2011 Saint Matthew Island Blue King Crab Stock Assessment

W. Gaeuman, ADF&G, Kodiak
September 2011

Executive Summary

1. Stock: Blue king crab, *Paralithodes platypus,* Saint Matthew Island, Alaska.

2. Catches: Peak historical harvest was 9.454 million pounds (4,288 t) in 1983/84. An apparent stock collapse in 1998/99 resulted in a ten-year closure of the fishery. The stock was declared rebuilt in 2009, and fishing resumed in 2009/10 with a TAC of 1.167 million pounds (529.3 t) and a fishery-reported retained catch of 0.461 million pounds (209 t). The 2010/11 TAC was 1.600 million pounds (725.7 t), and the fishery reported a retained catch of 1.264 million pounds (573.3 t). Total male discard mortality in the 2010/11 directed fishery is estimated from ADF&G crab-observer data at 0.140 million pounds (63 t), assuming 20% handling mortality. Total male bycatch mortality in the 2010/11 groundfish fisheries is estimated from NMFS observer data at 0.004 million pounds (2 t).

3. Stock biomass: Survey indices are generally consistent with increasing stock biomass in recent years. Trawl-survey estimated mature-male biomass has increased every year except one from 2.48 million pounds (1,130 t; estimated CV 0.32) in 2003, the lowest in the 34-year time series used in this assessment, to 17.95 million pounds (8,141 t; estimated CV 0.37) in 2010, and to 21.07 million pounds (9,557 t; estimated CV 0.53) in 2011. This latter value is the second highest in the time series after the 1982 estimate of 30.75 million pounds (13,950 t; estimated CV 0.32).

4. Recruitment: Information about recruitment is limited because of the generally small number of crab captured in the annual NMFS trawl-survey. Under the previous model-based assessment methodology, recruitment has been assessed in terms of the number of male crab entering the 90-104 mm CL size class in each year. Results from both the trawl and pot surveys suggest that recruitment has been strong in recent years, with the 2010 area-swept estimate of abundance in this size class at 3.927 million animals, the highest in the time series. Although the 2011 estimate of 1.693 million crab is less than half last year's number, it is still well above the 34-year average of 1.141 million.

5. Management performance: Estimated 2010/11 total male catch is 1.407 million pounds (638 t). This estimate sums fishery-reported retained catch, estimated total male discard mortality in the directed fishery, and estimated bycatch mortality in the groundfish fisheries. Given the 2010/11 OFL of 2.29 million pounds (1,040 t), there is thus no evidence of overfishing during the past fishery year; and with estimated 2010/11 stock biomass well above the MSST, neither is there evidence that the stock is overfished. See table below. (All biomass measures in millions of pounds with metric ton equivalents in parentheses.)

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL	ABC
2008/09	4.0 (1,800)	10.74 (4,870)	Fishery Closed		0.20 (91)	1.63[c] (739)	-
2009/10	3.4 (1,500)	12.76 (5,790)	1.167 (529.3)	0.461 (209)	0.530 (240)	1.72[d] (780)	-
2010/11	3.4[a] (1,500)	14.77[a] (6,700)	1.600 (725.7)	1.264 (573)	1.407 (638)	2.29[d] (1,040)	-
2011/12	TBD	15.80[b] (7,167)	TBD	NA	NA	3.21[e] (1,450)	3.17[e] (1,440)

[a] Based on current fall 2011 assessment.
[b] Fall 2011 projection assuming $F=F_{OFL}$.
[c] Retained catch OFL.
[d] Total male catch OFL.
[e] Total mature-male catch.

6. Basis for the OFL: Estimated Feb 15 mature-male biomass (MMB_{mating}) is used as the measure of biomass for this Tier 4 stock, with males measuring 105 mm CL or more considered mature. Past recommendations were to compute the B_{MSY} proxy as average estimated 1989/99 – 2009/10 MMB_{mating}, determined to be 6.85 million pounds (3,110 t) under the current survey-based methodology. The F_{MSY} proxy is the assumed 0.18yr^{-1} instantaneous natural mortality. See table below. (All biomass measures in millions of pounds with metric ton equivalents in parentheses.)

Year	Tier	B_{MSY}	B (MMB_{mating})	B/B_{MSY}	F_{OFL}	γ	Basis for B_{MSY}	Natural Mortality	P^*
2008/09	4a	7.39 (3,350)	10.74 (4,870)	1.45	0.18yr^{-1}	1	1989/90 - 2008/09	0.18yr^{-1}	-
2009/10	4a	6.95 (3,150)	12.76 (5,790)	1.84	0.18yr^{-1}	1	1989/90 -2009/10	0.18yr^{-1}	-
2010/11	4a	6.86 (3,110)	15.29 (6,940)	2.23	0.18yr^{-1}	1	1989/90 - 2009/10	0.18yr^{-1}	-
2011/12	4a	6.85[a] (3,106)	15.80[b](7,167)	2.31	0.18yr^{-1}	1	1989/90 - 2009/10	0.18yr^{-1}	0.49

[a] Based on current fall 2011 assessment.
[b] Fall 2011 projection assuming $F = F_{OFL}$.

7. Distribution of the OFL: Estimated OFL is assumed to have a median-unbiased lognormal distribution, inherited from the NMFS trawl-survey estimate of mature-male biomass.

8. Basis for the ABC: Current recommendations are to use $P^* = 0.49$, where $P(\,ABC > OFL\,) = P^*$. In view of 7), $ABC = exp[\sigma\Phi^{-1}(0.49)]\widehat{OFL}$, where $\sigma^2 = var[\ln(\widehat{OFL})]$ and Φ denotes the standard-normal distribution function. An estimate of $var[\ln(\widehat{OFL})]$ is available in terms of the trawl-survey estimate of the coefficient of variation of survey mature-male biomass.

9. Summary of rebuilding analyses: The stock was declared rebuilt in 2009.

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

Time series used in the analysis have been updated to include the 2010/11 fisheries and the 2011 NMFS EBS trawl survey. In addition, ADF&G crab-observer data for the years 1990/91-1998/99, 2009/10, and 2010/11have been incorporated into this assessment. These data provide information on catch and catch composition of both retained and discarded crab in the directed pot fishery.

Changes in Assessment Methodology

To circumvent some of the difficulties associated with the existing stock assessment model, as described in SSC and CPT comments given in §B, and to arrange that the assessment process for this stock be robust, transparent, and well documented, the author has developed an alternative 3-stage CSA assessment model. Jim Ianelli provided the author with some helpful assistance in that effort prior to the Feb 2010 CPT meeting, where a preliminary version of the proposed model was presented. An updated description of the model, along with results for the 2011 assessment year, is presented in Appendix A to this report. Pending approval of the proposed model, a completed 2011 survey-based assessment is here presented as the default approach.

Changes in Assessment Results

In spite of the different methodologies employed, as well as prosecution of another SMBKC fishery, results from this 2011 assessment are in keeping with those from the 2010 assessment, which likewise indicated increasing stock biomass well above B_{MSY} and moderate to strong recruitment. However, with stock biomass potentially near historical highs and evidence of reduced recruitment, reason exists to anticipate an end to the positive trends of the last few years.

B. Responses to SSC and CPT Comments

CPT and SSC Comments on Assessments in General

- May 2010 CPT
  Comments: *Some assessments provided results in metric tons. The CPT recommendation to use metric tons refers only to the ACL analysis and traditional assessment currencies (lbs) should continue to be used in stock assessments.*

  The team requested that all assessments explain how the groundfish bycatch data are used in the assessment and that all assessment chapters should be consistent in distinguishing and separately presenting groundfish bycatch from fixed gear fisheries and trawl gear fisheries.

  Response: See June SSC comments below regarding use of metric tons. In this document, groundfish bycatch data from the fixed-gear and trawl fisheries are treated separately and their use explained.

- June 2010 SSC
  Comments: *In order to have greater consistency between assessments, the SSC recommends that catch statistics reported in the executive summary section contain both metric tons and pounds (millions).*

  Response: Catch statistics here reported in the executive summary section are given in both units.

- Sept 2010 CPT
  Comments: No new comments.

- Oct 2010 SSC
  Comments: No new comments.

- May 2011 CPT
  Comments: *Each assessment author will provide an 'author's ABC' (with appropriate rationale), along with the max ABC…*

  Response: Noted.

- June 2011 SSC
  Comments: No new comments.

CPT and SSC Comments Specific to SMBKC Stock Assessment

- Sept 2010 CPT
  Comments: *The CPT recommended that MSST should be recalculated using the BMSY estimate from the current assessment and the assessment document updated. For the May 2011 assessment, the CPT recommends that the authors: 1) analyze why some*

parameters in Table 11 appear not to change from initial values; 2) calculate F35% per the ACL analysis for the May model; 3) add a more detailed description of model changes as an appendix to the May model; and 4) incorporate the 2010 ADF&G pot survey data.

Response: The fall 2010 MSST was appropriately updated. The 2010 ADF&G St Matthew Island blue king crab pot-survey data have been presented in this report (and also included in the alternative model-based assessment). In addition, 1990/91-1998/99, 2009/10, and 2010/11 ADF&G crab-observer data have been integrated into the assessment. Regarding items 1 - 3, see comments and responses from Feb 2011 NPFMC crab modeling workshop and subsequent SSC review with respect to implementation of a revised model.

- Oct 2010 SSC
  Comments: *St. Matthew blue king crabs are assessed with a four-stage catch survey analysis of males only and managed under a Tier 4 designation. The authors have been responsive in addressing previous SSC comments. The SSC looks forward to the results of the author's ongoing efforts to reconcile discrepancies in recruits estimated by the model and those indicated by pot surveys (see SSC's comments in June 2010). The SSC endorses the Crab Plan Team's recommendations for the May 2011 assessment.*

  Response: See comments and responses from Feb 2011 NPFMC crab modeling workshop and subsequent SSC review.

- Feb 2011 NPFMC Crab Modeling Workshop
  Comments concerning proposed use of existing SMBKC model for Pribilof Island RKC and BKC stocks: *The model is initialized based on the survey data and assumes no observation errors in the initial abundances. Ideally these should be estimated within the model to allow for the inclusion of observation errors.*

  The existing code is not well documented and there are a large number of undocumented fixed constants throughout the code. There are a number of recommendations that involve either developing a simplified model (i.e., similar to the model Andre Punt showed during the workshop), to reducing the current model structure from four stages to three stages, to completely rewriting the code such that the investigators are much more intimate with the assessment model. The time commitment for each of these could be considerable and the SSC should advise priorities for modeling work. In any case, the existing model should not be used until it is fully documented and the code itself is peer reviewed by an independent expert who is familiar with ADMB and nonlinear parameter estimation. Note that during the workshop, a few participants examined the code and it was questionable if the actual objective function was continuous and differentiable (e.g., inappropriate use of if statements in the calculations).

  Short - term Recommendations: 1) Collapse the postrecruits and recruits into one category (i.e., develop a three-stage model); 2) Develop a simplified assessment model *based on single estimated growth increment matix G: $N_{y+1}=G\,S_y\,N_y + R_{y+1}$ where N is a vector of numbers at length, S is a vector of survival rates (incl. effects of fishing), and R is a vector of new recruits; 3) Completely rewrite the current assessment model such that the assessment authors are more intimate with the data inputs, model equations, and various undocumented constants can then be addressed; 4)* ***Pribilof Islands and St. Matthew stock assessments share similar issues, and model development for both of these areas should be consistent. There was a strong consensus that the development of the assessment model should be done in concert for both of these areas*** [bold type added].

Response: See June 2011 SSC comments and response.

- March 2011 SSC review of Feb 2011 NPFMC Crab Modeling Workshop
  Comments concerning Pribilof Islands red and blue king crab and implications for St. Matthew Island blue king crab: *A preliminary 4-stage assessment model for Pribilof Island red and blue king crab was reviewed during the workshop. The workshop report highlighted issues with these models that relate to model initialization using survey data, code documentation and discontinuous objective function.*

  Workshop participants recommended that the existing model should not be used until it is fully documented and the code itself is peer reviewed by an independent expert who is familiar with ADMB and non-linear parameter estimation. The SSC concurs with this conclusion.

  Workshop participants made four short-term recommendations relating to treatment of post-recruits and recruits, simplification of models growth increment matrix, model documentation and consistency between stocks. The SSC agrees with these recommendations and encourages the stock assessment authors to move forward to address these issues. However, the SSC expresses some concern about the workshop recommendation to collapse post-recruits and recruits into one category so that the CSA model would become 3-stage instead of 4-stage. Estimates of recruits and post-recruits result from direct measurements of size and shell condition and include the highest quality data available from the survey and the only data available from commercial fishery. On the other hand, the two pre-recruit stages must be estimated based on size measurements, as well as estimates of molting probabilities and growth increments, both of which are estimated with error. The SSC would like to see results from both 3- and 4-stage CSA models prior to any change in assessment methodology.

  The highest priority should be placed on the workshop recommendations that encourage authors to carefully examine the assessment model equations, ensure constants are correct and documented and that the objective function is appropriate. ***Since directed fisheries for Pribilof red and blue king crab are closed, the most urgent issue is to document the model parameterization for St. Matthew blue king crab. This will ensure that the model provides an appropriate basis for OFL and ACL/ABC specifications. As a precaution against the possibility that the CPT does not approve use of the CSA***

model for St. Matthews blue king crab, the SSC requests that the authors also estimate biological reference points based on survey biomass or some other index of abundance.

Response: See June 2011 SSC comments and response.

- May 2011 CPT

  Comments: *Based on results of the NPFMC modeling workshop the author was requested to revise the stock assessment model, improve and or replace the model and prepare a survey-based assessment as a fallback.*

  The team recommends that the assessment author reformulate equations for survey-based assessment to be consistent with other Tier 4 assessments. The variance for the OFL is proposed to be based on the delta-method. If the author continue to use this approach, account will need to be taken of the variance of M (and hence the proxy for F_{MSY}). The OFL was computed in the assessment document as exploitation rate multiplied by legal biomass at the time the fishery with bycatch and discarded then added. This is incorrect and the retained catch OFL should be the total OFL less bycatch and discard mortality. The team recommends formulating a more generic model so that additional scenarios can be explored. The team recommends reviewing the model description and additional output from model in September to provide opportunity for additional feedback on model development.

  Response: It is unclear to the author exactly which equations are in need of reformulation or in what way they need to be reformulated. On the other hand, the author has revised both computation of the OFL and specification of its variance. See June 2011 SSC comments and response regarding proposed alternative model.

- June 2011 SSC

  Comments: *The St. Matthew Island blue king crab fishery has been managed under tier 4 based on a stock assessment using a four-stage catch-survey analysis (CSA). In June 2010, the SSC discussed difficulties of the model to duplicate the large proportion of recruits in the pot surveys. Other issues with the model have since emerged and were discussed during the crab modeling workshop held in Seattle in February 2011. In their report, the Crab Plan Team provided additional guidance to the author. The model and its code are currently being revised to address these problems, and a simpler three-stage version is also being developed as an alternative. As a precaution against the possibility that the Crab Plan Team does not approve the CSA model for use this year, in the SSC's March 2011 meeting report the author was advised to estimate biological reference points based on survey biomass or some other index of abundance. The April 2011 draft assessment for St. Matthew Island blue king crab contains such a proposed fall-back procedures for use in managing the fishery in 2012. Given the issues with the assessment model, the SSC wishes to receive a presentation on modeling efforts for St. Matthew Island blue king crab at the October 2011 meeting at which time OFL and ABC recommendations will be made.*

Response: The author has continued development of an alternative 3-stage CSA assessment model and included documentation and 2011 assessment-year results as an appendix to this report.

C. Introduction

Scientific Name
The blue king crab is a lithodid crab, *Paralithodes platypus* (Brant 1850).

Distribution
Blue king crab are sporadically distributed throughout their range in 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 of Cape Newenham (58°39' N. lat.) and south of Cape Romanzof (61°49' 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 based on a limited number of variable genetic markers using allozyme electrophoresis methods (1997, NOAA grant Bering Sea Crab Research II, NA16FN2621). Tag-return data from studies by the National Marine Fisheries Service (NMFS) on blue king crab in the Pribilof Islands (n = 317) and St. Matthew Island (n = 253) support the idea that legal-sized males do not migrate between the two areas (Otto and Cummiskey 1990). St. Matthew Island blue king crab (SMBKC) tend to be smaller than their Pribilof conspecifics, and the two stocks are managed separately, with legal sizes of 5.5 in carapace width (CW) in the St. Matthew Island Section and 6.5 in CW in the Pribilof District.

Life History
Like the red king crab, *Paralithodes camtshaticus*, the blue king crab is considered a shallow water species by comparison with its lithodid cousin the golden or brown king crab, *Lithodes aequispinus* (Donaldson and Byersdorfer 2005). Adult male blue king crab are found at an average depth of 70m (NPFMC 1998). Mature females have a biennial ovarian cycle and 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. Size at 50% maturity is estimated at 77 mm carapace length (CL) for SMBKC males and 81 mm CL for females. Otto and Cummiskey (1990) report an average growth increment of 14 mm CL for adult males.

