2013 Saint Matthew Island Blue King Crab Stock Assessment

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Executive Summary

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

2. Catches: Peak historical harvest was 9.454 million pounds (4,288 t) in 1983/84. 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 2.359 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; 80% of the TAC), respectively. In 2012/13, by contrast, harvesters landed 99% of a reduced TAC of 1.630 million pounds (739.4 t), though fishery efficiency, at about 10 crab per pot, was little changed from what it had been in each of the previous three years. Total male discard mortality in the 2012/13 directed fishery is estimated from ADF&G crab-observer data at 0.193 million pounds (87.5 t), assuming 20% handling mortality. Male bycatch mortality in the 2012/13 groundfish fisheries is estimated from NMFS observer data at 0.001 million pounds (0.5 t), and an additional estimated 0.0004 million pounds (0.2 t) of male biomass was removed from the stock as bycatch in the 2012/13 Bering Sea snow crab fishery.

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 have generally increased in recent years, with 2011 estimated mature male biomass at 21.07 million pounds (9,557 t; CV 0.53), the second highest in the 36-year time series used in this assessment. However, survey estimated mature male biomass decreased 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. Although the 2013 value is still higher than the post-collapse low of 2.812 million pounds (1,275 t; CV 0.36) reported in 2005, both the low value and the apparent downward trend give reason for concern.

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 marks a three-year exponential decline and is the lowest since 2005. The 2013 estimate is based on 14 captured animals (compared to 29 in 2012) from the 56 survey stations currently used to assess the SMBKC stock.

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. In 2012/13, ADF&G crab observers in the Bering Sea snow crab fishery additionally recorded some unusual bycatch of 59 male blue king crab in 20 sample pots from ADF&G statistical areas 745830 and 745900

southwest of St. Matthew Island; however, as fishery data indicate that only around 5.7% of all pots were fished in these two statistical areas, a reasonable estimate of SMBKC male bycatch mortality in the 2012/13 Bering Sea snow crab fishery is 11,888 lb × 0.057 × 0.5 = 339 lb, assuming 50% mortality. Including this amount for modeling purposes in the estimate of groundfish bycatch mortality yields an estimated 2012/13 SMBKC total male catch of 1.616 + 0.193 + (0.0011 + 0.0004) = 1.811 million pounds (821.2 t), which is comfortably below the 2012/13 OFL of 2.24 million pounds (1,020 t) so that no declaration of overfishing is warranted. On the other hand, the low 2013 survey estimate of stock biomass, along with the declining trends in both stock biomass and (model) recruitment, raises concern that the stock may be approaching 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 Catch	OFL[a]	ABC
2009/10	3.4 (1,500)	12.76 (5,790)	1.167 (529.3)	0.461 (209)	0.53 (240)	1.72 (780)	-
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[b] (2,850)	1.630 (739.4)	1.616 (733)	1.81 (821)	2.24 (1,020)	2.02 (916)
2013/14	3.4[c] (1,500)	6.64[d] (3,010)	TBD	TBD	TBD	1.24[e] (562)	1.10[e,f] (501)

[a] Total male catch OFL.
[b] Fall 2013 base-model estimate.
[c] Fall 2013 base-model estimate using the reference period 1978/79 – 2012/13.
[d] Fall 2012 base-model projection assuming OFL catch.
[e] From Fall 2013 base model.
[f] As described in §G with P* = 0.49 and 10% buffer.

6. <u>Basis for the OFL</u>: 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, 1978/79 – 2012/13, as the default reference period. Under the author-recommended base-model configuration that procedure results in an estimated 2013/14 B_{MSY} proxy of 6.756 million pounds (3,060 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^*
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	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)	6.639[a] (3,010)	0.98	0.18yr^{-1}	1	1978/79 – 2012/13	0.18yr^{-1}	0.49

[a] Fall 2013 base-model projection assuming OFL catch.

7. <u>Distribution of the OFL</u>: 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 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
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 as an alternative to a similar 4-stage model used prior to 2011. For 2013 the author has presented four additional model configurations to go with the seven considered for 2012. In addition, biomass has replaced abundance as the trawl-survey index used in model estimation, though this change has little practical impact on model behavior.

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 2012 CPT

  Comments: *The team would strongly encourage authors to follow the TOR in so much as it is applicable to individual assessments and encourages authors to seek internal review to improve the quality of the documents. The team requests that a meeting occur between the PT chairs, Council staff, RO staff and the heads of the respective agencies to discuss the need to improve the quality of the assessment documents being reviewed by the team on an annual basis.*

  Response: Noted. The author will review the TOR and take other measures to ensure the assessment document is clear, informative, and appropriately structured.

- Fall 2012 SSC

  Comments: No new recommendations.

  Response: NA

- Spring 2013 CPT

  Comments: No new recommendations.
  Response: NA

- Spring 2013 SSC

  Comments: No new recommendations.
  Response: NA

CPT and SSC Comments Specific to SMBKC Stock Assessment

- Fall 2012 CPT

  Comments: *The assessment author was commended for the elegance and simplicity of the model and the efforts to make the model understandable without getting lost in the details. The CPT discussed diagnostic tools and how one size doesn't fit all, noting that the utility of a particular diagnostic will vary among assessments. It may be useful to add something similar to Table 6 with residual values and number of estimated parameters to indicate how much of the residual variance is explained by different alternatives. The serial autocorrelation in the residual patterns from the all model scenarios indicate something happened about 10 years ago, and the CPT suggested looking at retrospective estimates of Q for stage 2 crab in May 2013. For May 2013 the CPT also requests that the author explore a model alternative that merges characteristics of models B and C, perhaps allowing flexibility in M while bounding Q.*

  One potential contributor to misspecification is the growth transition matrix, and the CPT suggested exploring whether additional information could be used to inform this matrix. The current matrix allows crabs from stage 1 to grow to stage 2 and then to stage 3 (all with a probability of 1 each year) but does not allow crab to grow from stage 1 to stage 3. The author is also encouraged to evaluate the use of biomass instead of abundance as the way to summarize the survey data.

Response: The author has included additional information along the lines of that suggested regarding last year's Table 6 (Table 8 in this document) for use in model selection. As Q (trawl-survey catchability) is fixed at 1 rather than model estimated, no retrospective estimates of this quantity are available. However, 2013 base-model retrospective estimates of stage-1 and stage-2 selectivity parameters are shown in Figure 21 of this document, and retrospective estimates of other model parameters are readily available. For this assessment, the author has presented two models additional model configurations, B1:C and B2:C, that merge models B1 and B2 with model C. Models T and TC presented in this document make use of an alternative presumably more biologically plausible transition matrix motivated by the author's review of Otto and Cummisky's (1990) work on Pribilof and St. Matthew Island blue king crab molting frequency and growth increment, and the author hopes to go forward with more in depth work on this matter in the future.

- Fall 2012 SSC

  Comments: *The SSC offers the following remarks to the assessment author. There is significant improvement in model evaluation. The SSC agrees with the Crab Plan Team on the need to develop diagnostic tools to understand and improve model performance (e.g., residual plots). For 2013, the SSC concurs with the Crab Plan Team that the author should explore an alternative model that merges characteristics of model B and model C, perhaps allowing two different Ms (one for 10 years ago and one for the recent 10 years). In addition, the SSC recommends that the author should fix the seed in the simulation, as it can help future reviewers to repeat and verify the simulation results. The Crab Plan Team offered some additional comments to the author, with which the SSC concurs. In addition, the SSC identified an important research need to investigate the annual molting frequency (and growth increment) with pre-molt size.*

  Response: The author has addressed most of these matters already in his previous response to Fall 2013 CPT comments and notes here only that, so far as he is aware, choice of random seed is not relevant for this particular model and manner of model estimation.

- Spring 2013 CPT

  Comments: *The base model and six alternative scenarios were addressed in the Fall 2012 SAFE chapter. These included different weighting on likelihood components, fixing or estimating various trawl survey selectivity parameters, and fixing or estimating natural mortality (M). Bill intends to repeat these scenarios in the fall 2013 for re-consideration by the CPT and SSC, and to add a seventh alternative scenario requested by the CPT and SSC that combines features of two of the six models. This seventh scenario merges aspects of scenarios B and C (as described in the Fall 2012 SAFE chapter) and incorporates two time periods for M.*

  Response: The author has presented hybrid B-C models, B1:C and B2:C. These allow M to vary by year around a geometric mean of 0.18 yr^{-1}. These results could inform further work of the type suggested by the CPT regarding two time periods for M, and the author is open to further guidance on how to proceed in regard to this matter.

- Spring 2013 SSC
  Comments: No new recommendations.
  Response: NA

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[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 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 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

[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 TAC was increased to 1.600 million pounds in 2010/11 and to 2.359 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 (80% of the TAC), respectively. CPUE remained around 10 crab per pot during the 2012/13 season, but harvesters landed 99% (1.616 million pounds) of the 1.630-million-pound TAC.

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 2012; 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 historically observed in the eastern Bering Sea snow crab fishery, and ADF&G crab observers recorded 57 male blue king crab in sampled pot lifts during the 2012/13 fishery in two ADF&G statistical areas southwest of St. Matthew Island. More typically, however, bycatch of blue king crab in the Bering Sea snow crab fishery has been negligible. During the three previous seasons, for example, observers recorded a total of 3 blue king crab in a combined 6,023 sampled pot lifts. 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.

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 (1978-2013; Table 2); results from the triennial ADF&G SMBKC pot survey (every third year 1995-2010; 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 (1992/93-2012/13; 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 Foy and Armistead (2012); 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, 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). Note that for this assessment the newly available NMFS groundfish observer data reported by ADF&G statistical area was not used.

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. 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].

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[3] J. Zheng, ADF&G, pers. comm.
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Model Selection and Evaluation

For the 2013 assessment, ten alternative model configurations, denoted Tbase, A1, A2, A3, B1, B2, C, TC, B1:C, and B2:C were examined along with the base-model configuration described in detail in Appendix A. With the exception of Tbase and TC, these alternatives were designed to address CPT and SSC requests and recommendations subsequent to the 2012 assessment. By comparison with the alternatives, the base-model configuration is characterized by 1) trawl and pot-survey 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; 3) natural mortality model estimated in 1998/99 and otherwise fixed at 0.18 yr^{-1}; and 4) stage-1 to stage-2 and stage-2 to stage-3 transition probabilities both fixed at 1.0. The ten alternative model configurations differ from the base model in one or at most two of these features.

Model configurations A1, A2, and A3 reflect different weighting schemes for the trawl and pot-survey indices, with the added difference that, following Francis (2011), 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. These configurations were introduced in Fall 2012 to address implausibly high estimates of stage-1 and, particularly, stage-2 selectivities under the other model configurations.

Configuration C modifies the base model to allow natural mortality M to vary across pre-assessment years according to $\log(M_t) = \log(0.18yr^{-1}) + \eta_t$, with the η_t subject to a moderate quadratic penalty $8.0\frac{\sum \eta_t^2}{2}$ and the constraint $\sum \eta_t = 0$. The purpose of this modification was to give the model more year-to-year flexibility as a way of improving its fit to the data, especially to the trawl-survey composition data. Models B1:C and B2:C are the obvious hybrid models and were introduced for this 2013 assessment in response to recent CPT and SSC recommendations. Within model estimation of 1998/99 natural mortality to account for an hypothesized anomalous mortality event (Zheng and Kruse 2002) proved a useful strategy in the context of the previous SMBKC stock assessment model (2010 SAFE), and this author previously verified in terms of conventional likelihood theory the utility of including this one extra parameter in the current base model (2012 SAFE). For these reasons, this strategy was again deployed in the base model and all other non-C model configurations.

Finally, model configurations Tbase and TC are presented at the author's initiative to investigate the effect on model behavior of using a different and presumably more biologically realistic stage-transition matrix. In these two models the matrix $\begin{bmatrix} 0.3 & 0.7 & 0 \\ 0 & 0.5 & 0.5 \\ 0 & 0 & 1 \end{bmatrix}$ replaces the stage-transition matrix $\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix}$ employed in all other model configurations. So, for example, in any given year, instead of 100%, only 70% of stage-1 crab molt and grow into stage-2 crab, with the other 30% remaining in stage 1, whether or not they molt. The alternative transition matrix is motivated by the work of Otto and Cummiskey (1990) on Pribilof and St. Matthew Island blue king crab molting and growth. The following table summarizes all eleven model configurations examined for this assessment.

Model configurations examined for the 2013 SMBKC stock assessment. Configurations Tbase and TC employ an alternative stage-transition matrix in model population dynamics. See text for details.

	survey-index objective function weight		trawl-survey selectivity parametrization			
model	trawl-survey	pot-survey	stage 1	stage 2	stage 3	yearly natural mortality[a]
base	1.0	1.0	s1	s2	Q = 1	0.18 yr^{-1}
Tbase	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[c]	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	estimated, with geometric mean 0.18 yr^{-1}
TC	1.0	1.0	s1	s2	Q = 1	estimated, with geometric mean 0.18 yr^{-1}
B1:C	1.0	1.0	s1	s2	s2	estimated, with geometric mean 0.18 yr^{-1}
B2:C	1.0	1.0	s1	Q = 1	s2	estimated, with geometric mean 0.18 yr^{-1}

[a] In all non-C models, a separate parameter is used to estimate M in 1998/99 .
[b] Model A2 excludes **all** pot-survey data, i.e. index and composition data component weights are both set to zero.

