2014 Saint Matthew Island Blue King Crab Stock Assessment

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Sept 2014

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. The fishery was closed for 10 years after the stock was declared overfished in 1999. Fishing resumed in 2009/10 with a fishery-reported retained catch of 0.461 million pounds (209 t), less than half the 1.167 million pound (529.3 t) TAC. Following three more years of modest harvests supported by a fishery CPUE of around 10 crab per pot lift, the fishery was again closed in 2013/14 due to declining trawl-survey estimates of abundance and concerns about the health of the stock. Non-negligible male bycatch mortality resulting from other fisheries with potential to impact the stock in 2013/14 consist only in an estimated 0.0006 million pounds (0.3 t) in the Bering Sea groundfish fisheries.

3. Stock biomass: Following a period of low numbers after the stock was declared overfished in 1999, trawl-survey indices of SMBKC stock abundance and biomass generally increased in subsequent years, with survey estimated mature male biomass reaching 21.07 million pounds (9,557 t; CV 0.53) in 2011, the second highest in the 36-year time series used in this assessment. Survey mature male biomass then declined to 12.46 million pounds (5,652 t; CV 0.33) in 2012 and to 4.459 million pounds (2,203 t; CV 0.22) in 2013 before going back up to 12.06 million pounds (5,443 t; CV 0.44) in 2014.

4. Recruitment: Because little information about the abundance of small crab is available for this stock, recruitment has been assessed in terms of the number of male crab entering the 90-104 mm CL size class in each year. The 2013 trawl-survey area-swept estimate of 0.335 million male SMBKC in this size class marked a three-year exponential decline and was the lowest since 2005. That decline came to an end with the 2014 survey, however, with an estimate of 0.723 million, more than double the previous year's value and very close to what it was in 2012.

5. Management performance: In recent assessments, estimated total male catch has been determined as the sum of fishery-reported retained catch, estimated male discard mortality in the directed fishery, and estimated male bycatch mortality in the groundfish fisheries, as these have been the only sources of non-negligible fishing mortality to consider. Because the directed fishery was closed in 2013/14, estimated total male fishing mortality consists only in an estimated male bycatch mortality of 0.0006 million pounds (0.3 t) in the Bering Sea groundfish fisheries, so that overfishing did not occur in 2013/2014. And while the available evidence suggests that stock biomass remains depressed, there is little basis for believing that the stock is overfished or nearing an overfished condition. See table below. (Biomass measures in millions of pounds with metric ton equivalents in parentheses.)

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Male Catch	OFL[a]	ABC
2010/11	3.4 (1,500)	14.77 (6,700)	1.600 (725.7)	1.264 (573)	1.41 (639)	2.29 (1,040)	-
2011/12	3.4 (1,500)	11.09 (5,030)	2.539 (1,151)	1.881 (853)	2.10 (953)	3.74 (1,700)	3.40 (1,540)
2012/13	4.0 (1,800)	6.29 (2,850)	1.630 (739.4)	1.616 (733)	1.81 (821)	2.24 (1,020)	2.02 (916)
2013/14	3.4 (1,500)	6.64 (3,010)	0	0	0.0006 (0.3)	1.24 (562)	0.99 (450)
2014/15	3.6[b] (1,600)	5.98[c] (2,710)	TBD	TBD	TBD	0.82[d] (370)	0.65[d,e] (290)

[a] Total male catch OFL.
[b] Fall 2014 model ST estimate using the reference period 1978/79 – 2013/14.
[c] Fall 2014 model ST projection assuming OFL catch.
[d] From Fall 2014 model ST.
[e] As described in §G with P* = 0.49 and 20% buffer.

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. The B_{MSY} proxy is obtained by averaging estimated MMB_{mating} over a specific reference period, and current CPT/SSC guidance recommends using the the full assessment time frame as the default reference period. Under the author-recommended model configuration ST that procedure results in an estimated 2014/15 B_{MSY} proxy of 7.24 million pounds (3,280 t). The F_{MSY} proxy is taken equal to the assumed 0.18 yr^{-1} instantaneous natural mortality (NPFMC 2007). See table below. (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^*
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 (3,110)	15.80 (7,167)	2.31	$0.18yr^{-1}$	1	1989/90-2009/10	$0.18yr^{-1}$	0.49
2012/13	4a	7.93 (3,560)	12.41 (5,629)	1.56	$0.18yr^{-1}$	1	1978/79-2011/12	$0.18yr^{-1}$	0.49
2013/14	4b	6.76 (3,060)	6.64 (3,010)	0.98	$0.18yr^{-1}$	1	1978/79-2012/13	$0.18yr^{-1}$	0.49
2014/15	4b	7.24 (3,280)	5.98[a] (2,710)	0.82	$0.14yr^{-1}$	1	1978/79-2013/14	$0.18yr^{-1}$	0.49

[a] Fall 2014 model ST projection assuming OFL catch.

7. Distribution of the OFL: It is recognized that the use of the assessment methodology to compute the OFL involves substantial inherent uncertainty by virtue of, among other things, its dependence on estimated quantities as key inputs. Accordingly, the calculated OFL may be viewed as a random variable with an associated probability distribution. Following recommendations developed during the Jan 2012 NPFMC crab modeling workshop, the model associated standard error of the logarithm of the estimated OFL is used to specify a probability distribution to quantify some of this uncertainty and to facilitate determination of the absolute biological catch (ABC). Details are provided in §G of this document.

8. Basis for the ABC: For determining an acceptable ABC and hence the annual catch limit (ACL), current instructions are to require that P[ABC > OFL] = P* with P* = 0.49. Implementation of this requirement to determine a maximum ABC relies on the assigned OFL probability distribution and is described in §G. To account for additional sources of uncertainty, and in keeping with past CPT and SSC guidance, the author recommends that the ABC be set at no more than 80% of the maximum value. Note that use of a 20% buffer rather than the previous default 10% value was proposed during the Fall 2013 CPT meeting as a result of concern about possible model misspecification. The author shares that concern.

9. Summary of rebuilding analyses: NA

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
All time series used in the assessment have been updated to include the most recent fishery and survey results, including those from the 2013 ADF&G triennial SMBKC pot survey, which were not yet available at the time of last year's assessment. This assessment also makes use of an updated full trawl-survey time series supplied by R. Foy in August 2014, as well as updated groundfish bycatch estimates based on 1999-2013 AKRO data also supplied by R. Foy.

Changes in Assessment Methodology
This assessment employs the 3-stage length-based assessment model first presented in May 2011 and accepted by the CPT in May 2012. The model was developed to replace a similar 4-stage model used prior to 2011. During each of the last two assessment cycles, a number of alternative model configurations have been considered and rejected in favor of the base-model configuration documented in Appendix A to this report. For this assessment the author is recommending use of a new alternative model configuration that is described in what follows.

Changes in Assessment Results
There are no major changes in assessment results at this time.

B. Responses to SSC and CPT Comments

CPT and SSC Comments on Assessments in General

Fall 2013 CPT
Comments: No new recommendations.

Fall 2013 SSC
Comments: No new recommendations.

Spring 2014 CPT
Comments: No new recommendations.

Spring 2015 SSC
Comments: No new recommendations relevant to this assessment.

CPT and SSC Comments Specific to SMBKC Stock Assessment

Fall 2013 CPT
Comments: *The Team recommends the author continue to develop a biologically plausible transition matrix.*

The Team also discussed the large retrospective pattern in the base model fit to the trawl data as shown in Figure 20 of the [2013] SAFE. While retrospective issue occurred throughout the time series, the last decade shows a pattern of the model retrospectively indicating lower biomass than the assessment during the year in which the estimate is made. This period also corresponds to natural mortality having increased variation around its mean for both hybrid models presented in this assessment. The Team noted that the retrospective patterns indicate a large amount of uncertainty in model projections that should be considered in setting the ABC.

Response: See Spring 2014 CPT/SCC comments and author's responses.

Fall 2013 SSC
Comments: *For next year's assessment, the SSC encourages the stock assessment author to focus on addressing the retrospective bias in the current assessment and offers the following recommendations:*

• *Develop a likelihood profile over a large range of Ms and provide diagnostics on model fits. Misspecification of M can lead to biases in abundance estimates.*

• *As suggested by the team, further work on a biologically defensible age-transition matrix may be fruitful. Alternative models should be developed using this approach.*

• *Investigate all other model assumptions to evaluate their potential contribution to the retrospective pattern.*

Response: See Spring 2014 CPT/SSC comments and author's responses.

Spring 2014 CPT
Comments: *The CPT previously requested the author "continue to develop a biologically plausible transition matrix" for use in the SMBKC assessment model . The author has acquired growth data from crab tagged during the 1995 ADF&G pot survey and recaptured during subsequent commercial seasons. He plans to use these data, along with earlier results from Otto and Cummiskey (1990), to develop a more "biologically plausible" stage-transition matrix/population dynamics model for use in September 2014 model configurations. Plots of individual growth increment vs. size-at-release were presented for recaptures from four fishing seasons. CPT members expressed concern over data quality and potential measurement errors. The author noted that the growth increments appeared constant (~15 mm CL, consistent with Otto and Cummisky) for crab in the 110-160 mm CL release size range, and CPT members raised the possibility that this was due to quantization (e.g., to 1 cm) in the measurements. In addition, the author noted that, these data would not be terribly informative to the model transition matrix in any case because almost all tagged crab fall into the largest size class in the mode.*

The SSC in October 2013 requested that the author address the "retrospective bias" in the current assessment. In an effort to obtain clarification on this issue, the author presented a ten-year retrospective plot of model-predicted 90+ mm CL male survey biomass. The CPT regarded the plot as indicating a substantial retrospective problem. Potential sources suggested for the bias included time-varying selectivity or growth. It was recommended that the author examine whether there are retrospective patterns in other model output (e.g., recruitment, fishing mortality), as well as residuals for evidence of time-varying growth or selectivity.

Response: See following author response to Spring 2014 SSC comments.

Spring 2014 SSC
Comments: *The Saint Matthew Island blue king crab stock is currently managed under Tier 4 using biomass estimates from a three-stage catch-survey analysis first approved by the CPT and SSC in 2012. While the model was judged adequate for setting reference points, some concerns with the model structure and performance were highlighted in the 2013 assessment cycle, including uncertainty in natural mortality, the use of an appropriate stage-transition matrix and a strong retrospective pattern. No document was available for review, but the author, at the CPT meeting, discussed efforts to improve the stage-transition matrix using growth data from crab tagged during the 1995 ADF&G pot survey and presented an updated ten-year retrospective plot. The SSC encourages these explorations and also re-iterates its request from the October 2013 minutes to explore the effects of varying natural mortality in the model, for example using a likelihood profile on M.*

Response: In accordance with NPFMC (2007), under all model configurations used for this and recent assessments natural mortality has been fixed at 0.18 yr^{-1} overall years except 1998/99, for which year it is model estimated to account for a hypothesized anomalous fatality event (Zheng and Kruse 2002). The "true" value likely differs from this. Global natural mortality can in fact be estimated in the base model, but the estimate unrealistically high at 1.29 yr^{-1} and, moreover, leads to nonsensical model behavior. On the other hand, as is clear from the associated ADMB profile likelihood, the assumed 0.18 yr^{-1} value is itself implausible within the base model framework (Figure 1). The author is unclear about what to make of this state of affairs.

For this assessment the author has again investigated use of a more biologically plausible stage-transition matrix based, as before, on Otto and Cummiskey (2002). It turns out that ADF&G tagging data, as noted at the 2014 Spring CPT meeting, have little to offer here because they are based almost entirely on animals measuring 120 mm CL or larger, model stage 3, at the time of release. The author has come to believe that, as so much is unknown, it is best to make use of any biologically meaningful information that can reasonably inform model structure and attempt to configure other model components around it so as to achieve reasonable model behavior. In keeping with that belief, the author-recommended model configuration for the 2014 assessment includes the more biologically plausible stage-transition matrix.

The base-model retrospective pattern of concern in 2013 (Figure 2) is associated with increasing retrospective estimates of stage-1 and stage-2 trawl-survey selectivity (Figure 3). In the base model, these two estimated parameters are treated as invariant in time whereas stage-3 trawl-survey selectivity is additionally set equal to catchability, which in turn is assumed equal to 1. These conventions are clearly simplifications: catchability is almost certainly not 1 and both it and relative stage selectivity undoubtedly vary over time. But all this is especially likely to be the case for the SMBKC stock given its proximity to Saint Matthew Island and the fact that the trawl survey does not and cannot survey areas in the vicinity of the island that are known to play a roll in seasonal movement of the population (Figure 4). It is to be expected that trawl-survey results could be greatly affected and potentially biased as a meaningful population index as crab move in and out of the surveyed area at different times, both within and across years. Such a mechanism may well underlie, for example, the sporadically large catches that have occurred in recent years at survey station R-24 near Hall Island to the north of Saint Matthew Island, which in 2014 accounted for more than a third (67) of the 181 model-size male SMBKC captured at the 56 stations comprising the SMBKC survey area (Figure 5). To address these issues, for this assessment the author has investigated the utility of time-varying trawl-survey selectivity, and the author-recommended model configuration includes this feature.

C. Introduction

Scientific Name

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

Distribution

Blue king crab are sporadically distributed throughout the North Pacific Ocean from Hokkaido, Japan, to southeastern Alaska (Figure 6). 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 7), 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[1]. NMFS tag-return data from studies on blue king crab in the Pribilof Islands and St. Matthew Island support the idea that legal-sized males do not migrate between the two areas (Otto and Cummiskey 1990). St. Matthew Island blue king crab tend to be smaller than their Pribilof conspecifics, and the two stocks are managed separately.

Life History

Like the red king crab, *Paralithodes camtshaticus*, the blue king crab is considered a shallow water species by comparison with its lithodid cousins the golden or brown king crab, *Lithodes aequispinus*, and the scarlet king crab, *Lithodes couesi* (Donaldson and Byersdorfer 2005). Adult male blue king crab are found at an average depth of 70m (NPFMC 1998). Mature females have a biennial ovarian cycle (cf. Jensen and Armstrong, 1989) 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. Somerton and MacIntosh (1983) estimated SMBKC male size at sexual maturity to be 77.0 mm CL. Paul et al. (1991) found that spermatophores were present in the vas deferens of 50% of the St. Matthew Island blue king crab males examined with sizes of 40–49 mm CL and in 100% of the males at least 100 mm CL. They noted, however, that although spermataphore presence indicates physiological sexual maturity it may not be an indicator of functional sexual maturity. For purposes of management of the St. Matthew Island blue king crab fishery, the State of Alaska uses 105 mm CL to define the lower size bound of functionally mature males (Pengilly and Schmidt 1995). Otto and Cummiskey (1990) report an average growth increment of 14.1 mm CL for adult SMBKC males.

Management History

The SMBKC fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990). Ten U.S. vessels harvested 1.202 million pounds in 1977, and harvests

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[1] NOAA grant Bering Sea Crab Research II, NA16FN2621, 1997.

peaked in 1983 when 164 vessels landed 9.454 million pounds (Fitch et al. 2012; Table 1). The fishing seasons were generally short, often lasting only a few days. The fishery was declared overfished and closed in 1999 when the stock biomass estimate was below the minimum stock-size threshold (MSST) of 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 1998/99 commercial fishery and 1999 ADF&G 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 (Table 2). In Nov 2000, Amendment 15 to the FMP for Bering Sea/Aleutian Islands king and Tanner crabs was approved to implement a rebuilding plan for the SMBKC stock (NPFMC 2000). The rebuilding plan included a regulatory harvest strategy (5 AAC 34.917), area closures, and gear modifications. In addition, commercial crab fisheries near St. Matthew Island were scheduled in fall and early winter to reduce the potential for bycatch mortality of vulnerable molting and mating crab.

NMFS declared the stock rebuilt on Sept 21, 2009, and the fishery was reopened after a 10-year closure on Oct 15, 2009 with a TAC 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 10,697 pot lifts and an estimated CPUE of 9.9 retained crab per pot lift. The fishery remained open the next three years with modest harvests and similar CPUE, but large declines in the NMFS trawl-survey estimate of stock abundance raised concerns about the health of the stock, prompting ADF&G to close the fishery again for the 2013/14 season.

