Draft 2011 Saint Matthew Island Blue King Crab Stock Assessment

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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. A 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 2009/10 directed fishery is estimated from ADF&G crab observer data at 0.048 million pounds (22 t) and at 0.118 million pounds (56 t) in 2010/11, assuming 20% handling mortality. Total male bycatch mortality in the 2009/10 groundfish fisheries is estimated from NMFS observer data at 0.011 million pounds (5.0 t), assuming handling mortalities of 80% and 50% in the trawl and fixed-gear fisheries, respectively. The 2010/11 estimate is not yet available.

3. Stock biomass: Indices of stock biomass from both the NMFS EBS trawl survey and the ADF&G Saint Matthew Island pot survey are consistent with increasing stock biomass since 2005/06. Trawl-survey area-swept estimated 2010 biomass of male crab with carapace length greater than or equal to 90mm was 24.5 million pounds (11,100 t; estimated CV 0.47) compared to 3.37 million pounds (1,530 t; estimated CV 0.37) in 2005. This is the second highest biomass estimate from the trawl survey in the last 33 years.

4. Recruitment: With the model-based approach, recruitment has been assessed in terms of the number of male crab entering the 90-104 mm CL size class in each year. With the survey-based approach invoked for this assessment, the default definition of recruitment is absolute abundance in the 90-104 mm size class. Results from both the trawl and pot surveys suggest that by either definition 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 on record.

5. Management performance: With MMB well above MSST based on last year's assessment, the stock was not considered overfished in 2009/10, and as estimated total male catch did not exceed the OFL, overfishing did not occur in 2009/10. Pending availability of NMFS SMBKC groundfish bycatch estimates, the same two conclusions appear likely for the most recent year, irrespective of assessment methodology. See table below. (All biomass measures in millions of pounds with metric ton equivalents in parentheses.)

Year	MSST	Biomass[a] (MMB)	TAC	Retained Catch	Total Catch	OFL	ABC
2005/06	-	5.3 (2,400)	Fishery Closed		0.47 (210)	-	-
2006/07	-	7.1 (3,200)	Fishery Closed		0.66 (300)	-	-
2007/08	-	9.7 (4,400)	Fishery Closed		0.35 (160)	-	-
2008/09	4.0 (1,800)	10.74 (4,870)	Fishery Closed		0.20 (91)	1.63[b] (739)	-
2009/10	3.4 (1,500)	12.76 (5,790)	1.167 (529.3)	0.461[c] (209)	0.530 (240)	1.72[d] (780)	-
2010/11	3.2[e] (1,500)	14.74[e] (6,686)	1.600 (725.7)	1.264[c] (573)	1.403[e] (636)	2.29[d] (1,040)	-
2011/12	NA	NA	NA	NA	NA	NA	NA

[a] From post-fishery fall assessment.
[b] Retained catch OFL.
[c] Fishery reported value from fish tickets.
[d] Total male catch OFL.
[e] May 2011 survey-based estimate, pending availability of 2010/11 NMFS groundfish bycatch estimates.

6. <u>Basis for the OFL</u>: Estimated Feb 15 mature male biomass (MMB) is used as the measure of biomass for this Tier 4 stock, with males measuring 105mm CL or more considered mature. The current B_{MSY} proxy is average estimated 1989/99 – 2009/10 MMB, determined to be 6.86 million pounds (3,110 t) in the 2010 assessment and 6.47 million pounds (2,930 t) using the current survey-based methodology. The F_{MSY} proxy is currently 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)	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[a](6,940)	2.23	$0.18yr^{-1}$	1	1989/90 - 2009/10	$0.18yr^{-1}$	-
2011/12[b]	4a	6.47 (2,930)	NA	NA	$0.18yr^{-1}$	1	1989/90 - 2009/10	$0.18yr^{-1}$	0.49

[a] 2010 model projection assuming F = F_{MSY} proxy.
[b] 2011/12 values provisional or anticipated, or pending 2011 NMFS EBS trawl survey results.

7. <u>Distribution of the OFL</u>: In this assessment the calculated OFL is assumed to inherit a lognormal distribution from the NMFS trawl-survey estimate of mature male biomass.

8. <u>Basis for the ABC</u>: Current recommendations are to use $P^* = 0.49$, where P(ABC > OFL) = P^*.

9. <u>Summary of rebuilding analyses</u>: 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

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 in the directed pot fishery. In addition, retained catch data in the directed fishery have been updated to include the 2010/11 season.

Changes in Assessment Methodology

To circumvent some of the difficulties associated with the existing 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 properly documented, the author has begun development of an alternative 3-stage CSA assessment model. Core ADMB code for this model can be found in Appendix A of this document. Jim Ianelli has reviewed both the existing and proposed models, as well as provided valuable additional support. For the current cycle, the author has chosen to draft an assessment based on survey biomass as the best option until a suitable assessment model is available.

Changes in Assessment Results

Final results for 2010/11 have yet to be determined. However, it is anticipated that results for 2010/11 will be consistent with last year's assessment indicating moderate-to-strong recent recruitment and stable or increasing biomass well above B_{MSY}, resulting in $F_{OFL} = F_{MSY}$.

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.

- Sep 2010 CPT
  Comments: No new comments.

- Oct 2010 SSC
  Comments: No new comments.

CPT and SSC Comments Specific to SMBKC Stock Assessment

- May 2010 CPT
  Comments: No new comments.

- June 2010 SSC
  Comments: *St. Matthew blue king crabs are assessed by a four-stage catch-survey analysis of males only. Five model scenarios will be analyzed using data updated with the 2010 survey data and 2009-2010 bycatch data when these become available. The SSC concurs with the CPT and author in the recommendation of a Tier 4 designation and the use of model scenario 1 (i.e., the same as used in the previous year with M fixed at 0.18 for 1978-1998 and 2000-2009 and estimated for 1999 and q fixed at 1.0). The SSC supports all of the CPT recommendations. With respect to the issue that the model cannot duplicate the large proportion of recruits seen in the pot surveys, the SSC recommends to the authors to attempt to identify the potential source(s) of this bias: 1) errors in the database, 2) mis-classification of shell age by the biologists on the surveys, and 3) different carapace wear/biofouling rates for this particular stock. Seemingly some of these issues can be addressed by a mark and recapture study, cross-training of staff, or other approaches. Finally, on Figure 15 (p. 410), the year axis should be re-labeled with actual years.*

  Response: These comments were previously addressed in the 2010 SAFE.

- Sep 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: MSST has been appropriately updated, and 2010 ADF&G St Matthew Island blue king crab pot-survey data have been presented in this report. In addition, 1990/91-1998/99, 2009/10, and 2010/11 ADF&G crab observer data have been integrated into the assessment. Otherwise, see comments and responses from Feb 2011 NPFMC crab modeling workshop and subsequent SSC review.

- 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 comments and response to SSC review of NPFMC crab modeling workshop.

- 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: To circumvent some of the difficulties associated with the existing model and arrange that the assessment process for this stock be robust, transparent, and properly documented, the author has begun development of an alternative 3-stage CSA assessment model. Core ADMB code for this model can be found in Appendix A of this document. Jim Ianelli has reviewed both the existing and proposed models, as well as provided valuable additional support. For the current cycle, the author has chosen to draft an assessment based on survey biomass as the best option until a suitable assessment model is available.

C. Introduction

Description of The Stock

Blue king crab, *Paralithodes platypus* (Brant 1850), 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. Adult blue king crabs are found at depths less than 180 meters and in average bottom water temperatures of 0.6° C (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.).

The Alaska Department of Fish and Game (ADF&G) Gene Conservation Laboratory division has detected regional population differences between blue king crabs 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 crabs 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). These two stocks are managed separately based on different life history characteristics and exploitation by the fishery.

Fishery and 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 mean catch increased to 3.297 million pounds during 1991-1998. After 1992, the St. Matthew and Pribilof Islands blue king crab fisheries were opened concurrently, dividing vessel effort between the two fisheries. To reduce total fishing effort and improve manageability of the relatively small allowable harvests, maximum limits of 60 pots and 75 pots were set in 1993 for vessels less than or greater than 38.1 m in length, respectively. Those limits reduced by a third the number of pots registered from 1992 to 1993; however, the number of pot lifts in the fishery increased slightly because the season length doubled and pot turnover rates increased. During 1996-1998 participation increased to an average of 123 vessels per year, and the average number of pot lifts increased 54% from 1992 (Bowers et al. 2011).

The fishery was declared overfished and closed in 1999 when the stock size 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. Watson (2005) has found similar trends in abundance indices for St. Matthew blue king crabs based on the 1995-2004 ADF&G triennial St. Matthew Island district pot survey.

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 by the Alaska Board of Fisheries and area closures to control bycatch, as well as gear modifications and an area closure for habitat protection. 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 crabs.

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 just 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. The fishery reported total landings of 1,263,982 pounds in 29,344 pot lifts for a CPUE of 10.2 crab per pot lift (B. Bechler, ADF&G, Dutch Harbor, 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 onboard observers in 2009/10 indicate 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 onboard observers recorded no blue king crab in 1,646 sampled pot lifts during the 2009/10 season (Gaeuman 2011). 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. Some limited SMBKC bycatch has also occurred in the eastern Bering Sea groundfish fisheries.

State Harvest Strategy

Subject to the federal overfishing limits, the current SMBKC TAC is determined based on the State harvest strategy (5 AAC 34.917), which was adopted by the BOF in March 2000 as part of a rebuilding plan developed for the stock (NPFMC 2000) and modified in 2009. The harvest strategy has three components for determining the TAC: 1) a threshold of 2.9-million pounds of mature male biomass; 2) an exploitation rate on mature male abundance that is a function of mature male biomass; and 3) a 40% cap on the harvest of legal males.

Mature male biomass (MMB) is defined for the harvest strategy as the biomass of males with a carapace length (CL) of 105 mm or greater in July prior to the start of the fishery. When MMB is below the 2.9-million-pound threshold of the State's harvest strategy, the stock is closed to commercial fishing. When the stock is above that threshold, an exploitation rate on mature male abundance, defined for management purposes as the abundance of all males at least 105 mm in CL, is determined as a function of MMB. The exploitation rate increases linearly from 10% when MMB equals 2.9-million pounds to 20% when MMB equals 11.6-million pounds. For MMB exceeding 11.6-million pounds, the exploitation rate remains at 20%. Application of the mature male exploitation rate to mature male abundance determines the targeted number of legal-size males for commercial harvest. Minimum legal size for the SMBKC stock is 5.5 in carapace width (CW), with 120 mm CL used as a proxy in stock-assessment computations. To protect from excessive harvest of the legal component of the mature male stock, the targeted number of legal males for commercial harvest is capped at 40% of the estimated legal-size male abundance.

