2011 Saint Matthew Island Blue King Crab Stock Assessment

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Executive Summary

1. <u>Stock</u>: Blue king crab, *Paralithodes platypus,* Saint Matthew Island, Alaska.

2. <u>Catches</u>: 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. The TAC was increased to 1.600 million pounds (725.7 t) in 2010/11 and to 2.539 million pounds (1,151 t) in 2011/12, but reported catches again fell short at 1.264 million pounds (573.3 t; 79% of the TAC) and 1.881 million pounds (853.2 t; 74% of the TAC), respectively. Total male discard mortality in the 2011/12 directed fishery is estimated from ADF&G crab-observer data at 0.217 million pounds (98.3 t), assuming 20% handling mortality. Male bycatch mortality in the 2011/12 groundfish fisheries is estimated from NMFS observer data at 0.0009 million pounds (0.4 t).

3. <u>Stock biomass</u>: Following a period of low numbers in the wake of a hypothesized 1998/99 stock collapse (Zheng and Kruse 2002), trawl-survey indices of SMBKC stock abundance and biomass have generally increased in recent years, with 2011 estimated mature male biomass at 21.07 million pounds (9,557 t; estimated CV 0.53), the second highest in the 35-year time series used in this assessment . Although the 2012 estimate of 12.46 million pounds (5,652 t; estimated CV 0.33) represents a marked decrease from the 2011 estimate, it is still among the highest values since 1988 and well above the post-collapse low of 2.812 million pounds (1,275 t; estimated CV 0.36) reported in 2005.

4. <u>Recruitment</u>: 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 2012 trawl-survey area-swept estimate of 0.705 million crab (estimated CV 0.44) is less than half the previous year's estimate of 1.693 million and the lowest since 2005. This 2012 estimate is based on 29 captured animals from the 56 survey stations used to assess the SMBKC stock.

5. <u>Management performance</u>: Estimated 2011/12 total male catch is 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. With the 2011/12 OFL at 3.74 million pounds (1,70 t) and estimated 2011/12 total male catch equal to 1.88 + 0.217 +0.0009 = 2.10 million pounds (953 t), no declaration of overfishing is warranted. Recent assessments of stock biomass suggest it is well above the MSST and that the stock is currently neither overfished nor approaching an overfished condition. See Table below. (All biomass measures in millions of pounds with metric ton equivalents in parentheses.)

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Catch	OFL[a]	ABC
2009/10	3.4 (1,500)	12.76 (5,790)	1.167 (529.3)	0.461 (209)	0.530 (240)	1.72 (780)	-
2010/11	3.4 (1,500)	14.77 (6,700)	1.600 (725.7)	1.264 (573)	1.408 (639)	2.29 (1,040)	-
2011/12	3.4 (1,500)	11.09[b] (5,030)	2.539 (1,151)	1.881 (853)	2.10 (953)	3.74 (1,700)	3.40 (1,540)
2012/13	4.0[c] (1,800)	12.41[d] (5,629)	TBD	TBD	TBD	2.24[e] (1,020)	2.02[e, f] (916)

[a] Total male catch OFL.

[b] Fall 2012 base-model estimate.

[c] Fall 2012 base-model estimate using the reference period 1978 – 2011/12.

[d] Fall 2012 base-model projection assuming OFL catch.

[e] From Fall 2012 base model.

[f] As described in §G with P* = 0.49 and additional 10% 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. Under the Fall 2011 survey-based methodology, the B_{MSY} proxy was computed as average estimated 1989/99 – 2009/10 MMB_{mating}, determined to be 6.85 million pounds (3,110 t). The current default and author recommendation is to use the full assessment time frame, 1978 – 2011, as the reference period, giving 7.93 million pounds (3,600 t) under the base-model configuration. The F_{MSY} proxy is taken equal to the assumed 0.18 yr^{-1} instantaneous natural mortality. See table below. (All biomass measures in millions of pounds with metric ton equivalents in parentheses.)

Year	Tier	B_{MSY}	B (MMB_{mating})	B/B_{MSY}	F_{OFL}	γ	Basis for B_{MSY}	Natural Mortality	P^*
2009/10	4a	6.95 (3,150)	12.76 (5,790)	1.84	$0.18yr^{-1}$	1	1989/90 -2009/10	$0.18yr^{-1}$	-
2010/11	4a	6.86 (3,110)	15.29 (6,940)	2.23	$0.18yr^{-1}$	1	1989/90 - 2009/10	$0.18yr^{-1}$	-
2011/12	4a	6.85 (3,110)	15.80 (7,167)	2.31[a]	$0.18yr^{-1}$	1	1989/90 - 2009/10	$0.18yr^{-1}$	0.49
2012/13	4a	7.93 (3,560)	12.41[a] (5,629)	1.56	$0.18yr^{-1}$	1	1978/79 - 2011/12	$0.18yr^{-1}$	0.49

[a] Fall 2012 base model projection assuming OFL catch.

7. Distribution of the OFL: It is recognized that 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 assessment 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 by which to quantify some of this uncertainty and to facilitate determination of the ABC. Details are provided in §G of this document.

8. Basis for the ABC: For determining an acceptable biological catch (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 90% of the maximum value.

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

A. Summary of Major Changes

Changes in Management of The Fishery

There are no new changes in management of the fishery.

Changes to The Input Data

All time series used in the assessment have been updated to include the most recent fishery and survey results.

Changes in Assessment Methodology

The Fall 2011 assessment employed a survey-based approach. This assessment makes use of a 3-stage length-based assessment model first presented in May 2011 and accepted by the CPT in May 2012. The model was developed as an alternative to a similar 4-stage model used prior to 2011.

Consistent with the most recent recommendations, the full assessment time frame 1978 – 2011 is now used as the default basis for determining the B_{MSY} proxy value, and the author has revised the approach used to specify a distribution for the OFL and set the ABC, as described in §G.

Changes in Assessment Results

There are no noteworthy changes in assessment results at this time. Results are in line with those from recent years.

B. Responses to SSC and CPT Comments

CPT and SSC Comments on Assessments in General

- Sept 2011 CPT

Comments: *The team discussed the necessity of including survey catch into assessments for total catch accounting purposes as needed under the revised MSA… Guidance will be sent out this winter in terms of the process for accounting for these catches in the next assessment cycle.*

Response: The author believes the impact of survey catches presently is inconsequential for this stock but remains open to further guidance on the issue.

- Sept 2011 SSC

  Comments: No new recommendations.

- Jan 2012 NPFMC Crab Modeling Workshop

The workshop included a day of discussion focusing on the choice of methodology for assigning a probability distribution to the OFL for use in determining the ABC.

Comments:

Shorter term considerations

1. Make clear distinctions between regulatory values (OFL and ABC), true but unknown values (μ_{OFL} *), and estimators (e.g.,* $\hat{X}_{OFL}$*)*

2. Calculate the pdf of the OFL using pragmatic approaches such as using point estimates of OFL and variances from the uncertainty estimates either from the Hessian or MCMC.

3. Simulation approaches as outlined above for crab Tier 3 and 4 should be implemented in a standard software package with clear documentation Note that there is potential for lack of transparency because since the simulation procedure is complex it may detract from other fundamental issues related to the probability that F_{msy} *will be exceeded.*

Longer-term broader considerations for both groundfish and crab control rules

4. Alternative candidate pdf estimators for OFL-ABC determinations might best be evaluated relative to F_{msy} *instead of relative to legally-defined OFL control rules (which have explicitly been designed to avoid exceeding* F_{msy}*, when biomass is estimated to be below* B_{msy}*)*

5. Evaluate/reconsider the utility of computing probabilities of proxies:

a. Do they accurately reflect the uncertainty in actual Fmsy estimates?

b. Should post-control rule computation of uncertainties (i.e., computing probabilities of exceeding control rule outputs rather than of Fmsy) be avoided?

c. What is the latitude for legal definitions of OFL (via a pre-specified control rule) versus OFL= $f(F_{msy})$*?*

6. Evaluate the consequences of applying control rules from lower tiers to higher-tier stocks to understand general consistency (in terms of risk aversion) and conditions where they vary

7. For crab examine method applied in 2010 to compute OFL pdfs for Tier 4 to a range of stocks including uncertainty in B_{msy} *(proxy) and consider bootstrapping to generate uncertainty similar to Tier 3 estimates (using MCMC). It may be difficult to predict how distributional assumptions will compare (e.g., log-normal vs normal since with larger variances more "samples" will be truncated/omitted).*

8. Quantify the impact of each source of uncertainty for pdf estimates based on multiple sources of uncertainty (e.g. the Tier 4 OFL control rule). For example, for Tier 4 stocks, what is the contribution to the variance for the OFL from the assumed level of uncertainty associated with natural mortality compared to that related to stock size and the B_{msy} *(proxy)? This could be done by successively turning off* *each source of uncertainty to evaluate the relative impact on results. This has been done in the Crab ACL analysis in conjunction with σ_B values.*

9. Examine model-based uncertainty compared to survey-based values. Uncertainty may be underestimated for data-poor stocks for which the assessment pre-specifies many parameters. For Alaska crab and groundfish, survey CVs may provide a consistent treatment across tier levels commensurate with the reliability of stock size estimates as observed in surveys. In general, the stock size and associated reference points of a stock with a high survey CV is considered more uncertain and in need of a larger buffer, then a stock with a low survey CV. However, assuming the uncertainty of the estimate of OFL is primarily due to survey CVs assumes uncertainty in biological rates plays a minor role, and that both survey catchability and selectivity is reasonably high.

10. The size of the buffer between the OFL and the ABC for crab stock is small because of the specification P = 0.49. Perhaps a comprehensive reconsideration of the Crab Tier system including both the OFL and ABC control rules should be pursued. There should be a "risk neutral" treatment of uncertainty and other measures inherent in current specifications process. For example, MMB as a measure of spawning biomass and treatment of 'total catch' when control rules currently applied to MMB (only) and females added in afterwards and B_{msy} includes only males and yet the MSST should conceptually include females. CPT to discuss progress towards using an alternative (and more appropriate) measure of effective spawning biomass/reproductive potential for crab stocks in May.*

11. Identifying additional uncertainty in OFL distribution

a. σ_B

b. asymmetry of the uncertainty (if assessment and OFL estimates are not "risk neutral")

c. The impact of pre-specifying rather than estimating parameters. For example, in stocks where fishery availability may change significantly from year to year due to spatial targeting of strong recruitments, more data would be needed to account for this process and model appropriately. In low data situations, the assessment would (typically) assume constant selectivity and hence likely overestimate the precision of abundance and mortalities.

Response: The author has revised the approach used to determine the ABC consistent with his understanding of the guidance provided. Details are given in §G of this document.

- May 2012 CPT: No new directives.
- June 2012 SSC: No new directives.

CPT and SSC Comments Specific to SMBKC Stock Assessment

- Sept 2011 CPT

Comments: *The author clarified that the OFL in the assessment was calculated for mature males only. The team discussed calculating the OFL in this manner and how to reconcile this* *with evaluating whether overfishing occurred. The team requested that the author recalculate the OFL to apply to total males.*

The team discussed the years used to calculate BMSYproxy and the author recommended the period from 1989/90 to 2009/10. The team ***recommends*** *that the assessment provide further justification for this choice of this period at the May 2012 meeting.*

St. Matthew model discussion: The team made ***recommendations*** *to adopt a standardized weighting procedure based on CVs for indices and catch biomass, to provide several model configurations [along with an author-preferred model] for evaluation by the team, and to provide diagnostics to evaluate the choices. The issues of effective sample size and survey representation should be evaluated. The team noted that the report from the team's modeling workshop in 2009 (and annual SAFE guidelines) provide additional guidance for addressing these issues.*

Response: Calculation of the OFL and determination of the B_{MSY} proxy have been revised with adoption of the 3-stage model for the 2012 assessment. Details are given in §F of this document. Recommendations with respect to the model have likewise been addressed since Fall 2011.

- Sept 2011 SSC

Comments: *The author continues to refine the stock assessment model following recommendations from the CPT, and the SSC looks forward to reviewing the model in 2012. The SSC found the material on the model to be nicely presented, but had some recommendations for the authors. The way effective sample size is determined differs from what others do, and some explanation would be helpful. Also, the assumption of high mortality in 1998/99, and a rationale for that assumption needs to be provided. Finally, a couple of alternative models would be useful for comparison, including one that does not rely on assumption of high mortality in 1998/99.*

Response: The author has revised computation of effective sample sizes and has presented some alternative models. This work appears to justify the assumption of high 1998/99 mortality.

- Jan 2012 NPFMC Crab Modeling Workshop

Comments: No new recommendations specific to this assessment.

- May 2012 CPT

Comments:

1. Present alternative models for September which (a) represent different values to weight the trawl and pot surveys (including giving the pot survey more weight than the trawl survey), (b) assume the same selectivity for stages 2-3 in the trawl survey to address concerns about the 1.24 value for the stage-3 trawl survey selectivity, and (c) assume that Q=1 applies to stage-2 rather than stage-3.

2. Avoid giving the pot or trawl surveys weights larger than 1.

3. Base the distribution for the OFL on its asymptotic sampling distribution (i.e., use the standard error for the logarithm of the OFL from the assessment).

4. Overlay model-predictions on Figure 1 showing the fits of the various alternative models to the trawl and pot survey data.

5. Include retrospective runs with plots of the mature male biomass.

6. Add a table of parameter correlations to aid in diagnosing potentially confounded parameters.

7. Add a plot with the number of stage-1 recruits (that could be used to determine $B_{35\%}$ *by multiplying* $SPR_{35\%}$ *if the CPT decided that this stock should be placed in Tier 3).*

8. Provide more information on the basis for the maturity assumption.

9. Calculate effective multinomial sample sizes for the compositional data: Neff = sum(p(1-p)/sum((o-p)^2 and plot the Neff versus the assumed sqrt transformed numbers with a 1:1 line on the graph. Consider using this to iteratively reweight sample sizes for a more parsimonious fit.