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 or more as high as the catch of legal crab (Moore et al. 2000; ADF&G Crab Observer Database). Pot-lift sampling by ADF&G crab observers (Gaeuman 2013; ADF&G Crab Observer Database) indicates similar bycatch rates of discarded male crab since the reopening of the fishery (Table 3), with total male discard mortality in the 2012/13 directed fishery estimated at about 12% (0.193 million pounds) of the reported retained catch weight, assuming 20% handling mortality. On the other hand, these same data suggest a significant reduction in the bycatch of females, which may be attributable to the later timing of the contemporary fishery[2]. Some bycatch of discarded blue king crab has also been observed historically in the eastern Bering Sea snow crab fishery, but in recent years it has generally been negligible, and observers recorded no bycatch of blue king crab in sampled pot lifts during 2013/14. The St. Matthew Island golden king crab fishery, the third commercial crab fishery to have taken place in the area, typically occurred in areas with depths exceeding blue king crab distribution. NMFS observer data suggest that variable but mostly limited SMBKC bycatch has also occurred in the eastern Bering Sea groundfish fisheries (Table 4).

[2] D. Pengilly, ADF&G, pers. comm.

D. Data

Summary of New Information

Data used in this assessment have been updated to include the most recently available fishery and survey numbers, including results from the 2013 ADF&G triennial SMBKC pot survey, which were not yet available in Fall 2013. In addition, this assessment makes use an updated trawl-survey time series provided by R. Foy in August 2014, as well as updated 1993-2013 groundfish bycatch estimates based on AKRO data also supplied by R. Foy.

Major Data Sources

Major data sources used in this assessment are annual directed-fishery retained-catch statistics from fish tickets (1978/79-1998/99, 2009/10-2012/13; Table 1); results from the annual NMFS eastern Bering Sea trawl survey (1978-2014; Table 2); results from the triennial ADF&G SMBKC pot survey (every third year 1995-2013; Table 3); size-frequency information from ADF&G crab-observer pot-lift sampling (1990/91-1998/99, 2009/10-2012/13; Table 4); and NMFS groundfish-observer bycatch biomass estimates (1992/93-2013/14; Table 5). Figure 3 maps stations from which SMBKC trawl-survey and pot-survey data were obtained. Further information concerning the NMFS trawl survey as it relates to commercial crab species is available in Daly et al. (2014); see Gish et al. (2012) for a description of ADF&G SMBKC pot-survey methods. It should be noted that the two surveys cover different geographic regions and that each has in some years encountered proportionally large numbers of male blue king crab in areas where the other is not represented (Figure 4). Crab-observer sampling protocols are detailed in the crab-observer training manual (ADF&G 2013). Groundfish SMBKC bycatch data come from NMFS Bering Sea reporting areas 521 and 524 (Figure 8). Note that for this assessment the newly available NMFS groundfish observer data reported by ADF&G statistical area was not used.

Other Data Sources

The alternative model configuration developed for this assessment makes use of a growth transition matrix based on Otto and Cummiskey (1990). Other relevant data sources, including assumed population and fishery parameters, are presented in Appendix A, which provides a detailed description of the base-model configuration used for the 2012 and 2013 assessments.

Major Excluded Data Sources

Groundfish bycatch size-frequency data available for selected years, though used in the model-based assessment in place prior to 2011, play no direct role in this analysis. This is because these data tend to be severely limited: for example, 2012/13 data include a total of just 4 90-mm+ CL male blue king crab from reporting areas 521 and 524.

E. Analytic Approach

History of Modeling Approaches for this Stock
A four-stage catch-survey-analysis (CSA) assessment model was used before 2011 to estimate abundance and biomass and prescribe fishery quotas for the SMBKC stock (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 (90-104 mm 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). Motivation for these stage definitions comes from the fact that for management of the SMBKC stock, male crab measuring at least 105 mm CL are considered mature, whereas 120 mm CL is considered a proxy for the legal size of 5.5 in carapace width, including spines. Additional motivation for these stage definitions derives from 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 model assumption that all stage-3 crab transition to stage 4 after one year[3].

Concerns about the pre-2011 assessment model led to CPT and SSC recommendations that included development of an alternative model with provisional assessment based on survey biomass or some other index of abundance. The author proposed an alternative 3-stage model to the CPT in May 2011 but was requested to proceed with a survey-based approach for the Fall 2011 assessment. In May 2012 the CPT approved for use a slightly revised and better documented version of the alternative model.

Assessment Methodology
The current SMBKC stock assessment model, first used in Fall 2012, is a variant of the previous four-stage SMBKC CSA model (2010 SAFE; Zheng et al. 1997) and similar in complexity to that described by Collie et al. (2005). Like the earlier model, it considers only male crab at least 90 mm in CL, but it combines stages 3 and 4 of the earlier model resulting in just three stages (male size classes) determined by carapace length measurements of (1) 90-104 mm, (2) 105-119 mm, and (3) 120 mm+. This consolidation was heavily driven by concern about the accuracy and consistency of shell-condition information, which had been used in distinguishing stages 3 and 4 of the earlier model. A detailed description of the base model and its implementation in the software AD Model Builder (ADMB Project 2009) is presented in technical Appendix A to this report. Basic model code was previously provided to the CPT in May 2012 and is available upon request from the author[4].

Model Selection and Evaluation
The base model described in Appendix A to this report was used for the 2012 and 2013 SMBKC assessments after comparison with a number of alternative model configurations, including ten in 2013 (2013 SAFE). Most of the alternative model configurations were designed to address previous CPT and SSC requests and recommendations. To address the most recent CPT and SSC

[3] J. Zheng, ADF&G, pers. comm.
[4] william.gaeuman@alaska.gov

concerns, for this assessment the author has chosen to consider three alternative model configurations in addition to the base model. The alternative models, here denoted S, T and ST, differ from the base model in one or both of two ways. In contrast to the base model, which estimates separate time-invariant stage-1 and stage-2 trawl-survey selectivity parameters, model S estimates only the geometric mean of stage-1 trawl-survey selectivity, with the geometric mean of stage-2 trawl-survey selectivity set equal to the average of it and 1 (Q), the default assumed stage-3 value in all models. Year-*t* stage-*j* selectivity is then given by $s_{j,t} = \bar{s}_j \exp(\epsilon_{j,t})$, where $\bar{s}_j$ is the geometric mean $\bar{s}_1$, $\bar{s}_2 = (\bar{s}_1 + 1)/2$ or $\bar{s}_3 = 1$ and $\epsilon_{j,t}$ are estimated zero-sum deviations subject to a first-difference smoothing penalty $\frac{\lambda}{0.5}\sum_t(\epsilon_{j,t-1} - \epsilon_{j,t})^2$. This specification enforces overall monotonicity on the geometric mean values of the three trawl-survey stage selectivity parameters while allowing them to vary individually across years (Figure 9a).

Model configuration T differs from the base model in that it employs a presumably more biologically realistic stage-transition matrix $\begin{bmatrix} 0.2 & 0.7 & 0.1 \\ 0 & 0.4 & 0.6 \\ 0 & 0 & 1 \end{bmatrix}$ in place of the matrix $\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix}$ used in the base model. So, for example, in any given year, instead of 100%, only 70% of stage-1 crab molt and grow into stage-2 crab, with 10% molting and growing into stage 3 and the remaining 20% staying in stage 1, whether or not they molt. The alternative transition matrix was developed based on the work of Otto and Cummiskey (1990) on Pribilof and St. Matthew Island blue king crab molting and growth. They report estimated molting probabilities of about 95% and 70% for crab measuring 97.5 and 112.5 mm CL, respectively, and model CL molt increment using a normal probability density function with mean 14.1 mm and standard deviation 3.1 mm.

The third alternative model configuration considered for this assessment, model ST, combines the defining features of configurations S and T. Use of the alternative model T stage-transition matrix evidently dampens some of the more extreme behavior displayed by model S estimates of trawl-survey selectivity parameters (Figure 9b). In all other respects the three alternative model configurations are identical to that of the base-model with, for example, natural mortality assumed equal to 0.18 yr^{-1} in all years except 1998/99, for which it is model estimated to account for a hypothesized anomalous fatality event in that year (Zheng and Kruse, 2002). Further details about the base model are provided in Appendix A.

Choice of the three alternative model configurations examined for this assessment was largely driven by CPT and SSC concerns about the biological implausibility of the base model transition matrix, on the one hand, and, on the other, about the retrospective pattern previously observed in the base-model fit to the trawl-survey biomass index data (Figure 2). Another concern about the base model was its very poor fit to the trawl-survey composition data, particularly in the last third of the 37-year time series (2013 SAFE).

Table 6 and Figures 8-13 facilitate basic comparison of the different model configurations with respect to these concerns and in terms of important measures of model behavior. Allowing trawl-survey selectivity to vary with time, model configurations S and ST, provides a substantially better fit to both the trawl-survey index (Table 6; Figure 10) with little impact on the fit to the pot-survey index data (Table 6; Figure 11). As is clear from Figures 12a-c, these models also provide a much better fit to the trawl-survey composition data. Fits to the pot-survey and observer composition data differ little across models and so are not considered further here. On the other hand, models T and ST, which make use of the alternative transition matrix, perform more similarly in terms of estimation of population abundance (Figure 13) and biomass (Figure 14), though model T estimates of these quantities are perhaps improbably large in the early years of the time series. Apparent deficiencies in model S include the extremely low estimates of abundance and biomass in the early years of the time series by comparison with the other three model configurations, resulting in implausibly high estimates of directed-fishery fishing mortality (Figure 15d), and there is some evidence in the likelihoods for preferring model ST to model S (Table 6). For these reasons the author recommends use of model ST for the 2014 assessment.

Results

Additional results are presented for model configuration ST, as the author-recommended choice for use in the Fall 2014 SMBKC stock assessment (Tables 7-9; Figures 16-20). Primary parameter estimates are all sensible and within the parameter space (Table 7), which is not the case for some of the competing model configurations, and there are no particularly worrisome correlations (Table 8). All in all, model ST offers the best overall fit to the data, is arguably the most biologically defensible, and shows no egregiously pathological behavior. Management implications of the model are presented in the next two sections.

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 managed as Tier 4 (2013 SAFE), and only a Tier 4 analysis is presented here. Thus given stock estimates or suitable proxy values of B_{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 quantified as mature-male biomass at mating MMB_{mating}, with time of mating assigned a nominal date of Feb 15. Note that as B is itself a function of the fishing mortality F_{OFL}, in case b) numerical approximation of F_{OFL} is required. As implemented for this assessment, all calculations proceed according to the model equations given in Appendix A. In particular, the OFL catch is computed using equations [A3], [A4], and [A5], given model configuration ST modifications, with F_{OFL} taken to be full-selection fishing mortality in the directed pot fishery and groundfish trawl and fixed-gear fishing mortalities set at their model geometric mean values over years for which there are data-based estimates of bycatch-mortality biomass.

The currently recommended Tier 4 convention is to use the full assessment period, currently 1978/79 -2013/14, to define a B_{MSY} proxy in terms of average estimated MMB_{mating} and to put $\gamma = 1.0$ with assumed stock natural mortality $M = 0.18$ yr^{-1} 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 these specifications and letting F_{OFL} determine directed-fishery fishing mortality, under the author recommended model configuration ST the B_{MSY} proxy is 7.24 million pounds, and case b) of the control rule obtains, with $F_{OFL} = 0.14$ yr^{-1} and a Tier 4b 2014/15 total male catch OFL of 0.82 million pounds. The retained catch component of the OFL is 0.79 million pounds. Complete partitioning of the OFL under model configuration ST is given in Table 10.

G. Calculation of The ABC

For determining an acceptable biological catch (ABC), and hence the annual catch limit (ACL), current recommendations are to require that $P[ABC > OFL] = P^*$, with $P*$ = 0.49. As implemented here, the maximum ABC is set equal to $\lambda \times ofl$, where *ofl* is the Tier 4 model-calculated overfishing level from the control rule and the multiplier λ is determined by the probability statement $P[\lambda\widehat{OFL} > OFL] = P^*$, under the assumptions that OFL = *median*$(\widehat{OFL})$ and $\log(\widehat{OFL}) \sim N(\log(OFL), \sigma)$, where σ is the ADMB-reported standard error of $\log(\widehat{OFL})$ from the model. With this set up, $P^* = P\left[\lambda\widehat{OFL} > OFL\right] = 1 - \Phi(-\frac{\log(\lambda)}{\sigma})$, so that

$\log(\lambda) = -\sigma\Phi^{-1}(1 - P^*)$ and $\lambda = \exp(\sigma\Phi^{-1}(P^*))$.

For the base model, this procedure yields $\lambda = \exp\left(0.3379\Phi^{-1}(0.49)\right) = 0.99$
and a maximum ABC of $\lambda \times ofl$ = 0.99 × 0.82 = 0.81million pounds. To account for additional sources of uncertainly and in keeping with current CPT and SSC guidance, the author recommends that the ABC be set at no more than 80% of the maximum value. In this instance, the use of an additional 20% buffer leads to a provisional author-recommended ABC of 0.65 million pounds.

H. Rebuilding Analysis

This stock is not currently subject to a rebuilding plan.

I. Data Gaps and Research Priorities

The CPT and SSC have identified as an important research need to investigate SMBKC annual molting frequency (and growth increment) as a function of pre-molt size. As the currently specified base-model transition matrix, requiring all stage-1 and 2 crab to transition in each year to stages 2 and 3, respectively, is likely unrealistic, the author concurs with this recommendation. For this assessment he has explored the use of a more biologically plausible transition matrix based on his review of Otto and Cummiskey's 1990 work on molting frequency and growth increment of Pribilof and St. Matthew Island blue king crab. Currently available ADF&G SMBKC tagging data are limited to larger crab, making them mostly uninformative in this regard. Additional specifically SMBKC tagging data covering a broader range of sizes would be useful.

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Table 1. The 1978/79 – 2013/14 directed St. Matthew Island blue king crab pot fishery. Source: Fitch et al. 2012; ADF&G Dutch Harbor staff, pers. comm.

			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	4.9	137.2
1984/85	09/01-09/08	2.0-4.0	841,017	3,764,592	73,320	11	4.5	135.5
1985/86	09/01-09/06	0.9-1.9	436,021	2,175,087	46,988	9	5.0	139.0
1986/87	09/01-09/06	0.2-0.5	219,548	1,003,162	22,073	10	4.6	134.3
1987/88	09/01-09/05	0.6-1.3	227,447	1,039,779	28,230	8	4.6	134.1
1988/89	09/01-09/05	0.7-1.5	280,401	1,236,462	21,678	13	4.4	133.3
1989/90	09/01-09/04	1.7	247,641	1,166,258	30,803	8	4.7	134.6
1990/91	09/01-09/07	1.9	391,405	1,725,349	26,264	15	4.4	134.3
1991/92	09/16-09/20	3.2	726,519	3,372,066	37,104	20	4.6	134.1
1992/93	09/04-09/07	3.1	545,222	2,475,916	56,630	10	4.5	134.1
1993/94	09/15-09/21	4.4	630,353	3,003,089	58,647	11	4.8	135.4
1994/95	09/15-09/22	3.0	827,015	3,764,262	60,860	14	4.9	133.3
1995/96	09/15-09/20	2.4	666,905	3,166,093	48,560	14	4.7	135.0
1996/97	09/15-09/23	4.3	660,665	3,078,959	91,085	7	4.7	134.6
1997/98	09/15-09/22	5.0	939,822	4,649,660	81,117	12	4.9	139.5
1998/99	09/15-09/26	4.0	635,370	2,968,573	91,826	7	4.7	135.8
1999/00-2008/09				**FISHERY CLOSED**				
2009/10	10/15-02/01	1.17	103,376	460,859	10,697	10	4.5	134.9
2010/11	10/15-02/01	1.60	298,669	1,263,982	29,344	10	4.2	129.3
2011/12	10/15-02/01	2.54	437,862	1,881,322	48,554	9	4.3	130.0
2012/13	10/15-02/01	1.63	379,386	1,616,054	37,065	10	4.3	129.8
2013/14				**FISHERY CLOSED**				

[a] Guideline Harvest Level/Total Allowable Catch in millions of pounds.
[b] Includes deadloss.
[c] Harvest number/pot lift.
[d] Harvest weight/harvest number, in pounds.
[e] Average CL of retained crab in millimeters, from dockside sampling of delivered crab.