D. Data

Summary of New Information

This assessment introduces into the assessment 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. In addition, retained catch data in the directed fishery have been updated to include the recently completed 2010/11 season.

Major Data Sources

Time series data sources used in this draft 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 (1978-2010; Table 2); ADF&G crab observer pot-lift sampling (1990/91-1998/99, 2009/10, 2010/11; Table 3); and NMFS groundfish observer catch sampling in both the trawl and fixed-gear fisheries (various years; Tables 4-6). Information concerning the NMFS trawl survey as it relates to commercial crab species is available in Chilton et al 2011. Data from the triennial ADF&G St Matthew Island blue king crab pot survey (1995, 1998, 2001, 2004, 2007, 2010; Table 7) are also included in this report for comparative purposes but were not directly incorporated into the assessment methodology. See Watson 2008 for a description of pot-survey methods. Figure 3 maps stations from which trawl and pot-survey data for the SMBKC assessment were obtained. Groundfish SMBKC bycatch data come from NMFS Bering Sea reporting areas 521 and 524, as shown in 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.
Trawl Survey Selectivities	1	Default.
Directed Fishery Handling Mortality	0.2	2010 SMBKC SAFE(?)
Directed Fishery Timing	Mid-season	Conventional assumption.
GF Trawl and Fixed-gear Handling Mortalities	0.8, 0.5	2010 SMBKC SAFE(?)
GF Fishery Timing	Feb 15	Simplifying approximation of conventional mid-year assumption.
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

Data from the triennial ADF&G St Matthew Island blue king crab pot survey (1995, 1998, 2001, 2004, 2007, 2010; Table 7) were not directly incorporated into the assessment methodology described in this report. These data are nevertheless useful in a comparative sense, especially as they represent a much more intensive sampling of the SMBKC population than do data from the trawl survey.

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 carapace length (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. To be of legal size in the SMBKC fishery, male crab must measure at least 5.5 in carapace width, including spines, for which 120 mm CL is considered a management proxy, with male crab measuring at least105 mm CL 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.

Since the 2010 assessment, various concerns have arisen about use of the existing model, culminating in NPFMC crab modeling workshop 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; SSC March 2011). In the wake of discussions at the Feb 2011 NPFMC crab modeling workshop, the current author began development of an alternative 3-stage CSA model along the lines of Collie et al 2005, for which core ADMB code can be found in appendix A of this document. The associated .dat and .ctl files are included in appendices B and C. Jim Ianelli has reviewed both an earlier version of this model and the existing one, as well as provided valuable additional support, but the limited time frame has prevented satisfactory resolution of the difficulties associated with appropriate use of either model. For the current cycle, the author has thus chosen to proceed with an assessment based on survey biomass as the best option until a suitable and properly documented model is available.

Assessment Methodology

For estimation of required management quantities, the approach presented here relies primarily on the annual NMFS EBS trawl survey for the years 1978-2010, with results from 2011 to be included later. It shares in common with the previous model-based approach that it accounts only for male crab measuring at least 90 mm CL. A natural consequence of this and the management based CL definitions of mature and legal crab is that the first two stages of the existing model remain, at least conceptually, intact, whereas stages 3 and 4 merge into a single “legal” class consisting of those males measuring not less than 120 mm CL. Note that this consolidation brings with it the considerable benefit of eliminating from the analysis the problematic notion of shell condition, which is needed to distinguish fully between the contributing two classes, resulting in three true CL size classes with ranges 90-104 mm, 105-119 mm, and 120 mm+. As described previously, “mature” crab are considered to be those in the 120 mm+ (“legal”) and 105-119 mm size classes. It is important to note that NMFS survey area-swept estimates of SMBKC abundance and biomass come with considerable uncertainty, as is evident from Figure 5, and that an assessment strategy based primarily on those estimates will necessarily be subject to the same limitation.

In this approach, assessment year mature and legal abundances at survey time, quantities required for the State harvest strategy, are estimated directly from the NMFS trawl survey results (Figure 6), as are corresponding measures of uncertainty. This information will become available for the fall 2011 assessment upon completion of the NMFS trawl survey. Estimation of assessment year mature male biomass at the time of mating MMB_{mating} begins with survey estimated mature male biomass MMB_{survey}, which is then discounted to the midpoint τ of the fishery under natural mortality M, at which point fishery reported retained catch biomass B_{ret} is subtracted, along with estimated directed fishery mature discard mortality B_{MMdis}. After discounting the resulting biomass to the time of mating, assumed to be Feb 15, estimated SMBKC bycatch mortality B_{GFmort} in the groundfish fisheries is also subtracted, on the assumption that groundfish bycatch impacts primarily the mature population, approximately as a Feb 15 pulse effect. (Note that both of these assumptions are likely conservative in the sense of overestimating MMB groundfish bycatch mortality.) Historical estimates through 2010/11 are shown in Figure 7. The calculation is given by

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

Directed fishery mature discard mortality B_{MMdis} is estimated from fishery-reported retained catch and ADF&G at-sea observer size-frequency sampling of animals in sampled pot lifts by the proportion of retained catch corresponding to the sample ratio of estimated total non-retained mature (105 mm+ CL) male weight to estimated total retained weight, after accounting for an assumed 20% handling mortality. Length-to-weight computations employ the coefficients developed by Chilton and Foy (2010). For fishery years lacking observer data, i.e. 1978/79-1989/90, the ratio of combined estimated discard bycatch to combined reported retained catch over pre-rationalization years with observer data is used. Groundfish bycatch B_{GFmort} is estimated by ½ the sum of 80% of the estimates reported for trawl, pelagic trawl, and non-pelagic trawl gear types and 50% of the estimates from 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. Bycatch mortality associated with the groundfish fisheries, however estimated, typically constitutes only a very small fraction of mature male biomass.

Producing a meaningful estimate of the uncertainty associated with this estimate of $\mathrm{MMB}_{\mathrm{mating}}$ is problematic; however, for the 2011 assessment year the estimate of survey MMB variance reported with the NMFS dataset can be used to formulate at least a rough estimate of variance for the Feb 15 value. Since the magnitudes of retained catch, discard mortality, and groundfish bycatch mortality are all likely to be small by comparison with MMB, even under assumption of moderately large CVs for those quantities $\mathrm{var}(MMB_{mating})$ will be determined by $\mathrm{var}(MMB_{survey})$ so that

$$\mathrm{var}(MMB_{mating}) \cong (\exp[-(0.63)M])^2\ \mathrm{var}(MMB_{survey})\ .$$

Thus, assuming M = 0.18 known without error and a reasonable estimate $\widehat{var}(MMB_{215})$ from the survey, we have

$$\widehat{var}(MMB_{mating}) = 0.80\widehat{var}(MMB_{survey}).$$

For the 2010/11 MMB_{mating} estimate of 17.95 million pounds, for example, this results in a standard error of about 5.4 million pounds. Additional uncertainty is of course associated with the natural mortality parameter M, which is not in fact known. Survey estimates of variance likewise conceal some additional and possibly important sources of variability, such as that associated with the allometric length-to-weight model and survey estimation of crab weights.

Model Selection and Evaluation

The survey-based approach taken 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

Survey-based estimates for important time series, excluding the current assessment year, are summarized in Figures 5-9. Availability of historical data has precluded proper accounting of the precision of the historical estimates, but variance estimates based on 2011 NMFS trawl-survey results, as described in this document, will be provided for key 2011/12 management quantities in time for the September draft.

F. Calculation of The OFL

The OFL (overfishing level) is the level of catch associated with directed 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}, F_{OFL} is determined as a function of biomass B and two additional parameters α and β according to 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 taken to be mature male biomass at the time of mating (MMB_{mating}), assumed to be Feb 15. Current recommendations for the stock are to use the period 1989-2009 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. Employing the current survey-based assessment methodology and averaging over1989-2009 results in a B_{MSY} proxy of 6.47 million pounds, as compared to 6.86 million pounds from the 2010 four-stage CSA model-based assessment. The parameters α and β are assigned their default values $\alpha = 0.10$ and $\beta = 0.25$. Note that as $B = MMB_{mating}$ is itself a function of fishing mortality, in case b) numerical approximation of F_{OFL} is required.

With mature male biomass as the appropriate currency, in terms of this survey-based assessment we have

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

with τ equal to the time from the survey to the midpoint of the directed fishery. Moreover, for this stock there are three catch components to consider: 1) directed-fishery retained catch; 2) directed-fishery mature-male discard mortality; and 3) bycatch mortality in the groundfish trawl and fixed-gear fisheries, so that

$$OFL = B_{ret} + B_{MMdis} + B_{GFTmort} + B_{GFFmort} \ . \tag{2}$$

Groundfish bycatch mortalities are estimated by the harmonic means of the previous five-year estimates, and mature male discard mortality B_{MMdis} is estimated by $0.20\rho B_{ret}$, where ρ is the ratio of mature male discard weight to retained catch weight from post-rationalization crab observer size frequency data and 0.20 is the assumed handling mortality in the directed fishery. Substitution into equation (2) then yields a retained catch OFL of

$$OFL_{ret} = \frac{OFL - B_{GFTmort} - B_{GFFmort}}{1 + 0.20\rho}. \tag{3}$$

Pending this summer's NMFS trawl-survey results, recent stock trends suggest that given any reasonable specification of B_{MSY} (provisionally 6.47 million pounds based on the analysis given here), for the fall 2011 assessment scenario a) of the OFL control rule will likely prevail, with F_{OFL} set equal to the F_{MSY} proxy, presently 0.18. Components of the total catch OFL, mandated beginning 2009/10, are listed in Table 8.