10. Plot standardized residuals and compute standard deviations of the mean absolute deviations (all should theoretically have an std=0.8 ~ sqrt(2/pi)) if all the data are properly weighted.

> Response:
> 1. – 7. The author has complied with all recommendations.
> 8. As noted in the body of this report, some justification for the 105mm CL proxy for male maturity is provided in Pengilly and Schmidt (1995), who used it in developing the current regulatory SMBKC harvest strategy.
> 9. Estimated effective multinomial sample sizes were computed for composition data and plotted against year for the trawl-survey, but the requested plots were uninformative and so not included. Iterative reweighting was not attempted at this time, though the author would like to experiment with this technique in the future.

10. The author requests additional explanation.

- June 2012 SSC

Comments:

The CPT recommended using the three-stage CSA for the fall 2012 fishery and the SSC concurs with this recommendation. *The assessment author has clearly described the model structure, data, parameters, and fitting procedure, including provision of the AD Model Builder code. The model fits the survey data reasonably well and residual fits to the three stage proportions are generally well behaved. The CPT has provided some very helpful recommendations to the assessment author, and the SSC supports these recommendations. In addition, the SSC offers the following comments and recommendations:*

1. Clarify that "recruits" corresponding to stage 1 are recruits to the model, not recruits to the fishery (page 2).

2. In the section on model population dynamics, it is stated that the impact of groundfish fisheries on the stock are small. However, the survey-based methods document (Table 4) indicates that 300,000 lbs of blue king crab were caught in fixed gear in 2007/08, resulting in an estimated PSC mortality of 150,000 lbs. Please address this and explain whether the proposed approach adequately addresses such situations.

3. On the bottom of page 3, please provide a little more explanation about the abundance index proportionality constants (Qs) and trawl or pot survey abundance indices (As). Are the Qs calculated as the abundance index for any one year divided by the largest abundance index in the time series? Also, please explain the units for the As. For the trawl survey, are these total area-swept abundances or mean station densities? For the pot survey, do the As represent mean catch per pot?

4. On the top of page 4, the stage mean weights are subscripted by year, suggesting that they are estimated annually. However, Table 5 indicates that the means for stage 1 and 2 are fixed and only the stage-3 mean weights are estimated annually. True stage-1 and -2 mean weights would vary by year depending on variability in year-class size and growth rates, so it should be mentioned that fixing these to constants is a simplifying assumption. Are data insufficient to reliably estimate these annually?

5. The SSC appreciates the author's attempts to explore various weighting scenarios. As pots are designed to catch crab, one might expect to put a higher weight on the pot survey compared to the trawl survey. However, the trawl surveys are conducted annually and cover a wider area.

Some additional explanation for the relative weights applied to pot and trawl surveys would be helpful.

6. In eq. (3), stage 3 selectivity is set to unity and the selectivities of the other two stages are estimated in the model. However, the model estimates the trawl selectivity of stage 2 crab to be 1.24 (Table 6). It does not seem plausible that smaller crab (stage 2) would have a higher selectivity than larger crab (stage 3). The Crab Plan Team provided advice on this issue, which the SSC supports.

7. The SSC appreciates the four alternative model scenarios that were considered. It would be more helpful if the alternative model fits were plotted with time series of survey estimates, as was done for the preferred model in Fig. 1. For viable alternatives, it would also be useful to plot residuals and other diagnostics, or using retrospective analysis to help confirm the model choice. The SSC is inclined to agree that it is best to estimate mortality for 1998/99, but remains interested in seeing a comparison of fits, as well as the diagnostics mentioned in the text.

8. The SSC requests the assessment author work toward future development of both Tier 3 and 4 reference points for this stock, including a description of the quality of data used for each and the author's recommendation for choice of tier level.

9. The SSC suggests estimating the natural mortalities corresponding to each size class. This can increase the understanding of the survival of this species directly and avoid confounding from movement and growth on the natural mortality estimate. With the three known size classes, the mathematical symbols are M_1, M_2, and M_3 and they are independent from time t.

10. The SSC suggests that the input data be corrected or adjusted for any bias due to the differences arising from data, index, or information collected at different time periods within a year.

11. The authors might consider using the "universally optimal" concept from statistical experimental design to determine the weighting of each component of the likelihood. Universally optimal means the variance covariance matrix of the model is close to a completely symmetric matrix.

12. The author might consider plotting the annual estimate of population size that is over the largest size class stated in the model.

Response:

1. – 4.The author has attempted to address these points by way of additional explanation in Appendix A describing model details.

5. A range of alternative weighting schemes for the two survey indices is presented in this report. Determining an appropriate choice is difficult. A concern in this context is that the assessment

data from the two surveys come from different areas and thus contribute potentially conflicting information about population status and trend. In each of the last three years, for example, a large number of all SMBKC crab captured in the trawl survey came from a single station north of St. Matthew Island (R29) that lies outside of the region used for the pot-survey assessment data.

6. This report includes the recommended strategies for dealing with the putative implausibility of the high model estimate of stage-2 trawl-survey selectivity.

7. The author has presented an expanded range of model scenarios together with additional results and diagnostics for comparison.

8. As this is the first use of the new model in the assessment process, the author has here completed only the Tier 4 approach to determining reference points. A Tier 3 analysis, which is more intimately linked to model structure and behavior, remains an option for future assessments once the author and CPT have become more familiar with model behavior.

9. Under all model configurations presented in this report, natural mortality (or its time geometric mean) is assumed equal to 0.18 yr^{-1} across all stages and all years, except in 1998/99, for which year it is model estimated to account for an apparent anomalous decline in stock abundance. Given current model structure, however, a global value of natural mortality cannot be meaningfully estimated. Moreover, estimation of separate stage-specific natural mortalities would require extensive revision of the existing code, aside from any necessary structural changes. For these reasons, the author requests further explanation and guidance before attempting to implement this recommendation.

10. Though a potentially worthwhile undertaking, adjusting the various assessment inputs for possible discrepancies in timing represents a significant bookkeeping exercise that was infeasible preliminary to this assessment.

11. Determining an appropriate objective function weighting scheme is both fundamentally important and notoriously difficult, and the author welcomes further guidance on the issue. With regard to the intriguing concept of universal optimality, some additional explanation or relevant references would be helpful.

12. It is unclear to the author what quantity is being referred to with this recommendation inasmuch as the largest size class comprises **all** male crab measuring at least 120 mm CL. Some indication as to the motivation behind this recommendation might help clarify what is intended.

C. Introduction

Scientific Name

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

Distribution

Blue king crab are sporadically distributed throughout the North Pacific Ocean from Hokkaido, Japan, to southeastern Alaska (Figure 1). In the eastern Bering Sea small populations are distributed around St. Matthew Island, the Pribilof Islands, St. Lawrence Island, and Nunivak Island. Isolated populations also exist in some other cold water areas of the Gulf of Alaska (NPFMC 1998). The St. Matthew Island Section for blue king crab is within Area Q2 (Figure 2), which is the Northern District of the Bering Sea king crab registration area and includes the waters north of 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 (NOAA grant Bering Sea Crab Research II, NA16FN2621, 1997). 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 BSAI 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 and seasonally migrate inshore, where they molt and mate. Unlike red king crab, juvenile blue king crab do not form pods but instead rely on cryptic coloration for protection from predators and require suitable habitat such as cobble and shell hash. Size at 50% maturity has been estimated at 77 mm carapace length (CL) for SMBKC males and 81 mm CL for females. Otto and Cummiskey (1990) report an average growth increment of 14 mm CL for adult males.

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, often last 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 November of 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), which was adopted by the Alaska Board of Fish (BOF) in March 2000 and modified in 2009, area closures, and gear modifications. In addition, commercial crab fisheries near St. Matthew Island were scheduled in the fall and early winter to reduce the potential for bycatch mortality of vulnerable molting and mating crab.

NMFS declared the stock rebuilt on Sept 21, 2009, and the fishery was reopened after a 10-year closure on Oct 15, 2009 with a TAC (total allowable catch) of 1.167 million pounds, closing again by regulation on Feb 1, 2010. Seven participating vessels landed a catch of 460,859 pounds with a reported effort of 10,697 pot lifts and an estimated CPUE of 9.9 retained crab per pot lift. The TAC was increased to 1.600 million pounds in 2010/11 and to 2.539 million pounds in 2011/12, with similarly low CPUEs and reported catches again falling short at 1.264 million pounds (79% of the TAC) and 1.881 million pounds (74% of the TAC), respectively.

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). Pot-lift sampling by ADF&G crab observers indicates similar bycatch rates of discarded male crab since the reopening of the fishery (Table 3), with total male discard mortality in the 2011/12 directed fishery estimated at about 10% (0.179 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 Gaeuman 2011), which may be attributable to the later timing of the contemporary fishery (D. Pengilly, ADF&G, Kodiak, pers. comm.). Some bycatch of discarded blue king crab has also been historically observed in the eastern Bering Sea snow crab fishery, but ADF&G crab observers recorded just 3 blue king crab in a combined 6,023 sampled pot lifts during the 2009/10 - 2011/12 Bering Sea snow crab fisheries (ADF&G Crab Observer Database). 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).

D. Data

Summary of New Information

Data used in this assessment have been updated to include the most recent fishery and survey numbers.

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, 2011/12; Table 1); the annual NMFS eastern Bering Sea trawl survey (1978-2012; Table 2); the triennial ADF&G SMBKC pot survey (every third year 1995-2010; Table 3); ADF&G crab-observer pot-lift sampling (1990/91-1998/99, 2009/10-2011/12; Table 4); and NMFS groundfish-observer bycatch biomass data (1992/93-2010/12; 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 Chilton et al 2011; see Gish et al (2012) for a description of ADF&G SMBKC pot-survey methods. It is especially to 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, e.g. Figure 4. Crab-observer sampling protocols are detailed in the crab-observer training manual (ADF&G 2011). Groundfish SMBKC bycatch data come from NMFS Bering Sea reporting areas 521 and 524 (Figure 5).

Other Data Sources

Other relevant data sources, including assumed population and fishery parameters, are discussed in Appendix A, which gives a detailed description of the assessment model.

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. These data tend to be severely limited: for example, 2011/12 data are based on a total of 5 male blue king crab. The timing of these data, and presumably also of the groundfish bycatch biomass data, is also problematic, with 2 of the 5 2011/12 recorded crab captured in June 2011 prior to the nominal July 1 start of the crab year.

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 ≥ 120 mm CL and newshell ≥ 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 (Z. Zheng, ADF&G, pers. comm.).

Concerns about the 2010 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 (NPFMC March 2011, CPT May 2011, SSC June 2011). The author proposed an alternative 3-stage model to the CPT in May 2011but 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 is similar in complexity to that described by Collie and Kruse (2005) and a variant of the previous four-stage SMBKC CSA model (2010 SAFE). 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 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 from the author upon request.

Model Selection and Evaluation

Six alternative model configurations, denoted A1, A2, A3, B1, B2, and C, were examined along with the base-model configuration described in detail in Appendix A, with five of the six alternatives designed to address CPT and SSC recommendations from Spring 2011. By comparison with the alternatives, the base-model configuration is characterized by 1) trawl and pot-survey abundance index component weights both equal to unity; 2) separate estimated parameters for stage-1 and stage-2 trawl-survey selectivity, with stage-3 selectivity equal to survey catchability assumed equal to unity; and 3) natural mortality model estimated in 1998/99 and otherwise fixed at 0.18 yr^{-1}. Model configurations A1, A2, and A3 reflect different weighting schemes for the trawl and pot-survey abundance index components, with the added difference that configuration A2 makes no use of the pot-survey data whatsoever: both pot-survey abundance index and pot-survey composition data components are assigned weights of zero. Model configurations B1 and B2 differ from the base model and from each other in how trawl-survey stage selectivities are parametrized. Configuration C modifies the base model to allow natural mortality M to vary by year according to $\log(M_t) = \log(0.18yr^{-1}) + \eta_t$, with the η_t subject to a moderate quadratic penalty $5.0\frac{\sum \eta_t{}^2}{2}$ and the requirement $\sum \eta_t = 0$. The following table summarizes all seven model configurations:

	abundance index component objective function weight		trawl-survey selectivity parametrization			
model	trawl-survey	pot-survey	stage 1	stage 2	stage 3	natural mortality[a]
base	1.0	1.0	s1	s2	Q = 1	0.18 yr^{-1}
A1	1.0	0.5	s1	s2	Q = 1	0.18 yr^{-1}
A2	1.0	0[b]	s1	s2	Q = 1	0.18 yr^{-1}
A3	0.5	1.0	s1	s2	Q = 1	0.18 yr^{-1}
B1	1.0	1.0	s1	s2	s2	0.18 yr^{-1}
B2	1.0	1.0	s1	Q = 1	s2	0.18 yr^{-1}
C	1.0	1.0	s1	s2	Q = 1	random, with geometric mean 0.18 yr^{-1}

[a] Except for model C, M is estimated in 1998/99 and otherwise fixed at the assumed value.

[b] Model A2 excludes **all** pot-survey data, i.e. index and composition data component weights are both set to zero.

Also considered was a variant of the base model in which natural mortality was fixed at 0.18 yr^{-1} in 1998/99, as well as all other years, rather than model estimated. Estimation of 1998/99 natural mortality proved a useful strategy with respect to the previous SMBKC stock assessment model (2010 SAFE), with Zheng and Kruse (2002) having provided a biological motivation. In the present context, estimation of the one additional parameter reduces the minimized value of the model objective function by 21 from 3,591 to 3,570, providing good justification at least in terms of conventional likelihood theory for continuing to prefer the more complex model and thus including the additional structure as part of the base-model configuration. The simpler model was not considered further.