Table 2. NMFS EBS trawl-survey area-swept estimates of male crab abundance (10^6 crab) and of mature male biomass (10^6 lb). Total number of captured male crab ≥ 90 mm CL is also given. Source: J.Zheng, ADF&G; R.Foy, NMFS.

	abundance					biomass		
	stage 1	stage 2	stage 3			mature male		number
year	(90-104mm CL)	(105-119mm CL)	(120mm+ CL)	Total	CV	(105mm+ CL)	cv	of crab
1978	2.421	2.227	1.702	6.350	0.41	11.574	0.39	163
1979	3.013	2.276	2.196	7.485	0.42	12.918	0.39	187
1980	2.931	2.630	2.608	8.169	0.57	16.141	0.47	188
1981	0.495	1.245	2.323	4.064	0.37	12.779	0.40	140
1982	1.713	2.495	5.987	10.194	0.38	30.748	0.32	269
1983	1.078	1.663	3.363	6.104	0.33	17.921	0.28	231
1984	0.447	0.499	1.478	2.424	0.18	7.684	0.19	104
1985	0.381	0.376	1.124	1.881	0.22	5.750	0.22	93
1986	0.206	0.457	0.377	1.039	0.43	2.579	0.39	46
1987	0.325	0.631	0.715	1.671	0.30	4.060	0.29	71
1988	0.410	0.816	0.957	2.183	0.29	5.693	0.24	81
1989	2.169	1.159	1.786	5.109	0.31	9.639	0.25	211
1990	1.053	1.031	2.338	4.422	0.30	11.955	0.26	170
1991	1.147	1.665	2.233	5.045	0.26	12.208	0.25	198
1992	1.074	1.382	2.291	4.746	0.21	12.649	0.20	220
1993	1.521	1.828	3.276	6.626	0.19	16.959	0.16	324
1994	0.883	1.298	2.257	4.438	0.19	11.696	0.18	211
1995	1.025	1.188	1.741	3.953	0.19	9.844	0.17	178
1996	1.238	1.891	3.064	6.193	0.26	17.111	0.24	285
1997	1.165	2.228	3.789	7.182	0.37	20.143	0.33	296
1998	0.660	1.661	2.849	5.170	0.37	15.054	0.36	243
1999	0.223	0.222	0.558	1.003	0.19	2.871	0.18	52
2000	0.282	0.285	0.740	1.307	0.30	3.794	0.31	61
2001	0.419	0.502	0.938	1.859	0.24	5.064	0.26	91
2002	0.111	0.230	0.640	0.981	0.31	3.311	0.32	38
2003	0.449	0.280	0.465	1.194	0.40	2.483	0.32	65
2004	0.247	0.184	0.562	0.993	0.37	2.705	0.29	48
2005	0.319	0.310	0.501	1.130	0.40	2.812	0.36	42
2006	0.917	0.642	1.240	2.798	0.34	6.494	0.36	126
2007	2.518	2.020	1.193	5.730	0.42	9.157	0.35	250
2008	1.352	0.801	1.457	3.609	0.29	7.353	0.29	167
2009	1.573	2.161	1.410	5.144	0.26	10.189	0.26	251
2010	3.937	3.253	2.458	9.648	0.54	17.949	0.37	385
2011	1.800	3.255	3.207	8.263	0.59	20.979	0.53	315
2012	0.705	1.967	1.808	4.483	0.36	12.461	0.33	193
2013	0.335	0.452	0.807	1.593	0.22	4.459	0.22	74
2014	0.723	1.627	1.809	4.160	0.50	12.063	0.44	181

Table 3. Observed proportion of crab by size class during ADF&G crab observer pot-lift sampling. Source: ADF&G Crab Observer Database.

year	pot lifts (sampled/total)	number of crab (90 mm+ CL)	stage 1 (90-104 mm CL)	stage 2 (105-119 mm CL)	stage 3 (120 mm+ CL)
1990/91	10/26,264	150	0.113	0.393	0.493
1991/92	125/37,104	3,393	0.133	0.177	0.690
1992/93	71/56,630	1,606	0.191	0.268	0.542
1993/94	84/58,647	2,241	0.281	0.210	0.510
1994/95	203/60,860	4,735	0.294	0.271	0.434
1995/96	47/48,560	663	0.148	0.212	0.640
1996/97	96/91,085	489	0.160	0.223	0.618
1997/98	133/81,117	3,195	0.182	0.205	0.613
1998/99	135/91,826	1,322	0.193	0.216	0.591
1999-2008			**FISHERY CLOSED**		
2009/10	989/10,484	19,802	0.141	0.324	0.535
2010/11	2,419/29,356	45,466	0.131	0.315	0.553
2011/12	3,359/48,554	58,666	0.131	0.305	0.564
2012/13	2,841/37,065	57,298	0.141	0.318	0.541
2013/14			**FISHERY CLOSED**		

Table 4. Size-class and total CPUE (90 mm+ CL) and estimated CV and total number of captured crab (90 mm+ CL) from the 96 common stations surveyed during the six triennial ADF&G SMBKC pot surveys. Source: D.Pengilly and R.Gish, ADF&G.

year	stage 1 (90-104mm CL)	stage 2 (105-119mm CL)	stage 3 (120mm+ CL)	CPUE	CV	number of crab
1995	1.919	3.198	6.922	12.042	0.13	4,624
1998	0.964	2.763	8.804	12.531	0.06	4,812
2001	1.266	1.737	5.487	8.477	0.08	3,255
2004	0.112	0.414	1.141	1.667	0.15	640
2007	1.086	2.721	4.836	8.643	0.09	3,319
2010	1.326	3.276	5.607	10.209	0.13	3,920
2013	0.878	1.398	3.367	5.643	0.19	2,167

Table 5. Groundfish SMBKC male bycatch biomass (10^3 pounds) estimates. Source: J. Zheng, ADF&G, and author estimates based on data from R. Foy, NMFS. AKRO estimates used after 2008/09.

	bycatch		
year	trawl[a]	fixed gear	total mortality[b]
1991/92	7.8	0.1	6.3
1992/93	4.4	5.0	6.0
1993/94	3.4	0.0	2.7
1994/95	0.7	0.2	0.7
1995/96	1.4	0.3	1.3
1996/97	0.0	0.1	0.1
1997/98	0.0	0.4	0.2
1998/99	0.0	2.0	1.0
1999/00	0.0	3.0	1.5
2000/01	0.0	0.0	0.0
2001/02	0.0	1.9	1.0
2002/03	1.6	0.9	1.7
2003/04	2.2	2.5	3.0
2004/05	0.2	1.4	0.9
2005/06	0.0	1.3	0.7
2006/07	6.2	3.2	6.6
2007/08	0.1	153.7	76.9
2008/09	0.6	14.6	7.8
2009/10	1.4	16.6	9.4
2010/11	0.8	21.1	11.2
2011/12	0.4	1.3	1.0
2012/13	1.3	0.0	1.1
2013/14	0.4	0.6	0.6

[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.

Table 6. Key base and alternative model quantities.

	model estimated trawl-survey selectivity			survey-index RMSE		objective function		management quantities (10^6 lb)		
model	stage 1	stage 2	stage 3	trawl	pot	min[a]	K[b]	Bmsy[c]	OFL[d]	MMB[e]
base	0.98	1.44	Q = 1	1.43	6.12	3,888	122 - 4	6.656	0.943	5.906
ST	0.60[f]	0.80[f]	Q = 1	1.10	6.29	3,845	232 - 7	7.243	0.820	5.968
S	0.89[f]	0.95[f]	Q = 1	1.08	6.06	3,858	232 - 7	6.139	1.303	6.846
T	0.62	0.86	Q = 1	1.47	6.33	3,890	122 - 4	7.781	0.940	6.711

[a] ADMB minimized objective function value.
[b] Number of model "parameters" – number of zero-sum constraints.
[c] Average 1978-2013 model MMBmating.
[d] Tier 4 assuming Fmsy = 0.18 yr^{-1}.
[e] Model projected 2015 MMBmating assuming OFL catch.
[f] Geometric mean value.

Table 7. Model ST ADMB parameter estimates and standard errors. Ranges are given for log recruit, log fishing mortality and log trawl-survey selectivity deviations.

parameter	estimate	standard error
1998/99 natural mortality	0.86	0.136
pot-survey proportionality constant	4.34	0.434
geometric mean trawl-survey stage-1 selectivity	0.60	0.053
pot-survey stage-1 selectivity	0.31	0.048
pot-survey stage-2 selectivity	0.71	0.077
pot-fishery stage-1 selectivity	0.33	0.038
pot-fishery stage-2 selectivity	0.50	0.047
log initial stage-1 abundance	7.96	0.238
log initial stage-2 abundance	7.56	0.290
log initial stage-3 abundance	6.67	0.449
mean log recruit abundance	6.83	0.073
mean log recruit abundance deviations (36)	[-1.96, 1.36]	[0.156, 0.530]
mean log directed fishing mortality	-1.08	0.102
log directed fishing mortality deviations (25)	[-3.03, 1.75]	[0.146, 0.647]
mean log GF trawl fishing mortality	-10.39	0.233
log GF trawl fishing mortality deviations (23)	[-1.76, 1.63]	[0.695, 0.713]
mean log GF fixed-gear fishing mortality	-9.61	0.230
log GF fixed-gear fishing mortality deviations (23)	[-2.25, 2.57]	[0.688, 0.702]
log trawl-survey s1 selectivity deviations (37)	[-0.59, 0.57]	[0.142, 0.225]
log trawl-survey s2 selectivity deviations (37)	[-0.37, 0.59]	[0.133, 0.224]
log trawl-survey s3 selectivity deviations (37)	[-0.33, 0.27]	[0.131, 0.302]

Table 8. Model ST ADMB primary parameter correlations. Does not include those for recruitment, fishing mortality and trawl-survey selectivity deviations.

index	parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1998/99 M	1													
2	PS Q	-0.18	1												
3	geometric mean TS s1 selectivity	-0.27	0.45	1											
4	PS s1 selectivity	-0.15	-0.26	0.06	1										
5	PS s2 selectivity	-0.18	-0.42	-0.02	0.22	1									
6	PF s1 selectivity	-0.17	-0.10	0.02	0.17	0.22	1								
7	PF s2 selectivity	-0.07	-0.21	-0.08	0.13	0.19	0.59	1							
8	log initial N1	-0.01	0.21	0.20	-0.03	-0.06	-0.04	-0.06	1						
9	log initial N2	-0.02	0.32	0.40	-0.05	-0.09	-0.09	-0.13	0.07	1					
10	log initial N3	0.00	0.39	0.45	-0.08	-0.13	-0.16	-0.20	0.20	0.22	1				
11	mean log PF F	-0.05	-0.32	-0.53	0.02	0.05	-0.11	-0.08	-0.33	-0.44	-0.57	1			
12	mean log recruits	0.37	-0.74	-0.63	-0.05	0.08	0.04	0.21	-0.29	-0.39	-0.44	0.36	1		
13	mean log GFT F	-0.06	0.33	0.20	-0.03	-0.07	-0.04	-0.09	0.09	0.14	0.17	-0.14	-0.33	1	
14	mean log GFF F	-0.06	0.34	0.21	-0.03	-0.07	-0.04	-0.09	0.09	0.14	0.17	-0.14	-0.34	0.15	1

Table 9. Contribution of negative loglikelihood and penalty components to minimized value of the objective function under model configuration ST. Relative contributions include weights.

Negative Loglikelihood Component	Weight	Contribution (%)
retained catch number	1,000	0.00
trawl-survey biomass	1	0.56
pot-survey CPUE	1	1.39
trawl-survey stage composition	1	47.98
pot-survey stage composition	1	15.95
directed pot-fishery stage composition	1	31.94
groundfish trawl mortality biomass	1	0.42
groundfish fixed-gear mortality biomass	1	0.46
log recruit deviations	1.25	0.33
log directed pot fishery fishing mortality deviations	0.001	0.00
log groundfish trawl fishing mortality deviations	1	0.33
log groundfish fixed-gear fishing mortality deviations	1	0.41
log trawl-survey selectivity deviation first differences	64	0.24

Table 10. Partitioning of the OFL. Catches are in millions of pounds, with metric ton equivalents in parentheses.

			OFL				
			directed fishery		groundfish bycatch mortality		
year	tier	F_{OFL} (yr^{-1})	retained	discard mortality	trawl	fixed gear	total male
2011/12	4a	0.18	3.36 (1,520)	0.296 (134)	0.001 (0.5)	0.009 (4)	3.74 (1,700)
2012/13	4a	0.18	2.14 (971)	0.095 (43)	0.0002 (0.1)	0.0009 (0.4)	2.24 (1,020)
2013/14	4b	0.18	1.20 (544)	0.044 (20)	0.0002 (0.09)	0.0007 (0.3)	1.24 (562)
2014/15[a]	4b	0.14	0.79 (360)	0.031 (14)	0.0002 (0.1)	0.0005 (0.2)	0.820 (370)

[a] From Fall 2014 model configuration ST.

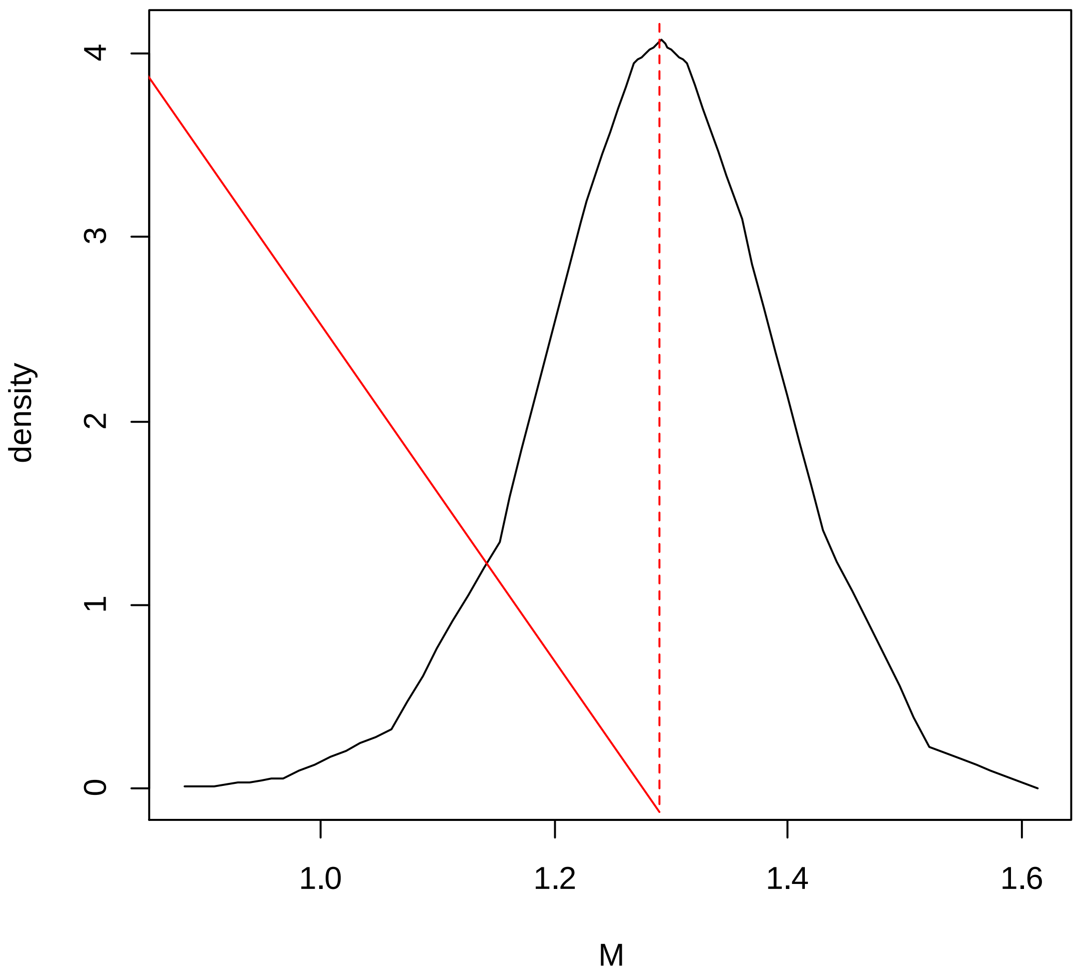

Figure 1. Base-model ADMB profile likelihood for estimated natural mortality parameter M with 2014 dataset. M = 0.18 yr^{-1} is assumed for assessment.