G. Calculation of The ABC

In view of equation (1) in §F, specification of a joint distribution for MMB_{survey}, M, and F_{OFL} immediately determines a distribution for the OFL. Provided that 2011 MMB_{survey} is sufficiently large by comparison with the current B_{MSY} proxy, it may be assumed that $F_{OFL} = M$ as determined by the control rule. Then treating $M = 0.18$ as known and further assuming that the survey estimate of MMB_{survey} is lognormally distributed, we have that the calculated value of the OFL is likewise lognormally distributed with estimated variance

$$\begin{aligned} \hat{var}(OFL) &= \exp(-2\tau M)\,[1 - \exp(-F_{OFL})]^2\,\hat{var}(MMB_{survey}) \\ &= \exp(-2(0.44)(0.18))\,[1 - \exp(-0.18)]^2\,\hat{var}(MMB_{survey}) \\ &= 0.02\,\hat{var}(MMB_{survey}). \end{aligned}$$

In setting the ABC, current recommendation is to take P* = 0.49, where P(ABC > OFL) = P*. However, determination of the ABC under this requirement additionally requires specification of the mean of the distribution of the OFL with respect to the target value, which remains to be done. Moreover, the author acknowledges that this analysis fails fully to account for important sources of uncertainty.

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

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. Fisheries Assessment and Management in Data-Limited Situations. Univeristy of Alaska Fairbanks, Alaska Sea Grant Report, 05-02, pp. 683-714.

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 – 2009/10St Matthew Island directed blue king crab fishery. (Source: Bowers et al. 2011 and B. Bechler, ADF&G, Dutch Harbor)

Season	Dates	GHL/TAC[a]	Harvest[b]		Pot Lifts	CPUE[c]	Avg Wt[d]	Avg CL[e]
			Crab	Pounds				
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[f]	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[f]	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[g]

[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.
[f] Actual season length was 60 hours.
[g] From ADF&G crab observer database.

Table 2**.** NMFS EBS trawl-survey area-swept estimates of crab abundance (millions of crab) by size class and total biomass (millions of pounds) of 90mm+ CL crab and associated CV. (Source: J. Zheng, ADF&G, Juneau and R. Foy, AFSC, Kodiak)

Year	90-104mm CL	105-119mm CL	120mm+ CL (Legal)	Biomass	CV	Number of Crab
1978	2.384	2.268	1.764	16.081	0.394	163
1979	2.939	2.225	2.223	18.128	0.404	187
1980	2.539	2.456	2.867	21.937	0.506	188
1981	0.477	1.233	2.346	14.141	0.402	140
1982	1.713	2.495	5.987	34.222	0.343	269
1983	1.078	1.663	3.363	20.611	0.297	231
1984	0.410	0.499	1.478	8.156	0.184	104
1985	0.381	0.376	1.124	6.455	0.210	93
1986	0.206	0.457	0.377	3.037	0.386	46
1987	0.325	0.631	0.715	4.881	0.291	71
1988	0.410	0.816	0.957	6.648	0.251	81
1989	2.164	1.158	1.792	13.771	0.271	211
1990	1.053	1.031	2.338	14.314	0.274	170
1991	1.135	1.680	2.236	15.059	0.249	198
1992	1.074	1.382	2.291	14.748	0.200	220
1993	1.521	1.828	3.276	21.110	0.169	324
1994	0.883	1.298	2.257	14.090	0.176	211
1995	1.025	1.188	1.741	11.828	0.178	178
1996	1.238	1.891	3.064	19.726	0.240	285
1997	1.165	2.228	3.789	23.179	0.337	296
1998	0.660	1.661	2.849	17.565	0.355	243
1999	0.223	0.222	0.558	3.469	0.182	52
2000	0.282	0.285	0.740	4.437	0.310	61
2001	0.419	0.502	0.938	6.123	0.246	91
2002	0.111	0.230	0.640	3.749	0.321	38
2003	0.449	0.280	0.465	3.477	0.335	65
2004	0.247	0.184	0.562	3.292	0.304	48
2005	0.319	0.310	0.501	3.372	0.370	42
2006	0.917	0.642	1.240	8.166	0.333	126
2007	2.518	2.020	1.193	13.574	0.384	250
2008	1.352	0.801	1.457	10.565	0.284	167
2009	1.573	2.161	1.410	13.754	0.256	251
2010	3.927	3.253	2.458	24.538	0.466	385
2011	NA	NA	NA	NA	NA	NA

Table 3. Observed proportion of crab by size class during ADF&G crab observer pot-lift sampling and estimated fishery total male discard mortality (pounds) calculated with respect to "sublegal" male crab measuring 90-119mm CL. (Source: ADF&G crab observer database)

Year	Sampled Pot Lifts	Number of Crab	90-104mm CL	105-119mm CL	120mm+ CL	DW/RW[a]	Discard Mortality[b]
1990/91	10	150	0.1133	0.3933	0.4933	0.587	202,559
1991/92	125	3,393	0.1329	0.1768	0.6902	0.188	126,675
1992/93	71	1,606	0.1905	0.2677	0.5417	0.309	153,353
1993/94	84	2,241	0.2806	0.2097	0.5095	0.263	158,152
1994/95	203	4,735	0.2941	0.2713	0.4344	0.397	298,629
1995/96	47	663	0.1478	0.212	0.6395	0.255	161,584
1996/97	96	489	0.1595	0.2229	0.6175	0.230	141,455
1997/98	133	3,195	0.1818	0.2053	0.6127	0.620	576,942
1998/99	135	1,322	0.1925	0.2162	0.5912	0.360	213,651
2009/10	989	19,802	0.1413	0.3235	0.5352	0.452	41,706
2010/11	2,419	45,466	0.1314	0.3152	0.5534	0.406	102,692

[a] Mature discard-to-retained weight ratio using SMBKC length-to-weight coefficients from Chilton and Foy 2010.
[b] Product of mature discard-to-retained weight ratio, fishery retained catch weight, and assumed 20% handling mortality.

Table 4. Groundfish trawl SMBKC bycatch size-class proportions data. (Source: J. Zheng, ADF&G, Juneau)

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

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 6. Groundfish SMBKC male bycatch biomass (pounds) data. (Source: J. Zheng, ADF&G, Juneau and R. Foy, AFSC, Kodiak)

	Biomass		Total Groundfish
Year	Trawl[a]	Fixed Gear	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	13,463
2009/10	1,722[c]	18,281[c]	10,518

[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 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, ADF&G, Kodiak and R. Gish, ADF&G, Kodiak)

Year	90-104mm CL	105-119mm CL	120mm+ CL (legal)	Biomass	CV	Number of Crab
1995	1.919	3.198	6.922	38.2186	0.130	4,624
1998	0.964	2.763	8.804	44.4576	0.062	4,812
2001	1.266	1.737	5.487	28.9935	0.079	3,255
2004	0.112	0.414	1.141	5.8859	0.152	640
2007	1.086	2.721	4.836	26.8409	0.097	3,319
2010	1.326	3.276	5.607	34.255	0.125	3,920

Tabel 8. Total male catch 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		
Year	Tier	F_{OFL}	Retained	Discard	Trawl	Fixed Gear	Total Male
2009/10	4a	$0.18yr^{-1}$	1.532 (694)	NA	NA	NA	1.723 (782)
2010/11	4a	$0.18yr^{-1}$	1.989 (902)	0.263 (119)	0.003 (1)	0.038 (17)	2.293 (1,040)
2011/12[a]	4a	$0.18yr^{-1}$	NA	NA	NA	NA	NA

[a] Determination of the 2011/12 OFL is pending availability of 2011 NMFS EBS trawl-survey results.

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

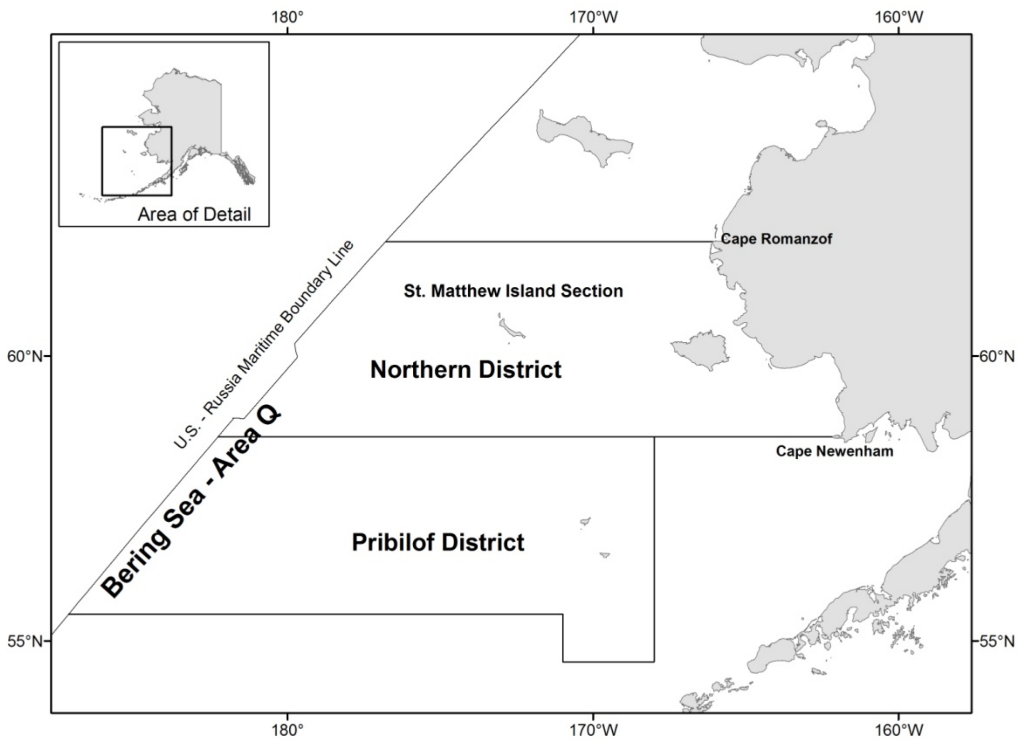

Figure 2. King crab Registration Area Q (Bering Sea).