Base-model ADMB parameter estimates, standard errors, and estimated correlations are given in Tables 6 and 7. As already observed, notably problematic are the implausibly high estimates of stage-1 and 2 trawl-survey selectivites. Another concern with the base model, evident in Figure 6, is its poor fit to the trawl-survey composition data, particularly in the last decade or so of the time series, possibly indicative of an important change in stock dynamics or distribution. Choice of alternative model configurations examined for this assessment, as for the 2012 assessment, has been largely driven by these two concerns. Another concern about the base model, and one that is undoubtedly linked to the first, is the biologically unrealistic default stage transition matrix determining model population dynamics, and alternative model configurations Tbase and TC represent the author's attempt to address it.

Table 8 and Figures 7 – 15 facilitate basic comparison of the different model configurations with respect to these concerns and in terms of important measures of model behavior. Figures 7, 8, and 9 show model fits to trawl and pot-survey indices, and Figures 10 – 15 display key model outputs with respect to management decisions. Table 8 makes clear that estimation of trawl-survey selectivity parameters is generally problematic. Among model configurations using the base-model default stage-transition matrix only configuration B1 leads to what might immediately be considered plausible values. For the others, stage-2 estimates, in particular, are unreasonably high. The exception is model B2 and its variant B2:C. These models assume stage-2 selectivity equal to unity, leading to a dome-shaped selectivity curve and questionably low estimates of stage-3 selectivity that ultimately result in what are likely inflated estimates of stock MMB and B_{MSY} (Table 8; Figures 12 and 13). By contrast, the two model configurations Tbase and TC, which make use of a more biologically defensible stage-transition matrix, yield considerably more appealing results in this regard.

Model fit to trawl-survey composition data is likewise generally problematic, with the base-model residual pattern exhibited in Figure 6 fairly typical across model configurations. Other than B2, which is suspect for other reasons, C-type model configurations that allow yearly variation in natural mortality tend to do better, with TC affording what might be judged the most satisfactory fit to the trawl-survey stage-proportion data (Figure 16). Judged by Table 8 and Figures 7 – 9, these model configurations offer a better fit to the data generally, and they do so based on a pattern of yearly mortality deviations that are remarkably small except for a few years in the latter part of the time series, again suggestive of some fundamental change subsequent to the 1998/99 stock decline (Figures 13 and 14).

In Fall 2012 CPT discussion of model selection, model configurations B1 and C were each proposed as potential alternatives to the base model. It was noted that B1 led to more plausible estimates of trawl-survey selectivity, whereas C provided a better fit to the data, especially the trawl-survey composition data. However, as no clear preference emerged, the CPT at that time opted to go with the base model as the default. In the author's view, similar considerations point to model configurations B1, C, TC, and Tbase as the most reasonable candidates for replacing the base model for use in the 2013 assessment. The difference this time around is the introduction of an alternative stage-transition matrix in configurations Tbase and TC that not only makes these models more structurally appealing from a biological perspective but also enables them to deliver more reasonable estimates of trawl-survey selectivity. That said, there is, on the one hand, some statistical evidence in Table 8 that model C is in fact to be preferred over model TC, and, on the other, none to suggest that model Tbase should be preferred over the base model. Moreover, whereas biological plausibility clearly deserves a major role in these matters, mere plausibility is insufficient on its own. In this instance, the author believes that more work is needed to develop a properly credible biologically appropriate stage-transition matrix before adopting it for assessment use. This again leaves models B1 and C as the potential alternatives to the base model, and as there is again no compelling reason to prefer either of these to the other given the weaknesses of each, the author recommends using the base model for this 2013 assessment. Whereas the fit of model B1

Results

Additional results are presented for the base-model, as the author-recommended choice for use in the Fall 2013 SMBKC stock assessment. As was previously noted, the high estimates of trawl-survey stage-1 and stage-2 selectivity (0.95 and 1.38 relative to Q = 1; Table 6) are a concern, as is the poor fit to the trawl-survey stage-proportion data (Figure 6). Despite these pathologies, however, in the author's view there is no compelling reason to prefer one of the competing alternative models, and by comparison with the alternatives base-model results generally seem reasonable overall. This was also the conclusion reached by the CPT in 2012.

In addition to results already mentioned, Figure 17 displays standardized residuals of base-model fits to the pot-survey and crab-observer stage-proportion data. The three components of 2012/13 fishing mortality are shown in Figure 18. Figure 19 provides a plot of estimated directed-fishery fishing mortality against estimated mature male biomass at time of mating, and Figure 20 shows a 12-year retrospective plot of trawl-survey model-male (90mm+ CL) biomass. Notable in this Figure is that the different trajectories are vertically ordered consistent with the sequence of terminal years, and that this ordering reverses itself following the large overall decline from 1998 to 1999, so that the trajectories with the more recent terminal years tend to be associated with the highest estimates of biomass before the decline but the lowest following it. This same general pattern occurs also for model-estimated mature male biomass (not shown). Figure 21 shows 2013 base-model retrospective estimates of trawl-survey stage-1 and stage-2 selectivities.

Whereas actual sample sizes (number of measured crab) range between 38 and 385 for the trawl-survey (Table 2) and are generally much higher for both the pot-fishery (Table 3) and pot-survey (Table 4) data, 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. 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 22). 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 64.4 to 1,946.9 for the pot-survey composition data (6 years) and from 32.5 to 399.8 for the pot-fishery composition data (13 years).

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 (2012 SAFE), and only a Tier 4 analysis is presented here, with development of a Tier 3 approach deferred subject to CPT/SSC recommendations 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

$$a)\quad F_{OFL} = F_{MSY}\text{, } when\ \ B/B_{MSY} > 1;$$

$$b)\quad F_{OFL} = F_{MSY}\,(B/B_{MSY} - \alpha)/(1-\alpha),\ when\ \ \beta < B/B_{MSY} \le 1;$$

$$c)\quad F_{OFL} < F_{MSY}\ \ with\ directed\ \ fishery\ F = 0,\ when\ \ B/B_{MSY} \le \beta\,,$$

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], 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, currently 1978/79 – 2012/13, 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 base-model configuration the B_{MSY} proxy is 6.76 million pounds, and case b) of the control rule obtains, resulting in a Tier 4b 2013/14 total male catch OFL of 1.24 million pounds with $F_{OFL} = F_{MSY} = 0.18$ yr^{-1}. The retained catch component of the OFL is 1.20 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 $\lambda = \exp\left(0.2714\Phi^{-1}(0.49)\right) = 0.99$ and a maximum ABC of $\lambda \times ofl = 0.99 \times 1.24 = 1.23$ 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 1.10 million pounds.

H. Rebuilding Analysis

This stock is not currently subject to a rebuilding plan.

I. Data Gaps and Research Priorities

In Fall 2012 the SSC identified 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. For the future, the author plans to look at historical ADF&G SMBKC tagging data as a possible basis for extending their efforts with the goal of formulating a credible biologically motivated model transition matrix.

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Table 1. The 1978/79 – 2011/12 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

[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 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		
year	stage 1 (90-104mm CL)	stage 2 (105-119mm CL)	stage 3 (120mm+ CL)	Total	CV	mature male (105mm+ CL)	cv	number 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
2013	0.335	0.452	0.807	1.593	0.22	4.459	0.22	74

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
2012/13	2,841/37,065	57,298	0.141	0.318	0.541

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) estimates. Source: J. Zheng, ADF&G, and author estimates based on data from 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
2012/13	0.8	1.0	1.1

[a] Trawl, pelagic trawl, and non-pelagic trawl gear types.
[b] Assuming handling mortalities of 0.8 for trawl and 0.5 for fixed gea

Table 6. 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	0.91	0.133
pot-survey proportionality constant	4.97	0.412
trawl-survey stage-1 selectivity	0.95	0.066
trawl-survey stage-2 selectivity	1.38	0.085
pot-survey stage-1 selectivity	0.39	0.062
pot-survey stage-2 selectivity	1.03	0.125
pot-fishery stage-1 selectivity	0.44	0.044
pot-fishery stage-2 selectivity	0.76	0.063
log initial stage-1 abundance	7.65	0.182
log initial stage-2 abundance	7.30	0.242
log initial stage-3 abundance	7.37	0.237
mean log recruit abundance	6.62	0.046
mean log recruit abundance deviations (34)	[-1.77, 1.27]	[0.104, 0.330]
mean log directed fishing mortality	-1.27	0.059
log directed fishing mortality deviations (24)	[-3.27, 1.31]	[0.084, 0.253]
mean log GF trawl fishing mortality	-10.60	0.228
log GF trawl fishing mortality deviations (21)	[-1.60, 1.77]	[0.698, 0.731]
mean log GF fixed-gear fishing mortality	-9.32	0.220
log GF fixed-gear fishing mortality deviations (21)	[-2.28, 2.48]	[0.688, 0.702]

Table 7. Base-model ADMB primary parameter correlations. Does not include those for recruit and fishing mortality 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	-0.32	1												
3	TS s1 selectivity	-0.27	0.13	1											
4	TS s2 selectivity	-0.23	0.13	0.44	1										
5	PS s1 selectivity	-0.11	-0.27	0.07	0.06	1									
6	PS s2 selectivity	-0.11	-0.41	0.06	0.06	0.20	1								
7	PF s1 selectivity	-0.12	-0.08	0.06	0.07	0.10	0.12	1							
8	PF s2 selectivity	-0.03	-0.15	0.01	0.00	0.07	0.10	0.48	1						
9	log initial N1	-0.03	0.01	0.07	0.07	0.01	0.01	0.03	0.03	1					
10	log initial N2	-0.03	0.01	0.14	0.00	0.01	0.01	0.02	0.02	0.08	1				
11	log initial N3	-0.09	0.05	0.25	0.28	0.03	0.02	0.04	0.03	-0.04	-0.23	1			
12	mean log PF F	-0.09	0.32	-0.19	-0.16	-0.06	-0.09	-0.31	-0.36	-0.17	-0.15	-0.42	1		
13	mean log recruits	0.49	-0.59	-0.36	-0.33	-0.09	-0.05	0.02	0.15	-0.12	-0.10	-0.18	-0.28	1	
14	mean log GFT F	-0.07	0.19	0.05	0.06	0.00	-0.01	-0.03	-0.05	0.01	0.01	0.02	0.12	-0.23	1
15	mean log FGF F	-0.07	0.20	0.05	0.06	0.00	-0.01	-0.03	-0.05	0.01	0.01	0.02	0.12	-0.23	0.07

Table 8. Key base and alternative model quantities.

Model	model estimated trawl-survey selectivity			survey-index RMSE		objective function		management quantities (10^6 lb)		
	stage 1	stage 2	stage 3	trawl	pot	min[a]	K[b]	Bmsy[c]	OFL[d]	MMBmating[e]
base	0.95	1.38	Q = 1	1.58	6.64	3,733	119 - 4	6.756	1.241	6.639
Tbase	0.57	0.69	Q = 1	1.66	6.91	3,735	119 - 4	8.498	1.173	8.012
A1	0.94	1.37	Q = 1	1.60	6.97	3,703	119 - 4	6.711	1.324	6.927
A2	0.92	1.34	Q = 1	1.66	NA	3,148	116 - 4	6.672	1.475	7.699
A3	1.01	1.46	Q = 1	2.01	6.73	3,715	119 - 4	7.404	1.219	6.910
B1	0.72	Q = 0.85		1.52	6.53	3,745	119 - 4	7.622	1.882	9.893
B2	0.66	Q = 1	0.48	1.60	6.41	3,710	119 - 4	13.085	2.210	12.092
C	0.90	1.33	Q = 1	1.24	3.04	3,673	154 - 5	6.073	0.732	4.963[f]
TC	0.54	0.66	Q = 1	1.27	3.13	3,698	154 - 5	7.777	0.723	6.196[f]
B1:C	0.92	Q = 1.31		1.58	2.63	3,701	154 - 5	4.551	0.562	3.845[f]
B2:C	0.69	Q = 1	0.56	1.36	3.47	3,693	154 - 5	10.641	1.451	8.978[f]

[a] ADMB minimized objective function value.
[b] Number of model “parameters” – number of zero-sum constraints.
[c] Average 1978-2012 model MMBmating.
[d] Tier 4 assuming Fmsy = 0.18 yr^{-1}.
[e] Model projected 2014 value assuming OFL catch.
[f] Assuming M = 0.18 yr^{-1} in 2013/14.

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	4a	0.18	2.14 (971)	0.095 (43)	0.0002 (0.1)	0.0009 (0.4)	2.24 (1,020)
2013/14	4a	0.18	1.20 (544)	0.044 (20)	0.0002 (0.09)	0.0007 (0.3)	1.24 (562)

[a] From Fall 2013 base-model configuration.