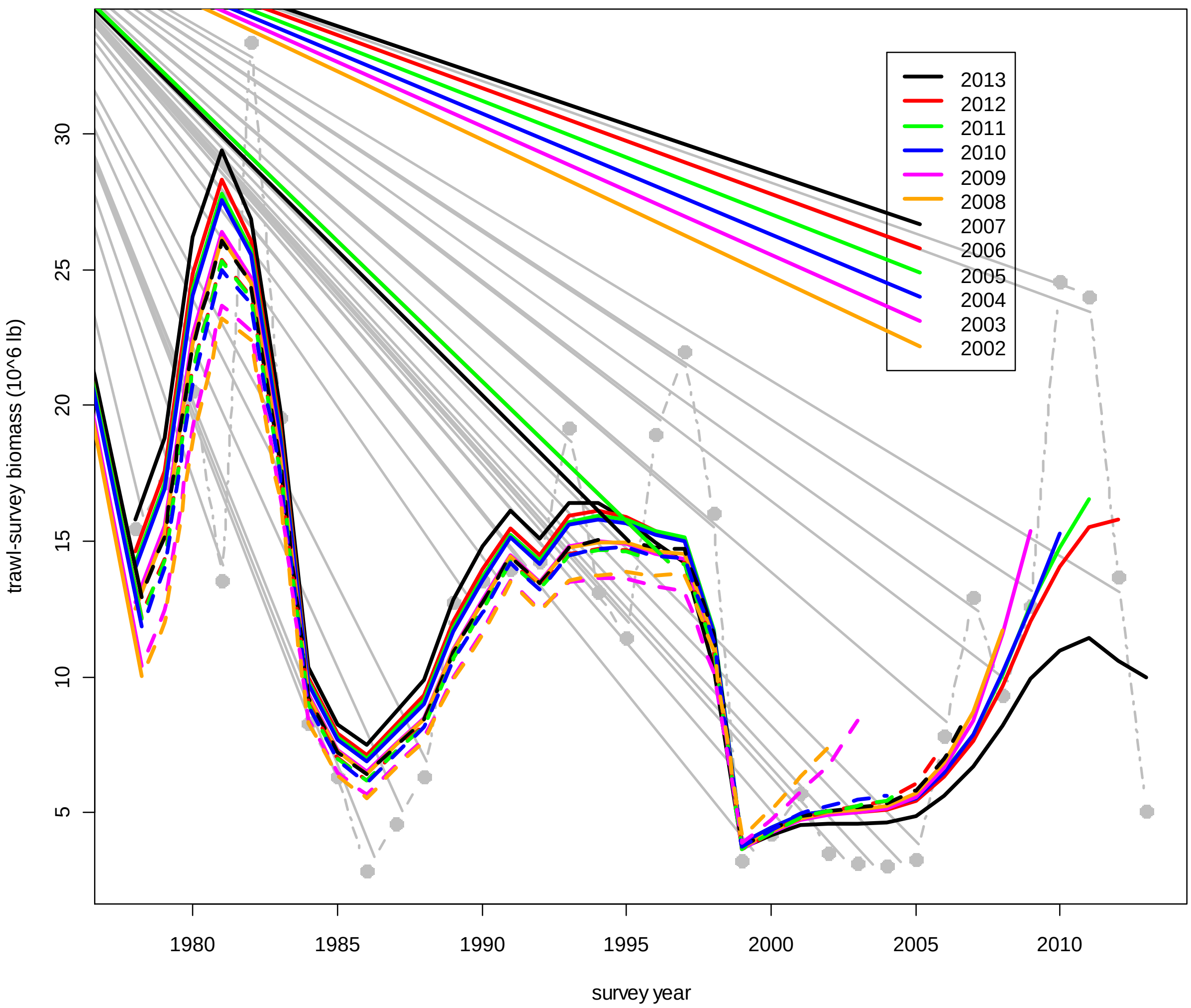

Figure 2. Retrospective plot of trawl-survey model-male (90mm+ CL) biomass for 2013 base-model configuration and terminal years 2002 – 2013. Estimates are based on all available data up to and including terminal-year trawl and pot surveys. Grey dotted line and points represent trawl-survey area-swept estimates. (From 2013 SAFE.)

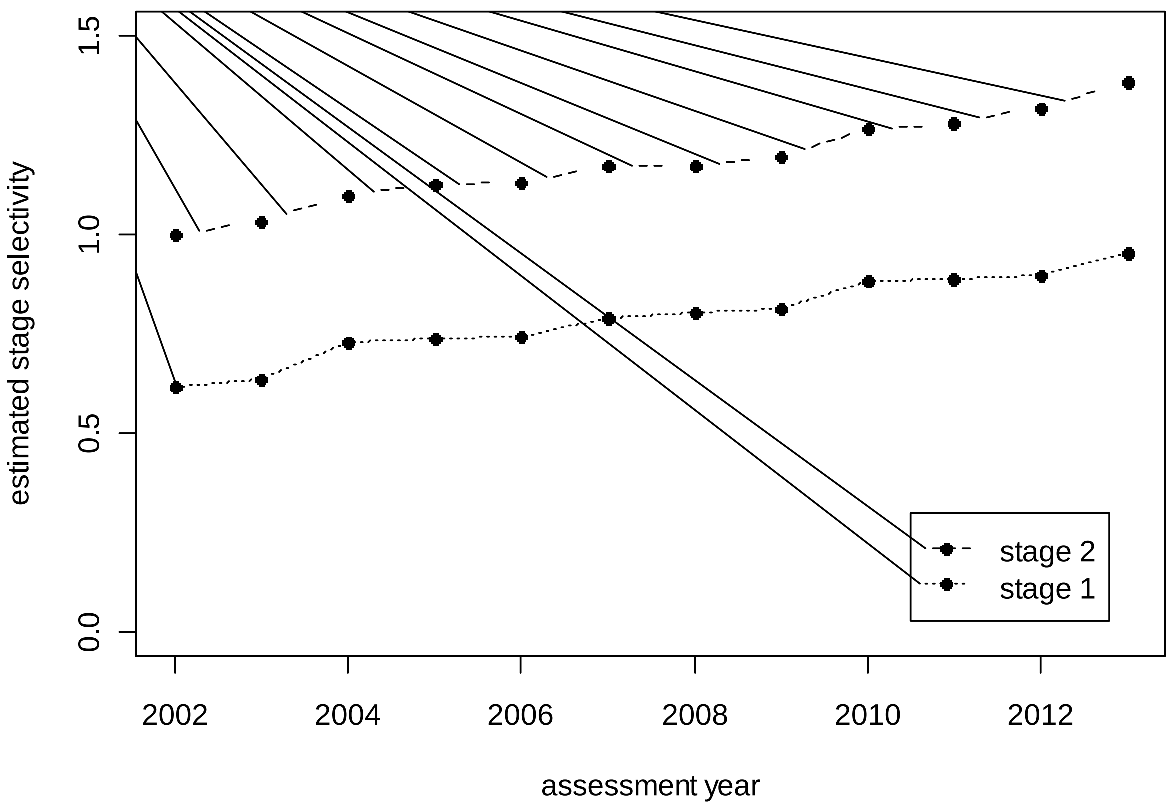

Figure 3. Base-model retrospective estimates of stage-1 and stage-2 trawl-survey selectivity for terminal years 2002/02-2013/14. Estimates are based on all available data up to and including terminal-year trawl and pot surveys.

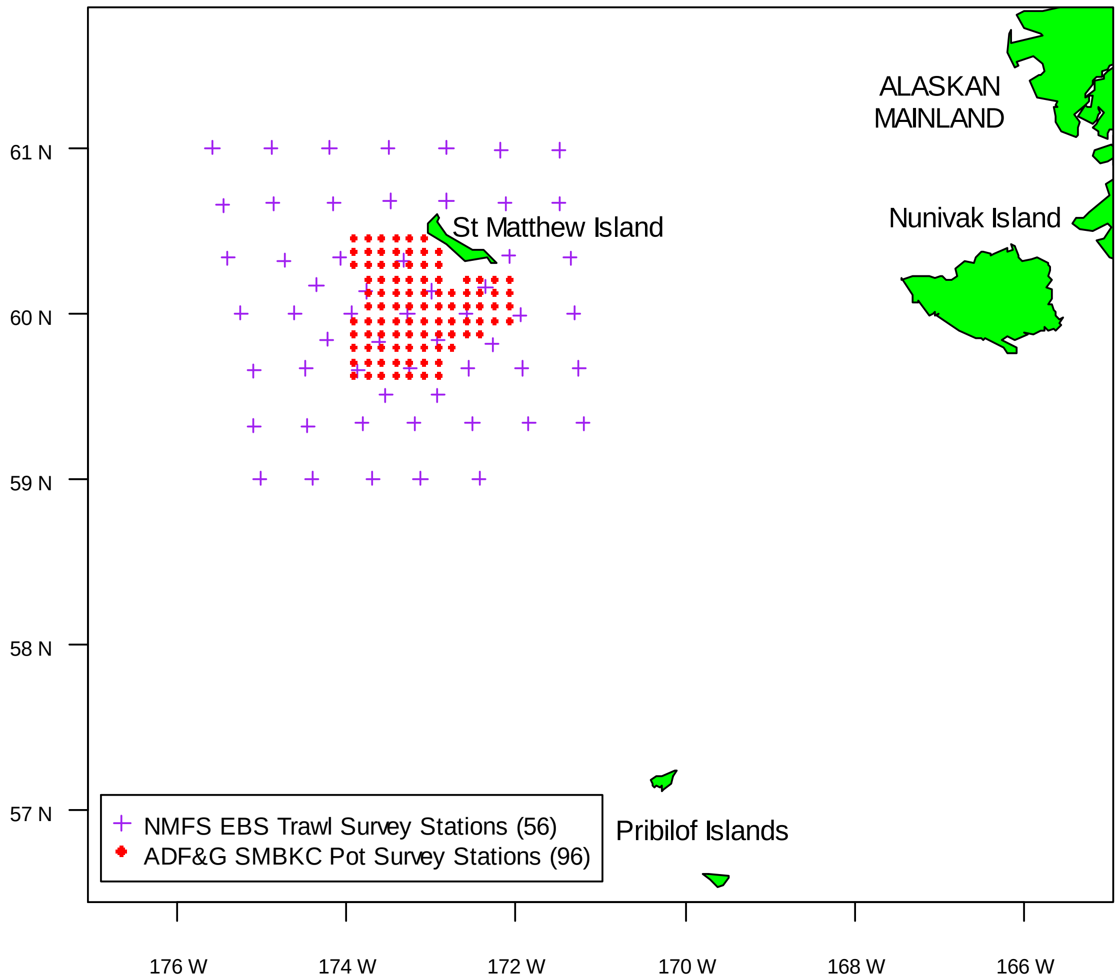

Figure 4. Trawl and pot-survey stations used in the SMBKC stock assessment.

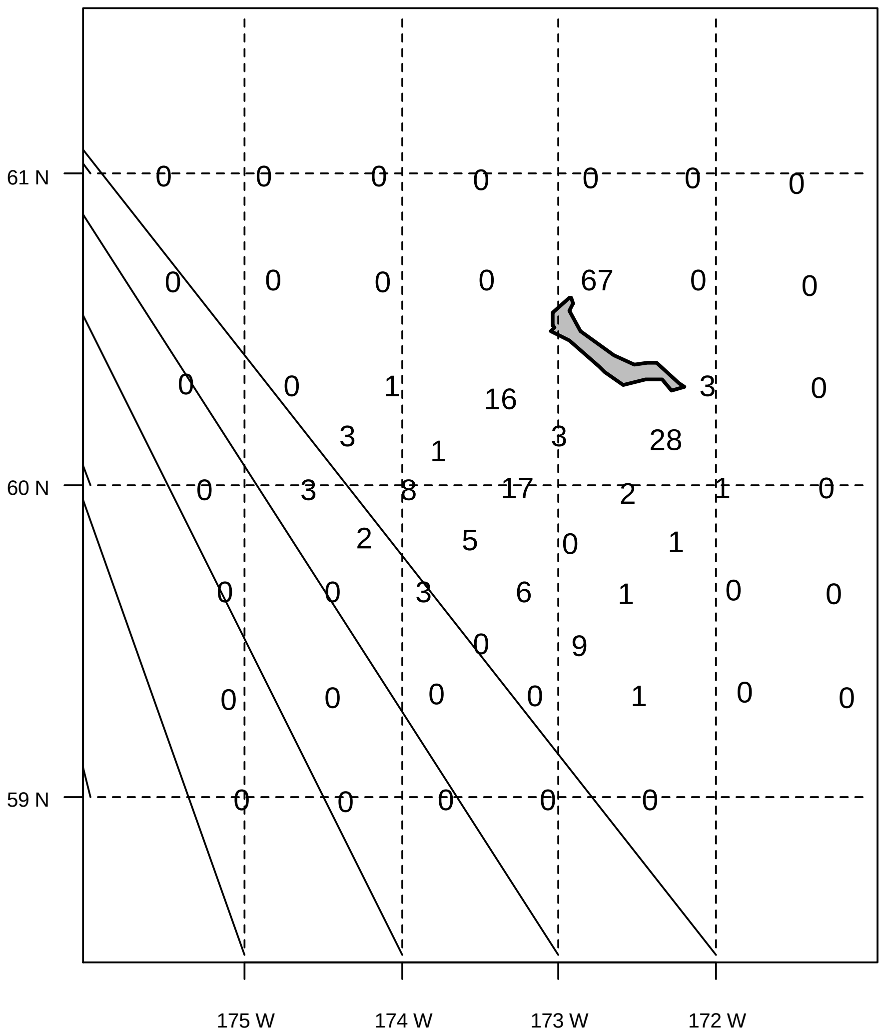

Figure 5. Catches of 181 male blue king crab measuring at least 90 mm CL from the 2014 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock. Note that the area north of St. Matthew Island, which includes the large catch of 67 crab at station R-24, is not represented in the ADF&G pot-survey data used in the assessment (cf. Figure 3).

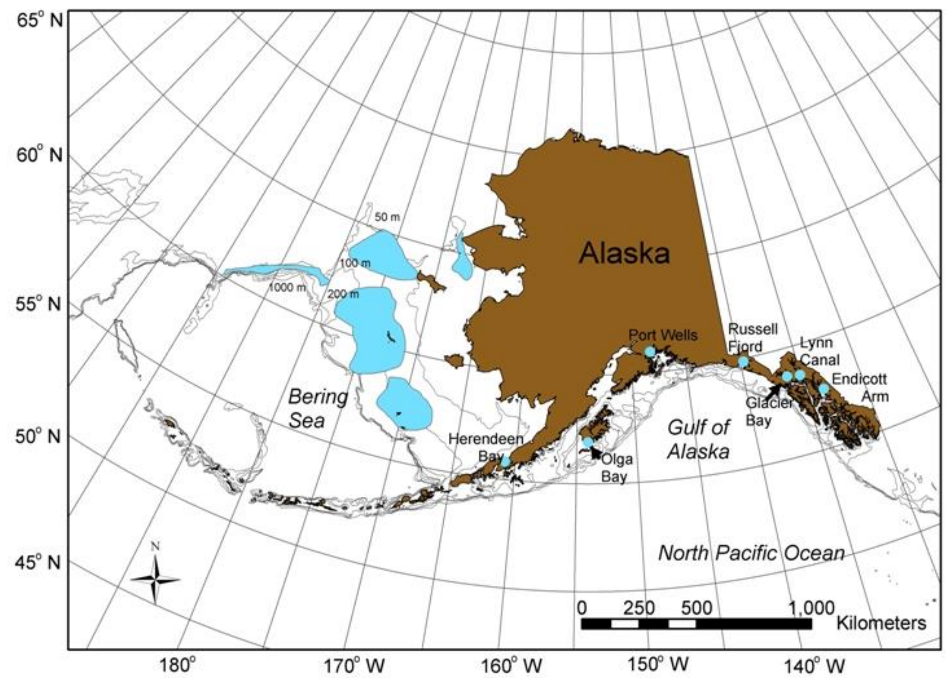

Figure 6. Distribution of blue king crab *Paralithodes platypus* in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters. Shown in blue.