Figures 6 – 17 and Table 6 facilitate basic comparison of the different model configurations examined for this assessment. Figures 6 and 7 show model fits to trawl and pot-survey abundance indices, and Figures 8 and 9 display model estimates of mature male biomass at time of mating. Note that each figure includes base-model results against which to compare results for alternative model configurations. Particularly striking in these figures are the high estimates of mature male biomass associated with model B2 over the entire assessment time frame. These high estimates result in a correspondingly high B_{MSY} and are themselves primarily the result of a pathologically low estimate of trawl-survey stage-3 selectivity (Table 6). Table 6 makes clear that estimation of trawl-survey selectivity parameters is generally problematic for the model; only configuration B1 leads to what might immediately be considered plausible values, though it is unclear that it should for that reason be preferred to some of the other model configurations. As Figures 10 – 16 indicate, model fit to trawl-survey composition data is likewise problematic, particularly over the last part of the time series. Other than B2, which is suspect for other reasons, model configuration C is perhaps the most satisfactory in this regard, but associated estimates of key management quantities are notably low by comparison with those of the other model configurations (Table 6), and overfitting bias may be a concern with allowing natural mortality to vary randomly with year. The pattern of deviations from the assumed geometric mean value 0.18 yr^{-1}, shown in Figure 17, is in any case consistent with the the hypothesis of high 1998/99 natural mortality and otherwise remarkably uniform except for a few years at the end of the time series. Figure 17 also displays model recruitment (stage-1 abundance) under the different configurations. In spite of some stability in the overall pattern, there is appreciable variation in magnitude, which could have important implications for a Tier 3 analysis.

Results

Additional results are here presented for the base-model configuration, which is described in detail in Appendix A. Table 7 lists AD Model Builder estimates and standard errors of model-estimated parameters, with main correlation structure shown in Table 8. The high estimate of trawl-survey stage-2 selectivity (1.37) is a concern and was previously identified by the CPT and SSC as a troubling feature of the model in their critique of the Spring 2012 implementation, which yielded an estimate of 1.24.

Base-model fits to trawl and pot-survey abundance index data are displayed in Figure 6, as well as Figure 7, in comparison to other model configurations. Figures 10, 18, an 19 display standardized residuals of base-model fits to trawl-survey, pot-survey, and pot-fishery composition data, respectively. Whereas actual samples sizes (number of measured crab) range between 38 and 385 for the trawl-survey (Table 2) and are generally several thousand for both the pot-fishery (Table 3) and pot-survey (Table 4), model effective sample sizes are set at 100 for the pot-fishery and pot-survey and are typically equal to, and never exceed, 50 for the trawl-survey. (See Appendix A for further details.) Despite a great deal of experimentation in the choice of model effective samples sizes, a satisfactory fit to the trawl-survey composition data in particular proved elusive under the base-model configuration. Methods such as iterative reweighting using estimated effective sample size were not attempted; however, estimated effective samples sizes were computed and are plotted against survey year for the trawl-survey (Figure 20). A plot of these values against model effective sample size, all but four of which are equal to 50, is less than enlightening and was omitted. Estimated effective sample sizes ranged from 62.3 to 3,937.9 for the pot-survey composition data (6 years) and from 29.8 to 285.6 for the pot-fishery composition data (12 years).

Historical model recruitment under the base-model configuration is included in Figure 17, and Figure 21 depicts the time series of retained catch and model discard mortality biomass. A retrospective plot of base-model mature male biomass at time of mating (Figure 22) appears to show clear evidence of the influence of data from the triennial pot-survey. This effect is particularly noticeable for the high biomass estimates of the early 80s, with the different trajectories obviously arranged in four ordered bundles associated with the 2001, 2004, 2007, and 2010 pot-surveys. Interestingly, the ordering of the bundles and of the trajectories within them mostly reverses itself after the large overall decline from 1998 to 1999, so that trajectories with the latest terminal years and the most dependence on pot-survey data tend to be associated with the highest estimates of biomass before the decline but the lowest following it.

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 (2011 SAFE), and only a Tier 4 analysis is presented here, with development of a Tier 3 approach deferred until the behavior of the new assessment model is better understood. 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}. 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 [3], [4], and [5] 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. This approach is consistent with that used under the previous model-based SMBKC stock assessment methodology (e.g. 2010 SAFE).

The currently recommended Tier 4 convention is to use the full assessment period 1978 – 2011 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 base-model configuration the B_{MSY} proxy is 7.93 million pounds and case a) of the control rule obtains, resulting in a Tier 4 2012/13 total male catch OFL of 2.24 million pounds with $F_{OFL} = F_{MSY} = 0.18$ yr^{-1}. The retained catch component of the OFL is 2.14 million pounds. Complete partitioning of the OFL under the base-model configuration is given in Table 9.

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 $\lambda = \exp\left(0.00359\Phi^{-1}(0.49)\right) \cong 1$ and a maximum ABC of $\lambda \times ofl$ = 1 × 2.24 = 2.24 million pounds. To account for additional sources of uncertainly and in keeping with past CPT and SSC guidance, the author recommends that the ABC be set at no more than 90% of the maximum value. In this instance, the use of an additional 10% buffer leads to a provisional author-recommended ABC of 2.02 million pounds.

H. Rebuilding Analysis

This stock is not currently subject to a rebuilding plan.

I. Data Gaps and Research Priorities

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

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Table 1. The 1978/79 – 2011/12 directed St. Matthew Island blue king crab pot fishery. Source: Bowers et al. 2011; ADF&G Dutch Harbor staff, pers. comm.; ADF&G Crab Observer Database.

			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

[a] Guideline Harvest Level/Total Allowable Catch in millions of pounds.

[b] Includes deadloss.

[c] Harvest number/pot lifts.

[d] Harvest weight/harvest number, in pounds.

[e] Average Carapace Length 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	2.384	2.268	1.764	6.416	0.46	11.876	0.39	163
1979	2.939	2.225	2.223	7.388	0.44	12.864	0.39	187
1980	2.539	2.456	2.867	7.861	0.57	16.724	0.47	188
1981	0.477	1.233	2.346	4.055	0.36	12.833	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	0.34	17.921	0.28	231
1984	0.410	0.499	1.478	2.387	0.24	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	0.44	2.578	0.39	46
1987	0.325	0.631	0.715	1.671	0.32	4.060	0.29	71
1988	0.410	0.816	0.957	2.183	0.30	5.693	0.24	81
1989	2.164	1.158	1.792	5.115	0.37	9.675	0.25	211
1990	1.053	1.031	2.338	4.422	0.32	11.955	0.26	170
1991	1.135	1.680	2.236	5.052	0.36	12.255	0.25	198
1992	1.074	1.382	2.291	4.746	0.33	12.649	0.20	220
1993	1.521	1.828	3.276	6.626	0.26	16.959	0.16	324
1994	0.883	1.298	2.257	4.438	0.18	11.696	0.18	211
1995	1.025	1.188	1.741	3.953	0.19	9.843	0.17	178
1996	1.238	1.891	3.064	6.193	0.25	17.112	0.24	285
1997	1.165	2.228	3.789	7.182	0.35	20.143	0.33	296
1998	0.660	1.661	2.849	5.170	0.34	15.054	0.36	243
1999	0.223	0.222	0.558	1.003	0.24	2.871	0.18	52
2000	0.282	0.285	0.740	1.307	0.30	3.795	0.31	61
2001	0.419	0.502	0.938	1.859	0.28	5.064	0.26	91
2002	0.111	0.230	0.640	0.981	0.30	3.311	0.32	38
2003	0.449	0.280	0.465	1.194	0.56	2.483	0.32	65
2004	0.247	0.184	0.562	0.993	0.45	2.705	0.29	48
2005	0.319	0.310	0.501	1.130	0.41	2.812	0.36	42
2006	0.917	0.642	1.240	2.798	0.36	6.494	0.36	126
2007	2.518	2.020	1.193	5.730	0.40	9.157	0.35	250
2008	1.352	0.801	1.457	3.609	0.36	7.354	0.29	167
2009	1.573	2.161	1.410	5.144	0.27	10.189	0.26	251
2010	3.927	3.253	2.458	9.638	0.58	17.948	0.37	385
2011	1.693	3.215	3.252	8.160	0.59	21.073	0.53	315
2012	0.705	1.967	1.808	4.483	0.36	12.461	0.33	193

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
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

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

Table 5. Groundfish SMBKC male bycatch biomass (10^3 pounds) data. Source: R.Foy, NMFS.

	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	1.7	18.3	10.5
2010/11	0.1	7.5	3.8
2011/12	0.0	1.8	0.9

[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. Base and alternative model estimates of trawl-survey selectivity parameters and of key management quantities.

	trawl-survey selectivity estimates			management quantities (millions of pounds)		
model	stage 1	stage 2	stage 3	Bmsy[a]	OFL[b]	MMBmating[c]
base	0.93	1.37	Q = 1	7.93	2.24	12.41
A1	0.90	1.34	Q = 1	7.86	2.25	14.01
A2	0.84	1.27	Q = 1	7.90	3.36	18.60
A3	1.01	1.48	Q = 1	8.72	2.10	11.469
B1	0.72	0.87	0.87	8.81	3.18	17.79
B2	0.65	Q = 1	0.49	14.57	3.25	17.87
C	0.85	1.29	Q = 1	6.81	1.63	9.27[d]

[a] Average 1978-2011 model MMBmating.

[b] Tier 4 assuming Fmsy = 0.18 yr^{-1}.

[c] Model projected 2013 value assuming OFL catch.

[d] Assuming M = 0.18 yr^{-1} in 2013.

Table 7. Base-model parameter estimates and standard errors. Ranges are given for log recruit and log fishing mortality deviations.

parameter	estimate	standard error
1998/99 natural mortality	1.03	0.135
pot-survey proportionality constant	3.88	0.359
trawl-survey stage-1 selectivity	0.93	0.066
trawl-survey stage-2 selectivity	1.37	0.087
pot-survey stage-1 selectivity	0.36	0.059
pot-survey stage-2 selectivity	0.99	0.122
pot-fishery stage-1 selectivity	0.42	0.045
pot-fishery stage-2 selectivity	0.74	0.066
log initial stage-1 abundance	7.69	0.182
log initial stage-2 abundance	7.34	0.243
log initial stage-3 abundance	7.40	0.249
mean log recruit abundance	6.80	0.054
mean log recruit abundance deviations (34)	[-1.69, 1.12]	[0.103, 0.369]
mean log directed fishing mortality	-1.42	0.068
log directed fishing mortality deviations (24)	[-3.17, 1.39]	[0.089, 0.272]
mean log GF trawl fishing mortality	-10.92	0.237
log GF trawl fishing mortality deviations (21)	[-1.61, 1.78]	[0.698, 0.734]
mean log GF fixed-gear fishing mortality	-9.58	0.228
log GF fixed-gear fishing mortality deviations (21)	[-2.20, 2.44]	[0.689, 0.701]

Table 8. Base-model ADMB parameter correlations. Does not include those for recruit and fishing mortality deviations.

parameter	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1 1998/99 M	1													
2 PS Q	-0.26	1												
3 TS s1 selectivity	-0.34	0.22	1											
4 TS s2 selectivity	-0.29	0.21	0.46	1										
5 PS s1 selectivity	-0.14	-0.23	0.10	0.09	1									
6 PS s2 selectivity	-0.14	-0.36	0.09	0.08	0.22	1								
7 PF s1 selectivity	-0.15	-0.06	0.10	0.12	0.15	0.16	1							
8 PF s2 selectivity	-0.07	-0.13	0.05	0.05	0.11	0.14	0.51	1						
9 log initial N1	-0.05	0.02	0.09	0.10	0.02	0.02	0.05	0.05	1					
10 log initial N2	-0.05	0.03	0.17	0.04	0.02	0.02	0.04	0.04	0.09	1				
11 log initial N3	-0.13	0.09	0.29	0.32	0.05	0.04	0.07	0.05	0.00	-0.16	1			
12 mean log PF F	0.00	0.30	-0.21	-0.21	-0.10	-0.13	-0.37	-0.41	-0.21	-0.18	-0.44	1		
13 mean log recruits	0.46	-0.68	-0.43	-0.38	-0.11	-0.06	0.01	0.13	-0.12	-0.12	-0.22	-0.24	1	
14 mean log GFT F	-0.06	0.23	0.09	0.08	0.00	-0.01	-0.03	-0.05	0.01	0.01	0.03	0.12	-0.26	1
15 mean log GFF F	-0.06	0.24	0.09	0.08	0.00	-0.01	-0.03	-0.05	0.01	0.01	0.03	0.12	-0.27	0.09

Table 9. 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
2009/10	4a	0.18	1.53 (694)	NA	NA	NA	1.72 (780)
2010/11	4a	0.18	1.90 (862)	0.263 (119)	0.003 (1)	0.038 (17)	2.29 (1,040)
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[a]	4a	0.18	2.14 (971)	0.095 (43)	0.0002 (0.1)	0.0009 (0.4)	2.24 (1,020)

[a] Under Fall 2012 base-model configuration.

