Saint Matthew Island Blue King Crab Stock Assesssment 2022

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Executive Summary

1. **Stock**: Blue king crab, *Paralithodes platypus*, Saint Matthew Island (SMBKC), Alaska.
2. **Catches**: Peak historical harvest was 4,288 t (9.454 million pounds) in 1983/84[1]. 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 209 t (0.461 million pounds), less than half the 529.3 t (1.167 million pound) TAC. Following three more years of modest harvests supported by a fishery catch per unit effort (CPUE) of around 10 crab per pot lift, the fishery was again closed in 2013/14 due to declining trawl-survey estimates of abundance and concerns about the health of the stock. The directed fishery resumed again in 2014/15 with a TAC of 300 t (0.655 million pounds), but the fishery performance was relatively poor with a retained catch of 140 t (0.309 million pounds). The retained catch in 2015/16 was even lower at 48 t (0.105 million pounds) and the fishery has remained closed since 2016/17.
3. **Stock biomass**: The 1978-2022 NMFS trawl survey mean biomass is 5,448 t with the 2022 value being the 13th lowest (2,366 t; the tenth lowest since 2000). The 2022 biomass of $\geq$ 90 mm carapace length (CL) male crab is 5.22 million pounds (2,366t with a CV of 50%) which is 43% of the long term mean, and an 23% increase from the 2021 biomass. The most recent 3-year average of the NMFS survey is 46% of the mean value, indicating a decline in biomass compared to historical survey estimates, notably in 2010 and 2011 that were over four times the current average. However, the 2022 value increased from 2021, similar to the increase observed in the 2019 survey data. The ADFG pot survey last occurred in 2018, when the relative biomass index was the lowest in the time series (12% of the mean from the 11 surveys conducted since 1995). This survey is scheduled for 2022 but will not be completed until after the 2022 assessment cycle. Data will be included in the 2024 assessment. The assessment model estimates temper this increase and suggest that the stock (in survey biomass units) is presently at about 39% of the long term model-predicted survey biomass average, up some from the last three years. The trend from these values suggests a steady state in the last few years, which does not fit the 2019 observed survey data point well.
4. **Recruitment**: Recruitment is based on estimated number of male crab within the 90-104 mm CL size class in each year. The 2022 trawl-survey area-swept estimate of 0.617 million male SMBKC in this size class is ranked 20th, about the middle of the 44 years since 1978 and increased some from the last 5 years of survey data. The recent six-year (2016 - 2022) average recruitment is only 37% of the long-term mean. In the pot-survey, the abundance of this size group in 2017 was also the second-lowest in the time series (22% of the mean for the available pot-survey data) whereas in 2018 the value was the lowest observed at only 10% of the mean value.
5. **Management performance**: In this assessment, estimated total male catch is the sum of fishery-reported retained catch, estimated male discard mortality in the directed fishery, and estimated male bycatch mortality in the groundfish fisheries. Based on the reference model for SMBKC, the estimate

[1]1983/84 refers to a fishing year that extends from 1 July 1983 to 30 June 1984.

for mature male biomass was below the minimum stock-size threshold (MSST) in 2018/19 and is in an "overfished" condition, despite a directed fishery closure since the 2016/17 season (and hence overfishing has not occurred) (Tables 1, 3, and 4). Computations which indicate the relative impact of fishing (i.e., the "dynamic B_0") suggests, that the current spawning stock biomass has been reduced to 61% of what it would have been in the absence of fishing, assuming the same level of recruitment as estimated.

Table 1: Status and catch specifications (1000 t) for the base model.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained catch	Total male catch	OFL	ABC
2018/19	1.74	1.15	0.00	0.00	0.001	0.04	0.03
2019/20	1.67	1.06	0.00	0.00	0.001	0.04	0.03
2020/21	1.65	1.14	0.00	0.00	0.001	0.05	0.04
2021/22	1.63	1.18	0.00	0.00	0.001	0.05	0.04
2022/23		1.31				0.066	0.0497

Table 2: Status and catch specifications (million pounds) for the base model.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained catch	Total male catch	OFL	ABC
2018/19	3.84	2.54	0.000	0.000	0.002	0.08	0.07
2019/20	3.68	2.34	0.000	0.000	0.002	0.096	0.08
2020/21	3.64	2.52	0.000	0.000	0.002	0.112	0.08
2021/22	3.59	2.59	0.000	0.000	0.002	0.112	0.08
2022/23		2.9				0.146	0.11

6. **Basis for the OFL**: Estimated mature-male biomass (MMB) on 15 February is used as the measure of biomass for this Tier 4 stock, with males measuring $\geq$ 105 mm CL considered mature. The B_{MSY} proxy is obtained by averaging estimated MMB over a specific reference period, and current CPT/SSC guidance recommends using the full assessment time frame (1978 - 2021) as the default reference period.

Table 3: Basis for the OFL (1000 t) from the base model.

Year	Tier	B_{MSY}	Biomass (MMB_{mating})	B/B_{MSY}	F_{OFL}	γ	Basis for B_{MSY}	Natural mortality
2018/19	4b	3.7	1.15	0.35	0.043	1	1978-2017	0.18
2019/20	4b	3.48	1.06	0.31	0.042	1	1978-2018	0.18
2020/21	4b	3.34	1.14	0.32	0.047	1	1978-2019	0.18
2021/22	4b	3.30	1.18	0.34	0.048	1	1978-2020	0.18
2022/23	4b	3.26	1.31	0.4	0.061	1	1978-2021	0.18

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

Data used in this assessment have been updated to include the most recently available fishery data and survey data. This assessment includes two new survey data points from the 2021 and 2022 NMFS trawl-survey, which is included here since this assessment is now on a biennial cycle. The triennial ADF&G pot surveys were last conducted in 2018, and are back on a semi-triennial cycle, with the next survey planned for fall 2022, but will not be available for this assessment. There are new size composition data from the trawl survey. The assessment was updated with 2010-2021 groundfish trawl and fixed gear bycatch estimates based on NMFS Alaska Regional Office (AKRO) data. The directed fishery has been closed since 2016/17, so no recent fishery data are available.

Changes in Assessment Methodology

This assessment has used the General Model for Alaska Crab Stocks (GMACS) framework since 2016. The model is configured to track three stages of length categories and was first presented in May 2011 by W.Gaeuman, ADF&G, and accepted by the CPT in May 2012. A difference from the original approach and that used here is that natural and fishing mortalities are continuous within 5 discrete time blocks within a year (using the appropriate catch equation rather than assuming an applied pulse removal). The time blocks within a year in GMACS are controlled by changing the proportion of natural mortality that is applied to each block. Diagnostic output includes estimates of the "dynamic B_0" which simply computes the ratio of the estimated spawning biomass relative to the spawning biomass that would have occurred had there been no historical fishing mortality. Details of this implementation and other model details are provided in Appendix A.

Changes in Assessment Results

Both surveys indicate a low population over the past few years, with a declining trend from 2015 to 2020. Recent survey results, in 2019 and 2022, suggst some potential for growth in this stock. The "reference" model (model 16.0) is that which was selected for use in 2020, the year of the last full assessment. The base model presented here is the reference model with updated groundfish bycatch data for the 2020/21 and 2021/22 crab seasons and updated survey data - biomass and size composition - from the 2021 and 2022 NMFS trawl survey (model 16.0 2022).

Alternative models were considered in May 2022 but none were deemed candidates for fall 2022 specfications, therefore the "reference" model is the only one presented here.

B. Responses to SSC and CPT

CPT and SSC Comments on Assessments in General

Comment: *Regarding general code development, the SSC and CPT outstanding requests continue to be as follows:*

1. *Continued exploration of data weighting (Francis and other approaches) and evaluation of models with and without the 1998 natural mortality spike. The authors are encouraged to bring other models forward for CPT and SSC consideration*

   We continued with the iterative re-weighting for composition data (Table 13). We did not address models without the natural mortality spike. These have been considered previously.

2. *Retrospective analyses*

   These were provided in the Sept. 2020 SAFE document and are provided again in the Sept. 2022 final SAFE.

Comment: *Explore potential explanations for the discrepancy in the time trends of the two types of survey data, including movement hypotheses using spatial models (not necessarily VAST)*

Exploration of the spatial extent and density differences between the two surveys (NMFS and ADF&G) was done on all male crab ($\geq$ 90 mm CL) and all years of overlap between the two surveys included in the model for May 2022 (May 2022 documentation Appendix C). The authors plan to use this and further analyses to better characterize catchability/availability for the pot survey.

Comment: *Explore VAST estimates compared to design based, and ones that combine the two surveys*

Progress is underway to refine the SMBKC VAST estimates using preliminary code that incorporates the island effect. Jon Richar (NMFS) is working on these estimates. At the time of this final SAFE there are no additional improvements to this data set and therefore the VAST model is not presented as a model option. Future work on VAST models for this stock includes VAST data output for the NMFS trawl survey incorporating the island effect and VAST output using both survey data sets together.

Comment: *Random walk or exploration of catchability*

The initial model of time blocks for Q did not show much potential for this in May 2020, therefore time blocks were not a focus for May 2022. More coding work is needed to make a true random walk for catchability in GMACS and this will be added to model development.

Comment: *Consider increasing the number of size bins so that cohorts might be more easily tracked and growth better estimated*

A full review of the research and literature for blue king crab is underway but no changes to the assessment model size bins were considered in this review due to the lack of a concrete basis for these changes and concern over sample size reductions with increased size bins.

Comment: *Explore the assumed and estimated life history parameters (e.g., natural mortality, growth, and maturity) to ensure the best available science is being used to assess this stock.*

Specific research on St.Matthew blue king crab life history parameters is not available and therefore these are borrowed from other stocks/species. At this time only sensitivities of the model to increased natural mortality (M) were looked at in May 2022. Sensitivities to the model assumptions on growth and maturity will be explored at a later date.

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 Q (Figure 2), which is the Northern District of the Bering Sea king crab registration area and includes the waters north 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, has detected regional population differences between blue king crab collected from St. Matthew Island and the Pribilof Islands[2]. The 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 other lithodids such as golden 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 70 m (NPFMC 1998). The reproductive cycle appears to be annual for the first two reproductive cycles and biennial thereafter (Jensen and Armstrong 1989), and mature crab 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 mm carapace length (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. Spermataphore diameter also increased with increasing CL with an asymptote at ~ 100 mm CL. It was noted, however, that although spermataphore presence indicates physiological sexual maturity, it may not be an indicator of functional sexual maturity. For purposes of management of the St. Matthew Island blue king crab fishery, the State of Alaska uses 105 mm CL to define the lower size bound of functionally mature males (Pengilly and Schmidt 1995). Otto and Cummiskey (1990) report an average growth increment of 14.1 mm CL for adult SMBKC males.

Management History

The SMBKC fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990). Ten U.S. vessels harvested 545 t (1.202 million pounds) in 1977, and harvests peaked in 1983 when 164 vessels landed 4,288 t (9.454 million pounds) (Fitch et al. 2012; Table 7).

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 4,990 t (11.0 million pounds) as defined by the Fishery Management Plan (FMP) 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 the low numbers across all male crab size groups caught in the annual

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

NMFS eastern Bering Sea trawl survey from 1999 to 2005 (see survey data in next section). In November 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 State of Alaska regulatory harvest strategy (*5 AAC 34.917*), area closures, and gear modifications. In addition, commercial crab fisheries near St. Matthew Island were limited to fall and early winter to reduce the potential for bycatch mortality of vulnerable molting and mating crab.

NMFS declared the stock rebuilt on 21 September 2009, and the fishery was reopened after a 10-year closure on 15 October 2009 with a TAC of 529 t (1.167 million pounds), closing again by regulation on 1 February 2010. Seven participating vessels landed a catch of 209 t (0.461 million pounds) with a reported effort of 10,697 pot lifts and an estimated CPUE of 9.9 retained individual crab per pot lift. The fishery remained open the next three years with modest harvests and similar CPUE, but large declines in the NMFS trawl-survey estimate of stock abundance raised concerns about the health of the stock. This prompted ADF&G to close the fishery again for the 2013/14 season. The fishery was reopened for the 2014/15 season with a low TAC of 297 t (0.655 million pounds) and in 2015/16 the TAC was further reduced to 186 t (0.411 million pounds) then completely closed the 2016/17 season.

Although historical observer data are limited due to low sampling effort, bycatch of female and sublegal male crab from the directed blue king crab fishery off St. Matthew Island was relatively high historically, with estimated total bycatch in terms of number of crab captured sometimes more than twice as high as the catch of legal crab (Moore et al. 2000; ADF&G Crab Observer Database). Pot-lift sampling by ADF&G crab observers (Gaeuman 2013; ADF&G Crab Observer Database) indicates similar bycatch rates of discarded male crab since the reopening of the fishery (Table 5), with total male discard mortality in the 2012/13 directed fishery estimated at about 12% (88 t or 0.193 million pounds) of the reported retained catch weight, assuming 20% handling mortality.

These data suggest a reduction in the bycatch of females, which may be attributable to the later timing of the contemporary fishery and the more offshore distribution of fishery effort since reopening in 2009/10[3]. Some bycatch of discarded blue king crab has also been observed historically in the eastern Bering Sea snow crab fishery, but in recent years it has generally been negligible. 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. The NMFS observer data suggest that variable, but mostly limited, SMBKC bycatch has also occurred in the eastern Bering Sea groundfish fisheries (Table 6).

D. Data

Summary of New Information

Data used in this assessment were updated to include the most recently available fishery and survey estimates. Since this stock is now on a biennial assessment cycle, the new data for these models include updated bycatch estimates and 2021 and 2022 NMFS trawl survey biomass and size composition data. The assessment uses updated 1993-2021 groundfish and fixed gear bycatch estimates based on NMFS AKRO data. The directed fishery has been closed since the 2016/17 season, and therefore no directed fishery catch data are available. The data used in each of the new models are shown in Figure 3.

Major Data Sources

Major data sources used in this assessment include annual directed-fishery retained-catch statistics from fish tickets (1978/79-1998/99, 2009/10-2012/13, and 2014/15-2015/16; Table 7); results from the annual NMFS eastern Bering Sea trawl survey (1978-2022; Table 8); results from the ADF&G SMBKC pot survey (every third year during 1995-2013, then every year during 2015-2018; Table 9); mean somatic mass given

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

length category by year (Table 10); size-frequency information from ADF&G crab-observer pot-lift sampling (1990/91-1998/99, 2009/10-2012/13, and 2014/15-2016/17; Table 5); and the NMFS groundfish-observer bycatch biomass estimates (1991/92-2021/22; Table 6).

Figure 4 maps stations from which SMBKC trawl-survey and pot-survey data were obtained. Further information concerning the NMFS trawl survey as it relates to commercial crab species is available in Daly et al. (2014); see Gish et al. (2012) for a description of ADF&G SMBKC pot-survey methods. It should be noted that the two surveys cover different geographic regions and that each has in some years encountered proportionally large numbers of male blue king crab in areas not covered by the other survey (Figure 5). Crab-observer sampling protocols are detailed in the crab-observer training manual (ADF&G 2013). Groundfish SMBKC bycatch data come from the NMFS Regional office and have been compiled to coincide with the SMBKC management area.

Other Data Sources

The growth transition matrix used is based on Otto and Cummiskey (1990), as in the past. Other relevant data sources, including assumed population and fishery parameters, are presented in Appendix A, which also provides a detailed description of the model configuration used for this assessment.

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. 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 $\geq$ 90 mm 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 $\geq$ 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 comes from an estimated average growth increment of about 14 mm per molt for SMBKC (Otto and Cummiskey 1990).

Concerns about the pre-2011 assessment model led to the CPT and SSC recommendations that included development of an alternative model with provisional assessment based on survey biomass or some other index of abundance. An alternative 3-stage model was proposed to the CPT in May 2011, but a survey-based approach was requested for the Fall 2011 assessment. In May 2012 the CPT approved a slightly revised and better documented version of the alternative model for assessment. Subsequently, the model developed and used since 2012 was a variant of the previous four-stage SMBKC CSA model and similar in complexity to that described by Collie et al. (2005). Like the earlier model, it considered only male crab $\geq$ 90 mm in CL, but combined stages 3 and 4 of the earlier model, resulting in three stages (male size classes) defined by CL measurements of (1) 90-104 mm, (2) 105-119 mm, and (3) 120 mm+ (i.e., 120 mm and above). This consolidation was 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.

In 2016 the accepted SMBKC assessment model made use of the modeling framework GMACS encompassing a three-stage model structure (Webber et al. 2016). In that assessment, an effort was made to match the 2015 SMBKC stock assessment model to bridge a framework which provided greater flexibility and opportunity to evaluate model assumptions more fully.

Assessment Methodology

This assessment model again uses the modeling framework GMACS and is detailed in Appendix A. An updated version of GMACS (version 2.01.F, 2022-04-16) was used.

Model Selection and Evaluation

The base model is presented here as the last accepted model in 2020, with updated data from the 2020 crab year (fishery, survey, etc.) and 2021 survey, which was presented in May 2022. The current year's base model includes updated data from the 2021 crab year (fishery, survey, etc.) and 2022 survey data.

In summary, the following lists the models presented and the naming convention used:

1. **16.0 - 2021** : 2020 accepted model, fixed M = 0.18 all years except 1998 time block where M is estimated updated with 2020/21 groundfish bycatch & 2021 NMFS trawl survey data
2. **16.0 - 2022** : 2021 model (16.0 - 2021) updated with 2021/22 groundfish bycatch & 2022 NMFS trawl data

Note the change in naming convention (per SSC comments). The base model is model 16.0 since that was the year of model development and acceptance.

Results

a. Sensitivity to new data

The last accepted model for SMBKC was in Sept. 2020, new data added to the model listed here as "2021" includes both groundfish bycatch data for the 2020/21 crab season and NMFS trawl survey data - biomass and length compostions - from the 2021 summer survey. Additionally, the groundfish bycatch data were updated for past years due to some changes in the weights used to estimate crab bycatch in the groundfish fisheries (per. comm. NMFS AKRO). The 2022 reference model is compared here to the 2021 version of accepted model (both model 16.0) which was presented in May 2022 documentation. Comparison of the 2021 base model vs the current year (2022) is shown in Figures 6 and 7 with recruitment and spawning biomass shown in Figures 8 and 9, respectively. The 2021 and the 2022 base model have identical fits to the survey data, which is expected since there is only one new survey data point between these models. Historic estimates of SSB and recruitment are nearly identical also, but current year trends differ due to increased abundance in the 2022 survey data. As has been noted in the past, the reference model (16.0) still does not capture the recent survey declines in the ADF&G pot survey, or fit post 2005 trawl survey data points well.

b. Effective sample sizes and weighting factors

Observed and estimated effective sample sizes are compared in Table 11. Data weighting factors, standard deviation of normalized residuals (SDNRs), and median absolute residual (MAR) are presented in Table 13. Currently the SDNR and MAR are not outputting correctly for the survey data in GMACS. This is on the list to address at the next modeling workshop. In Sept. 2019 the SDNR for the trawl survey was acceptable at 1.66 in the base model. Francis (2011) weighting was applied in 2017 but given the relatively few size bins in this assessment, this application was suspended for this assessment.

In Sept. 2019 the SDNRs for the pot surveys showed a similar pattern in each of the scenarios, but are much higher suggesting an inconsistency between the pot survey data and the model structure and other data components. Rather than re-weighting, we chose to retain the values as specified, noting that down-weighting these data would effectively exclude the signal from this series. The MAR values for the trawl and pot surveys showed the same pattern among each of the scenarios as the SDNR. The MAR values for the trawl survey and pot survey size compositions were adequate, ranging from 0.61 to 0.69 for the reference case. The SDNRs for the directed pot fishery and other size compositions were similar to previous estimates.

c. Parameter estimates

Model parameter estimates for the GMACS reference model are summarized in Tables 12. Negative log-likelihood values and management measures for the reference model are provided in Tables 4 and 14.

Model fit and parameter estimates are very similar to the 2021 base model runs presented in May 2022 and compared here. Selectivity estimates for the directed fishery (Figure 10) as well as recruitment (Figure 8 are identical with an additional year of data. Fits to the NMFS trawl survey data and estimated mature male biomass (MMB) on 15 February are nearly identical among the models (Figure 9).

Estimated natural mortality in each year (M_t) is presented in Figure 11, showing the mortality event in the late 90s for all models. Estimates of fishing mortality, from the base model (16.0 2022), are shown to assist with the rebuilding and reference point time frame discussions (Figure 21). Fishing mortality can not be ruled out as being an influential factor in the current low stock status.

d. Evaluation of the fit to the data.

The base model (model 16.0 2022) fit to total male ($\geq$ 90 mm CL) NMFS trawl survey biomass tends to miss the recent peak around 2010 and fits recent survey data points on the lower end of their error bars (Figures 12). These fits are most likely being pulled down by the recent decline in the ADF&G pot survey data points, since the **no pot** model that was run in the 2020 final SAFE captures more of the error bars for these data points when the NMFS trawl survey data is the only abundance index in the model. However, this model, similar to the additional CV models presenting in May 2020, tend to overfit the recent trawl survey data points (Figure 12).

The base model fit to the pot survey CPUE is similar to past reference models, fitting the overall trends in the data but not capturing some of the high and recent low points (Figure 13).

For the trawl survey the standardized residuals for all model scenarios have a positive residual pattern in the last 16 years, continually under predicting the observed data points (Figure 14). The standardized residuals for the ADF&G pot survey have similar patterns to past reference model iterations (Figure 15).

Fits to the size compositions for trawl survey, pot survey, and commercial observer data are reasonable but miss the largest size category in some years (Figures 16, 17, and 18). Representative residual plots of the composition data generally have a similar fit to the three composition data sources (Figures 19). The model fits to different types of retained and discarded catch values performed as expected given the assumed levels of uncertainty on the input data (Figure 20).

e. Retrospective and historical analyses

The retrospective pattern of MMB for 10 peels for model 16.0 - 2022 is shown in Figure 24. The Mohn's rho value of -0.183 shows some degree of misspecification but not severe, especially for the last few years.

f. Uncertainty and sensitivity analyses.

Estimated standard deviations of parameters and selected management measures for the models are summarized for each individual model in Table 12. Model estimates of mature male biomass and OFL in 2022/23 are presented in Section F.

g. Comparison of alternative model scenarios.

Currently, the base model is still the most appropriate model for setting reference points and model specifications. Research on alternative model specifications that may address the disparities between the trawl and pot survey data are ongoing, and a preliminary spatial overview is presented in May 2022 document Appendix C.
Additionally, the overfished status of this stock lends itself to maintaining the status quo base model until an appropriate resolution is found to deal with the trawl and pot survey data fit issues. The recommended model for fall 2022 would be the base model (16.0) to maintain consistency for this stock during the rebuilding time frame.

F. Calculation of the OFL and ABC

The overfishing level (OFL) is the total catch associated with the F_{OFL} fishing mortality. The SMBKC stock is currently managed as Tier 4, and only a Tier 4 analysis is presented here. Thus, given stock estimates or suitable proxy values of B_{MSY} and F_{MSY}, along with two additional parameters α and β, F_{OFL} is determined by the control rule

$$F_{OFL} = \begin{cases} F_{MSY}, & \text{when } B/B_{MSY} > 1 \\ F_{MSY}\frac{(B/B_{MSY}-\alpha)}{(1-\alpha)}, & \text{when } \beta < B/B_{MSY} \leq 1 \end{cases} \tag{1}$$

$$F_{OFL} < F_{MSY} \text{ with directed fishery } F = 0 \text{ when } B/B_{MSY} \leq \beta$$

where B is quantified as mature-male biomass (MMB) at mating with time of mating assigned a nominal date of 15 February. Note that B is a function of the fishing mortality F_{OFL} (therefore numerical approximation of F_{OFL} is required). As implemented for this assessment, all calculations proceed according to the model equations given in Appendix A. F_{OFL} is taken to be full-selection fishing mortality in the directed pot fishery, and groundfish trawl and fixed-gear fishing mortalities set at their geometric mean values over years for which there are data-based estimates of bycatch-mortality biomass.

The currently recommended Tier 4 convention is to use the full assessment period, currently 1978 - 2021, to define a B_{MSY} proxy in terms of average estimated MMB and to set $\gamma = 1.0$ 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 $\beta = 0.25$. The F_{OFL}, OFL, ABC, and MMB in 2022/23 for the current base model are summarized in Table 4. The currently recommended ABC is 75% of the OFL (ABC buffer = 25%).

Table 4: Comparisons of management measures for the base model. Biomass and OFL are in tons.

Component	Ref
MMB_{2022}	1175.056
B_{MSY}	3255.221
MMB/B_{MSY}	0.404
F_{OFL}	0.061
OFL_{2022}	66.333
ABC_{2022}	49.749

G. Rebuilding Analysis and Update

This stock was declared overfished in fall of 2018 and a rebuilding plan was approved by the NPFMC in June 2020. The most updated rebuilding plan can be found on the NPFMC website for the June 2020 meeting. This assessment was moved to a biannual assessment in early 2021, with full assessments performed in even numbered years which falls in line with the two year rebuilding progress updates required under the rebuilding plan.