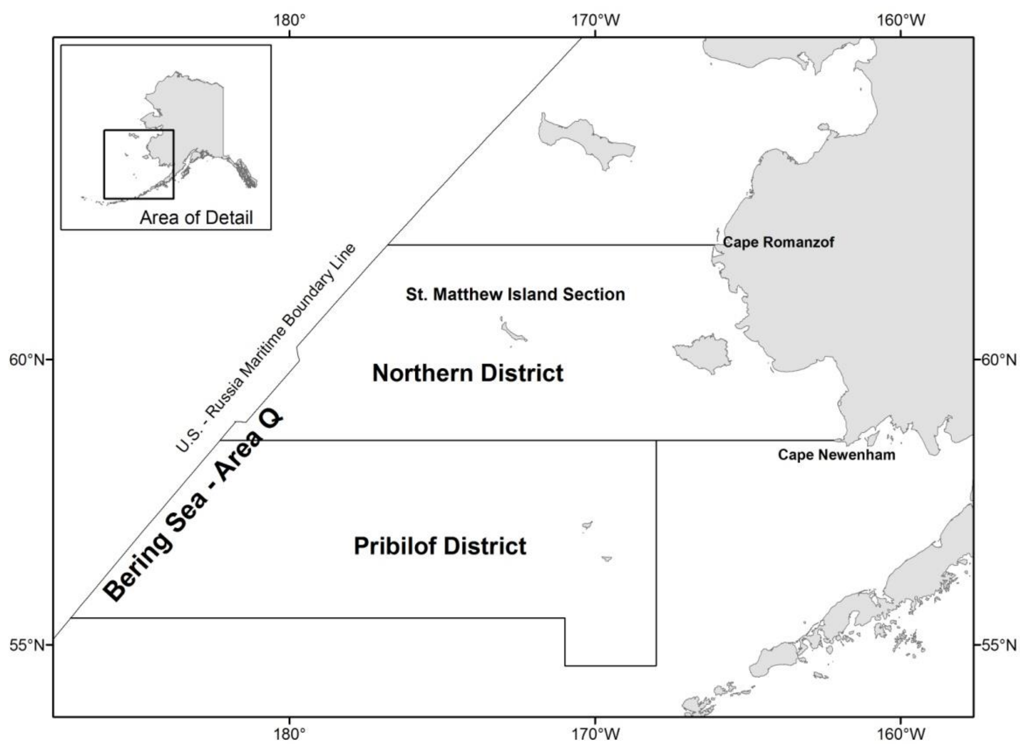

Figure 7. King crab Registration Area Q (Bering Sea).

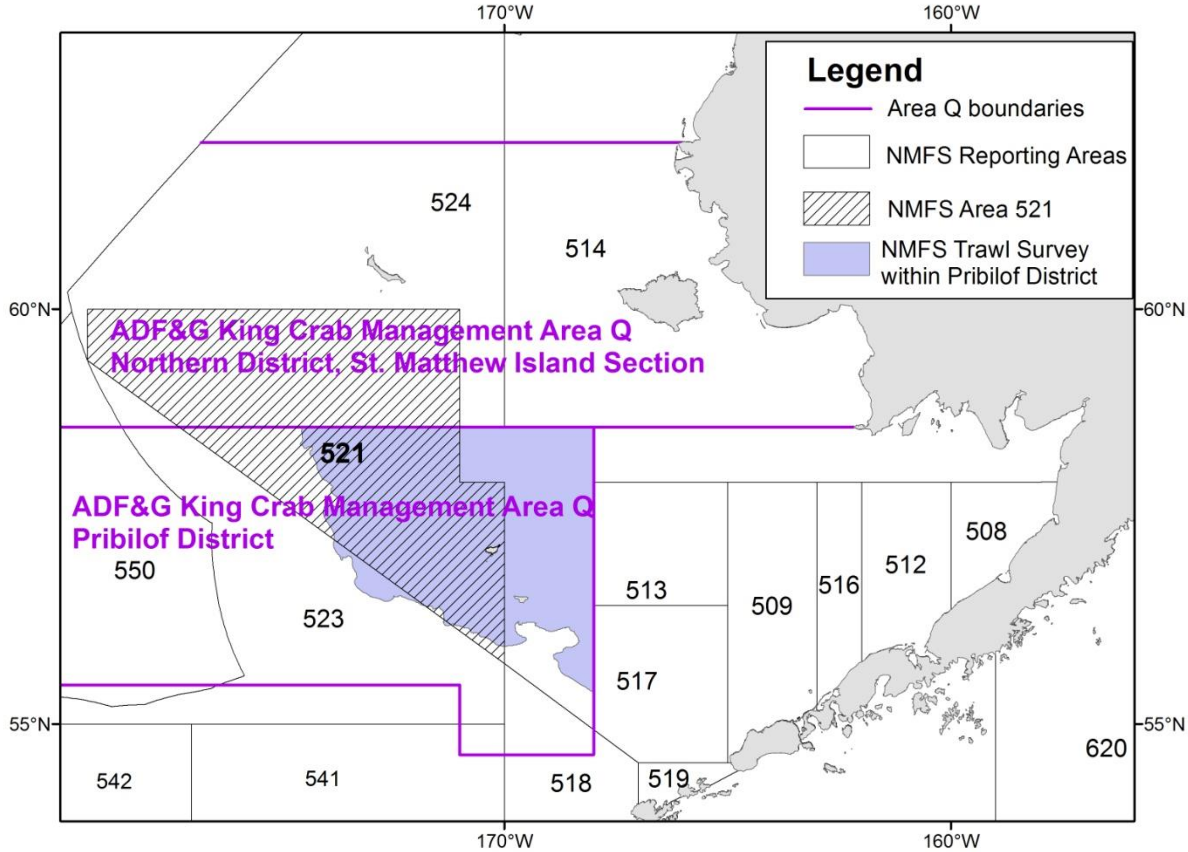

Figure 8. NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.

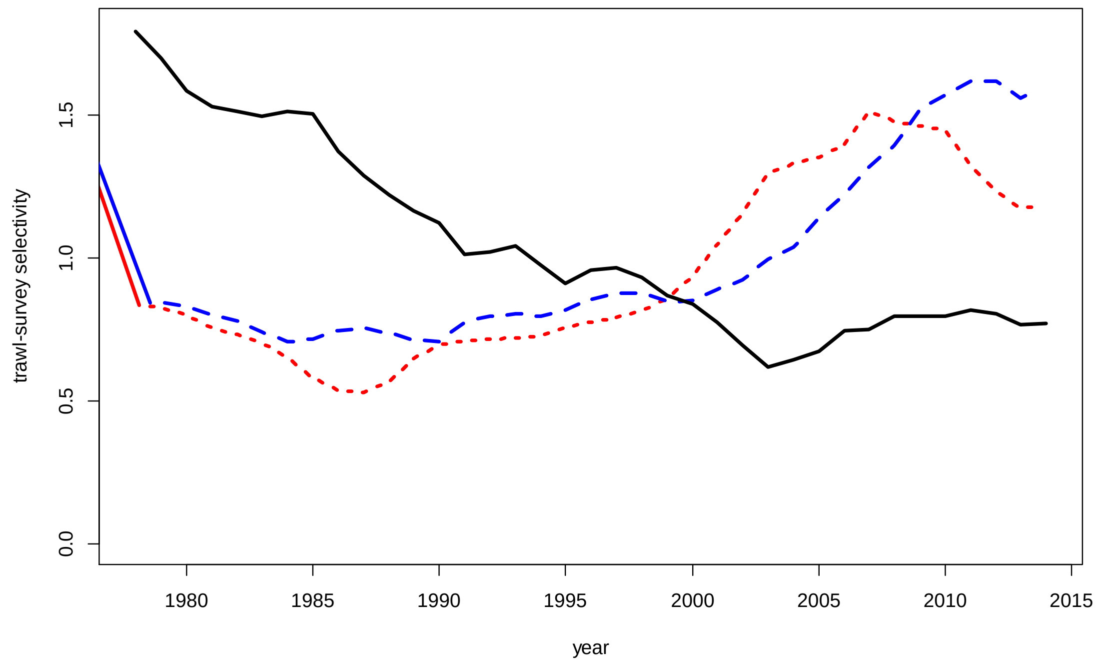

Figure 9a. Model S stage-1(dotted red curve), stage-2 (dashed blue curve) and stage-3 (solid black curve) trawl-survey selectivities. Geometric means are respectively 0.89, 0.95 = (0.89 + 1)/2 and 1 (Q).

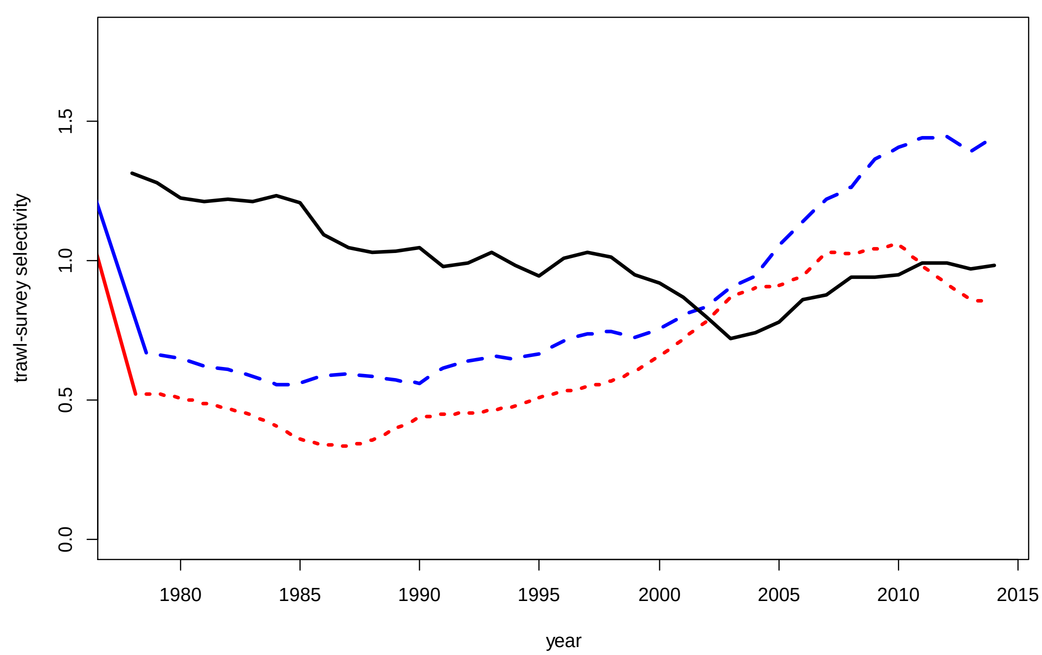

Figure 9b. Model ST stage-1(dotted red curve), stage-2 (dashed blue curve) and stage-3 (solid black curve) trawl-survey selectivities. Geometric means are respectively 0.60, 0.80 = (0.60 + 1)/2 and 1 (Q).

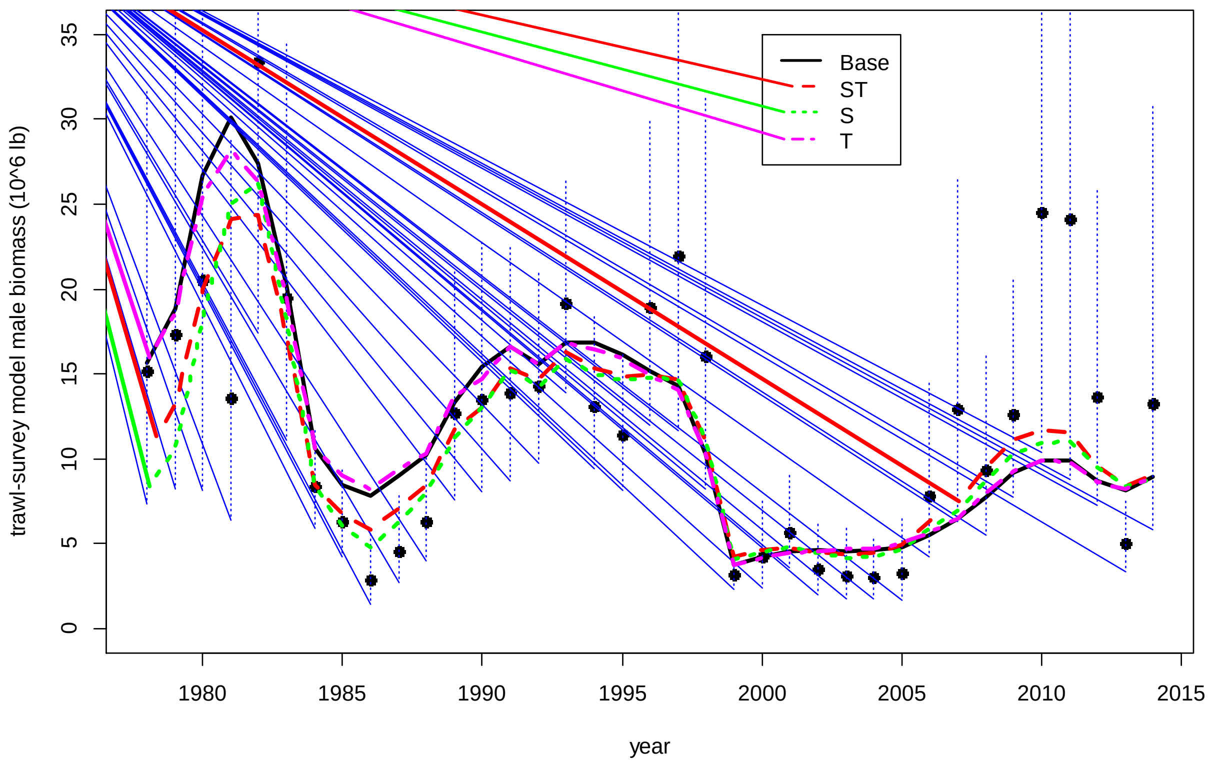

Figure 10. Plots of base and alternative model estimated trawl-survey model male (90+ mm CL) biomass with area-swept estimates (points).

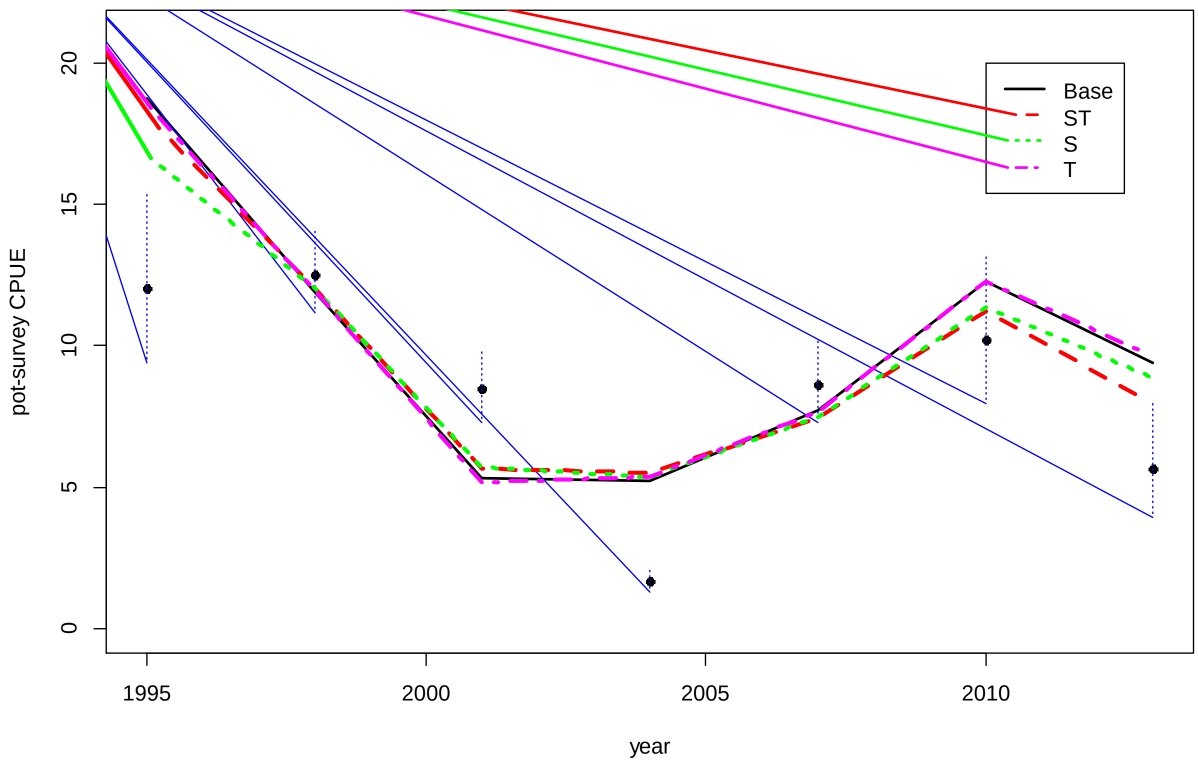

Figure 11. Plots of base and alternative model estimated pot-survey model male (90+ mm CL) CPUE.