The estimate of instantaneous natural mortality for all species of king crabs in the eastern Bering Sea is 0.2 as defined by the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs (NPFMC 1998). In the analysis described here, natural mortality is assumed to be 0.18 based on a maximum age of 25 and the 1% rule (Zheng 2005), consistent with recent model-based assessments for this stock (2009 and 2010 SAFE).

Management History

The SMBKC fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990). Ten U.S. vessels harvested 1.202 million pounds in 1977, and harvests peaked in 1983 when 164 vessels landed 9.454 million pounds (Table 1). The fishing seasons were generally short, lasting less than a month. From 1986 to 1990 the fishery was fairly stable, harvesting a mean of 1.252 million pounds. The fishery was declared overfished and closed in 1999 when the stock biomass estimate was below the minimum stock size threshold (MSST) of 11.0 million pounds as defined by the Fishery Management Plan 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 commercial fishery and in the 1999 ADF&G near-shore pot survey, as well as the low numbers across all male crab size groups caught in the annual NMFS eastern Bering Sea trawl survey from 1999 to 2005. In November of 2000, Amendment 15 to the FMP for the 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 harvest strategy established in regulation (5 AAC 34.917), which was adopted by the BOF in March 2000 and modified in 2009 by the Alaska Board of Fisheries, and area closures to control bycatch, as well as gear modifications and an area closure for habitat protection. In addition, commercial crab fisheries near St. Matthew Island were scheduled in the fall and early winter to reduce the potential for bycatch mortality of vulnerable molting and mating crab.

NMFS declared the SMBKC stock rebuilt on Sept 21, 2009, and the fishery was reopened after a 10-year closure on Oct 15, 2009 with a TAC (total allowable catch) of 1.167 million pounds, closing again by regulation on Feb 1, 2010. Seven participating vessels landed a catch of 460,859 pounds with a reported effort of 10,484 pot lifts and an estimated CPUE of 9.9 retained crab per pot lift (Bowers et al. 2011). In 2010/11 ADF&G increased the TAC to 1.600 million pounds. Harvest again fell short of the TAC, with the fishery reporting total landings of 1,263,982 pounds in 29,344 pot lifts for a CPUE of 10.2 retained crab per pot lift (B. Bechler, ADF&G, pers. comm.).

Though historical observer data are limited, bycatch of female and sublegal male crab from the directed blue king crab fishery off St. Matthew Island was relatively high in past years, with estimated total bycatch in terms of number of crab captured sometimes twice as high or higher than total catch of legal crab (Moore et al. 2000). By comparison, pot-lift sampling by ADF&G crab observers in 2009/10 indicates a significant reduction in the bycatch of nontarget animals (Gaeuman 2011), which may be attributable to the later timing of the contemporary fishery (D. Pengilly, ADF&G, Kodiak, pers. comm.). In addition to bycatch in the directed fishery, some limited bycatch of non-retained SMBKC has historically been observed in the eastern Bering Sea snow crab fishery, although ADF&G crab observers recorded no blue king crab in 1,646 sampled pot lifts during the 2009/10 snow crab season and just two sublegal males in 2,142 sampled pot lifts during the 2010/11 season (ADF&G Crab Observer Database). The St. Matthew Island golden king crab fishery, the third commercial crab fishery in the area, typically occurs in areas with depths exceeding blue king crab distribution. Variable but mostly limited SMBKC bycatch has also occurred in the eastern Bering Sea groundfish fisheries.

D. Data

Summary of New Information

This assessment incorporates ADF&G crab observer data for the years 1990/91-1998/99, 2009/10, and 2010/11. These data provide information on catch and catch composition in the directed pot fishery. Trawl-survey and fisheries data time series have been updated.

Major Data Sources

Time series data sources used in this assessment are annual directed-fishery retained-catch statistics from fish tickets (1978/79-1998/99, 2009/10, 2010/11; Table 1); the annual NMFS Eastern Bering Sea trawl survey (1978-2011; Table 2); ADF&G crab-observer pot-lift sampling (1990/91-1998/99, 2009/10, 2010/11; Table 3); and NMFS groundfish-observer bycatch biomass data (1992/93-2010/11; Table 4). Information concerning the NMFS trawl survey as it relates to commercial crab species is available in Chilton et al 2011. Figure 3 maps stations from which SMBKC trawl-survey data were obtained. Crab-observer sampling protocols are detailed in the crab-observer training manual (ADF&G 2010). Groundfish SMBKC bycatch data come from NMFS Bering Sea reporting areas 521 and 524 (Figure 4).

Other Data Sources

Key population, survey, and fishery parameters assumed in the survey-based assessment presented here are listed in the following table.

Parameter	Value	Justification
Natural Mortality	0.18 yr^{-1}	Zheng 2005.
Trawl Survey Catchability	1	Default.
Directed Fishery Handling Mortality	0.2	2010 SMBKC SAFE.
Directed Fishery Timing	Mid-season	Default.
GF Trawl and Fixed-gear Handling Mortalities	0.8, 0.5	2010 SMBKC SAFE.
GF Fishery Timing	Feb 15	Simplifying approximation.
SMBKC Length-to-weight Coefficients[a]	0.000502, 3.107158	Chilton and Foy 2010, unpublished.

[a] $W = 0.000502 * CL^{3.107158}$, where weight W is in grams and carapace length CL is in millimeters.

Major Excluded Data Sources

Groundfish bycatch size-frequency data (various years; Tables 5 and 6), though used in the 2010 model-based assessment, played no direct role in this analysis. Data from the triennial ADF&G SMBKC pot survey (1995, 1998, 2001, 2004, 2007, 2010; Table 7) were likewise not directly incorporated into the assessment methodology described in this report. The pot-survey data are nevertheless useful in a comparative sense as a credible index of abundance, especially as they arguably represent a more intensive sampling of an important SMBKC population component than do data from the trawl survey (Figure 3). See Watson (2008) for a description of ADF&G SMBKC pot-survey methods. The pot-survey data are used in the alternative model-based assessment presented in Appendix A.

E. Analytic Approach

History of Modeling Approaches for this Stock

A four-stage catch-survey-analysis (CSA) assessment model has been used in recent years to estimate abundance and biomass and prescribe fishery quotas for the SMBKC stock (2010 SAFE, 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 of 90 mm or more is modeled in terms of four crab stages: stage 1 (90-104mm CL); stage 2 (105-119 mm CL); stage 3 (newshell 120-133 mm CL); and stage 4 (oldshell $\geq$ 120 mm CL and newshell $\geq$ 134 mm CL). These stage definitions are motivated by an estimated average growth increment of about 14 mm per molt for SMBKC (Otto and Cummiskey 1990), with the slightly narrower stage-3 size range intended to buttress the assumption that all stage-3 crab transition to stage 4 after one year (Z. Zheng, ADF&G, pers. comm.). To be of legal size in the SMBKC fishery, male crab must measure at least 5.5 in CW, including spines, for which 120 mm CL is considered a management proxy, whereas male crab measuring at least105 mm CL are considered mature. It follows that for assessment purposes stages 3 and 4 comprise the “legal” crab, whereas stages 2, 3, and 4 comprise the “mature” crab. The model was implemented using the software AD Model Builder (ADMB Project 2009).

Since the 2010 assessment, various concerns have arisen about use of the existing model, culminating in NPFMC crab modeling workshop, CPT, and SSC recommendations that include development of an alternative potentially simpler model and provisional assessment based on survey biomass or some other index of abundance (NPFMC March 2011, CPT May 2011, SSC June 2011). In the wake of discussions at the 2011 NPFMC crab modeling workshop, the author began development of an alternative 3-stage CSA model along the lines of Collie et al (2005) and presented a description of that model to the CPT in May 2011. The author has continued development of the alternative model and included documentation and 2011 assessment year results in Appendix A. The survey-based assessment described in what follows is intended as the default pending acceptance of the alternative model.

Assessment Methodology

For estimation of required management quantities, the approach used here relies primarily on directed-fishery reported catch (Table 1) and results from the annual NMFS EBS trawl survey (Table 2). ADF&G crab-observer data (Table 3) are used to develop estimates of discard mortality biomass in the directed fishery, whereas estimates of groundfish bycatch mortality are based on NMFS groundfish observer bycatch biomass data (Table 4). Note that NMFS survey area-swept estimates of SMBKC abundance and biomass come with considerable uncertainty and that any assessment methodology based primarily on them will necessarily suffer the same limitation.

State harvest strategy (5 AAC 34.917) requires estimates of assessment-year mature-male biomass MMB_{survey} and mature and legal-male abundances MMA_{survey} and LMA_{survey} at the time of the survey. Such estimates are directly available from NMFS trawl-survey results (Table 2), as are measures of their uncertainty. Determination of the federal overfishing level (OFL), including specification of a B_{MSY} proxy, requires estimation of mature-male biomass at time of mating MMB_{mating}, the Tier-4 proxy measure of stock biomass.

To estimate MMB_{mating}, the survey estimate of mature-male biomass MMB_{survey} is first discounted to the midpoint τ of the fishery under natural mortality M, assumed equal to 0.18 yr^{-1}. Fishery-reported retained-catch biomass B_{ret} (Table 1) is then subtracted, along with estimated directed-fishery mature-male discard mortality MMB_{dis} (Table 3). After further discounting the resulting biomass to Feb 15, the assumed time of mating, estimated bycatch mortality MMB_{GFmort} in the groundfish fisheries (Table 4) is additionally subtracted on the assumption that groundfish bycatch impacts primarily the mature population, approximately as a Feb 15 pulse effect. Figure 5 displays the four biomass time-series inputs. The calculation is given by

$$MMB_{mating} = (MMB_{survey} \exp(-\tau M) - B_{ret} - MMB_{dis}) \exp[-(0.63 - \tau) M] - MMB_{GFmort} . \qquad [1]$$

Directed-fishery mature-male discard mortality MMB_{dis} is estimated from fishery-reported retained catch and ADF&G crab-observer size-frequency sampling of animals in sampled pot lifts by the proportion of retained catch corresponding to the sample ratio ρ (Table 3) of estimated total mature-male discard weight to estimated total retained weight, after accounting for an assumed 20% handling mortality. Length-to-weight computations employ coefficients developed by Chilton and Foy (2010). For fishery years lacking observer data, i.e. 1978/79-1989/90 and the projection year 2011/12, the ratio is imputed from years with data. Groundfish bycatch mortality B_{GFmort} is estimated by ½ the sum of 80% of the blue-king-crab bycatch estimates reported for trawl, pelagic trawl, and non-pelagic trawl gear types and 50% of the estimates for all other gear types. The multipliers 0.80 and 0.50 represent assumed handling mortalities, whereas the factor ½ adjusts (crudely) for the male component of the bycatch. Groundfish bycatch estimates used in these computations come from NMFS reporting areas 521 and 524 (Figure 4.)

As Figure 5 shows, the magnitudes of retained catch, discard mortality, and groundfish bycatch mortality are typically small by comparison with mature-male biomass so that [1] leads to the approximation

$$MMB_{mating} \cong \exp[-(0.63) M] MMB_{survey}, \qquad [2]$$

which allows variance estimation and construction of approximate confidence intervals under the assumption that the survey estimate is lognormally distributed around the true value. It follows in any case that

$$\widehat{var}(MMB_{mating}) \cong 0.8 \widehat{var}(MMB_{survey}), \qquad [3]$$

with M = 0.18 yr^{-1} is considered given. Additional uncertainty is of course associated with, among other things, the natural mortality parameter M, which is not in fact known–and is almost certainly not identically 0.18 yr^{-1}.

Model Selection and Evaluation

The survey-based approach offered here is presented as a basic, comparatively simple, and more transparent alternative to what is at this time possible in terms of a model-based approach. It is expected that substantive results will be in line with those likely to come out of any reasonable model, modulo the considerable inherent uncertainty associated with trawl-survey area-swept estimates of crab abundance and biomass.

Results

Figure 6 displays the 34-year time series of estimated mature-male biomass at time of mating MMB_{mating}, together with approximate 95% confidence intervals based on [2] and the further assumption that MMB_{mating} inherits a median unbiased lognormal distribution from the survey estimate; Table 8 provides the numbers. The time series indicates a period of low stock biomass after an abrupt 1998/99 decline, which prompted a ten-year closure of the directed fishery and near-zero total fishing mortality. Stock biomass appears to begin rebuilding about midway through the closure, estimated MMB_{mating} showing a nearly monotone-increasing trend from 2003/04 through the 2011/12 OFL projection of 15.80 million pounds, second in the 34-year time series only to the 1982/83 estimate of 18.97 million pounds. In light of the high uncertainty associated with these estimates, it is worth noting here that the triennial ADF&G SMBKC pot survey data from 1995 – 2010 tell a similar story (Table 7): the 2001 and 2004 surveys signal a precipitous decline in stock biomass from 1998, followed by substantial increases in both 2007 and 2010. On the other hand, modest CPUEs and harvests falling well short of the TAC in each of the two fisheries prosecuted since its reopening in 2009 (Table 1) give some reason for skepticism. Nevertheless, the author believes the collective evidence supports the conclusion that stock biomass is at a high level relative to its status over the last three to four decades and that it is likely well above any reasonable B_{MSY} candidate.

Figure 7 shows survey-estimated mature and recruit abundances, as well as estimates of mature-male fishing mortality F relative to the F_{MSY} proxy $M = 0.18$ yr^{-1}. See Table 9 for the corresponding numbers. F was computed as $F = -\ln(1 - r)$ from the exploitation rate r determined by the ratio of estimated mature-male total fishing mortality biomass to estimated mature-male biomass from the survey discounted to the time of the fishery under natural mortality M. Both abundance time series generally reflect the same behavior described for MMB_{mating}, though the considerable 2011 down turn in recruitment compared to last year's estimate is a perhaps noteworthy exception. If real, it could portend decreasing stock biomass in the next year or two. By default, recruitment for this stock is poorly characterized in terms of males 90 – 104 mm CL. For that reason and given the available information, eg. Figure 7, it is unclear what link might exist between fishing pressure and recruitment, or between stock biomass and recruitment. For the time being, it can be expected that the limited knowledge of SMBKC biology and stock dynamics along with the considerable lack of precision associated with inputs needed for standard fisheries stock analysis methods will continue to trump meaningful application of many of those methods.

F. Calculation of The OFL

The overfishing level (OFL) is the fishery-related mortality biomass associated with fishing mortality F_{OFL}. The SMBKC stock is currently considered Tier 4 (NPFMC 2007). Thus given stock estimates or suitable proxy values of B_{MSY} and F_{MSY}, along with two additional parameters α and β, F_{OFL} is determined by the control rule

$$a)\quad F_{OFL} = F_{MSY}\,,\ when\ \ B / B_{MSY} > 1;$$
$$b)\quad F_{OFL} = F_{MSY}\,(B / B_{MSY} - \alpha)/(1-\alpha),\ when\ \ \beta < B / B_{MSY} \le 1;$$
$$c)\quad F_{OFL} < F_{MSY}\ \ with\ directed\ \ fishery\ F = 0,\ when\ \ B / B_{MSY} \le \beta\,,$$

where B is specified to be mature-male biomass at mating MMB_{mating}. Note that as B is itself a function of F_{OFL}, here taken to be

$$B=MMB_{survey}exp(-0.63M)exp(-F_{OFL}), \qquad [4]$$

in case b) numerical approximation of F_{OFL} is required. Previous recommendations for the stock are to use the period 1989/90-2009/10 to define a B_{MSY} proxy in terms of average estimated MMB_{mating} and to put $\gamma = 1.0$ with assumed stock natural mortality $M = 0.18$ in setting the F_{MSY} proxy value γM. The parameters α and β are assigned their default values $\alpha = 0.10$ and $\beta = 0.25$.

With F_{OFL} determined via the control rule, the (total mature-male catch) OFL is then calculated as

$$OFL = MMB_{survey}\ \exp(-\tau M)[1-\exp(-F_{OFL})], \qquad [5]$$

where τ is the time from the survey to the midpoint of the directed fishery.

For this stock there are three catch biomass components to consider: 1) directed-fishery retained catch B_{ret}; 2) directed-fishery mature-male discard mortality B_{dis}; and 3) mature-male bycatch mortality $B_{GFTmort}$ and $B_{GFFmort}$ in the groundfish trawl and fixed-gear fisheries. Accordingly, the OFL can be partitioned as

$$OFL = B_{ret} + B_{dis} + B_{GFTmort} + B_{GFFmort}\ , \qquad [6]$$

with B_{ret} constituting the retained catch portion of the OFL. For projection of assessment year quantities, groundfish bycatch mortalities are estimated by the averages $\bar{B}_{GFTmort}$ and $\bar{B}_{GFFmort}$ of estimates of male groundfish bycatch mortality from the prevous three years, and mature-male discard mortality B_{dis} is estimated using $0.2\rho B_{ret}$, where ρ is the ratio of mature-male discard weight to retained-catch weight from 2010/11 crab-observer size-frequency data and 0.2 is the assumed handling mortality in the directed fishery. Substitution into [6] then yields a retained-catch OFL of

$$OFL_{ret} = \frac{OFL-\bar{B}_{GFTmort}-\bar{B}_{GFFmort}}{1+0.2\rho}. \qquad [7]$$

Associated *OFL* directed-fishery discard mortality is back calculated as $0.2\rho OFL_{ret}$.

