**Norton Sound Red King Crab Stock Assessment for the fishing year 2014/15**

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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. Summer commercial fishery started in 1977, and its catch quickly reached a peak 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. As the crab population rebounds, retained catches have been increasing. For past several years, retained catch is around 0.4 million pounds.
3. Stock Biomass. Estimated mature male biomass (MMB) shows an increasing trend since 1997 following the dramatic decrease in abundance from a peak in 1977 to a historic low in 1982. However, estimates of historical biomass are highly uncertain due in part to infrequent trawl surveys (every 3 to 5 years) and limited geographic coverage of the winter pot survey.
4. Recruitment. Model estimated recruitment was weak during the late 1970s, high during the early 1980s, and showed a slight decreasing trend from 1983 to 1993. Estimated recruitment has been highly variable but with an increasing trend in recent years.
5. Management performance.

*Status and catch specifications (million lb)*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **MSST** | **Biomass (MMB)** | **GHL** | **Retained Catch** | **Total Catch** | **OFL** | **ABC** |
| 2010/11 | 1.56A | 5.44 | 0.40 | 0.42 | 0.46 | 0.73A |  |
| 2011/12 | 1.56B | 4.70 | 0.36 | 0.40 | 0.43 | 0.66B | 0.59 |
| 2012/13 | 1.78C | 4.59 | 0.47 | 0.47 | 0.47 | 0.53C | 0.48 |
| 2013/14 | 2.06D | 5.00 | 0.50 | 0.35 | 0.35 | 0.58D | 0.52 |
| 2014/15 | 2.11E | 3.71 | TBD | TBD | TBD | 0.46E | 0.42 |

*Status and catch specifications (1000t)*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **MSST** | **Biomass**  **(MMB)** | **GHL** | **Retained**  **Catch** | **Total Catch** | **OFL** | **ABC** |
| 2010/11 | 0.71A | 2.47 | 0.18 | 0.19 | 0.21 | 0.33A |  |
| 2011/12 | 0.71B | 2.13 | 0.16 | 0.18 | 0.20 | 0.30B | 0.27 |
| 2012/13 | 0.80C | 2.08 | 0.21 | 0.21 | 0.21 | 0.24C | 0.22 |
| 2013/14 | 1.02D | 2.16 | 0.23 | 0.16 | 0.16 | 0.26D | 0.24 |
| 2014/15 | 1.04E | 1.83 | TBD | TBD | TBD | 0.23E | 0.21 |

Notes:

MSST was calculated as BMSY/2

A-Calculated from the assessment reviewed by the Crab Plan Team in May 2010

B-Calculated from the assessment reviewed by the Crab Plan Team in May 2011

C-Calculated from the assessment reviewed by the Crab Plan Team in May 2012

D-Calculated from the assessment reviewed by the Crab Plan Team in May 2013

E-Calculated from the assessment reviewed by the Crab Plan Team in May 2014

Conversion to Metric ton: 1 Metric ton = 2.024 × 1000 lb

*Biomass in millions of pounds*

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Tier** | **BMSY** | **Current MMB** | **B/BMSY (MMB)** | **FOFL** | **Years to define**  **BMSY** | **M** | **1-Buffer** | **ABC** |
| 2010/11 | 4a | 3.12 | 5.44 | 1.7 | 0.18 | 1983-2010 | 0.18 |  |  |
| 2011/12 | 4a | 2.97 | 4.70 | 1.6 | 0.18 | 1983-2011 | 0.18 | 0.9 | 0.59 |
| 2012/13 | 4a | 3.51 | 4.25 | 1.2 | 0.18 | 1980-2012 | 0.18 | 0.9 | 0.48 |
| 2013/14 | 4a | 4.12 | 5.00 | 1.2 | 0.18 | 1980-2013 | 0.18 | 0.9 | 0.52 |
| 2014/15 | 4b | 4.19 | 3.71 | 0.9 | 0.16 | 1980-2014 | 0.18 | 0.9 | 0.42 |

*Biomass in 1000t*

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Year** | **Tier** | **BMSY** | **Current MMB** | **B/BMSY (MMB)** | **FOFL** | **Years to define**  **BMSY** | **M** | **1-Buffer** | **ABC** |
| 2010/11 | 4a | 1.42 | 2.47 | 1.7 | 0.18 | 1983-2010 | 0.18 |  |  |
| 2011/12 | 4a | 1.35 | 2.18 | 1.6 | 0.18 | 1983-2011 | 0.18 | 0.9 | 0.27 |
| 2012/13 | 4a | 1.59 | 1.93 | 1.2 | 0.18 | 1980-2012 | 0.18 | 0.9 | 0.22 |
| 2013/14 | 4a | 1.86 | 2.27 | 1.2 | 0.18 | 1980-2013 | 0.18 | 0.9 | 0.24 |
| 2014/15 | 4b | 2.07 | 1.83 | 0.9 | 0.16 | 1980-2014 | 0.18 | 0.9 | 0.21 |

1. Probability Density Function of the OFL



OFL profile. Model estimated CV 0.3 and mcmc estimates.