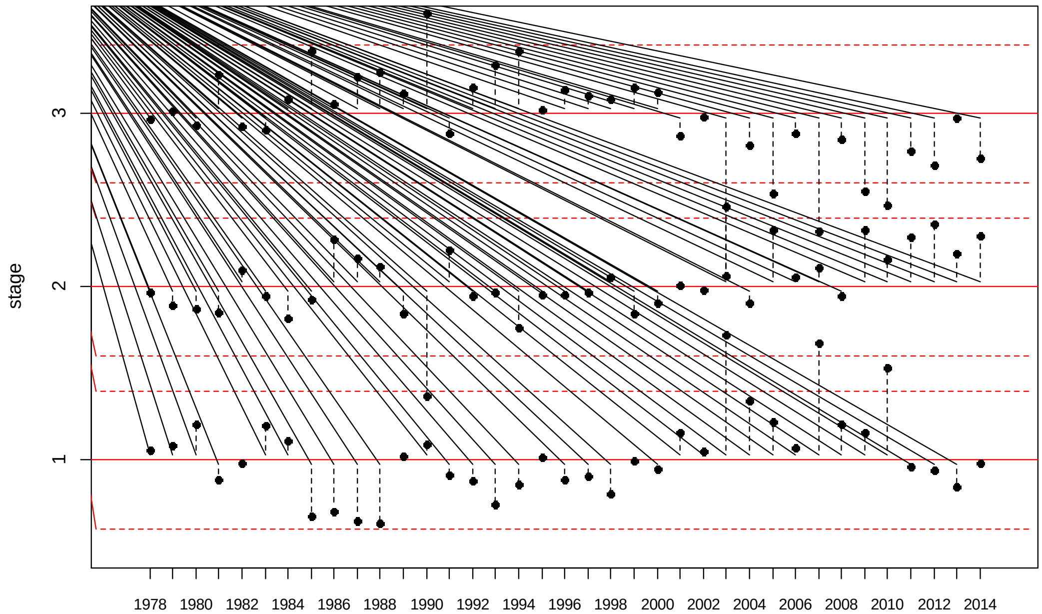

Figure 12a. Base-model fits to trawl-survey composition data.

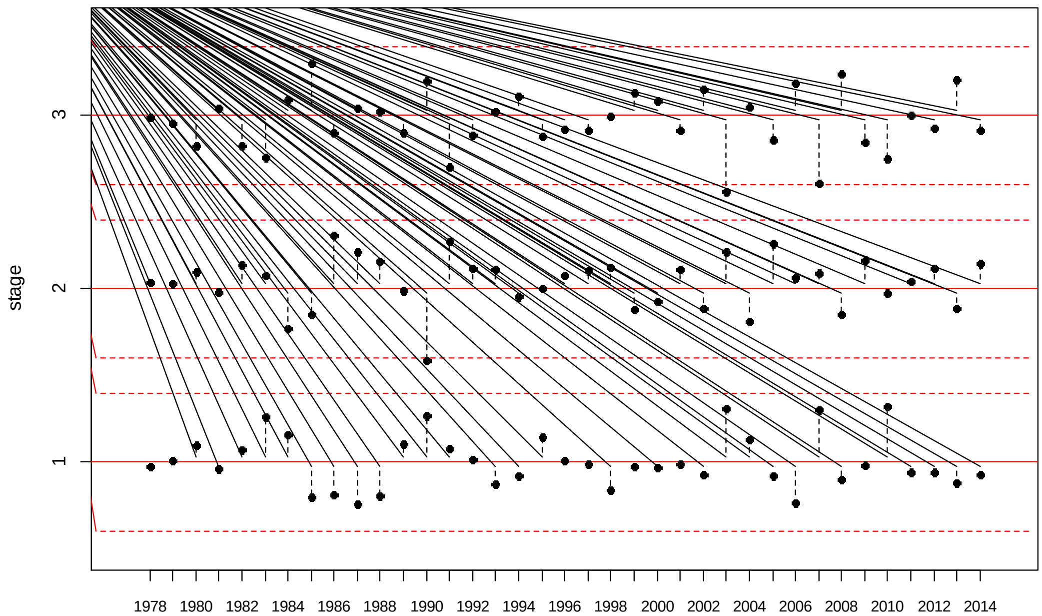

Figure 12b. Model ST fits to trawl-survey composition data.

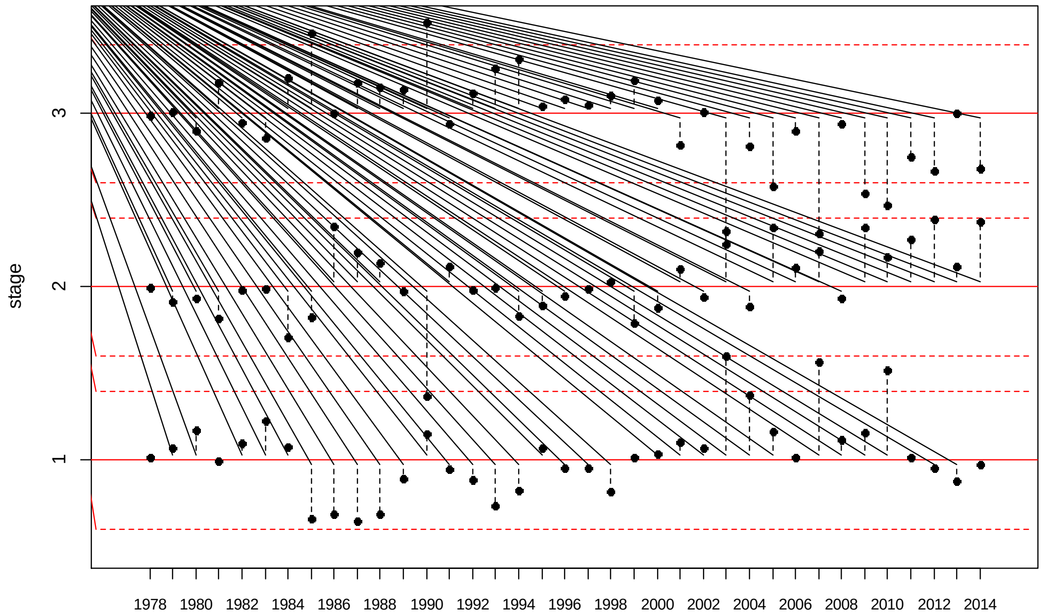

Figure 12c. Model T fits to trawl-survey composition data.

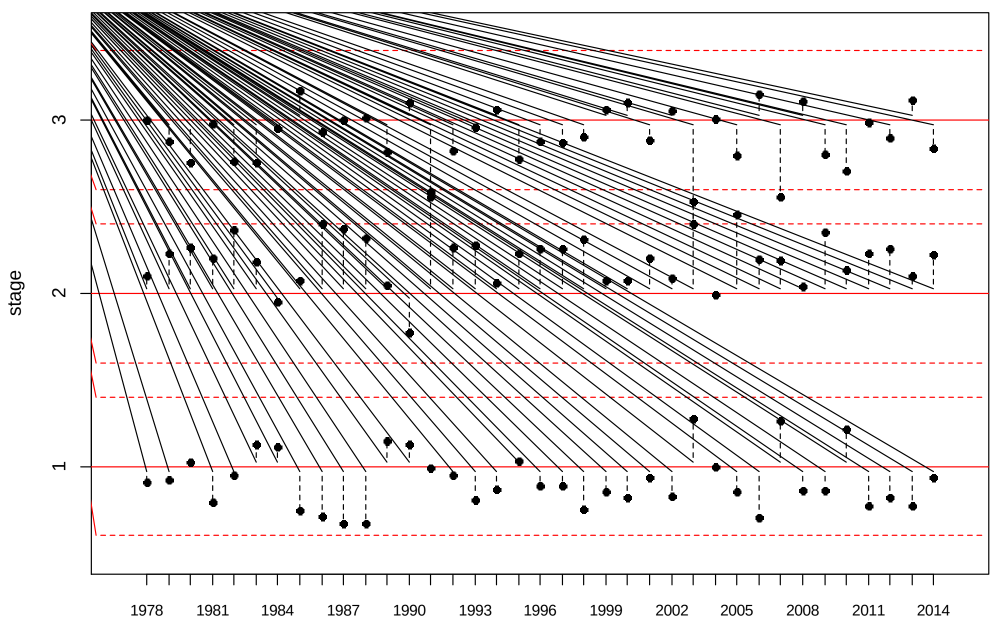

Figure 12d. Model S fits to trawl-survey composition data.

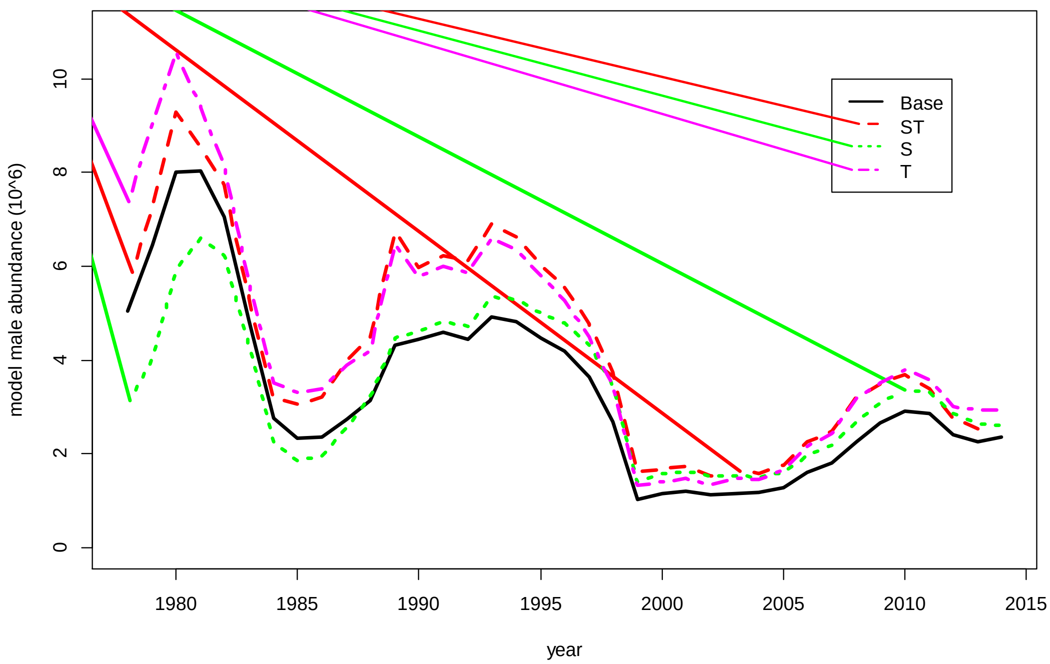

Figure 13. Plots of base and alternative model estimated model male (90+ mm CL) abundance.

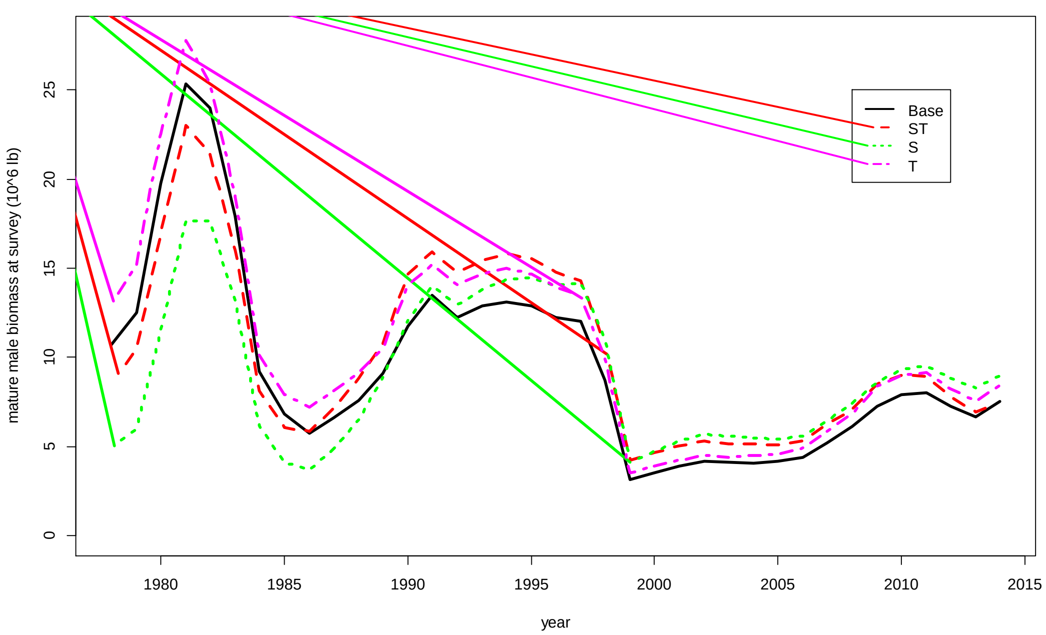

Figure 14. Plots of base and alternative model estimated mature-male biomass at time of survey.

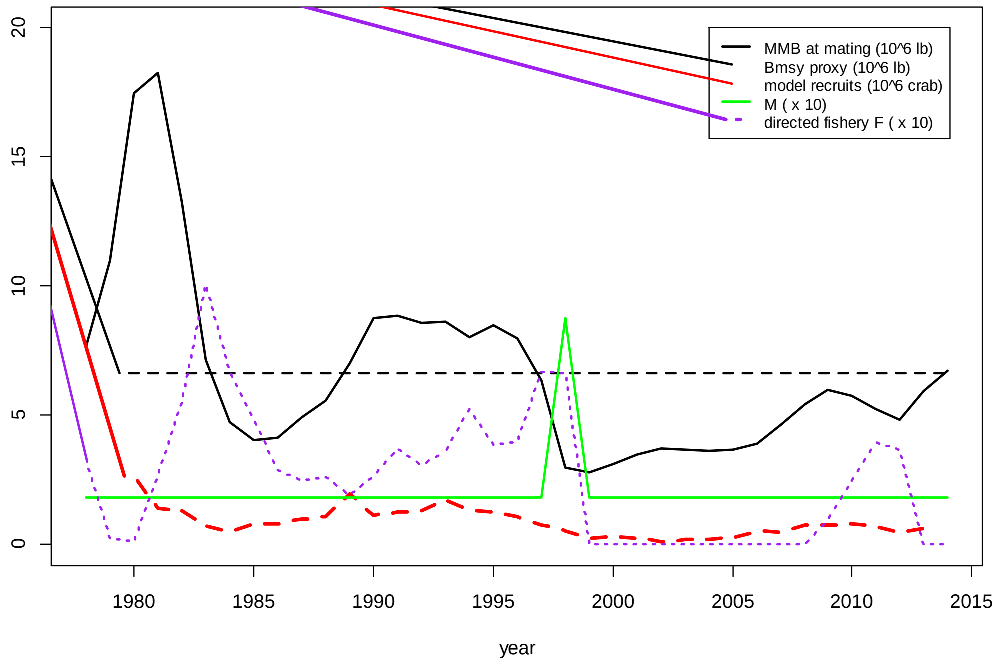

Figure 15a. Base-model estimates of important SMBKC management quantities.