The recovery of this stock is highly dependent upon successful recruitment, which is likely linked to climate variability but not well understood. Survey biomass of males in the model has been low in 2021 and 2022, although both increased slightly from the low level in 2018 (Figure 6). Estimated MMB increased slightly in 2022, mostly due to an increase in recruitment and perhaps low fishing mortality on mature biomass. Model estimates of recruitment increased both in 2021 and 2022 suggesting some potential for future stock growth (Figures 8, 24 and 25). Projections of the stock 10 years into the future, under two potential recruitment periods, suggest stock growth under no directed fishery pressure (Figures 24 and 25). However, projections using a recent low recruitment period (1996 to 2021) have much more limited population growth than those using the entire recruitment time series to draw from. The 2022 ADF&G pot survey results, expected later this year, will aid in understanding the current status of this stock and its future trajectory.

H. Data Gaps and Research Priorities

The following topics have been listed as areas where more research on SMBKC is needed:

1. Growth increments and molting probabilities as a function of size.
2. Trawl survey catchability and selectivities.
3. Pot survey catchability and selectivities.
4. Temporal changes in spatial distributions near the island.
5. Natural mortality.

I. Projections and outlook

The outlook for recruitment is pessimistic and the abundance relative to the proxy B_{MSY} is low. The NMFS survey results in 2019 noted ocean conditions warmer than normal with an absence of a “cold pool” in the region. This could have detrimental effects on the SMBKC stock and should be carefully monitored. Relative to the impact of historical fishing, we again conducted a “dynamic-B_0” analysis. This procedure simply projects the population based on estimated recruitment but removes the effect of fishing. For the reference case, this suggests that the impact of fishing has reduced the stock to about 61% of what it would have been in the absence of fishing (Figure 22), supporting the hypothesis that fishing pressure is not the sole contributor to the decline of this stock in recent years. The other non-fishing contributors to the observed depleted stock trend (ignoring stock-recruit relationship) may reflect variable survival rates due to environmental conditions and also range shifts.

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Tables

Table 5: Observed proportion of crab by size class during the ADF&G crab observer pot-lift sampling. Source: ADF&G Crab Observer Database.

Year	Total pot lifts	Pot lifts sampled	Number of crab (90 mm+ CL)	Stage 1	Stage 2	Stage 3
1990/91	26,264	10	150	0.113	0.393	0.493
1991/92	37,104	125	3,393	0.133	0.177	0.690
1992/93	56,630	71	1,606	0.191	0.268	0.542
1993/94	58,647	84	2,241	0.281	0.210	0.510
1994/95	60,860	203	4,735	0.294	0.271	0.434
1995/96	48,560	47	663	0.148	0.212	0.640
1996/97	91,085	96	489	0.160	0.223	0.618
1997/98	81,117	133	3,195	0.182	0.205	0.613
1998/99	91,826	135	1.322	0.193	0.216	0.591
1999/00 - 2008/09			FISHERY CLOSED			
2009/10	10,484	989	19,802	0.141	0.324	0.535
2010/11	29,356	2,419	45,466	0.131	0.315	0.553
2011/12	48,554	3,359	58,666	0.131	0.305	0.564
2012/13	37,065	2,841	57,298	0.141	0.318	0.541
2013/14			FISHERY CLOSED			
2014/15	10,133	895	9,906	0.094	0.228	0.679
2015/16	5,475	419	3,248	0.115	0.252	0.633
2016/17 - 2021/22			FISHERY CLOSED			

Table 6: Groundfish SMBKC male bycatch biomass (t) estimates. Trawl includes pelagic trawl and non-pelagic trawl types. Source: J. Zheng, ADF&G, and author estimates based on data from R. Foy, NMFS. Estimates used after 2008/09 are from NMFS Alaska Regional Office.

Year	Trawl bycatch	Fixed gear bycatch
1978	0.000	0.000
1979	0.000	0.000
1980	0.000	0.000
1981	0.000	0.000
1982	0.000	0.000
1983	0.000	0.000
1984	0.000	0.000
1985	0.000	0.000
1986	0.000	0.000
1987	0.000	0.000
1988	0.000	0.000
1989	0.000	0.000
1990	0.000	0.000
1991	3.538	0.045
1992	1.996	2.268
1993	1.542	0.500
1994	0.318	0.091
1995	0.635	0.136
1996	0.500	0.045
1997	0.500	0.181
1998	0.500	0.907
1999	0.500	1.361
2000	0.500	0.500
2001	0.500	0.862
2002	0.726	0.408
2003	0.998	1.134
2004	0.091	0.635
2005	0.500	0.590
2006	2.812	1.451
2007	0.045	69.717
2008	0.272	6.622
2009	0.638	7.522
2010	0.360	9.564
2011	0.170	0.796
2012	0.011	0.739
2013	0.163	0.341
2014	0.010	0.490
2015	0.010	0.711
2016	0.229	1.630
2017	0.048	5.935
2018	0.001	1.224
2019	0.030	1.124
2020	0.001	0.671
2021	0.000	0.323

Table 7: Fishery characteristics and update. Columns include the 1978/79 to 2015/16 directed St. Matthew Island blue king crab pot fishery. The Guideline Harvest Level (GHL) and Total Allowable Catch (TAC) are in millions of pounds. Harvest includes deadloss. Catch per unit effort (CPUE) in this table is simply the harvest number / pot lifts. The average weight is the harvest weight / harvest number in pounds. The average CL is the average of retained crab in mm from dockside sampling of delivered crab. Source: Fitch et al 2012; ADF&G Dutch Harbor staff, pers. comm. Note that management (GHL) units are in pounds, for conserving space, conversion to tons is ommitted.

			Harvest					
Year	Dates	GHL/TAC	Crab	Pounds	Pot lifts	CPUE	avg wt	avg CL
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	8.0	1,931,990	9,454,323	133,944	14	4.9	137.2
1984/85	09/01 - 09/08	2.0-4.0	841,017	3,764,592	73,320	11	4.5	135.5
1985/86	09/01 - 09/06	0.9-1.9	436,021	2,175,087	46,988	9	5.0	139.0
1986/87	09/01 - 09/06	0.2-0.5	219,548	1,003,162	22,073	10	4.6	134.3
1987/88	09/01 - 09/05	0.6-1.3	227,447	1,039,779	28,230	8	4.6	134.1
1988/89	09/01 - 09/05	0.7-1.5	280,401	1,236,462	21,678	13	4.4	133.3
1989/90	09/01 - 09/04	1.7	247,641	1,166,258	30,803	8	4.7	134.6
1990/91	09/01 - 09/07	1.9	391,405	1,725,349	26,264	15	4.4	134.3
1991/92	09/16 - 09/20	3.2	726,519	3,372,066	37,104	20	4.6	134.1
1992/93	09/04 - 09/07	3.1	545,222	2,475,916	56,630	10	4.5	134.1
1993/94	09/15 - 09/21	4.4	630,353	3,003,089	58,647	11	4.8	135.4
1994/95	09/15 - 09/22	3.0	827,015	3,764,262	60,860	14	4.9	133.3
1995/96	09/15 - 09/20	2.4	666,905	3,166,093	48,560	14	4.7	135.0
1996/97	09/15 - 09/23	4.3	660,665	3,078,959	91,085	7	4.7	134.6
1997/98	09/15 - 09/22	5.0	939,822	4,649,660	81,117	12	4.9	139.5
1998/99	09/15 - 09/26	4.0	635,370	2,968,573	91,826	7	4.7	135.8
1999/00 - 2008/09				FISHERY CLOSED				
2009/10	10/15 - 02/01	1.17	103,376	460,859	10,697	10	4.5	134.9
2010/11	10/15 - 02/01	1.60	298,669	1,263,982	29,344	10	4.2	129.3
2011/12	10/15 - 02/01	2.54	437,862	1,881,322	48,554	9	4.3	130.0
2012/13	10/15 - 02/01	1.63	379,386	1,616,054	37,065	10	4.3	129.8
2013/14				FISHERY CLOSED				
2014/15	10/15 - 02/05	0.66	69,109	308,582	10,133	7	4.5	132.3
2015/16	10/19 - 11/28	0.41	24,076	105,010	5,475	4	4.4	132.6
2016/17				FISHERY CLOSED				
2017/18				FISHERY CLOSED				
2018/19				FISHERY CLOSED				
2019/20				FISHERY CLOSED				
2020/21				FISHERY CLOSED				
2021/22				FISHERY CLOSED				

Table 8: NMFS EBS trawl-survey area-swept estimates of male crab abundance (10^6 crab) and male (≥ 90 mm CL) biomass (10^6 lbs). Total number of captured male crab ≥ 90 mm CL is also given. Source: J.Richar, NMFS. The "+" refer to plus group.

	Abundance					Biomass		
Year	Stage-1 (90-104 mm)	Stage-2 (105-119 mm)	Stage-3 (120+ mm)	Total	CV	Total (90+ mm CL)	CV	Number of crabs
1978	2.213	1.991	1.521	5.726	0.411	15.064	0.394	157
1979	3.061	2.281	1.808	7.150	0.472	17.615	0.463	178
1980	2.856	2.563	2.541	7.959	0.572	22.017	0.507	185
1981	0.483	1.213	2.263	3.960	0.368	14.443	0.402	140
1982	1.669	2.431	5.884	9.984	0.401	35.763	0.344	271
1983	1.061	1.651	3.345	6.057	0.332	21.240	0.298	231
1984	0.435	0.497	1.452	2.383	0.175	8.976	0.179	105
1985	0.379	0.376	1.117	1.872	0.216	6.858	0.210	93
1986	0.203	0.447	0.374	1.025	0.428	3.124	0.388	46
1987	0.325	0.631	0.715	1.671	0.302	5.024	0.291	71
1988	0.410	0.816	0.957	2.183	0.285	6.963	0.252	81
1989	2.169	1.154	1.786	5.109	0.314	13.974	0.271	208
1990	1.053	1.031	2.338	4.422	0.302	14.837	0.274	170
1991	1.147	1.665	2.233	5.046	0.259	15.318	0.248	197
1992	1.074	1.382	2.291	4.746	0.206	15.638	0.201	220
1993	1.521	1.828	3.276	6.626	0.185	21.051	0.169	324
1994	0.883	1.298	2.257	4.438	0.187	14.416	0.176	211
1995	1.025	1.188	1.741	3.953	0.187	12.574	0.178	178
1996	1.238	1.891	3.064	6.193	0.263	20.746	0.241	285
1997	1.165	2.228	3.789	7.182	0.367	24.084	0.337	296
1998	0.660	1.661	2.849	5.170	0.373	17.586	0.355	243
1998	0.223	0.222	0.558	1.003	0.192	3.515	0.182	52
2000	0.282	0.285	0.740	1.307	0.303	4.623	0.310	61
2001	0.419	0.502	0.938	1.859	0.243	6.242	0.245	91
2002	0.111	0.230	0.640	0.981	0.311	3.820	0.320	38
2003	0.449	0.280	0.465	1.194	0.399	3.454	0.336	65
2004	0.247	0.184	0.562	0.993	0.369	3.360	0.305	48
2005	0.319	0.310	0.501	1.130	0.403	3.620	0.371	42
2006	0.917	0.642	1.240	2.798	0.339	8.585	0.334	126
2007	2.518	2.020	1.193	5.730	0.420	14.266	0.385	250
2008	1.352	0.801	1.457	3.609	0.289	10.261	0.284	167
2009	1.573	2.161	1.410	5.144	0.263	13.892	0.256	251
2010	3.937	3.253	2.458	9.648	0.544	24.539	0.466	388
2011	1.800	3.255	3.207	8.263	0.587	24.099	0.558	318
2012	0.705	1.970	1.808	4.483	0.361	13.669	0.339	193
2013	0.335	0.452	0.807	1.593	0.215	5.043	0.217	74
2014	0.723	1.627	1.809	4.160	0.503	13.292	0.449	181
2015	0.992	1.269	1.979	4.240	0.774	12.958	0.770	153
2016	0.535	0.660	1.178	2.373	0.447	7.685	0.393	108
2017	0.091	0.323	0.663	1.077	0.657	3.955	0.600	42
2018	0.154	0.232	0.660	1.047	0.298	3.816	0.281	62
2019	0.403	0.482	1.170	2.056	0.352	6.990	0.337	105
2021	0.423	0.168	0.682	1.273	0.496	4.253	0.427	59
2022	0.620	0.372	0.763	1.754	0.452	5.216	0.497	75

Table 9: Size-class and total CPUE (90+ mm CL) with estimated CV and total number of captured crab (90+ mm CL) from the 96 common stations surveyed during the ADF&G SMBKC pot surveys. Source: ADF&G.

Year	Stage-1 (90-104 mm)	Stage-2 (105-119 mm)	Stage-3 (120+ mm)	Total CPUE	CV	Number of crabs
1995	1.919	3.198	6.922	12.042	0.13	4624
1998	0.964	2.763	8.804	12.531	0.06	4812
2001	1.266	1.737	5.487	8.477	0.08	3255
2004	0.112	0.414	1.141	1.667	0.15	640
2007	1.086	2.721	4.836	8.643	0.09	3319
2010	1.326	3.276	5.607	10.209	0.13	3920
2013	0.878	1.398	3.367	5.643	0.19	2167
2015	0.198	0.682	1.924	2.805	0.18	1077
2016	0.198	0.456	1.724	2.378	0.19	777
2017	0.177	0.429	1.083	1.689	0.25	643
2018	0.076	0.161	0.508	0.745	0.14	286

Table 10: Mean weight (kg) by stage used in all of the models (provided as a vector of weights at length each year to GMACS).

Year	Stage-1	Stage-2	Stage-3
1978	0.7	1.2	1.9
1979	0.7	1.2	1.7
1980	0.7	1.2	1.9
1981	0.7	1.2	1.9
1982	0.7	1.2	1.9
1983	0.7	1.2	2.1
1984	0.7	1.2	1.9
1985	0.7	1.2	2.1
1986	0.7	1.2	1.9
1987	0.7	1.2	1.9
1988	0.7	1.2	1.9
1989	0.7	1.2	2.0
1990	0.7	1.2	1.9
1991	0.7	1.2	2.0
1992	0.7	1.2	1.9
1993	0.7	1.2	2.0
1994	0.7	1.2	1.9
1995	0.7	1.2	2.0
1996	0.7	1.2	2.0
1997	0.7	1.2	2.1
1998	0.7	1.2	2.0
1999	0.7	1.2	1.9
2000	0.7	1.2	1.9
2001	0.7	1.2	1.9
2002	0.7	1.2	1.9
2003	0.7	1.2	1.9
2004	0.7	1.2	1.9
2005	0.7	1.2	1.9
2006	0.7	1.2	1.9
2007	0.7	1.2	1.9
2008	0.7	1.2	1.9
2009	0.7	1.2	1.9
2010	0.7	1.2	1.8
2011	0.7	1.2	1.8
2012	0.7	1.2	1.8
2013	0.7	1.2	1.9
2014	0.7	1.2	1.9
2015	0.7	1.2	1.9
2016	0.7	1.2	1.9
2017	0.7	1.2	1.9
2018	0.7	1.2	1.9
2019	0.7	1.2	1.9
2020	0.7	1.2	1.9
2021	0.7	1.2	1.9

Table 11: Observed and input sample sizes for observer data from the directed pot fishery, the NMFS trawl survey, and the ADF&G pot survey.

	Number measured			Input sample sizes		
Year	Observer pot	NMFS trawl	ADF&G pot	Observer pot	NMFS trawl	ADF&G pot
1978		157			50	
1979		178			50	
1980		185			50	
1981		140			50	
1982		271			50	
1983		231			50	
1984		105			50	
1985		93			46.5	
1986		46			23	
1987		71			35.5	
1988		81			40.5	
1989		208			50	
1990	150	170		15	50	
1991	3393	197		25	50	
1992	1606	220		25	50	
1993	2241	324		25	50	
1994	4735	211		25	50	
1995	663	178	4624	25	50	100
1996	489	285		25	50	
1997	3195	296		25	50	
1998	1323	243	4812	25	50	100
1999		52			26	
2000		61			30.5	
2001		91	3255		45.5	100
2002		38			19	
2003		65			32.5	
2004		48	640		24	100
2005		42			21	
2006		126			50	
2007		250	3319		50	100
2008		167			50	
2009	19802	251		50	50	
2010	45466	388	3920	50	50	100
2011	58667	318		50	50	
2012	57282	193		50	50	
2013		74	2167		37	100
2014	9906	181		50	50	
2015	3248	153	1077	50	50	100
2016		108	777		50	100
2017		42	643		21	100
2018		62	286		31	100
2019		105			50	
2020						
2021		59			50	
2022		75			50	

Table 12: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the base (16.0) model 2022.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.582	0.136
$\log(\bar{R})$	13.872	0.194
$\log(n^0_1)$	14.954	0.174
$\log(n^0_2)$	14.513	0.210
$\log(n^0_3)$	14.328	0.207
q_{pot}	3.775	0.244
$\log(\bar{F}^{\text{df}})$	-2.132	0.052
$\log(\bar{F}^{\text{tb}})$	-9.892	36.302
$\log(\bar{F}^{\text{fb}})$	-8.098	0.072
log Stage-1 directed pot selectivity 1978-2008	-0.920	0.180
log Stage-2 directed pot selectivity 1978-2008	-0.560	0.132
log Stage-1 directed pot selectivity 2009-2017	-0.542	0.163
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.314	0.065
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.721	0.125
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.061	0.007
OFL	66.333	11.990

Table 13: Comparisons of data weights, SDNR and MAR (standard deviation of normalized residuals and median absolute residual) values for the model scenarios.

Component	Ref
NMFS trawl survey weight	1.00
ADF&G pot survey weight	1.00
Directed pot LF weight	1.00
NMFS trawl survey LF weight	1.00
ADF&G pot survey LF weight	1.00
SDNR NMFS trawl survey	0.00
SDNR ADF&G pot survey	0.00
SDNR directed pot LF	0.67
SDNR NMFS trawl survey LF	1.28
SDNR ADF&G pot survey LF	0.95
MAR NMFS trawl survey	0.00
MAR ADF&G pot survey	0.00
MAR directed pot LF	0.45
MAR NMFS trawl survey LF	0.57
MAR ADF&G pot survey LF	0.69

Table 14: Comparisons of negative log-likelihood values for the selected model scenarios.

Component	Ref
Pot Retained Catch	-68.46
Pot Discarded Catch	6.69
Trawl bycatch Discarded Catch	-8.54
Fixed bycatch Discarded Catch	-8.50
NMFS Trawl Survey	5.58
ADF&G Pot Survey CPUE	85.59
Directed Pot LF	-104.67
NMFS Trawl LF	-267.94
ADF&G Pot LF	-91.24
Recruitment deviations	62.93
F penalty	9.66
M penalty	6.46
Prior	13.71
Total	-358.73
Total estimated parameters	153.00

Table 15: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey and mature male biomass (MMB) in tons on 15 February for the **model configuration used in 2021**.

Year	n_1	n_2	n_3	MMB	CV MMB
1978	3122937	2004519	1667550	4565	0.177
1979	4231872	2371147	2291325	6466	0.123
1980	3797136	3181545	3465448	10173	0.084
1981	1436971	3206679	4831857	10634	0.063
1982	1605397	1832149	4862920	7554	0.072
1983	799872	1446836	3446713	4507	0.099
1984	655623	859410	1970674	3006	0.124
1985	920947	622428	1399170	2644	0.144
1986	1356725	704394	1181578	2590	0.140
1987	1321951	985240	1273467	3063	0.129
1988	1234325	1057437	1479166	3349	0.126
1989	2910079	1030542	1632387	3837	0.121
1990	1862455	1965213	1936234	4979	0.093
1991	1914728	1671906	2423614	5005	0.094
1992	2095878	1585932	2386042	5180	0.085
1993	2371914	1673774	2497020	5438	0.077
1994	1616875	1849901	2578653	5224	0.070
1995	1750933	1474195	2483692	5116	0.072
1996	1756356	1439471	2384211	4831	0.074
1997	914406	1429722	2287656	4208	0.093
1998	610090	941635	1867261	2784	0.108
1999	373770	312892	719259	1697	0.101
2000	413487	315665	793863	1840	0.083
2001	377241	339208	861544	1993	0.075
2002	131183	326398	926405	2099	0.070
2003	295947	182471	950601	1982	0.071
2004	188966	228330	913756	1965	0.071
2005	479186	182859	896277	1881	0.071
2006	715147	332562	886380	2030	0.072
2007	414453	515628	975313	2372	0.068
2008	855895	400471	1098998	2504	0.059
2009	696265	617941	1200387	2549	0.053
2010	612147	590641	1277639	2167	0.055
2011	469143	519068	1126466	1575	0.068
2012	231482	402707	809190	1022	0.105
2013	254986	235691	519700	1181	0.094
2014	210664	222775	577197	1112	0.101
2015	166431	189375	548146	1093	0.102
2016	173025	155983	545710	1141	0.100
2017	134486	149776	550552	1141	0.098
2018	145340	125652	546903	1109	0.097
2019	249238	124051	533288	1084	0.098
2020	183324	182525	531584	1145	0.109
2021	451372	164485	553444	1117	0.112

Table 16: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tons on 15 February for the 2022 base model.

Year	n_1	n_2	n_3	MMB	CV MMB
1978	3122850	2007780	1669435	4572	0.177
1979	4230979	2372239	2294531	6472	0.123
1980	3796217	3181409	3468595	10178	0.084
1981	1436807	3206116	4834331	10638	0.063
1982	1605055	1831905	4864719	7557	0.072
1983	800746	1446615	3448094	4510	0.099
1984	655832	859858	1971849	3009	0.124
1985	920343	622711	1400407	2647	0.144
1986	1357717	704181	1182710	2592	0.140
1987	1321809	985748	1274413	3065	0.128
1988	1234033	1057541	1480204	3351	0.126
1989	2910802	1030431	1633288	3838	0.121
1990	1863529	1965606	1937010	4980	0.093
1991	1915552	1672653	2424568	5007	0.094
1992	2096870	1586656	2387297	5183	0.085
1993	2373667	1674589	2498534	5442	0.077
1994	1618658	1851178	2580505	5229	0.070
1995	1754308	1475636	2486068	5123	0.072
1996	1759039	1441852	2387240	4839	0.073
1997	917159	1432036	2291635	4218	0.092
1998	612050	943970	1872032	2793	0.108
1999	374349	313362	720756	1700	0.101
2000	414408	316149	795406	1843	0.083
2001	377962	339891	863164	1996	0.075
2002	131439	327034	928173	2103	0.070
2003	296676	182827	952423	1986	0.071
2004	189493	228862	915527	1969	0.071
2005	479600	183334	898074	1885	0.071
2006	716037	332954	888161	2034	0.072
2007	416164	516263	977084	2376	0.068
2008	856425	401647	1100964	2509	0.058
2009	697517	618632	1202672	2554	0.052
2010	614006	591585	1280020	2172	0.054
2011	470738	520432	1129118	1581	0.067
2012	232754	404067	812254	1029	0.104
2013	256602	236895	523111	1188	0.093
2014	212116	224092	580807	1119	0.099
2015	167716	190636	551970	1101	0.101
2016	174500	157130	549664	1149	0.098
2017	135681	150994	554574	1149	0.096
2018	146980	126734	550991	1118	0.096
2019	253255	125340	537406	1093	0.097
2020	184191	185233	536057	1155	0.107
2021	433019	165874	558629	1175	0.119
2022	622385	300791	591585	1314	0.121

Figures

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

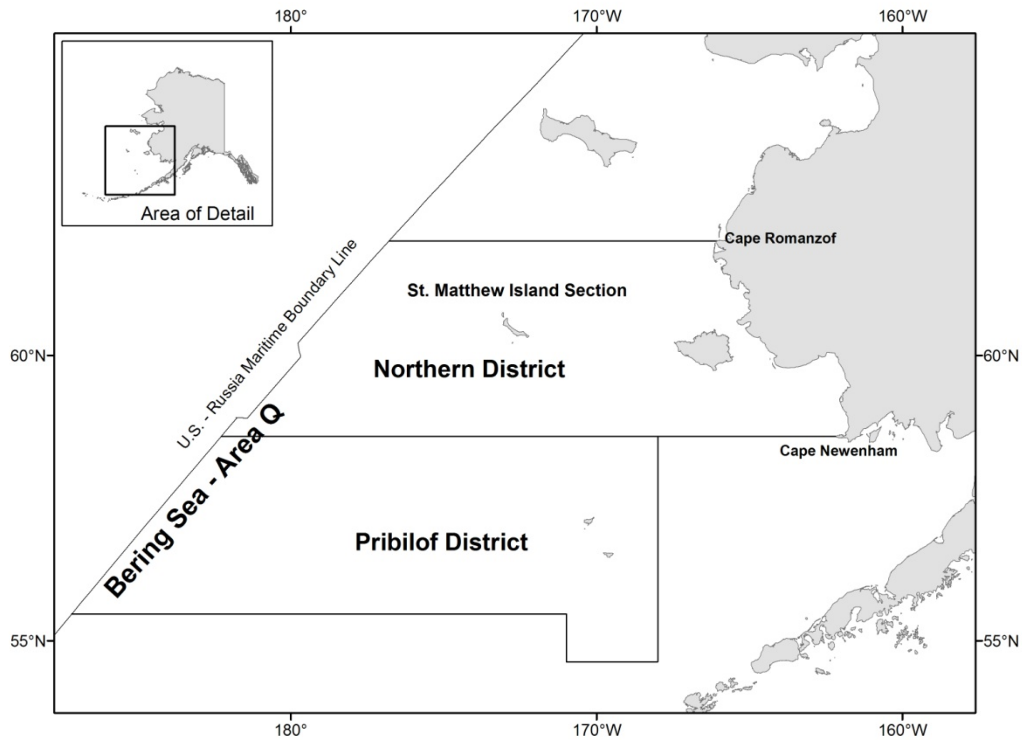

Figure 2: Blue king crab Registration Area Q (Bering Sea)

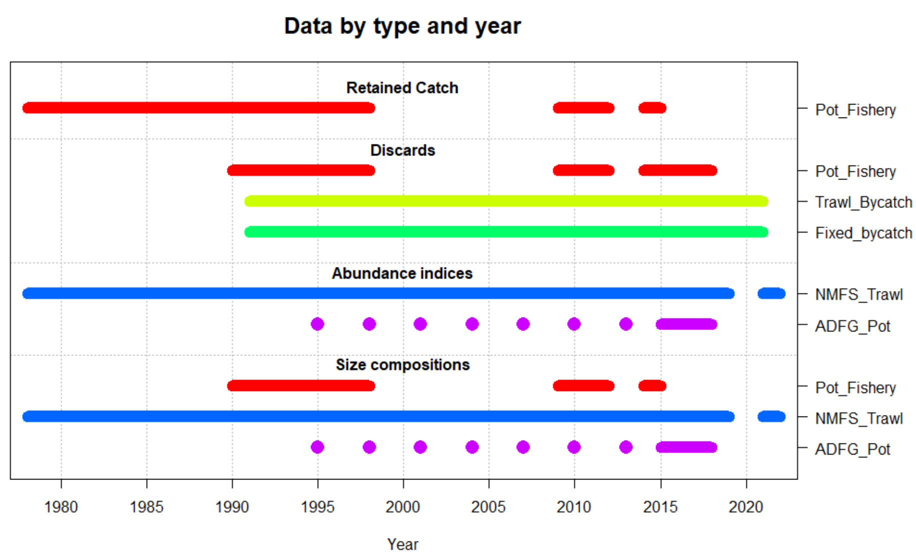

Figure 3: Data extent for the SMBKC assessment.