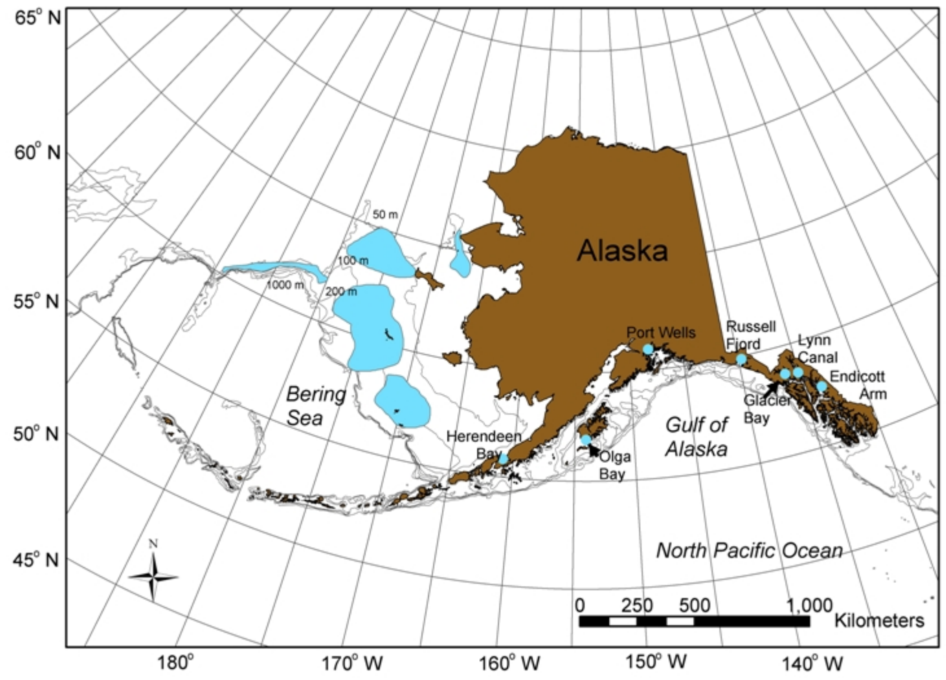

Figure 1. Distribution of blue king crab *Paralithodes platypus* in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters. Shown in blue.

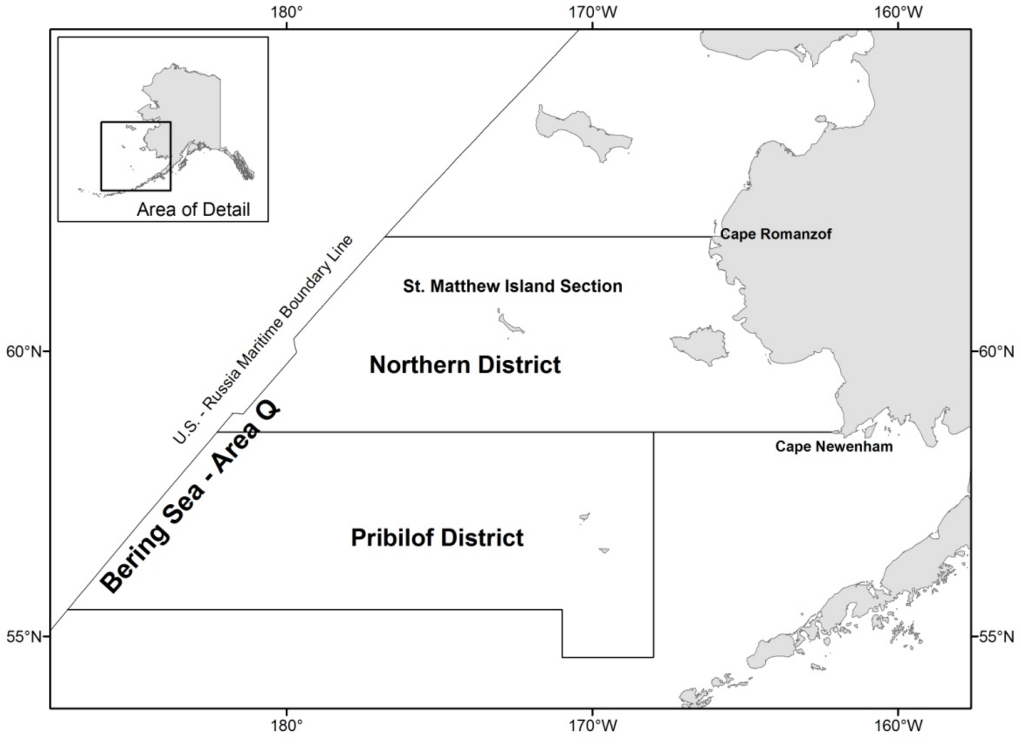

Figure 2. King crab Registration Area Q (Bering Sea).

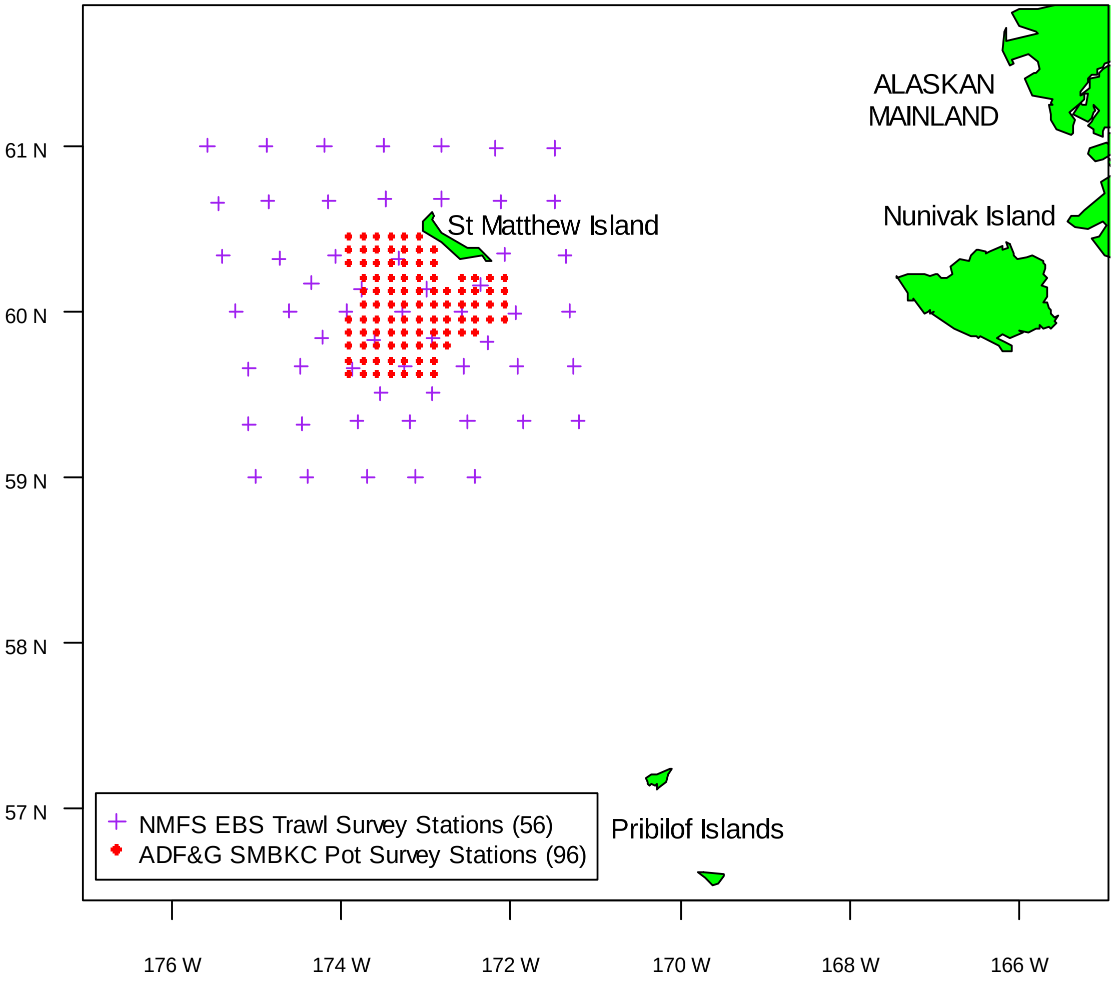

Figure 3: Trawl and pot-survey stations used in the SMBKC stock assessment.

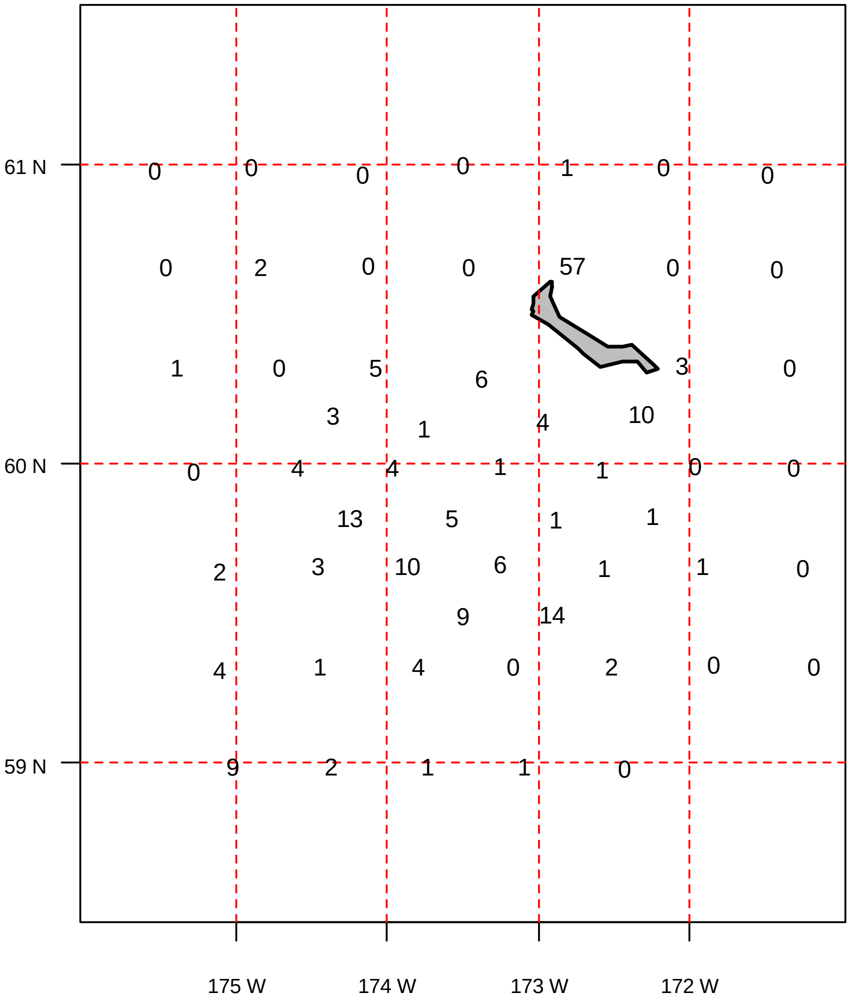

Figure 4. Catches of male blue king crab measuring at least 90 mm CL from the 2012 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock. Note that the area north of St. Matthew Island is not represented in the ADF&G pot-survey data used in the assessment.

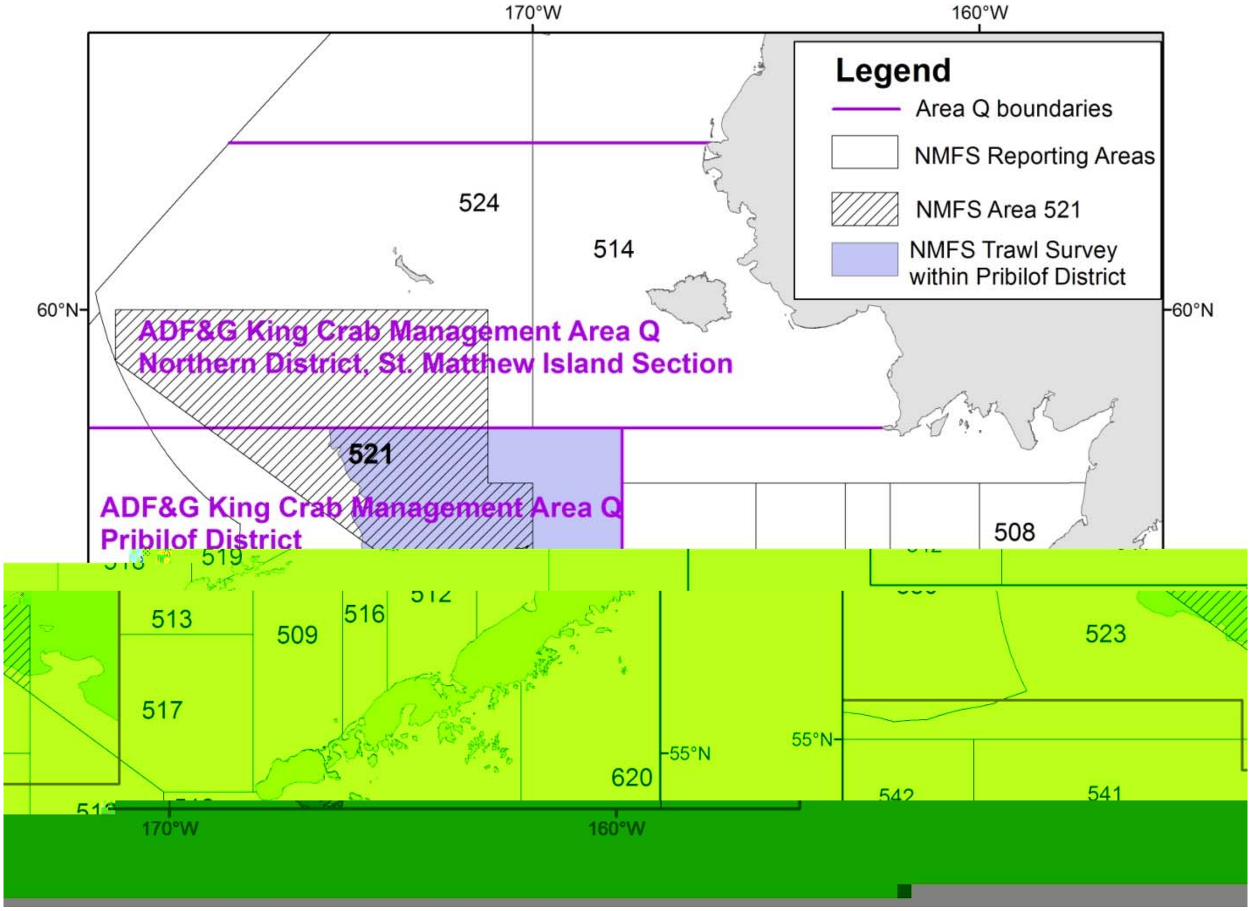

Figure 5. NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.