1. The basis for the ABC recommendation

For Tier 4 stocks, the default maximum ABC 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 in 2011.

**For 2014 fishery, we chose 90% OFL (10% Buffer)**

1. A summary of the results of any rebuilding analyses.

N/A

1. ***Summary of Major Changes in 2013***
2. Changes to the management of the fishery**:**

None

1. Changes to the input data

Updated

* 1. 2013 summer commercial fishery, 2012/2013 winter commercial and subsistence catch.

New Data included into the assessment model

* 1. 2013 summer commercial fishery observer data, standardized commercial catch CPUE and CV.
  2. Winter pot survey CPUE 1980-2011

Revised Data

* 1. 1976-1991 NMFS survey NSRKC crab abundance estimates were revised based on original survey data.

1. Changes to the assessment methodology:

None

1. Changes to the assessment results.

None

1. ***Response to SSC and CPT Comments***

CPT Review Sept 17 – 20, 2013

The team had the following comments:

* The model incorporating 2013 observer length frequency data led to an unusually high terminal year mature male abundance whereas the model that disregarded the 2013 observer data led to a reasonable estimate of terminal stock abundance. Therefore, the OFL estimate based on the biomass determined by the model that excluded the 2013 observer data should be considered for developing harvest specifications for 2014.

Author response:

The model estimates using all finalized data did not show observable discrepancies when including or excluding observer data.

* The authors assumed a constant M value of 0.18yr-1 to exclude the possibility of confounding with molting. Show the likelihood profile of M.

Author response:

Profile of M was provided. In this, all estimated parameters, except ms6 (mortality multiplier for the last length class), changed depending on value of M. The parameter ms6 was set to 1.0, which assumes constant mortality for all length classes as opposed to the original assumption that mortality of the last length class is 3.6 times higher (M = 0.648) than other length classes. The profile analysis showed that M = 0.42 generated the lowest negative log likelihood.

* Calculate the non-retained OFL as well as the total OFL.

Author response: Implemented.

* Report the estimate of the additional variance that is added to the variance assumed for the CPUE data.

Author response: The variance has been reported on table 11 (log\_*w2t*). We also show this in Figures 9a and 9b.

* Estimate separate selectivity patterns for the NMFS and ADFG trawl surveys and evaluate whether the assumption that they are the same can be justified.

Author response:

The analysis shows that trawl selectivity of the ADF&G differed from NMFS survey. However, standard error of the selectivity function parameter was very high (CV 2-5 ×105 %). Selectivity both surveys was 0.999 for all length classes.

* Increase weight of recruit penalty from 0.01 to 0.5

Author response:

Implemented.

Recruit penalty was described as standard deviation (sd) (i.e., sd = 0.5) converted from the original multiplier (WR) form



With sd = 0.5, the conversion increased weight from WR = 0.01 to = 4.75. (WR = 1/2sd2).

The effects of this weight change were reported at the 2014 workshop, and the proposed weight was considered appropriate.

SSC Review on September 30-October1, 2013

* Conduct sensitivity analyses on weighting.

See January 14-17 modeling workshop report.

Crab modeling workshop on January 14-17, 2014

* A full assessment should be conducted with a range of suggested scenarios so the May CPT can recommend an OFL and an ABC for the 2014-15 management cycle. The assessment will need to be revised again for the September 2014 CPT meeting and the September specification cycle.

Author response:

2014 summer commercial harvest season also coincides with triennial assessment. It is unlikely that both commercial harvest assessment and triennial survey assessment will be finalized before the September 2014 CPT meeting. Similar to 2013 CPT meeting, it is possible that summer commercial fishery is not finished.

* Provide alternative model runs where selectivity for the ADFG and NMFS trawl surveys are assumed the same, and where different selectivity patterns are estimated for each survey.

Author response:

In the revised model, selectivity for ADFG and NMFS trawl surveys were identical, so that combining or not combining the two did not change model outcomes (c.f. alternative models 0 and 1). However, we separate the two selectivity because the selectivity may differ in alternative models and the assumption of identical selectivity will most likely be challenged in the future.

* Provide alternative model runs in which the growth transition matrix incorporates both growth and molting probabilities. If possible, develop a model that incorporates the growth data and in which the growth transition matrix is estimated.

Author response:

Three models (2.i, 2.io, 2.ii) estimated the growth transition matrix from tagging data.

* Provide alternative model runs in which: 1) the size-composition data from the winter pot survey are excluded, and 2) the CPUE data for the winter pot survey are included.

Author response:

Inclusion of the winter pot CPUE decreased model fit, and exclusion of winter pot data did not improve model fit. Further, removing the winter pot data resulted in the loss of the model’s ability to estimate winter pot selectivity.

* Review the data used to calculate the growth transition matrix, and provide an overview of the new tagging program and the data that it is expected to provide.

Author response:

A growth transition matrix was developed using historical tag recovery data. In this assessment we combined all historical tag recovery data (through recoveries in 2013). The Tagging study is ongoing as a NPRB funded projects (2013-14) and we expect recovery of tagged crabs for coming years.