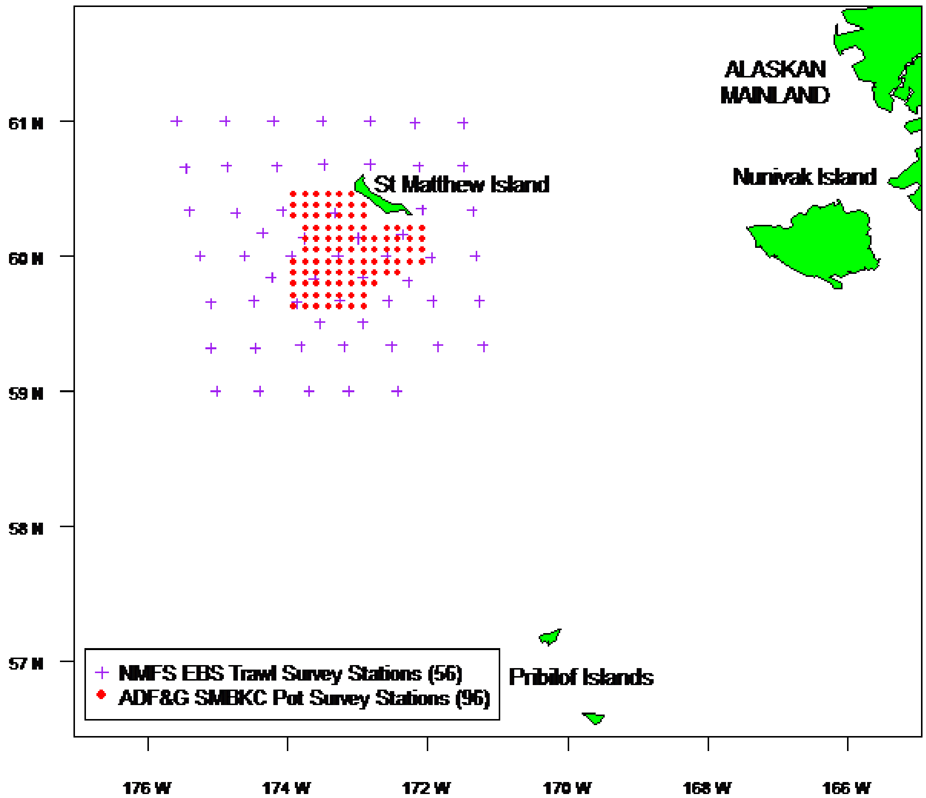

Figure 4: Trawl and pot-survey stations used in the SMBKC stock assessment.

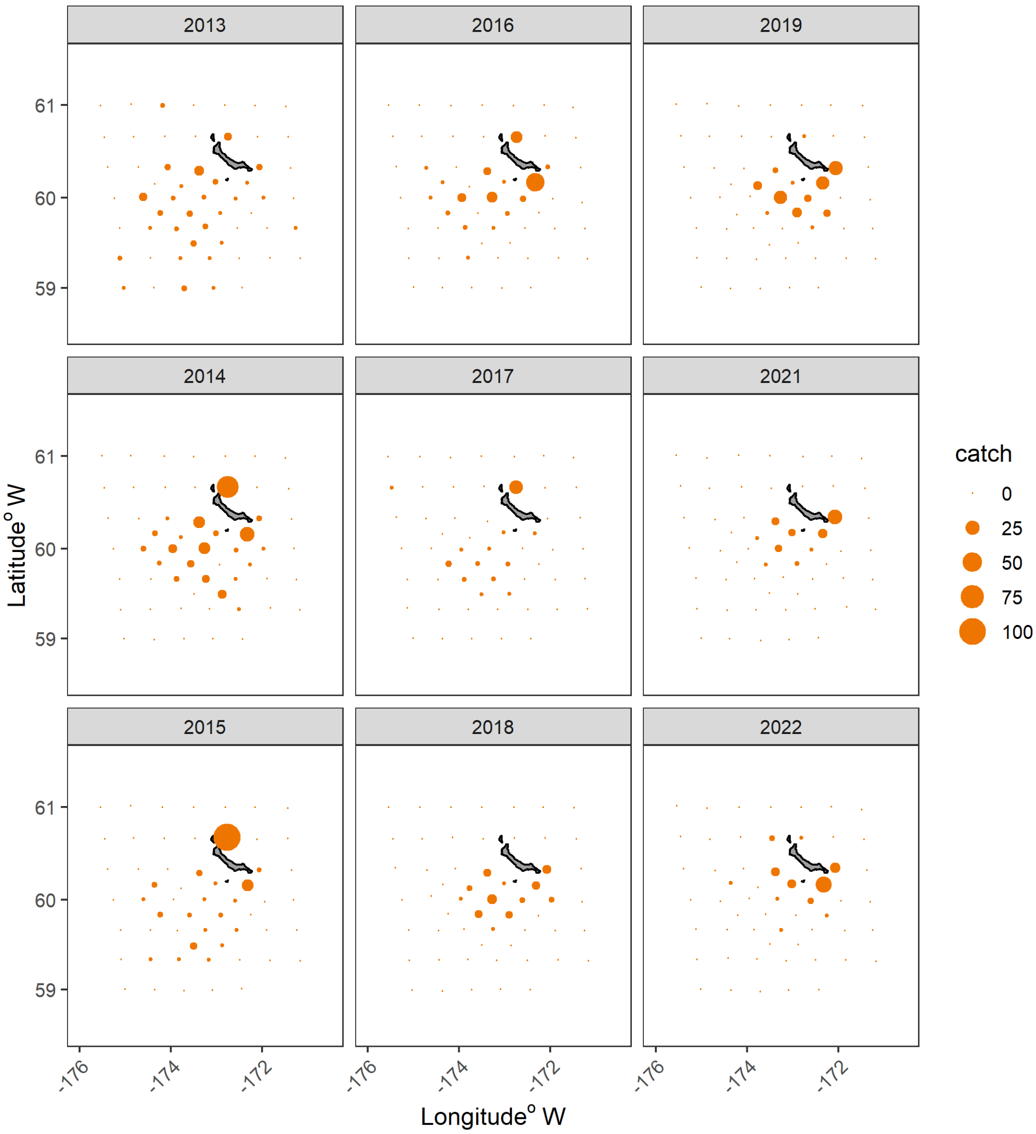

Figure 5: Catches (in numbers) of male blue king crab > 90mm CL from the 2013-2022 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock.

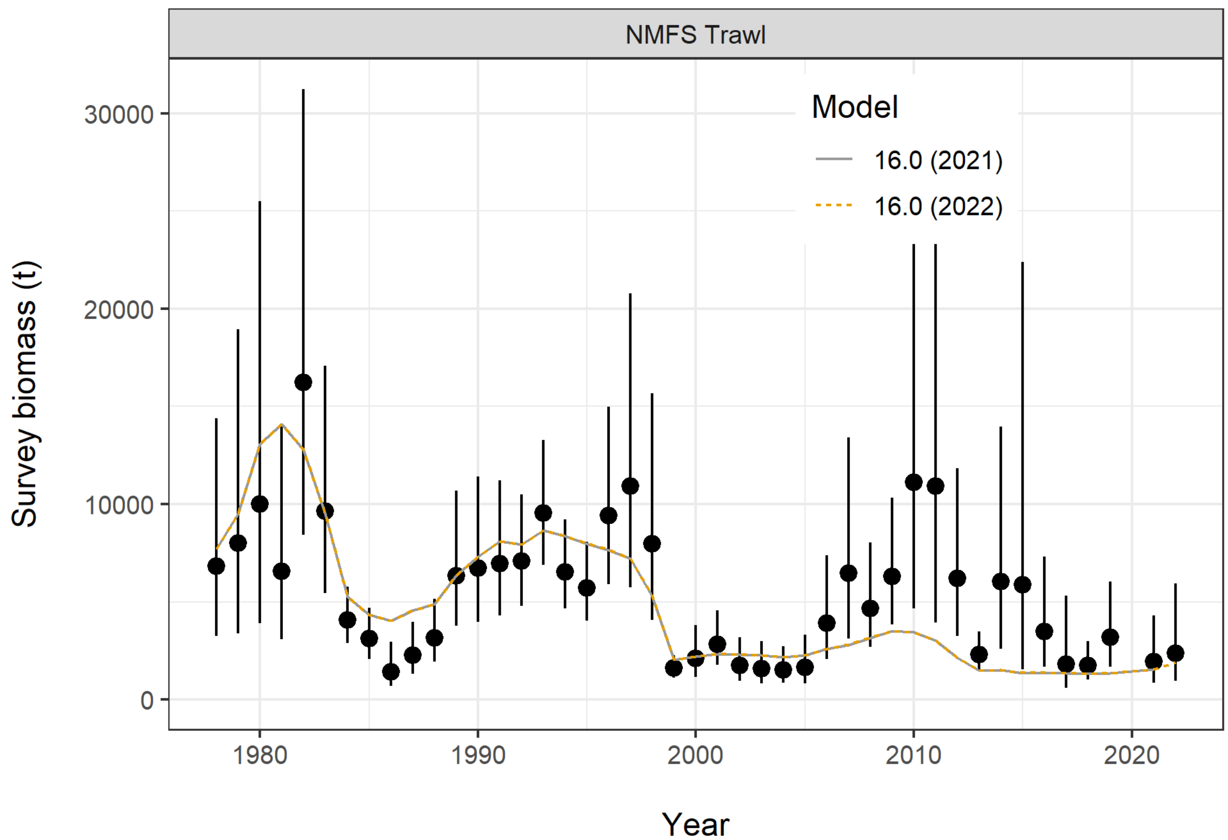

Figure 6: Fits to NMFS area-swept trawl estimates of total (> 90mm) male survey biomass for the base model only (16.0 ref for 2022 and 16.0 2021 accepted model). Both models have identical fits, as expected. Error bars are plus and minus 2 standard deviations.

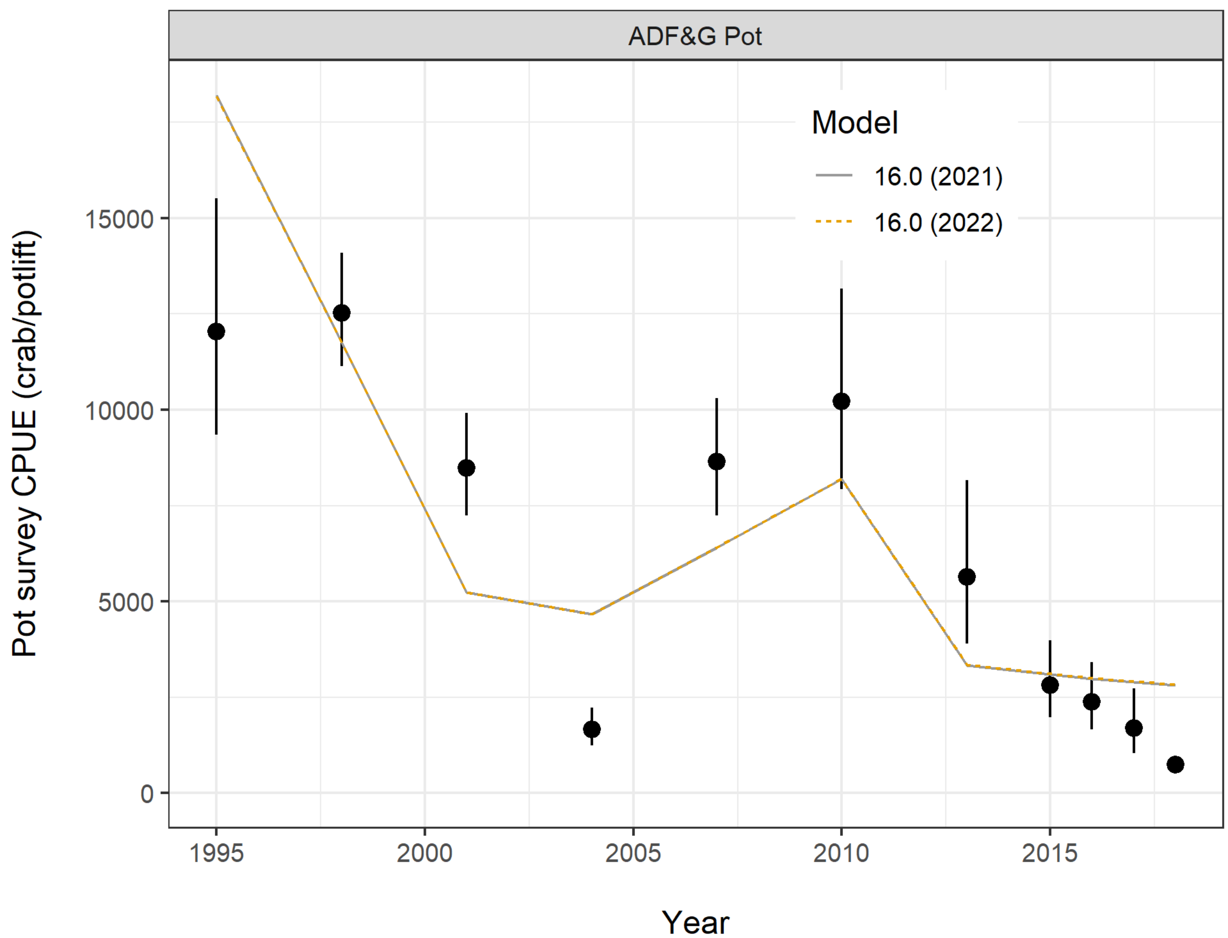

Figure 7: Comparisons of fits to CPUE from the ADFG pot surveys for model 16.0 the reference model in 2021 and 2022. Error bars are plus and minus 2 standard deviations.

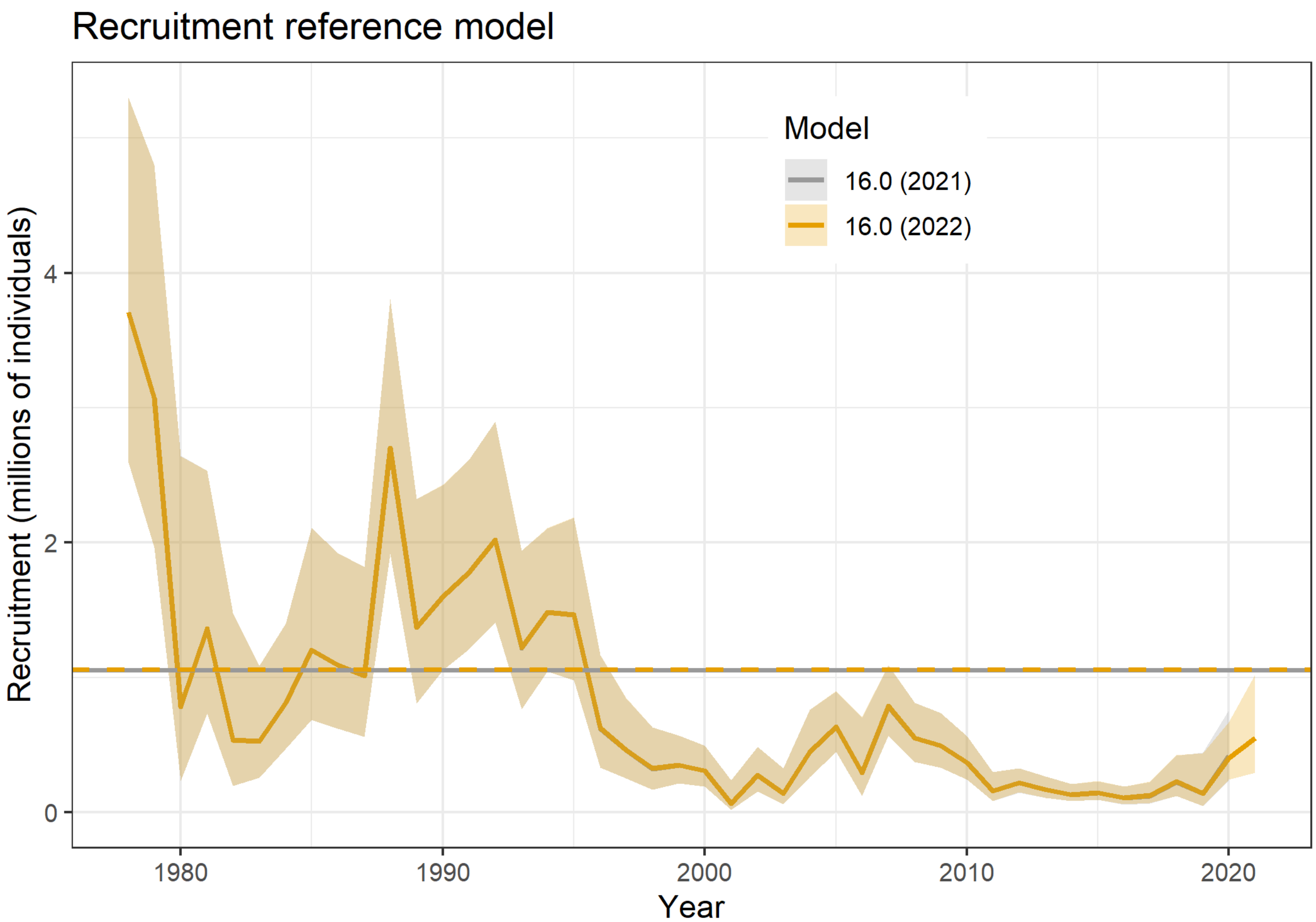

Figure 8: Estimated recruitment 1979-2021 comparing ref model (16.0) for 2021 and 2022. The solid horizontal lines in the background represent the estimate of the average recruitment parameter ($\bar{R}$) in each model scenario.

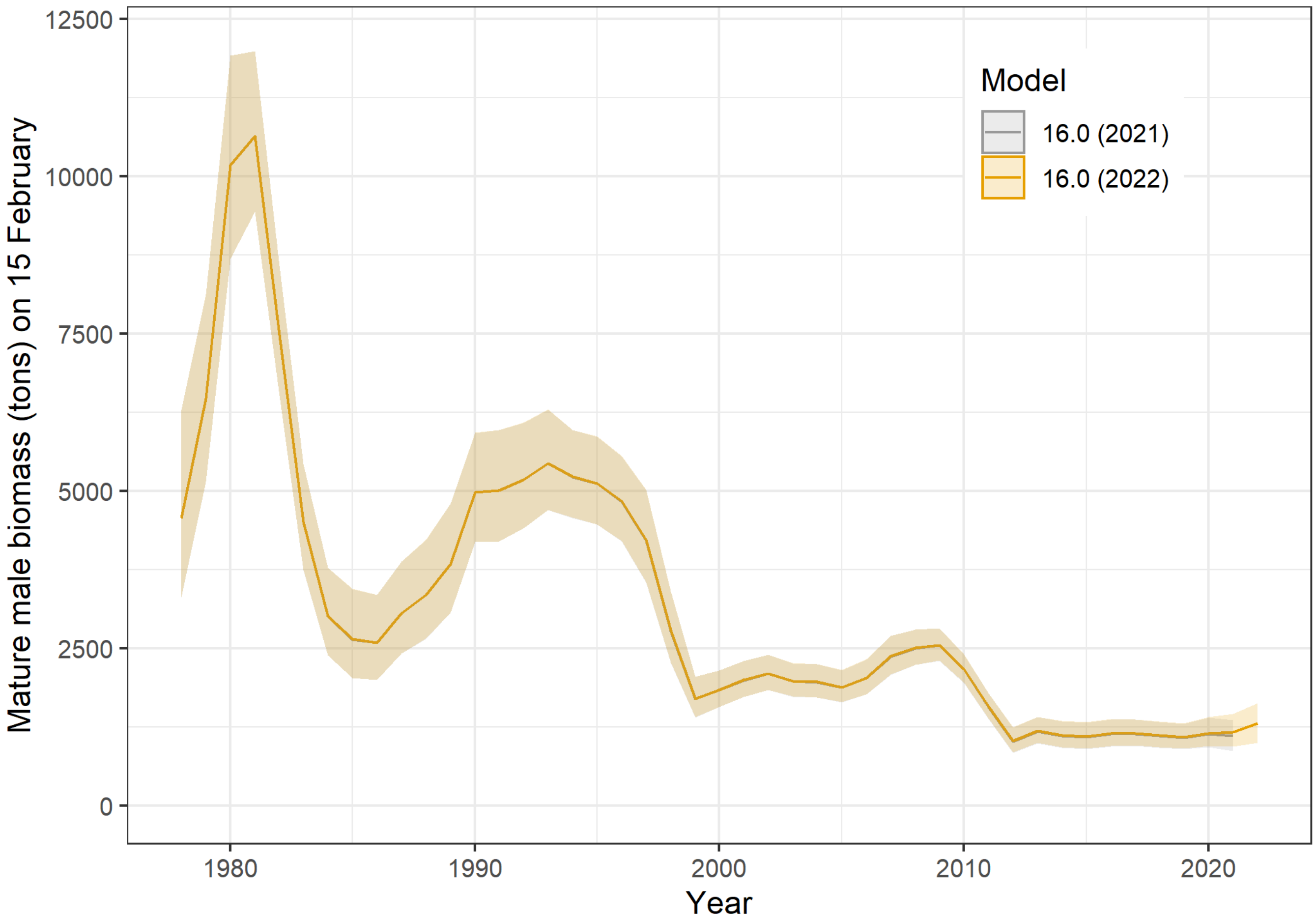

Figure 9: Sensitivity of new data in 2022 on estimated mature male biomass (MMB); 1978-2022.