For the 2011/12 assessment year, averaging over 1989/90-2009/10 estimates of MMB_{mating} results in a B_{MSY} proxy of 6.85 million pounds. (This compares to 6.86 million pounds from last year's four-stage model-based assessment.) Using [4] gives $B = MMB_{mating}$ = 15.80 million pounds with $F_{OFL} = 0.18$, so that B/B_{MSY} = 2.31 > 1 and case a) of the control rule applies. The total catch *OFL* is thus 3.21 million pounds by [5], with the retained-catch portion equal to 2.96 million pounds by [7]. Complete partitioning of the 2011/12 OFL is provided in Table 9.

G. Calculation of The ABC

Given that stock biomass is very likely well above B_{MSY}, it may be assumed that, with high probability, the control rule would result in F_{OFL} equal to the F_{MSY} proxy under replication of the current assessment methodology. Assuming further that the survey estimate of mature-male biomass is lognormally distributed around the true value and treating τ (time to midpoint of fishery) and M (natural mortality) as known, we have by way of [5] that

$$\ln\left(\widehat{OFL}\right) = \ln\left(\widehat{MMB}_{survey}\right) - \tau M + \ln([1 - \exp(-M)]), \qquad [8]$$

so that $\ln\left(\widehat{OFL}\right)$ is normal with $\mathrm{var}\left[\ln\left(\widehat{OFL}\right)\right] = \mathrm{var}\left[\ln\left(\widehat{MMB}_{survey}\right)\right]$, which we can estimate using the survey estimate of survey-biomass coefficient of variation $\widehat{CV}_{survey}$ by $\ln(1 + \widehat{CV}_{survey}^2)$. In setting the allowable biological catch (ABC), current recommendation is to take *P* = 0.49*, where *P(ABC > OFL) = P**. Under the above assumptions, it then follows that

$$ABC = \exp[\sigma \Phi^{-1}(0.49)]\widehat{OFL}, \qquad [9]$$

where $\sigma^2 = var\left[\ln\left(\widehat{OFL}\right)\right]$ and Φ denotes the standard-normal distribution function. Putting τ = 0.44 and M = 0.18 yr^{-1}, this formulation then yields an author recommended

$$\begin{aligned} ABC &= \exp\left[\sqrt{\ln(1 + 0.525^2)}\,(-0.0251)\right](3.21) \text{ million pounds} \\ &= 3.17 \text{ million pounds.} \end{aligned} \qquad [10]$$

The author acknowledges that the full set of assumptions underlying this analysis, including, for example, that τ and M are known, is probably untenable and that some amount of additional uncertainty should therefore be included. The suggested ABC is accordingly presented as a maximum value consistent with the recommendation that *P* = 0.49.* A more general approach to setting the ABC is needed in the event that stock biomass appears more likely to be close to B_{MSY}.

H. Rebuilding Analysis

This stock is not currently under a rebuilding plan.

I. Data Gaps and Research Priorities

Currently, no recommendations regarding research priorities for this stock have been advanced.

I. References

ADF&G. 2010. Crab Observer Training and Deployment Manual. ADF&G Shellfish Observer Program, Dutch Harbor. Unpublished.

ADMB Project. 2009. AD Model Builder: automatic differentiation model builder. Developed by David Fournier and feely available from admb-project.org.

Bowers, F.R., M. Schwenzfeier, K. Herring, M. Salmon, K. J. Shaishnikoff, H. Fitch, J. Alas, R. and B. Baechler. 2011. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the westward region's shellfish observer program, 2009/10. Alaska Department of Fish and Game, Fishery Management Report No. 11-05, Anchorage. 251 pp.

Chilton, E.A., C.E. Armistead, and R.J. Foy. 2011. The 2010 eastern Bering Sea continental shelf bottom trawl survey: results for commercial crab species. NOAA technical Memorandum NMFS-AFSC-216, pp. 139.

Collie, J.S., A.K. Delong, and G.H. Kruse. 2005. Three-stage catch-survey analysis applied to blue king crabs. In: Fisheries Assessment and Management in Data-Limited Situations. Univeristy of Alaska Fairbanks, Alaska Sea Grant Report, 05-02, pp. 683-714.

Donaldson, W.E., and S.C. Byersdorfer. Biological Field Techniques for Lithodid Crabs. University of Alaska Fairbanks, Alaska Sea Grant Program.

Gaeuman, W.B. 2011. Summary of the 2009/10 mandatory crab observer program database for the Bering Sea/Aleutian Islands commercial crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 11-04, Anchorage, 76 pp.

Moore, H., L.C. Byrne, and D. Connolly. 2000. Alaska Department of Fish and Game summary of the 1998 mandatory shellfish observer program database. Alaska Dept. Fish and Game, Commercial Fisheries Division, Reg. Inf. Rep. 4J00-21, Kodiak. 146 pp.

North Pacific Fishery Management Council (NPFMC). 1998. Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs. North Pacific Fishery Management Council, Anchorage, Alaska.

North Pacific Fishery Management Council (NPFMC). 1999. Environmental assessment/Regulatory Impact review/initial regulatory flexibility analysis for Amendment 11 to the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner crabs. North Pacific Fishery Management Council, Anchorage, Alaska.

North Pacific Fishery Management Coucil (NPFMC). 2000. Environmental assessment/regulatory impact review/initial regulatory flexibility analysis for proposed Amendment 15 to the Fishery Management Plan for king and Tanner crab fisheries in the Bering Sea/Aleutian Islands and regulatory amendment to the Fishery Management Plan for the groundfish fishery of the Bering Sea and Aleutian Islands area: A rebuilding plan for the St. Matthew blue king crab stock. North Pacific Fishery Management Council, Anchorage, AK. Draft report.

Otto, R.S. 1990. An overview of eastern Bering Sea king and Tanner crab fisheries. In: Proceedings of the international symposium on king and Tanner crabs. University of Alaska Fairbanks, Alaska Sea Grant Program Report 90-4, pp. 9-26.

Otto, R.S., and P.A. Cummiskey. 1990. Growth of adult male blue crab (*Paralithodes platypus*). In: Proceedings of the international symposium on king and Tanner crabs. University of Alaska Fairbanks, Alaska Sea Grant Report 90-4, pp. 245-258.

Watson, L.J. 2005. The 2004 triennial St. Matthew Island blue king crab survey and comparisons to the 1995, 1998, and 2001 survey. Alaska Department of Fish and Game, Fishery Management Report 05-22, Anchorage.

Watson, L. J. 2008. The 2007 triennial St. Matthew Island blue king crab survey and comparisons to historic surveys. Alaska Department of Fish and Game, Fishery Management Report No. 08-41, Anchorage.

Zheng, J. 2005. A review of natural mortality estimation for crab stocks: data-limited for every stock? In: Fisheries Assessment and Management in Data-Limited Situations. University of Alaska Fairbanks, Alaska Sea Grant Program Report, 05-02, pp. 595-612.

Zheng, J., and G.H. Kruse. 2002. Assessment and management of crab stocks under uncertainty of massive die-offs and rapid changes in survey catchability. In: A.J. Paul, E.G. Dawe, R. Elner, G.S. Jamieson, G.H. Kruse, R.S. Otto, B. Sainte-Marie, T.C. Shirley, and D. Woodby (eds.). Crabs in Cold Water Regions: Biology, Management, and Economics. University of Alaska Fairbanks, Alaska Sea Grant Report, 02-01, pp. 367-384.

Zheng, J., M.C. Murphy, and G.H. Kruse. 1997. Application of catch-survey analysis to blue king crab stocks near Pribilof and St. Matthew Islands. Alaska Fish. Res. Bull. 4:62-74.

Table 1. The 1978/79 – 2009/10 directed St. Matthew Island blue king crab pot fishery. (Source: Bowers et al. 2011 and B. Bechler, ADF&G)

			Harvest[b]					
Season	Dates	GHL/TAC[a]	Crab	Pounds	Pot Lifts	CPUE[c]	Avg Wt[d]	Avg CL[e]
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	1,931,990	9,454,323	133,944	14	4.8	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	441,479	2,200,781	47,748	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	302,098	1,325,185	23,058	30	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	4.6	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	4.6	133.3
1995/96	09/15-09/20	2.4	666,905	3,166,093	48,560	14	4.8	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	9	4.7	135.8
1999/00-2008/09				**FISHERY CLOSED**				
2009/10	10/15-02/01	1.17	103,376	460,859	10,697	9.9	4.5	134.9
2010/11	10/15-02/01	1.60	298,669	1,263,982	29,344	10.2	4.2	129.3

[a] Guideline Harvest Level/Total Allowable Catch in millions of pounds.
[b] Includes deadloss.
[c] Average number of retained crab per pot lift.
[d] Pounds.
[e] Average Carapace Length of retained crab in millimeters.

Table 2. NMFS EBS trawl-survey area-swept estimates of male crab abundance (10^3 crab) by size class and mature male (≥ 105 mm CL) biomass (10^3 lb) and estimated CV. Total number of captured male crab ≥ 90 mm CL is also given. (Source: J.Zheng, ADF&G and R.Foy, NMFS)

Year	Recruit (90-104mm CL)	Sublegal Mature (105-119mm CL)	Mature (105mm+ CL)	Legal (120mm+ CL)	Mature Male Biomass	CV	Number of Crab
1978	2.384	2.268	4.032	1.764	11.876	0.391	163
1979	2.939	2.225	4.448	2.223	12.864	0.391	187
1980	2.539	2.456	5.322	2.867	16.724	0.474	188
1981	0.477	1.233	3.579	2.346	12.833	0.404	140
1982	1.713	2.495	8.482	5.987	30.748	0.316	269
1983	1.078	1.663	5.027	3.363	17.921	0.282	231
1984	0.410	0.499	1.977	1.478	7.684	0.187	104
1985	0.381	0.376	1.500	1.124	5.750	0.217	93
1986	0.206	0.457	0.833	0.377	2.578	0.389	46
1987	0.325	0.631	1.346	0.715	4.060	0.285	71
1988	0.410	0.816	1.772	0.957	5.693	0.242	81
1989	2.164	1.158	2.951	1.792	9.675	0.250	211
1990	1.053	1.031	3.370	2.338	11.955	0.264	170
1991	1.135	1.680	3.916	2.236	12.255	0.245	198
1992	1.074	1.382	3.672	2.291	12.649	0.204	220
1993	1.521	1.828	5.104	3.276	16.959	0.163	324
1994	0.883	1.298	3.555	2.257	11.696	0.176	211
1995	1.025	1.188	2.929	1.741	9.843	0.173	178
1996	1.238	1.891	4.956	3.064	17.112	0.241	285
1997	1.165	2.228	6.017	3.789	20.143	0.329	296
1998	0.660	1.661	4.510	2.849	15.054	0.359	243
1999	0.223	0.222	0.780	0.558	2.871	0.182	52
2000	0.282	0.285	1.025	0.740	3.795	0.309	61
2001	0.419	0.502	1.440	0.938	5.064	0.255	91
2002	0.111	0.230	0.870	0.640	3.311	0.322	38
2003	0.449	0.280	0.745	0.465	2.483	0.316	65
2004	0.247	0.184	0.746	0.562	2.705	0.286	48
2005	0.319	0.310	0.811	0.501	2.812	0.360	42
2006	0.917	0.642	1.882	1.240	6.494	0.357	126
2007	2.518	2.020	3.212	1.193	9.157	0.348	250
2008	1.352	0.801	2.257	1.457	7.354	0.287	167
2009	1.573	2.161	3.571	1.410	10.189	0.264	251
2010	3.927	3.253	5.711	2.458	17.948	0.373	385
2011	1.693	3.215	6.467	3.252	21.073	0.525	315

Table 3. Observed proportion of crab by size class during ADF&G crab observer pot-lift sampling and estimated fishery mature male discard mortality (pounds). (Source: ADF&G Crab Observer Database)

Year	Pot Lifts (Sampled/Total)	Number of Crab	90-104mm CL	105-119mm CL	120mm+ CL	ρ[a]	Mature Discard Mortality[b]
1990/91	10/26,264	150	0.1133	0.3933	0.4933	0.587	202,559
1991/92	125/37,104	3,393	0.1329	0.1768	0.6902	0.188	126,675
1992/93	71/56,630	1,606	0.1905	0.2677	0.5417	0.309	153,353
1993/94	84/58,647	2,241	0.2806	0.2097	0.5095	0.263	158,152
1994/95	203/60,860	4,735	0.2941	0.2713	0.4344	0.397	298,629
1995/96	47/48,560	663	0.1478	0.212	0.6395	0.255	161,585
1996/97	96/91,085	489	0.1595	0.2229	0.6175	0.242	149,108
1997/98	133/81,117	3,195	0.1818	0.2053	0.6127	0.610	566,970
1998/99	135/91,826	1,322	0.1925	0.2162	0.5912	0.364	215,845
2009/10	989/10,484	19,802	0.1413	0.3235	0.5352	0.452	41,706
2010/11	2,419/29,356	45,466	0.1314	0.3152	0.5534	0.406	102,692

[a] Mature-discard-to-legal-retained weight ratio using crab observer size frequency data and SMBKC length-to-weight coefficient from Chilton and Foy 2010.
[b] Product of ρ, fishery reported retained catch weight, and assumed 20% handling mortality.

Table 4. Groundfish SMBKC male bycatch biomass (pounds) data. (Source: J.Zheng, ADF&G and R.Foy, NMFS)

Year	Bycatch Trawl[a]	Bycatch Fixed Gear	Total Groundfish Bycatch Mortality[b]
1992/93	993	5,355	3,472
1993/94	5,232	57	4,214
1994/95	808	199	746
1995/96	2,191	446	1,976
1996/97	64	30	66
1997/98	18	769	399
1998/99	0	2,566	1,283
1999/00	24	6,922	3,480
2000/01	46	91	82
2001/02	70	4,380	2,246
2002/03	3,157	2,154	3,603
2003/04	3,510	4,914	5,265
2004/05	394	3,087	1,859
2005/06	0	2,845	1,423
2006/07	5,962	6,783	8,161
2007/08	286	299,895	150,176
2008/09	705	25,797	13,535
2009/10	1,722[c]	18,281[c]	10,518
2010/11	75[c]	7,471[c]	3,796

[a] Trawl, pelagic trawl, and non-pelagic trawl gear types.
[b] Assuming handling mortalities of 0.8 for trawl and 0.5 for fixed gear.
[c] Half the total estimate from NMFS reporting areas 521 and 524.

Table 5. Groundfish trawl SMBKC male byctach size-class proportions data. (Source: J.Zheng, ADF&G)

Year	90-104mm CL	105-119mm CL	120mm+ CL (legal)	Number of Crab
1989/90	0.0000	0.0000	1.0000	3
1990/91	0.0000	0.0000	1.0000	27
1991/92	0.0385	0.2692	0.6923	26
1992/93	0.0370	0.0741	0.8889	27
1995/96	0.2917	0.1905	0.5179	168
1996/97	0.0000	0.1429	0.8571	7
1998/99	0.0000	0.0000	1.0000	3
1999/00	0.0000	0.2500	0.7500	4
2002/03	0.0000	0.0769	0.9231	13
2003/04	0.0455	0.1364	0.8182	22
2004/05	0.2000	0.2000	0.6000	5
2006/07	0.1667	0.2083	0.6250	24

Table 6. Groundfish fixed-gear SMBKC male bycatch size-class proportions data. (Source: J.Zheng, ADF&G)

Year	90-104mm CL	105-119mm CL	120mm+ CL (legal)	Number of Crab
1996/97	0.0000	0.0000	1.0000	3
1997/98	0.0270	0.0649	0.9081	185
1998/99	0.1006	0.1538	0.7456	169
1999/00	0.0167	0.1172	0.8661	239
2000/01	0.0264	0.0793	0.8943	416
2001/02	0.1083	0.1529	0.7388	471
2002/03	0.1310	0.2018	0.6672	1,893
2003/04	0.0703	0.1333	0.7964	825
2004/05	0.0321	0.0856	0.8823	374
2005/06	0.0330	0.0858	0.8812	303
2006/07	0.0824	0.1412	0.7764	340
2007/08	0.3835	0.1770	0.4395	1,017
2008/09	0.1905	0.2381	0.5714	21

Table 7. Size-class CPUE and estimates of mean pot biomass (pounds) and its CV from the 96 common stations surveyed during the six triennial ADF&G SMBKC pot surveys. (Source: D.Pengilly and R.Gish, ADF&G)

Year	90-104mm CL	105-119mm CL	120mm+ CL (legal)	Biomass	CV	Number of Crab
1995	1.919	3.198	6.922	38.219	0.130	4,624
1998	0.964	2.763	8.804	44.458	0.062	4,812
2001	1.266	1.737	5.487	28.994	0.079	3,255
2004	0.112	0.414	1.141	5.886	0.152	640
2007	1.086	2.721	4.836	26.841	0.097	3,319
2010	1.326	3.276	5.607	34.255	0.125	3,920

Table 8. Estimated mature male biomass (10^6 lb) at time of mating (Feb 15) with approximate 95% confidence intervals based on assuming median unbiased lognormality of the survey estimate of mature male biomass. The 2011 value is from the 2011/12 OFL projection.