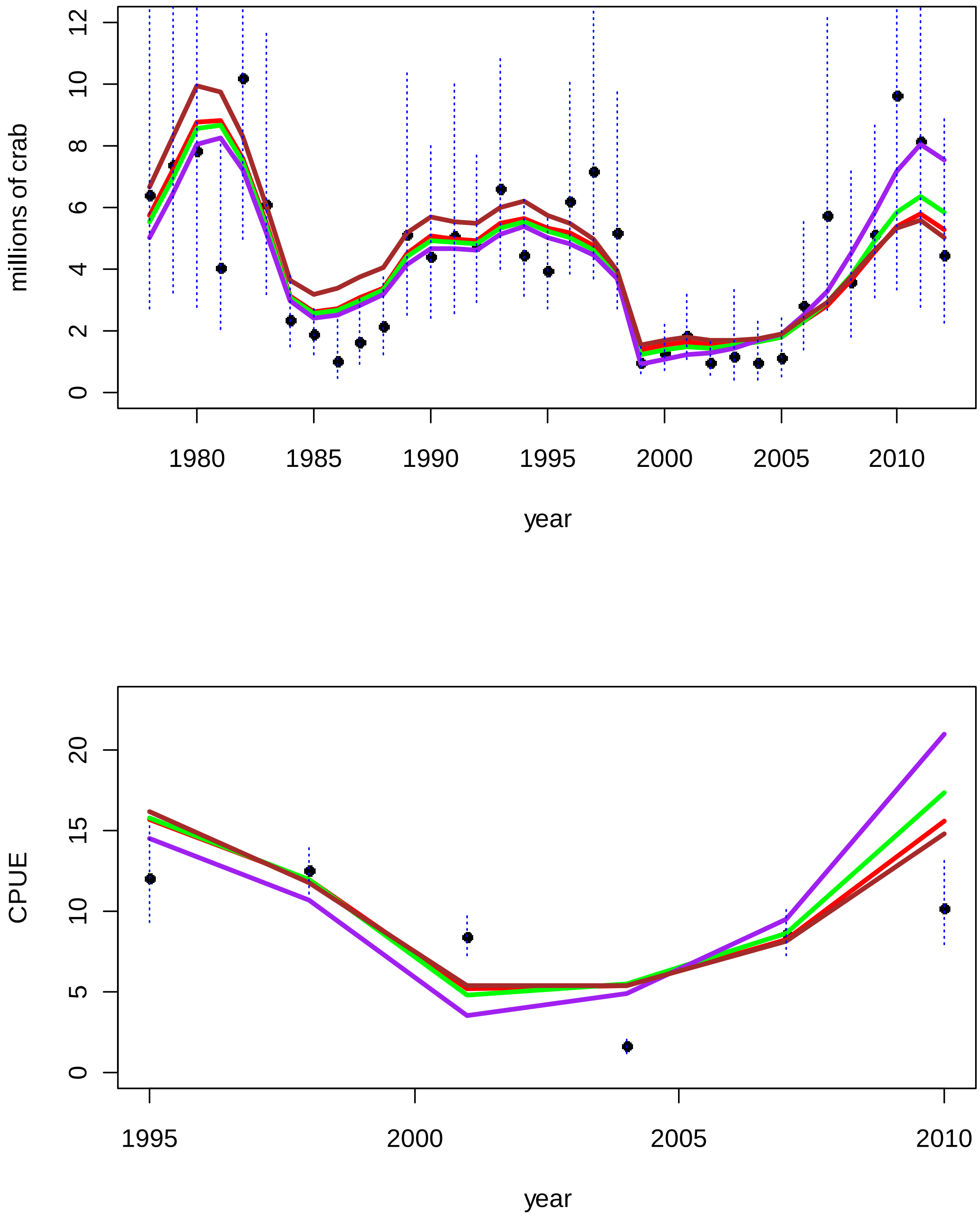

Figure 6. Model fits to trawl (top panel) and pot-survey abundance indices (points) for base model (red) and model configurations A1 (green), A2 (purple), and A3 (brown).

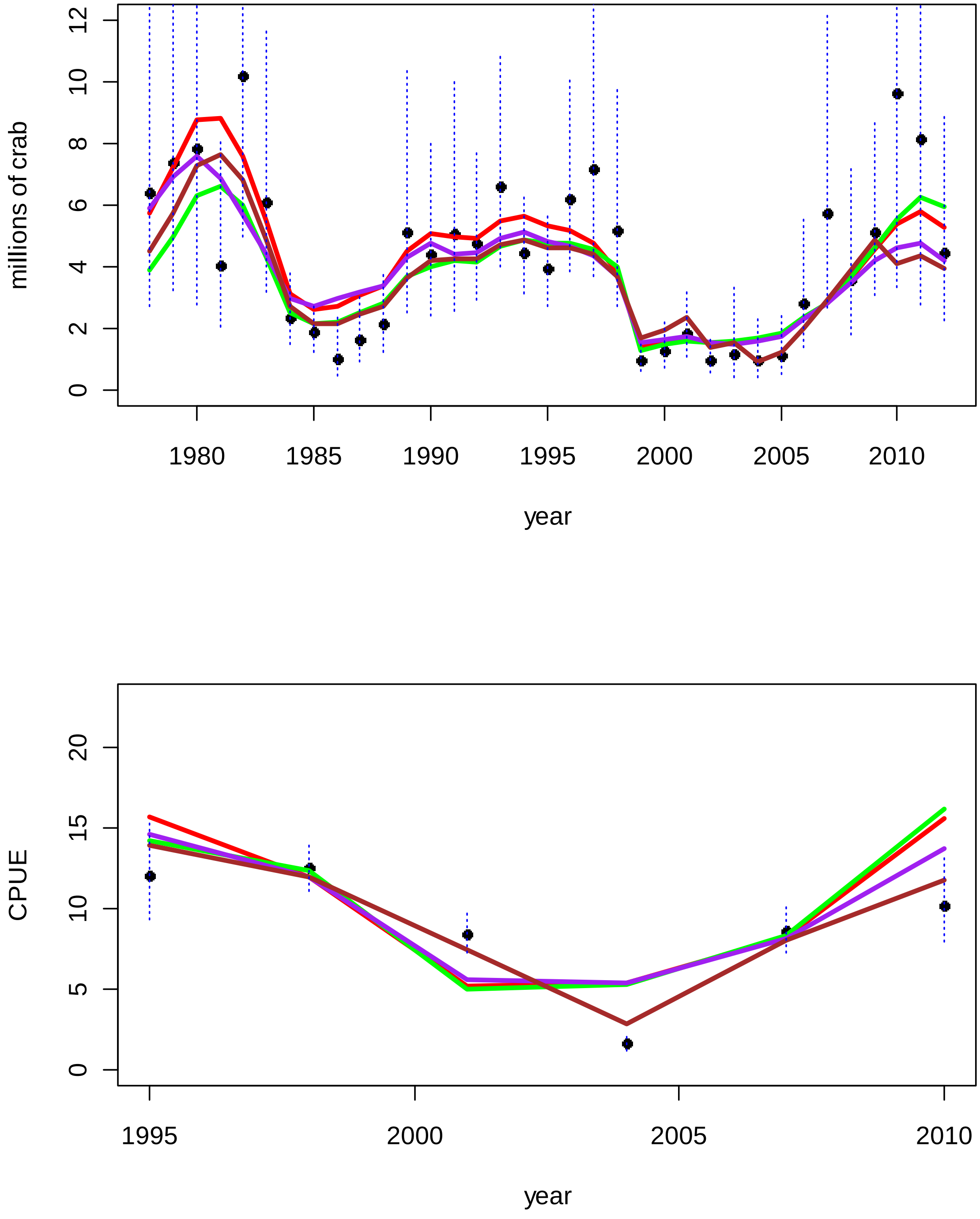

Figure 7. Model fits to trawl (top panel) and pot-survey abundance indices (points) for base model (red) and model configurations B1 (green), B2 (purple), and C (brown).

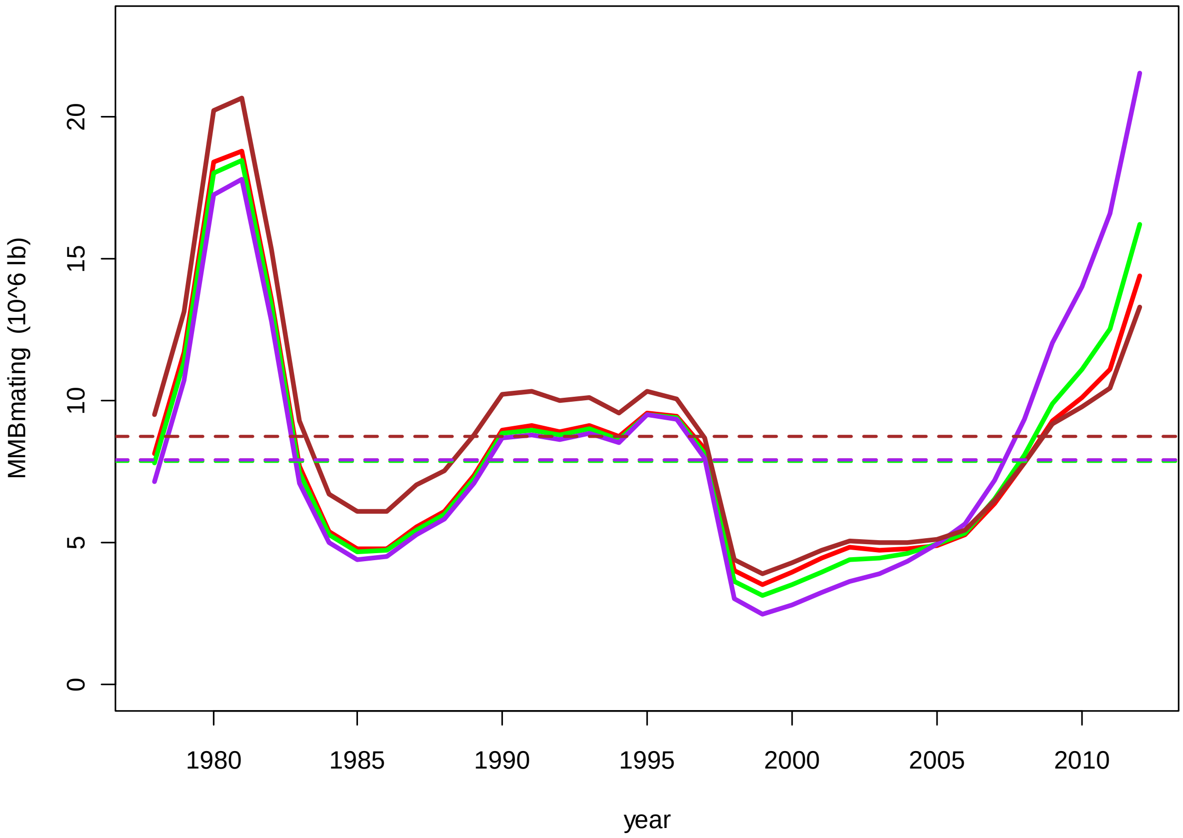

Figure 8. Model mature male biomass at time of mating for base model (red) and model configurations A1 (green), A2 (purple) and A3 (brown). Terminal 2012 estimate assumes no directed fishery. Dotted lines represent respective B_{MSY} proxy values calculated as 1978-2011 average.

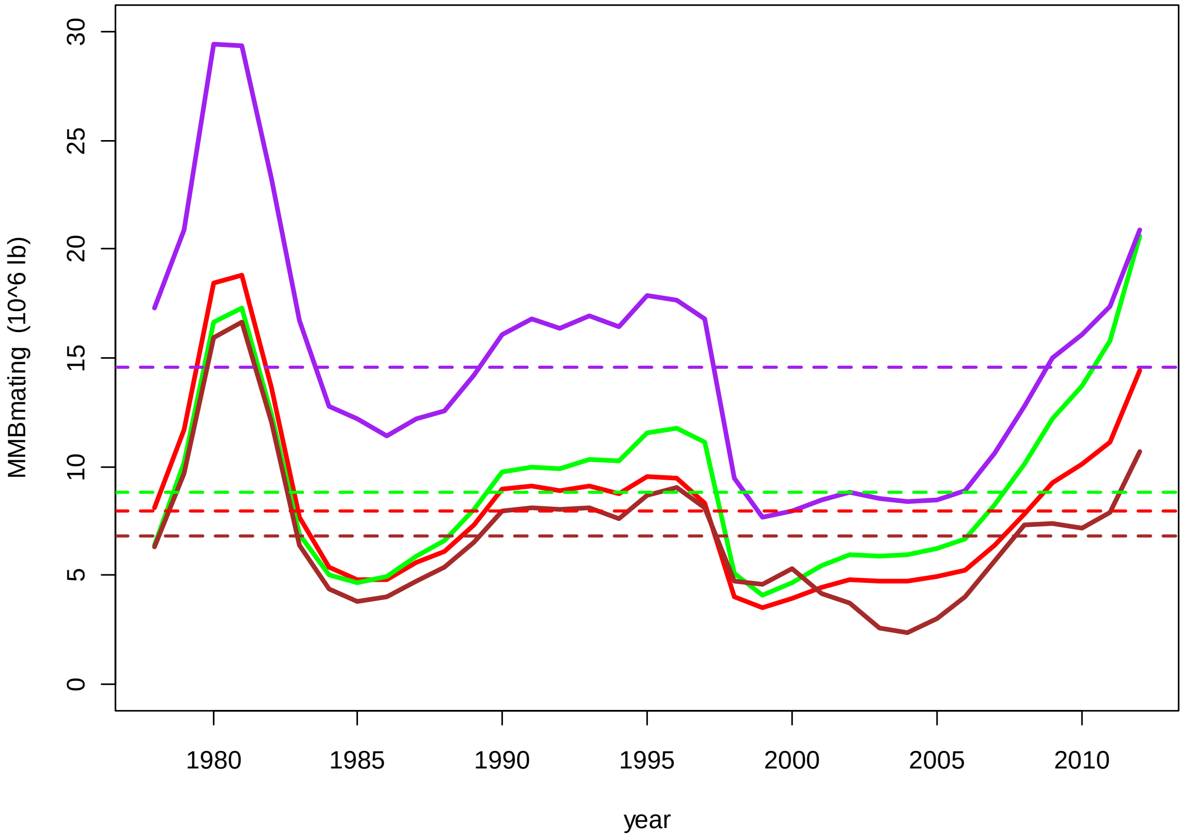

Figure 9. Model mature male biomass at time of mating for base model (red) and model configurations B1 (green), B2 (purple) and C (brown). Terminal 2012 estimate assumes no directed fishery. Dotted lines represent respective B_{MSY} proxy values calculated as 1978-2011 average.