1. ***Introduction***

Species: red king crab (*Paralithodes camtschaticus*) in Norton Sound, Alaska.

* + - 1. 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 167-168o W. longitude with depths less than 30 m and summer bottom temperatures above 4oC. 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°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.
      2. 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.
      3. 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 ± 6 (SD) m and bottom temperatures of 7.4 ± 2.5 (SD) o C during summer. Norton Sound red king crab are consistently abundant offshore of Nome.

Norton Sound red king crab migrate between deeper offshore waters during molting/feeding and inshore shallow waters during the mating period. Timing of the inshore mating migration is unknown; but is assumed to be during March-June. Offshore migration likely occurs in May-July. 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. There is limited information on the timing of male molting, but at least some males likely molt late August – September based on increased catches of post-molt crabs in the fishery.

* + - 1. 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 in winter (December – May) (Menard et al. 2011). The majority of red king crab are harvested by the summer commercial fisheries, whereas the majority of the winter harvest is in the subsistence fishery occurring near the coast (Table 2).

Summer Commercial Fishery

Summer commercial crab fishery started in 1977 (Table 1). A large-vessel summer commercial crab fishery existed in the Norton Sound Section 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 the Norton Sound, a legal crab is defined as ≥ 4-3/4 inch carapace width (Menard et al. 2011). Since 2005, commercial buyers started accepting only legal crabs of ≥ 5 inch carapace.

Not all Norton Sound area is open for commercial fisheries. Since the beginning of the commercial fisheries in 1977, nearshore areas near Nome area have been closed during the summer commercial crab fishery, possibly to protect crab nursery grounds (Figure 2). The spatial extent of closed area has varied through time.

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 they make their first delivery. Fishers operate under authority of the CDQ group and each CDQ group decides how their crab quota is to be harvested. During the March 2002 BOF meeting, new regulations were adopted that affected the CDQ crab fishery and relaxed closed-water boundaries in eastern Norton Sound and waters west of Sledge Island. At its March 2008, the BOF changed the start date of the Norton Sound open-access portion of the fishery to be opened by emergency order and as early as June 15. The CDQ fishery may open at any time (as soon as ice is out), by emergency order. It is possible that the fishery starts BEFORE determination of OFL and ABC.

Winter Commercial Fishery

Winter commercial crab fishery is a small fishery using hand lines and pots through the nearshore ice. Approximately 10 permit holders participated in this fishery harvesting, on average, 2,500 crabs during 1978-2009 (Table 2). During 2006-2013 the winter commercial catch increased to 3,000 – 23,000. The winter commercial fishery catch is influenced not only by crab abundance, but also by changes in nearshore crab distribution, sea ice conditions, number of participants, and market condition.

Subsistence Fishery

Harvest statistics are available for the winter subsistence fishery since 1977/78 (Table 2). The majority of harvest occurs during winter using hand lines and pots through the nearshore ice. Average annual winter subsistence harvest was 5,400 crabs (1977-2010). Subsistence harvesters are required to obtain a permit before fishing and record daily effort and catch. There is no size limit in the subsistence fishery. The subsistence fishery catch is influenced not only by crab abundance, but also by changes in crab 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 in 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 crabs per year. Since this harvest is very small, summer subsistence fishery was not included in the assessment model.

* + - 1. Brief description of the annual ADF&G harvest strategy

beginning in Norton Sound red king crab was managed based on a guideline harvest limit (GHL) since 1997. Detailed historical methods of GHL determination are unknown. From 1999 to 2011, GHL 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) ≤ 5% of legal male abundance when the estimated legal biomass falls within the range 1.5-2.5 million lb.; and (3) ≤ 10% of legal male when estimated legal biomass >2.5 million lb.

has been The method of GHL determination was revised in 2012 to: (1) 0% harvest rate of legal crab when estimated legal biomass < 1.25 million lb.; (2) ≤ 7% of legal male abundance when the estimated legal biomass falls within the range 1.25-2.0 million lb.; (3) ≤ 13% of legal male abundance when the estimated legal biomass falls within the range 2.0-3.0 million lb.; and (4) ≤ 15% of legal male when estimated legal biomass >3.0 million lb.

|  |  |
| --- | --- |
| Year | Notable historical management changes |
| 1976 | Periodic fishery-independent surveys began |
| 1977 | Large vessel commercial fisheries began |
| 1991 | Fishery closed due to staff constraints |
| 1994 | Participation of large vessels in the commercial fishery ended by super exclusive designation. Fishery effectively becomes small-vessel only.  The majority of commercial fishery effort and catch subsequently shifted to east of 164oW line. |
| 1998 | Community Development Quota (CDQ) allocation into effect |
| 1999 | Guideline Harvest Level (GHL) into effect |
| 2000 | North Pacific License Limitation Program (LLP) into effect. |
| 2002 | Change in closed water boundaries (Figure 2) |
| 2005 | Commercially accepted legal crab size changed from ≥ 4-3/4 inch CW to ≥ 5 inch CW |
| 2006 | The Statistical area Q3 section expanded (Figure 1) |
| 2008 | Start date of the open access fishery changed from July1 to after June 15 by emergency order.  Pot configuration requirement: at least 4 escape rings (>4½ inch diameter) per pot located within one mesh of the bottom of the pot, or at least ½ of the vertical surface of a square pot or sloping side-wall surface of a conical or pyramid pot with mesh size > 6½ inches. |
| 2012 | Board of fisheries adopted a revised GHL |

* + - 1. Summary of the history of the *B*MSY.