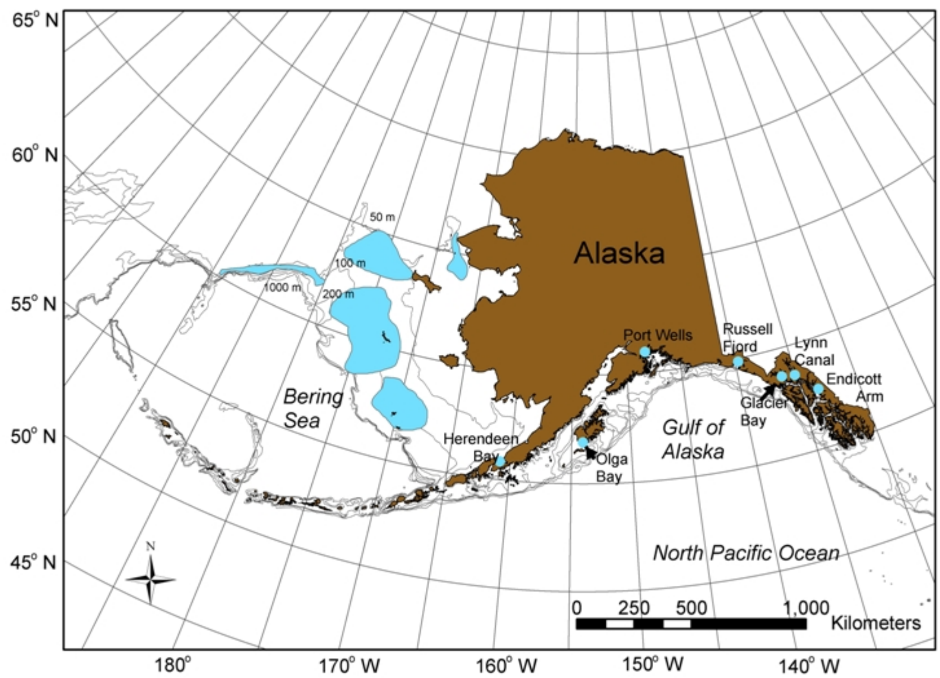


Figure 1. Distribution of blue king crab *Paralithodes platypus* in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters. Shown in blue.

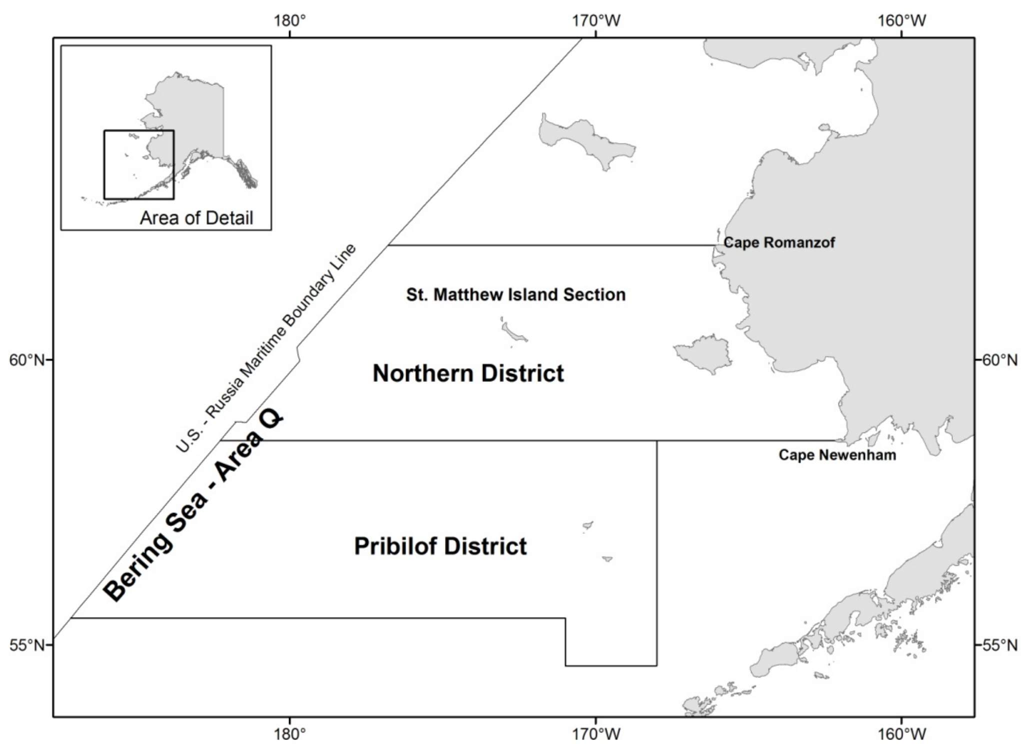


Figure 2. King crab Registration Area Q (Bering Sea).

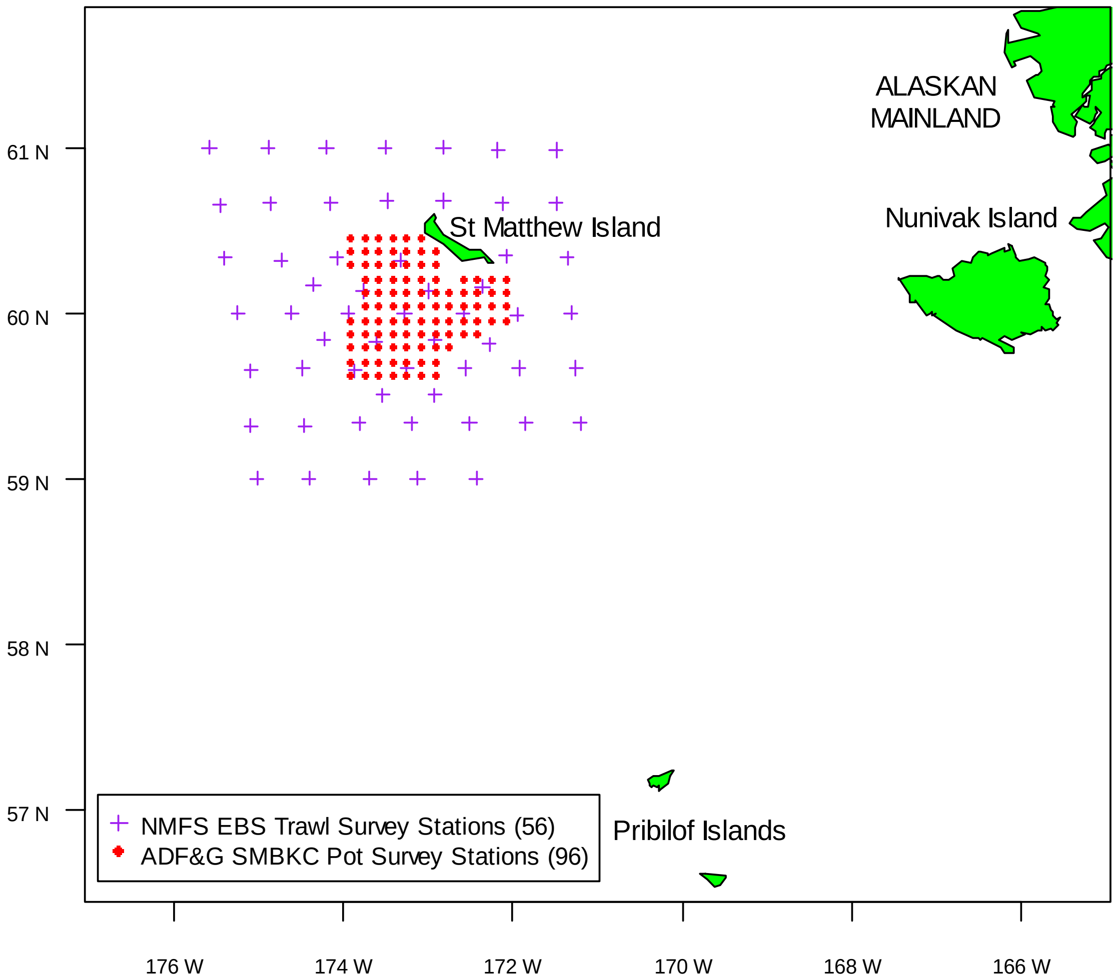


Figure 3. Trawl and pot-survey stations used in the SMBKC stock assessment.

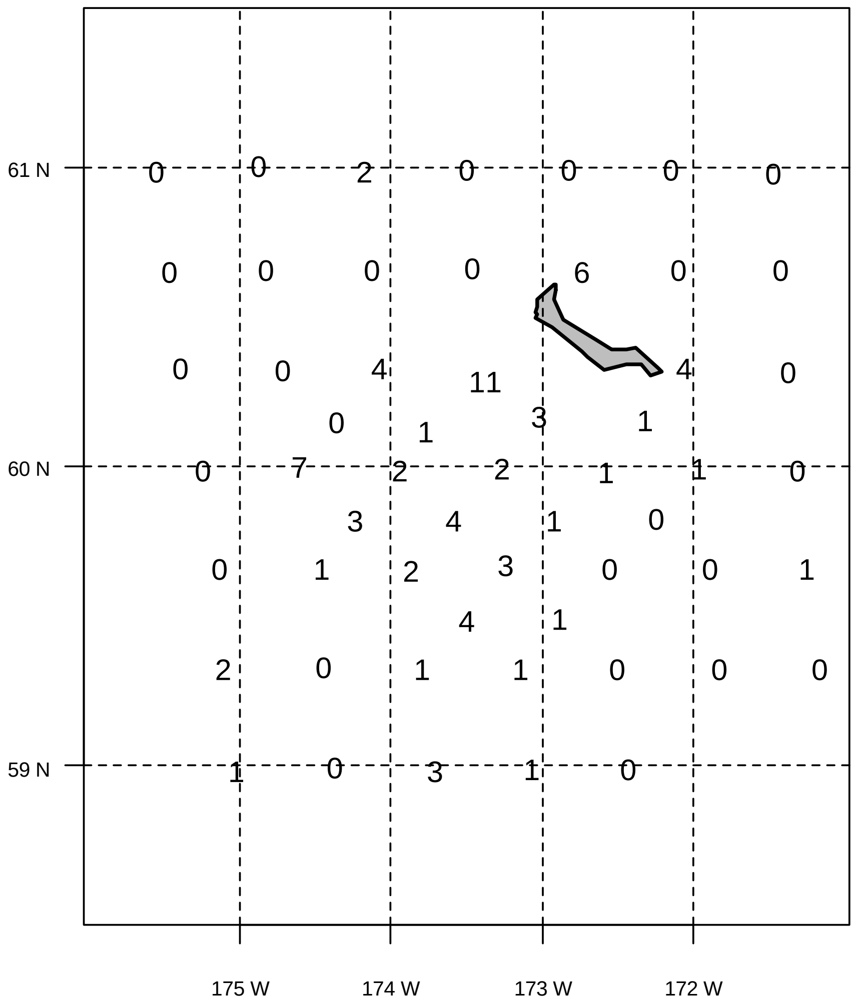


Figure 4. Catches of male blue king crab measuring at least 90 mm CL from the 2013 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock. Note that the area north of St. Matthew Island is not represented in the ADF&G pot-survey data used in the assessment.

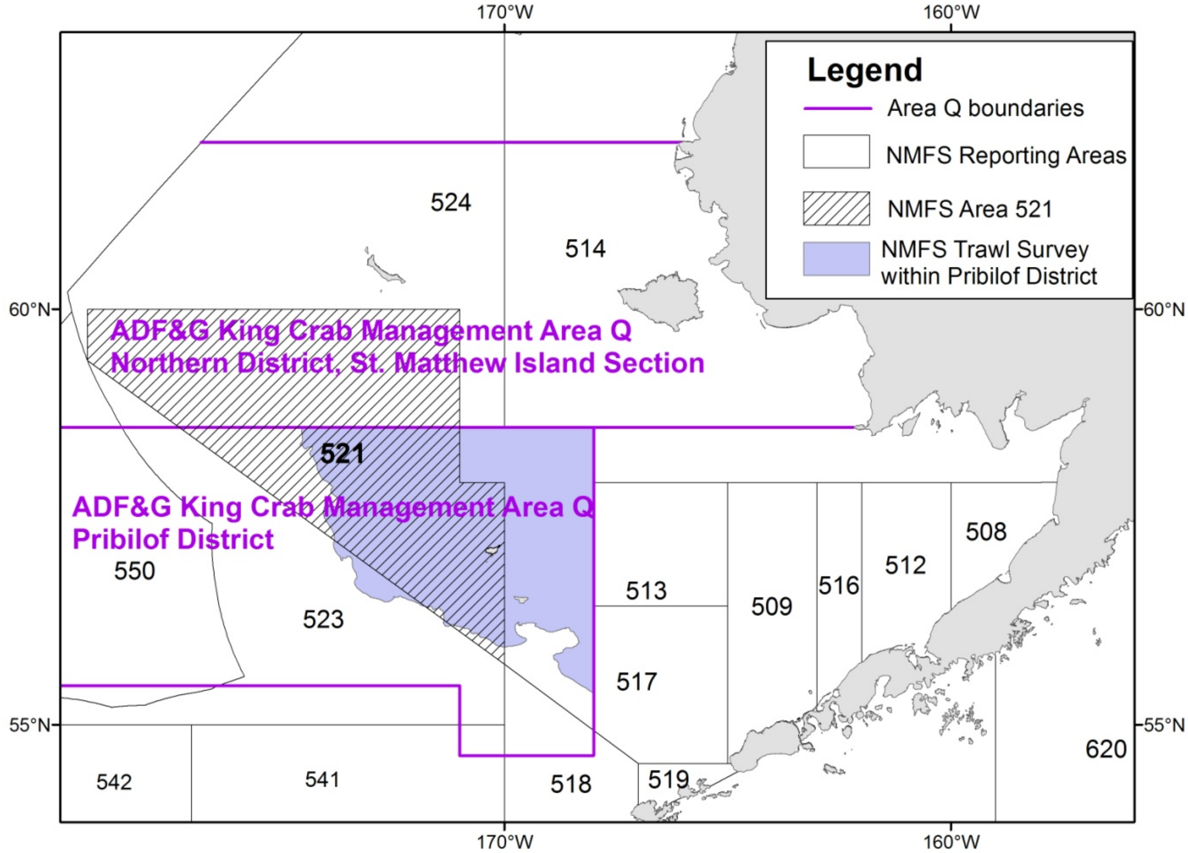


Figure 5. NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.