Survey Year	MMBmating	Lower	Upper
1978	8.719	3.521	21.593
1979	11.333	5.262	24.409
1980	14.856	5.989	36.851
1981	7.020	2.101	23.462
1982	18.969	7.904	45.524
1983	6.784	2.012	22.871
1984	3.205	1.478	6.954
1985	2.986	1.446	6.167
1986	1.322	0.385	4.541
1987	2.615	1.217	5.620
1988	3.798	2.014	7.163
1989	7.527	4.278	13.245
1990	8.949	4.825	16.598
1991	7.750	3.944	15.227
1992	8.926	5.359	14.869
1993	12.281	8.233	18.318
1994	6.727	3.924	11.533
1995	5.746	3.407	9.691
1996	12.360	6.880	22.205
1997	13.237	5.616	31.199
1998	10.553	4.398	25.321
1999	2.572	1.792	3.692
2000	3.404	1.861	6.227
2001	4.541	2.748	7.504
2002	2.967	1.582	5.565
2003	2.222	1.197	4.125
2004	2.425	1.383	4.250
2005	2.521	1.254	5.070
2006	5.818	2.908	11.641
2007	8.065	4.053	16.048
2008	6.584	3.746	11.570
2009	8.643	4.996	14.950
2010	14.771	6.756	32.298
2011	15.800	4.985	50.074

Table 9. OFL determination based on directed-fishery retained catch, directed-fishery discard mortality, and groundfish bycatch mortality. Catches are in millions of pounds, with metric ton equivalents in parentheses.

			OFL				
			Directed Fishery		Groundfish Bycatch Mortality		
Year	Tier	F_{OFL}	Retained	Discard Mortality	Trawl	Fixed Gear	Total Male
2009/10	4a	$0.18yr^{-1}$	1.53 (694)	NA	NA	NA	1.72 (782)
2010/11	4a	$0.18yr^{-1}$	1.90 (902)	0.263 (119)	0.003 (0.1)	0.038 (17)	2.29 (1,040)
2011/12	4a	$0.18yr^{-1}$	2.96 (1,342)	0.240[a] (109)	0.009[b] (0.3)	0.009[b] (4)	3.21[c] (1,455)

[a] Assumes 2010/11 mature-male bycatch ratio from crab observer data.
[b] Average of estimates from previous three years.
[c] Total mature-male OFL.

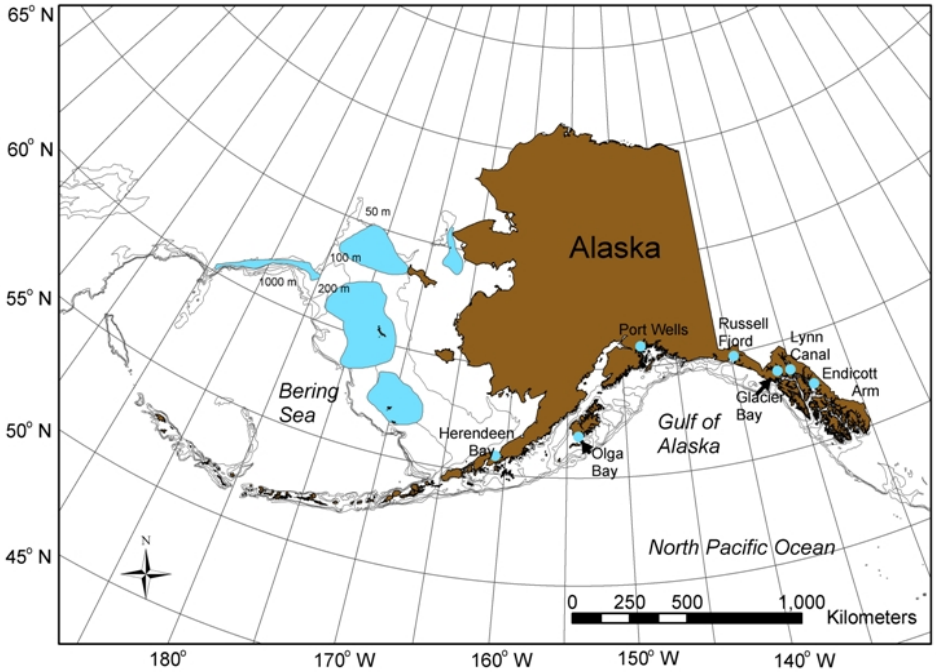

Figure 1. Distribution of blue king crab *Paralithodes platypus* in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters. Shown in blue.

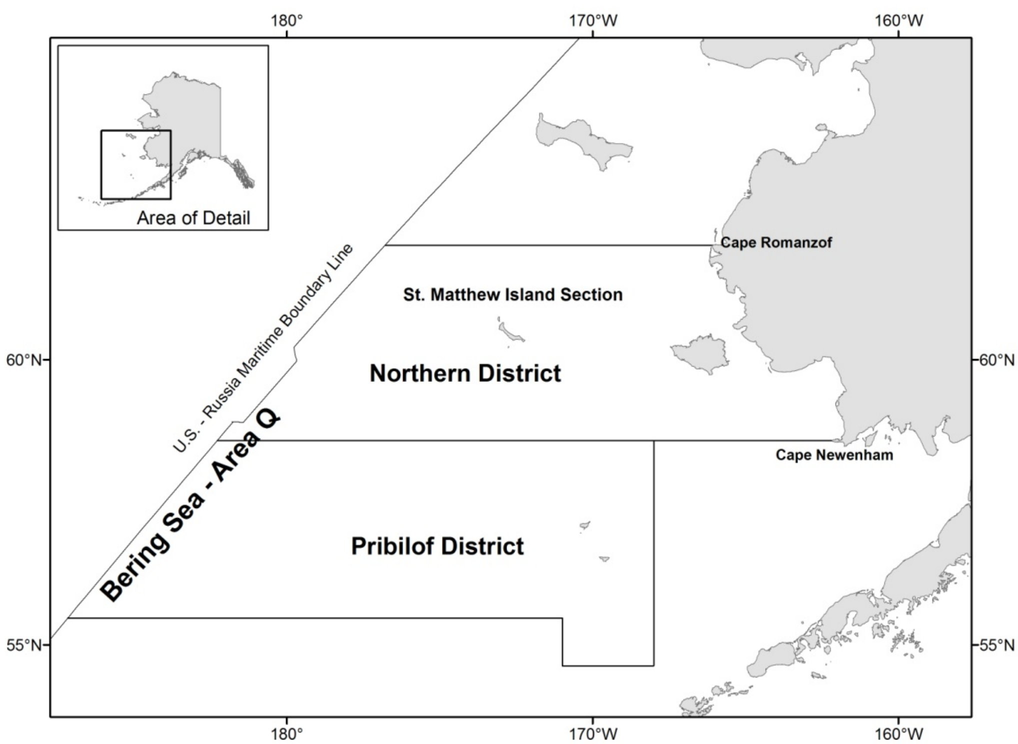

Figure 2. King crab Registration Area Q (Bering Sea).

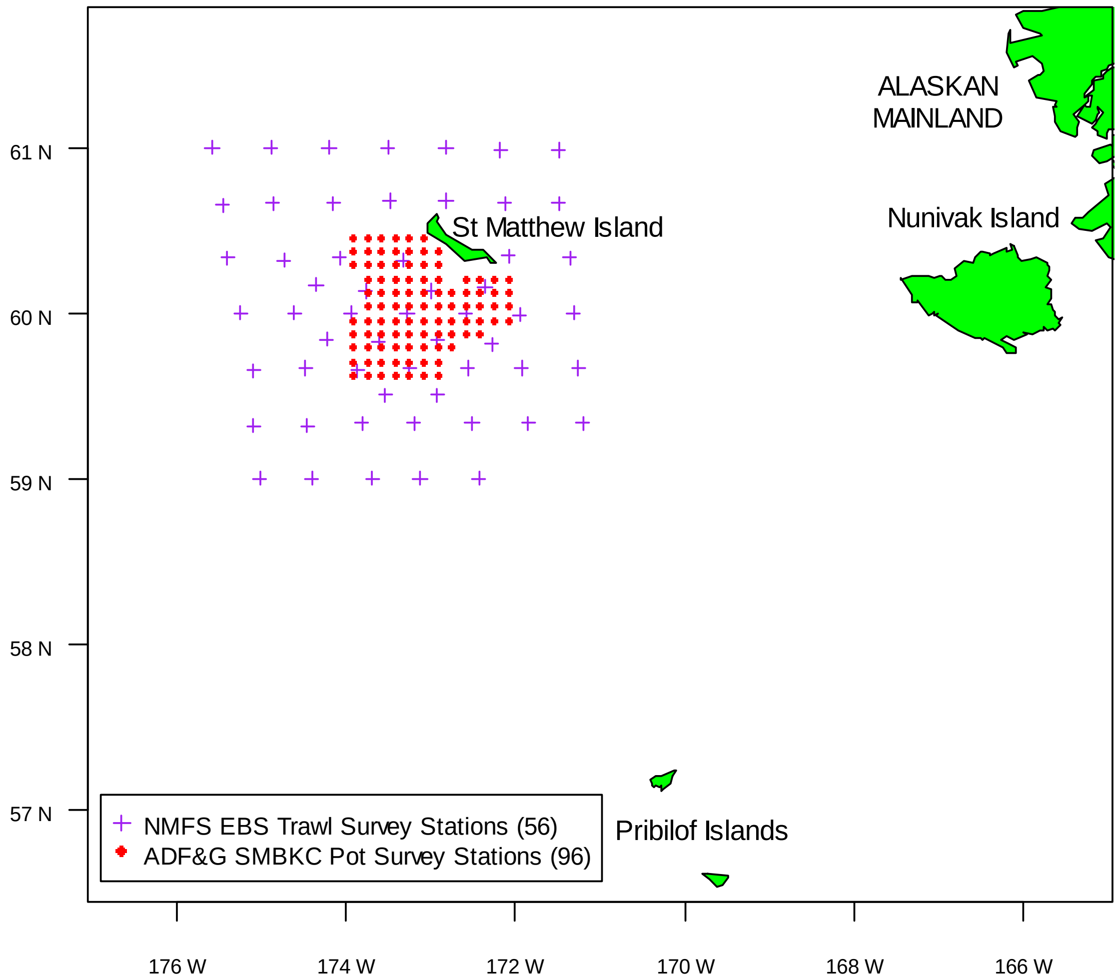

Figure 3: Trawl and pot-survey stations used in the SMBKC stock assessment.

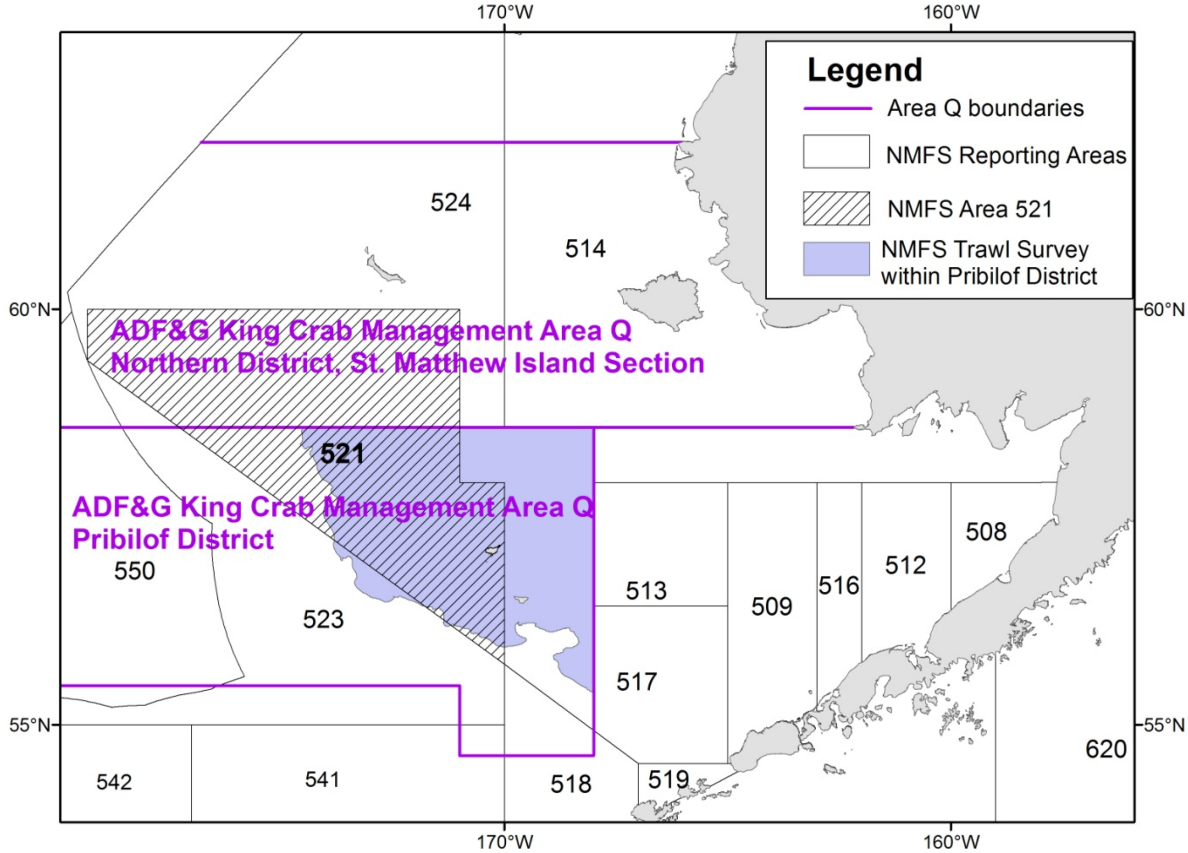

Figure 4. NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.

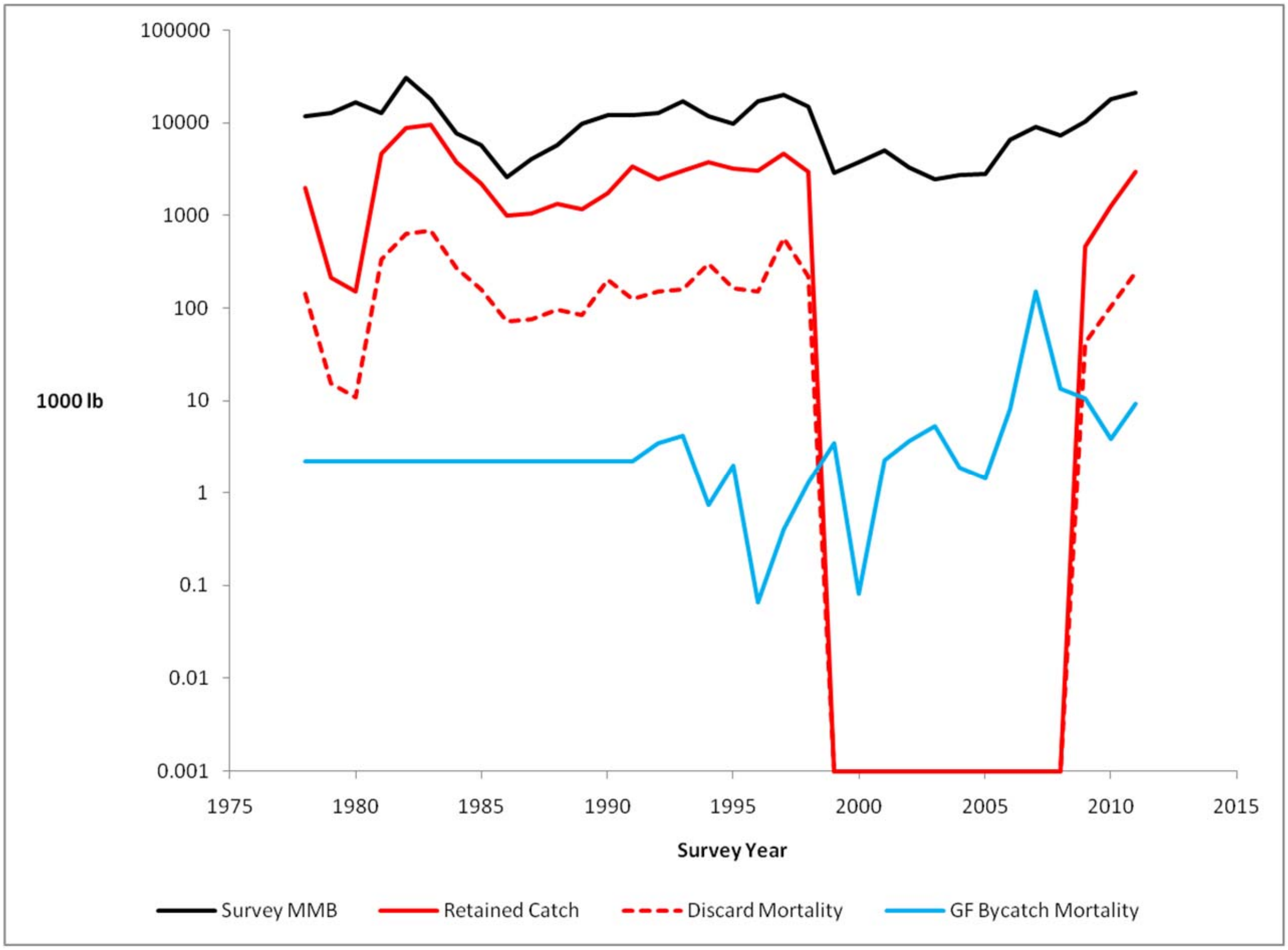

Figure 5. Inputs to computation of estimated 1978/79-2011/12 mature-male biomass at time of mating (Feb 15). Retained-catch and discard and bycatch mortality biomasses for the last survey year 2011 are 2011/12 OFL projections. Note log scale on vertical axis.