NSRKC is a Tier4a crab stock. Direct estimation of the *B*MSY is not possible. *B*MSY is calculated as mean model estimated mature male biomass (MMB) from 1980 to present. Choice of this period was based on the possibility that a regime shift in ocean-atmosphere circulation dynamics indexed by the Pacific Decadal Ocscillation (PDO) occurred in 1976-77 may have influenced stock productivity.

1. ***Data***
2. Summary of new information:
   1. Winter pot survey CPUE. Data have been available but have not previously been incorporated into the model.
   2. 2014 winter commercial and subsistence catches (Model year 2013­). **Because these data are not available at the time of assessment values were assumed to be the same as 2013.**
3. Available survey, catch, and tagging data:

|  |  |  |  |
| --- | --- | --- | --- |
| Data Source | Years | Data Types | Representation |
| Summer trawl survey\* | 76,79,82,85,88,91,96, 99, 02,06,08,10,11 | Abundance | Table 3 |
| Length proportion | Table 5, Figure 3 |
| Winter pot survey | 81-87, 89-91,93,95-00,02-12 | CPUE | Table 2 |
| Length proportion | Table 6, Figure 3 |
| Summer commercial fishery | 76-90,92-13 | Retained catch number | Table 1 |
| Standardized CPUE, | Table 1 |
| Length proportion | Table 4, Figure 3 |
| Summer commercial Observer | 87-90,92,94, 2012-2013 | Length proportion  (sub-legal only) | Table 7, Figure 3 |
| Winter subsistence fishery | 76-13 | Number of crab caught | Table 2 |
| Retained catch number | Table 2 |
| Winter commercial fishery | 78-13 | Retained catch number | Table 2 |
| Tagging recovery | 80-13 | Recovered tagged crab | Table 9 |

\*: Triennial trawl surveys were conducted by the NMFS (1976-1991, 2010) and by the ADF&G (1996-2011) (Table 3). The NMFS survey was conducted using the 83-112 Eastern Otter Trawl, whereas the ADF&G survey was conducted using the 400 Eastern Otter Trawl (Soong 2008). In both surveys, survey design was based on 10×10nm square, except for the NMFS survey in 2010 where survey grid was 20×20nm. Abundance of crabs were estimated by area-swept methods (Alverson and Pereyra 1969). Historical NMFS trawl survey abundance (Schwarz 1984, Stevens and MaIntosh 1986, Stevens 1989, 1992; Wolotira et al 1977) was re-estimated from the original raw data in 2013 (Robert Foy, NMFS personal communication).

Data available but not used for assessment

|  |  |  |  |
| --- | --- | --- | --- |
| Data Source | Years | Data Types | Reason not used |
| Summer pot survey | 80-82,85 | Abundance | Uncertainties on how estimates were made. |
| Length proportion |
| Summer preseason survey | 95 | Length proportion | Just one year of data |
| Summer subsistence fishery | 2005-2013 | retained catch | Too few catches compared to commercial |

4. Catches in other fisheries: None.

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1. Other miscellaneous data: None.

Data aggregated

Growth-per-molt, estimated from tagging data (1991-2007) (Table 8)

Proportions of legal size crab in crab length classes, estimated from trawl survey and observer data. (Table 9)

***Analytic Approach***

1. **History of the modeling approach.**

The Norton Sound red king crab stock IS assessed using a length-based synthesis model (Zheng et al. 1998).

Since adoption of the model a, the major challenge was the apparent conflict between the model and observed data, especially the model overestimating the abundance/proportion of large length classes, which resulted in overestimation of the projected biomass (Figure 12). This problem has been dealt with using the following approaches: (1) increase M of the last length class, (2) implement a dome-shaped catch selectivity for winter pot survey/catch), (3) reduce effective sample size of length composition data, and (4) increase M. Although all three approaches improve model fits and projections, none of those approaches are without major criticisms. Approaches (1) and (2) have unusual biological/fishery assumptions without supportive data. Approach (3) is biologically simpler and reasonable approach; however, it greatly increases the OFL and ABC, without any supportive evidence that the population can withstand a higher exploitation rate. Attempts to estimate M directly from the model itself failed, because of confounding effects between molting probability and natural mortality.

At the 2013-2014 crab modeling workshop, extensive examination of the model was conducted, including revision of historical survey abundance data, inclusion and exclusion of data (e.g., exclusion of summer pot survey data, inclusion/exclusion of winter pot survey CPUE), reduction of the number of parameters (e.g., molting probability, selectivity), and reevaluation of growth transition matrix.