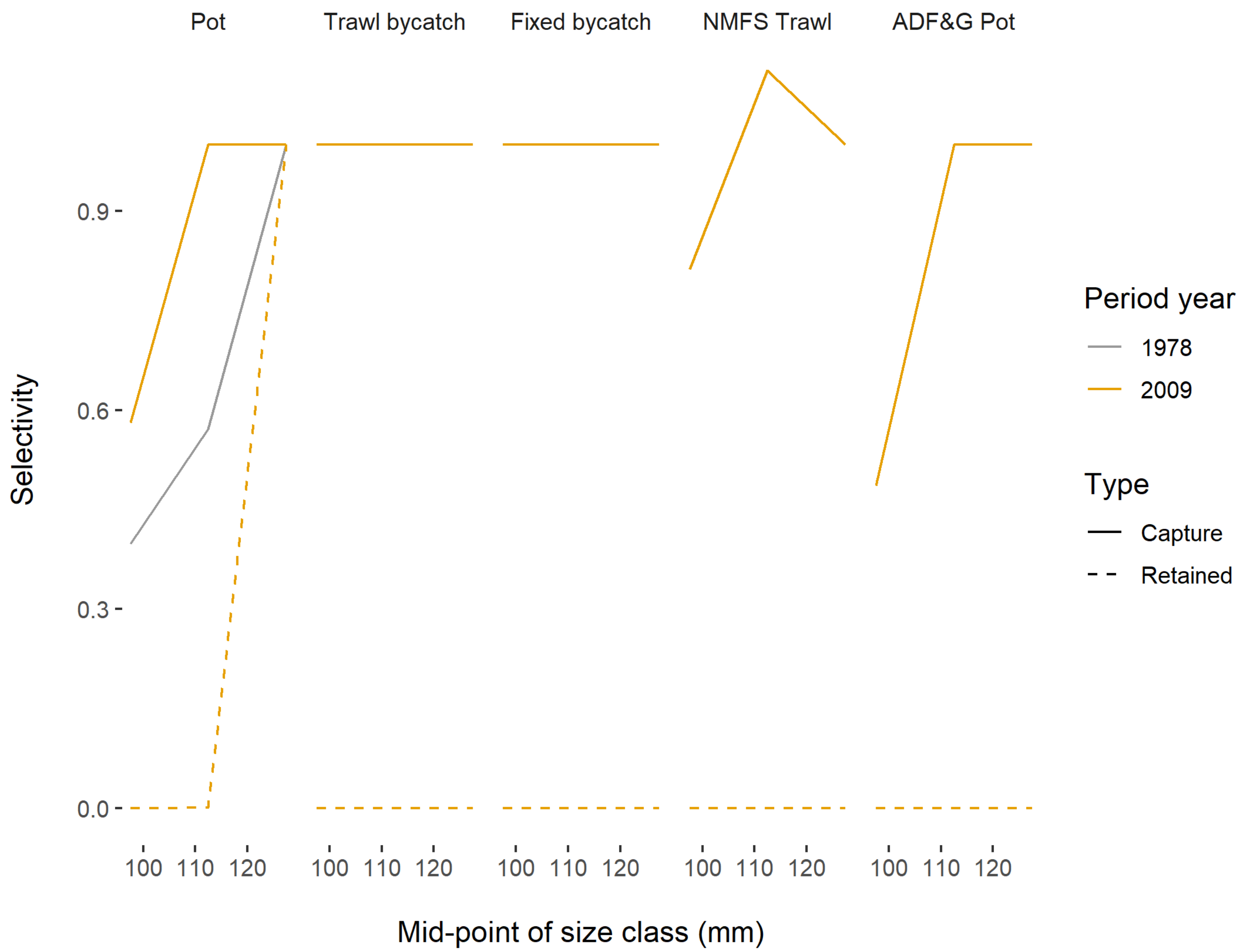

Figure 10: Comparisons of the estimated stage-1 and stage-2 selectivities for the different model scenarios (the stage-3 selectivities are all fixed at 1). Estimated selectivities are shown for the directed pot fishery, the trawl bycatch fishery, the fixed bycatch fishery, the NMFS trawl survey, and the ADFG pot survey. Two selectivity periods are estimated in the directed pot fishery, from 1978-2008 and 2009-2022.

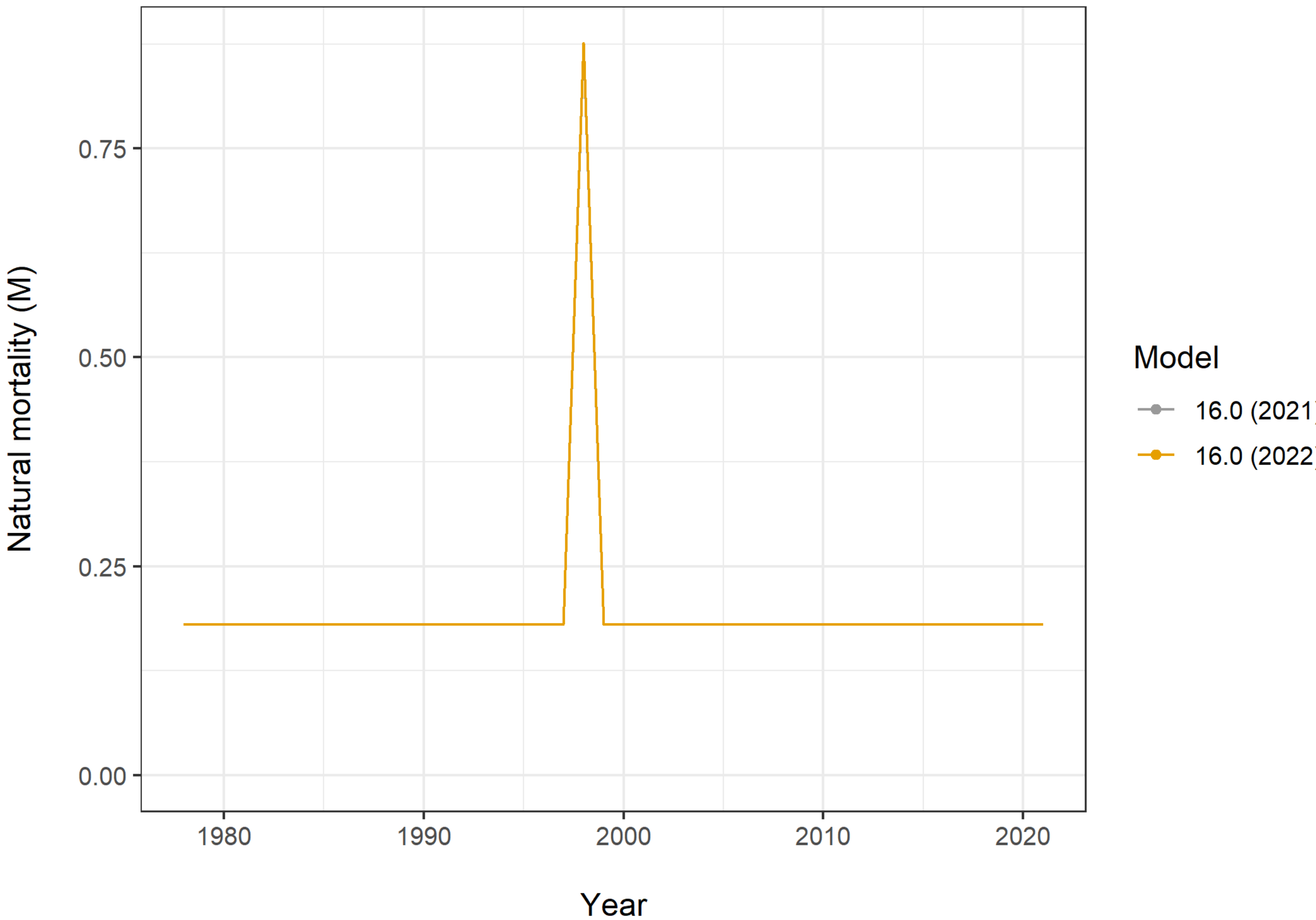

Figure 11: Time-varying natural mortality (M_t). Estimated pulse period occurs in 1998/99 (i.e. M_{1998}).

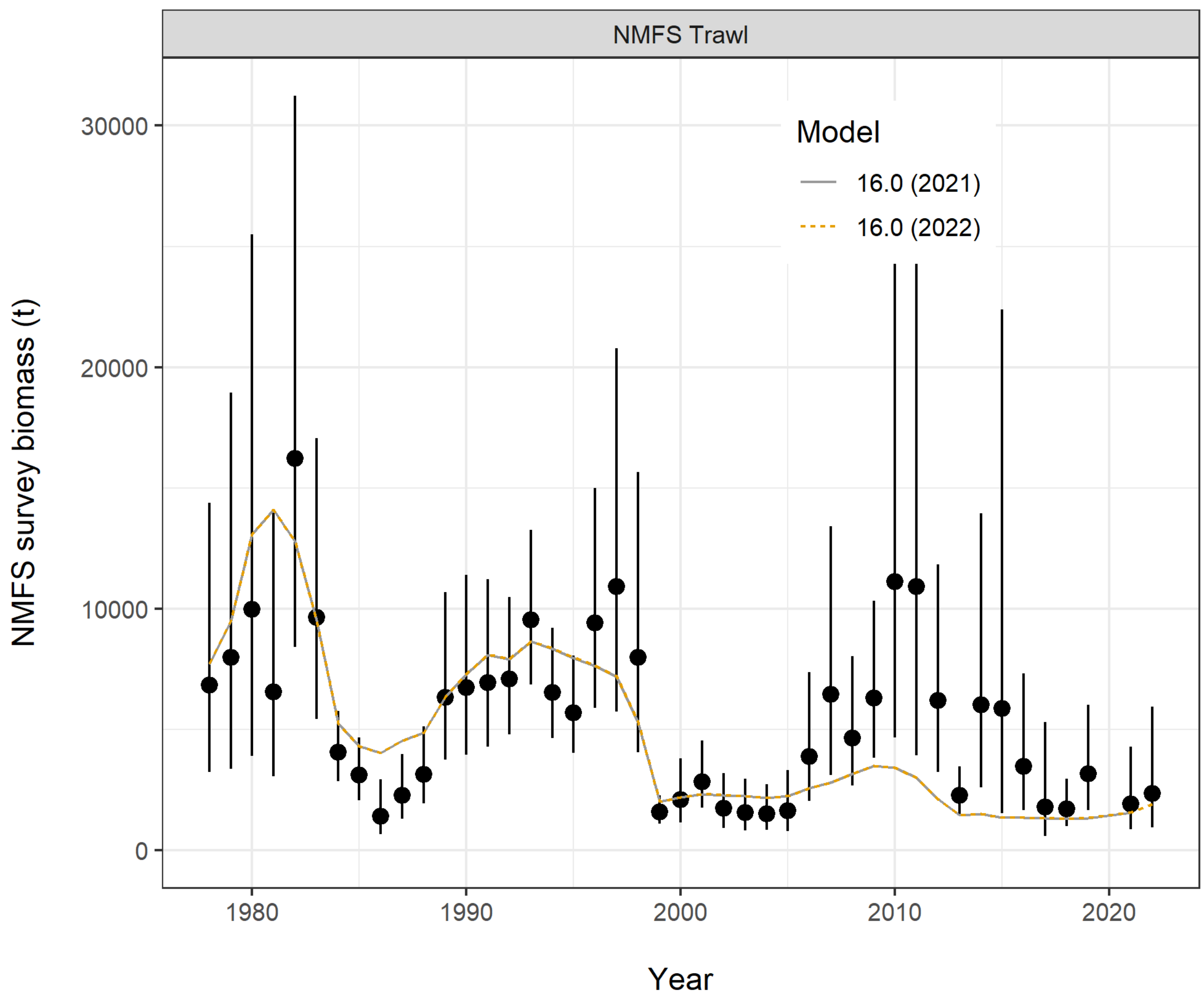

Figure 12: Comparisons of area-swept estimates of total (90+ mm CL) male survey biomass (tons) and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

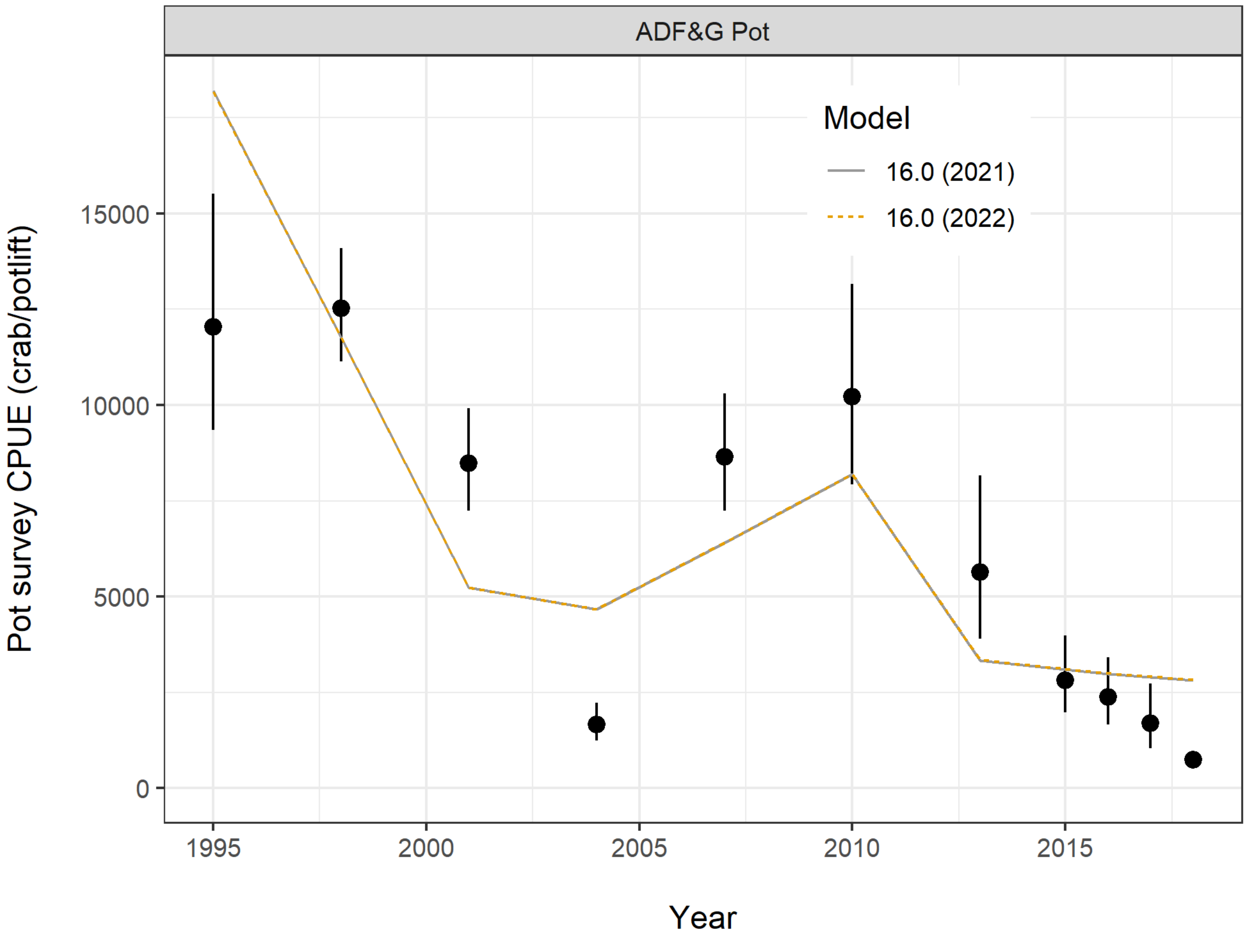

Figure 13: Comparisons of total (90+ mm CL) male pot survey CPUEs and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

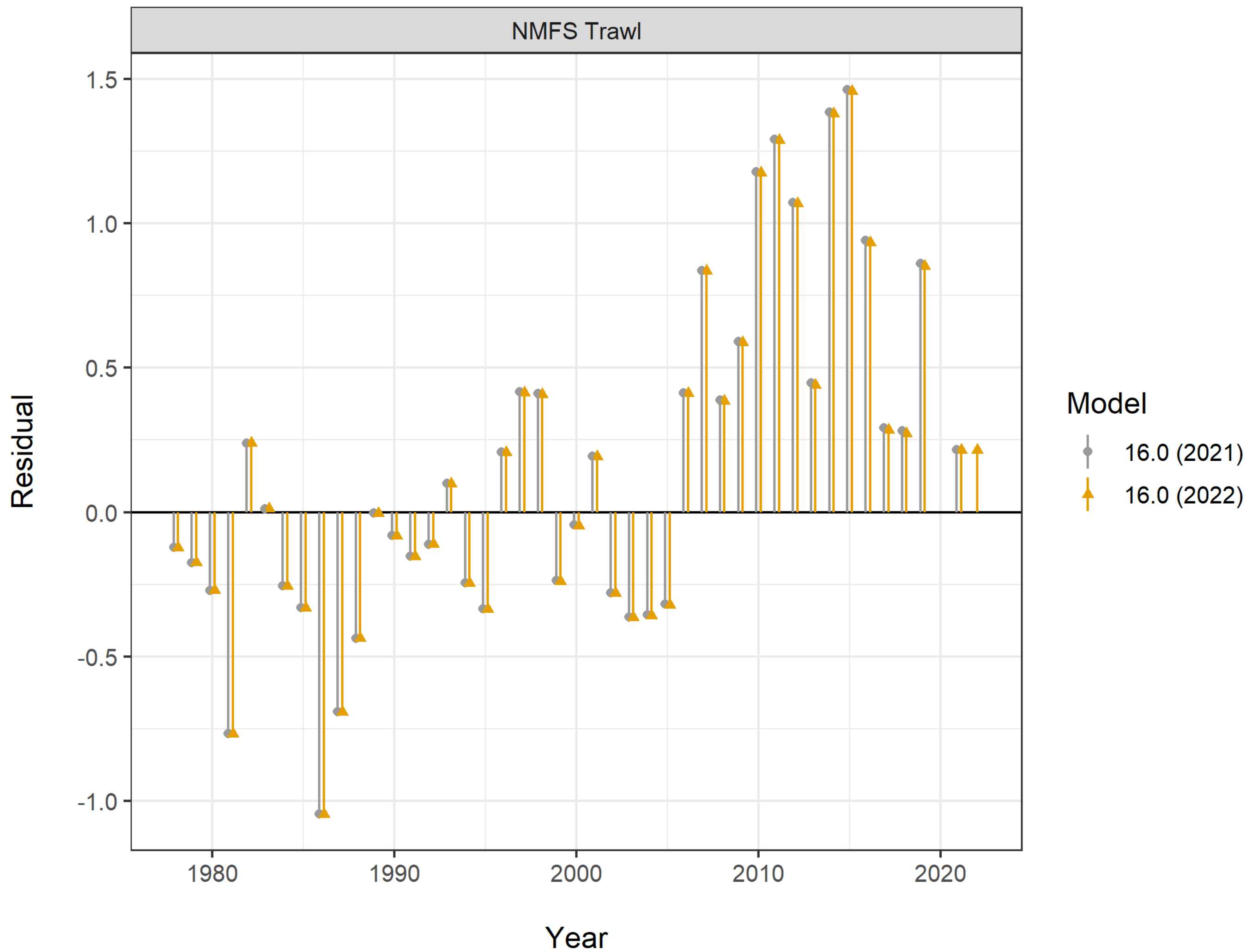

Figure 14: Standardized residuals for area-swept estimates of total male survey biomass for the model scenarios.

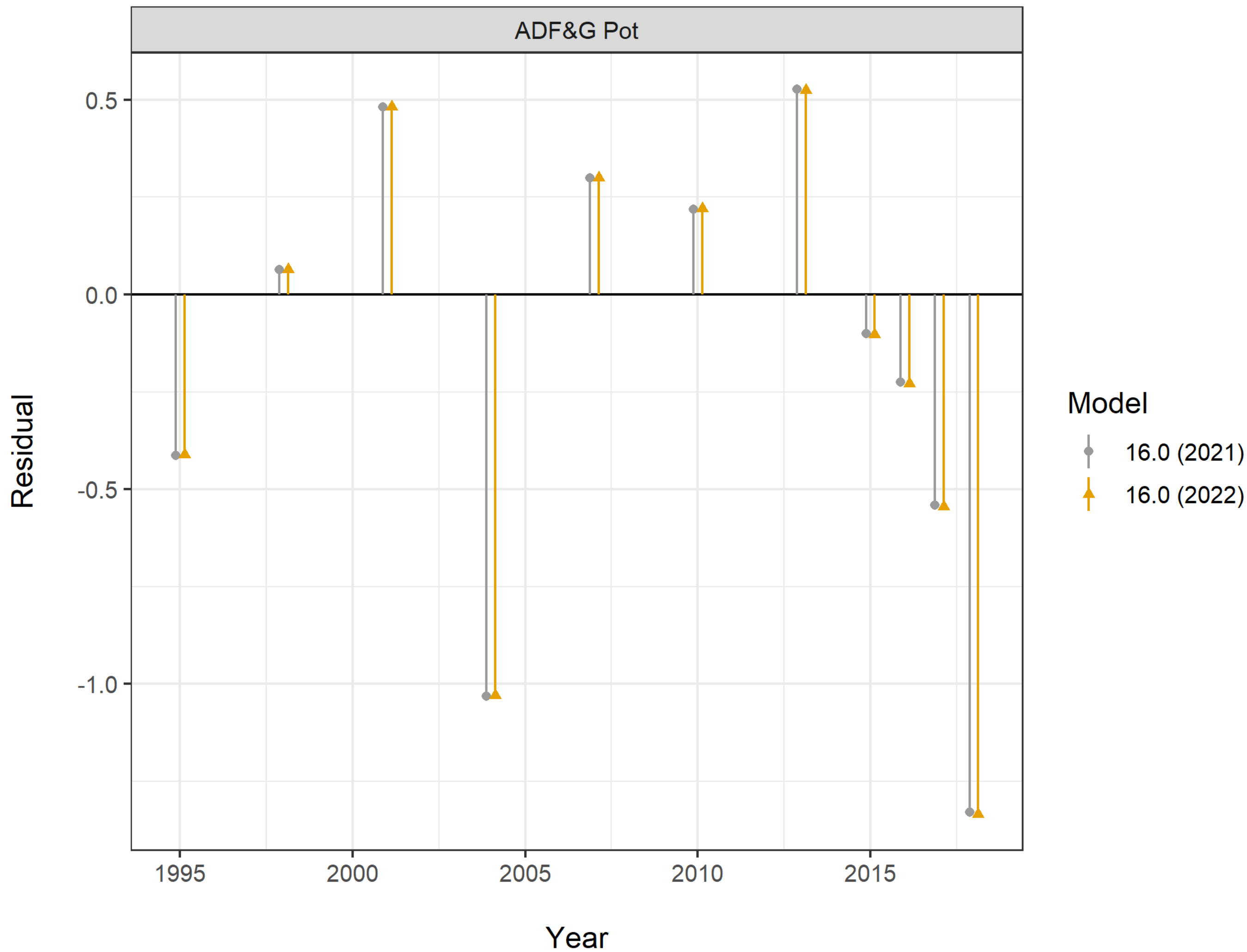

Figure 15: Standardized residuals for total male pot survey CPUEs for each of the GMACS model scenarios.

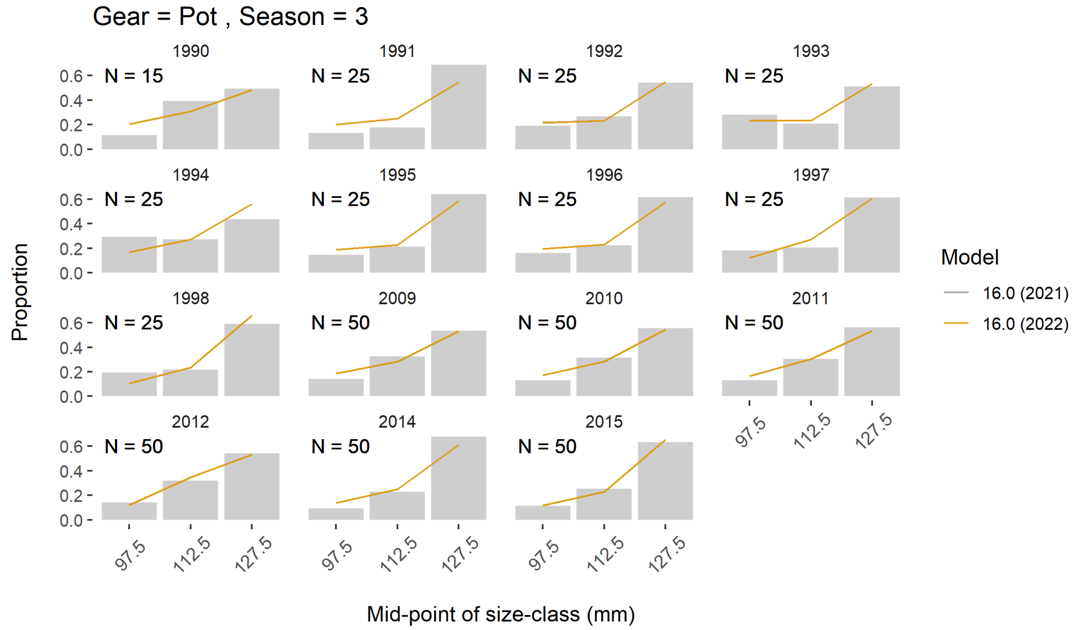

Figure 16: Observed and model estimated size-frequencies of SMBKC by year retained in the directed pot fishery for the model scenarios.