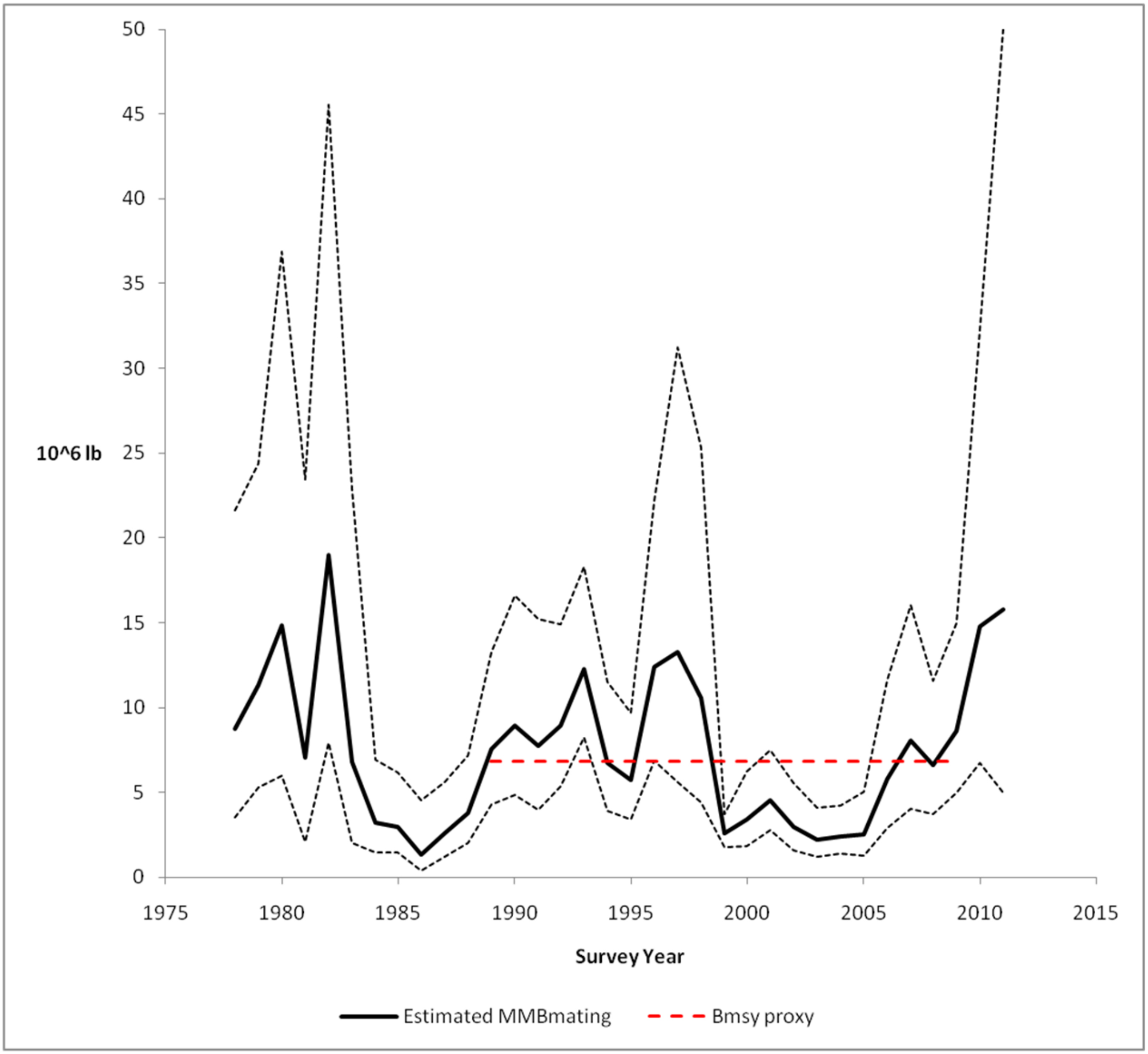

Figure 6. Estimated mature-male biomass at time of mating (Feb 15) with approximate 95% confidence intervals based on [2] and assumed median-unbiased lognormality of the survey estimate of mature-male biomass. The 2011 value is from the 2011/12 OFL projection. Displayed B_{MSY} proxy is 1989/90-2009/10 average.

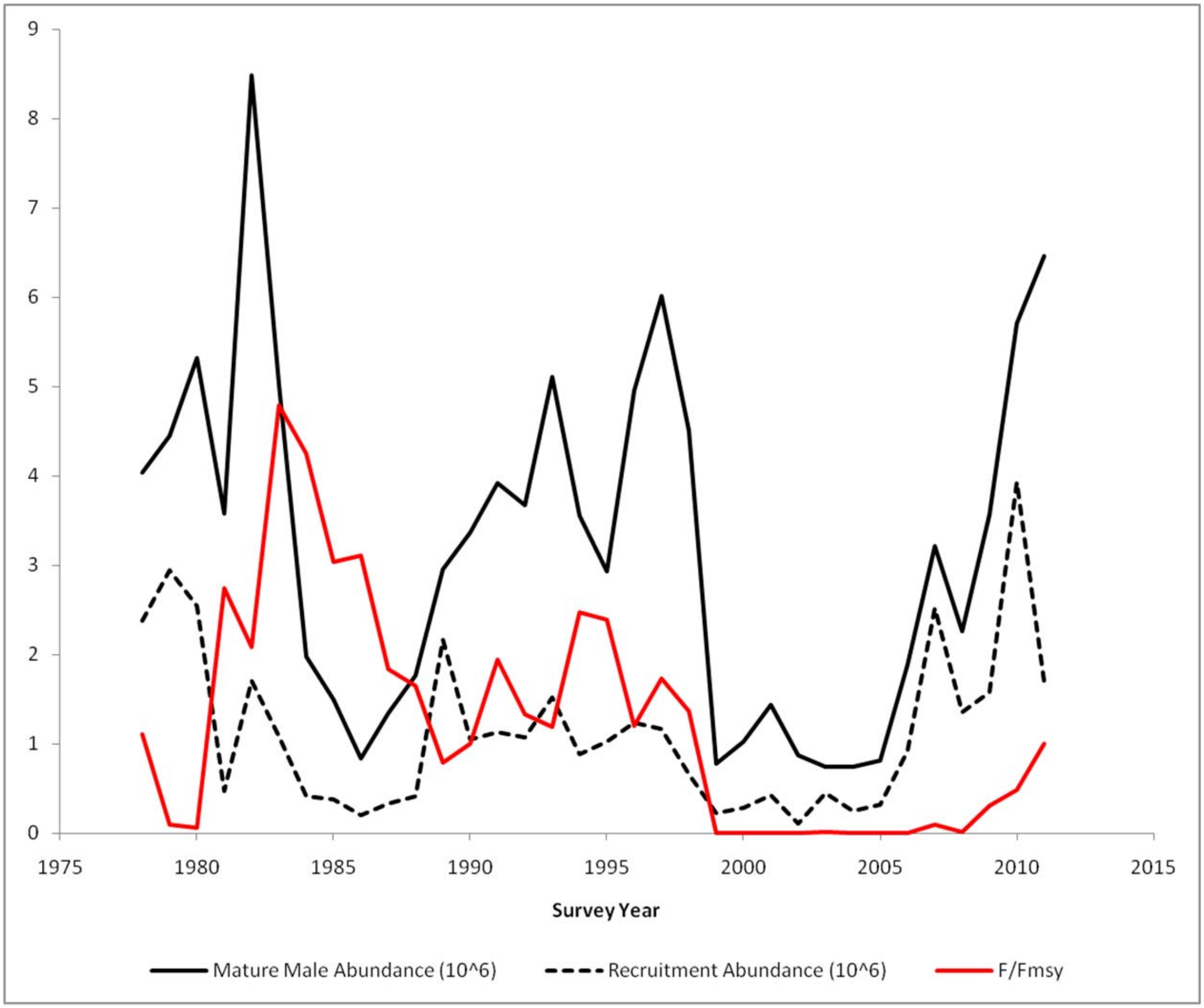

Figure 7. Survey estimates of mature-male (105 mm+ CL) and recruitment (90 – 104 mm CL) abundances and relative estimated mature-male fishing mortality *F* during the subsequent fishery year. Survey year 2011 $F = F_{MSY}$ proxy = 0.18 yr^{-1} for 2011/12 OFL determination. See text for details regarding computation of F.

Appendix A: Alternative 3-Stage Model-Based 2011 Assessment

Introduction

The model is a variant of the one previously developed by Zheng for the St Matthew Island blue king crab (SMBKC) stock (2010 Crab SAFE). Like the earlier model, it considers only male crab at least 90mm in carapace length (CL). The model employs three male size classes (stages) determined by carapace length measurements of (1) 90-104mm, (2) 105-119mm, and (3) 120mm+. By contrast, Zheng partitioned the last stage into "recruits," consisting of new-shell crab measuring 120-133mm CL, and "post recruits," consisting of all crab measuring at least 134mm CL and old-shell crab at least 120mm CL. Consolidation of these two groups into a single stage was heavily driven by concern about the accuracy and consistency of shell-condition information. For management of the SMBKC fishery, male crab measuring at least 105mm CL are considered mature, whereas 120mm CL is considered a proxy for the legal size of 5.5in carapace width, including spines. Accordingly, in what follows the three stages will be referred to as "recruits," "sublegal mature," and "legal."

Model Population Dynamics

Within the model framework, the beginning of the crab year is assumed contemporaneous with the NMFS trawl survey, nominally assigned a date of July 1. With boldface letters indicating vector quantities, let $\boldsymbol{N}_t = [\, N_{1,t}, N_{2,t}, N_{3,t}\,]^{\mathrm{T}}$ designate the vector of stage abundances at the start of year t. Then the basic population dynamics underlying model construction are described by the linear equation

$$\boldsymbol{N}_{t+1} = \boldsymbol{G}e^{-M_t}\boldsymbol{N}_t + \boldsymbol{N}^{new}{}_{t+1}, \qquad [1]$$

where the scalar factor e^{-M_t} accounts for the effect of year-t natural mortality M_t and the hypothesized transition matrix $\boldsymbol{G}$ has the simple structure

$$\boldsymbol{G} = \begin{bmatrix} 1-\pi_{12} & \pi_{12} & 0 \\ 0 & 1-\pi_{23} & \pi_{23} \\ 0 & 0 & 1 \end{bmatrix}, \qquad [2]$$

with π_{jk} equal to the proportion of stage-j crab that molt and grow into stage k from any one year to the next. The vector $\boldsymbol{N}^{new}{}_{t+1} = [\, N^{new}{}_{1,t+1},\, 0\,, 0\,]^{\mathrm{T}}$ registers the number $N^{new}{}_{1,\,t+1}$ of new crab entering the model in year $t+1$, all of which are assumed to go into stage 1. Aside from natural mortality and molting and growth, only the directed fishery and some limited bycatch mortality in the groundfish fisheries are assumed to affect the stock. The directed fishery is modeled as a mid-season pulse occurring at time τ_t with full-selection fishing mortality F_t^{df} relative to stage-3 crab. Year-t directed-fishery removals from the stock are computed as

$$\boldsymbol{R}_t^{df} = \boldsymbol{H}^{df}\boldsymbol{S}^{df}(1-e^{-F_t^{df}})e^{-\tau_t M}\boldsymbol{N}_t, \qquad [3]$$

where the diagonal matrices $\boldsymbol{S}^{df} = \begin{bmatrix} s_1^{df} & 0 & 0 \\ 0 & s_2^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix}$ and $\boldsymbol{H}^{df} = \begin{bmatrix} h^{df} & 0 & 0 \\ 0 & h^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix}$ account for stage selectivities s_1^{df} and s_2^{df} and discard handling mortality h^{df} in the directed fishery, both assumed independent of year. Yearly stage removals resulting from bycatch mortality in the groundfish trawl and fixed-gear fisheries are calculated as Feb 15 (0.63 yr) pulse effects in terms of the respective fishing mortalities F_t^{gt} and F_t^{gf} by

$$\boldsymbol{R}_t^{gt} = e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})\frac{F_t^{gt}}{F_t^{gt}+F_t^{gf}}(1-e^{-(F^{gt}+F^{gf})})h^{gt} \qquad [4]$$

$$\boldsymbol{R}_t^{gf} = e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})\frac{F_t^{gf}}{F_t^{gt}+F_t^{gf}}(1-e^{-(F^{gt}+F^{gf})})h^{gf}. \qquad [5]$$

These last two computations assume that the groundfish fisheries affect all stages proportionally, i.e. all stage selectivities equal one, and that handling mortalities h^{gt} and h^{gf} are constant across both stages and years. My belief is that the available composition data from these fisheries are of such dubious quality as to preclude meaningful use in estimation. Moreover, the impact of these fisheries on the stock is typically very small. These considerations suggest that more elaborate efforts to model that impact are unwarranted. Model population dynamics are thus completely determined by the equation

$$\boldsymbol{N}_{t+1} = \boldsymbol{G}e^{-0.37M_t}(e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df}) - (\boldsymbol{R}_t^{gt} + \boldsymbol{R}_t^{gf})) + \boldsymbol{N}^{new}{}_{t+1}, \qquad [6]$$

for $t \geq 1$ and initial stage abundances $\boldsymbol{N}_1$.

Necessary biomass computations, such as required for management purposes or for integration of groundfish bycatch biomass data into the model, are based on application of the SMBKC length-to-weight relationship of Chilton and Foy (2010) to the stage-1 and stage-2 CL interval midpoints and use fishery reported average retained weights for stage-3 ("legal") crab.

Model Data

Data inputs used in model estimation are listed in Table 1. All quantities relate to male SMBKC ≥ 90mm CL.

Table 1. Data inputs used in model estimation.