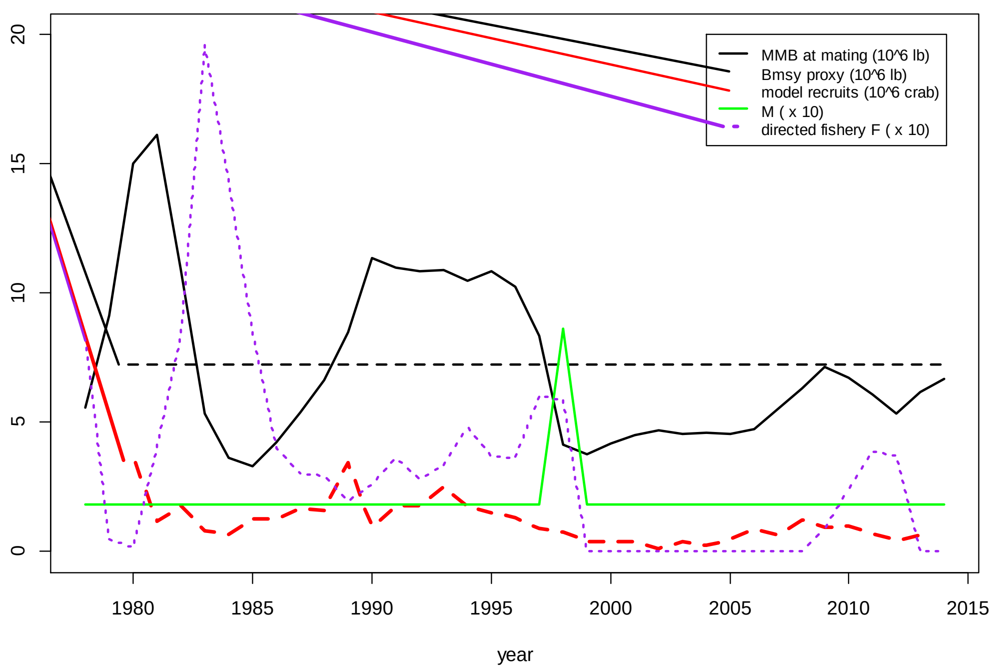

Figure 15b. Model ST estimates of important SMBKC management quantities.

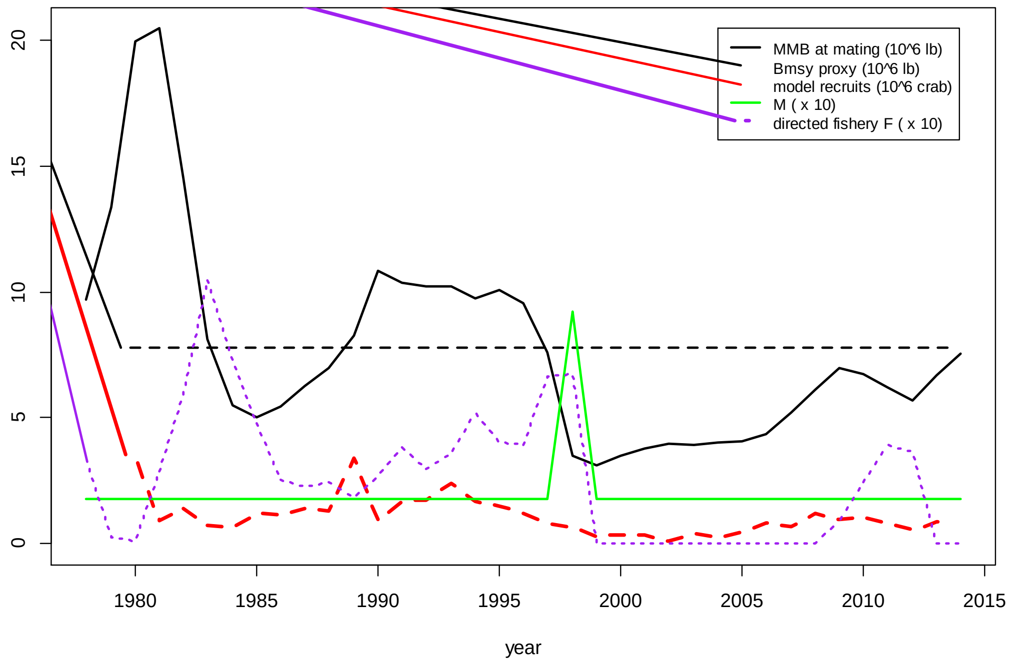

Figure 15c. Model T estimates of important SMBKC management quantities.

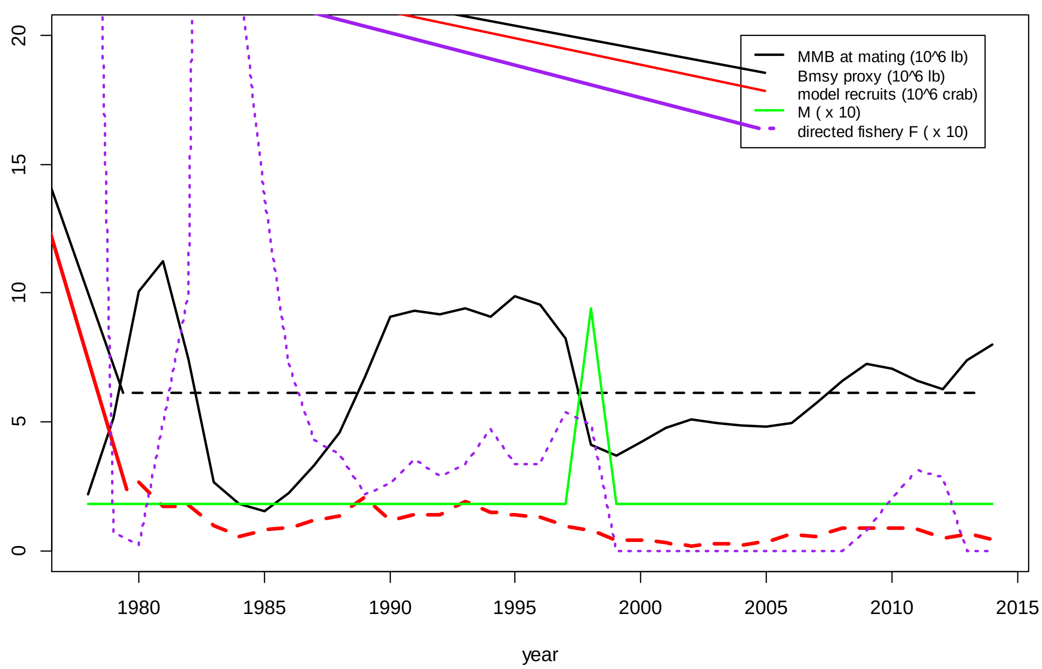

Figure 15d. Model S estimates of important SMBKC management quantities.

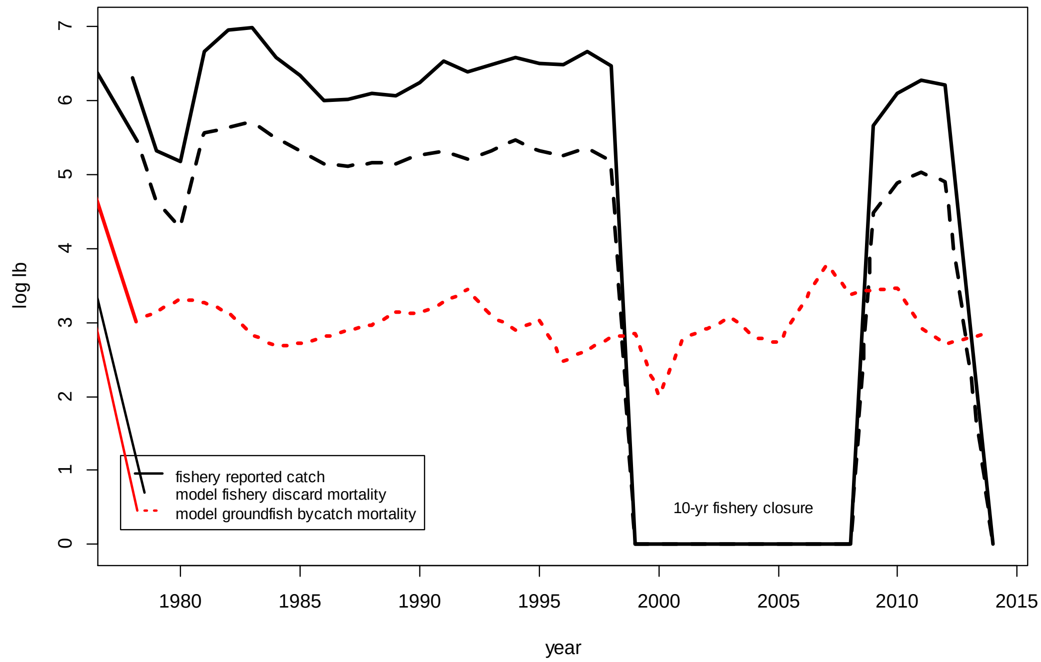

Figure 16. Model ST SMBKC fishing mortality.

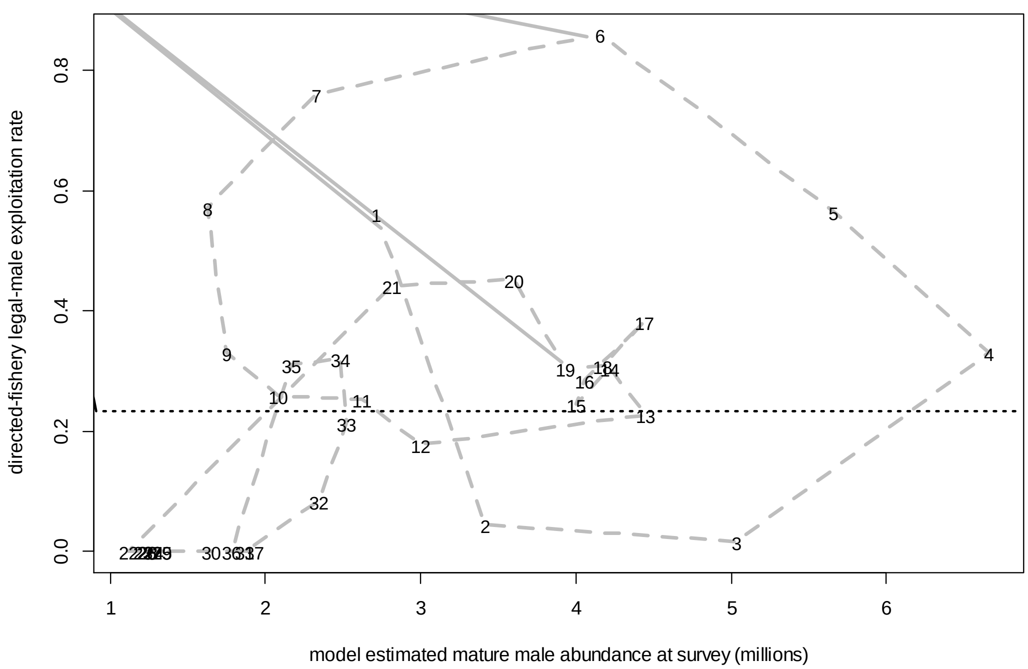

Figure 17. Model ST SMBKC exploitation rate versus mature male abundance.

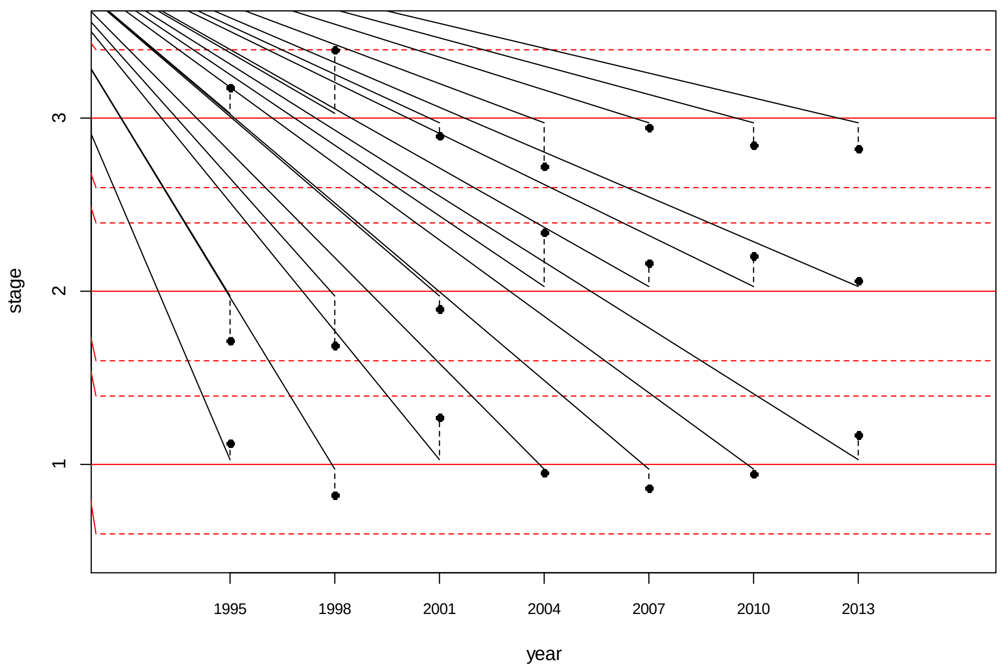

Figure 18. Model ST fits to SMBKC triennial pot-survey composition data.

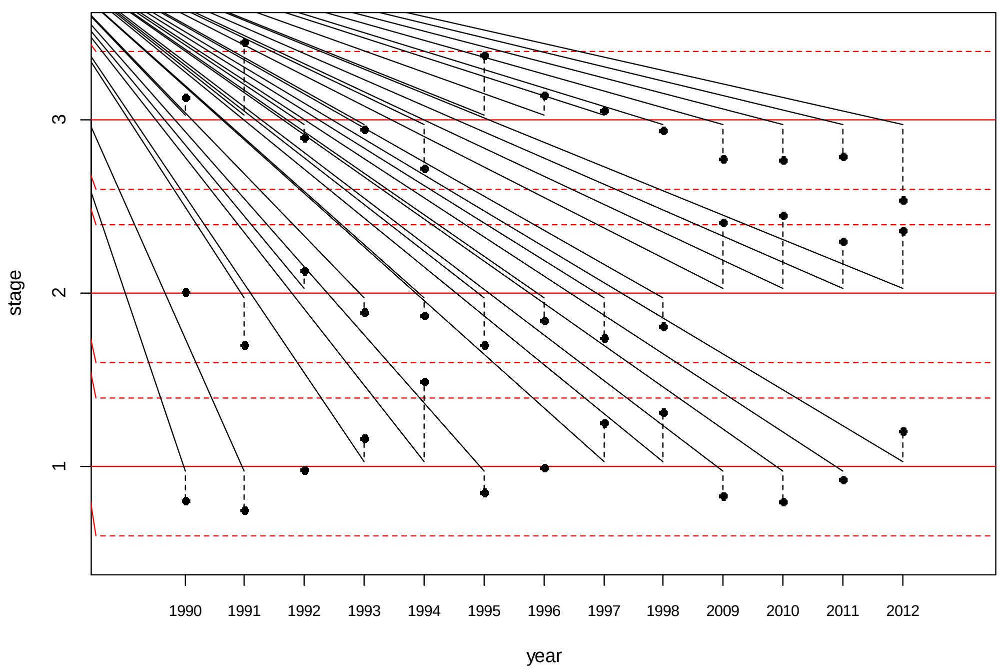

Figure 19. Model ST fits to SMBKC pot-fishery observer composition data.