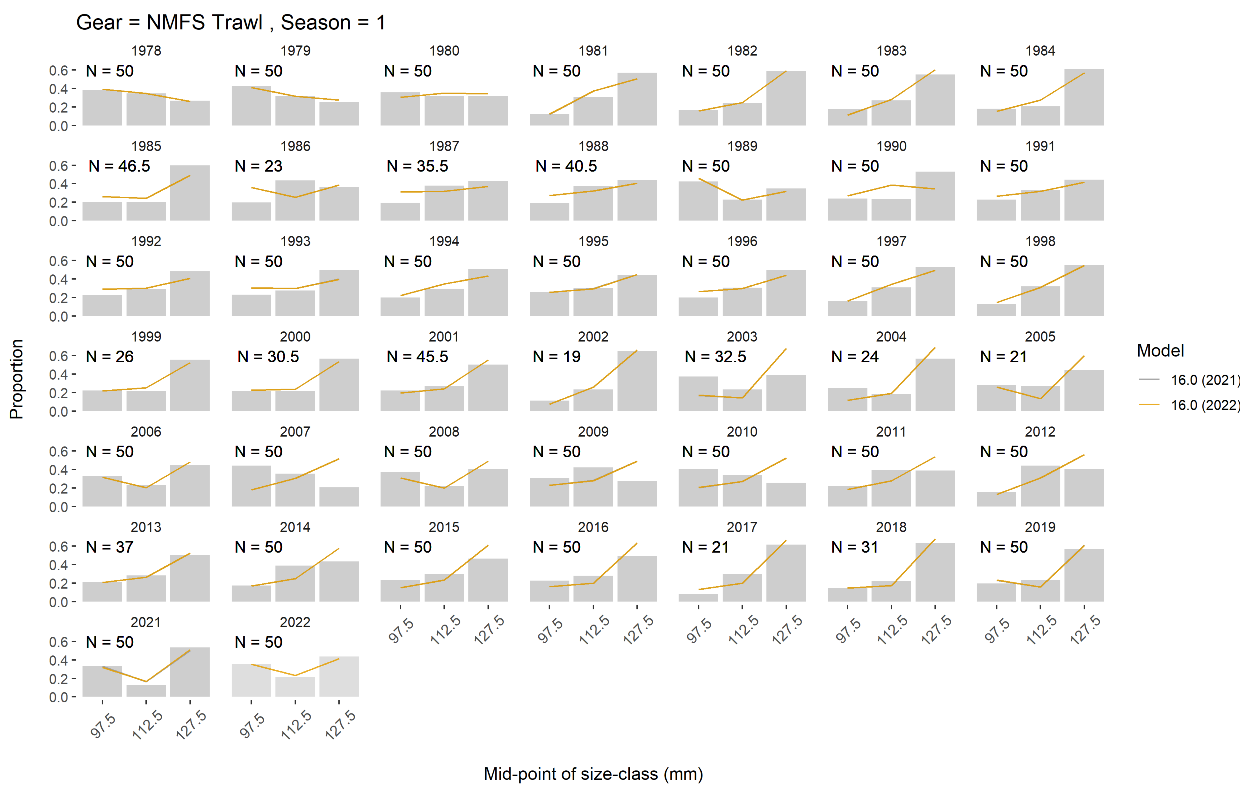

Figure 17: Observed and model estimated size-frequencies of discarded male SMBKC by year in the NMFS trawl survey for the model scenarios.

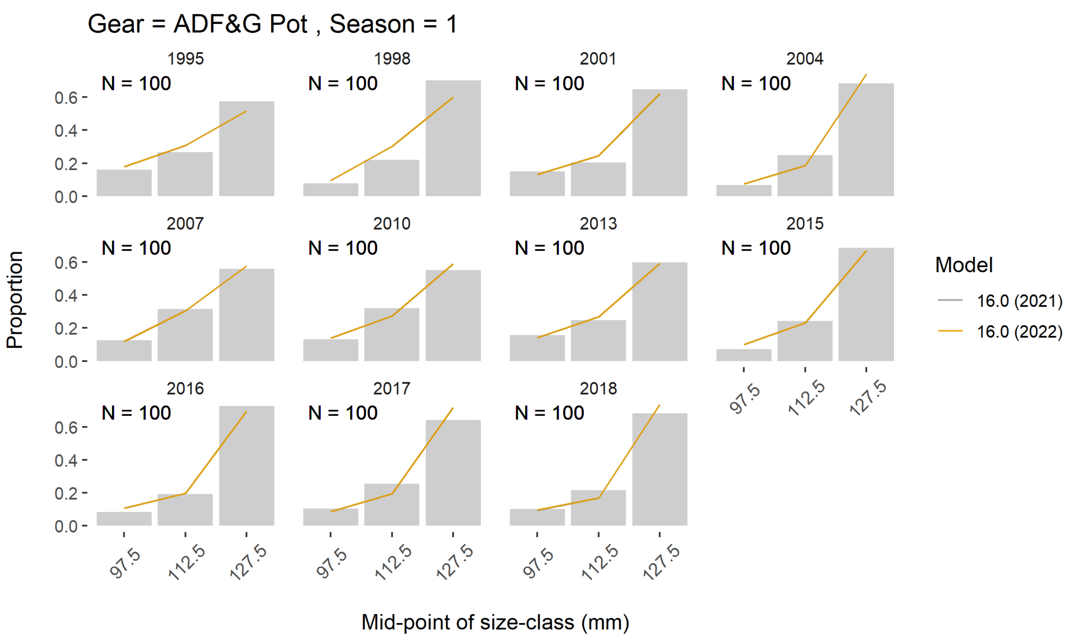

Figure 18: Observed and model estimated size-frequencies of discarded SMBKC by year in the ADFG pot survey for the model scenarios.

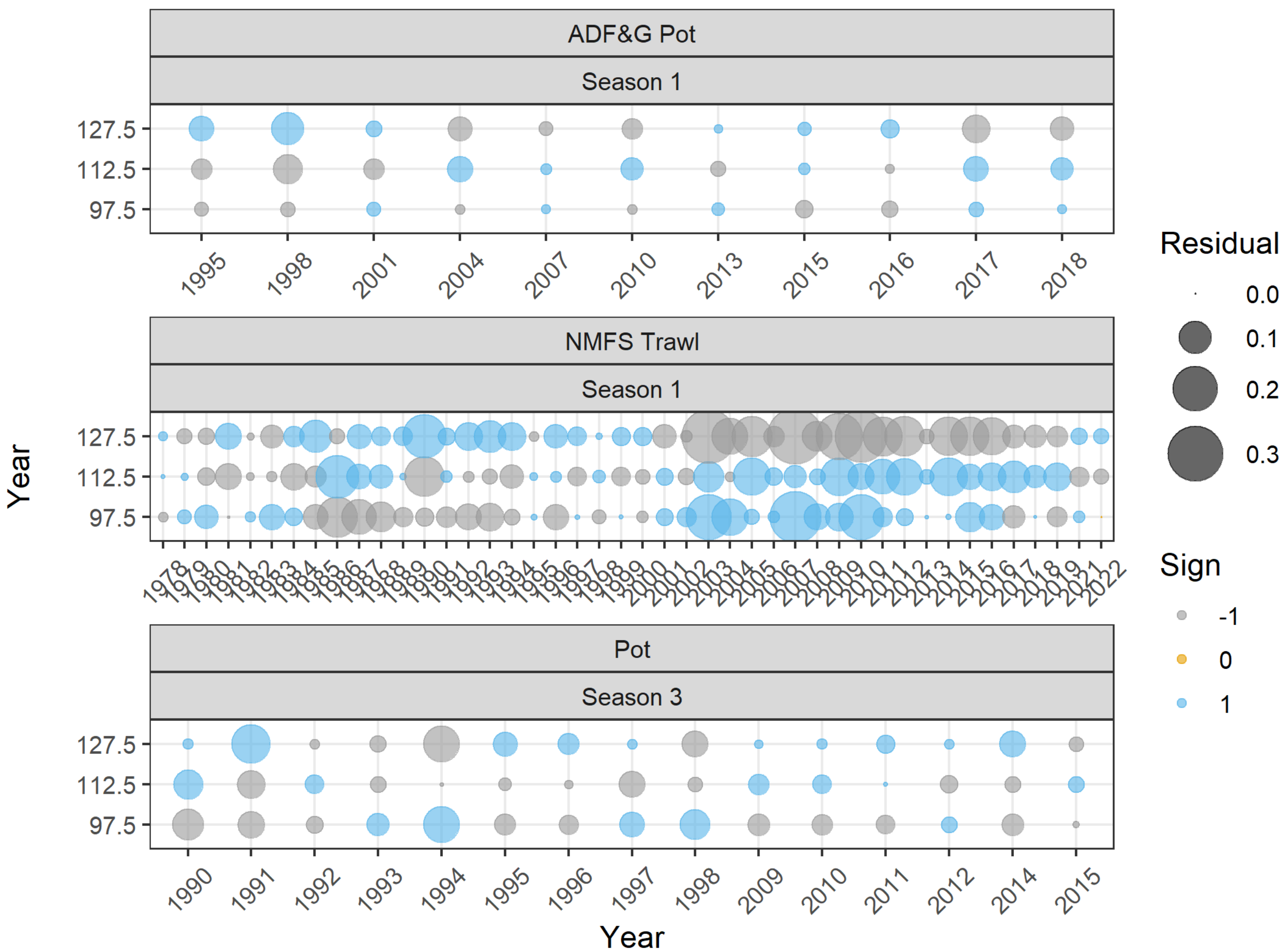

Figure 19: Bubble plots of residuals by stage and year for the all the size composition data sets (ADFG pot survey, NMFS trawl survey, and the directed pot fishery) for SMBKC in the 'base' model (16.0) 2022.

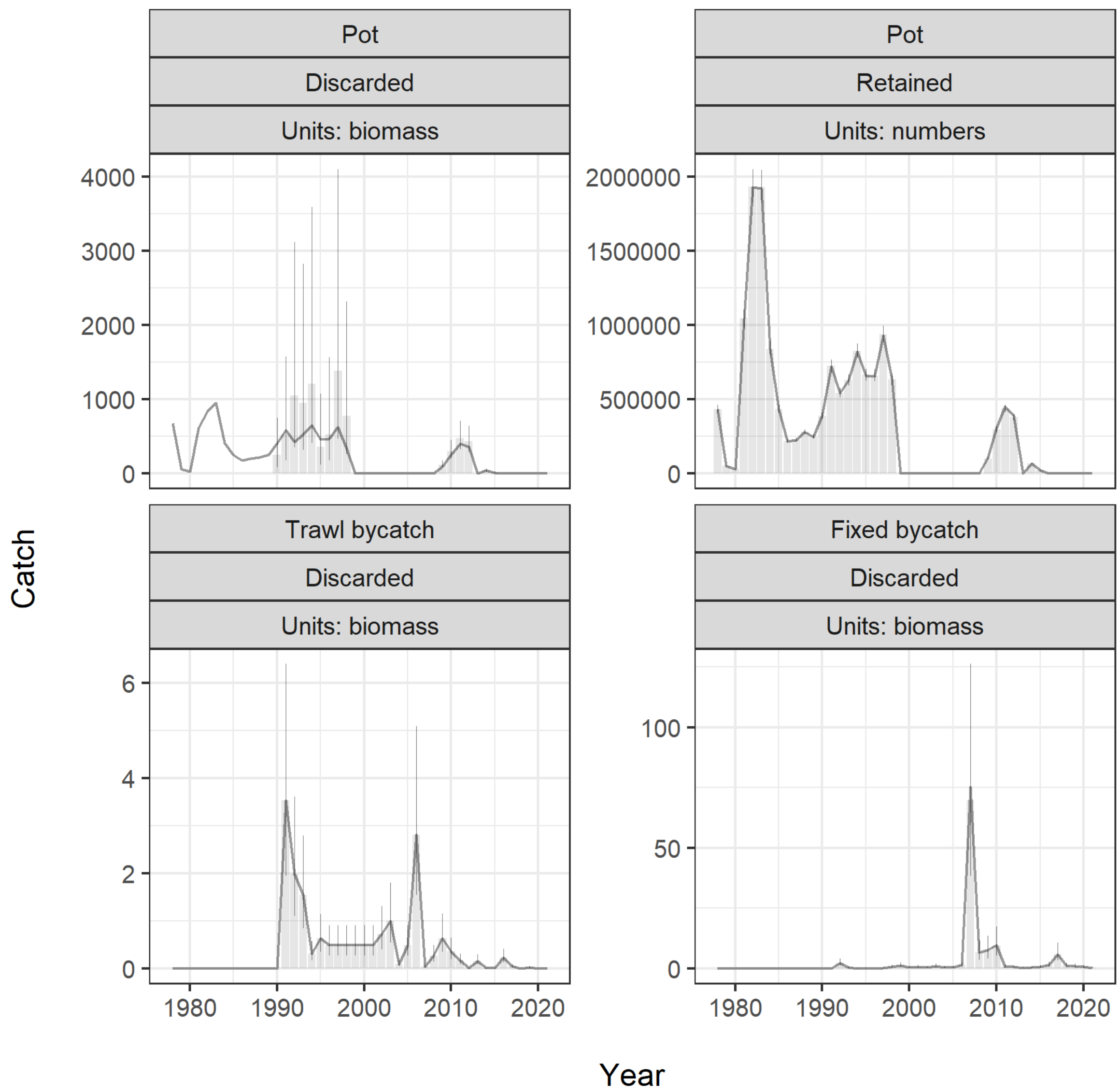

Figure 20: Comparison of observed and model predicted retained catch and bycatches in each of the GMACS models. Note that difference in units between each of the panels, some panels are expressed in numbers of crab, some as biomass (tons).

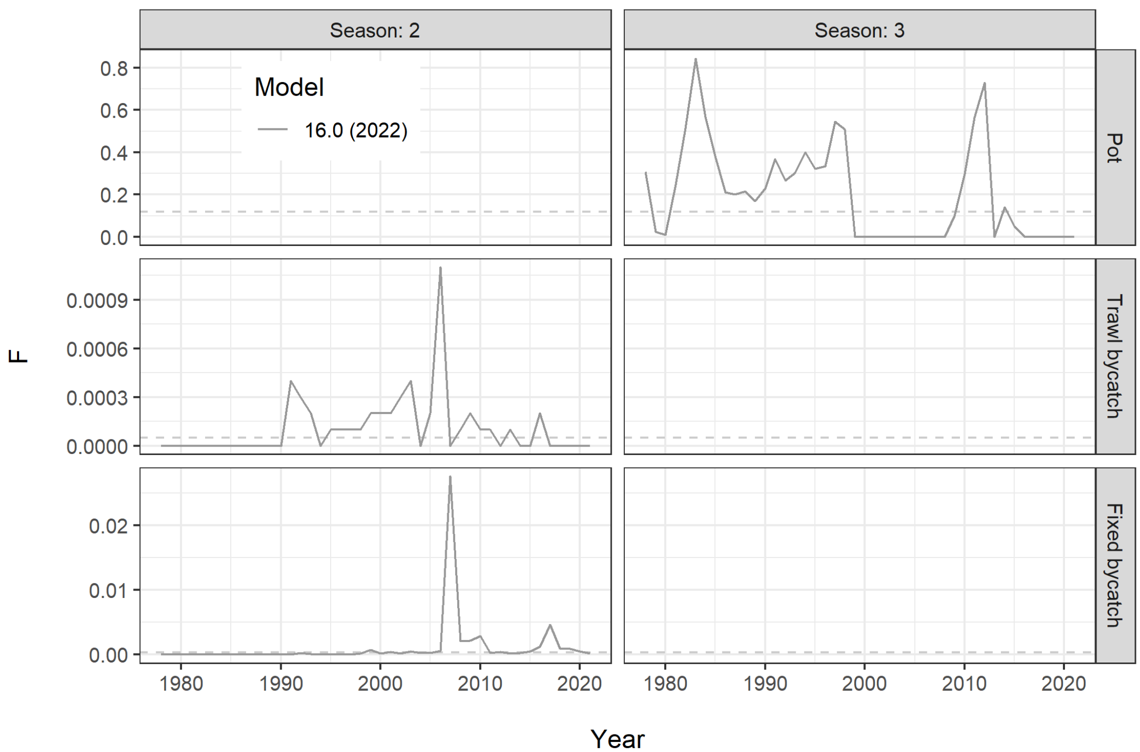

Figure 21: Fishing mortality estimates from the base model (16.0) for directed and bycatch fleets

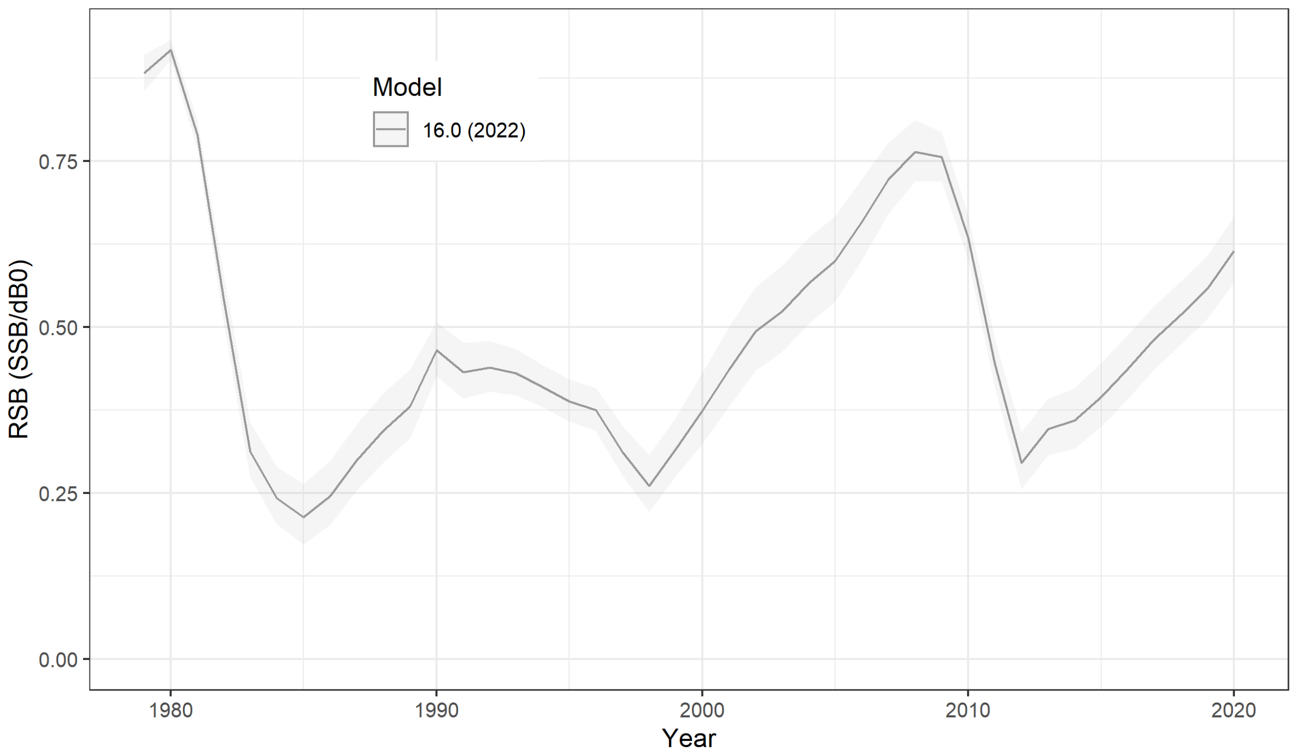

Figure 22: Comparison of mature male biomass relative to the dynamic B zero value, (15 February, 1978-2019) for model 16.0 (2022).

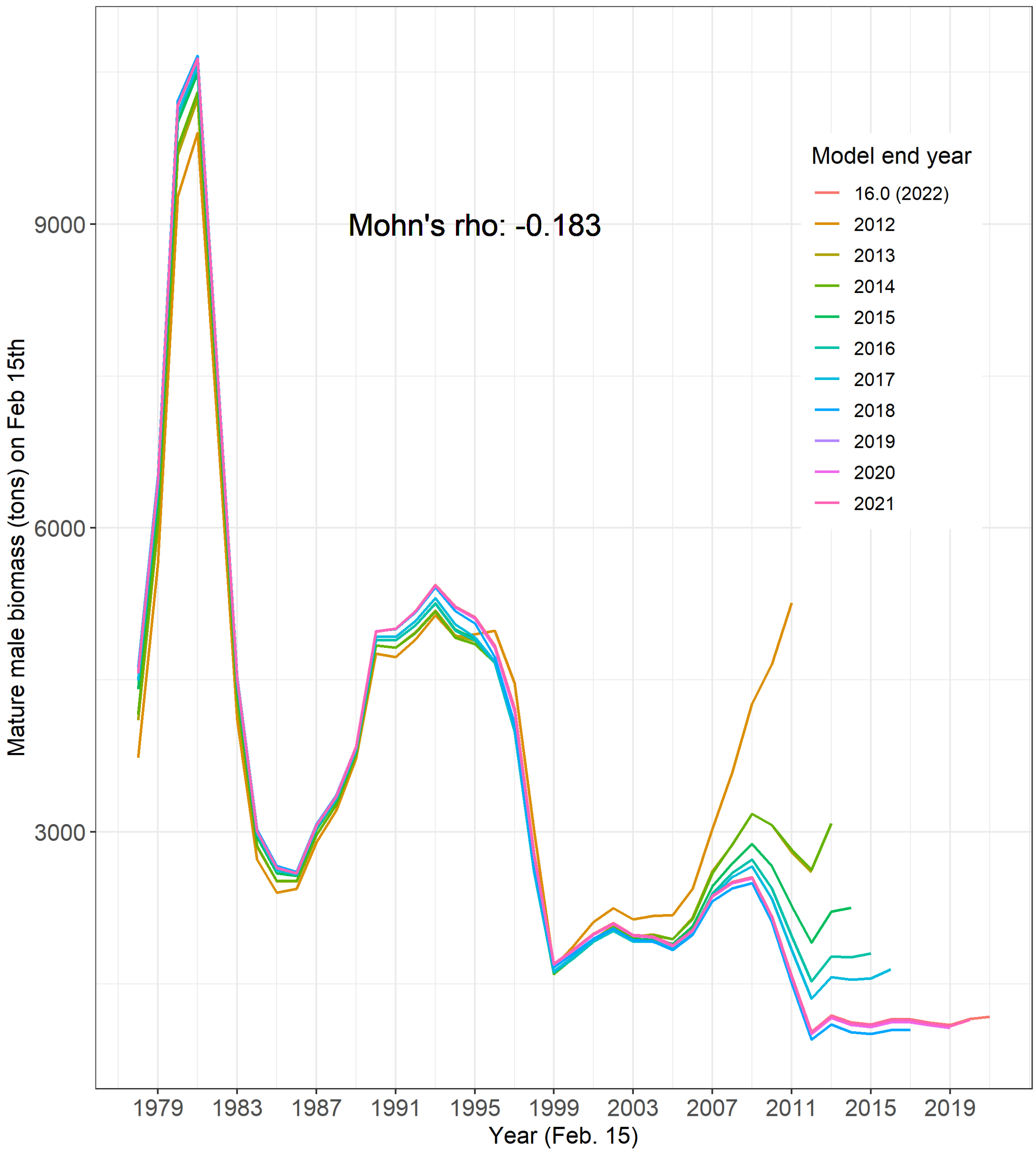

Figure 23: Retrospective pattern in mature male biomass (MMB (t)) for the reference (base) model (16.0).