Data Quantity	Years	Source
Directed-fishery retained-catch number	1978/79-1998/99 2009/10-2010/11	Fish tickets (no fishery 1999/00-2008/09)
Trawl-survey abundance index and estimated CV	1978-2011	NMFS EBS trawl survey
Pot-survey abundance index and estimated CV	Triennial 1995-2010	ADF&G SMBKC pot survey
Trawl-survey stage proportions and total number of measured crab	1978-2011	NMFS EBS trawl survey
Pot-survey stage proportions and total number of measured crab	Triennial 1995-2010	ADF&G SMBKC pot survey
Pot-fishery stage proportions and total number of measured crab	1990/91-1998/99 2009/10-2010/11	ADF&G crab observer program
Groundfish trawl bycatch biomass	1992/93-2010/11	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93-2010/11	NMFS groundfish observer program

Extending the previous notation, let Q^{ts} and Q^{ps} denote trawl-survey and pot-survey abundance-index proportionality constants, and let s_j^{ts} and s_j^{ps} denote stage-j trawl-survey selectivities. Model-predicted retained-catch number C_t, trawl and pot-survey abundance indices A_t^{ts} and A_t^{ps}, and trawl-survey, pot-survey, and directed-fishery stage proportions $\boldsymbol{P}_t^{ts}$, $\boldsymbol{P}_t^{ps}$, and $\boldsymbol{P}_t^{df}$ are given by

$$C_t = e^{-\tau_t M_t} N_{3,t}(1 - e^{-F^{df}}) \quad [7]$$

$$A_t^{ts} = Q^{ts}(N_{1,t} + s_2^{ts} N_{2,t} + N_{3,t}) \quad [8]$$

$$A_t^{ps} = Q^{ps}(s_1^{ps} N_{1,t} + s_2^{ps} N_{2,t} + N_{3,t}) \quad [9]$$

$$\boldsymbol{P}_t^{ts} = \frac{Q^{ts}}{A_t^{ts}} \begin{bmatrix} s_1^{ts} & 0 & 0 \\ 0 & s_2^{ts} & 0 \\ 0 & 0 & 1 \end{bmatrix} \boldsymbol{N}_t \quad [10]$$

$$\boldsymbol{P}_t^{ps} = \frac{Q^{ps}}{A_t^{ps}} \begin{bmatrix} s_1^{ps} & 0 & 0 \\ 0 & s_2^{ps} & 0 \\ 0 & 0 & 1 \end{bmatrix} \boldsymbol{N}_t \quad [11]$$

$$\boldsymbol{P}_t^{df} = \frac{1}{[s_1^{df}, s_2^{df}, 1](e^{-\tau_t M_t} \boldsymbol{N_t} - \frac{1}{2} \boldsymbol{R}_t^{df})} \begin{bmatrix} s_1^{df} & 0 & 0 \\ 0 & s_2^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix} (e^{-\tau_t M_t} \boldsymbol{N_t} - \frac{1}{2} \boldsymbol{R}_t^{df}). \quad [12]$$

Note that the model analogue of retained catch is assumed to be precisely those stage-3 crab captured in the directed fishery. With $\boldsymbol{wt}_t = [wt_{1,t}, wt_{2,t}, wt_{3,t}]^T$ an estimate of stage mean weights in year t as described above, model predicted groundfish bycatch mortality biomasses in the trawl and fixed-gear fisheries are given by

$$B_t^{gt} = \boldsymbol{wt_t}^T \boldsymbol{R}_t^{gt} \text{ and } B_t^{gf} = \boldsymbol{wt_t}^T \boldsymbol{R}_t^{gf}. \quad [13]$$

Model Objective Function

The objective function consists of a sum of eight "negative loglikelihood" terms characterizing the hypothesized error structure of the principal data inputs with respect to their true, i.e. model-predicted, values, and four "penalty" terms associated with year-to-year variation in model recruit abundance and fishing mortality in the directed fishery and groundfish trawl and fixed-gear fisheries. Sample sizes n_t (observed number of male SMBKC $\geq$ 90mm CL) and estimated coefficients of variation $\widehat{cv}_t$ were used to develop appropriate variances for stage-proportion and abundance-index components. Table 2 lists all components of the objective function. Upper and lower case letters designate model predicted and data computed quantities, respectively. As above, boldface letters indicate vector quantities.

Table 2. Components of model objective function. The w_k are weights, described in text.

Component		Form
Legal retained-catch number	Normal	$w_1 \sum (c_t - C_t)^2$
Trawl-survey abundance index	Lognormal	$\frac{w_2}{\ln(1+\widehat{cv_t^{ts}}^2)} \sum [\ln(a_t^{ts}) - \ln(A_t^{ts})]^2$
Pot-survey abundance index	Lognormal	$\frac{w_3}{\ln(1+\widehat{cv_t^{ps}}^2)} \sum [\ln(a_t^{ps}) - \ln(A_t^{ps})]^2$
Trawl-survey stage proportions	Multinomial	$\sum w_4(t)(n_t^{ts})(\boldsymbol{p}_t^{ts})^T \ln(\boldsymbol{P}_t^{ts})$
Pot-survey stage proportions	Multinomial	$\sum w_5(t)(n_t^{ps})(\boldsymbol{p}_t^{ps})^T \ln(\boldsymbol{P}_t^{ps})$
Directed-fishery stage proportions	Multinomial	$\sum w_6(t)(n_t^{df})(\boldsymbol{p}_t^{df})^T \ln(\boldsymbol{P}_t^{df})$
Groundfish trawl mortality biomass	Lognormal	$w_7 \sum [\ln(b_t^{gt}) - \ln(B_t^{gt})]^2$
Groundfish fixed-gear mortality biomass	Lognormal	$w_8 \sum [\ln(b_t^{gf}) - \ln(B_t^{gf})]^2$
$\ln(N_{1,t}^{new})$ deviations	Quadratic	$w_9 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{df})$ deviations	Quadratic	$w_{10} \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{gft})$ deviations	Quadratic	$w_{11} \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{gff})$ deviations	Quadratic	$w_{12} \sum \Delta_t^2$, with $\sum \Delta_t = 0$

The weights/weighting functions w_j appearing in the above expressions play the role of "tuning" parameters in the modeling procedure. The particular weights w_1, w_9, w_{10}, w_{11}, and w_{12} are interpretable as reciprocals of normal variances. The weighting functions $w_4(t), w_5(t)$, and $w_6(t)$ can be viewed as the effective sample sizes for the multinomial distributions describing empirical stage-proportion error structure with respect to model predicted values. Each depends on two parameters N_{max} and N_o in such way that effective sample size n_{eff} is given as a piecewise linear function of the observed number of crab n by $n_{eff} = \frac{N_{max}}{N_o} n$ for $n < N_o$ and $n_{eff} = n_{max}$ if $n \geq N_o$, as shown in Figure 1. N_{max} and N_o will in general vary between data sources, whereas n will depend also on year.

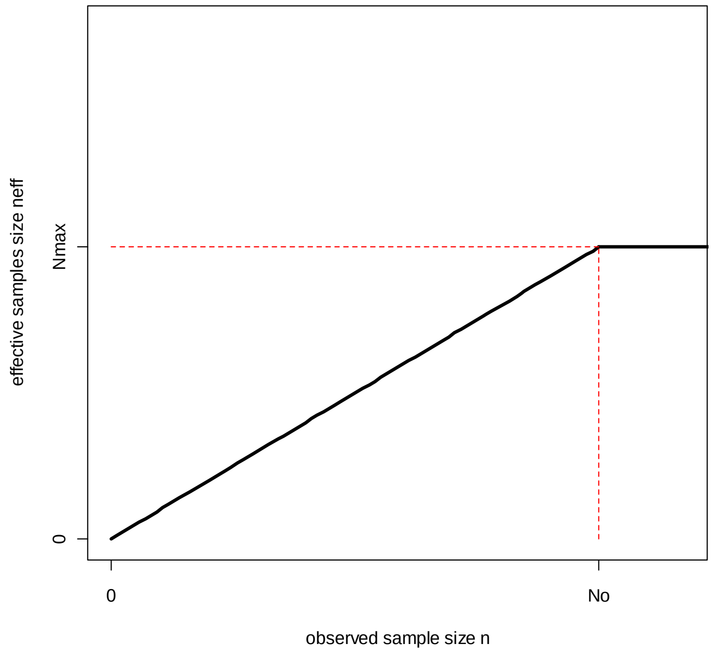

Figure 1. Relation between observed sample size and effective sample size for stage-proportion multinomial distributions, given data-dependent parameters N_{max} and N_o.

Model Parameters

Model estimated parameters are listed in Table 3. Note that in any year with no directed fishery, and hence zero retained catch, F_t^{df} is set to zero rather than model estimated. Similarly, for years in which no groundfish bycatch data are available, F_t^{gf} and F_t^{gt} are imputed to be the geometric means of the estimates from years for which there are data. Table 4 lists additional externally determined parameters used in model computations.

Table 3. Model estimated parameters.

Parameter	Number
Log initial stage abundances	3
Logit transition probabilities	2
1998/99 natural mortality	1
Pot-survey “catchability”	1
Trawl-survey selectivities	2
Pot-survey selectivities	2
Directed-fishery selectivities	2
Mean log recruit abundance	1
Log recruit abundance deviations	33[a]
Mean log directed-fishery mortality	1
Log directed-fishery mortality deviations	23[a]
Mean log groundfish trawl fishery mortality	1
Log groundfish trawl fishery mortality deviations	19[a]
Mean log groundfish fixed-gear fishery mortality	1
Log groundfish fixed-gear fishery mortality deviations	19[a]
Total	111

[a] Subject to zero-sum constraint.

Table 4. Fixed parameters used in model computations.

Parameter	Value	Source
Trawl-survey “catchability”, i.e. abundance-index proportionality constant	1.0	Previous CPT, SSC recommendations.
Natural mortality (except 1998/99)	0.18 yr^{-1}	Previous CPT, SSC recommendations.
Stage-1 and 2 mean weights	1.65, 2.57 lb	Chilton and Foy (2010) length-weight equation applied to stage mid-lengths.
Stage-3 mean weights	depend on year	Fishery-reported average retained weight from fish tickets.
Directed-fishery handling mortality	0.20	2010 Crab SAFE (?)
Groundfish trawl handling mortality	0.80	2010 Crab SAFE (?)
Groundfish fixed-gear handling mortality	0.50	2010 Crab SAFE (?)

2011 Results

The model was implemented in AD Model Builder (ADMB Project 2009). Figures 2-11 document basic model results using the objective-function weighting scheme presented in Table 5. Associated model parameter estimates and AD Model Builder reported asymptotic normal standard errors based on maximum likelihood theory are given in Table 6. Table 7 lists the contributions of each component of the objective function, including weights, to the minimized value.

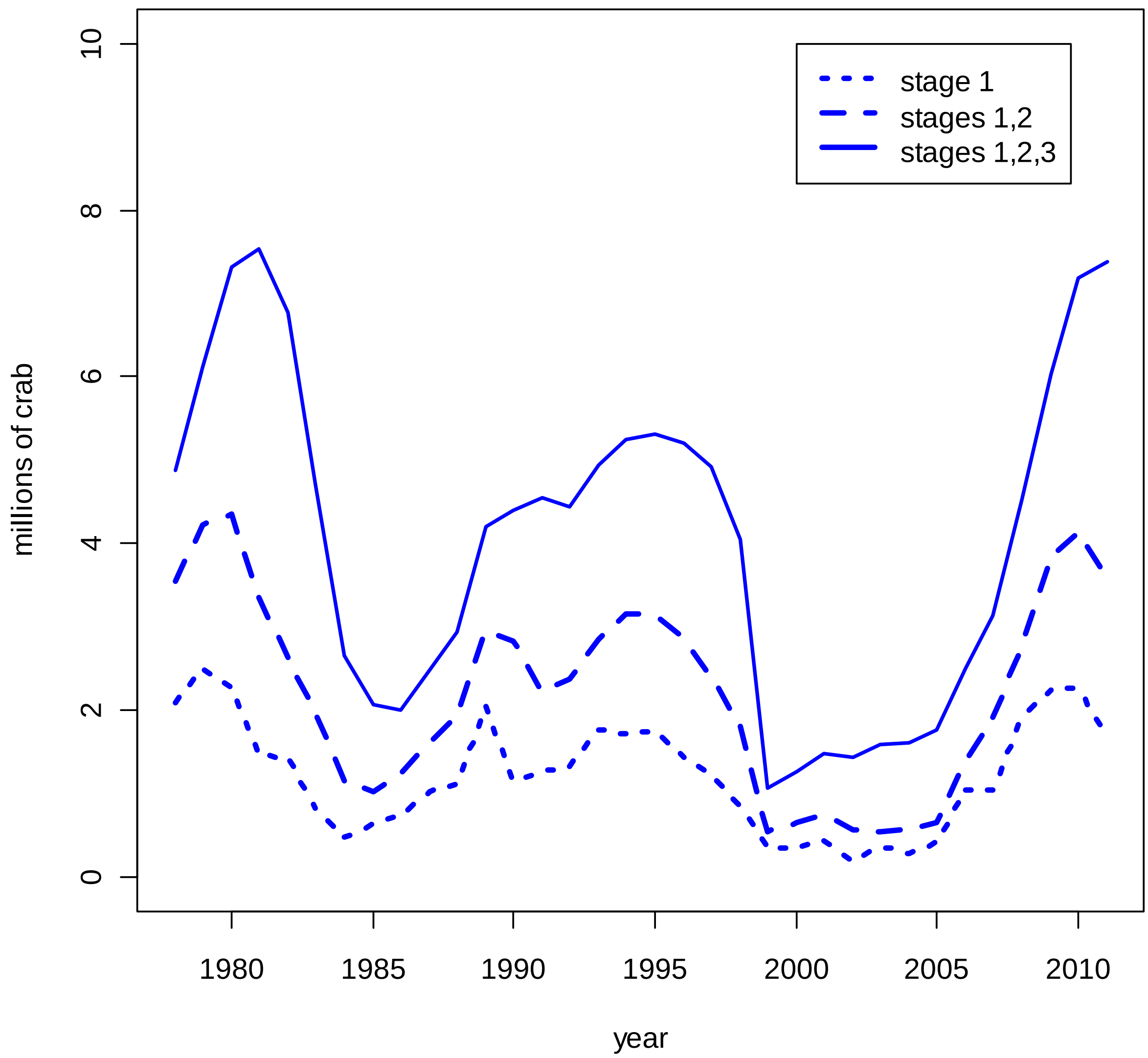

Figure 2. Model-estimated SMBKC stage abundances at time of survey. See text for stage definitions.

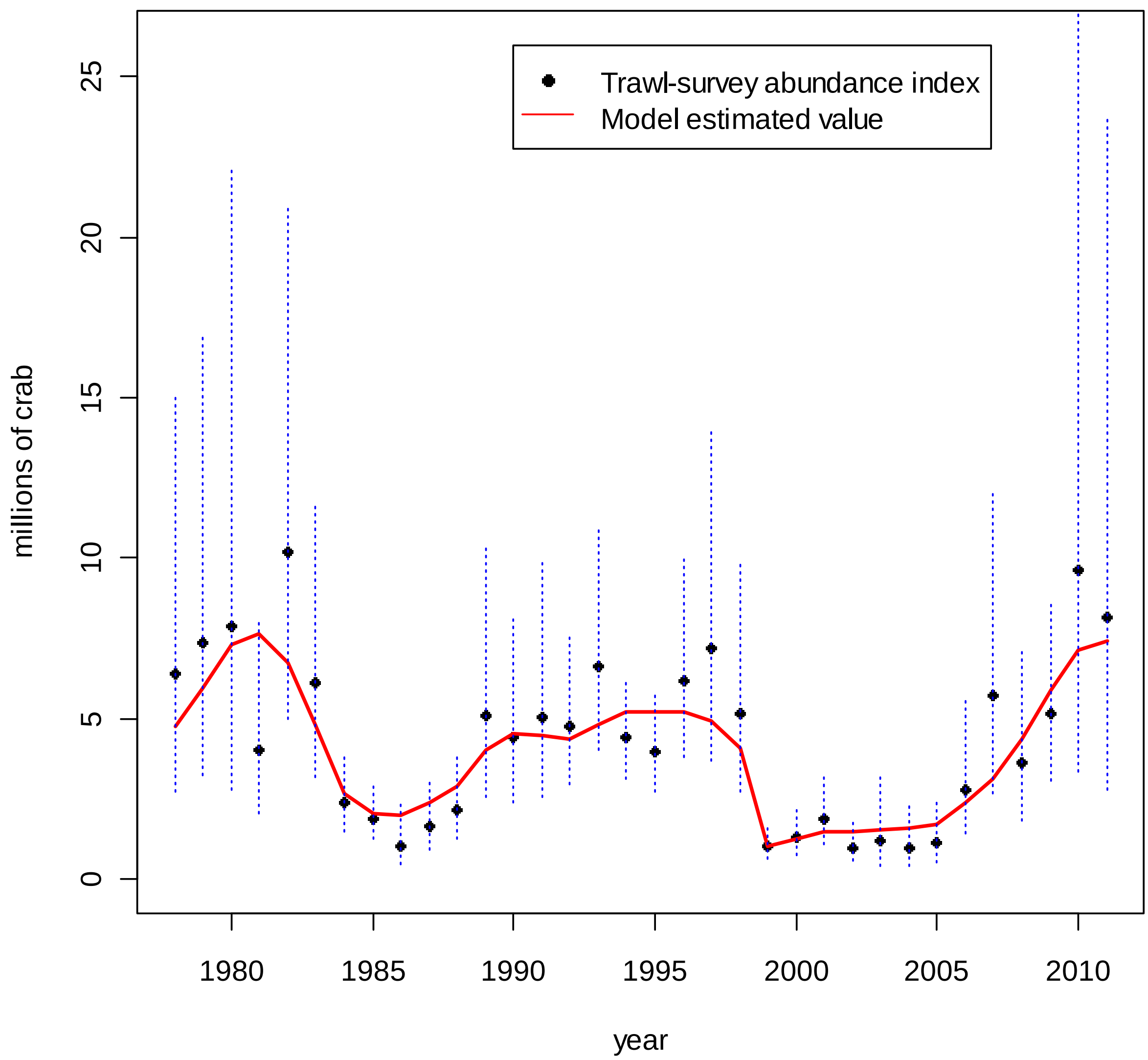

Figure 3. Total abundance of male SMBKC crab ≥ 90mm CL. Approximate 95% confidence intervals (dotted blue lines) based on trawl-survey estimated CV.