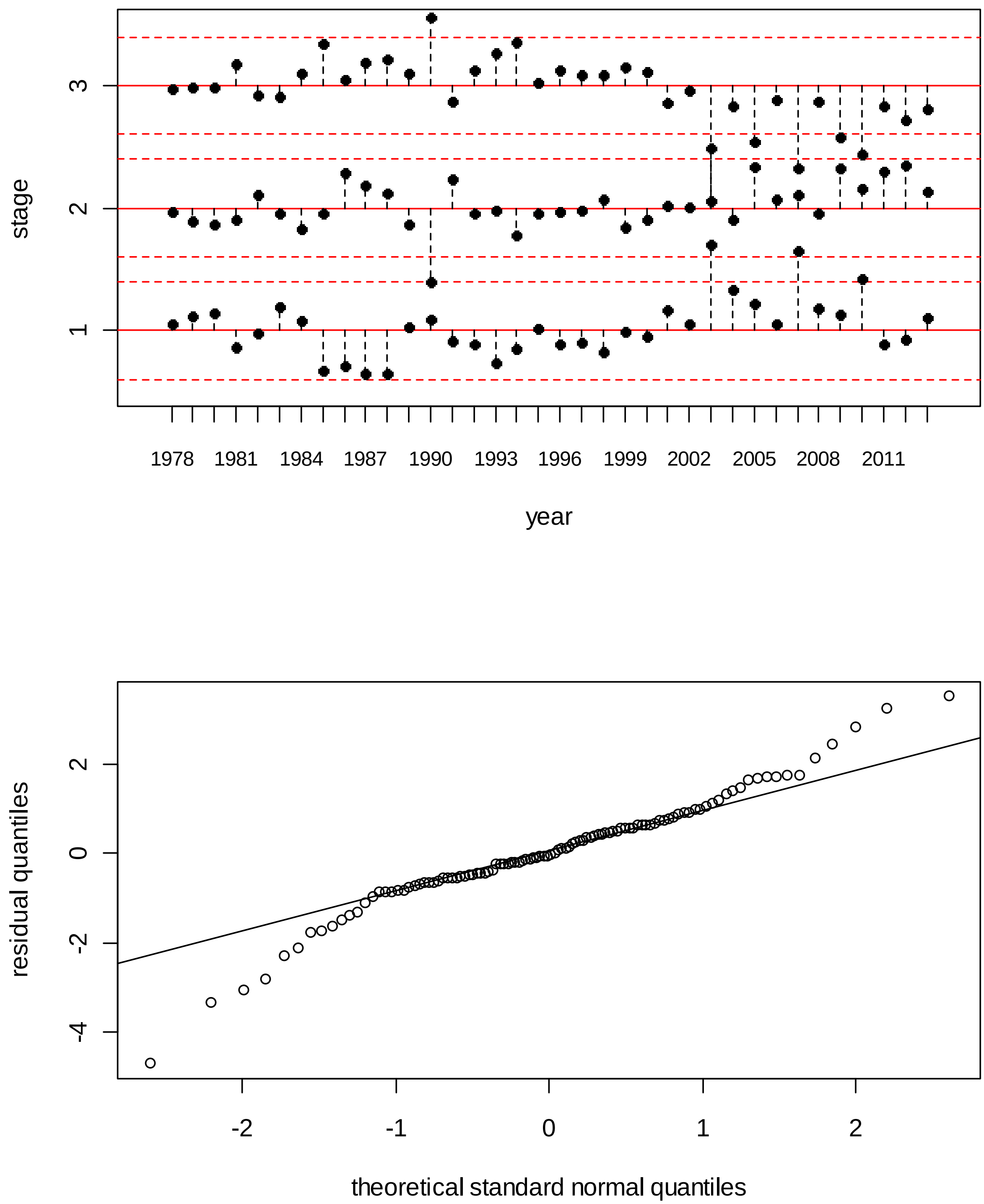


Figure 6. Base-model trawl-survey stage-proportion standardized residuals and normal qq-plot.

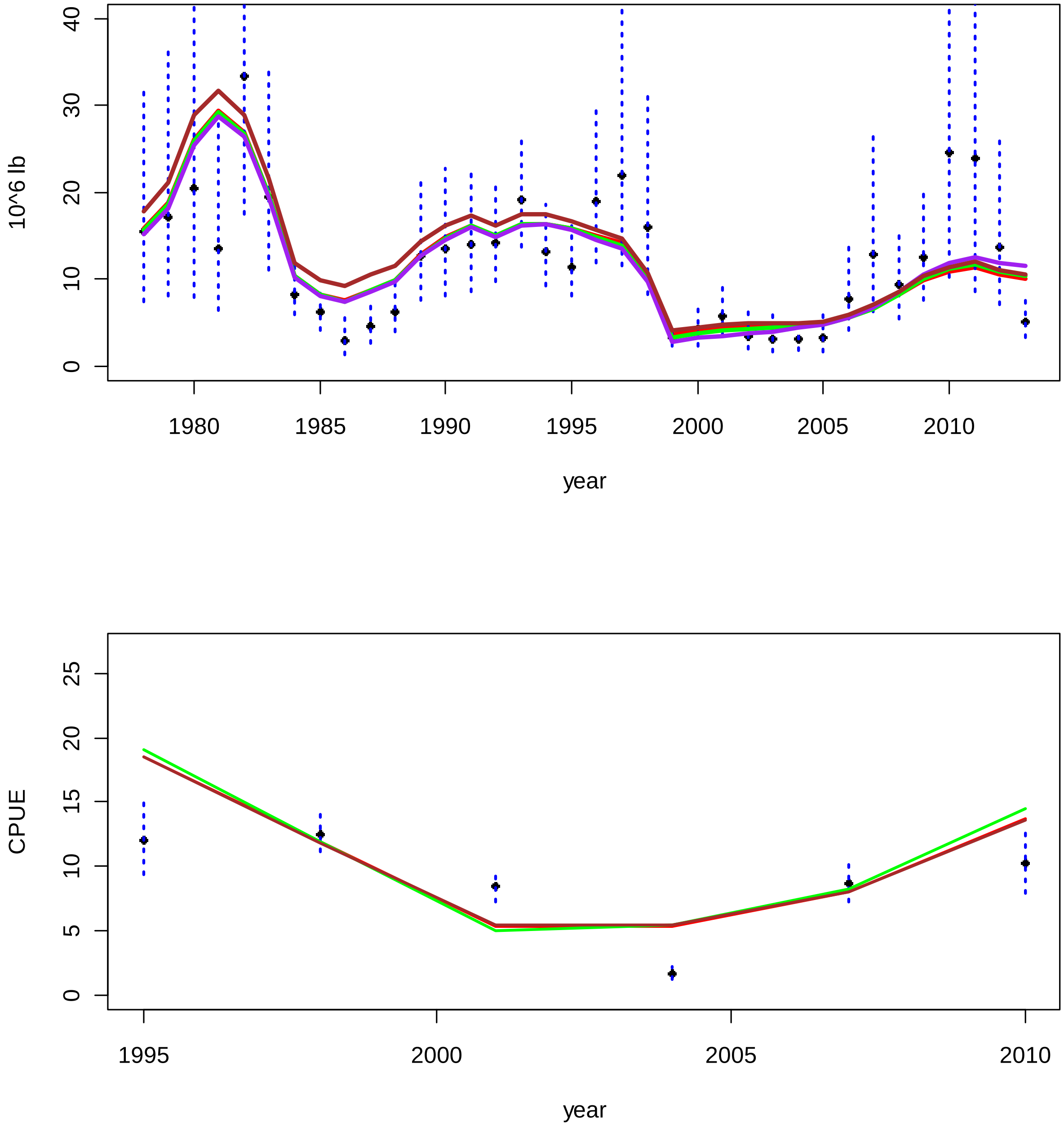


Figure 7. Model fits to trawl (top panel) and pot-survey indices (points) for base model (red) and model configurations A1 (green), A2 (purple), and A3 (brown). Note that model A2 makes no use of pot-survey data so no results for that model are displayed in the lower panel.

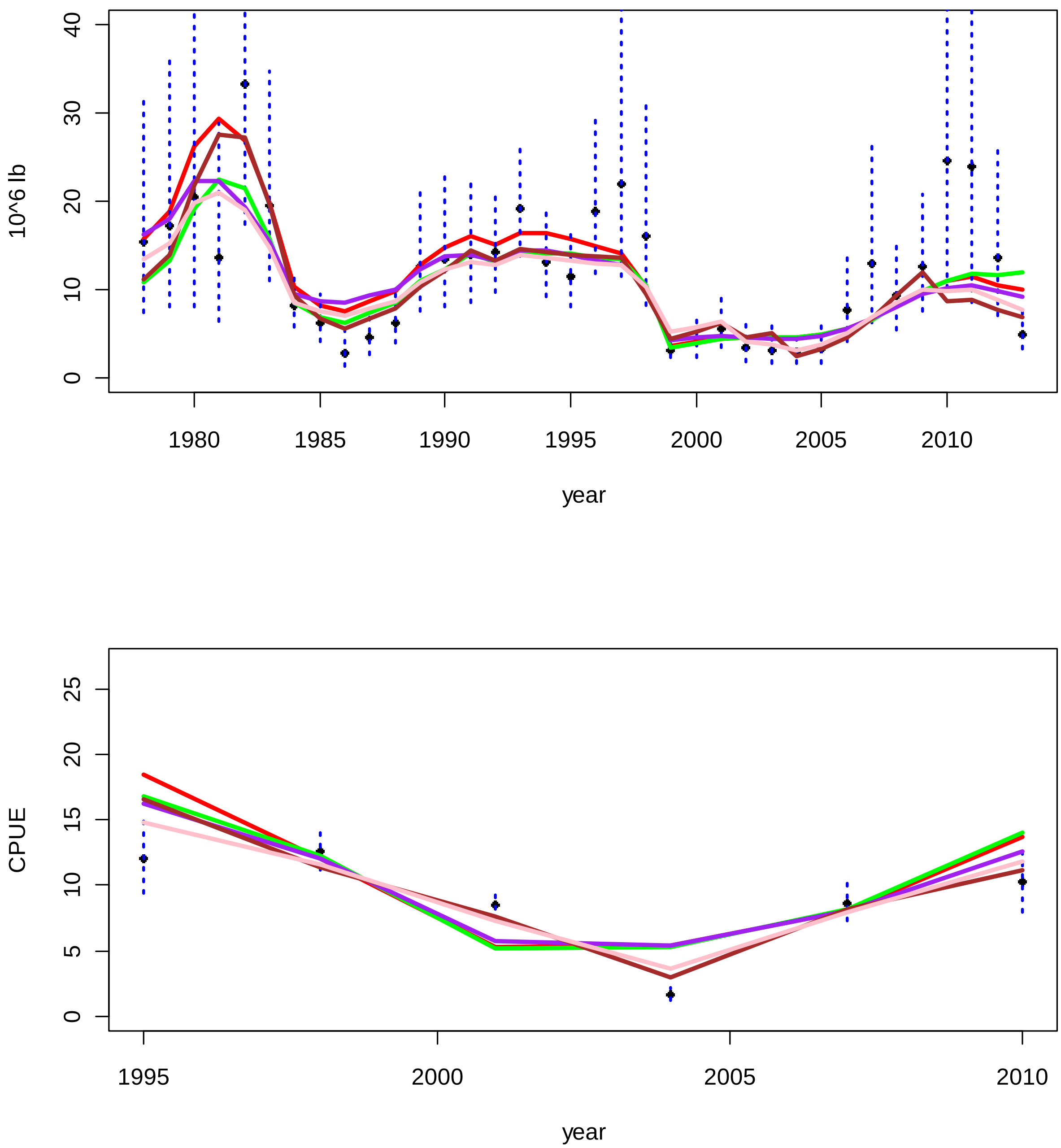


Figure 8. Model fits to trawl (top panel) and pot-survey indices (points) for base model (red) and model configurations B1 (green), B2 (purple), B1:C (brown), and B2:C (pink).