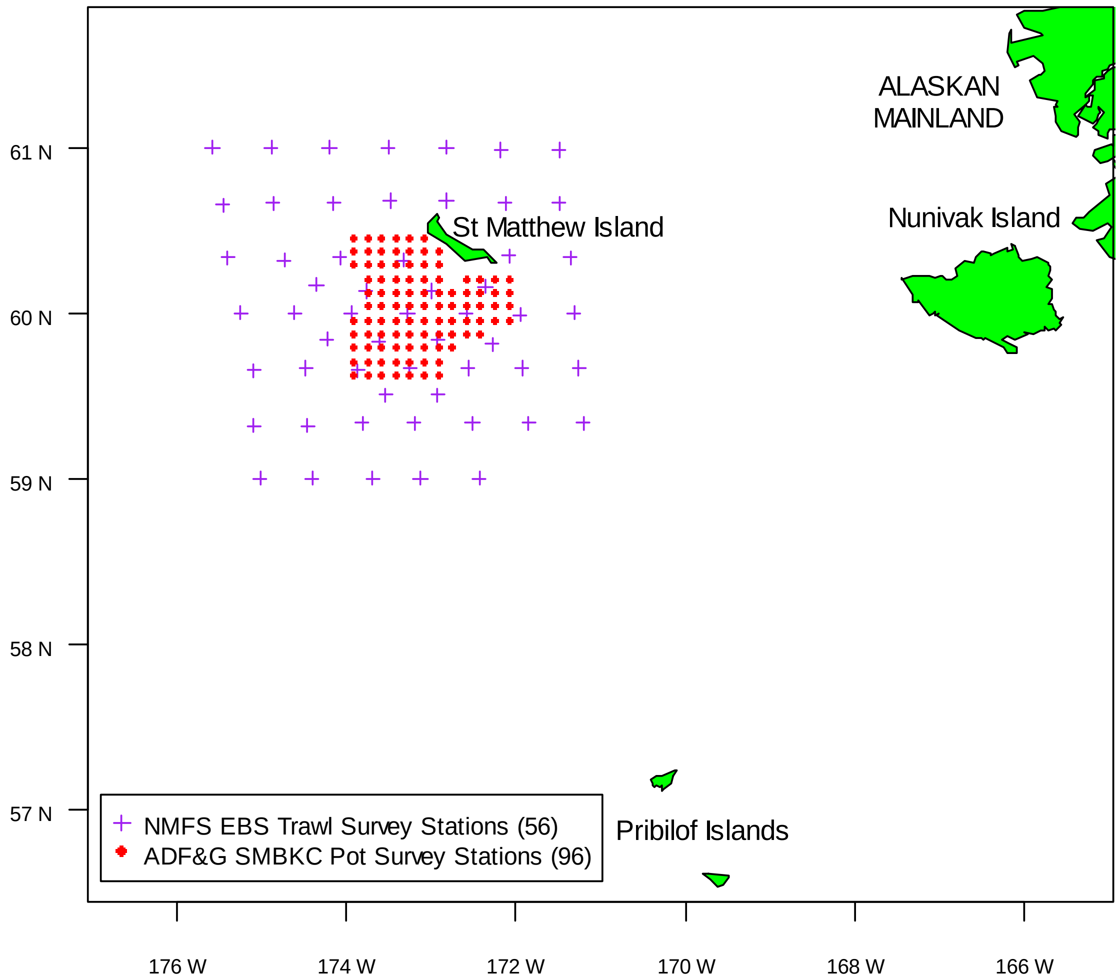

Figure 3: Trawl and pot-survey stations used in the SMBKC stock assessment.

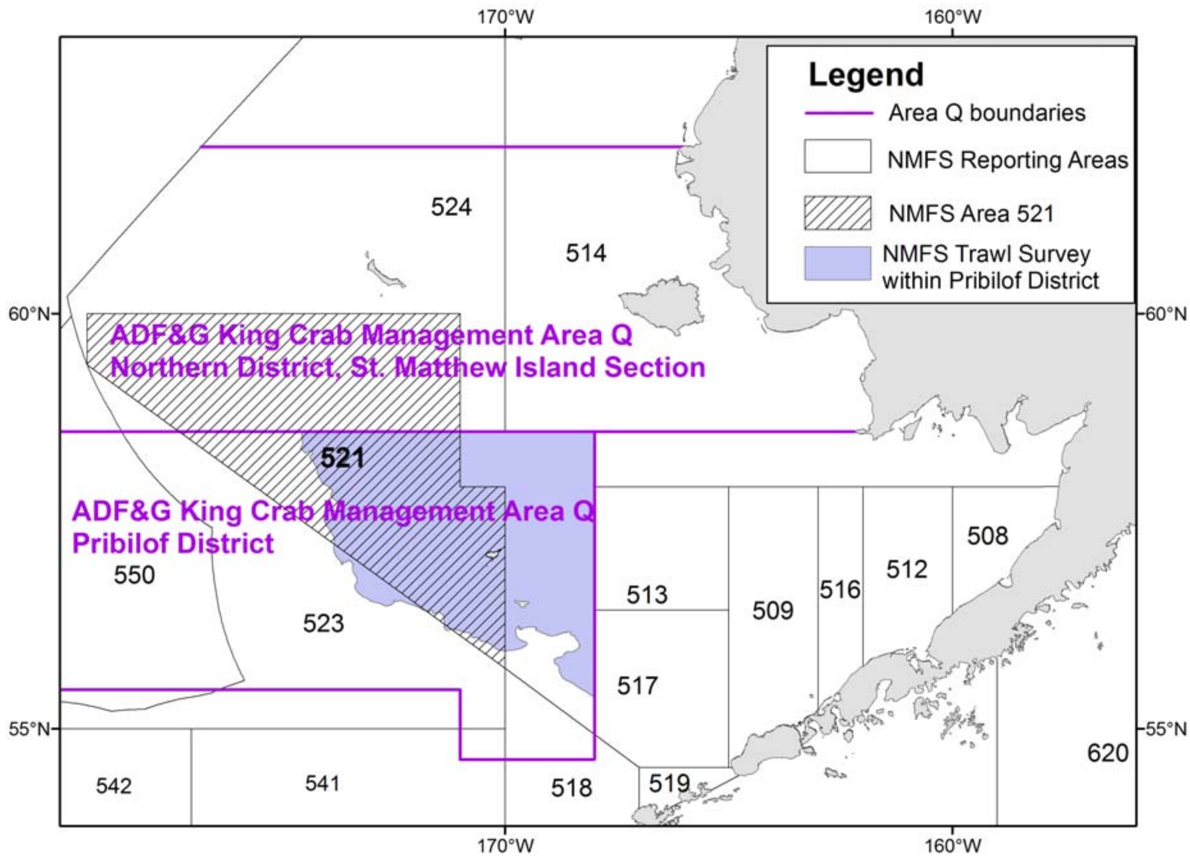

Figure 4. NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.

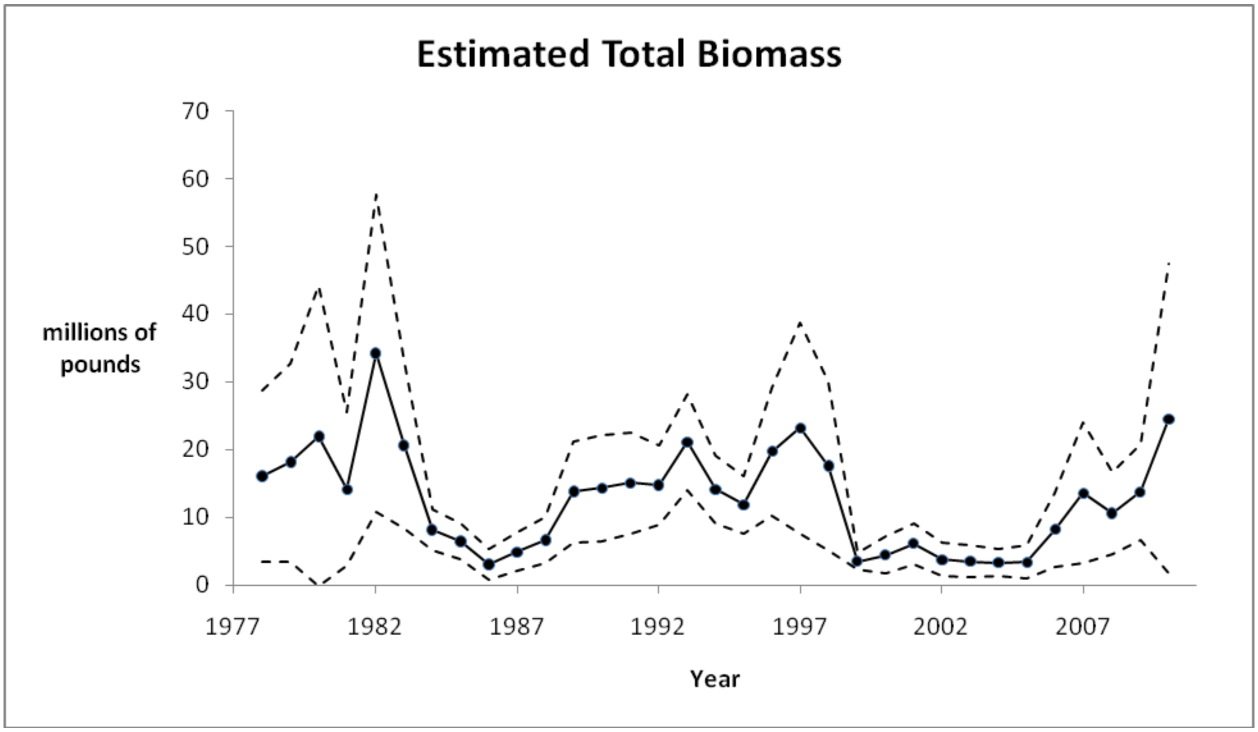

Figure 5. NMFS trawl-survey area-swept estimates of SMBKC biomass of males greater than 90mm CL, with estimated 95% confidence intervals.

