued

|  |  | Year | Vessels ${ }^{a}$ | Pounds Leased (10001bs) |  |  | Cost (\$1000) |  |  | Lease Price (\$/pound) ${ }^{b}$ |  | $\begin{gathered} \text { Lease Rate } \\ (\text { percent of } \\ \text { ex-vessel price) }{ }^{c} \end{gathered}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  | Total | Median | Mean | Total | Median | Mean | Median | $\begin{array}{r} \text { Wtd } \\ \text { mean } \end{array}$ | Median | Wtd mean |
| SMB | CVO A | 2012 | 17 | 1,149.28 | 49.07 | 67.61 | \$1,719.94 | \$69.85 | \$101.17 | \$1.45 | \$1.50 | $32 \%$ | $34 \%$ |
|  |  | 2014 | 3 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2015 | 3 | * | * | * | * | * | * | * | * | * | * |
|  | CVO B + CPO | 2012 | 10 | 143.73 | 11.56 | 11.06 | \$219.20 | \$18.94 | \$16.86 | \$1.50 | \$1.53 | $32 \%$ | $35 \%$ |
|  |  | 2014 | 2 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2015 | 3 | * | * | * | * | * | * | * | * | * | * |
|  | $\mathrm{CVC}+\mathrm{CPC}$ | 2012 | 9 | 94.70 | 2.48 | 10.52 | \$47.54 | \$5.66 | \$5.28 | \$1.50 | \$0.50 | $34 \%$ | 11\% |
|  |  | 2014 | 2 | * | * | * | * | * | * | * | * | * | * |
|  |  | 2015 | 2 | * | * | * | * | * | * | * | * | * | * |
|  | $\mathrm{CDQ}+\mathrm{ACA}$ | 2012 | 3 | * | * | * | * | * | * | * | * | * | * |
|  |  |  | 1 | * | * | * | * | * | * | * | * | * | * |

Notes: Other fishery data is not shown due to insufficient observations. Lease data shown represent arms-length lease transactions reported by quota purchasers in the EDR. Harvest quota types are categorized in this report as the following: CVO A (catcher vessel owner Class A IFQ), CVO B + CPO (catcher vessel owner Class B IFQ and catcher/processor owner IFQ), and CVC + CPC (catcher vessel crew IFQ and catcher/processor crew IFQ). Statistics reported represent results pooled over all quota types and/or regional designations within each category.
${ }^{a}$ Vessels column shows total count of vessel-level observations for fishery-year where both pounds and cost of quota leased were reported as non-zero values; in a small number of observations where leased pounds was reported for a given fishery/quota type but lease cost was missing, the mean price over all complete observations was used to impute the missing data in computing the total aggregate lease cost over all vessels.
${ }^{b}$ Average lease price statistics by fishery and quota type are calculated as the median and arithmetic mean, respectively, over all observations where both pounds and cost for one or more quota type within the respective category were reported as non-zero values.
${ }^{c}$ Average lease rate statistics by fishery and quota type are calculated as the median and mean, respectively, of the ratio of lease price to ex-vessel price, over all observations where both ex-vessel and lease pounds, and ex-vessel revenue and lease cost, were reported as non-zero values. Lease rate for each quota type is calculated with respect to ex-vessel value of crab sold using the same quota type. As such, variation in lease price and lease rate in a given fishery may not be consistent between different quota types.
Source: NMFS AFSC BSAI Crab Economic Data Report (EDR) database.


[^0]:    North Pacific Fishery Management Council 605 W. 4th Avenue, \#306
    Anchorage, AK 99501

[^1]:    [1] For Tiers 3 and 4 where $B_{\text {Mss }}$ or $B_{\text {Msproxy }}$ is estimable, the years refer to the time period over which the estimate is made. For Tier 5 stocks it is the years upon which the catch average for OFL is obtained. [2] MMB as projected for 2/1/2017 for Norton Sound red king crab, 2/15/2017 for AIGKC, and 2/15/2018 for other stocks. [3] AIGKC OFL and ABC calculated by author outside the chapter for using the Approach 2 combination of EAG and WAG and $25 \%$ buffer between OFL and ABC. [4] Additional mortality males: two periods-1980-1985; 1968-1979 and 1986-2013. Females three periods: 1980-1984;

[^2]:    This information is distributed solely for the purpose of pre-dissemination peer review under applicable information quality guidelines. It has not been formally disseminated by the National Marine Fisttries Service and should not be construed to represent any agency determination or policy.