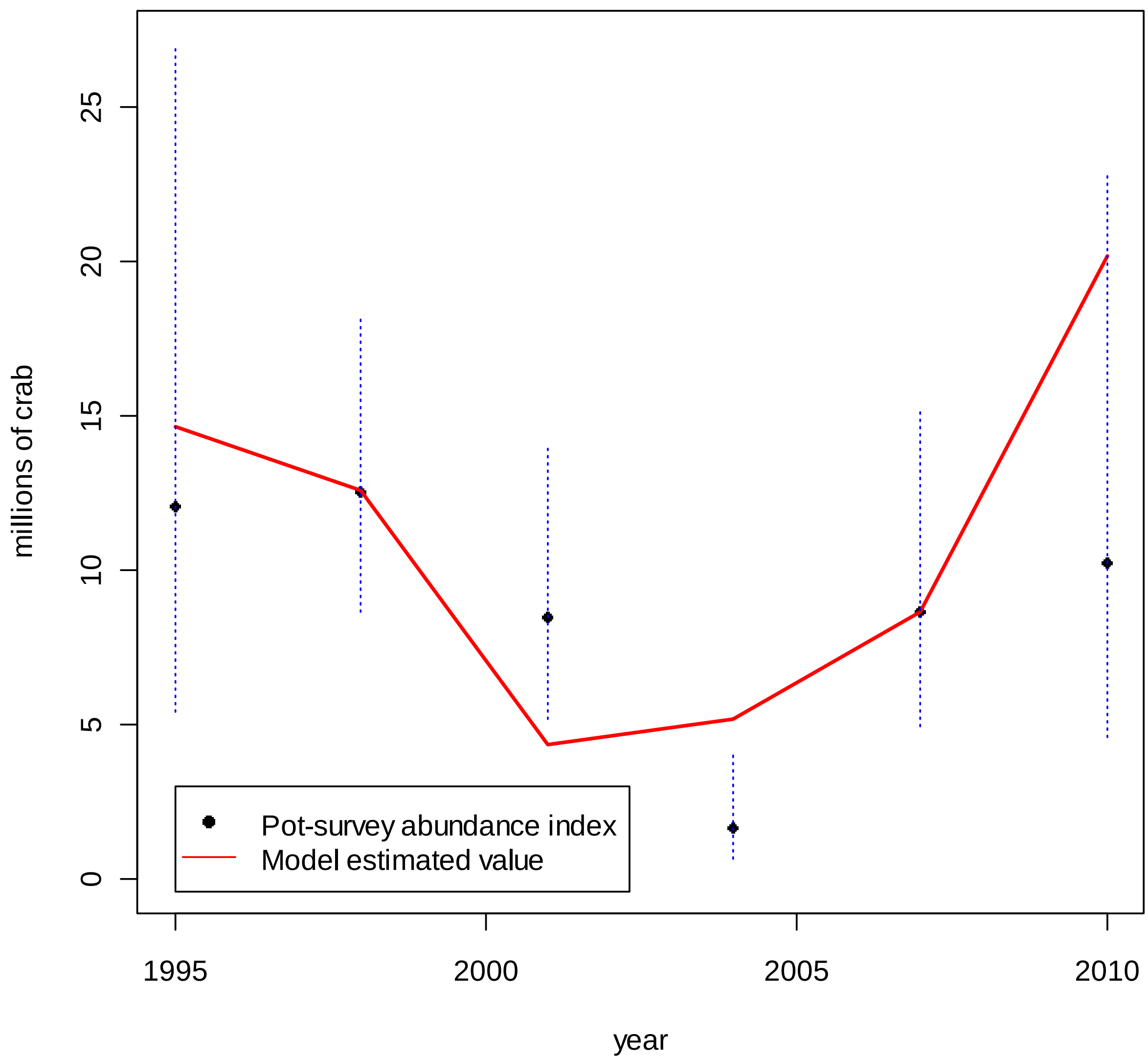

Figure 4. Model-estimated and observed abundance index from ADF&G triennial SMBKC pot survey. Approximate 95% confidence intervals (dotted blue lines) are based on pot-survey estimated CV and reflect model likelihood weighting.

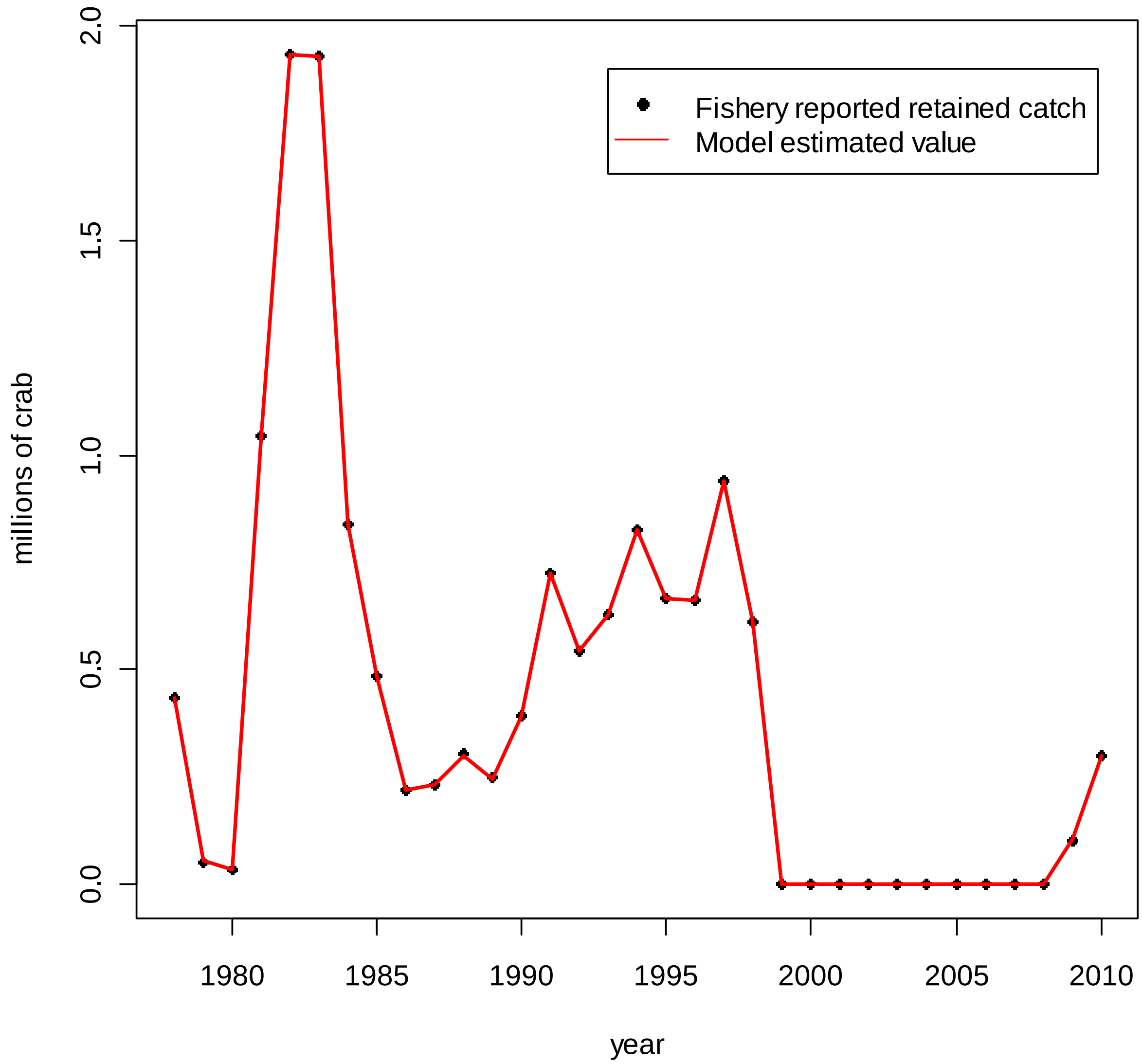

Figure 5. Directed SMBKC fishery catch. The fishery was closed 1999/00 – 2008/09.

Figure 6. Trawl-survey stage-proportion studentized residuals. Dotted red lines indicate approximate 95% confidence intervals.

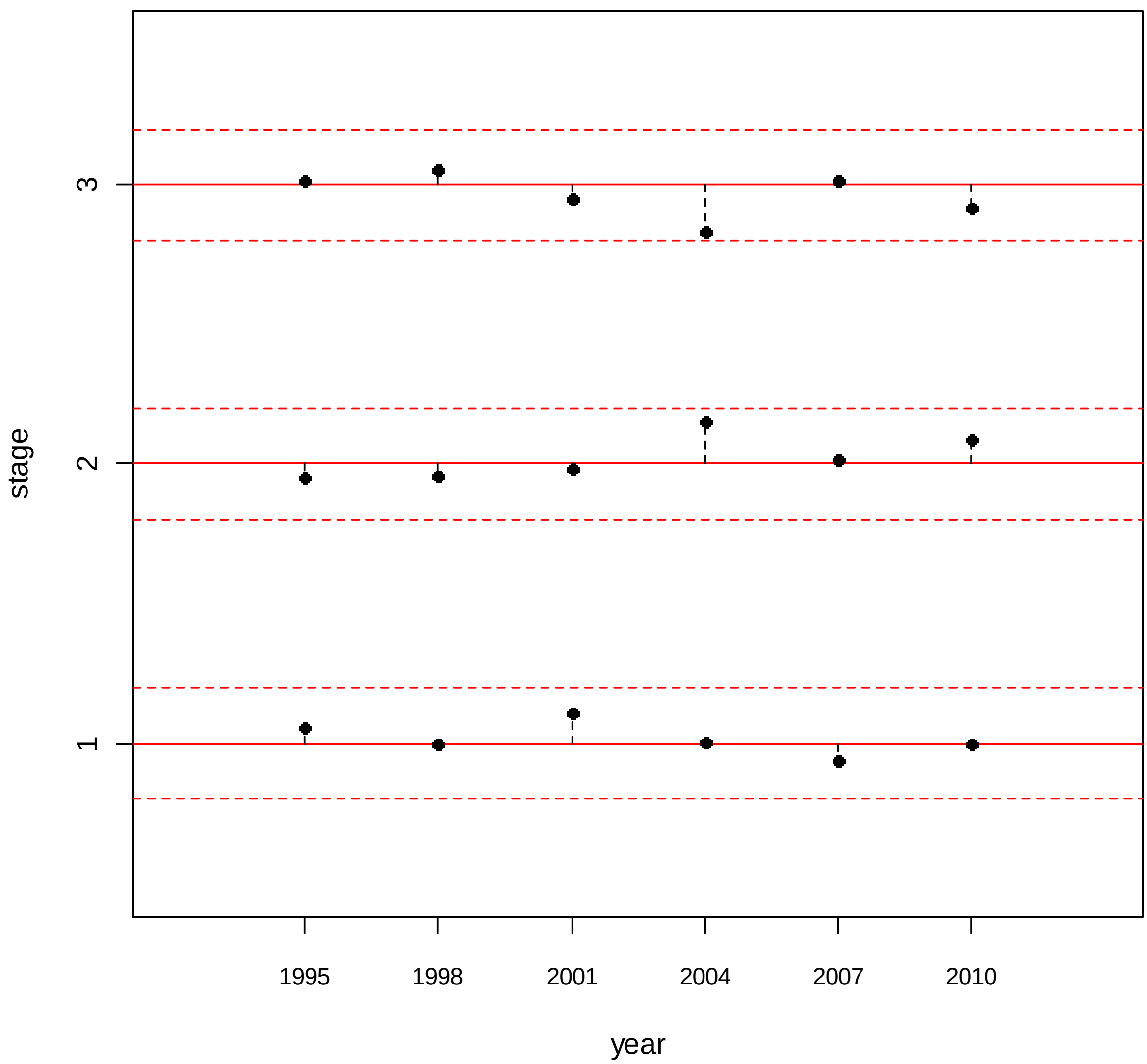

Figure 7. Pot-survey stage-proportion studentized residuals. Dotted red lines indicated approximate 95% confidence intervals.

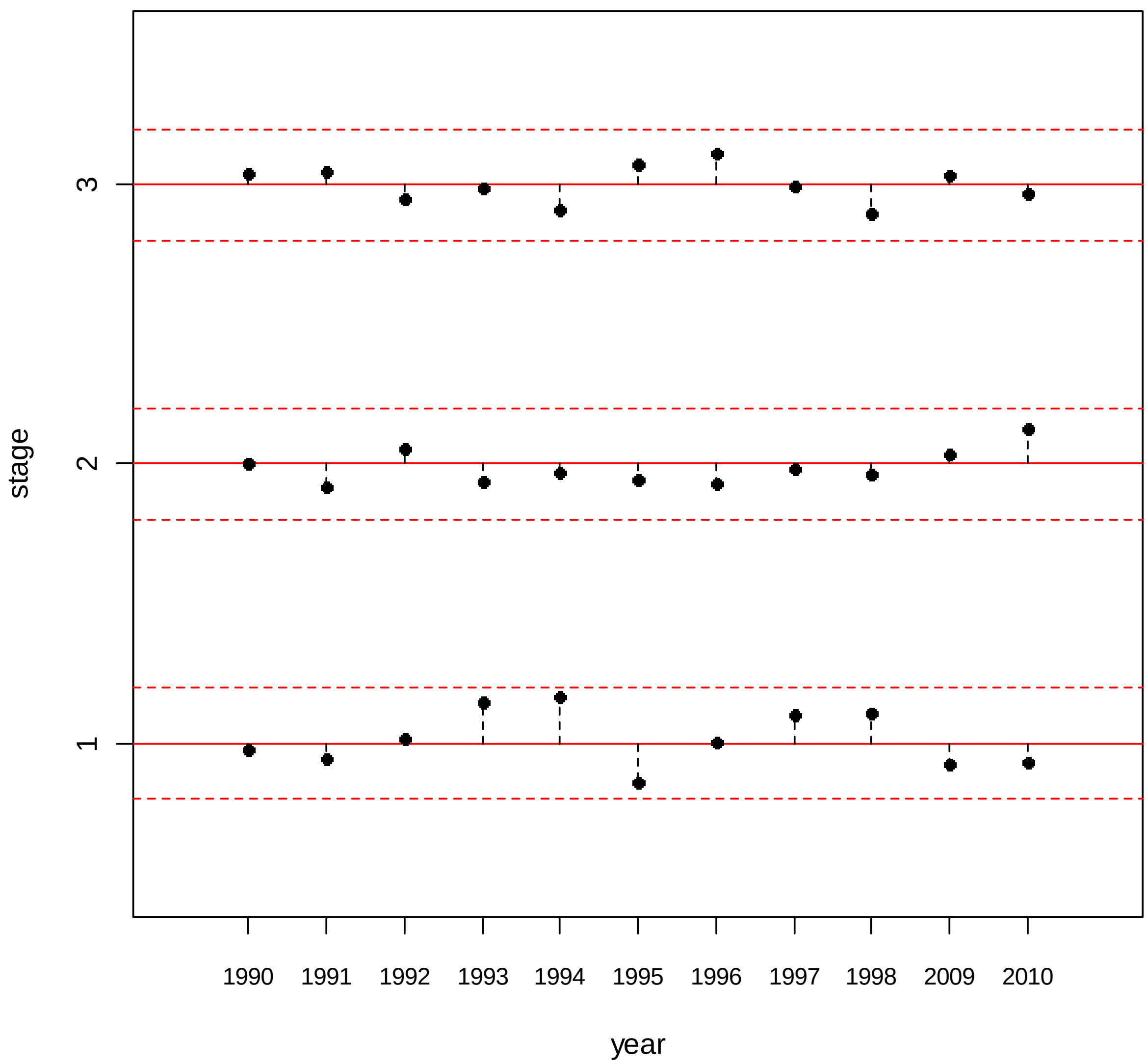

Figure 8. Stage-proportion studentized residuals from pot-lift sampling by ADF&G crab observers. Dotted red lines indicate approximate 95% confidence intervals.