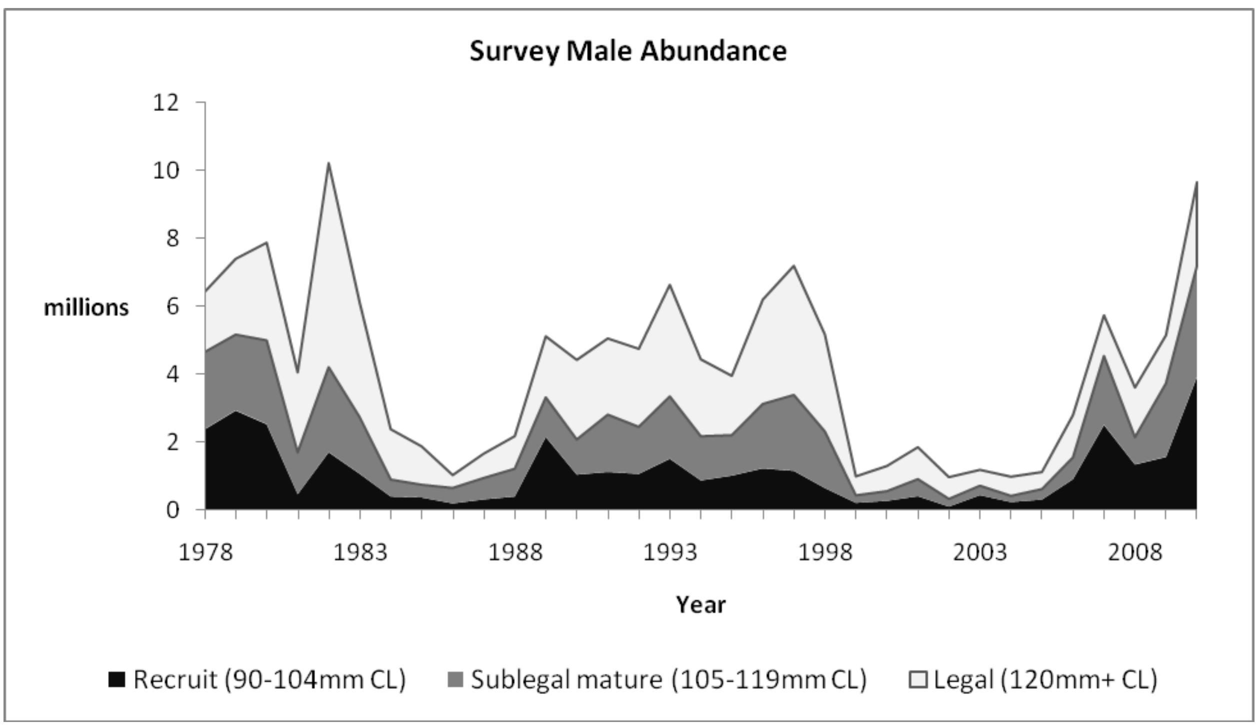

Figure 6. Historical NMFS EBS trawl-survey SMBKC abundance estimates.

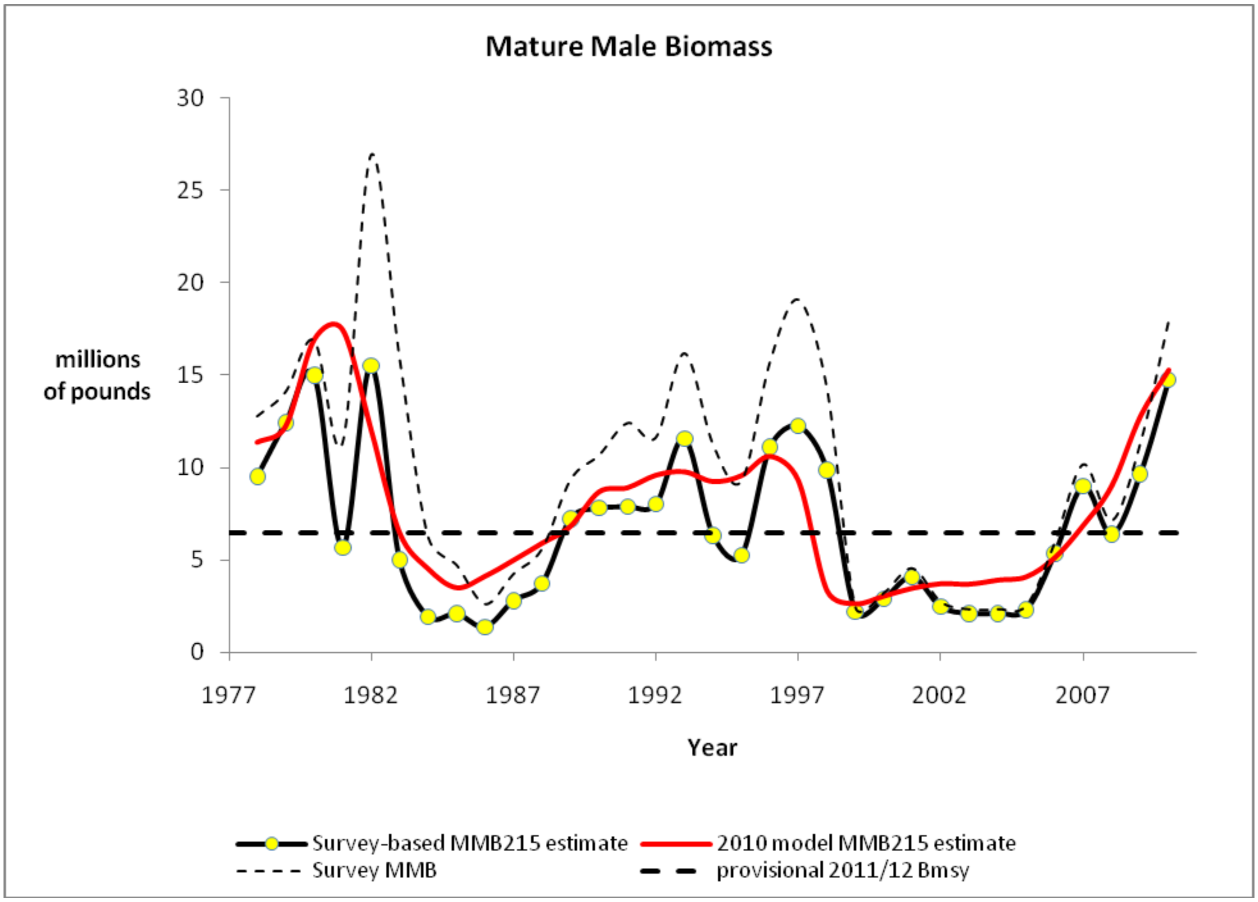

Figure 7. Survey-based estimates of historical Feb 15 MMB computed from correpsonding survey MMB estimates, and associated B_{MSY} using the 1989/90-2009/10 average. 2010 assessment model-based estimates are also shown for comparison.

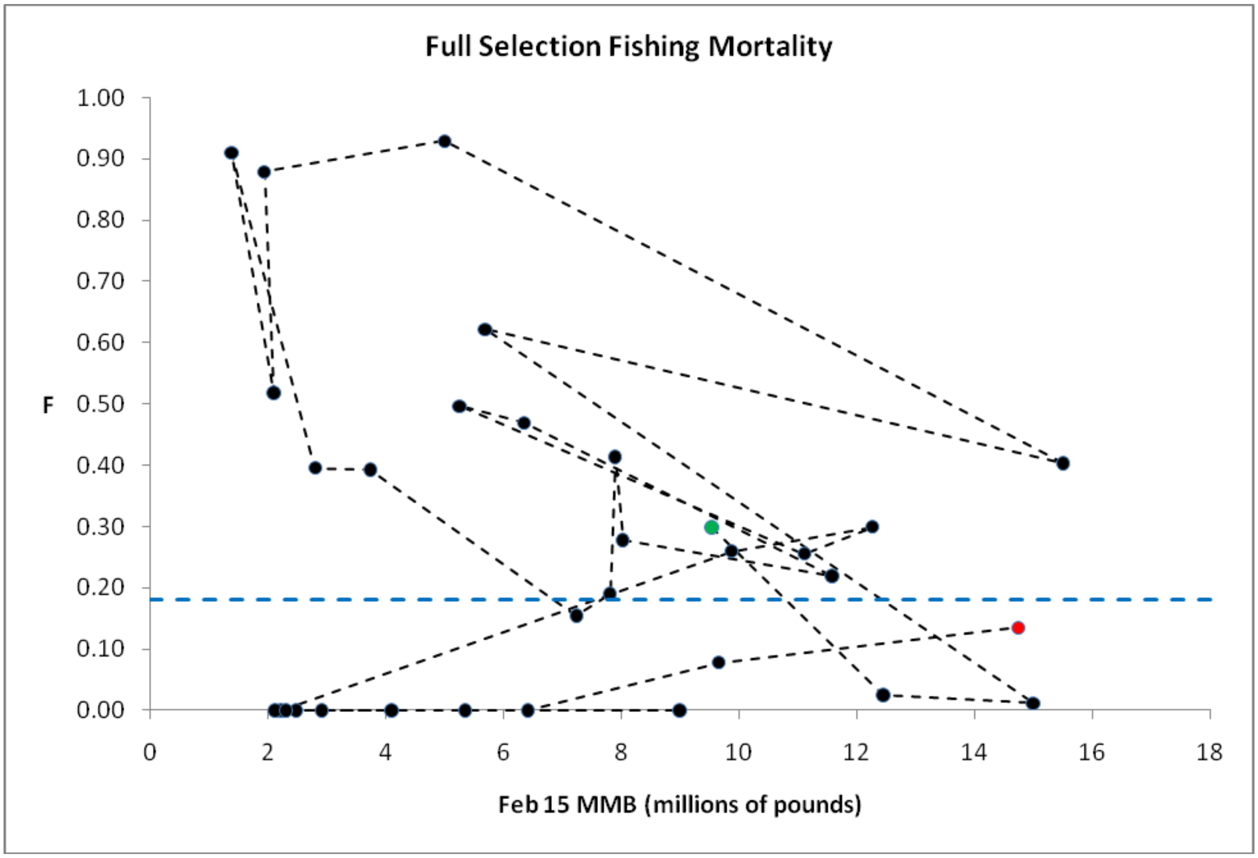

Figure 8. Estimated historical full-selection fishing mortality defined with respect to "legal" abundance versus estimated Feb 15 mature male biomass. Also shown (dashed horizontal line) is the anticipated 2011/12 F_{OFL} = 0.18. (The green and red points mark the first and last fishery years of the 33-year series, 1978/79-2010/11.)