[^3]:    A-Estimated at time of mating for the year concerned. This is a revised estimate, based on the subsequent assessment.
    B-Projected biomass from the current stock assessment. This value will be updated next year.
    C-Based on the author's preferred model (Model B2b).

[^4]:    $1^{\text {https://aws.state.ak.us/OnlinePublicNotices/Notices/Attachment.aspx?id=100244 }}$

[^5]:    3 https://github.com/wStockhausen/wtsTCSAM02.git

[^6]:    ${ }^{1} 1983 / 84$ refers to a fishing year that extends from 1 July 1983 to 30 June 1984.

[^7]:    ${ }^{2}$ NOAA grant Bering Sea Crab Research II, NA16FN2621, 1997.

[^8]:    ${ }^{3}$ D. Pengilly, ADF\&G, pers. comm.

[^9]:    ${ }^{1}$ The author acknowledges help from Martin Dorn, Jim Ianelli, and Paul Spencer, AFSC, in getting this paragraph completed.

[^10]:    Note: NA = Not available, FC = fishery closed, CF = confidential.
    ${ }^{\text {a }}$ Deadloss included.
    ${ }^{\text {b }}$ GHL includes all king crab species. Golden king crab incidental to red king crab.
    c January/February 2001 Petrel Bank survey.
    ${ }^{\text {d }}$ November 2001 Petrel Bank survey.

[^11]:    ${ }^{1}$ There are currently 11 distinctly managed fisheries on the 10 crab stocks managed under the FMP; catch allocations and other management elements are administered separately for the Eastern and Western components of the Bering Sea Tanner crab stock, and for the Eastern and Western components of the Aleutian Islands golden king crab stock, and the Pribilof Island blue and red king crab stocks are managed collectively as a single fishery. For fisheries characterized by a small number of participating entities, individual statistics where indicated in Tables 1 - 3 , and elsewhere in the report, are suppressed due to confidentiality restrictions; this includes most values for the Pribilof Island golden king (PIG) crab fishery and the Norton Sound red king (NSR) crab fisheries, and statistics for both Aleutian Islands golden king crab fisheries and both Bering Sea Tanner crab fisheries are reported in aggregate, respectively. Values that are indicated as suppressed for a specific fishery are also excluded from values reported in aggregate over multiple crab fisheries. Except where noted, the suppressed values are sufficiently small that they have minimal effect on the accuracy of aggregate information at the level of precision reported here.
    ${ }^{2}$ Most activity in the BSS and BST fisheries occur during January through March of the crab season/year, such that effects of closing the $2016 / 17$ BST fishery occurred primarily during calendar year 2017 and are not reflected in this report.

[^12]:    ${ }^{3}$ All monetary values in the report, unless otherwise noted, are inflation-adjusted to 2015-equivalent dollars using the GDP-chaintype price index (https://research.stlouisfed.org/fred2/series/GDPCTPI). The GDP price index is used to adjust fishery production revenues and costs to account for the change in general US production prices over time.

[^13]:    ${ }^{4}$ BSAI Crab Economic Data Report (EDR) data are collected for CR fisheries only. The NSR and Pribilof Island golden king (PIG) crab fisheries are managed by the State of Alaska under the FMP, but are not included in the CR program.

[^14]:    ${ }^{5}$ Note that the aggregate count of vessels indicates the total number of distinct vessels, while the count of crew positions counts positions separately by fishery and vessel, such that individual crew members are counted more than once.

[^15]:    ${ }^{6}$ In addition to revenue-share payments, income is derived by some crew and many captains from royalties for harvesting quota shares held by either the captain or crew. While this may become an increasingly important source of income as opportunities for investment in QS ownership are advanced, there is no evidence to date that the proportion of CR fishery quota share pools held by crab crew members has changed in recent years, following a small amount of consolidation occurring during the initial years of the program (see NMFS Alaska Region, Restricted Access Management Program, Bering Sea and Aleutian Islands Crab Rationalization Program Report, Fishing Year 2011/12 for information on quota allocation and transfer activity, and other current CR program administration details).

[^16]:    ${ }^{7}$ Differences between median and mean average values shown in Table 3 are most pronounced in the per-vessel pounds and cost statistics; this primarily reflects the relati8e concentration of high-volume quota leasing activity by a NPFMC Bering SealAleutian nistands Crab SAFE category ${ }_{1610}$

[^17]:    Continued on next page.