Here is chronology of model modifications

2010

1) M =0.18,

2) include summer commercial discards mortality,

3) weight of fishing effort = 20,

4) the maximum effective sample size for commercial catch and winter surveys = 100,

5) M of the last length class = 0.288.

2012

1) M of the last length class = 0.648,

2) the maximum effective sample size for commercial catch and winter surveys = 50

3) weight of fishing effort = 50.

2013

1) replace likelihood of commercial catch effort to that of standardized commercial catch CPUE with weight = 1.0,

2) eliminate summer pot survey data from likelihood,

3) estimate survey selectivity of 1976-1991 NMFS survey with maximum of 1.0, and

4) reduce the maximum effective sample size for commercial catch and winter surveys = 20.

The model described here has been adjusted to accommodate 1) revised functional forms for selectivity and molting probability to improve parameter estimates, 2) inclusion of the winter pot survey CPUE, and 3) inclusion of the growth transition matrix estimated from tagging data.

1. **Model Description**
2. 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, commercial and survey selectivity, molting probability and growth. (See Appendix A for full model description). Model cycle is July 1st to June 30th of following year.

b-f. See Appendix A.

1. Critical assumptions of the model:
2. Male crab mature at 94mm CL.

The basis for this assumption have not been located. No formal study has been conducted to test this assumption.

1. Instantaneous natural mortality *M* is 0.18 for all length classes, except for the last length group (> 123mm) where M =0.648 (0.18 × 3.6). M is constant over time.

This mortality is based on Bristol Bay red king crab, estimated with a maximum age 25 and the 1% rule (Zheng 2005), and was adopted for NSRKC by CPT. The assumption of the higher M for the last length group is based not on biological data, but rather a working hypothesis attempting to explain the lower than model predicted proportion of this group in summer commercial fisheries (Figures 10, 13).). It is possible, that the last length group moved into areas inaccessible to commercial fisheries (CPT review 2010). However, this does not explain the low proportion observed in the summer trawl survey, when all of the Norton Sound Area was surveyed. In addition, lowering the catch selectivity did not result in lower log likelihood than increasing the mortality (CPT 2010).

1. Trawl survey selectivity is a logistic function with 0.999 for length classes 5-6. Selectivity is constant over time, separated between NMFS and ADFG survey.

This assumption was not based on biological/mechanistic data and reasoning, but rather an attempt to improve model fit.

1. Winter pot survey selectivity is a dome shaped function: logistic function for length classes 1-4, 0.999 for length class 5, and model estimate for the last length group. Selectivity is constant over time.

This assumption is based on a belief (but no empirical data) that very large crab may be infrequently present in the nearshore area where the winter surveys occur.

1. Summer commercial fisheries selectivity is an asymptotic logistic function of 0.999 at the length class 5 and 6. It has two selectivity curves: (1) 1977-1992, and (2) 1993-present, reflecting changes in fishing vessel composition and pot configuration.

Since 2005 commercial buyers accept only legal crab of CW ≥ 5.0 inch and unknown numbers of legal crab with CW < 5.0 are discarded. Further, since 2008, commercial pots are required to install escapement rings for sublegal crabs. Hence one can argue that the catch selectivity changed in 2005. However, the model was not able to accurately estimate selectivity parameters for 2005-2013. Consequently, selectivity for both 1993-2004 and 2005-2013 were combined.

1. 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 after February 1st.

Winter commercial king crab pots can be any dimension (5AAC 34.925(d)). No data exists about length composition of crab harvested in commercial and subsistence fishery. However, because commercial fishers are also subsistence fishers, it is reasonable to assume that the commercial fishers used crab pots that they also used for subsistence harvest. Hence both fisheries have the same selectivity.

1. Growth increments, which are estimated based on tag recovery data, are a function of length and are constant over time.
2. Molting probability is an inverse logistic function of length for males.
3. The summer directed fishing season is short.
4. Discard handling mortality in all fisheries is 20%.

No empirical estimate is available.

1. Annual retained catches is measured without error.
2. All legal size crabs (≥ 4-3/4 inch CW) are taken to the commercial dock.

Since 2005, buyers announced that only legal crab with ≥ 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, because inclusion of this factor did not change the results, this factor was not included in the assessment model.

1. All sublegal size crab or commercially unacceptable size crab (< 5 inch CW, since 2005) are discarded.
2. Length compositions have a multinomial error structure, and abundances have a log-normal error structure..
3. Changes of assumptions since last assessment:

None

1. Code validation. Model code was reviewed at the CPT modeling workshop in 2013 and 2014.2014. It is available from the authors.