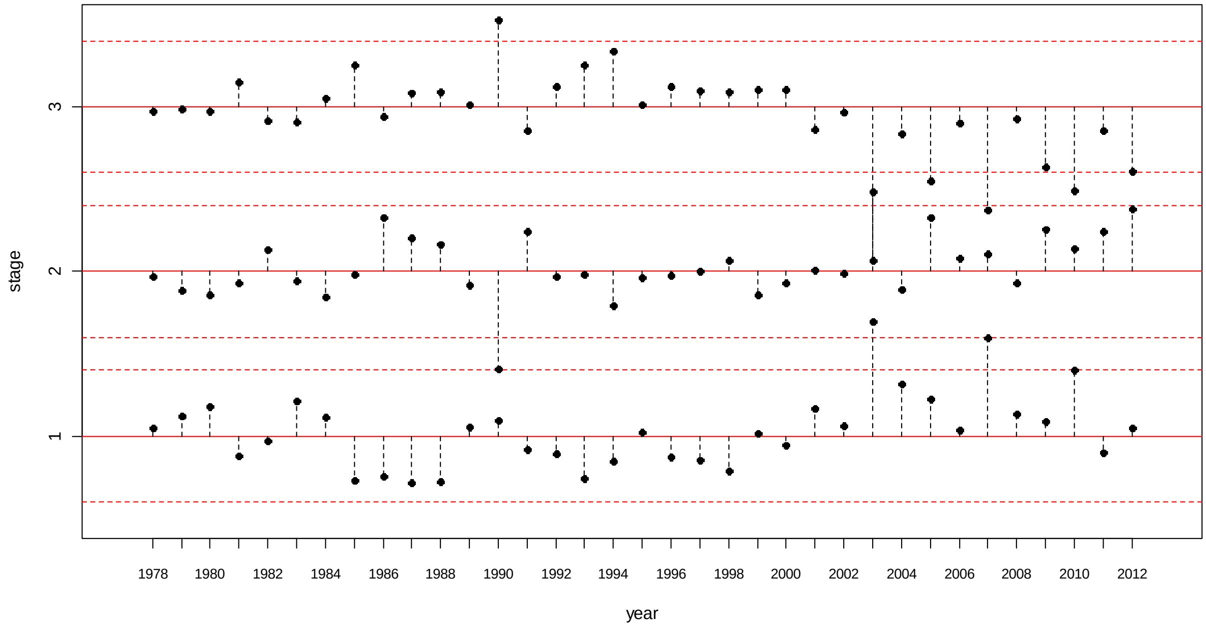

Figure 10. Base-model trawl-survey composition data standardized residuals.

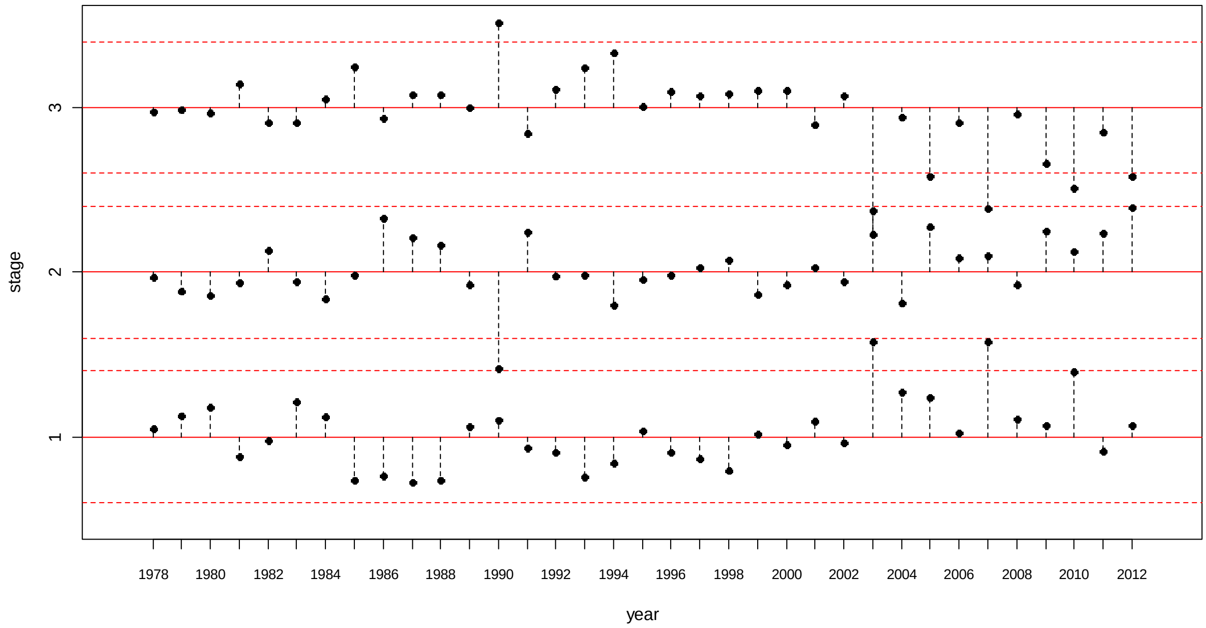

Figure 11. Model A1 trawl-survey composition data standardized residuals.

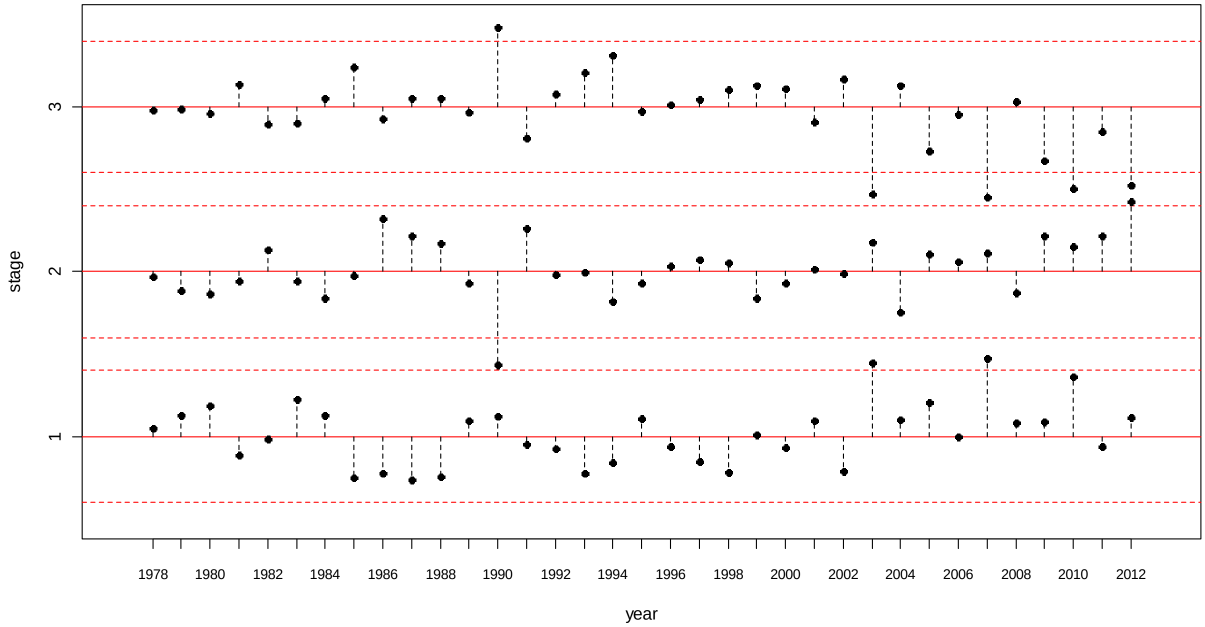

Figure 12. Model A2 trawl-survey composition data standardized residuals.

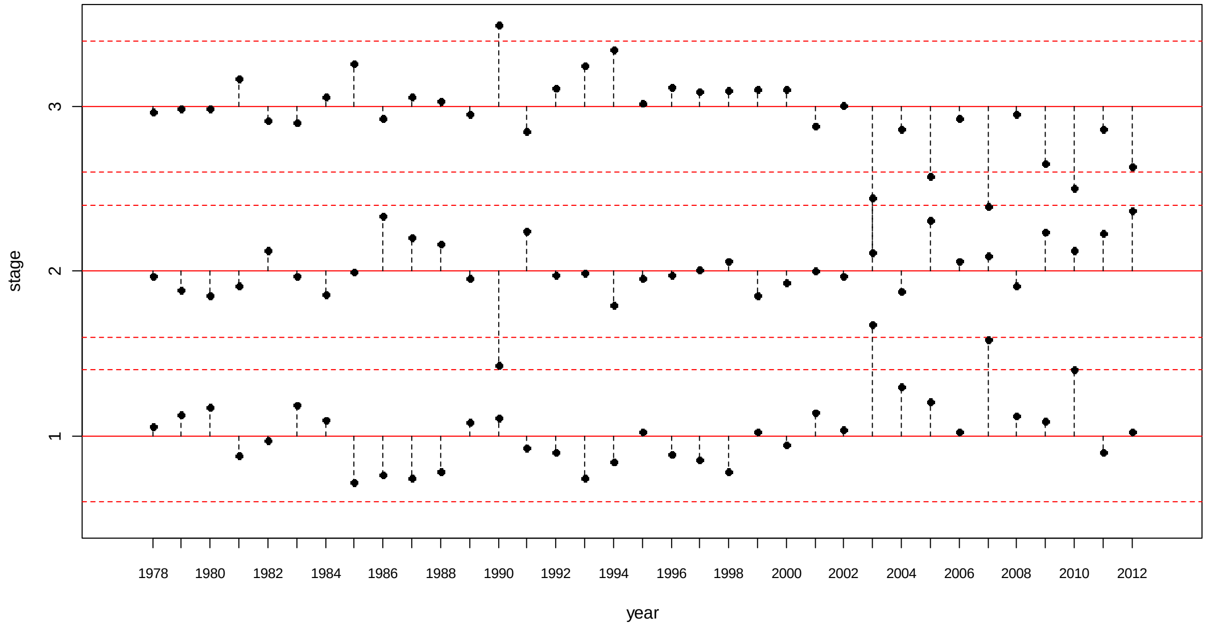

Figure 13. Model A3 trawl-survey composition data standardized residuals.

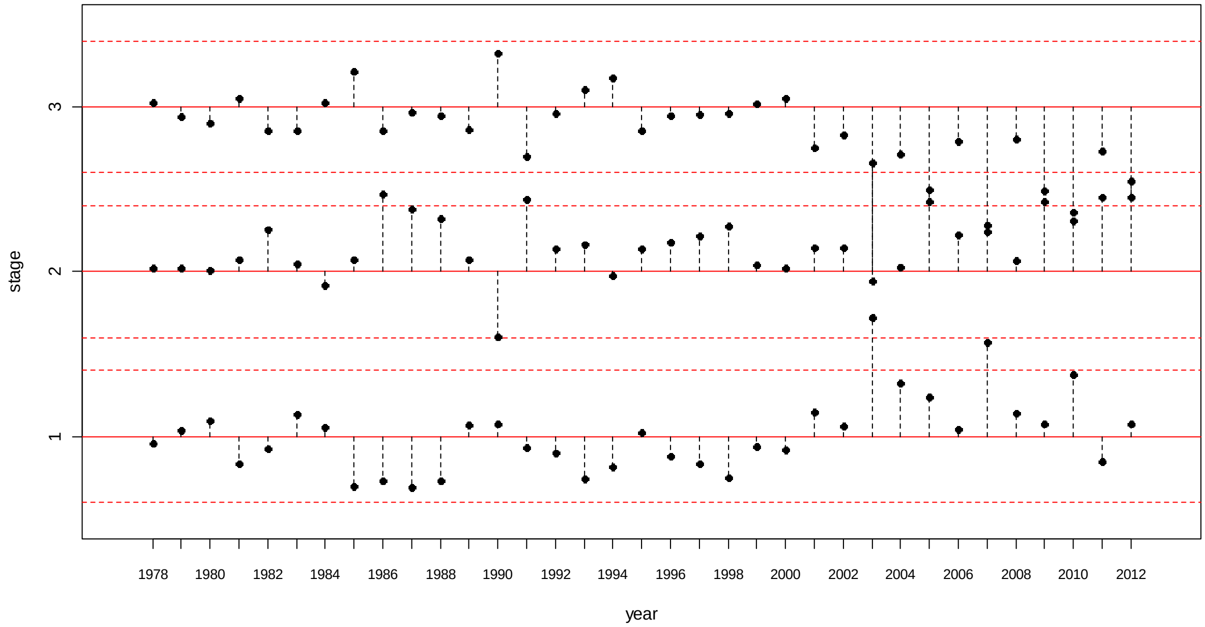

Figure 14. Model B1 trawl-survey composition data standardized residuals.