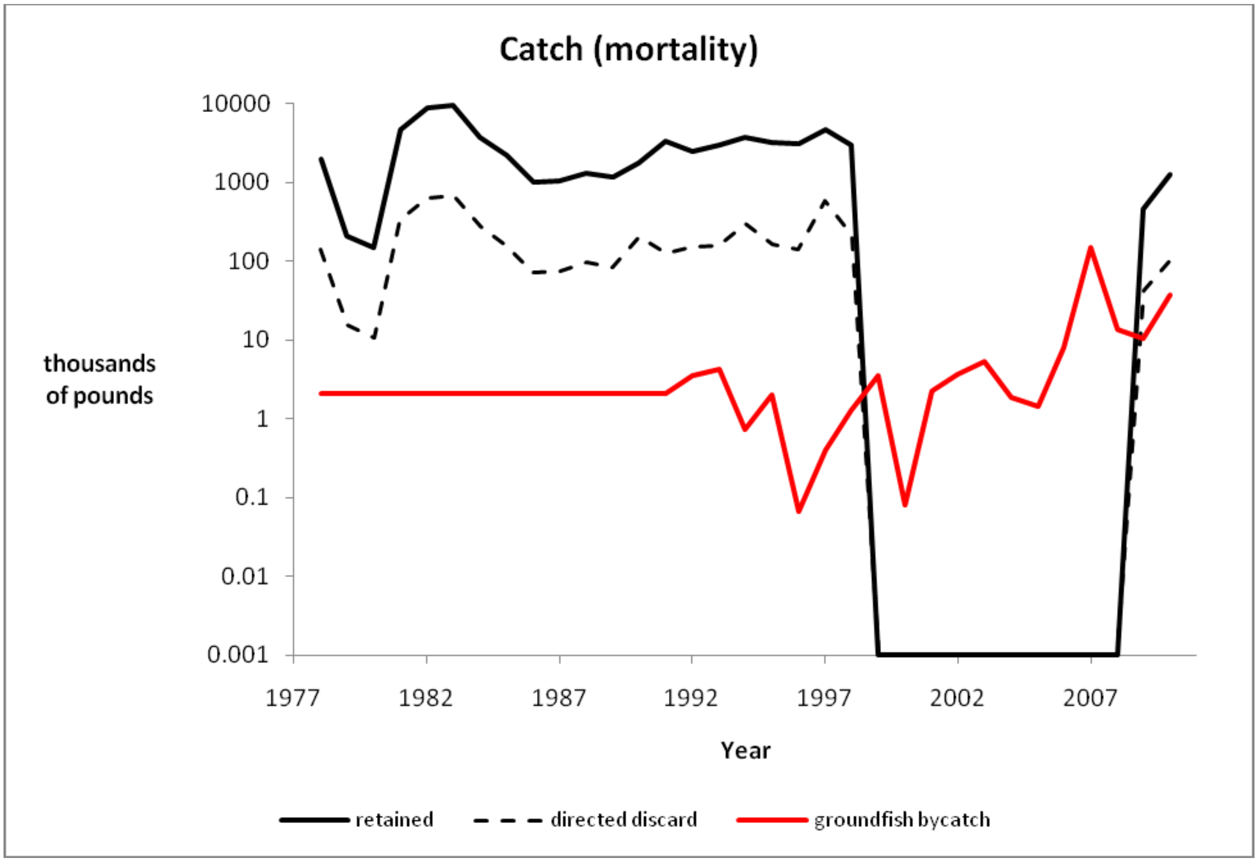

Figure 9. Estimated SMBKC mature-male stock catch components based on handling mortalities of 20% (directed pot fishery), 50% (groundfish fixed-gear), and 80% (groundfish trawl). The directed fishery was closed 1998/99-2008/09.