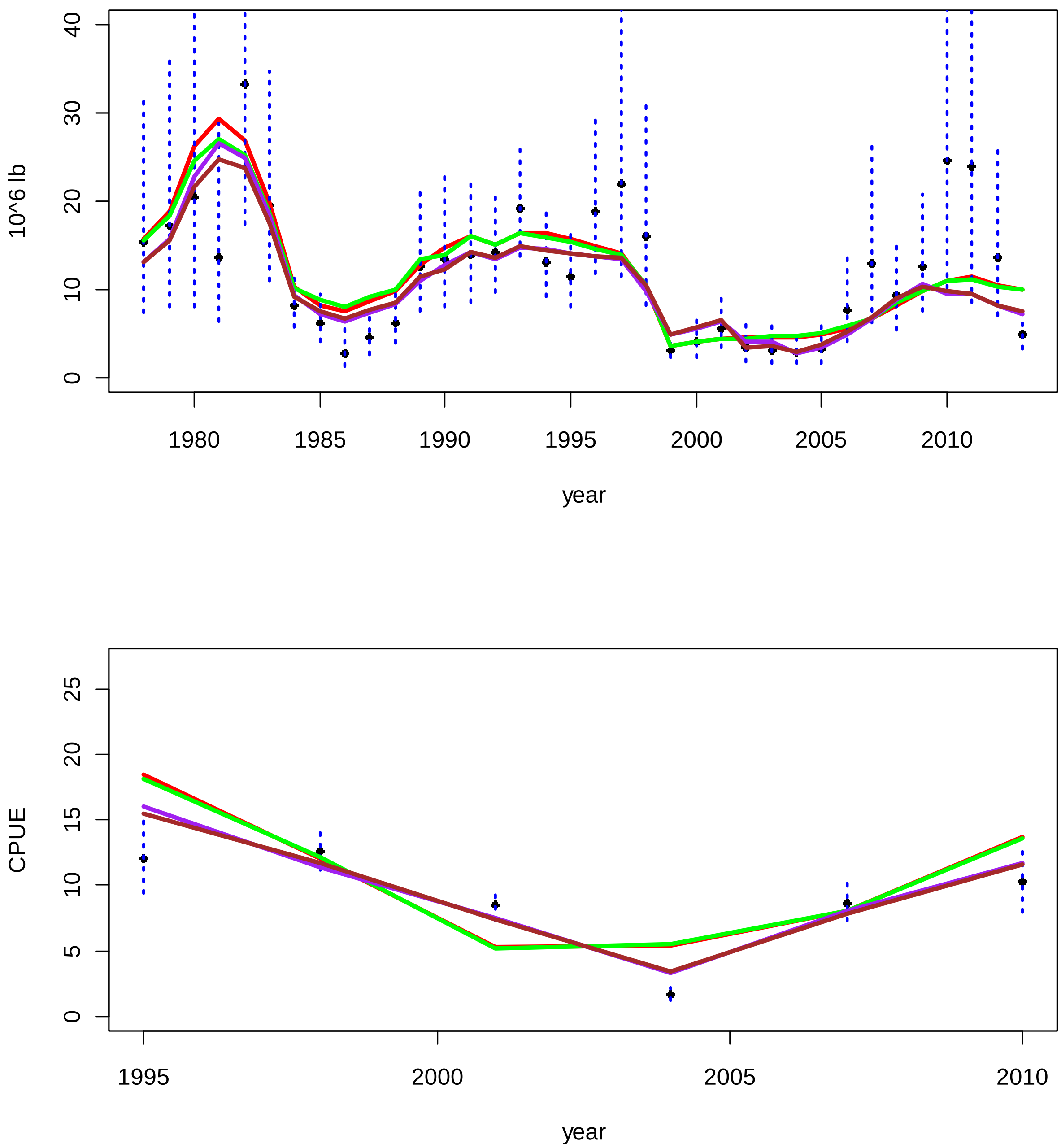
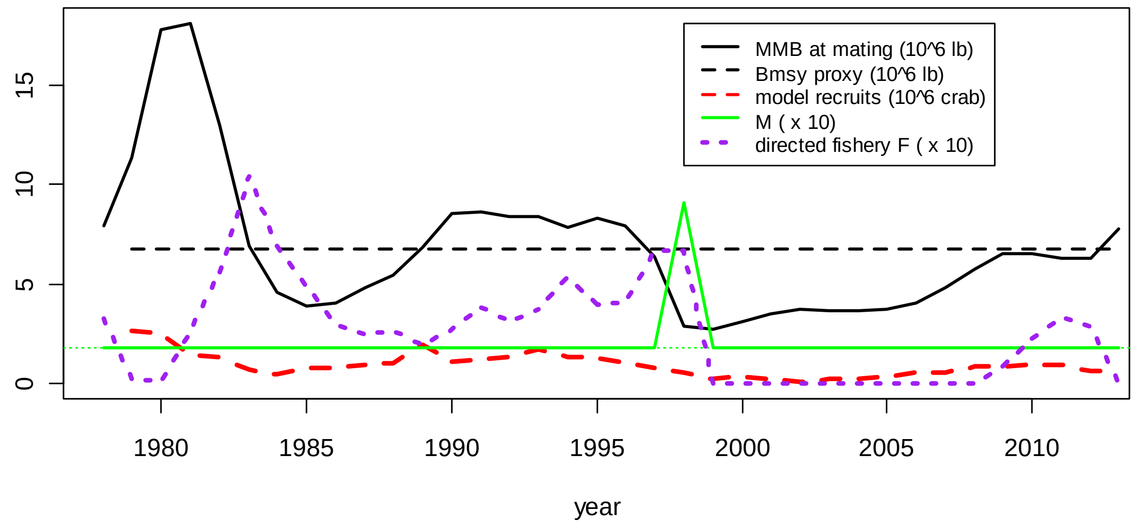


Figure 9. Model fits to trawl (top panel) and pot-survey indices (points) for base model (red) and model configurations Tbase (green), C (purple), and TC (brown).



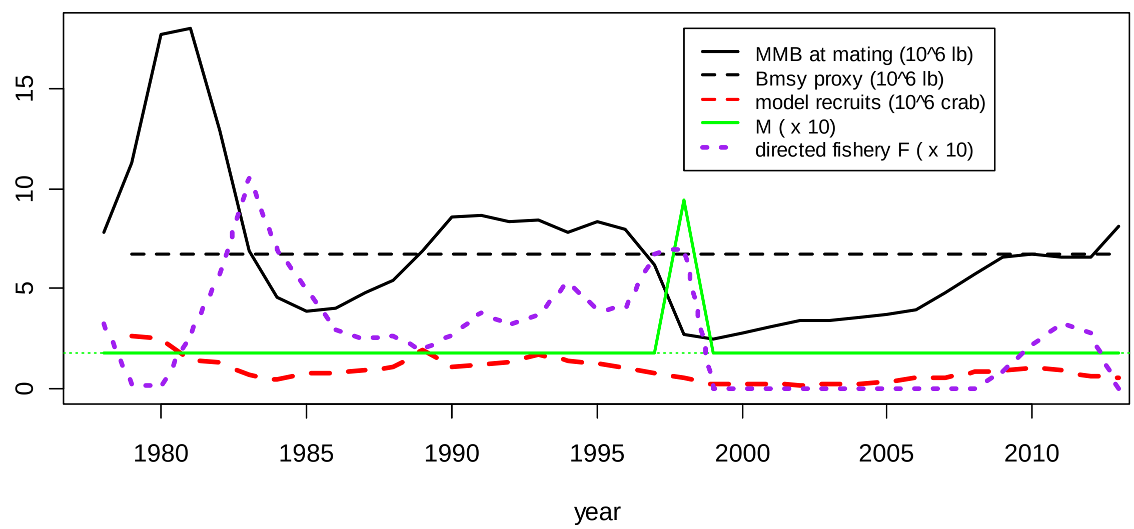


Figure 10. Base-model (top) and model A1 key results. Assessment year (2013/14) MMBmating assumes F = 0 in directed fishery.

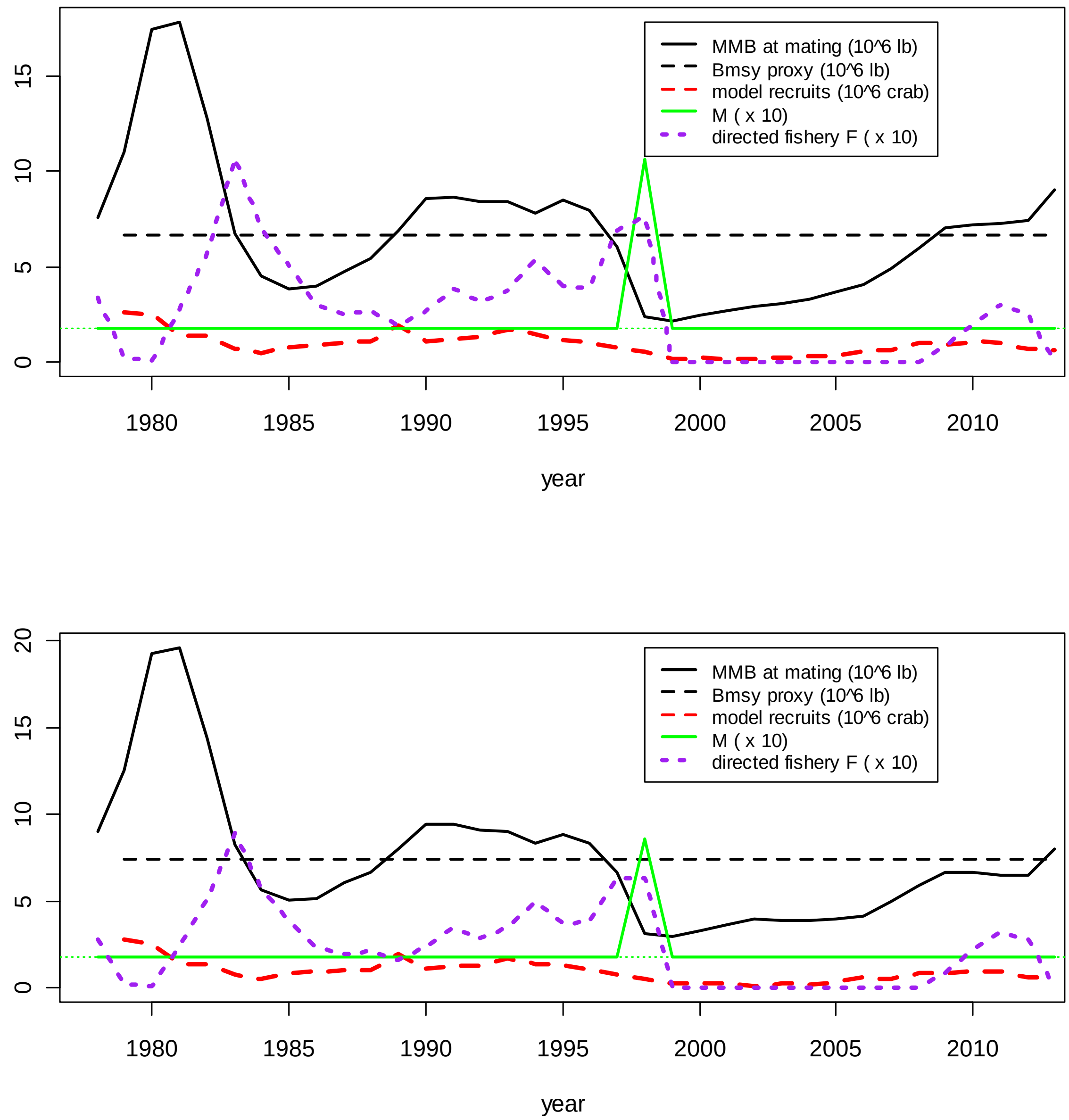


Figure 11. Model A2 (top) and A3 key results. Assessment year (2013/14) MMBmating assumes F = 0 in directed fishery.

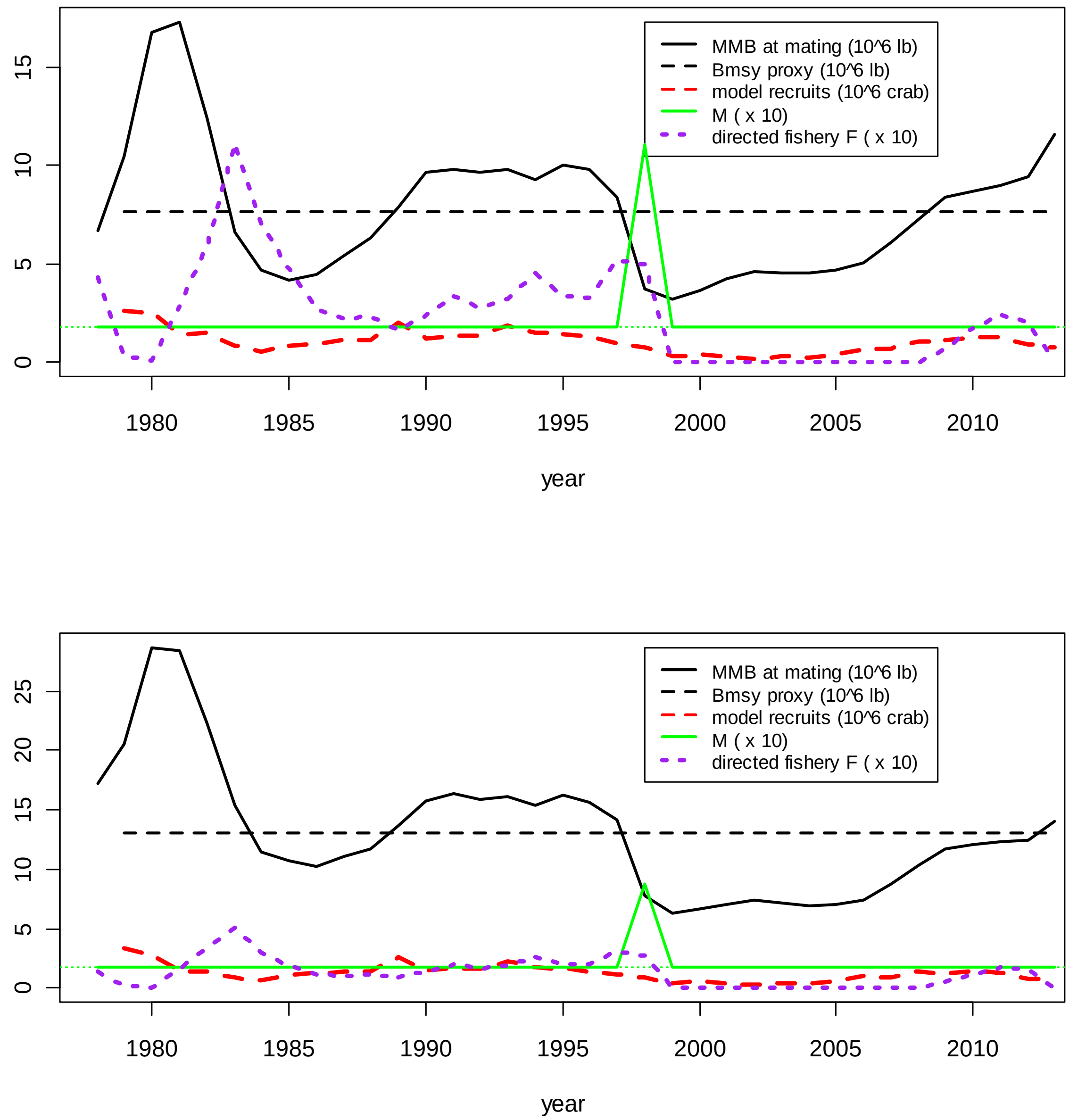
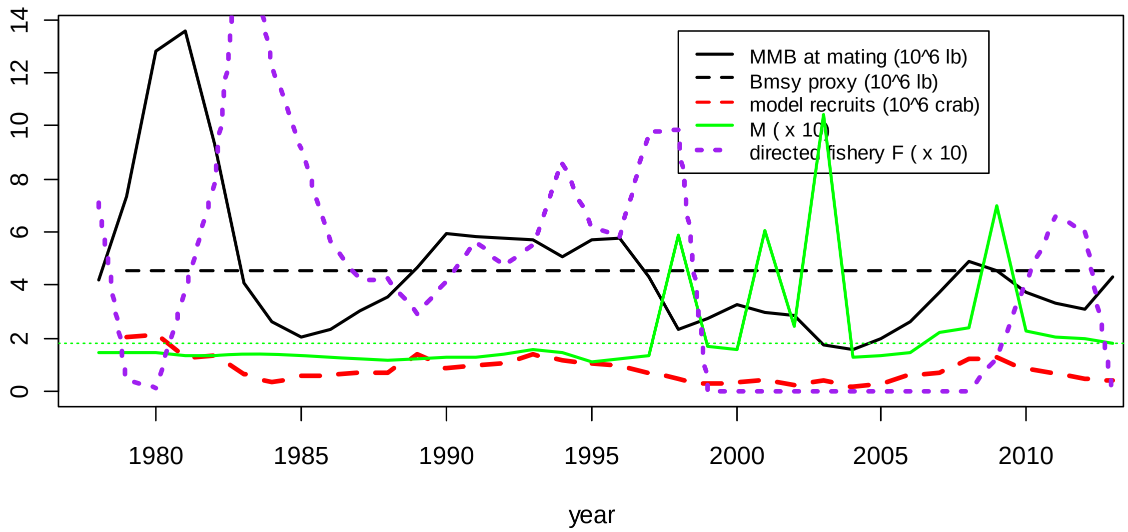