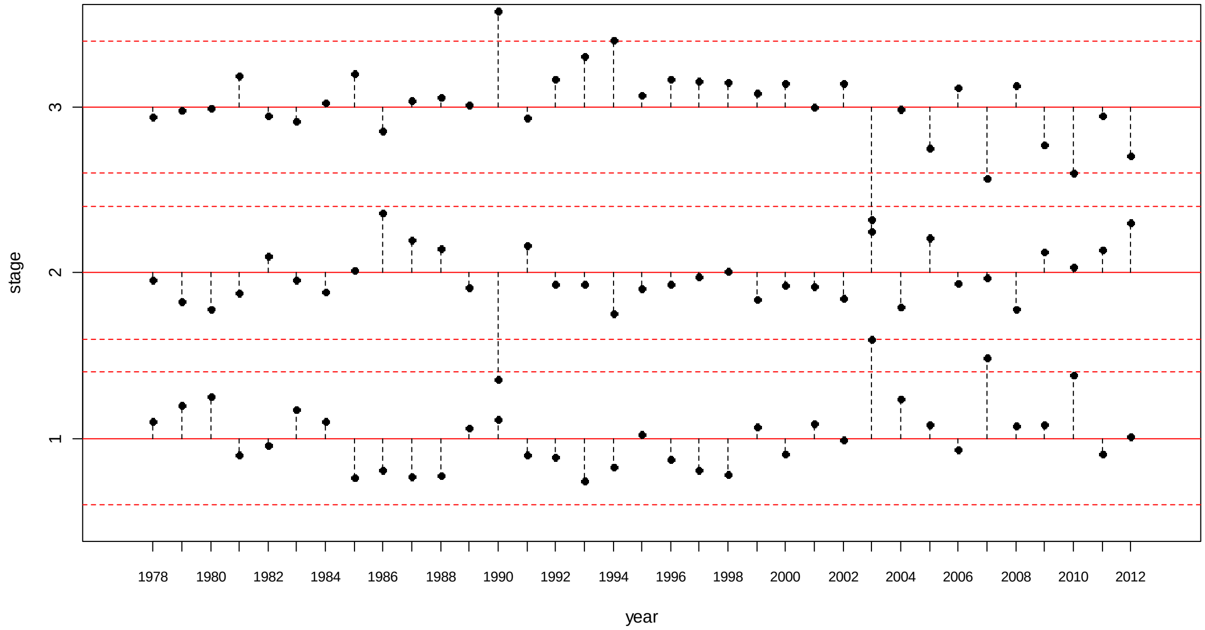

Figure 15. Model B2 trawl-survey composition data standardized residuals.

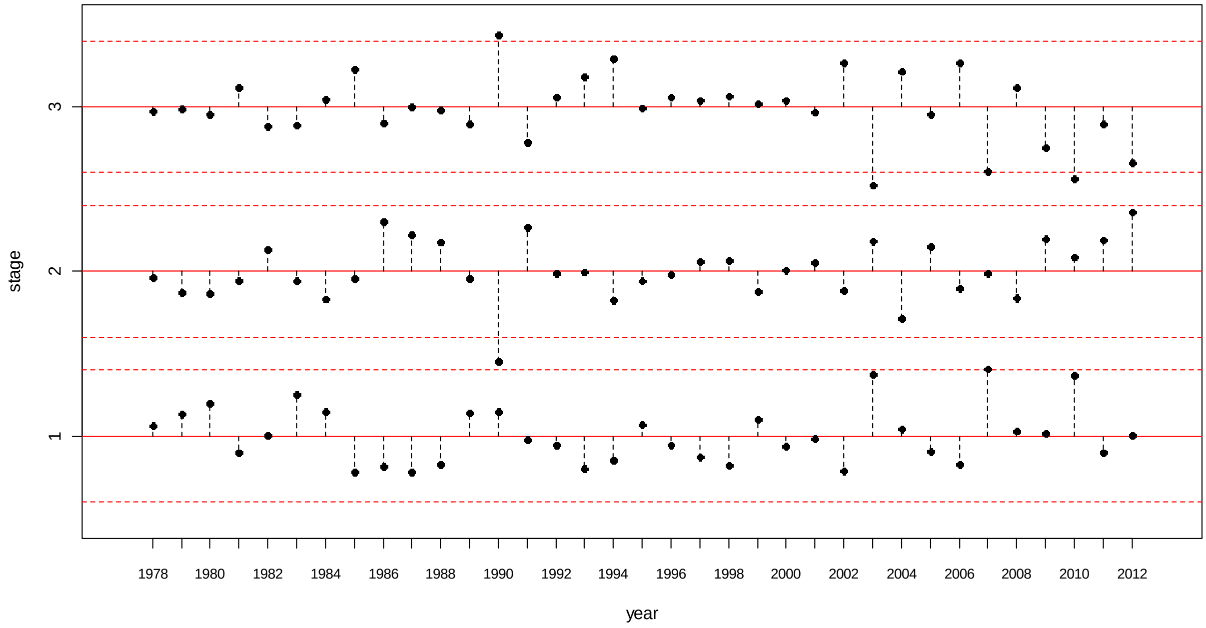

Figure 16. Model C trawl-survey composition data standardized residuals.

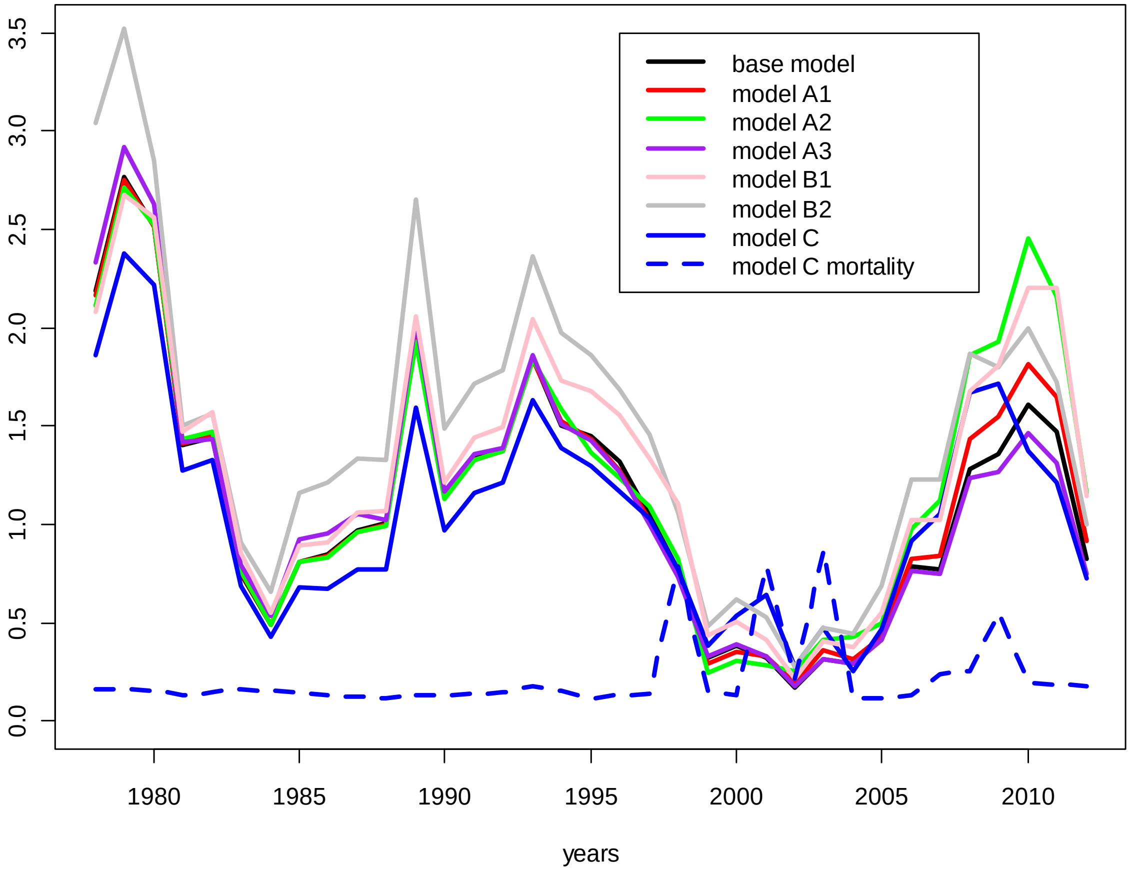

Figure 17. Model recruitment (stage-1 abundance; millions of crab) under the alternative model configurations. Random natural mortality under model configuration C is also shown.

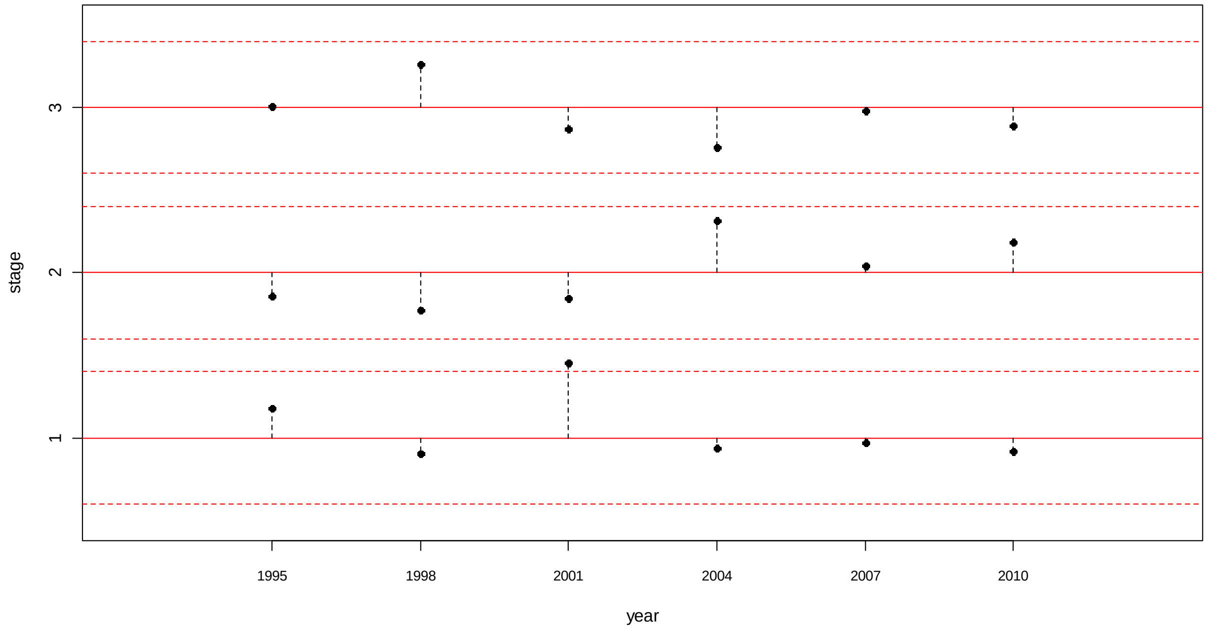

Figure 18. Base-model pot-survey composition data standardized residuals.

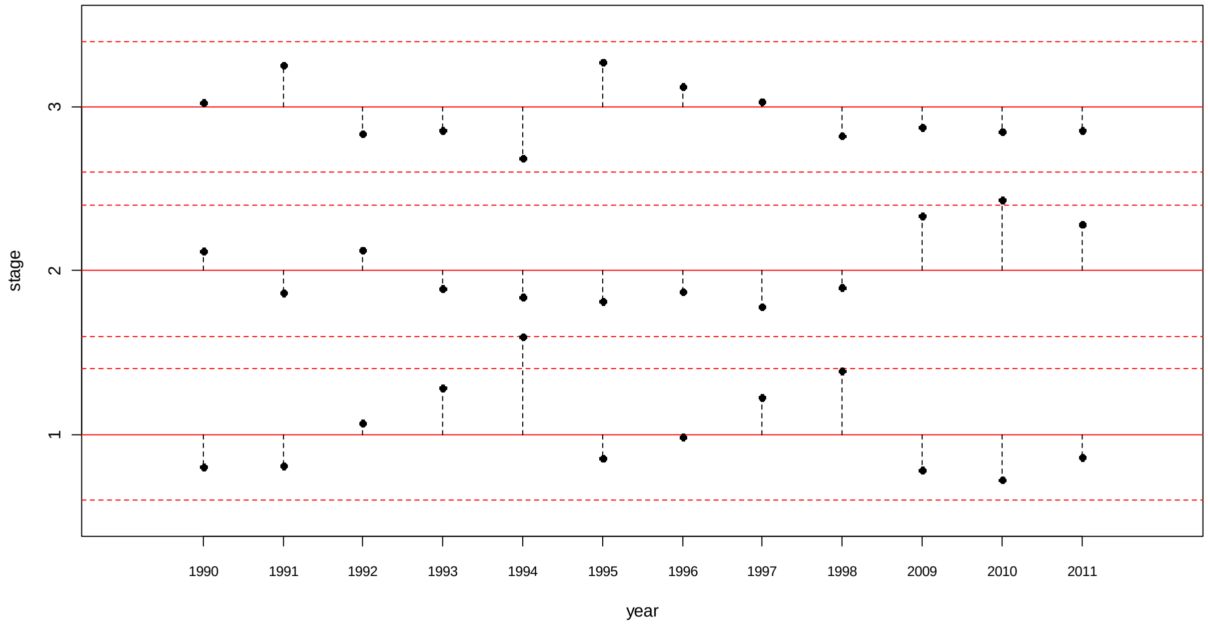

Figure 19. Base-model observer pot-fishery composition data standardized residuals.