Appendix A: ADMB Code for Alternative 3-Stage SMBKC Assessment Model

```
// Basic three-stage male-only catch-survey-analysis (CSA) model for St Matthew Island blue king crab
// Constructed by Bill Gaeuman March 2011
// Stage 1 = 90-104mm CL; Stage 2 = 105-119mm CL; Stage 3 = 120mm+ CL

// Data used in objective function:
//  1) trawl survey composition and total abundance + CV
//  2) pot survey composition and total abundance + CV
//  3) fishery retained catch number
//  4) crab-observer composition data from observed count proportions
//  5) groundfish bycatch biomass data

// Directed fishery assumed to occur as pulse at midpoint of season.
// Groundfish fishery assumed to occur as a Feb 15 pulse.
// Abundances in 1000s of crab (crab per 1000 pot lifts for pot survey estimate).
// Biomasses in 1000s of lb (lb per 1000 pot lifts for pot survey estimate).
// Effort in 1000s of pot lifts [not currently used]
//_______________________________________________________

DATA_SECTION
 init_int start_yr                     // Beginning year, e.g. 1978
 init_int nyrs                         // Model time frame in years, e.g. 33 [years through last trawl survey]
 init_vector wt(1,3)                   // Stage mean weights for necessary biomass computations
 init_vector hm(1,3)                   // Directed and groundfish fixed-gear and trawl fishery handling mortalities

 init_int nyrs_ts                      // Number of years of trawl survey data
 init_ivector yid_ts(1,nyrs_ts)        // Trawl survey data year indices
 init_matrix ts_data(1,nyrs_ts,1,6)    // Sample size, stage abundance indices, total abundance, CV

 init_int nyrs_ps                      // Number of years of pot survey data
 init_ivector yid_ps(1,nyrs_ps)        // Pot survey data year indices
 init_matrix ps_data(1,nyrs_ps,1,6)    // Sample size, stage abundance indices, total abundance, CV

 init_int nyrs_pf                      // Number of years of directed pot fishery data (other than zero catch)
 init_ivector yid_pf(1,nyrs_pf)        // Fishery data year indices
 init_matrix pf_data(1,nyrs_pf,1,4)    // Catch number, time to midpoint of fishery, effort (not used), catch weight

 init_int nyrs_ob                      // Number of years of observer data
 init_ivector yid_ob(1,nyrs_ob)        // Observer data year indices
 init_matrix ob_data(1,nyrs_ob,1,3)              // Observed stage counts,

 init_int nyrs_gf                      // Number of years of groundfish bycatch biomass data
 init_vector yid_gf(1,nyrs_gf)         // Groundfish data year indices
 init_matrix gf_data(1,nyrs_gf,1,2)    // Trawl and fixed-gear bycatch biomass [NOT mortality]
 //_______________________________________________________________

 //Error trap to ensure all data have been read
 init_int eof;
 !! if(eof != 999){cout<<"DATA READING ERROR"<<endl; exit(1);};
 //_______________________________________________________________

 ivector yrs(1,nyrs)                   // Model years, e.g. 1978, 1979,..., 2010
```

```
 vector n_ts(1,nyrs_ts)              // TS, PS, obs sample sizes [number of male crab >= 90mm CL]
 vector n_ps(1,nyrs_ps)
 vector n_ob(1,nyrs_ob)

 vector x_ts(1,nyrs_ts)              // Survey estimated total abundances and ret catch number
 vector x_ps(1,nyrs_ps)
 vector x_ret(1,nyrs_pf)

 vector eff(1,nyrs_pf)               // Effort
 vector lag_pf(1,nyrs)               // Time to pot fishery [= zero if no fishery]
 !!lag_pf.initialize();
 vector ret_wt(1,nyrs)               // Retained catch weight [=0 if no fishery; considerd known]
 !!ret_wt.initialize();
 vector avg_ret_wt(1,nyrs);          // Avg retained weight for biomass computations [obvious quotients or their
average]

 vector cv_ts(1,nyrs_ts)             // Survey estimated CVs
 vector cv_ps(1,nyrs_ps)

 matrix p_ts(1,nyrs_ts,1,3)          // Survey and fishery (from observer data) stage proportions
 matrix p_ps(1,nyrs_ps,1,3)
 matrix p_ob(1,nyrs_ob,1,3)

 vector gft_mort(1,nyrs_gf)          // Groundfish bycatch mortality (from NMFS groundfish obs data)
 vector gff_mort(1,nyrs_gf)

 !! ad_comm::change_datafile_name("smbkc3.ctl");
 init_int ph_M
 init_int ph_M98
 init_int ph_Qts
 init_int ph_Qps
 init_int ph_logN1o
 init_int ph_logN2o
 init_int ph_logN3o
 init_int ph_logit_p12
 init_int ph_logit_p23
 init_int ph_s_ts
 init_int ph_s_ps
 init_int ph_s_pf
 init_int ph_mean_log_Fpf
 init_int ph_log_Fpf_dev
 init_int ph_mean_log_New
 init_int ph_log_New_dev

 init_vector Lw(1,8)
 init_vector Pw(1,4)

 init_number M_start
 init_number M98_start
 init_number Qts_start
 init_number Qps_start
 init_number logN1o_start
 init_number logN2o_start
 init_number logN3o_start
```

```
 init_number logit_p12_start
 init_number logit_p23_start
 init_number s_ts_start
 init_number s_ps_start
 init_number s_pf_start
 init_number mean_log_Fpf_start
 init_number mean_log_New_start

 //Error trap to ensure all data have been read
 init_int eof_ctl;
 !! if(eof_ctl != 999){cout<<"CTL DATA READING ERROR"<<endl; exit(1);};
//______________________________________________________________________________


PARAMETER_SECTION
 // Natural mortality [allows distinct value for 1998/99]
 init_number M(ph_M)
 init_number M98(ph_M98)

 // Trawl survey "catchability"
 init_number Qts(ph_Qts)

  // Pot survey proportionality constant
 init_bounded_number Qps(0.1,1.0,ph_Qps)

 // Trawl-survey stage 1 and 2 selectivies
 init_bounded_vector s_ts(1,2,0.2,2.0,ph_s_ts)

 // Pot-survey stage 1 and 2 selectivities
 init_bounded_vector s_ps(1,2,0.2,1.5,ph_s_ps)

 // Pot_fishery stage 1 and 2 slectivities
 init_bounded_vector s_pf(1,2,0.2,1.5,ph_s_pf)

 // Log initial stage abundances
 init_bounded_number logN1o(5.0,10.0,ph_logN1o)
 init_bounded_number logN2o(5.0,10.0,ph_logN2o)
 init_bounded_number logN3o(5.0,10.0,ph_logN3o)

 // Logit p12 and p23 transition probabilities
 init_number logit_p12(ph_logit_p12)
 init_number logit_p23(ph_logit_p23)

 // Mean log fishing mortality and deviations
 init_bounded_number mean_log_Fpf(-3.0,0.0,ph_mean_log_Fpf)
 init_bounded_dev_vector log_Fpf_dev(1,nyrs_pf,-10.0,10.0,ph_log_Fpf_dev)

 // Mean log recruitment and deviations
 init_bounded_number mean_log_New(5.0,10.0,ph_mean_log_New)
 init_bounded_dev_vector log_New_dev(2,nyrs,-5.0,3.0,ph_log_New_dev)

 // Mean log groundfish fishing mortalities and deviations
 init_bounded_number mean_log_Fgft(-12.0,-8.0,4)
 init_bounded_number mean_log_Fgff(-12.0,-8.0,4)
```

```
init_bounded_dev_vector log_Fgft_dev(1,nyrs_gf,-5.0,5.0,5)
init_bounded_dev_vector log_Fgff_dev(1,nyrs_gf,-5.0,5.0,5)
//______________________________________________________________

// Yearly natural mortality [= M98 in year 21 and otherwise = M]
vector MM(1,nyrs)

// Row-stage-to-column-stage transition matrix (molting + growth)
matrix TM(1,3,1,3)

// Fishing mortalitites [= 0 in years with no fishery]
vector Fpf(1,nyrs)
!! Fpf.initialize();

// Groundfish fishing mortalities [= HM in years with no data]
vector Fgft(1,nyrs);
vector Fgff(1,nyrs);

// Model recruitment [note: New(t) contributes to N1(t); nyrs+1 = harmonic mean]
vector New(2,nyrs)

// Yearly stage abundances at beginning of year [survey time]
matrix N(1,nyrs,1,3)

// Model predicted fishery stage removal (mortality) numbers [= 0 in years with no fishery]
matrix R_pf(1,nyrs,1,3)
!! R_pf.initialize();

// Model predicted groundfish bycatch removal (mortality) numbers and biomasses
matrix R_gft(1,nyrs,1,3)
matrix R_gff(1,nyrs,1,3)
vector B_gft(1,nyrs)        // Only years nyrs_gf used in likelihood; based on mean_log_Fgf otherwise
vector B_gff(1,nyrs)

// Directed fishery discard mortality [= 0 in years with no fishery]
vector Dis_mort(1,nyrs);
!! Dis_mort.initialize();

// Model predicted abundances and ret catch
vector X_ts(1,nyrs_ts)
vector X_ps(1,nyrs_ps)
vector X_ret(1,nyrs_pf)

// Model predicted composition measures
matrix P_ts(1,nyrs_ts,1,3)
matrix P_ps(1,nyrs_ps,1,3)
matrix P_ob(1,nyrs_ob,1,3)

// Model predicted Feb 15 mature male biomass
vector MMB215(1,nyrs)

objective_function_value f

// Components of objective function for model diagnostics
```

```
 vector LogLike(1,8);
 vector Pen(1,4);
//____________________________________________________________________________

INITIALIZATION_SECTION
// See ctl file
 M M_start
 M98 M98_start
 Qts Qts_start
 Qps Qps_start
 logN1o logN1o_start
 logN2o logN2o_start
 logN3o logN3o_start
 logit_p12 logit_p12_start
 logit_p23 logit_p23_start
 s_ts s_ts_start
 s_ps s_ps_start
 s_pf s_pf_start
 mean_log_Fpf mean_log_New_start
 mean_log_New mean_log_New_start
//_____________________________________________________________________________

PRELIMINARY_CALCS_SECTION
 int k;

 // Vector of years
 yrs.fill_seqadd(start_yr,1);

 //Extract data
 // Trawl Survey Data
 n_ts=column(ts_data,1);
 x_ts=column(ts_data,5);
 cv_ts=column(ts_data,6);
 for(k=1;k<=nyrs_ts;k++)
   p_ts(k)=--ts_data(k)(2,4)/sum(ts_data(k)(2,4));

 // Pot Survey Data
 n_ps=column(ps_data,1);
 x_ps=column(ps_data,5);
 cv_ps=column(ps_data,6);
 for(k=1;k<=nyrs_ps;k++)
   p_ps(k)=--ps_data(k)(2,4)/sum(ps_data(k)(2,4));

 // Pot Fishery Data
 x_ret = column(pf_data,1);
 eff = column(pf_data,3);
 for(k=1;k<=nyrs_pf;k++)
 {
   lag_pf(yid_pf(k)) = pf_data(k,2);       // = 0 in years with no fishery
   ret_wt(yid_pf(k)) = pf_data(k,4);     // = 0 in years with no fishery
 }

 // Observer Data
 n_ob=rowsum(ob_data);
```

```
 for(k=1;k<=nyrs_ob;k++)
   p_ob(k)=ob_data(k)/n_ob(k);

 // Avg retained weights for biomass computations [obvious quotients or their average]
 avg_ret_wt = sum(elem_div(ret_wt(yid_pf),x_ret))/double(nyrs_pf);
 for(k=1;k<=nyrs_pf;k++)
   avg_ret_wt(yid_pf(k)) = ret_wt(yid_pf(k))/x_ret(k);

 // Groundfish bycatch mortality after adjusting for handling mortalitiesis harmonic mean in years with no data
 gft_mort = column(gf_data,1)*hm(3);
 gff_mort = column(gf_data,2)*hm(2);
//______________________________________________________________________________

PROCEDURE_SECTION
 get_numbers();
 run_pop_dynamics();
 predict_data();
 calculate_obj_function();
//______________________________________________________________________________

 FUNCTION get_numbers
 int j;

 // Natural mortality for years 1 to nyrs
 MM = M; MM(21) = M98;

 //Transition matrix depends on 2 estimated parameters logit_p12, logit_p23
 dvariable p12, p23;
 p12 = 1.0/( 1.0+mfexp(-logit_p12) );
 p23 = 1.0/( 1.0+mfexp(-logit_p23) );
 TM(1,1)=1.0-p12; TM(1,2)=p12;     TM(1,3)=0.0;
 TM(2,1)=0.0;     TM(2,2)=1.0-p23; TM(2,3)=p23;
 TM(3,1)=0.0;     TM(3,2)=0.0;     TM(3,3)=1.0;

 // Estimated fishing mortalities [= 0 in years with no fishery]
 for(j=1;j<=nyrs_pf;j++)
   Fpf(yid_pf(j)) = mfexp(mean_log_Fpf+log_Fpf_dev(j));

 // Estimated model recruitment [New(t) contributes to N(t,1)]
 for(j=2;j<=nyrs;j++)
   New(j) = mfexp(mean_log_New+log_New_dev(j));

 // Initial stage abundances
 N(1,1)=mfexp(logN1o); N(1,2)=mfexp(logN2o); N(1,3)=mfexp(logN3o);

 // Directed fishery discard mortality weight for output
 Dis_mort = column(R_pf,1)*wt(1)+column(R_pf,2)*wt(2);

 // Groundfish killing constants same for all stages [= HM in years with no data]
 Fgft = exp(mean_log_Fgft);
 Fgff = exp(mean_log_Fgff);
 for(j=1;j<=nyrs_gf;j++)
 {
   Fgft(yid_gf(j)) = mfexp(mean_log_Fgft + log_Fgft_dev(j));
```

```
  Fgff(yid_gf(j)) = mfexp(mean_log_Fgff + log_Fgff_dev(j));
 }
 //____________________________________________________________________________

FUNCTION run_pop_dynamics
 int t;
 dvar_vector NN;
 dvariable S,D,PS;

 for(t=1;t<=nyrs;t++)
 {
  // Survival to directed pot fishery, full-selection fishery mortality fraction,
  // post-fishery survival
  S=mfexp(-lag_pf(t)*MM(t));
  D=(1.0-mfexp(-Fpf(t)));
  PS=mfexp(-(1.0-lag_pf(t))*MM(t));

  // Calculate fishery removals
  R_pf(t,1)=N(t,1)*S*D*s_pf(1)*hm(1);
  R_pf(t,2)=N(t,2)*S*D*s_pf(2)*hm(1);
  R_pf(t,3)=N(t,3)*S*D;

  // Take out fishery removals and discount to Feb 15
  NN = (N(t)*S-R_pf(t))*mfexp(-(0.63-lag_pf(t))*MM(t));

  // Calculate and take out groundfish removals wrt Feb 15
  R_gft(t) = Fgft(t)/(Fgft(t)+Fgff(t))*NN*(1.0-mfexp(-(Fgft(t)+Fgff(t))));
  R_gff(t) = Fgff(t)/(Fgft(t)+Fgff(t))*NN*(1.0-mfexp(-(Fgft(t)+Fgff(t))));
  NN = NN-R_gft(t)-R_gff(t);

  // Calculate Feb 15 mature male biomass
  MMB215(t) = NN(2)*wt(2)+NN(3)*avg_ret_wt(t);

  // Discount what's left to end of year
  NN = NN*mfexp(-(0.37*MM(t)));

  // Calculate next year's abundances
  if(t<nyrs)
  {
   N(t+1,1)=TM(1,1)*NN(1)+New(t+1);
   N(t+1,2)=TM(1,2)*NN(1)+TM(2,2)*NN(2);
   N(t+1,3)=TM(2,3)*NN(2)+NN(3);
  }
 }
//____________________________________________________________________________

FUNCTION predict_data
 int j;

 // Predicted retained catch number (of "legals")
 for(j=1;j<=nyrs_pf;j++)
  X_ret(j) = R_pf(yid_pf(j),3);

 // Predicted trawl survey total abundance and proportions
```

```
 for(j=1;j<=nyrs_ts;j++)
 {
  X_ts(j) = N(yid_ts(j),1)*s_ts(1) + N(yid_ts(j),2)*s_ts(2) + N(yid_ts(j),3);
  P_ts(j,1)= N(yid_ts(j),1)*s_ts(1)/X_ts(j);
  P_ts(j,2)= N(yid_ts(j),2)*s_ts(2)/X_ts(j);
  P_ts(j,3)= N(yid_ts(j),3)/X_ts(j);
 }
 X_ts = Qts*X_ts;

 // Predicted pot-survey total abundance and proportions
 for(j=1;j<=nyrs_ps;j++)
 {
  X_ps(j) = N(yid_ps(j),1)*s_ps(1) + N(yid_ps(j),2)*s_ps(2) + N(yid_ps(j),3);
  P_ps(j,1)= N(yid_ps(j),1)*s_ps(1)/X_ps(j);
  P_ps(j,2)= N(yid_ps(j),2)*s_ps(2)/X_ps(j);
  P_ps(j,3)= N(yid_ps(j),3)/X_ps(j);
 }
 X_ps = X_ps/Qps;

 // Predicted observer proportions using stage removals [after accounting for handling mortality]
 for(j=1;j<=nyrs_ob;j++)
 {
  P_ob(j,1) = R_pf(yid_ob(j),1)/hm(1);
  P_ob(j,2) = R_pf(yid_ob(j),2)/hm(1);
  P_ob(j,3) = R_pf(yid_ob(j),3);
  P_ob(j) = P_ob(j) / sum(P_ob(j));
 }

 // Groundfish mortality biomass from predicted removals and stage weights [assume equal stage selectivities]
 for(j=1;j<=nyrs;j++)
 {
  B_gft(j) = R_gft(j)(1,2)*wt(1,2)+R_gft(j,3)*avg_ret_wt(j);
  B_gff(j) = R_gff(j)(1,2)*wt(1,2)+R_gff(j,3)*avg_ret_wt(j);
 }
//___________________________________________________________________________________

FUNCTION calculate_obj_function
 int j;

 // Trawl and pot-survey abundance data standard deviations for between-years relative weighting
 dvector sig_ts(1,nyrs_ts);
 sig_ts = sqrt( log(square(cv_ts) + 1.0) );
 dvector sig_ps(1,nyrs_ps);
 sig_ps = sqrt( log(square(cv_ps) + 1.0) );

 // Between-years effective sample size relative weighting for composition data
 dvector effn_ts(1,nyrs_ts);
 effn_ts = n_ts/max(n_ts);
 dvector effn_ps(1,nyrs_ps);
 effn_ps = n_ps/max(n_ps);
 dvector effn_ob(1,nyrs_ob);
 effn_ob = n_ob/max(n_ob);

 // Loglikelihoods (less additive constants)
```

```
// 1. Retained catch number of "legals"
LogLike(1) = -0.5*norm2(log(x_ret)-log(X_ret));

// 2. Trawl suvey abundance lognormally distributed about predicted value
LogLike(2) = -0.5*norm2(elem_div(log(x_ts)-log(X_ts),sig_ts));

// 3. Pot survey abundance lognormally distributed about predicted value
LogLike(3) = -0.5*norm2(elem_div(log(x_ps)-log(X_ps),sig_ps));

// 4. Trawl survey proportions are multinomial wrt predicted proportions
LogLike(4) = effn_ts*rowsum(elem_prod(p_ts,log(P_ts + 0.01)));

// 5. Pot survey proportions are multinomial wrt predicted proportions
LogLike(5) = effn_ps*rowsum(elem_prod(p_ps,log(P_ps + 0.01)));

// 6. Observer proportions are multinomial wrt predicted proportions
LogLike(6) = effn_ob*rowsum(elem_prod(p_ob,log(P_ob + 0.01)));

// 7. + 8. Groundfish trawl and fixed-gear mortality biomass
LogLike(7) = 0.0; LogLike(8) = 0.0;
for(j=0;j<=nyrs_gf;j++)
{
  LogLike(7) += -0.5*square(log(1000*gft_mort(j) + 1.0) - log(1000*B_gft(yid_gf(j)) + 1.0));
  LogLike(8) += -0.5*square(log(1000*gff_mort(j) + 1.0) - log(1000*B_gff(yid_gf(j)) + 1.0));
}

// Penalties [0.5 here so penalty weights interpretable as 1/normal variance]

// 1. Model recruit deviations
Pen(1) = 0.5*norm2(log_New_dev);

// 2. Directed fishery log fishing mortality deviations
Pen(2) = 0.5*norm2(log_Fpf_dev);

// 3. + 4. Gft and Gff log fishing mortality deviations
Pen(3) = 0.5*norm2(log_Fgft_dev);
Pen(4) = 0.5*norm2(log_Fgff_dev);

// Objective function
f = Pw*Pen - Lw*LogLike;
//************************************ END OF CODE *************************************
```