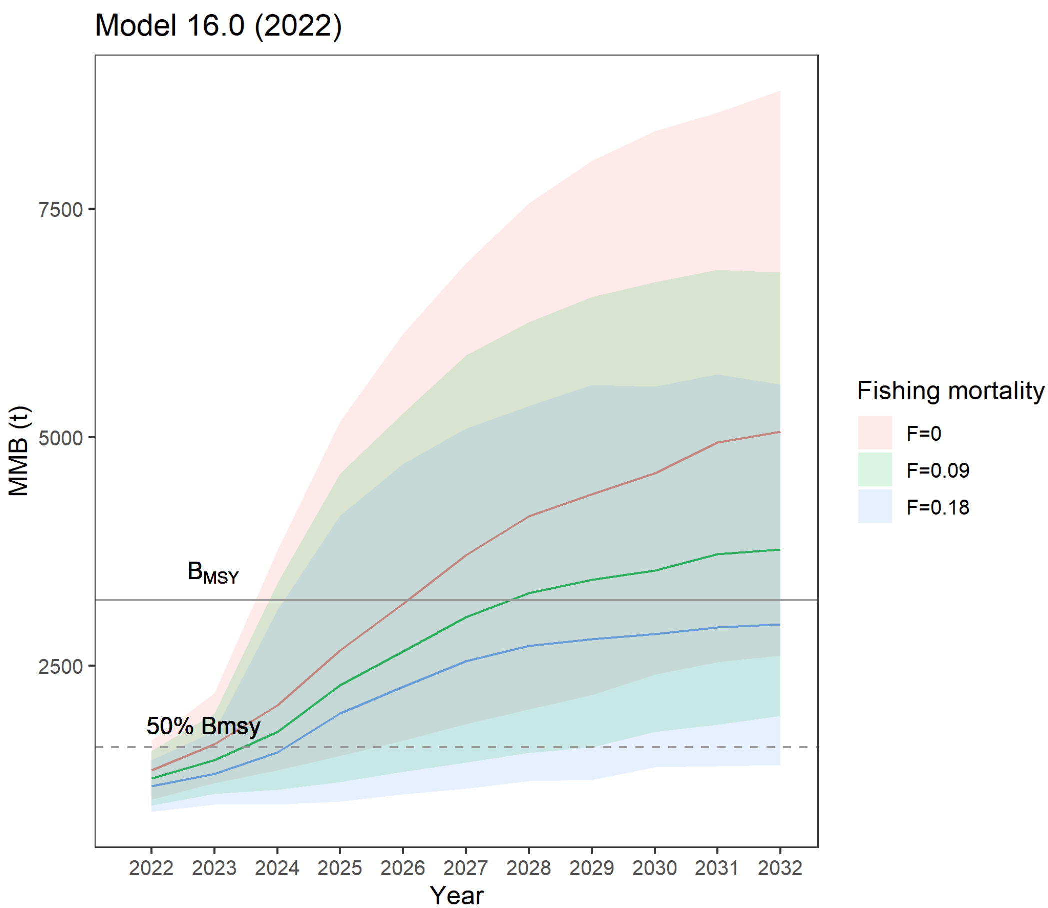

Figure 24: Mature male biomass (MMB) projections for the next ten years using mean recruitment (1978 - 2021) and average bycatch levels from the last 5 years.

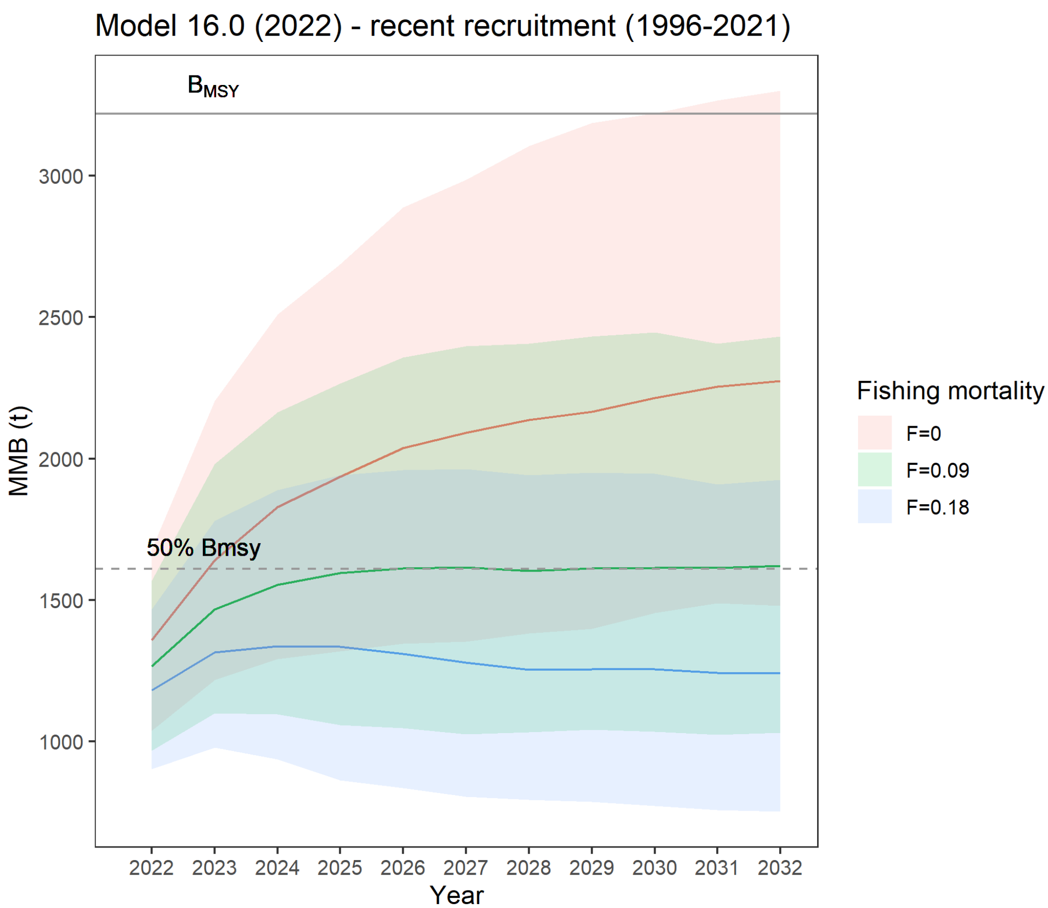

Figure 25: Mature male biomass (MMB) projections for the next ten years using recent recruitment draws (1996 - 2021) and average bycatch levels from the last 5 years.

Appendix A: SMBKC Model Description

1. Introduction

The GMACS model has been specified to account only for male crab $\geq$ 90 mm in carapace length (CL). These are partitioned into three stages (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 inch carapace width (CW), whereas 105 mm CL is the management proxy for mature-male size (state regulation *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 GMACS base model configuration.

2. Model Population Dynamics

Within the model, the beginning of the crab year is assumed contemporaneous with the NMFS trawl survey, nominally assigned a date of 1 July. Although the timing of the fishery is different each year, MMB is estimated at 15 February, which is the reference date for calculation of federal management biomass quantities. To accommodate this, each model year is split into 5 seasons (t) and a proportion of the natural mortality (τ_t), scaled relative to the portions of the year, is applied in each of these seasons where $\sum_{t=1}^{t=5} \tau_t = 1$. Each model year consists of the following processes with time-breaks denoted here by "Seasons." However, it is important to note that actual seasons are survey-to-fishery, fishery-to Feb 15, and Feb 15 to July 1. The following breakdown accounts for events and fishing mortality treatments:

1. Season 1 (survey period)
   - Beginning of the SMBKC fishing year (1 July)
   - $\tau_1 = 0$
   - Surveys
2. Season 2 (natural mortality until pulse fishery)
   - τ_2 ranges from 0.05 to 0.44 depending on the time of year the fishery begins each year (i.e., a higher value indicates the fishery begins later in the year)

   ee Table
   reftab:smbkc-fishery)
3. Season 3 (pulse fishery)
   - $\tau_3 = 0$
   - fishing mortality applied
4. Season 4 (natural mortality until spawning)
   - $\tau_4 = 0.63 - \sum_{i=1}^{i=4} \tau_i$
   - Calculate MMB (15 February)
5. Season 5 (natural mortality and somatic growth through to June 30th)
   - $\tau_5 = 0.37$
   - Growth and molting

- Recruitment (all to stage-1)

The proportion of natural mortality (τ_t) applied during each season in the model is provided in Table 17, see Table 7 for season 2 interaction with directed fishery timing. The beginning of the year (1 July) to the date that MMB is measured (15 February) is 63% of the year. Therefore 63% of the natural mortality must be applied before the MMB is calculated. Because the timing of the fishery is different each year, τ_2 varies and thus τ_4 varies also.

With boldface lower-case letters indicating vector quantities we designate the vector of stage abundances during season t and year y as

$$\boldsymbol{n}_{t,y} = n_{l,t,y} = \left[n_{1,t,y}, n_{2,t,y}, n_{3,t,y}\right]^\top . \tag{2}$$

The number of new crab, or recruits, of each stage entering the model each season t and year y is represented as the vector $\boldsymbol{r}_{t,y}$. The SMBKC formulation of GMACS specifies recruitment to stage-1 only during season $t = 5$, thus the recruitment size distribution is

$$\phi_l = \left[1, 0, 0\right]^\top , \tag{3}$$

and the recruitment is

$$\boldsymbol{r}_{t,y} = \begin{cases} 0 & \text{for} \quad t < 5 \\ \bar{R}\phi_l \delta_y^R & \text{for} \quad t = 5. \end{cases} \tag{4}$$

where $\bar{R}$ is the average annual recruitment and δ_y^R are the recruitment deviations each year y

$$\delta_y^R \sim \mathcal{N}\left(0, \sigma_R^2\right) . \tag{5}$$

Using boldface upper-case letters to indicate a matrix, we describe the size transition matrix $\boldsymbol{G}$ as

$$\boldsymbol{G} = \begin{bmatrix} 1 - \pi_{12} - \pi_{13} & \pi_{12} & \pi_{13} \\ 0 & 1 - \pi_{23} & \pi_{23} \\ 0 & 0 & 1 \end{bmatrix} , \tag{6}$$

with π_{jk} equal to the proportion of stage-j crab that molt and grow into stage-k within a season or year.

The natural mortality each season t and year y is

$$M_{t,y} = \bar{M}\tau_t + \delta_y^M \text{ where } \delta_y^M \sim \mathcal{N}\left(0, \sigma_M^2\right) \tag{7}$$

Fishing mortality by year y and season t is denoted $F_{t,y}$ and calculated as

$$F_{t,y} = F_{t,y}^{\text{df}} + F_{t,y}^{\text{tb}} + F_{t,y}^{\text{fb}} \tag{8}$$

where $F_{t,y}^{\text{df}}$ is the fishing mortality associated with the directed fishery, $F_{t,y}^{\text{tb}}$ is the fishing mortality associated with the trawl bycatch fishery, $F_{t,y}^{\text{fb}}$ is the fishing mortality associated with the fixed bycatch fishery. Each of these are derived as

$$\begin{aligned} F_{t,y}^{\text{df}} &= \bar{F}^{\text{df}} + \delta_{t,y}^{\text{df}} \quad \text{where} \quad \delta_{t,y}^{\text{df}} \sim \mathcal{N}\left(0, \sigma_{\text{df}}^2\right) , \\ F_{t,y}^{\text{tb}} &= \bar{F}^{\text{tb}} + \delta_{t,y}^{\text{tb}} \quad \text{where} \quad \delta_{t,y}^{\text{df}} \sim \mathcal{N}\left(0, \sigma_{\text{tb}}^2\right) , \\ F_{t,y}^{\text{fb}} &= \bar{F}^{\text{fb}} + \delta_{t,y}^{\text{fb}} \quad \text{where} \quad \delta_{t,y}^{\text{df}} \sim \mathcal{N}\left(0, \sigma_{\text{fb}}^2\right) , \end{aligned} \tag{9}$$

where $\delta_{t,y}^{\text{df}}$, $\delta_{t,y}^{\text{tb}}$, and $\delta_{t,y}^{\text{fb}}$ are the fishing mortality deviations for each of the fisheries, each season t during each year y, $\bar{F}^{\text{df}}$, $\bar{F}^{\text{tb}}$, and $\bar{F}^{\text{fb}}$ are the average fishing mortalities for each fishery. The total mortality $Z_{l,t,y}$ represents the combination of natural mortality $M_{t,y}$ and fishing mortality $F_{t,y}$ during season t and year y

$$\boldsymbol{Z}_{t,y} = Z_{l,t,y} = M_{t,y} + F_{t,y} . \tag{10}$$

The survival matrix $\boldsymbol{S}_{t,y}$ during season t and year y is

$$\boldsymbol{S}_{t,y} = \begin{bmatrix} 1-e^{-Z_{1,t,y}} & 0 & 0 \\ 0 & 1-e^{-Z_{2,t,y}} & 0 \\ 0 & 0 & 1-e^{-Z_{3,t,y}} \end{bmatrix}. \tag{11}$$

The basic population dynamics underlying GMACS can thus be described as

$$\begin{aligned} \boldsymbol{n}_{t+1,y} &= \boldsymbol{S}_{t,y}\boldsymbol{n}_{t,y}, && \text{if } t < 5 \\ \boldsymbol{n}_{t,y+1} &= \boldsymbol{G}\boldsymbol{S}_{t,y}\boldsymbol{n}_{t,y} + \boldsymbol{r}_{t,y} && \text{if } t = 5. \end{aligned} \tag{12}$$

3. Model Data

Data inputs used in model estimation are listed in Table 18.

4. Model Parameters

Table 19 lists fixed (externally determined) parameters used in model computations. In all scenarios, the stage-transition matrix is

$$\boldsymbol{G} = \begin{bmatrix} 0.2 & 0.7 & 0.1 \\ 0 & 0.4 & 0.6 \\ 0 & 0 & 1 \end{bmatrix} \tag{13}$$

which is the combination of the growth matrix and molting probabilities.

Estimated parameters are listed in Table 20 and include an estimated natural mortality deviation parameter in 1998/99 (δ^{M}_{1998}) assuming an anomalous mortality event in that year, as hypothesized by Zheng and Kruse (2002), with natural mortality otherwise fixed at 0.18 yr^{-1}.

5. Model Objective Function and Weighting Scheme

The objective function consists of the sum of several "negative log-likelihood" terms characterizing the hypothesized error structure of the principal data inputs (Table 14). A lognormal distribution is assumed to characterize the catch data and is modelled as

$$\sigma^{\text{catch}}_{t,y} = \sqrt{\log\left(1+\left(CV^{\text{catch}}_{t,y}\right)^2\right)} \tag{14}$$

$$\delta^{\text{catch}}_{t,y} = \mathcal{N}\left(0, \left(\sigma^{\text{catch}}_{t,y}\right)^2\right) \tag{15}$$

where $\delta^{\text{catch}}_{t,y}$ is the residual catch. The relative abudance data is also assumed to be lognormally distributed

$$\sigma^{\text{I}}_{t,y} = \frac{1}{\lambda}\sqrt{\log\left(1+\left(CV^{\text{I}}_{t,y}\right)^2\right)} \tag{16}$$

$$\delta^{\text{I}}_{t,y} = \log\left(I^{\text{obs}}/I^{\text{pred}}\right)/\sigma^{\text{I}}_{t,y} + 0.5\sigma^{\text{I}}_{t,y} \tag{17}$$

and the likelihood is

$$\sum \log\left(\delta^{\text{I}}_{t,y}\right) + \sum 0.5\left(\sigma^{\text{I}}_{t,y}\right)^2 \tag{18}$$

GMACS calculates standard deviation of the normalised residual (SDNR) values and median of the absolute residual (MAR) values for all abundance indices and size compositions to help the user come up with resonable likelihood weights. For an abundance data set to be well fitted, the SDNR should not be much greater than 1 (a value much less than 1, which means that the data set is fitted better than was expected, is not a cause for concern). What is meant by "much greater than 1" depends on m (the number of years in the data set). Francis (2011) suggests upper limits of 1.54, 1.37, and 1.26 for $m = 5$, 10, and 20, respectively. Although an SDNR not much greater than 1 is a necessary condition for a good fit, it is not sufficient. It is important to plot the observed and expected abundances to ensure that the fit is good.

GMACS also calculates Francis weights for each of the size composition data sets supplied (Francis 2011). If the user wishes to use the Francis iterative re-weighting method, first the weights applied to the abundance indices should be adjusted by trial and error until the SDNR (and/or MAR) are adequte. Then the Francis weights supplied by GMACS should be used as the new likelihood weights for each of the size composition data sets the next time the model is run. The user can then iteratively adjust the abudance index and size composition weights until adequate SDNR (and/or MAR) values are achieved, given the Francis weights.

6. Estimation

The model was implemented using the software AD Model Builder (Fournier et al. 2012), with parameter estimation by minimization of the model objective function using automatic differentiation. Parameter estimates and standard deviations provided in this document are AD Model Builder reported values assuming maximum likelihood theory asymptotics.

Table 17: Proportion of the natural mortality (τ_t) that is applied during each season (t) in the model.

Year	Season 1	Season 2	Season 3	Season 4	Season 5
1978	0.00	0.07	0.00	0.56	0.37
1979	0.00	0.06	0.00	0.57	0.37
1980	0.00	0.07	0.00	0.56	0.37
1981	0.00	0.05	0.00	0.58	0.37
1982	0.00	0.07	0.00	0.56	0.37
1983	0.00	0.12	0.00	0.51	0.37
1984	0.00	0.10	0.00	0.53	0.37
1985	0.00	0.14	0.00	0.49	0.37
1986	0.00	0.14	0.00	0.49	0.37
1987	0.00	0.14	0.00	0.49	0.37
1988	0.00	0.14	0.00	0.49	0.37
1989	0.00	0.14	0.00	0.49	0.37
1990	0.00	0.14	0.00	0.49	0.37
1991	0.00	0.18	0.00	0.45	0.37
1992	0.00	0.14	0.00	0.49	0.37
1993	0.00	0.18	0.00	0.45	0.37
1994	0.00	0.18	0.00	0.45	0.37
1995	0.00	0.18	0.00	0.45	0.37
1996	0.00	0.18	0.00	0.45	0.37
1997	0.00	0.18	0.00	0.45	0.37
1998	0.00	0.18	0.00	0.45	0.37
1999	0.00	0.18	0.00	0.45	0.37
2000	0.00	0.18	0.00	0.45	0.37
2001	0.00	0.18	0.00	0.45	0.37
2002	0.00	0.18	0.00	0.45	0.37
2003	0.00	0.18	0.00	0.45	0.37
2004	0.00	0.18	0.00	0.45	0.37
2005	0.00	0.18	0.00	0.45	0.37
2006	0.00	0.18	0.00	0.45	0.37
2007	0.00	0.18	0.00	0.45	0.37
2008	0.00	0.18	0.00	0.45	0.37
2009	0.00	0.44	0.00	0.19	0.37
2010	0.00	0.44	0.00	0.19	0.37
2011	0.00	0.44	0.00	0.19	0.37
2012	0.00	0.44	0.00	0.19	0.37
2013	0.00	0.44	0.00	0.19	0.37
2014	0.00	0.44	0.00	0.19	0.37
2015	0.00	0.44	0.00	0.19	0.37
2016	0.00	0.44	0.00	0.19	0.37
2017	0.00	0.44	0.00	0.19	0.37
2018	0.00	0.44	0.00	0.19	0.37
2019	0.00	0.44	0.00	0.19	0.37
2020	0.00	0.44	0.00	0.19	0.37
2021	0.00	0.44	0.00	0.19	0.37

Table 18: Data inputs used in model estimation.

Data	Years	Source
Directed pot-fishery retained-catch number (not biomass)	1978/79 - 1998/99 2009/10 - 2015/16	Fish tickets (fishery closed 1999/00 - 2008/09 and 2016/17 - 2018/19)
Groundfish trawl bycatch biomass	1992/93 - 2018/19	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93 - 2018/19	NMFS groundfish observer program
NMFS trawl-survey biomass index (area-swept estimate) and CV	1978-2019	NMFS EBS trawl survey
ADF&G pot-survey abundance index (CPUE) and CV	1995-2018	ADF&G SMBKC pot survey
NMFS trawl-survey stage proportions and total number of measured crab	1978-2019	NMFS EBS trawl survey
ADF&G pot-survey stage proportions and total number of measured crab	1995-2018	ADF&G SMBKC pot survey
Directed pot-fishery stage proportions and total number of measured crab	1990/91 - 1998/99 2009/10 - 2015/16	ADF&G crab observer program (fishery closed 1999/00 - 2008/09 and 2016/17 - 2018/19)

Table 19: Fixed model parameters for all scenarios.

Parameter	Symbol	Value	Source/rationale
Trawl-survey catchability	q	1.0	Default
Natural mortality	M	0.18 yr^{-1}	NPFMC (2007)
Size transition matrix	$\boldsymbol{G}$	Equation 13	Otto and Cummiskey (1990)
Stage-1 and stage-2 mean weights	w_1, w_2	0.7, 1.2 kg	Length-weight equation (B. Foy, NMFS) applied to stage midpoints
Stage-3 mean weight	$w_{3,y}$	Depends on year	Fishery reported average retained weight from fish tickets, or its average, and mean weights of legal males
Recruitment SD	σ_R	1.2	High value
Natural mortality SD	σ_M	10.0	High value (basically free parameter)
Directed fishery handling mortality		0.2	2010 Crab SAFE
Groundfish trawl handling mortality		0.8	2010 Crab SAFE
Groundfish fixed-gear handling mortality		0.5	2010 Crab SAFE

Table 20: The lower bound (LB), upper bound (UB), initial value, prior, and estimation phase for each estimated model parameter.

Parameter	LB	Initial value	UB	Prior	Phase
Average recruitment $\log(\bar{R})$	-7	10.0	20	Uniform(-7,20)	1
Stage-1 initial numbers $\log(n_1^0)$	5	14.5	20	Uniform(5,20)	1
Stage-2 initial numbers $\log(n_2^0)$	5	14.0	20	Uniform(5,20)	1
Stage-3 initial numbers $\log(n_3^0)$	5	13.5	20	Uniform(5,20)	1
ADF&G pot survey catchability q	0	3.0	5	Uniform(0,5)	1
Stage-1 directed fishery selectivity 1978-2008	0	0.4	1	Uniform(0,1)	3
Stage-2 directed fishery selectivity 1978-2008	0	0.7	1	Uniform(0,1)	3
Stage-1 directed fishery selectivity 2009-2017	0	0.4	1	Uniform(0,1)	3
Stage-2 directed fishery selectivity 2009-2017	0	0.7	1	Uniform(0,1)	3
Stage-1 NMFS trawl survey selectivity	0	0.4	1	Uniform(0,1)	4
Stage-2 NMFS trawl survey selectivity	0	0.7	1	Uniform(0,1)	4
Stage-1 ADF&G pot survey selectivity	0	0.4	1	Uniform(0,1)	4
Stage-2 ADF&G pot survey selectivity	0	0.7	1	Uniform(0,1)	4
Natural mortality deviation during 1998 δ_{1998}^M	-3	0.0	3	Normal(0, σ_M^2)	4
Recruitment deviations δ_y^R	-7	0.0	7	Normal(0, σ_R^2)	3
Average directed fishery fishing mortality $\bar{F}^{\text{df}}$	-	0.2	-	-	1
Average trawl bycatch fishing mortality $\bar{F}^{\text{tb}}$	-	0.001	-	-	1
Average fixed gear bycatch fishing mortality $\bar{F}^{\text{fb}}$	-	0.001	-	-	1

Appendix B. Data files for the reference model (16.0)