**Model Selection and Evaluation**

1. Description of alternative model configurations.

Based on recommendations provided at the 2014 crab workshop, for this assessment the following alternative model configurations were examined:

* 1. Base Model at January 2014 crab workshop
  2. NMFS and ADF&G trawl survey selectivity assumed identical
  3. Growth transition matrix estimated within the assessment model
     1. Molting probability estimated

io. Molting probability estimated (include Oldshell into likelihood)

* + 1. Molting probability fixed at1.0 for all length classes
  1. Winter survey CPUE included, in addition to winter survey length composition data
  2. All winter survey data (CPUE and length composition) excluded

Explanations:

The growth matrix and molting probability

The growth-transition matrix has been estimated inside and outside independently of the assessment model using tag-recovery data. However, because tag-recovery is confounded with catch selectivity it is preferable to estimate the matrix it within the assessment model. There is some question whether molting probability was simultaneously estimable. We examined both cases: model 2.i: estimate molting probability using base model likelihood (newshell and oldshell combined), model 2.io: estimate molting probability revised likelihood (newshell and oldshell separate), and model 2.ii assume molting probability 1.0 for all length classes.

Winter survey data usage

In the base model only length composition data from the winter survey is used. At the January 2014 workshop, an omission of associated abundance information was noted as unconventional and it was recommended to either (1) include the pot survey CPUE data as an index of abundance or (2) remove all winter pot survey data from the model. For this assessment we have explored both of those options.

Trawl survey selectivity

At the September 2013 meeting, the CPT recommended separate NMFS and ADF&G trawl survey selectivity curves, which approach was implemented at the January 2014 workshop. Here we compare results of that approach with those of the other alternative models.

1. Evaluation of alternative model results

Log-likelihood

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Scenario | Total | TBA | CCPUE | WCPUE | TLP | WLP | CLP | REC | OBS | TAG | BMSY | MMB | OFL |
| 0 | 61.5 | 7.0 | -21.4 |  | 13.8 | 18.9 | 23.8 | 8.8 | 10.6 |  | 4.2 | 3.7 | 0.45 |
| 1 | 61.5 | 7.0 | -21.4 |  | 13.8 | 18.9 | 23.8 | 8.8 | 10.6 |  | 4.2 | 3.7 | 0.46 |
| 2.i | 141.9 | 6.9 | -21.5 |  | 15.3 | 25.9 | 21.1 | 9.5 | 10.7 | 74.0 | 4.2 | 3.7 | 0.46 |
| 2.io | 213.6 | 6.5 | -22.3 |  | 16.4 | 50.6 | 53.4 | 11.9 | 23.0 | 74.0 | 4.2 | 3.7 | 0.46 |
| 2.ii | 141.8 | 6.9 | -21.5 |  | 15.4 | 25.9 | 21.1 | 9.4 | 10.7 | 73.9 | 4.2 | 3.7 | 0.46 |
| 3 | 115.7 | 10.6 | -19.3 | 45.5 | 14.4 | 20.2 | 26.0 | 8.6 | 9.7 |  | 3.7 | 3.5 | 0.47 |
| 4 | 39.3 | 7.3 | -22.8 |  | 13.5 |  | 23.3 | 8.1 | 9.8 |  | 4.3 | 3.6 | 0.41 |
| 2.i-3 | 196.0 | 10.3 | -19.5 | 45.4 | 14.6 | 27.5 | 23.2 | 9.6 | 9.9 | 73.8 | 3.7 | 3.5 | 0.48 |
| 2.i-4 | 112.2 | 7.1 | -23.2 |  | 16.1 |  | 21.3 | 7.9 | 9.7 | 73.2 | 4.4 | 3.7 | 0.44 |
| 2.ii-4 | 112.2 | 7.1 | -23.2 |  | 16.1 |  | 21.3 | 7.9 | 9.7 | 73.2 | 4.4 | 3.7 | 0.44 |

TBA: Trawl survey abundance

CCPUE: Commercial catch CPUE

WCPUE: Winter survey CPUE

TLP: Trawl survey length composition

WLP: Winter pot survey length composition

CLP: Summer commercial catch length composition

REC: Recruitment deviation penalty

OBS: Summer commercial catch observer discard length composition

TAG: Tag recovery data composition

1. Search for balance:

Summary of results from fitting alternative models:

There was no change in log-likelihood between combining and separating NMFS and ADF&G trawl survey selectivity.

Including tag recovery data resulted in a an estimated molting probability of 0.999 when newshell and oldshell were combined in the likelihood. However, when oldshell and newshell were separated in the likelihood molting probability was estimable (Table 11).

Including tag recovery data resulted in a winter pot survey selectivity estimated at 0.999 for length classes 1 – 5, and low selectivity for size class 6 (Figure 5).

Including winter pot survey CPUE resulted in poorer model fits (higher log-likelihood for each component).

Removing the winter pot survey data did not lower the log-likelihood of each component and caused difficulty of meaningfully estimating winter pot survey selectivity.

Regardless of the differences in model configurations all alternative models resulted in similar estimates of Bmsy, MMB, and OFL values.