Appendix B: 3-Stage Model .dat File

```
# Start year
1978

# Number of years
33

# Stage mean weights [First two from new allometry applied to midpoint;  stage-3 wild guess from hist ret avg
# weights; use current empirical or model estimated value instead]
1.66 2.60 4.5

# DF, GFP, GFT handling mortalities
0.2 0.5 0.8

# Trawl survey data years and year indices
33
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33

# Trawl survey sample size (# crab >= 90mm CL), stage abundance indices (1000 crab),
# total abundance (1000 crab), CV
163  2383.953  2267.881  1763.845  6415.679  0.39
187  2939.465  2225.224  2223.035  7387.724  0.40
188  2538.596  2455.871  2866.546  7861.013  0.51
140  476.513  1232.574  2346.203  4055.29  0.40
269  1712.626  2495.21  5986.638  10194.474  0.34
231  1077.954  1663.271  3363.261  6104.486  0.30
104  409.983  499.327  1477.702  2387.012  0.18
93  380.799  376.362  1123.509  1880.67  0.21
46  205.746  456.502  376.719  1038.967  0.39
71  324.853  631.447  714.729  1671.029  0.29
81  410.042  815.615  956.848  2182.505  0.25
211  2163.89  1158.441  1792.259  5114.59  0.27
170  1052.505  1031.312  2338.24  4422.057  0.27
198  1135.368  1679.787  2236.354  5051.509  0.25
220  1073.975  1381.761  2290.595  4746.331  0.20
324  1521.091  1827.941  3276.482  6625.514  0.17
211  882.631  1298.458  2256.571  4437.66  0.18
178  1024.932  1187.954  1740.559  3953.445  0.18
285  1237.52  1891.225  3064.331  6193.076  0.24
296  1165.177  2228.021  3788.648  7181.846  0.34
243  659.734  1660.708  2849.292  5169.734  0.35
52  223.11  222.054  557.883  1003.047  0.18
61  281.517  284.922  740.249  1306.688  0.31
91  418.787  501.603  938.334  1858.724  0.25
38  110.517  230.059  639.942  980.518  0.32
65  449.169  280.004  464.91  1194.083  0.33
48  247.092  183.531  562.339  992.962  0.30
42  319.33  310.2  500.942  1130.472  0.37
126  916.712  641.737  1239.883  2798.332  0.33
250  2517.558  2019.884  1192.533  5729.975  0.38
167  1351.674  800.761  1456.517  3608.952  0.28
251  1572.586  2161.295  1410.063  5143.944  0.26
385  3927.464  3252.942  2458.051  9638.457  0.47
```

```
# Pot survey data years and year indices
6
18 21 24 27 30 33

# Pot survey sample size (# crab >= 90mm CL), stage abundance indices (crab per 1000 pot lifts),
# total abundance (crab per 1000 pot lifts), CV
4624 1919 3198 6925 12042 0.13
4812 964 2763 8804 12531 0.06
3255 1266 1737 5474 8477 0.08
640 112 414 1141 1667 0.15
3319 1086 2721 4836 8643 0.09
3920 1326 3276 5607 10209 0.13

# Fishery data years and year indices
23
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 32 33

# Catch number (1000s), time to midpoint of fishery (yr), pot lifts (1000s), retained weight (1000 lb)
436.126 0.07 43.754 1984.251
052.966 0.06 9.877 210.819
033.162 0.07 1.651  150.232
1045.619 0.05 58.550 4627.761
1935.886 0.07 165.618 8844.789
1931.990 0.12 133.944 9454.323
841.017 0.10 73.320 3764.592
484.836 0.14 47.748 2200.781
219.548 0.14 22.073 1003.162
234.521 0.14 28.230 1039.779
302.053 0.14 23.085 1325.185
247.641 0.14 30.803 1166.258
391.405  0.14 26.264 1725.349
726.519 0.18 37.104 3372.066
544.945  0.14 56.630 2475.916
629.874 0.18 58.647 3003.089
827.015 0.18 60.860 3764.262
666.905  0.18 48.560 3166.093
661.226 0.18 91.085 3078.959
939.822 0.18 81.117 4649.660
612.346 0.18 91.826 2968.573
103.376 0.44 10.697 460.859
298.669 0.44 29.344 1263.982


# Observer data years and year indices
11
13 14 15 16 17 18 19 20 21 32 33

# Onboard observer stage counts (actual counts)
17 59 74
451 600 2342
306 430 870
629 470 1142
1393 1285 2057
```

98 141 424
78 109 302
581 656 1958
255 286 782
2798 6405 10599
5974 14331 25161

Groundfish biomass years and year indices
18
15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32

Trawl and fixed-gear bycatch biomasses (1000 lb)
0.993 5.355
5.232 0.283
0.808 0.199
2.191 0.446
0.064 0.030
0.018 0.769
0.0   2.566
0.024 6.922
0.046 0.091
0.070 4.380
3.157 2.154
3.510 4.914
0.394 3.087
0.0   2.845
5.962 6.783
50.286 299.895
0.705 25.797
1.722 18.280

#eof
999

Appendix C: 3-Stage Model .ctl File

```
#phases:
#M
-1
#M98
1
#Qts
-1
#Qps
2
#logNo
1 1 1
#logitp
1 1
#TS selectivities
3
#PS selectivities
3
#pf sel
3
#Fpf and dev
1 2
#New and dev
1 2

#likelihood weights: catch, ts abund, ps abundance, ts comp, ps comp, obs comp, gft biomass, gff biomass
100.0 1.0 1.0 200.0 200.0 200.0, 1.0, 1.0
#penalty weights [recruit and df, gft, gff fishing-mortality deviations]
1.0 1.0 1.0 1.0

#starting values:
#M (assumed)
0.18
#M98
0.8
#Qts (assumed)
1.0
#Qps
0.3
#logNo: from initial trawl-survey numbers
7.8 7.7 7.5
#logitp
1.0 1.2
#TS selectivities
1.0
#PS selectivities
0.5
#pf selectivities
0.5
#mean log F
-1.5
#mean log New
6.6 # from log stage-1 ts time series
#eof
999
```