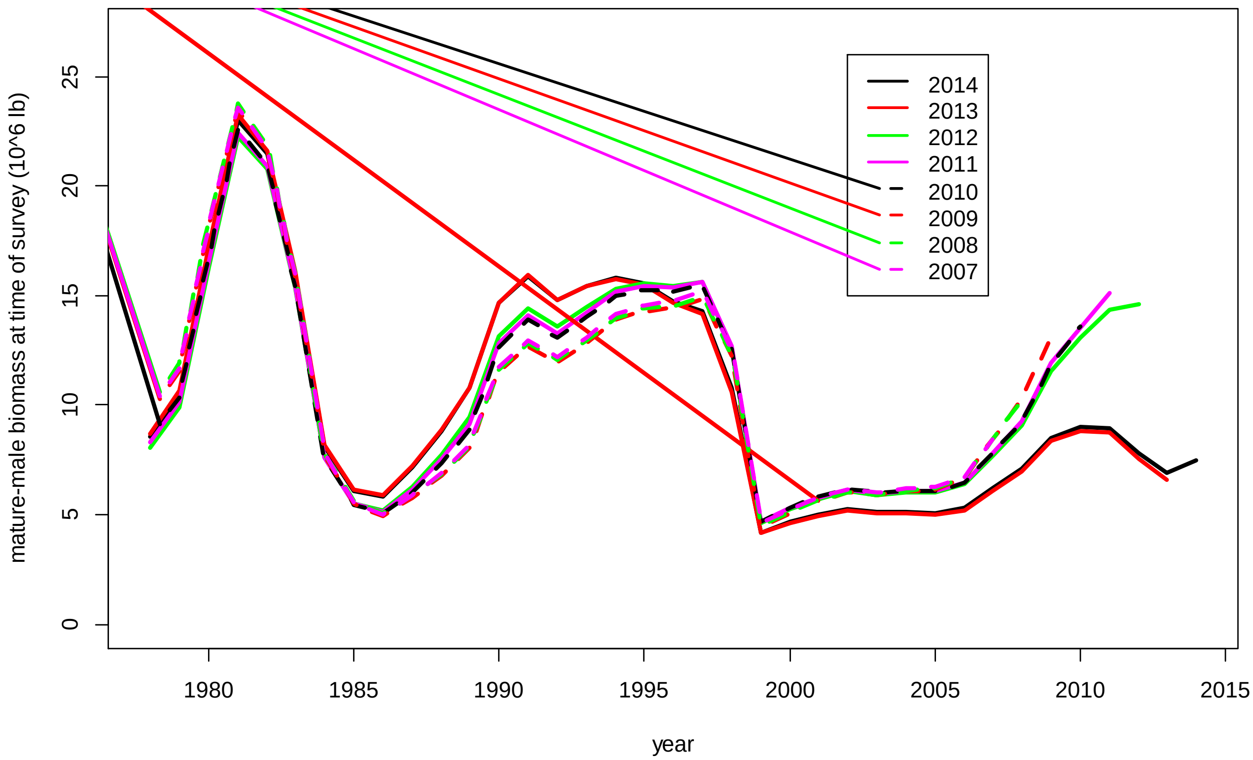

Figure 20. Retrospective plot of model-estimated mature male biomass at time of survey for 2014 model configuration ST and terminal years 2007-2014. Estimates are based on all available data up to and including terminal-year trawl and pot surveys.

Appendix A: SMBKC Base Model Description

1. Introduction

The model accounts only for male crab at least 90 mm in carapace length (CL). These are partitioned into three stages (male size classes) determined by CL measurements of (1) 90-104 mm, (2) 105-119 mm, and (3) 120 mm+. For management of the St. Matthew Island blue king crab (SMBKC) fishery, 120 mm CL is used as the proxy value for the legal measurement of 5.5 in carapace width (CW), whereas 105mm CL is the management proxy for mature-male size (5 AAC 34.917 (d)). Accordingly, within the model only stage-3 crab are retained in the directed fishery, and stage-2 and stage-3 crab together comprise the collection of mature males. Some justification for the 105 mm value is presented in Pengilly and Schmidt (1995), who used it in developing the current regulatory SMBKC harvest strategy. The term "recruit" here designates recruits to the model, i.e. annual new stage-1 crab, rather than recruits to the fishery. The following description of model structure reflects the base-model configuration.

2. 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

$$\boldsymbol{N}_{t+1} = \boldsymbol{G} e^{-M_t} \boldsymbol{N}_t + \boldsymbol{N}^{new}{}_{t+1}, \qquad \text{[A1]}$$

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

$$\boldsymbol{G} = \begin{bmatrix} 1-\pi_{12} & \pi_{12} & 0 \\ 0 & 1-\pi_{23} & \pi_{23} \\ 0 & 0 & 1 \end{bmatrix}, \qquad \text{[A2]}$$

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, or "recruits," entering the model at the start of 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. (In the event of nontrivial bycatch mortality with another fishery, as in 2012/13, it is accounted for in the model in the estimate of groundfish bycatch mortality.) 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

$$\boldsymbol{R}_t^{df} = \boldsymbol{H}^{df} \boldsymbol{S}^{df} (1 - e^{-F_t^{df}}) e^{-\tau_t M} \boldsymbol{N}_t, \qquad \text{[A3]}$$

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 constant over time. 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

$$\boldsymbol{R}_t^{gt} = \frac{F_t^{gt}}{F_t^{gt}+F_t^{gf}} e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})(1-e^{-(F^{gt}+F^{gf})})h^{gt} \qquad \text{[A4]}$$

$$\boldsymbol{R}_t^{gf} = \frac{F_t^{gf}}{F_t^{gt}+F_t^{gf}} e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})(1-e^{-(F^{gt}+F^{gf})})h^{gf}. \qquad \text{[A5]}$$

These last two computations assume that the groundfish fisheries affect all stages proportionally, i.e. that all stage selectivities equal one, and that handling mortalities h^{gt} and h^{gf} are constant across both stages and years. The author believes that the available composition data from these fisheries are of such dubious quality as to preclude meaningful use in estimation. Moreover, evidently with the exception of 2007/08, which in the author's view is suspiciously anomalous, the impact of these fisheries on the stock has typically been small. These considerations suggest that more elaborate efforts to model that impact are unwarranted. Model population dynamics are thus completely determined by the equation

$$\boldsymbol{N}_{t+1} = \boldsymbol{G}e^{-0.37M_t}(e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df}) - (\boldsymbol{R}_t^{gt} + \boldsymbol{R}_t^{gf})) + \boldsymbol{N}^{new}{}_{t+1}, \qquad \text{[A6]}$$

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. In years with no fishery, including the current assessment year, the time average value over years with a fishery is used. The author believes this approach to be an appropriate simplification given the data limitations associated with the stock.

3. 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 pot-fishery retained-catch number	1978/79-1998/99 2009/10-2012/13	Fish tickets (fishery closed 1999/00-2008/09)
NMFS trawl-survey biomass index (area-swept estimate) and CV	1978-2014	NMFS EBS trawl survey
ADFG pot-survey abundance index (CPUE) and CV	Triennial 1995-2013	ADF&G SMBKC pot survey
NMFS trawl-survey stage proportions and total number of measured crab	1978-2014	NMFS EBS trawl survey
ADFG pot-survey stage proportions and total number of measured crab	Triennial 1995-2013	ADF&G SMBKC pot survey
Directed pot-fishery stage proportions and total number of measured crab	1990/91-1998/99 2009/10-2012/13	ADF&G crab observer program (fishery closed 1999/00-2008/09)
Groundfish trawl bycatch biomass	1992/93-2013/14	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93-2013/14	NMFS groundfish observer program

Model-predicted retained-catch number C_t is calculated assuming catch consists precisely of those stage-three crab captured in the directed fishery so that

$$C_t = e^{-\tau_t M_t} N_{3,t}(1 - e^{-F^{df}}), \tag{A7}$$

which is just the third component of [3]. In fact, in the actual pot fishery a small number of captured stage-3 males are discarded, whereas some captured stage-2 males are legally retained, but data from onboard observers and dockside samplers suggest that [7] here provides a serviceable approximation (ADF&G Crab Observer Database). Model analogs of trawl-survey biomass and pot-survey abundance indices are given by

$$B_t^{ts} = Q^{ts}(s_1^{ts} N_{1,t} w_1 + s_2^{ts} N_{2,t} w_2 + N_{3,t} w_{3,t}) \tag{A8}$$

$$A_t^{ps} = Q^{ps}(s_1^{ps} N_{1,t} + s_2^{ps} N_{2,t} + N_{3,t}), \tag{A9}$$

these being year-*t* trawl-survey area-swept biomass and year-*t* pot-survey CPUE, respectively, both with respect to 90 mm+ CL males. In these expressions, Q^{ts} and Q^{ps} denote model proportionality constants, assumed independent of year and with $Q^{ts} = 1.0$ under all scenarios considered for this assessment, and s_j^{ts} and s_j^{ps} denote corresponding stage-*j* survey selectivities, also assumed independent of year. Model trawl-survey, pot-survey, and directed-fishery stage proportions $\boldsymbol{P}_t^{ts}$, $\boldsymbol{P}_t^{ps}$, and $\boldsymbol{P}_t^{df}$ are then determined by

$$\boldsymbol{P}_t^{ts} = \frac{Q^{ts}}{A_t^{ts}} \begin{bmatrix} s_1^{ts} & 0 & 0 \\ 0 & s_2^{ts} & 0 \\ 0 & 0 & 1 \end{bmatrix} \boldsymbol{N}_t \tag{A10}$$

$$\boldsymbol{P}_t^{ps} = \frac{Q^{ps}}{A_t^{ps}} \begin{bmatrix} s_1^{ps} & 0 & 0 \\ 0 & s_2^{ps} & 0 \\ 0 & 0 & 1 \end{bmatrix} \boldsymbol{N}_t \tag{A11}$$

$$\boldsymbol{P}_t^{df} = \frac{1}{\langle (\boldsymbol{H}^{df})^{-1} \boldsymbol{R}_t^{df},\ \boldsymbol{1} \rangle} (\boldsymbol{H}^{df})^{-1} \boldsymbol{R}_t^{df}. \tag{A12}$$

Letting $\boldsymbol{w}_t = [w_1, w_2, w_{3,t}]^T$ be 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

$$B_t^{gt} = \boldsymbol{w}_t{}^T \boldsymbol{R}_t^{gt} \text{ and } B_t^{gf} = \boldsymbol{w}_t{}^T \boldsymbol{R}_t^{gf}. \tag{A13}$$

Recall that stage-1 and stage-2 mean weights do not depend on year, being based on the length-to-weight relationship of Chilton and Foy (2010), whereas stage-3 mean weight is set equal to year-*t* fishery reported average retained weight or its time average for years with no fishery.

4. Model Parameters

Base-model estimated parameters are listed in Table 2 and include an estimated parameter for natural mortality in 1998/99 on the assumption of an anomalous mortality event in that year, as hypothesized by Zheng and Kruse (2002), with natural mortality otherwise fixed at 0.18 yr^{-1}. 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 3 lists additional externally determined parameters used in model computations.

Both surveys are assigned a nominal date of July 1, the start of the crab year. The directed fishery is treated as a season midpoint pulse. Groundfish bycatch is likewise modeled as a pulse effect, occurring at the nominal time of mating, Feb 15, which is also the reference date for calculation of federal management biomass quantities.

Table 2. Base-model estimated parameters.

Parameter	Number
Log initial stage abundances	3
1998/99 natural mortality	1
Pot-survey "catchability"	1
Stage 1 and 2 Trawl-survey selectivities	2
Stage 1 and 2 Pot-survey selectivities	2
Stage 1 and 2 Directed-fishery selectivities	2
Mean log recruit abundance	1
Log recruit abundance deviations	36[a]
Mean log directed-fishery mortality	1
Log directed-fishery mortality deviations	25[a]
Mean log groundfish trawl fishery mortality	1
Log groundfish trawl fishery mortality deviations	23[a]
Mean log groundfish fixed-gear fishery mortality	1
Log groundfish fixed-gear fishery mortality deviations	23[a]
Total	122

[a] Subject to zero-sum constraint.

Table 3. Base-model fixed parameters.

Parameter	Value	Source/Rationale
Trawl-survey "catchability", i.e. abundance-index proportionality constant	1.0	Default
Natural mortality (except 1998/99)	0.18 yr^{-1}	NPFMC (2007)
Stage 1 and 2 transition probabilities	1.0, 1.0	Default
Stage-1 and 2 mean weights	1.65, 2.57 lb	Chilton and Foy (2010) length-weight equation applied to stage size-interval midpoints.
Stage-3 mean weight	depends on year	Fishery-reported average retained weight from fish tickets, or its average.
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

5. Model Objective Function and Weighting Scheme

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. See Table 4, where upper and lower case letters designate model-predicted and data-computed quantities, respectively, and boldface letters again indicate vector quantities. 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. The weights λ_j appearing in the objective function component expressions in Table 4 play the role of "tuning" parameters in the modeling procedure.

Table 4. Loglikelihood and penalty components of base-model objective function. The λ_k are weights, described in text; the $neff_t$ are effective sample sizes, also described in text. All summations are with respect to years over each data series.

Component		Form
Legal retained-catch number	Lognormal	$-\lambda_1 0.5\sum[\log(c_t+0.001)-\log(C_t+0.001)]^2$
Trawl-survey biomass index	Lognormal	$-\lambda_2 0.5\sum[\frac{\ln(b_t^{ts})-\ln(B_t^{ts})}{\ln(1+\widehat{cv_t^{ts}}^2)}]^2$
Pot-survey abundance index	Lognormal	$-\lambda_3 0.5\sum[\frac{\ln(a_t^{ps})-\ln(A_t^{ps})}{\ln(1+\widehat{cv_t^{ps}}^2)}]^2$
Trawl-survey stage proportions	Multinomial	$\lambda_4\sum neff_t^{ts}(\boldsymbol{p}_t^{ts})^T\ln(\boldsymbol{P}_t^{ts}+0.01)$
Pot-survey stage proportions	Multinomial	$\lambda_5\sum neff_t^{ps}(\boldsymbol{p}_t^{ps})^T\ln(\boldsymbol{P}_t^{ps}+0.01)$
Directed-fishery stage proportions	Multinomial	$\lambda_6\sum neff_t^{df}(\boldsymbol{p}_t^{df})^T\ln(\boldsymbol{P}_t^{df}+0.01)$

Groundfish trawl mortality biomass	Lognormal	$-\lambda_7 \sum [\ln(b_t^{gt}) - \ln(B_t^{gt})]^2$
Groundfish fixed-gear mortality biomass	Lognormal	$-\lambda_8 \sum [\ln(b_t^{gf}) - \ln(B_t^{gf})]^2$
$\ln(N_{1,t}^{new})$ deviations	Quadratic/Normal	$\lambda_9 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{df})$ deviations	Quadratic/Normal	$\lambda_{10} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{gft})$ deviations	Quadratic/Normal	$\lambda_{11} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{gff})$ deviations	Quadratic/Normal	$\lambda_{12} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$

Determination of the weighting scheme involved a great deal of trial and error with respect to graphical and other diagnostic tools; however, the author's basic strategy was to begin with a baseline weighting scheme that was either unity or otherwise defensible in terms of plausible variances and then proceed in the spirit of Francis (2011). The CPT noted in May 2012 that survey weights should generally not exceed unity, and the author has complied with that advice for this assessment.

Table 5 shows the weighting scheme used for the base-model scenario. The weight of 1,000 applied to the lognormal fishery catch-number component (λ_1) corresponds to a coefficient of variation of approximately 3% for the fishery estimate of catch number. The weights λ_2 and λ_3 on the lognormal trawl-survey and pot-survey abundance components are set at 1.0, allowing the yearly conventional survey-based CV estimates to govern the terms contributed by these two series. The default 1.0 weights on the lognormal groundfish bycatch mortality biomass components (λ_7 and λ_8) correspond to implied CVs of about 130%, which this author judges probably appropriate given the nature of the data. The weight of 1.25 applied to the quadratic/normal recruit-deviation penalty (λ_9) is approximately the inverse of the sample variance of trawl-survey time-series estimates of 90-104 mm male crab ("recruit") abundance. With λ_4, λ_5, and λ_6 equal to 1.0, the factors denoted by $neff_t$ appearing in the multinomial loglikelihood expressions of the objective function represent effective sample sizes describing observed survey and fishery stage-proportion error structure with respect to model predicted values. Each set is determined by a single set-specific parameter N_{max} such that the effective sample size in any given year $neff_t$ is equal to the observed number of crab n_t if $n_t < N_{max}$ and otherwise equal to N_{max}. For the base-model configuration, N_{max} was assigned a value of 50 for trawl-survey composition data and 100 for both pot-survey and fishery observer composition data. Graphical displays of the standardized residuals, including normal Q-Q plots, provided some guidance in making this choice, although model fit to the composition data tends to be rather poor under all scenarios.

Table 5. Base-model objective-function weighting scheme.

Objective-Function Component	Weight λ_j
Legal retained-catch number	1000
Trawl-survey abundance index	1.0
Pot-survey abundance index	1.0
Trawl-survey stage proportions	1.0
Pot-survey stage proportions	1.0
Directed-fishery stage proportions	1.0
Groundfish trawl mortality biomass	1.0
Groundfish fixed-gear mortality biomass	1.0
Log model recruit-abundance deviations	1.25
Log directed fishing mortality deviations	0.001
Log groundfish trawl fishing mortality deviations	1.0
Log groundfish fixed-gear fishing mortality deviations	1.0

6. Estimation

The model was implemented using the software AD Model Builder (ADMB Project 2009), with parameter estimation by minimization of the model objective function using automatic differentiation. Standard errors and estimated parameter correlations provided in this document are AD Model Builder reported values assuming maximum likelihood theory asymptotics.