From the perspective of estimating all parameters within the assessment model, inclusion of tagging data (alternatives 2.i, 2.io, and 2.ii) is preferred. The difference between 2.i and 2.ii is whether molting probability is model estimated or assumed equal to 1.0. The assumption and model estimation of molting probability is 1.0 (model 2.i and 2.ii) implies that all crab are newshell, or absence of oldshell crabs. This, in reality, is not the case. Probable reason for this model estimate (2.i) is because proportion of newshell and oldshell crabs was combined for calculation of likelihood (Appendix A). On the other hand, when oldshell components are separated in the likelihood calculation (model 2.io), the model was able to estimate molting probability. Even so, in terms of overall model fit there was little difference among all the three models. A further result of the models 2.i, 2.io, and 2.ii was changing estimates of winter pot selectivity to 1.0 for all length classes, except for the last length class (Figures 5 a b). This seems unrealistic, and further investigation on this issue is warranted.

Inclusion of the winter pot survey CPUE (model 3) resulted in a poorer model fit (i.e., increased log-likelihood) to trawl survey abundance and commercial catch CPUE. This may indicate presence of internal conflicts between summer and winter abundance indices. The winter pot survey data may not reflect abundance and length composition of the population. The survey occurred on ice fields inshore of Nome where popular commercial and subsistence fishery occurred. The above reasons may favor removal of the winter survey data from the assessment model (model 4). However, removal of the winter survey data also resulted in a loss of the model’s ability to estimate winter pot survey selectivity, leading to convergence failure. In the assessment model, winter pot selectivity is used as a proxy for a selectivity of winter commercial and subsistence harvests. Unrealistic selectivity may result in unrealistic estimates of the length composition of discards and catch and the overall winter harvest.

One option to counter this problem is to include an assumed winter pot selectivity, such as assuming 1.0 for all length classes or use the selectivity of the base model. However, because winter harvest is small, uncertainties of selectivity is unlikely to impact overall model fit and projections. Monitoring of the length composition of the winter commercial and subsistence fisheries is a priority objective due to recent increases in the magnitude of the winter harvest (Table 2).

Considering the above, we recommend the use of model 2.io for the assessment. The model uses all available data and has makes fewer assumptions. While our results suggest that some model simplification might be appropriate, (e.g., combining trawl NMFS and ADFG survey selectivity, winter pot selectivity = 1.0 for length classes 1-5), our preference is to not to simplify the model. It is our experience that re-evaluation of the reasons for model simplification are often requested each time composition of CPT membership changes.

**Results**

* 1. List of effective sample sizes and weighting factors (Figures 4a,b)

Estimated implied effective sample sizes were calculated as



where and are observed and estimated length compositions in year *t* and length group *l*, respectively. Estimated effective sample sizes vary greatly by year through the time series (Figures 4a,b,c).

Input effective sample sizes for length proportion data:

|  |  |
| --- | --- |
| Survey data | Sample size |
| Summer commercial, winter pot,  and summer observer | minimum of 0.1× actual sample size or 10 |
| Summer trawl and pot survey | minimum of 0.5× actual sample size or 20 |

Weighting factor:

Recruitment SD: *SDR* = 0.5

Winter pot survey CPUE SD: *SDRw* = 0.3

2. Tables of estimates.

1. Model Parameter estimates (Tables 10, 11, 12, 13).
2. Abundance and biomass time series (Table 14)
3. Recruitment time series (Table 14).
4. Time series of catch and biomass (Table 15)

3. Graphs of estimates.

a. Molting probability and trawl and pot survey selectivity (Figure 5)

b. Trawl survey abundance and model abundance (Figure 6)

c. Estimated male abundances (recruit, legal, and total) (Figure 7)

d. Estimated mature male biomass (Figure 8)

e. Time series of catch standardized CPUE (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 (Figure 9, 11)

b. Model fits to survey numbers (Figure 6, 11).

c. Model fits to catch and survey length-class proportions (Figure 12, 13, 14, 15, 16).

d. Marginal distribution for the fits to the composition data: (Figure 13).

1. Plots of input vs. implied effective sample size: frequency (Figure 4a), correlation (Figure 4b), and time series (Figure 4c).

f. Tables of RMSEs for the indices:

|  |  |  |  |
| --- | --- | --- | --- |
| Indices | Model 0 | Model 2.i | Model 2.io |
| Trawl survey | 0.284 | 0.282 | 0.268 |
| CPUE | 0.493 | 0.497 | 0.500 |

1. QQ plots and histograms of residuals (Figure 11).

5. Retrospective analyses (Figure 17)

1. Uncertainty and sensitivity analyses.

None

1. ***Calculation of the OFL***

1. Specification of the Tier level and stock status.

The Norton Sound red king crab stock is currently placed in Tier 4 (NPFMC 2007). 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 capture the essential population dynamics. Whereas tier 4 stocks are assumed to have reliable estimates of current survey biomass and instantaneous M, the estimates for the Norton Sound red king crab stock remain uncertain. Survey biomass is based on triennial trawl surveys with CVs ranging from 15-42% (Table 4).