Figure 12. Model B1 (top) and B2 key results. Assessment year (2013/14) MMBmating assumes F = 0 in directed fishery.



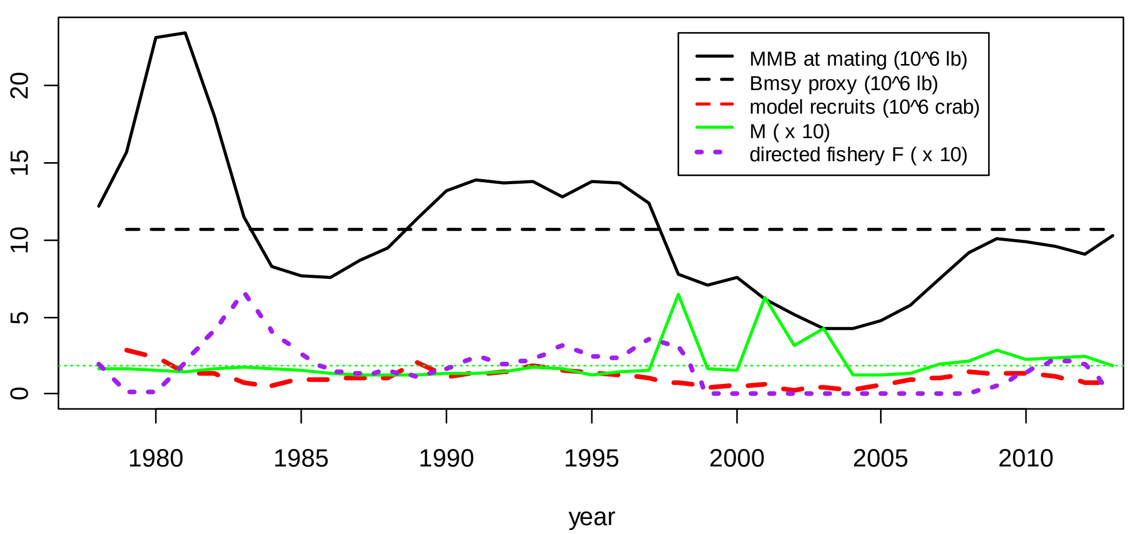


Figure 13. Model B1:C (top) and B2:C key results. Assessment year (2013/14) MMBmating assumes F = 0 in directed fishery.

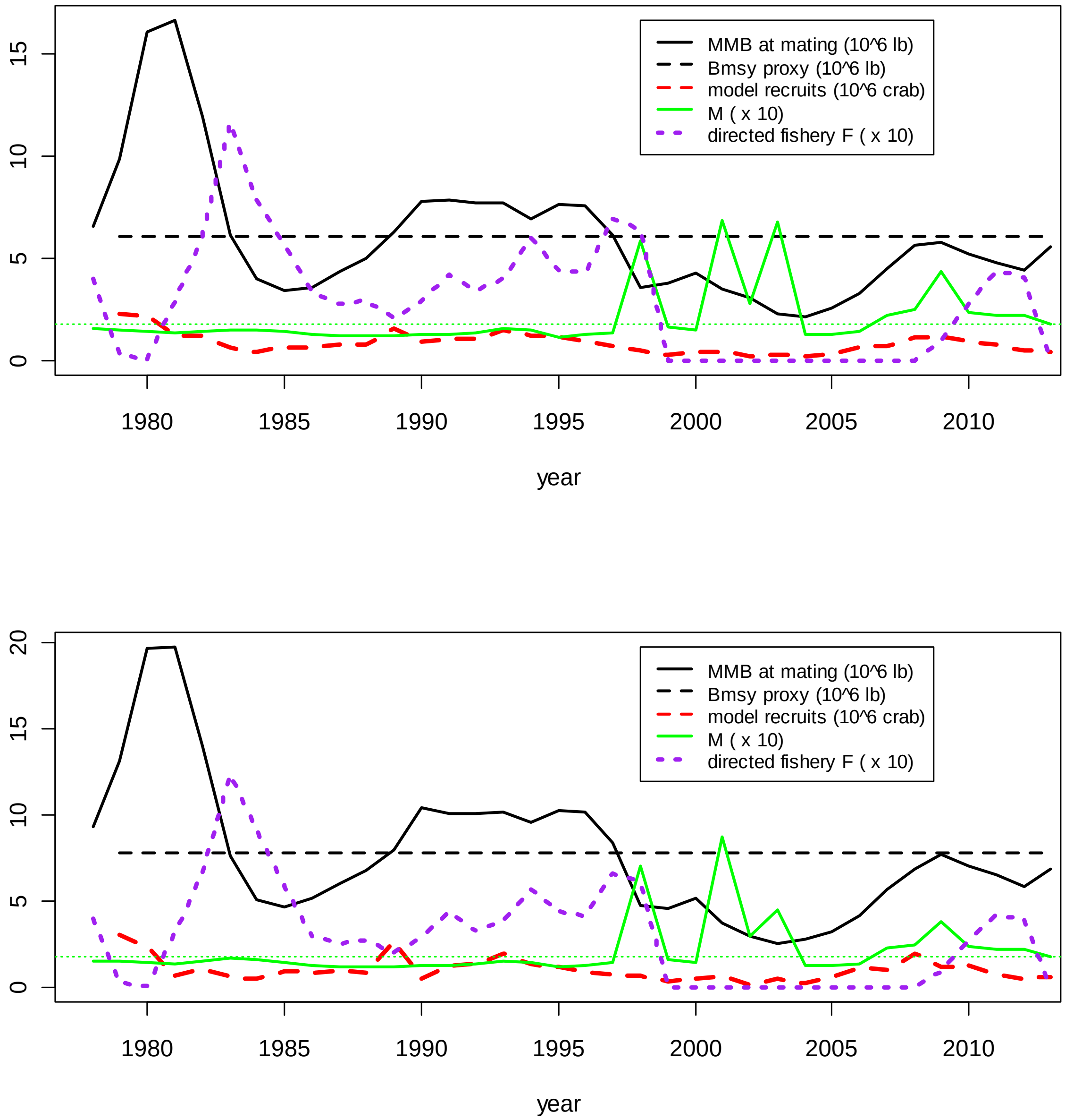
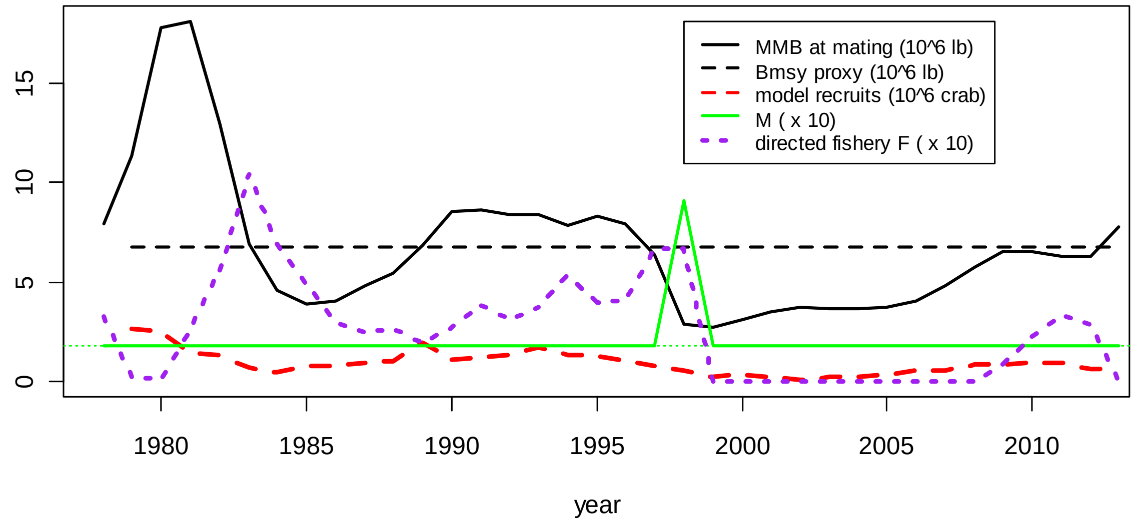


Figure 14. Model C (top) and TC key results. Assessment year (2013/14) MMBmating assumes F = 0 in directed fishery.



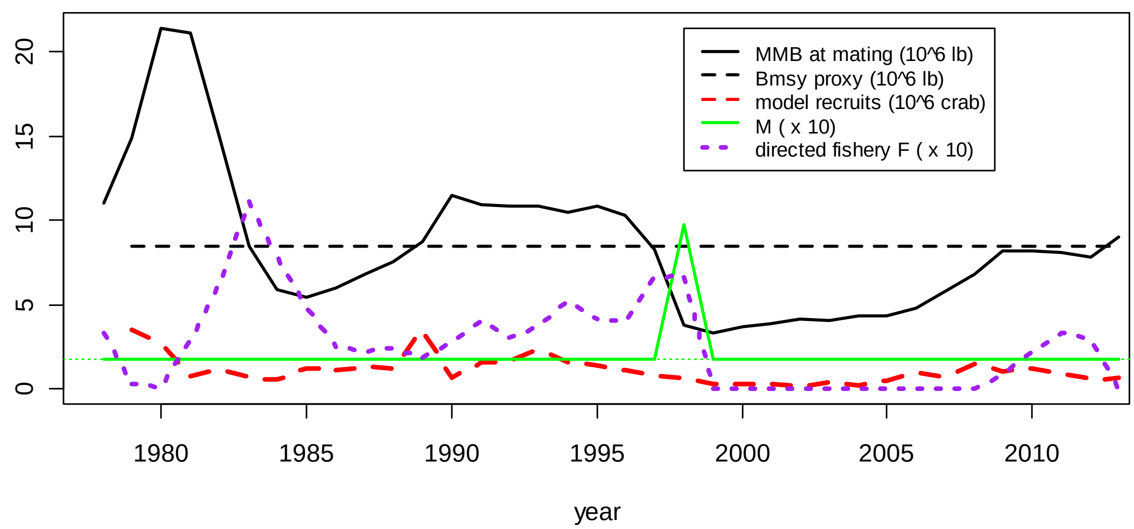


Figure 15. Base-model (top) and model Tbase key results. Assessment year (2013/14) MMBmating assumes F = 0 in directed fishery.