The reference model (16.0) data file for 2022

```
#======================================================================================================
# Gmacs Main  Data  File  Version 1.1:  Sept 2022 - SM22f sept 2022 version, updated bycatch & survey for 22
# GEAR_INDEX  DESCRIPTION
#   1      : Pot fishery retained catch.
#   1      : Pot fishery with discarded catch.
#   2      : Trawl bycatch
#   3      : Fixed bycatch
#   4      : NMFS Trawl survey
#   5      : ADF&G Pot survey
#======================================================================================================
# Fisheries:  1 Pot Fishery,  2 Pot Discard,  3 Trawl by-catch, 3 Fixed by-catch
# Surveys:   4 NMFS Trawl Survey, 5 Pot Survey
#======================================================================================================
1978  # Start year
2021  # End year (updated) last year of fishery does NOT include current survey year
5    # Number of seasons
5    # Number of fleets (fisheries and surveys)
1    # Number of sexes
1    # Number of shell condition types
1    # Number of maturity types
3    # Number of size-classes in the model
5    # Season recruitment occurs
5    # Season molting and growth occurs
4    # Season to calculate SSB
1    # Season for N output
# maximum size-class (males then females)
3
# size_breaks (a vector giving the break points between size intervals with dimension nclass+1)
90  105  120  135
# Natural mortality per season input type (1 = vector by season, 2 = matrix by season/year)
2
# Proportion of the total natural mortality to be applied each season (each row must add to 1)
0.000   0.070   0.000   0.560   0.370 #1978
0.000   0.060   0.000   0.570   0.370 #1979
0.000   0.070   0.000   0.560   0.370 #1980
0.000   0.050   0.000   0.580   0.370 #1981
0.000   0.070   0.000   0.560   0.370 #1982
0.000   0.120   0.000   0.510   0.370 #1983
0.000   0.100   0.000   0.530   0.370 #1984
0.000   0.140   0.000   0.490   0.370 #1985
0.000   0.140   0.000   0.490   0.370 #1986
0.000   0.140   0.000   0.490   0.370 #1987
0.000   0.140   0.000   0.490   0.370 #1988
0.000   0.140   0.000   0.490   0.370 #1989
0.000   0.140   0.000   0.490   0.370 #1990
0.000   0.180   0.000   0.450   0.370 #1991
0.000   0.140   0.000   0.490   0.370 #1992
0.000   0.180   0.000   0.450   0.370 #1993
0.000   0.180   0.000   0.450   0.370 #1994
0.000   0.180   0.000   0.450   0.370 #1995
0.000   0.180   0.000   0.450   0.370 #1996
0.000   0.180   0.000   0.450   0.370 #1997
0.000   0.180   0.000   0.450   0.370 #1998
0.000   0.180   0.000   0.450   0.370 #1999
0.000   0.180   0.000   0.450   0.370 #2000
0.000   0.180   0.000   0.450   0.370 #2001
0.000   0.180   0.000   0.450   0.370 #2002
0.000   0.180   0.000   0.450   0.370 #2003
0.000   0.180   0.000   0.450   0.370 #2004
0.000   0.180   0.000   0.450   0.370 #2005
0.000   0.180   0.000   0.450   0.370 #2006
0.000   0.180   0.000   0.450   0.370 #2007
0.000   0.180   0.000   0.450   0.370 #2008
0.000   0.440   0.000   0.190   0.370 #2009
0.000   0.440   0.000   0.190   0.370 #2010
0.000   0.440   0.000   0.190   0.370 #2011
```

```
0.000   0.440   0.000   0.190   0.370 #2012
0.000   0.440   0.000   0.190   0.370 #2013
0.000   0.440   0.000   0.190   0.370 #2014
0.000   0.440   0.000   0.190   0.370 #2015
0.000   0.440   0.000   0.190   0.370 #2016
0.000   0.440   0.000   0.190   0.370 #2017
0.000 0.440 0.000 0.190 0.370 #2018
0.000   0.440   0.000   0.190   0.370 #2019 (updated)
0.000 0.440 0.000 0.190 0.370 #2020 (updated 4-14-22)
0.000 0.440 0.000 0.190 0.370 #2021 (updated 8-25-22)
#0  0.0025  0  0.6245  0.373
# Fishing fleet names (delimited with spaces no spaces in names)
Pot_Fishery Trawl_Bycatch Fixed_bycatch
# Survey names (delimited with spaces no spaces in names)
NMFS_Trawl ADFG_Pot
# Are the fleets instantaneous (0) or continuous (1)
1 1 1 1 1
# Number  of  catch data  frames
4
# Number  of  rows  in  each  data  frame
27  18 31  31 #(updated - all should increase 1 if value for current year NO placeholder for direct fishery if closed)
##  CATCH DATA
##  Type of catch: 1 = retained, 2 = discard
##  Units of catch: 1 = biomass, 2 = numbers
##  for SMBKC Units are in number of crab for landed & 1000 kg for discards.
##  Male Retained
# year  seas   fleet  sex   obs    cv type  units mult effort  discard_mortality
1978   3     1     1     436126  0.03   1     2     1     0     0.2
1979   3     1     1     52966   0.03   1     2     1     0     0.2
1980   3     1     1     33162   0.03   1     2     1     0     0.2
1981   3     1     1     1045619 0.03   1     2     1     0     0.2
1982   3     1     1     1935886 0.03   1     2     1     0     0.2
1983   3     1     1     1931990 0.03   1     2     1     0     0.2
1984   3     1     1     841017  0.03   1     2     1     0     0.2
1985   3     1     1     436021  0.03   1     2     1     0     0.2
1986   3     1     1     219548  0.03   1     2     1     0     0.2
1987   3     1     1     227447  0.03   1     2     1     0     0.2
1988   3     1     1     280401  0.03   1     2     1     0     0.2
1989   3     1     1     247641  0.03   1     2     1     0     0.2
1990   3     1     1     391405  0.03   1     2     1     0     0.2
1991   3     1     1     726519  0.03   1     2     1     0     0.2
1992   3     1     1     545222  0.03   1     2     1     0     0.2
1993   3     1     1     630353  0.03   1     2     1     0     0.2
1994   3     1     1     827015  0.03   1     2     1     0     0.2
1995   3     1     1     666905  0.03   1     2     1     0     0.2
1996   3     1     1     660665  0.03   1     2     1     0     0.2
1997   3     1     1     939822  0.03   1     2     1     0     0.2
1998   3     1     1     635370  0.03   1     2     1     0     0.2
2009   3     1     1     103376  0.03   1     2     1     0     0.2
2010   3     1     1     298669  0.03   1     2     1     0     0.2
2011   3     1     1     437862  0.03   1     2     1     0     0.2
2012   3     1     1     379386  0.03   1     2     1     0     0.2
2014   3     1     1     69109   0.03   1     2     1     0     0.2
2015   3     1     1     24407   0.03   1     2     1     0     0.2
#2016   3     1     1     10.000  0.03   1     2     1     0     0.2
#2017   3     1     1     10.000  0.03   1     2     1     0     0.2
#2018   3     1     1     10.000  0.03   1     2     1     0     0.2 # placeholder no fishery
# Male  discards  Pot fishery
1990   3     1     1    254.9787861    0.6    2     1     1     0     0.2
1991   3     1     1    531.4483252    0.6    2     1     1     0     0.2
1992   3     1     1    1050.387026    0.6    2     1     1     0     0.2
1993   3     1     1    951.4626128    0.6    2     1     1     0     0.2
1994   3     1     1    1210.764588    0.6    2     1     1     0     0.2
1995   3     1     1    363.112032     0.6    2     1     1     0     0.2
1996   3     1     1    528.5244687    0.6    2     1     1     0     0.2
1997   3     1     1    1382.825328    0.6    2     1     1     0     0.2
1998   3     1     1    781.1032977    0.6    2     1     1     0     0.2
2009   3     1     1    123.3712279    0.2    2     1     1     0     0.2
2010   3     1     1    304.6562225    0.2    2     1     1     0     0.2
2011   3     1     1    481.3572126    0.2    2     1     1     0     0.2
2012   3     1     1    437.3360731    0.2    2     1     1     0     0.2
2014   3     1     1    45.4839749     0.2    2     1     1     0     0.2
```

```
2015   3    1    1    21.19378597    0.2    2    1    1    0    0.2
2016   3    1    1    0.021193786    0.2    2    1    1    0    0.2
2017   3    1    1    0.021193786    0.2    2    1    1    0    0.2
2018   3    1    1    0.214868020    0.2    2    1    1    0    0.2  # (updated)
#2019  3    1    1    0.0    0.2    2    1    1    0    0.2
#2020  3    1    1    0.0    0.2    2    1    1    0    0.2
#2021  3    1    1    0.0    0.2    2    1    1    0    0.2
#   Trawl   fishery discards
1991    2   2   1   3.538   0.31    2   1   1   0   0.8
1992    2   2   1   1.996   0.31    2   1   1   0   0.8
1993    2   2   1   1.542   0.31    2   1   1   0   0.8
1994    2   2   1   0.318   0.31    2   1   1   0   0.8
1995    2   2   1   0.635   0.31    2   1   1   0   0.8
1996    2   2   1   0.500   0.31    2   1   1   0   0.8
1997    2   2   1   0.500   0.31    2   1   1   0   0.8
1998    2   2   1   0.500   0.31    2   1   1   0   0.8
1999    2   2   1   0.500   0.31    2   1   1   0   0.8
2000    2   2   1   0.500   0.31    2   1   1   0   0.8
2001    2   2   1   0.500   0.31    2   1   1   0   0.8
2002    2   2   1   0.726   0.31    2   1   1   0   0.8
2003    2   2   1   0.998   0.31    2   1   1   0   0.8
2004    2   2   1   0.091   0.31    2   1   1   0   0.8
2005    2   2   1   0.500   0.31    2   1   1   0   0.8
2006    2   2   1   2.812   0.31    2   1   1   0   0.8
2007    2   2   1   0.045   0.31    2   1   1   0   0.8
2008    2   2   1   0.272   0.31    2   1   1   0   0.8
2009    2   2   1   0.638   0.31    2   1   1   0   0.8
2010    2   2   1   0.360   0.31    2   1   1   0   0.8
2011    2   2   1   0.170   0.31    2   1   1   0   0.8
2012    2   2   1   0.011   0.31    2   1   1   0   0.8
2013    2   2   1   0.163   0.31    2   1   1   0   0.8
2014    2   2   1   0.010   0.31    2   1   1   0   0.8
2015    2   2   1   0.010   0.31    2   1   1   0   0.8
2016    2   2   1   0.229   0.31    2   1   1   0   0.8
2017    2   2   1   0.048   0.31    2   1   1   0   0.8 # updated in 2020 was 0.052, now 0.48?
2018    2   2   1   0.001   0.31    2   1   1   0   0.8 # (data is 0 but small value for placeholder)
2019  2 2 1 0.030 0.31  2 1 1 0 0.8 # (updated )
2020  2 2 1 0.001 0.31  2 1 1 0 0.8 # (4-14-22)
2021  2 2 1 0.000 0.31  2 1 1 0 0.8 # (8-25-22)
#   Fixed   fishery discards
1991    2   3   1   0.045   0.31    2   1   1   0   0.5
1992    2   3   1   2.268   0.31    2   1   1   0   0.5
1993    2   3   1   0.500   0.31    2   1   1   0   0.5
1994    2   3   1   0.091   0.31    2   1   1   0   0.5
1995    2   3   1   0.136   0.31    2   1   1   0   0.5
1996    2   3   1   0.045   0.31    2   1   1   0   0.5
1997    2   3   1   0.181   0.31    2   1   1   0   0.5
1998    2   3   1   0.907   0.31    2   1   1   0   0.5
1999    2   3   1   1.361   0.31    2   1   1   0   0.5
2000    2   3   1   0.500   0.31    2   1   1   0   0.5
2001    2   3   1   0.862   0.31    2   1   1   0   0.5
2002    2   3   1   0.408   0.31    2   1   1   0   0.5
2003    2   3   1   1.134   0.31    2   1   1   0   0.5
2004    2   3   1   0.635   0.31    2   1   1   0   0.5
2005    2   3   1   0.590   0.31    2   1   1   0   0.5
2006    2   3   1   1.451   0.31    2   1   1   0   0.5
2007    2   3   1   69.717  0.31    2   1   1   0   0.5
2008    2   3   1   6.622   0.31    2   1   1   0   0.5
2009    2   3   1   7.522   0.31    2   1   1   0   0.5
2010    2   3   1   9.564   0.31    2   1   1   0   0.5
2011    2   3   1   0.796   0.31    2   1   1   0   0.5
2012    2   3   1   0.739   0.31    2   1   1   0   0.5
2013    2   3   1   0.341   0.31    2   1   1   0   0.5
2014    2   3   1   0.490   0.31    2   1   1   0   0.5
2015    2   3   1   0.711   0.31    2   1   1   0   0.5
2016    2   3   1   1.630   0.31    2   1   1   0   0.5 # updated from 1.632
2017    2   3   1   5.935   0.31    2   1   1   0   0.5 # updates was 6.032
2018    2   3   1   1.224   0.31    2   1   1   0   0.5 # updated was 1.281
2019  2 3 1 1.124 0.31  2 1 1 0 0.5 # (updated - bycatch_groundfish.R)
2020  2 3 1 0.671 0.31  2 1 1 0 0.5 # (4-14-22 - bycatch_groundfish.R)
2021  2 3 1 0.323 0.31  2 1 1 0 0.5 # (8-25-22 - bycatch_groundfish.R)
##  RELATIVE  ABUNDANCE DATA
```

```
##  Units of abundance: 1 = biomass, 2 = numbers
##  for SMBKC pot survey Units are in  crabs for Abundance.
##  Number  of  relative  abundance indicies
2
# Index Type  (1=Selecivity; 2=retention)
# AEPAEP
1 1
##  Number  of  rows  in  each  index, need to update when survey data is added
55
# Survey data (abundance indices, units are mt for trawl survey and crab/potlift for pot survey)
#   Index, Year,    Seas,   Fleet,  Sex,    Maturity,   Abundance,  CV   abundance units     timing
1        1978      1       4        1     0         6832.819   0.394          1            0
1        1979      1       4        1     0         7989.881   0.463          1                  0
1   1980     1  4   1   0   9986.83 0.507   1 0
1   1981     1  4   1   0   6551.132    0.402   1    0
1   1982     1  4   1   0   16221.933   0.344   1    0
1   1983    1   4   1   0   9634.25 0.298   1 0
1   1984    1   4   1   0   4071.218    0.179   1 0
1   1985    1   4   1   0   3110.541    0.21    1 0
1   1986    1   4   1   0   1416.849    0.388   1 0
1   1987    1   4   1   0   2278.917    0.291   1 0
1   1988    1   4   1   0   3158.169    0.252   1 0
1   1989    1   4   1   0   6338.622    0.271   1 0
1   1990    1   4   1   0   6730.13 0.274   1 0
1   1991    1   4   1   0   6948.184    0.248   1 0
1   1992    1   4   1   0   7093.272    0.201   1 0
1   1993    1   4   1   0   9548.459    0.169   1 0
1   1994    1   4   1   0   6539.133    0.176   1 0
1   1995    1   4   1   0   5703.591    0.178   1 0
1   1996    1   4   1   0   9410.403    0.241   1 0
1   1997    1   4   1   0   10924.107   0.337   1 0
1   1998    1   4   1   0   7976.839    0.355   1 0
1   1999    1   4   1   0   1594.546    0.182   1 0
1   2000    1   4   1   0   2096.795    0.31    1 0
1   2001    1   4   1   0   2831.44   0.245 1 0
1   2002    1   4   1   0   1732.599    0.32    1 0
1   2003    1   4   1   0   1566.675    0.336   1 0
1   2004    1   4   1   0   1523.869    0.305   1 0
1   2005    1   4   1   0   1642.017    0.371   1 0
1   2006    1   4   1   0   3893.875    0.334   1 0
1   2007    1   4   1   0   6470.773    0.385   1 0
1   2008    1   4   1   0   4654.473    0.284   1 0
1   2009    1   4   1   0   6301.47   0.256 1 0
1   2010    1   4   1   0   11130.898   0.466   1 0
1   2011    1   4   1   0   10931.232   0.558   1 0
1   2012    1   4   1   0   6200.219    0.339   1 0
1   2013    1   4   1   0   2287.557    0.217   1 0
1   2014    1   4   1   0   6029.22   0.449 1 0
1   2015    1   4   1   0   5877.433    0.77    1 0
1   2016    1   4   1   0   3485.909    0.393   1 0
1   2017    1   4   1   0   1793.76   0.599 1 0
1   2018    1   4   1   0   1730.742    0.281   1 0
1   2019    1   4   1   0   3170.467    0.337   1    0  #   (updated    -   EBSsurvey_analysis.R)
1 2021  1 4 1 0 1929.298  0.427 1  0    # updated 4-14-22
1 2022  1 4 1 0 2365.760  0.497 1  0  # updated 8-25-22
2   1995    1   5   1   0   12042   0.13    2 0
2   1998    1   5   1   0   12531   0.06    2 0
2   2001    1   5   1   0   8477    0.08    2 0
2   2004    1   5   1   0   1667    0.15    2 0
2   2007    1   5   1   0   8643    0.09    2 0
2   2010    1   5   1   0   10209   0.13    2 0
2   2013    1   5   1   0   5643    0.19    2 0
2   2015    1   5   1   0   2805    0.18    2 0
2   2016    1   5   1   0   2378    0.186   2 0
2   2017    1   5   1   0   1689    0.25    2 0
2   2018    1   5   1   0   745 0.14    2    0 #    no  smbkc   pot survey  in  2019, 2020, 2021
#2 2022 1 5 1 0 # will be 2022 survey but not until after assessment
##  Number  of  length  frequency matrices
3
##  Number  of  rows  in  each  matrix
15  44  11 # (updated 8-25-22)
##  Number  of  bins  in  each  matrix  (columns  of  size  data)
```

```
3  3  3
##  SIZE  COMPOSITION DATA  FOR ALL FLEETS
##  SIZE  COMP  LEGEND
##  Sex:  1 = male, 2 = female, 0 = both  sexes combined
##  Type  of  composition:  1 = retained, 2 = discard,  0 = total composition
##  Maturity  state:  1 = immature, 2 = mature, 0 = both  states  combined
##  Shell condition:  1 = new shell,  2 = old shell,  0 = both  shell types combined
##length  proportions of  pot discarded males
##Year, Seas, Fleet,  Sex,  Type, Shell,  Maturity, Nsamp,  DataVec
  1990  3 1 1 0 0 0 15  0.1133  0.3933  0.4933
  1991  3 1 1 0 0 0 25  0.1329  0.1768  0.6902
  1992  3 1 1 0 0 0 25  0.1905  0.2677  0.5417
  1993  3 1 1 0 0 0 25  0.2807  0.2097  0.5096
  1994  3 1 1 0 0 0 25  0.2942  0.2714  0.4344
  1995  3 1 1 0 0 0 25  0.1478  0.2127  0.6395
  1996  3 1 1 0 0 0 25  0.1595  0.2229  0.6176
  1997  3 1 1 0 0 0 25  0.1818  0.2053  0.6128
  1998  3 1 1 0 0 0 25  0.1927  0.2162  0.5911
  2009  3 1 1 0 0 0 50  0.1413  0.3235  0.5352
  2010  3 1 1 0 0 0 50  0.1314  0.3152  0.5534
  2011  3 1 1 0 0 0 50  0.1314  0.3051  0.5636
  2012  3 1 1 0 0 0 50  0.1417  0.3178  0.5406
  2014  3 1 1 0 0 0 50  0.0939  0.2275  0.6786
  2015  3 1 1 0 0 0 50  0.1148  0.2518  0.6333 #no fishery so not updated
##length  proportions of  trawl survey  males
##Year, Seas, Fleet,  Sex,  Type, Shell,  Maturity, Nsamp,  DataVec
  1978  1 4 1 0 0 0 50  0.3865  0.3478  0.2657
  1979  1 4 1 0 0 0 50  0.4281  0.3190  0.2529
  1980  1 4 1 0 0 0 50  0.3588  0.3220  0.3192
  1981  1 4 1 0 0 0 50  0.1219  0.3065  0.5716
  1982  1 4 1 0 0 0 50  0.1671  0.2435  0.5893
  1983  1 4 1 0 0 0 50  0.1752  0.2726  0.5522
  1984  1 4 1 0 0 0 50  0.1823  0.2085  0.6092
  1985  1 4 1 0 0 0 46.5 0.2023  0.2010  0.5967
  1986  1 4 1 0 0 0 23  0.1984  0.4364  0.3652
  1987  1 4 1 0 0 0 35.5 0.1944  0.3779  0.4277
  1988  1 4 1 0 0 0 40.5 0.1879  0.3737  0.4384
  1989  1 4 1 0 0 0 50  0.4246  0.2259  0.3496
  1990  1 4 1 0 0 0 50  0.2380  0.2332  0.5288
  1991  1 4 1 0 0 0 50  0.2274  0.3300  0.4426
  1992  1 4 1 0 0 0 50  0.2263  0.2911  0.4826
  1993  1 4 1 0 0 0 50  0.2296  0.2759  0.4945
  1994  1 4 1 0 0 0 50  0.1989  0.2926  0.5085
  1995  1 4 1 0 0 0 50  0.2593  0.3005  0.4403
  1996  1 4 1 0 0 0 50  0.1998  0.3054  0.4948
  1997  1 4 1 0 0 0 50  0.1622  0.3102  0.5275
  1998  1 4 1 0 0 0 50  0.1276  0.3212  0.5511
  1999  1 4 1 0 0 0 26  0.2224  0.2214  0.5562
  2000  1 4 1 0 0 0 30.5 0.2154  0.2180  0.5665
  2001  1 4 1 0 0 0 45.5 0.2253  0.2699  0.5048
  2002  1 4 1 0 0 0 19  0.1127  0.2346  0.6527
  2003  1 4 1 0 0 0 32.5 0.3762  0.2345  0.3893
  2004  1 4 1 0 0 0 24  0.2488  0.1848  0.5663
  2005  1 4 1 0 0 0 21  0.2825  0.2744  0.4431
  2006  1 4 1 0 0 0 50  0.3276  0.2293  0.4431
  2007  1 4 1 0 0 0 50  0.4394  0.3525  0.2081
  2008  1 4 1 0 0 0 50  0.3745  0.2219  0.4036
  2009  1 4 1 0 0 0 50  0.3057  0.4202  0.2741
  2010  1 4 1 0 0 0 50  0.4081  0.3371  0.2548
  2011  1 4 1 0 0 0 50  0.2179  0.3940  0.3881
  2012  1 4 1 0 0 0 50  0.1573  0.4393  0.4034
  2013  1 4 1 0 0 0 37  0.2100  0.2834  0.5065
  2014  1 4 1 0 0 0 50  0.1738  0.3912  0.4350
  2015  1 4 1 0 0 0 50  0.2340  0.2994  0.4666
  2016  1 4 1 0 0 0 50  0.2255  0.2780  0.4965
  2017  1 4 1 0 0 0 21  0.0849  0.2994  0.6157
  2018  1 4 1 0 0 0 31  0.1475  0.2219  0.6306 #55
  2019  1 4 1 0 0 0 50  0.1961  0.2346  0.5692 #105 no survey so not updated
  2021  1 4 1 0 0 0 50  0.3323  0.1320  0.5357 #59  updated 4-14-22
  2022  1 4 1 0 0 0 50  0.3531  0.2121  0.4348 #75 updated 8-25-22
  ##length  proportions of  pot survey
  ##Year, Seas, Fleet,  Sex,  Type, Shell,  Maturity, Nsamp,  DataVec
```

```
  1995  1 5 1 0 0 0 100 0.1594  0.2656  0.5751
  1998  1 5 1 0 0 0 100  0.0769  0.2205  0.7026
  2001  1 5 1 0 0 0 100  0.1493  0.2049  0.6457
  2004  1 5 1 0 0 0 100  0.0672  0.2484  0.6845
  2007  1 5 1 0 0 0 100  0.1257  0.3148  0.5595
  2010  1 5 1 0 0 0 100  0.1299  0.3209  0.5492
  2013  1 5 1 0 0 0 100  0.1556  0.2477  0.5967
  2015  1 5 1 0 0 0 100  0.0706  0.2431  0.6859
  2016  1 5 1 0 0 0 100  0.0832  0.1917  0.7251
  2017  1 5 1 0 0 0 100  0.1048  0.2540  0.6412
  2018  1 5 1 0 0 0 100  0.10201 0.21611 0.68188 # no survey so not updated
##  Growth data (increment)
# Type of growth increment (0=ignore;1=growth increment with a CV;2=size-at-release; size-at)
0
# nobs_growth
0
#3
# MidPoint Sex Increment CV
# 97.5  1  14.1  0.2197
#112.5  1  14.1  0.2197
#127.5  1  14.1  0.2197
#  97.5  1 13.8 0.2197
#  112.5  1 14.1 0.2197
#  127.5  1 14.4 0.2197
## eof
9999
```