The OFL is determined using the OFL control rule

|  |  |
| --- | --- |
|  | (1) |
|  | (2) |
|  | (3) |

where *B* is mature male biomass (MMB), *BMSY* proxy is average mature male biomass over a specified time period, *M* = 0.18 is instantaneous natural mortality, and *γ* = 1. For Norton Sound red king crab, MMB is defined as the biomass of male crab measuring at least 94mm CL. The default data used for the selection of the *BMSY* proxy is the survey MMB. The only available survey MMB data for the Norton Sound red king crab stock are triennial trawl surveys. We used the *model estimated* MMB for calculation of *BMSY* proxy from 1980 to present.

*BMSY* proxy = average model estimated MMB from 1980-2014

OFL was calculated for retained catch and total model male catch. The retained catch OFL is based on legal crab biomass catchable to summer commercial pot fisheries (*Legal\_B*) that was calculated as: Projected legal abundance (July 1st) × Commercial pot selectivity × Proportion of legal crab per length class × Average weight (lb) by length class.







where *Ns,l* and *Os,l* are summer abundances of newshell and oldshell crabs in length class *l* in the terminal year, *Ll* is the proportion of legal males in length class *l*, *Ss,l* is summer commercial catch selectivity, *wml* is average weight in length class *l* and *hm* is handling mortality rate.

The total model male OFL is



Predicted legal male and mature male biomass in 2014 are:

Legal male biomass:

3.05 million lb with a standard deviation of 0.46 million lb. (model 0)

3.22 million lb with a standard deviation of 0.49 million lb. (model 2.i)

3.19 million lb with a standard deviation of 0.48 million lb. (model 2.io)

Mature male biomass:

3.66 million lb with a standard deviation of 0.66 million lb. (model 0)

3.72 million lb with a standard deviation of 0.64 million lb. (model 2.i)

3.71 million lb with a standard deviation of 0.64 million lb. (model 2.io)

*BMSY* proxy was calculated as an average MMB during 1980-2014 periods.

4.18 million lb (model 0)

4.21 million lb (model 2.i)

4.19 million lb (model 2.io)

Since projected MMB for 2014was less than *BMSY* proxy, *FOFL* calculation was based on equation (2),



*FOFL* = 0.156 Model 0

*FOFL* = 0.157 Model 2.i

*FOFL* = 0.157 Model 2.io

Retained OFL for summer commercial fishery is

OFLr = 0.437 million lb. Model 0

OFLr = 0.464 million lb. Model 2.i

OFLr = 0.463 million lb. Model 2.io

Non retained OFL for summer commercial fishery is

OFLnr = 0.017 million lb. Model 0

OFLnr = 0.013 million lb. Model 2.i

OFLnr = 0.014 million lb. Model 2.io

Total OFL for summer commercial fishery is

OFLT = 0.454 million lb. Model 0

OFLT = 0.477 million lb. Model 2.i

OFLT = 0.477 million lb. Model 2.io

1. ***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 2013 as follows:

**Tier 4 crab stocks**

Calculation of a distribution for the OFL for Tier 4 stocks involves repeating four steps (detailed below). The aim is to have the median of the distribution for the OFL equal the point estimate (so that P\*=0.5 implies that the ABC equals to the point estimate of the OFL). The proposed steps are: (a) Sample current MMB from a normal distribution with mean given by the point estimate of current MMB and CV equal to the sampling CV. (b) The *B*MSY proxy is the average MMB over a pre-specified set of years. Uncertainty in the *B*MSY proxy only accounts for uncertainty in MMB for the years for which it is assumed the stock was “at *B*MSY” and not uncertainty in the years concerned. For each of the years used when defining the *B*MSY proxy, sample MMB from a distribution with mean given by its point estimate and CV equal to the sampling CV. The pseudo BMSY proxy is then the average of the samples values. (c)Sample *M* from a normal distribution with mean equal to the assumed *M* and CV equal to an assumed CV (e.g. 0.2). (d) Compute the OFL. Form a cumulative distribution for the OFL from the sampled values. Find the median of this distribution. Using normal quantiles to rescale the distribution so that the median equals the OFL (similar to a bias-corrected bootstrap).

For the Norton Sound red king crab, calculation of the OFL is based on MMB and applied to summer commercial retained legal male biomass. For calculation of the ABC, default percentile is P\* = 49; however, for the Norton Sound Stock the NPFMC adopted 10% buffer of OFL (i.e., ABC = 0.9×OFL) in 2012.. Based on the status change from 4a to 4b a larger buffer may be recommended.

Retained ABC for legal male crab is 90% of OFL

ABC = 0.9\*OFL

ABC = 0.394 million lb. Model 0

ABC = 0.417 million lb. Model 2.i

ABC = 0.417 million lb. Model 2.io

This ABC is inclusive of both summer commercial and winter commercial/subsistence fishery.

1. ***Rebuilding Analyses***

Not applicable

1. ***Data Gaps and Research Priorities***

The major data gap that hinder this year’s OFL/ABC calculation is uncertainties regarding biomass of Norton Sound red king crab. In addition, life-history of the Norton Sound red king crab stock is poorly understood. This includes size-at-maturity, natural mortality rate, timing and locations of reproduction, and location of females during summer.

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