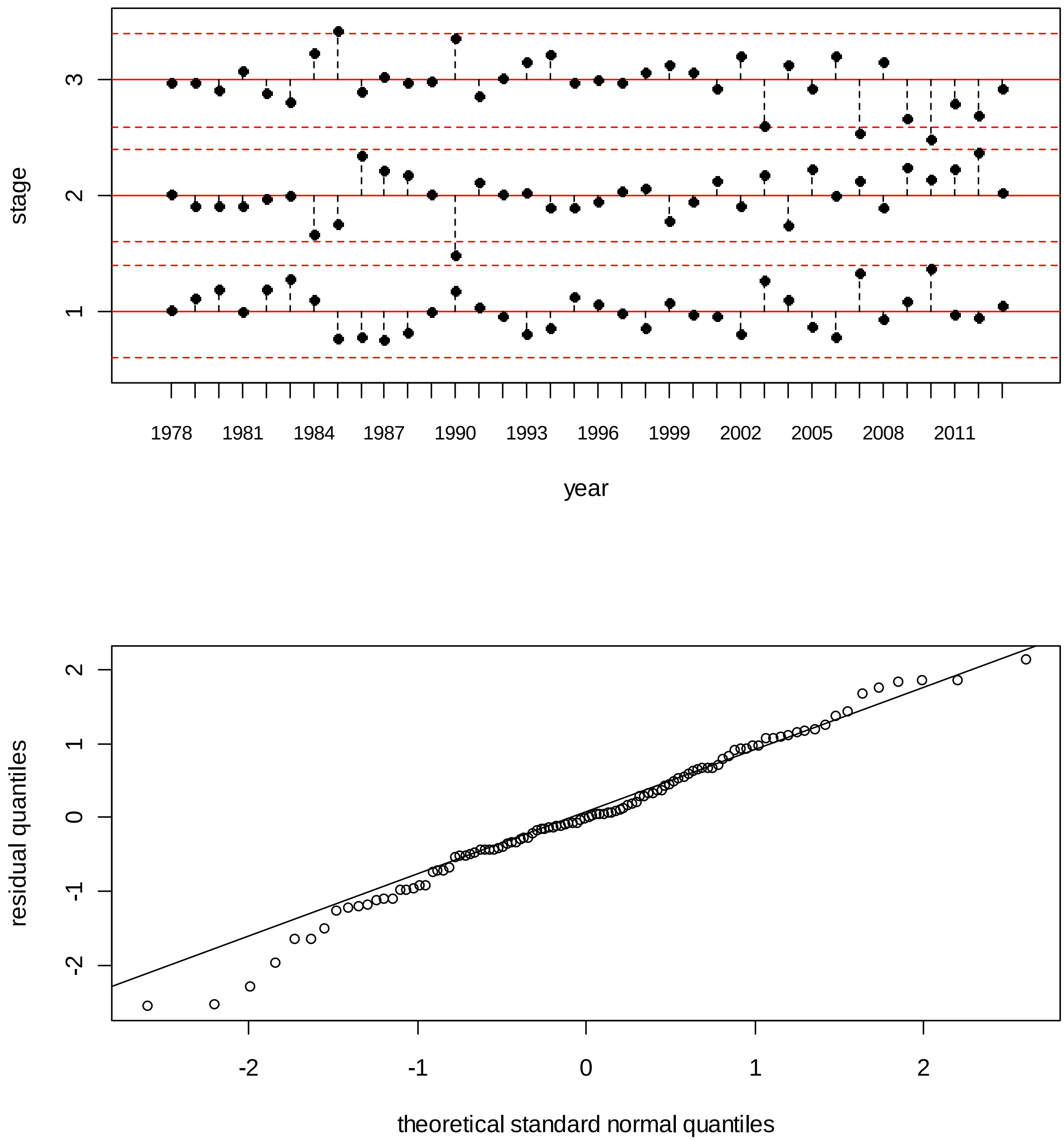


Figure 16. Model TC trawl-survey stage-proportion standardized residuals and normal qq-plot. This display should be compared against Figure 6.

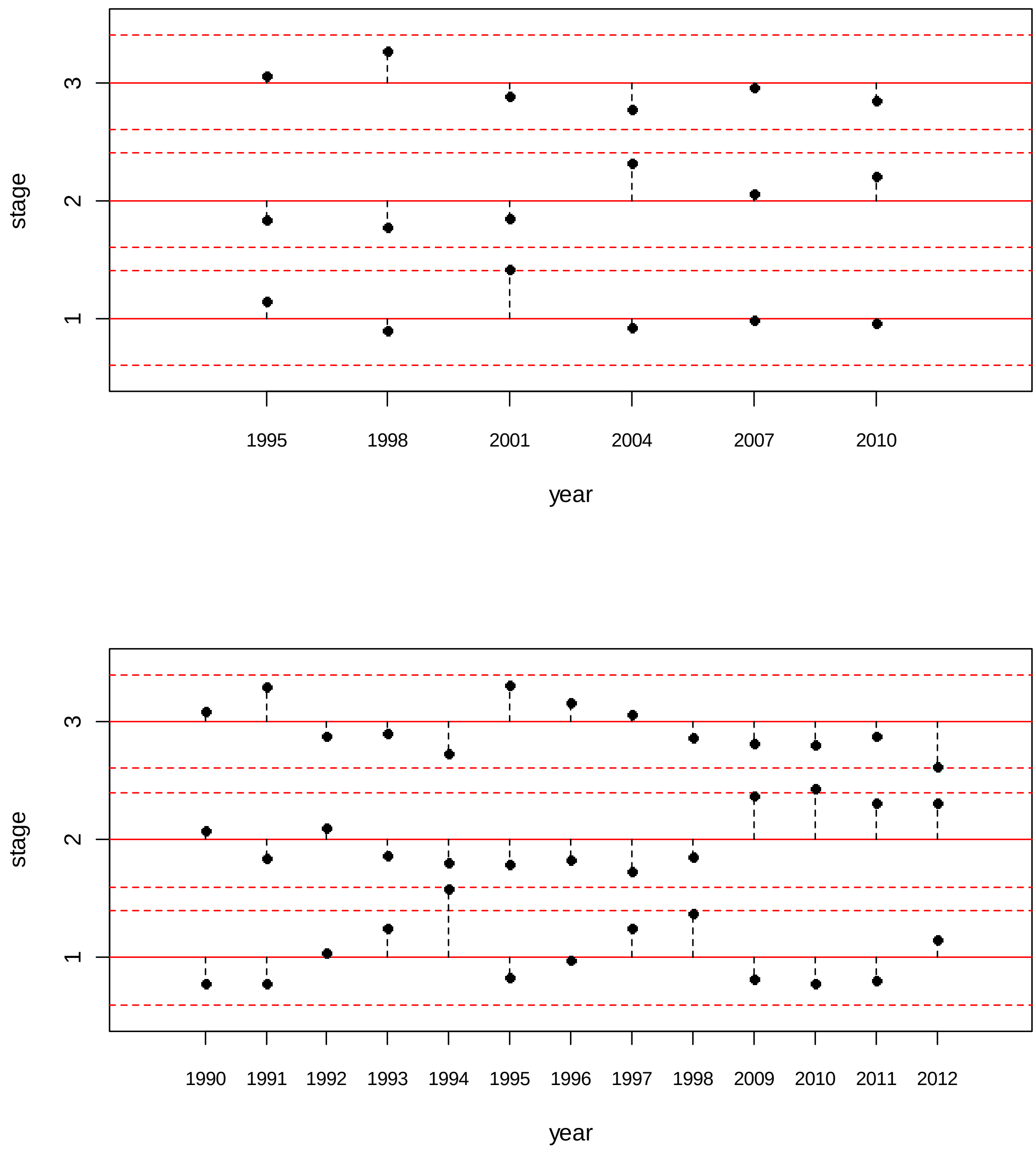


Figure 17. Base-model pot-survey (top panel) and crab-observer composition data standardized residuals.

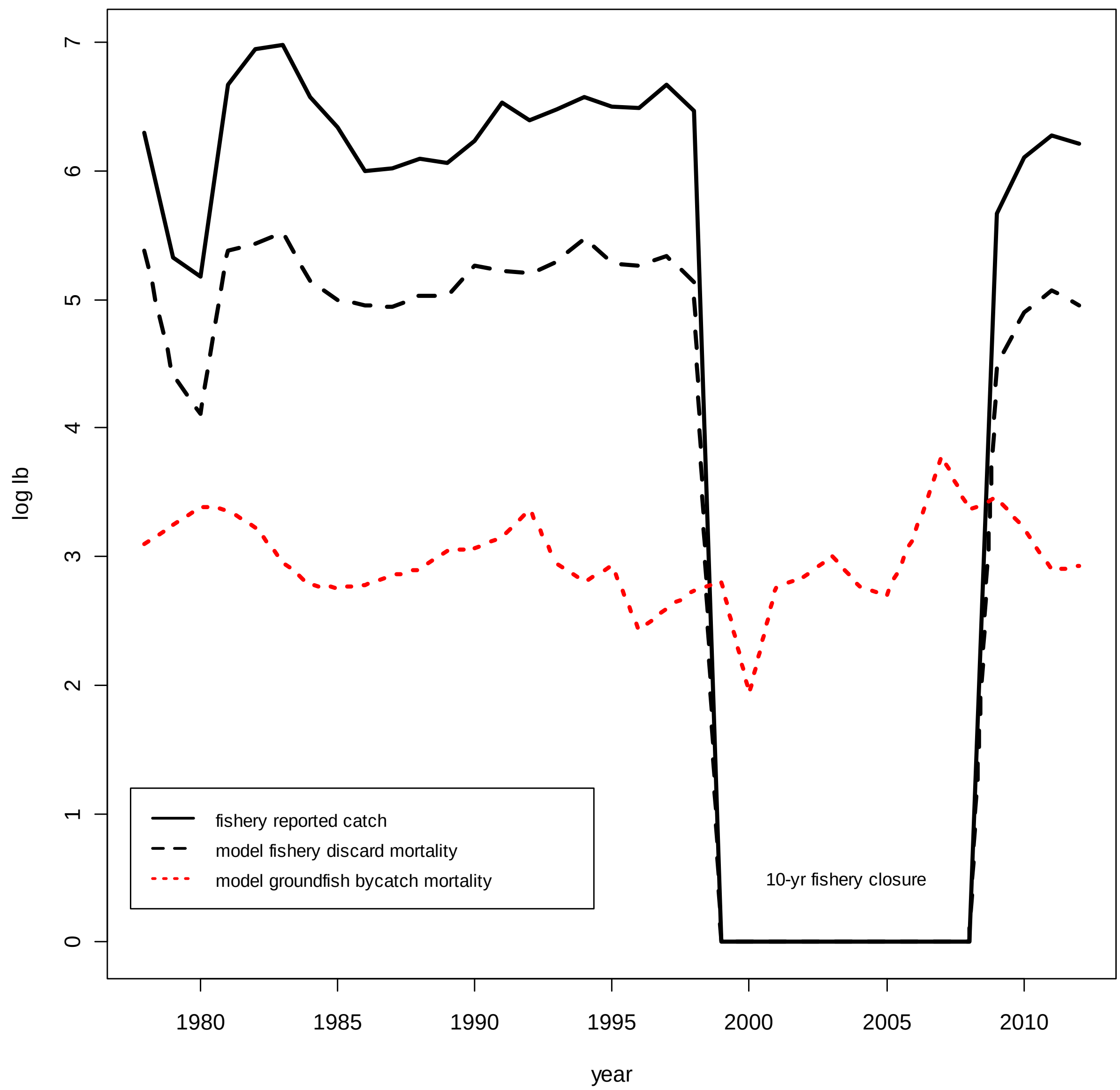


Figure 18. Components of SMBKC fishing mortality biomass for the years 1978/79 – 2012/13. Note logarithmic scale on the vertical axis.

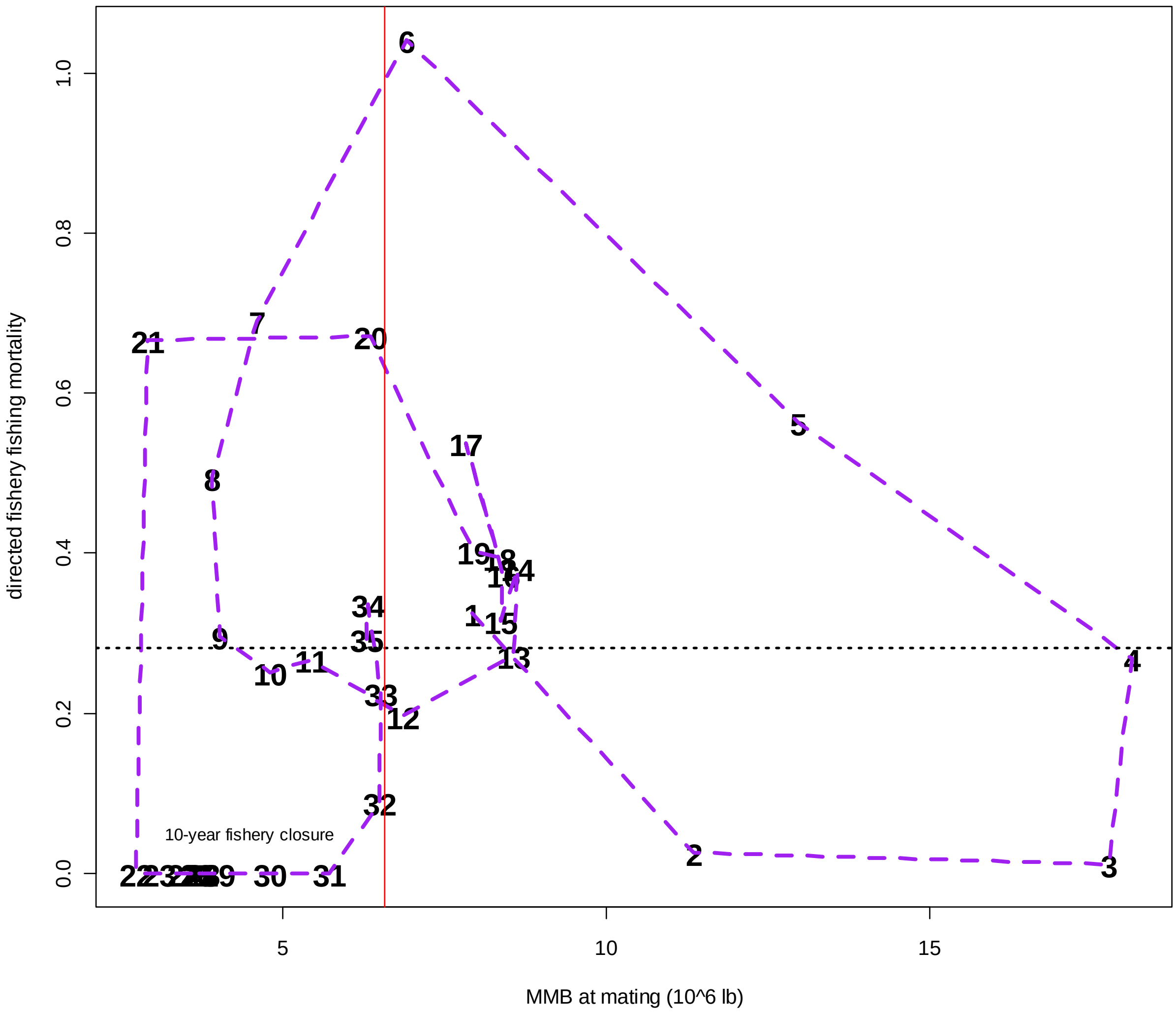


Figure 19. Base-model directed-fishery fishing mortality versus mature male biomass at time of mating for fishery years 1978/79 - 2012/13. Dotted horizontal line indicates model estimated geometric mean fishing mortality over years with a fishery. Vertical red line indicates model estimated B_{MSY} = average MMB_{MATING}.