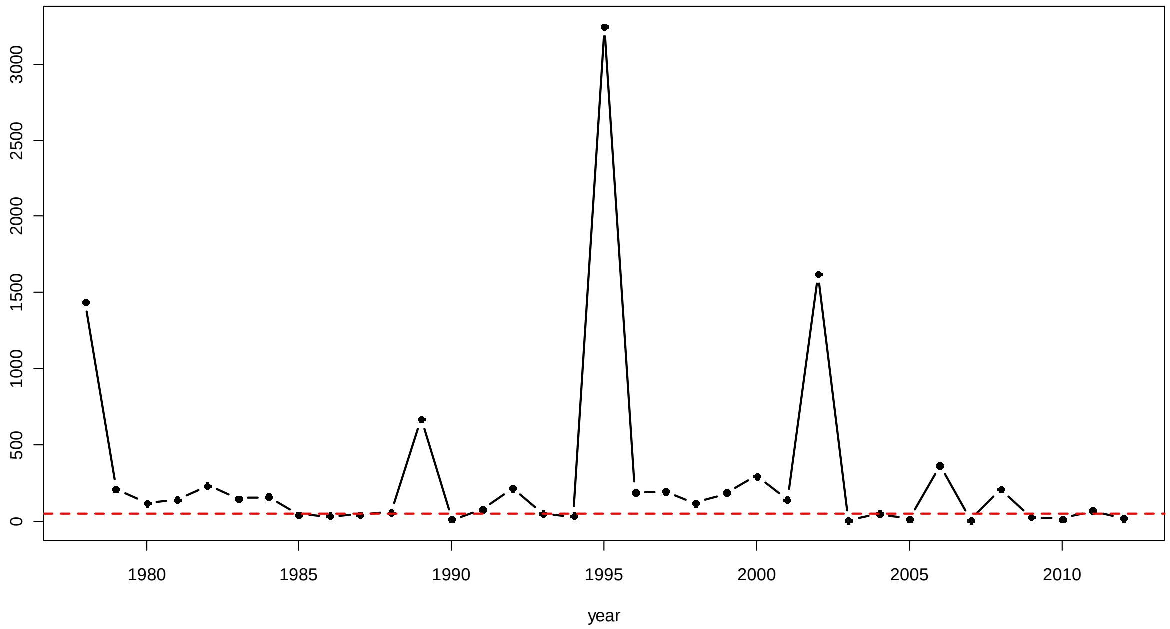

Figure 20. Estimated effective samples sizes for trawl-survey composition data. Model effective sample size is equal to the assumed maximum value 50 (dotted red line) in all but 4 years.

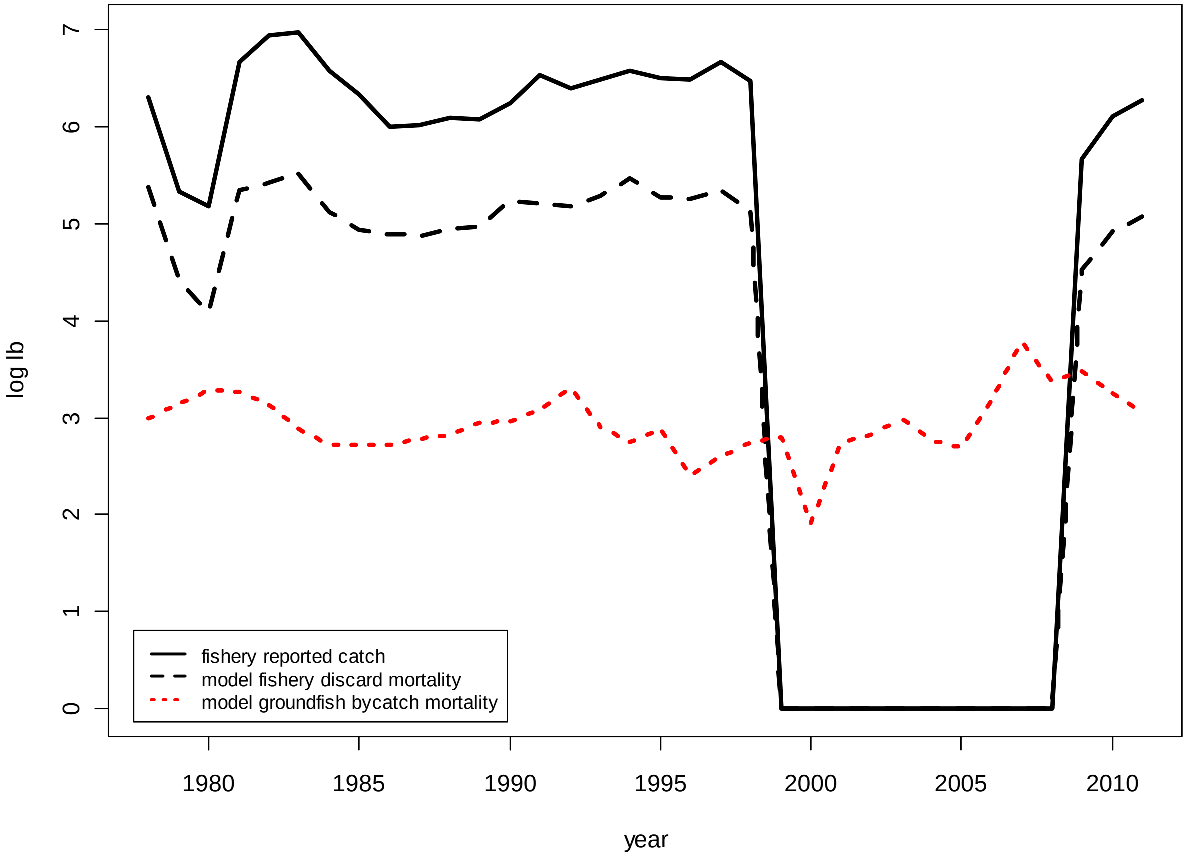

Figure 21. Components of SMBKC fishing mortality biomass for the years 1978/79 – 2011/12. Note logarithmic scale.

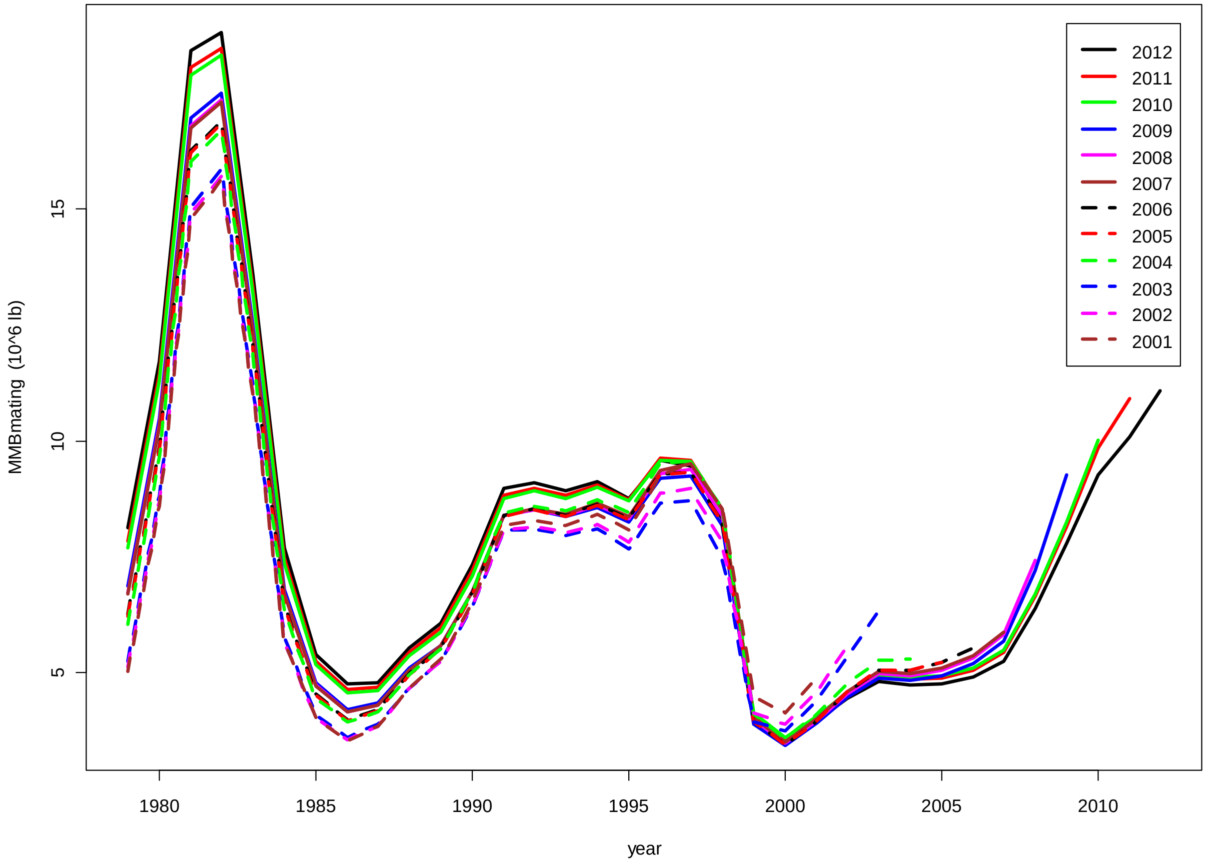

Figure 22. Retrospective plot of mature male biomass at time of mating for base-model configuration and terminal years 2001 – 2012. Estimates are for Feb 15 biomass in the indicated year based on all assessment data up to and including terminal year surveys.

Appendix A: SMBKC Stock Assessment 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. 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. Differences characterizing alternative model scenarios considered in this document are described under **Model Selection and Evaluation** of §G.

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

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

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

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

with π_{jk} equal to the proportion of stage-*j* crab that molt and grow into stage *k* from any one year to the next. The vector $\boldsymbol{N}^{new}{}_{t+1} = [\, N^{new}{}_{1,t+1}, 0, 0 \,]^{\mathrm{T}}$ registers the number $N^{new}{}_{1,t+1}$ of new crab, 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. The directed fishery is modeled as a mid-season pulse occurring at time τ_t with full-selection fishing mortality F_t^{df} relative to stage-3 crab. Year-*t* directed-fishery removals from the stock are computed as

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

where the diagonal matrices $\boldsymbol{S}^{df} = \begin{bmatrix} s_1^{df} & 0 & 0 \\ 0 & s_2^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix}$ and $\boldsymbol{H}^{df} = \begin{bmatrix} h^{df} & 0 & 0 \\ 0 & h^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix}$ account for stage selectivities s_1^{df} and s_2^{df} and discard handling mortality h^{df} in the directed fishery, both assumed 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

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

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

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

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

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

Necessary biomass computations, such as required for management purposes or for integration of groundfish bycatch biomass data into the model, are based on application of the SMBKC length-to-weight relationship of Chilton and Foy (2010) to the stage-1 and stage-2 CL interval midpoints and use fishery reported average retained weights for stage-3 ("legal") crab. 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 2009/10-2011/12	Fish tickets (fishery closed 1999/00-2008/09)
NMFS trawl-survey abundance index (area-swept estimate) and CV	1978-2012	NMFS EBS trawl survey
ADFG pot-survey abundance index (CPUE) and CV	Triennial 1995-2010	ADF&G SMBKC pot survey
NMFS trawl-survey stage proportions and total number of measured crab	1978-2011	NMFS EBS trawl survey
ADFG pot-survey stage proportions and total number of measured crab	Triennial 1995-2010	ADF&G SMBKC pot survey
Directed pot-fishery stage proportions and total number of measured crab	1990/91-1998/99 2009/10-2011/12	ADF&G crab observer program (fishery closed 1999/00-2008/09)
Groundfish trawl bycatch biomass	1992/93-2011/12	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93-2011/12	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

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

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 and pot-survey abundance indices are given by

$$A_t^{ts} = Q^{ts}\left(s_1^{ts} N_{1,t} + s_2^{ts} N_{2,t} + N_{3,t}\right) \tag*{[8]}$$

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

these being year-*t* trawl-survey area-swept abundance and year-*t* pot-survey CPUE, respectively, both with respect to 90mm+ 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

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

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

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

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

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

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. Note, in particular, that under all model configurations examined for this assessement, stage 1 to 2 and stage 2 to 3 transition probabilities are assumed equal to 1.0, consistent with Otto and Commiskey (2009).

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 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	34[a]
Mean log directed-fishery mortality	1
Log directed-fishery mortality deviations	24[a]
Mean log groundfish trawl fishery mortality	1
Log groundfish trawl fishery mortality deviations	21[a]
Mean log groundfish fixed-gear fishery mortality	1
Log groundfish fixed-gear fishery mortality deviations	21[a]
Total	115

[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	Conventional calibration strategy
Natural mortality (except 1998/99)	0.18 yr^{-1}	Zheng 2005
Stage 1 and 2 transition probabilities	1.0, 1.0	Otto and Commiskey 2009
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. Upper and lower case letters designate model predicted and data computed quantities, respectively. As above, boldface letters indicate vector quantities. Sample sizes n_t (observed number of male SMBKC ≥ 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 2 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 abundance index	Lognormal	$\lambda_2 0.5 \sum [\frac{\ln(a_t^{ts}) - \ln(A_t^{ts})}{\ln(1 + \widehat{cv_t^{ts}}^2)}]^2$
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. 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 automatic differentiation and minimization of the model objective function. Standard errors and estimated parameter correlations provided in this document are AD Model Builder reported values assuming maximum likelihood theory asymptotics.