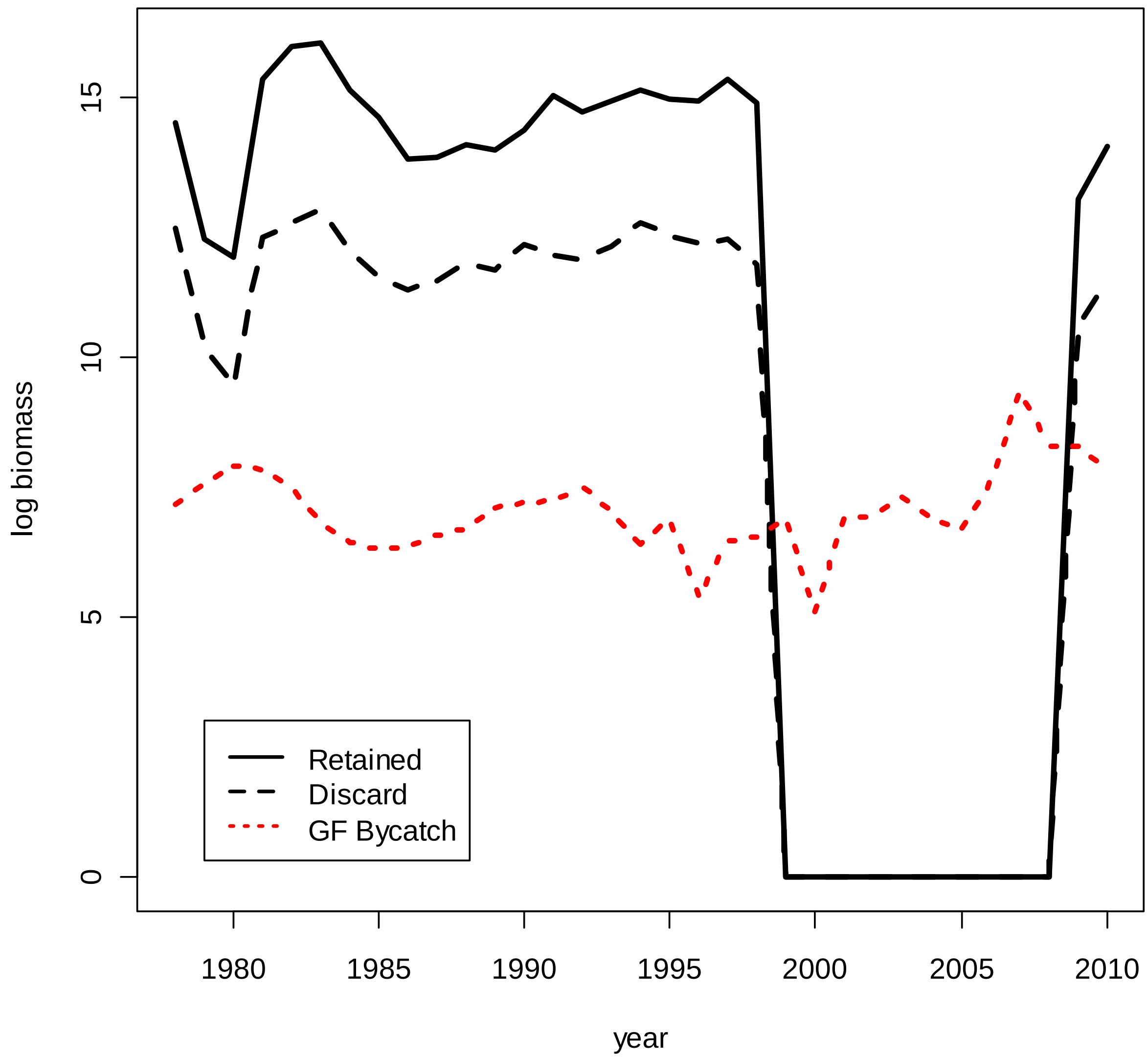

Figure 9. Yearly SMBKC fishing-mortality biomass. The directed fishery was closed 1999/00 – 2008/09.

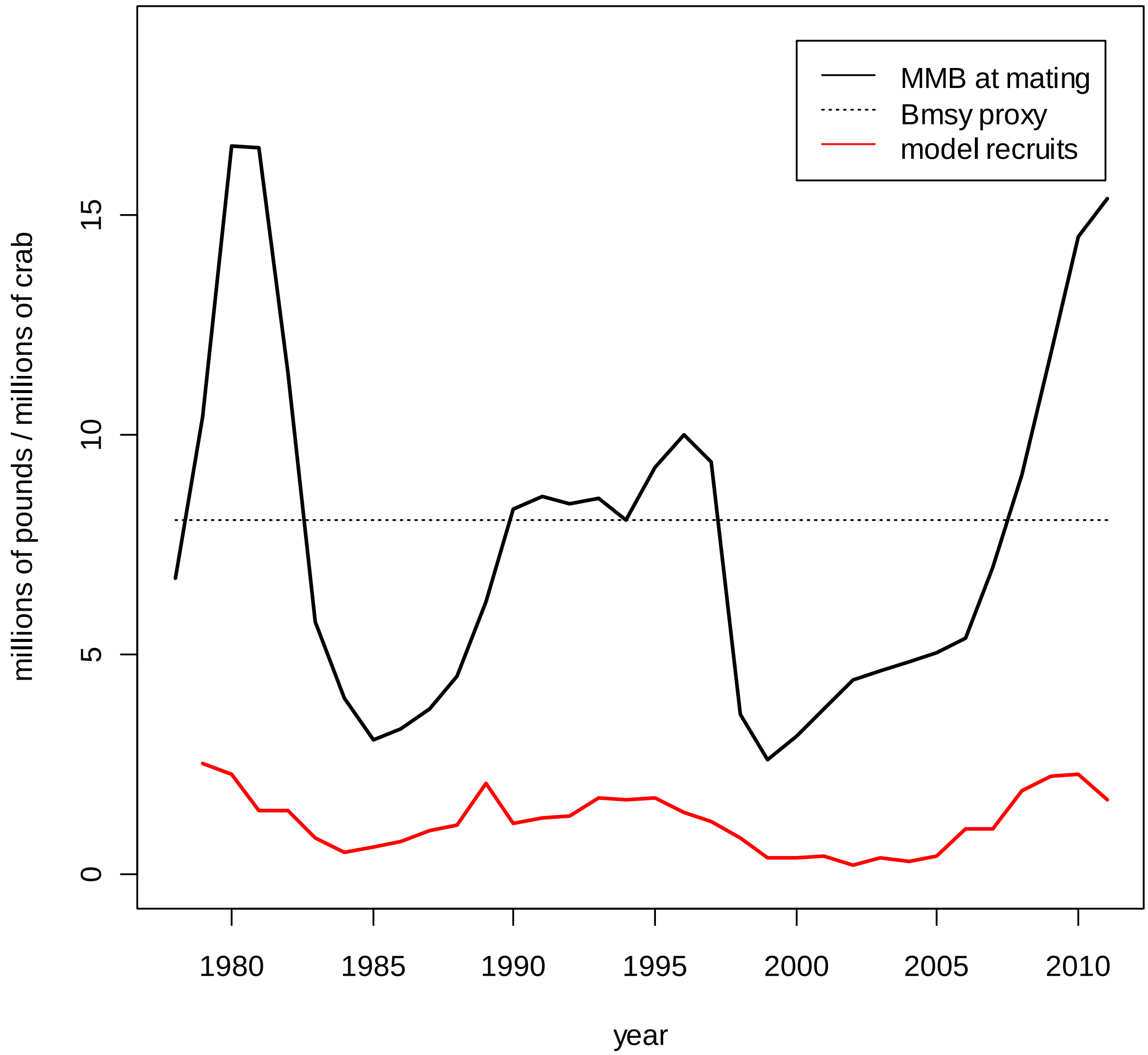

Figure 10. Model-estimates of mature-male biomass at time of mating and model recruit abundance. The model-estimated $F_{35\%}$ B_{MSY} proxy (8.05 million pounds) is also shown. MMB_{mating} for 2011/12 is the OFL projection. The retained-catch portion of the OFL is 4.78 million pounds.

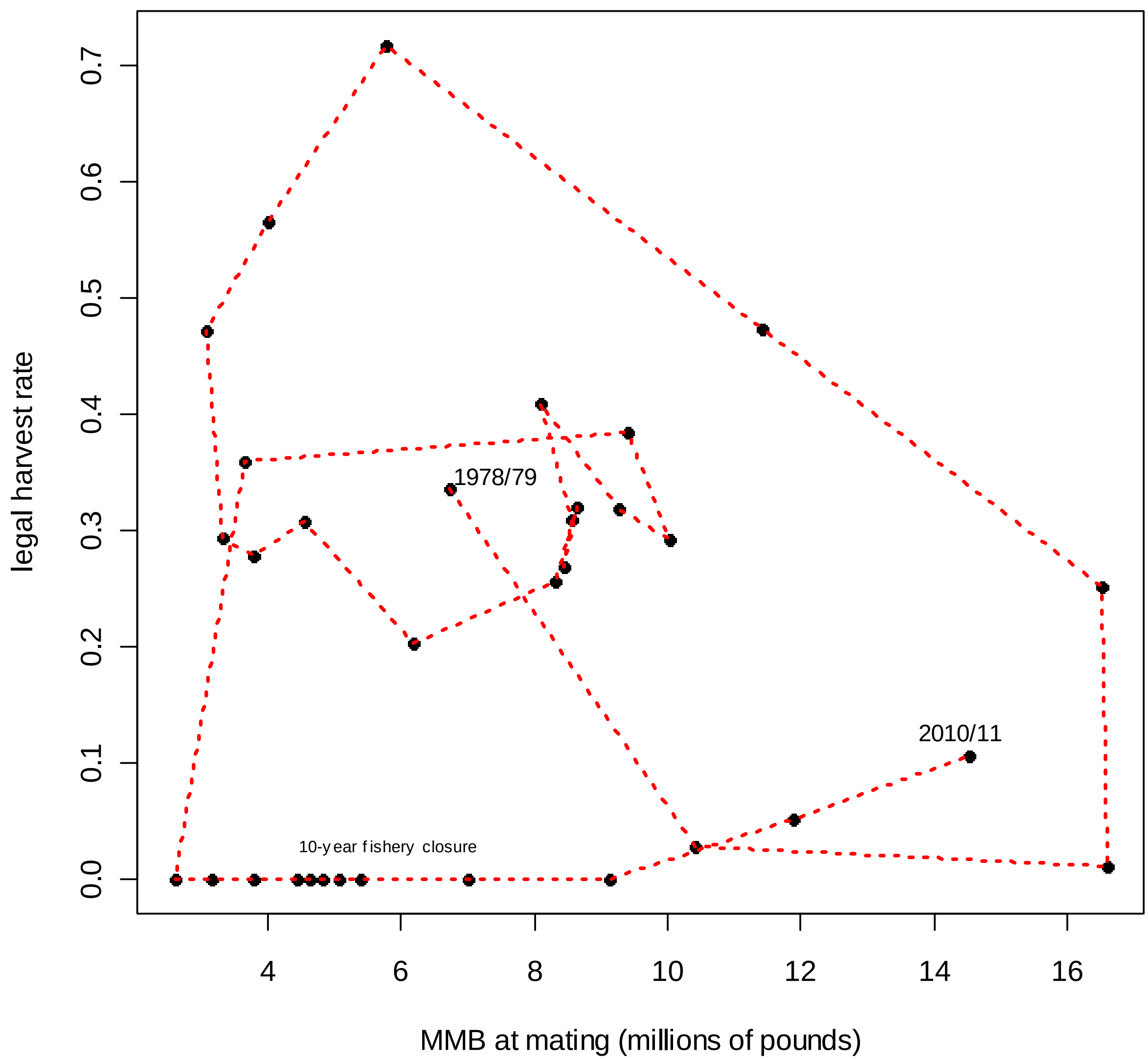

Figure 11. Model-estimated legal harvest rate vs model-estimated MMB_{mating}.

Table 5. Objective-function weighting scheme generating 2011 example results.

Objective-Function Component	Weight w_j
Legal retained-catch number	0.005
Trawl-survey abundance index	1.0
Pot-survey abundance index	0.1
Trawl-survey stage proportions	$N_o = 300$; $N_{max} = 50$
Pot-survey stage proportions	$N_o = 3000$; $N_{max} = 100$
Directed-fishery stage proportions	$N_o = 5000$; $N_{max} = 100$
Groundfish trawl mortality biomass	0.1
Groundfish fixed-gear mortality biomass	0.1
Log model recruit-abundance deviations	1.0
Log directed fishing mortality deviations	0.1
Log groundfish trawl fishing mortality deviations	0.1
Log groundfish fixed-gear fishing mortality deviations	0.1

Table 6. Model-based parameter estimates and standard errors from 2011 example results.

Parameter	Value	Standard Error
Log initial stage abundances	7.650, 7.284, 7.182	0.288, 0.390, 0.417
Logit p1,2 and p2,3 transition probabilities	32.8, 26.8	10^7, 10^5
Pot-survey abundance index proportionality constant	3.87	0.60
1998/99 natural mortality	1.49	0.30
Trawl-survey selectivities	0.81, 1.19	0.08, 0.11
Pot-survey selectivities	0.31, 0.78	0.06, 0.12
Directed-fishery selectivities	0.39, 0.70	0.06, 0.10
Mean log recruit abundance	6.899	0.068
Log recruit abundance deviations	[-1.599, 0.930]	[0.134, 0.412]
Mean log directed fishing mortality	-1.269	0.099
Log directed fishing mortality deviations	[-3.148, 1.501]	[0.134, 0.485]
Mean log groundfish trawl fishing mortality	-10.920	0.717
Log groundfish trawl fishing deviations	[-2.411, 1.663]	[2.175, 2.206]
Mean log grounfish fixed-gear fishing mortality	-9.058	0.718
Log groundfish fixed-gear fishing mortality deviations	[-2.392, 2.420]	[2.177, 2.254]

Table 7. Component contributions to the optimized objective function value. Listed values include weights.

Component	Value	Percent
Retained catch	< 0.1	< 0.1
Trawl-survey abundance index	13.7	0.8
Pot-survey abundance index	7.9	0.5
Trawl-survey stage proportions	637.7	36.4
Pot-survey stage proportions	543.5	31.0
Directed-fishery stage proportions	530.6	30.3
Groundfish trawl bycatch mortality biomass	7.5	0.2
Groundfish fixed-gear bycatch mortality biomass	2.71	0.2
Log recruit deviations penalty	1.3	0.4
Log directed fishing morality deviations	1.3	<0.1
Log groundfish trawl fishing mortality deviations	1.1	< 0.1
Log groundfish fixed-gear fishing mortality deviations	1.2	< 0.1
Total	1,751	100

Determination of The OFL

The overfishing level (OFL) is the fishery-related mortality biomass associated with fishing mortality F_{OFL}. The SMBKC stock is currently considered Tier 4 (NPFMC 2007). Thus given stock estimates or suitable proxy values of B_{MSY} and F_{MSY}, along with two additional parameters α and β, F_{OFL} is determined by the control rule

$$a)\quad F_{OFL} = F_{MSY}\,,\ when\ \ B/B_{MSY} > 1;$$
$$b)\quad F_{OFL} = F_{MSY}\,(B/B_{MSY} - \alpha)/(1-\alpha),\ when\ \ \beta < B/B_{MSY} \le 1;$$
$$c)\quad F_{OFL} < F_{MSY}\ \ with\ directed\ \ fishery\ F = 0,\ when\ \ B/B_{MSY} \le \beta\,,$$

where B is specified to be mature-male biomass at time of mating MMB_{mating}. Note that since B is itself a function of fishing mortality and hence of F_{OFL}, in case b) numerical approximation of F_{OFL} is required. Previous recommendations for the SMBKC stock are to use the period 1989/90-2009/10 to define a B_{MSY} proxy in terms of average estimated MMB_{mating} and to put $\gamma = 1.0$ with assumed stock natural mortality $M = 0.18$ in setting the F_{MSY} proxy value γM. The parameters α and β are assigned their default values $\alpha = 0.10$ and $\beta = 0.25$.

In the approach used here, the F_{MSY} proxy is taken to be $F_{35\%}$, the fishing mortality that would result in a stable per-recruit mature-male biomass $SBPR_{35\%}$ equal to 35% of its pristine or unfished value SBPR_0 under model dynamics. A corresponding alternative *Bmsy* proxy is then the product of $SBPR_{35\%}$ and mean, i.e. average estimated, recruit abundance. In all of this, it is full-selection fishing mortality F^{df} in the directed fishery that is treated as the control variable in determining F_{OFL}, with fishing mortality in the groundfish fisheries assumed constant and equal to the geometric means $\exp(mean\_ln\_F^{gt})$ and $\exp(mean\_ln\_F^{gf})$ of the yearly model-estimated values. Assessment-year OFL is then projected as the sum of 1) directed- fishery retained-catch biomass B_{ret}, 2) directed-fishery discard-mortality biomass B_{dis}, and 3) groundfish bycatch-mortality biomasses $B_{GFTmort}$ and $B_{GFFmort}$ assuming full-selection fishing mortality F_{OFL} in the directed fishery, so that

$$OFL = B_{ret} + B_{dis} + B_{GFTmort} + B_{GFFmort} \ ,$$

with B_{ret} constituting the retained-catch portion of the OFL.

For the 2010/12 assessment example presented here, this approach leads to a B_{MSY} proxy of 8.05 million pounds, an OFL of 5.05 million pounds, 4.80 of which is allotted to retained catch, and an OFL-projected MMB_{mating} equal to 15.40 million pounds. By contrast, the B_{MSY} proxy based on 1989/90-2009/10 average model-estimated MMB_{mating} is 6.78 million pounds, though its use has no effect on the other $F_{35\%}$ quantities resulting from the model-based analysis presented here.