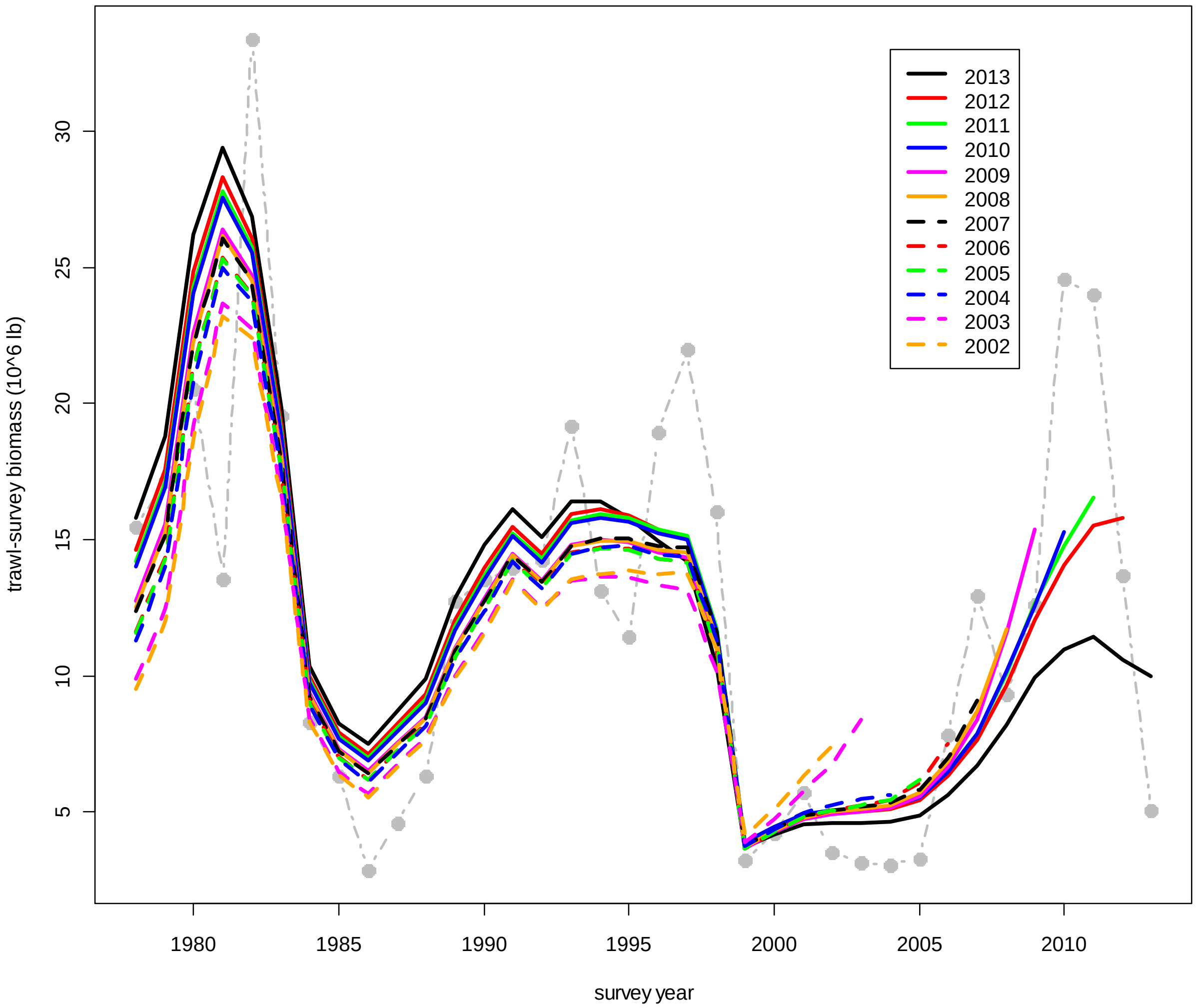


Figure 20. Retrospective plot of trawl-survey model-male (90mm+ CL) biomass for 2013 base-model configuration and terminal years 2002 – 2013. Estimates are based on all available data up to and including terminal-year trawl and pot surveys. Grey dotted line and points represent trawl-survey area-swept estimates.

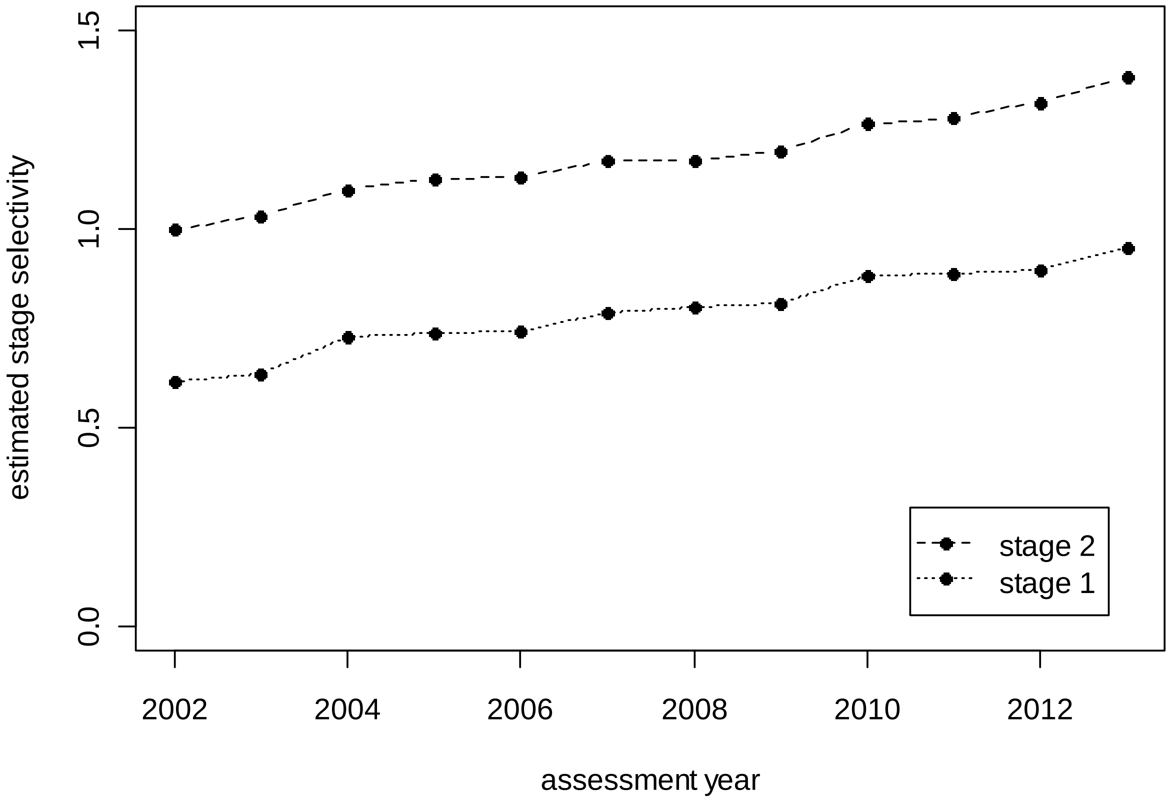


Figure 21. Retrospective 2013 base-model estimates of trawl-survey stage-1 and stage-2 selectivity for assessment years 2002 through 2013.

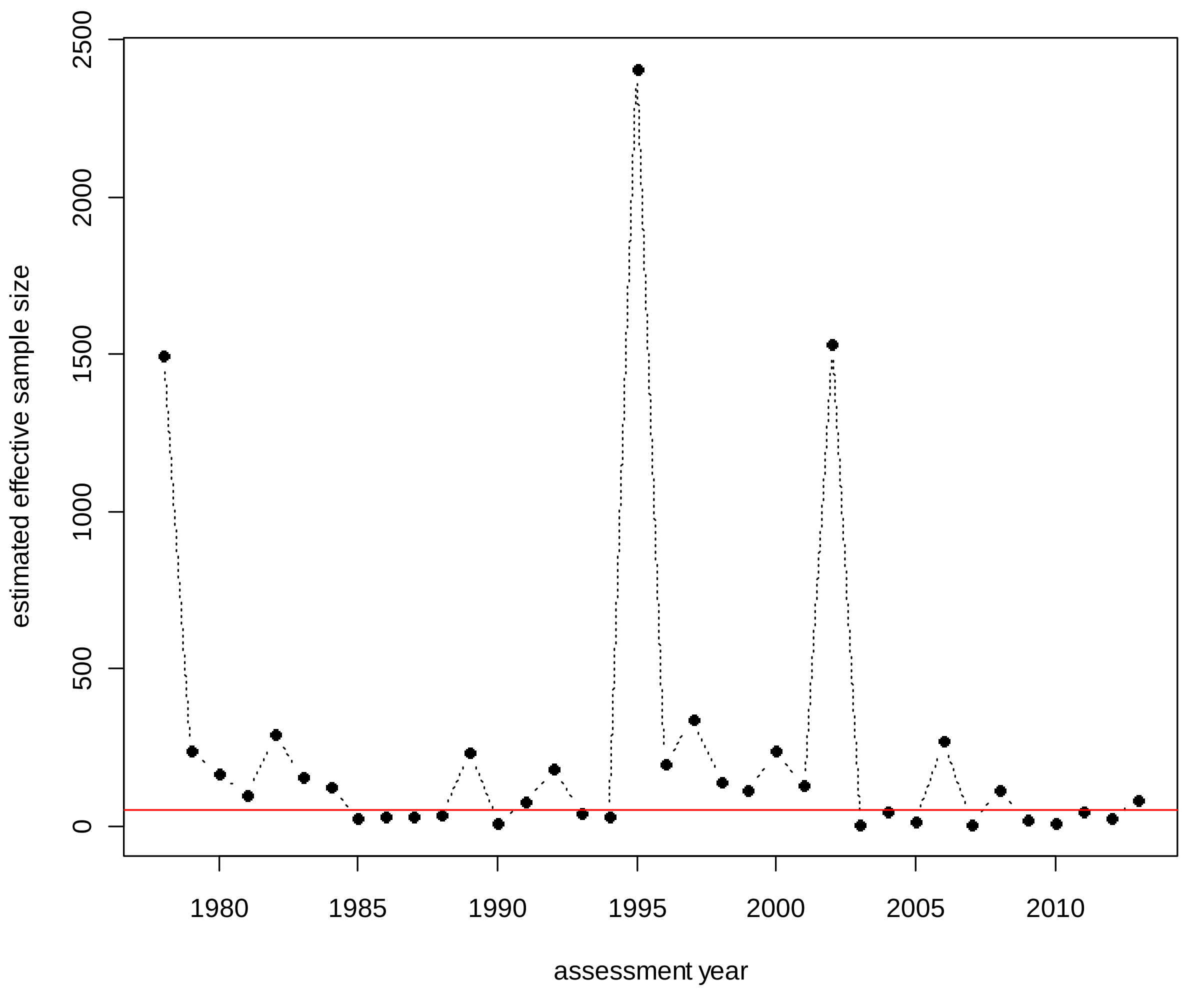


Figure 22. Trawl survey estimated effective sample size. The red line indicates the maximum model effective sample size (50).

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 (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. Differences characterizing alternative model scenarios considered in this document are described under **Model Selection and Evaluation** of §G. It is to be noted that for this 2013 assessment, biomass has replaced abundance as the trawl-survey index used in base-model estimation.

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	1978-2013	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	1978-2013	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 2009/10-2012/13	ADF&G crab observer program (fishery closed 1999/00-2008/09)
Groundfish trawl bycatch biomass	1992/93-2012/13	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93-2012/13	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

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

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

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

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

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

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

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

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

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

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

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. Note, in particular, that under all model configurations examined for this assessment, 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 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	35[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	22[a]
Mean log groundfish fixed-gear fishery mortality	1
Log groundfish fixed-gear fishery mortality deviations	22[a]
Total	119

[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 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.