The reference model (16.0) control file for 2022

```
## Sept 2022 smbkc base model 16.0 version
## ============================================== updated for sept 2022 base model     ##
## LEADING PARAMETER CONTROLS                                                          ##
#  Controls  for  leading  parameter  vector  theta
#  LEGEND  FOR  PRIOR:
#  0 = uniform, 1 = normal, 2 = lognormal, 3 =  beta, 4 =  gamma
#  â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€
#  ntheta
  12
## ==================================================================================== ##
# ival        lb        ub        phz   prior     p1      p2         # parameter         #
  0.18      0.01         1        -4       2   0.18    0.02          # M
  14.3      -7.0        30        -2       0    -7       30          # log(R0)
  10.0      -7.0        20        -1       1   -10.0     20          # log(Rini)
  13.39     -7.0        20         1       0    -7       20          # log(Rbar) (MUST be PHASE 1)
  80.0      30.0       310        -2       1    72.5    7.25         # Recruitment size distribution expected value
  0.25       0.1         7        -4       0    0.1     9.0          # Recruitment size scale (variance component)
  0.2      -10.0      0.75        -4       0  -10.0    0.75          # log(sigma_R)
  0.75      0.20      1.00        -2       3    3.0    2.00          # steepness
  0.01      0.00      1.00        -3       3    1.01   1.01          # recruitment autocorrelation
 14.5       5.00     20.00         1       0    5.00  20.00          # logN0 vector of initial numbers at length
 14.0       5.00     20.00         1       0    5.00  20.00          # logN0 vector of initial numbers at length
 13.5       5.00     20.00         1       0    5.00  20.00          # logN0 vector of initial numbers at length

# weight-at-length input method (1 = allometry i.e. w_l = a*l^b, 2 = vector by sex, 3 = matrix by sex)
3
# Male weight-at-length
0.000748427    0.001165731    0.001930510
0.000748427    0.001165731    0.001688886
0.000748427    0.001165731    0.001922246
0.000748427    0.001165731    0.001877957
0.000748427    0.001165731    0.001938634
0.000748427    0.001165731    0.002076413
0.000748427    0.001165731    0.001899330
0.000748427    0.001165731    0.002116687
0.000748427    0.001165731    0.001938784
0.000748427    0.001165731    0.001939764
0.000748427    0.001165731    0.001871067
0.000748427    0.001165731    0.001998295
0.000748427    0.001165731    0.001870418
```

```
0.000748427    0.001165731    0.001969415
0.000748427    0.001165731    0.001926859
0.000748427    0.001165731    0.002021492
0.000748427    0.001165731    0.001931318
0.000748427    0.001165731    0.002014407
0.000748427    0.001165731    0.001977471
0.000748427    0.001165731    0.002099246
0.000748427    0.001165731    0.001982478
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001891628
0.000748427    0.001165731    0.001795721
0.000748427    0.001165731    0.001823113
0.000748427    0.001165731    0.001807433
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001894627
0.000748427    0.001165731    0.001850611
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932
0.000748427    0.001165731    0.001930932 # (updated - should this change?)
0.000748427    0.001165731    0.001930932 # (add line here each year - 4-14-22)
0.000748427    0.001165731    0.001930932 # (add line here each year - 8-25-22)
# Proportion mature by sex
0 1 1
# Proportion legal by sex
0 0 1
## â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€
## GROWTH PARAM CONTROLS                                                                ##
##     Two lines for each parameter if split sex, one line if not                       ##
## â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€
# Use custom transition matrix (0=no, 1=growth matrix, 2=transition matrix, i.e. growth and molting)
# Use growth transition matrix option (1=read in growth-increment matrix; 2=read in size-transition; 3=gamma distribution for size-increment; 4=ga
# option 8 is normal distributed growth incrment, size after incrment is normal
1
# growth increment model (0=prespecified;1=alpha/beta; 2=estimated by size-class;3=pre-specified/emprical)
0
# molt probability function (0=pre-specified; 1=flat;2=declining logistic)
2
# Maximum size-class for recruitment(males then females)
1
## number of size-increment periods
1
## Year(s) molt period changes (blank if no change)

## Two lines for each parameter if split sex, one line if not                           ##
## number of molt periods
1
## Year(s) molt period changes (blank if no changes)

## Beta parameters are relative (1=Yes;0=no)
1
# AEP Growth parameters
## â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€
# ival        lb        ub     phz   prior      p1      p2         # parameter         #
# â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"
#  14.1      10.0      30.0         -3       0    0.0   999.0         # alpha males or combined
#   0.0001    0.0       0.01        -3       0    0.0   999.0         # beta males or combined
#   0.45      0.01      1.0         -3       0    0.0   999.0         # gscale males or combined
 121.5      65.0     145.0         -4       0    0.0   999.0         # molt_mu males or combined
   0.060     0.0       1.0         -3       0    0.0   999.0         # molt_cv males or combined

# The custom growth matrix (if not using just fill with zeros)
```

```
# Alternative TM (loosely) based on Otto and Cummiskey (1990)
   0.1761   0.0000   0.0000
   0.7052   0.2206   0.0000
   0.1187   0.7794   1.0000
#   0.1761   0.7052   0.1187
#   0.0000   0.2206   0.7794
#   0.0000   0.0000   1.0000

# custom molt probability matrix


## ================================================================================ ##
## SELECTIVITY CONTROLS                                                             ##
##     Selectivity P(capture of all sizes). Each gear must have a selectivity and a     ##
##     retention selectivity. If a uniform prior is selected for a parameter then the   ##
##     lb and ub are used (p1 and p2 are ignored)                                   ##
## LEGEND                                                                           ##
##     sel type: 0 = parametric (nclass), 1 = individual parameter for each class(nclass), ##
##               2 = logistic (2, inflection point and slope), 3 = logistic95 (2, 50% and 95% selection), ##
##               4 = double normal (3 parameters, NIY)                              ##
##    5: Flat equal to zero (1 parameter; phase must be negative), UNIFORM1         ##
##    6: Flat equal to one (1 parameter; phase must be negative), UNIFORM0          ##
##    7: Flat-topped double normal selectivity (4 parameters)                       ##
##    8: Declining logistic selectivity with initial values (50% and 95% selection plus extra)  ##
##  Extra (type 1): number of selectivity parameters to be estimated                ##
##     gear index: use +ve for selectivity, -ve for retention                       ##
##     sex dep: 0 for sex-independent, 1 for sex-dependent                          ##
## ================================================================================ ##
## ivector for number of year periods or nodes                                      ##
## POT       TBycatch FBycatch  NMFS_S   ADFG_pot
## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
   2         1        1         1        1         # Selectivity periods
   0         0        0         0        0         # sex specific selectivity, 0 male only fishery
   0         3        3         0        0         # male selectivity type (0=flat, or logistic or double normal)
   0         0        0         0        0         # within another gear insertion of fleet in another
   0         0        0         0        0         # extra parameters
## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
   1         1        1         1        1         # Retention time periods
   0         0        0         0        0         # sex specific retention, 0 for male only fishery
   3         6        6         6        6         # male retention type (flat equal to one, 1 parameter)
   1         0        0         0        0         # male retention flag (0 -> no, 1 -> yes)
   0         0        0         0        0         # extra parameters
   1         1        1         1        1         # determines fi maximum selectivity at size if forced to equal 1 or not
##  â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â
##  Selectivity  P(capture  of  all  sizes)
## â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€
## gear  par   sel                                                 phz     start  end    ##
# index index par sex  ival      lb    ub   prior    p1     p2    mirror period period  ##
## â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€
# Gear-1
   1     1     1   0    0.4    0.001 1.0    0       0      1    3      1978   2008
   1     2     2   0    0.7    0.001 1.0    0       0      1    3      1978   2008
   1     3     3   0    1.0    0.001 2.0    0       0      1    -2     1978   2008
   1     1     1   0    0.4    0.001 1.0    0       0      1    3      2009   2021 # update end yr
   1     2     2   0    1.0    0.001 1.0    0       0      1    3      2009   2021 # update end yr
   1     3     3   0    1.0    0.001 2.0    0       0      1    -2     2009   2021 # update end yr
# Gear-2
   2     7     1   0    40      10.0  200    0      10    200   -3     1978   2021 # update end yr
   2     8     2   0    60      10.0  200    0      10    200   -3     1978   2021 # update end yr
# Gear-3
   3     9     1   0    40      10.0  200    0      10    200   -3     1978   2021 # update end yr
   3    10     2   0    60      10.0  200    0      10    200   -3     1978   2021 # update end yr
# Gear-4
   4     11    1   0    0.7     0.001 1.0    0       0      1    4      1978   2022 # update end yr
   4     12    2   0    1.0     0.001 1.0    0       0      1    4      1978   2022 # update end yr
   4     13    3   0    0.9     0.001 1.0    0       0      1    -5     1978   2022 # update end yr
# Gear-5
   5     14    1   0    0.4     0.001 1.0    0       0      1    4      1978   2022 # update end yr
   5     15    2   0    1.0     0.001 1.0    0       0      1    4      1978   2022 # update end yr
   5     16    3   0    1.0     0.001 2.0    0       0      1    -2     1978   2022 # update end yr
## Retained
# Gear-1
```

```
  -1     17    1   0    120        50 200    0      1    900    -7     1978   2021 # update end yr
  -1     18    2   0    123       110 200    0      1    900    -7     1978   2021 # update end yr
# Gear-2
  -2     19    1   0   595    1    999    0      1    999   -3     1978   2021 # update end yr
# Gear-3
  -3     20    1   0   595    1    999    0      1    999   -3     1978   2021 # update end yr
# Gear-4
  -4     21    1   0   595    1    999    0      1    999   -3     1978   2022 # update end yr
# Gear-
  -5     22    1   0   595    1    999    0      1    999   -3     1978   2022 # update end yr

# Number of asymptotic parameters
1
# Fleet   Sex     Year       ival  lb   ub    phz
      1     1     1978   0.000001   0    1     -3

## ================================================================================ ##
## PRIORS FOR CATCHABILITY
##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
##     and p2 are ignored). ival must be > 0                                          ##
## only allowed to use uniform or lognormal prior                                     ##
## if analytic q estimation step is chosen, turn off estimating q by changing the estimation phase to be -ve ##
## LEGEND                                                                             ##
##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma             ##
## ================================================================================ ##
##  LAMBDA: Arbitrary relative weights for each series, 0 = do not fit.
## SURVEYS/INDICES ONLY
## Analytic (0 = not analytically solved q, use uniform or lognormal prior; 1 = anaylytic) ##
## Lambda = multiplier for input CV, Emphasis = multiplier for likelihood                 ##
## ival    lb      ub    phz   prior   p1       p2    Analytic?   LAMBDA Emphasis
   1.0     0.5      1.2   -4    0       0        9.0   0           1             1 # NMFS trawl
 0.003      0        5     3    0       0        9.0   0           1             1 # ADF&G pot
## ================================================================================ ##
## if uniform prior is specified then use lb and ub rather than p1 and p2
## ================================================================================ ##
## ADDITIONAL CV FOR SURVEYS/INDICES                                                  ##
##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
##     and p2 are ignored). ival must be > 0                                          ##
## LEGEND                                                                             ##
##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma             ##
## ================================================================================ ##
## ival                  lb     ub     phz    prior     p1      p2
   0.0000001      0.000000001   10.0      -4    4         1.0     100   # NMFS (PHASE -4)
   0.0000001      0.000000001   10.0      -4    4         1.0     100   # ADF&G
## ================================================================================ ##
### Pointers to how the additional CVs are used (0 ignore; >0 link to one of the paramters)
0 0
## ================================================================================ ##
## PENALTIES FOR AVERAGE FISHING MORTALITY RATE FOR EACH GEAR
## ================================================================================ ##
## Mean_F   Female Offset STD_PHZ1   STD_PHZ2   PHZ_M   PHZ_F Fbar_l Fbar_h Fdev_L Fdev_h Foff_l Foff_h
   0.2             0.0     3.0      50.0       1       -1     -12     4     -10     10    -10     10  # Pot
   0.0001          0.0     4.0      50.0       1       -1     -12     4     -10     10    -10     10  # Trawl
   0.0001          0.0     4.0      50.0       1       -1     -12     4     -10     10    -10     10  # Fixed
   0.00            0.0     2.00     20.00      -1      -1     -12     4     -10     10    -10     10  # NMFS
   0.00            0.0     2.00     20.00      -1      -1     -12     4     -10     10    -10     10  # ADF&G
## ================================================================================ ##

## ================================================================================ ##
## OPTIONS FOR SIZE COMPOSTION DATA (COLUMN FOR EACH MATRIX)
## ================================================================================ ##
## LIKELIHOOD OPTIONS
##   -1) Multinomial with estimated/fixed sample size
##   -2) Robust approximation to multinomial
##   -3) logistic normal (NIY)
##   -4) multivariate-t (NIY)
##   -5) Dirichlet
## AUTOTAIL COMPRESSION
##   pmin is the cumulative proportion used in tail compression.
## ================================================================================ ##
#  1   1   1  # Type of likelihood
  2   2   2  # Type of likelihood
```

```
#  5   5   5   # Type of likelihood
  0   0   0   # Auto tail compression (pmin)
  1   1   1   # Initial value for effective sample size multiplier
 -4  -4  -4   # Phz for estimating effective sample size (if appl.)
  1   2   3   # Composition aggregator
  1   2   2   # set to 2 for survey-like predictions; 1 for catch like predictions #AEP
  1   1   1   # LAMBDA
  1   1   1   # Emphasis
## ================================================================================ ##

## ================================================================================ ##
## TIME VARYING NATURAL MORTALIIY RATES                                             ##
## ================================================================================ ##
## TYPE:
##      0 = constant natural mortality
##      1 = Random walk (deviates constrained by variance in M)
##      2 = Cubic Spline (deviates constrained by nodes & node-placement)
##      3 = Blocked changes (deviates constrained by variance at specific knots)
##       4 = Changes in pre-specified blocks                                        ##
##       5 = Changes in some knots                                                  ##
##       6 = Changes in Time blocks                                                 ##
## ================================================================================ ##
## M Type
6
## M is relative (YES = 1; NO = 0)

## Phase of estimation (only use if parameters are default)
3
## STDEV in m_dev for Random walk
10.0
## Number of nodes for cubic spline or number of step-changes for option 3
2
## Year position of the knots (vector must be equal to the number of nodes)
1998 1999
## Number of Breakpoints in M by size
0
## Size-class of breakpoint
#3
## Specific initial values for the natural mortality devs (0-no, 1=yes)
1
## ======================================================================================= ##
## ival        lb        ub        phz   extra    prior     p1      p2        # parameter     ##
## ======================================================================================= ##
 1.600000       0          2         3      0                        # Males
 0.000000      -2          2       -99      0                        # Dummy to retun to base value
# 2.000000       0          4        -1      0                        # Size-specific M
## ================================================================================ ##

##  â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â
##  TAGGING controls  CONTROLS
##  â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â
0          # emphasis on tagging data

# maturity specific natural mortality? (yes = 1; no = 0; only for use if nmature > 1) # NEW april 22?
0
## â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€
##  ival        lb    ub    phz   prior p1    p2        # parameter     ##
## â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€"â€
  0     -1    1   -1    0  1    1
#  0     -1    1   -1    0  1    1

## ================================================================================ ##
## OTHER CONTROLS
## ================================================================================ ##
1978       # First rec_dev
2021       # last rec_dev (updated annually, should be last completed crab year?)
   3       # Estimated rec_dev phase
  -3       # Estimated sex_ratio
 0.5       # initial sex-ratio
  -3       # Estimated rec_ini phase
   1       # VERBOSE FLAG (0 = off, 1 = on, 2 = objective func)
   2       # Initial conditions (0 = Unfished, 1 = Steady-state fished, 2 = Free parameters)
```

```
   1       # Lambda (proportion of mature male biomass for SPR reference points)
   0       # Stock-Recruit-Relationship (0 = None, 1 = Beverton-Holt)
  10       # Maximum phase (stop the estimation after this phase).
  -1       # Maximum number of function calls, if 1, stop at fn1 call; if -1 run as long as it takes
  1        # Calculate referene point (0=no)
  200      # Years to compute equilibria
## ======================================================================================= ##
## EMPHASIS FACTORS (CATCH)
## ======================================================================================= ##
#Ret_POT Disc_POT Disc_trawl Disc_fixed
      1        1          1          1

## EMPHASIS FACTORS (Priors) by fleet: Fdev_total, Fdov_total, Fdev_year, Fdov_year
1 0 0.000 0 # Pot fishery
1 0 0.000 0 # Trawl bycatch
1 0 0.000 0 # fixed gear bycatch
1 0 0.000 0 # NMFS survey
1 0 0.000 0 # ADF&G survey

## ======================================================================================= ##
## EMPHASIS FACTORS (Priors)
## ======================================================================================= ##
# Log_fdevs   meanF      Mdevs  Rec_devs Initial_devs Fst_dif_dev Mean_sex-Ratio    Molt_prob  Free selectivity  Init_n_at_len Fvecs Fdovss (!!!N
      10000       0        1.0         1           0           0             1            0                 0                    0     0      0

## EOF
9999
```

Appendix C. Ecosystem and Socioeconomic Profile of the Saint Matthew Blue King Crab stock - Report Card

Erin Fedewa, Brian Garber-Yonts and Kalei Shotwell

September 2022

With Contributions from:

Matt Callahan, Curry Cunningham, Ben Daly, Jean Lee, Jens Nielsen, Katie Palof, Darren Pilcher, Dale Robinson, and Abigail Tyrell

Current Year Update

The ecosystem and socioeconomic profile or ESP is a standardized framework for compiling and evaluating relevant stock-specific ecosystem and socioeconomic indicators and communicating linkages and potential drivers of the stock within the stock assessment process (Shotwell et al., *In Review*). The ESP process creates a traceable pathway from the initial development of indicators to management advice and serves as an on-ramp for developing ecosystem-linked stock assessments.

Please refer to the last full and partial ESP documents (Fedewa et al., 2019, Appendix E, pp. 99 – 120 and Fedewa et al., 2020, Appendix D, pp. 87 – 100) which are available within the Saint Matthew blue king crab (SMBKC) stock assessment and fishery evaluation or SAFE report for further information regarding the ecosystem and socioeconomic linkages for this stock.

Management Considerations

The following are the summary considerations from current updates to the ecosystem and socioeconomic indicators evaluated for SMBKC:

- In 2022, bottom temperatures returned to near-average and the cold pool extended into the majority of the St. Matthew Island management area. The return of cold-water habitat following a 2018-2019 heat wave suggests optimal conditions for the highly specific thermal and habitat requirements of SMBKC.
- Despite repeated fishery closures, SMBKC recruitment remains below-average, although recruit abundance increased from 2021 to 2022.
- SMBKC have experienced a steady decline in bottom water pH since 2017, reaching 7.82 in 2022. Persistent, corrosive bottom waters surrounding St. Matthew Island suggest potential impacts on shell formation, growth and survival of BKC although laboratory studies suggest that negative impacts are not likely until pH reaches 7.5.
- Above average chlorophyll-a biomass and benthic invertebrate density in recent years suggests optimal foraging conditions for both larval and benthic stages of SMBKC.
- The SMBKC fishery has remained closed to targeted fishing since 2015 (the 2015/2016 crab season).
- Incidental catch of SMBKC biomass in EBS groundfish fisheries during 2021 declined substantially from the previous year, to 359 kg, the lowest value in the available time series and continuing a declining trend observed since a recent high in 2017.

Modeling Considerations

The following are the summary results from the intermediate and advanced stage monitoring analyses for SMBKC:

- The highest ranked predictor variable (> 0.50 inclusion probability) in the advanced stage monitoring analysis was SMBKC recruit biomass. Due to concerns with autocorrelation in model-based estimates of mature male biomass, indicator importance tests in future SMBKC ESP updates will use recruitment estimates as a response variable.
- The advanced stage indicator analysis provides updates on developing research ecosystem linked models that are not yet included as a model alternative in the main stock assessment. We have not received updates on new research ecosystem linked models for SMBKC at this time.

Assessment

Ecosystem and Socioeconomic Processes

We summarize important processes that may be helpful for identifying productivity bottlenecks and dominant pressures on the stock in conceptual models detailing 1) ecosystem processes by RKC life history stage (Figure 1a) and 2) socioeconomic performance metrics (Figure 1b). The ecosystem conceptual model highlights abiotic and biotic processes identified by each life stage from the literature, process studies and laboratory rearing experiments.

During the early life stages, successful settlement of BKC larvae has been linked to shallow, nearshore waters (<50m) and hard substrate such as shell hash, gravel or rock due to the reliance on crypsis to evade predation (Armstrong et al., 1985; Daly and Long, 2014). Unlike RKC, juvenile BKC lack a heavy covering of carapace spines and do not form pods to offer protection from predation, emphasizing the role of habitat complexity in BKC survival (Stevens, 2014). While late juvenile and adult BKC are less reliant on habitat with complex substrate, temperature and depth are habitat requisites given that mature female BKC migrate to relatively shallow, nearshore waters south of St. Matthew Island during the spring and summer months when bottom temperatures reach their maximum (Pengilly and Vanek, 2014). The biannual molt and reproductive strategy characteristic of BKC in contrast to most other *Paralithodes* spp. suggests that energetic restrictions imposed by temperature or prey conditions may be a limitation in reproductive dynamics (Webb, 2014; Jensen et al., 1985).

The socioeconomic conceptual model highlights fishery performance indicators that represent processes most directly involved in prosecution of the SMBKC fishery, and thus have the potential to differentially affect the condition of the stock depending on how they influence the timing, spatial distribution, selectivity, and other aspects of fishing pressure. Implementation of the Crab Rationalization Program and the allocation of tradable crab harvest quota shares resulted in rapid consolidation of the SMBKC fleet and changed the timing of the fishery. These and other institutional changes continue to influence the geographic and inter-sectoral distribution of benefits produced by the SMBKC fleet.

Indicator Suite

The following list of indicators for SMBKC is organized by categories: three for ecosystem indicators (physical, lower trophic, and upper trophic) and two for socioeconomic indicators (fishery performance and economic). A title, short description and contact name for the indicator contributor are provided. We also include the anticipated sign of the proposed relationship between the indicator and the stock population dynamics where relevant. Please refer to the last full ESP document for detailed information regarding the ecosystem and socioeconomic indicator descriptions and proposed mechanistic linkages for this stock (Fedewa et al., 2019). Time series of the ecosystem and socioeconomic indicators are provided in Figure 2a and Figure 2b, respectively. Please note, we are not including the ROMS spring bottom temperature indicator at this time as more seasonal skill testing is necessary before use in a stock assessment context. A ROMS ocean acidification indicator was updated with current-year data, however the whole time series is presented as pH values instead of aragonite saturation states to simplify interpretation and relate to results of laboratory studies.

In addition, Saint Matthew Island summer bottom temperature and cold pool extent indicators were developed using EBS bottom trawl survey temperature data, whereas in the last partial SMBKC ESP, these respective indicators were developed from Bering 10K ROMS model hindcasts due to the cancellation of the 2020 EBS bottom trawl survey. Two socioeconomic indicators have been discontinued due to concerns over redundancy with the stock assessment model and in an effort to emphasize those indicators that are most closely associated with the health and condition of the stock. The two discontinued indicators are the following: are community-focused indicators - annual active processors in the Bristol Bay red king crab fishery, annual active processors in the Saint Matthew Island blue king crab fishery, and annual local quotient of Saint Matthew Island blue king crab landed catch in Saint Paul Island - which are not directly associated with the condition of the stock and are thus not directly relevant to ABC or TAC decision-making. Detailed community information for BSAI crab fisheries, including the above indicators, are available in the Annual Community Engagement and Participation Overview (ACEPO) report (Wise et al., 2021). We did add one socioeconomic indicator of ex-vessel value of the Saint Matthew Island blue king crab fishery landings to be consistent with other ESP report cards.

Ecosystem Indicators:

Physical Indicators (Figure 2a. a-e)

- a.) The areal extent of the summer cold pool (EBS bottom trawl survey stations with bottom temperatures < 2ºC; contact: Erin Fedewa). Proposed sign of relationship is positive.
- b.) Summer bottom temperatures in Saint Matthew Island management area from the AFSC eastern Bering Sea bottom trawl survey (contact: E. Fedewa). Proposed sign of relationship is positive.
- c.) Spring pH index in Saint Matthew Island from the Bering10K ROMS model (Pilcher et al., 2019) (contact: D. Pilcher). Proposed sign of relationship is positive.
- d.) Summer wind stress (m/s) in Saint Matthew Island from NOAA/NCDC blended winds and Metop-A ASCAT satellite (Zhang et al., 2006, NOAA/NESDIS, CoastWatch) (contact: D. Robinson). Proposed sign of relationship is negative.

Lower Trophic Indicators (Figure 2a.f)

- e.) Spring chlorophyll-a biomass in Saint Matthew Island from MODIS satellites (contact: M. Callahan and J. Nielsen). Proposed sign of relationship is positive

Upper Trophic Indicators (Figure 2a.g-m)

- f.) Summer Pacific cod density in Saint Matthew Island management area from the AFSC eastern Bering Sea bottom trawl survey (contact: E. Fedewa). Proposed sign of relationship is negative.
- g.) Summer benthic invertebrate density in Saint Matthew Island management area from the AFSC eastern Bering Sea bottom trawl survey. Invertebrates include brittle stars, sea stars, sea cucumber, bivalves, non-commercial crab species, shrimp and polychaetes (contact: E. Fedewa). Proposed sign of relationship is positive.
- h.) Annual blue king crab recruit abundance (105 - 119 mm CL) in Saint Matthew Island management area from the AFSC eastern Bering Sea bottom trawl survey (contact: E. Fedewa). Proposed sign of relationship is positive.

Socioeconomic Indicators: (all monetary values are inflation-adjusted to $2021 value)

Fishery Performance Indicators (Figure 2b.a-d)

- a.) Annual catch-per-unit-effort (CPUE), expressed as mean number of legal crabs per potlift, in the SMBKC fishery, representing relative efficiency of fishing effort (contact: B. Daly)
- b.) Annual total potlifts in the SMBKC fishery, representing the level of fishing effort expended by the active fleet (contact: B. Daly)
- c.) Annual number of active vessels in the SMBKC fishery, representing the level of fishing effort assigned to the fishery (contact: J. Lee)
- d.) Estimated total incidental catch of SMBKC biomass (kg) in EBS groundfish fisheries (contact: J. Lee)

Economic Indicators (Figure 2b.e-h)

- e.) Percentage of the annual SMBKC total allowable catch (TAC) (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing (contact: B. Garber-Yonts) f.) Annual ex-vessel value ($2021) of SMBKC fishery landings, representing gross economic returns to the harvest sector, as a principal driver of fishery behavior (contact: J. Lee)

g.) Annual ex-vessel price per pound ($2021) of SMBKC fishery landings, representing per-unit gross economic returns to the harvest sector, as a principal driver of fishery behavior (contact: J. Lee)

h.) Annual ex-vessel revenue share, expressed as average proportion of total annual gross landings revenue from all fisheries earned from SMBKC landings by vessels active in the fishery (contact: J. Lee)

Indicator Monitoring Analysis

There are up to three stages (beginning, intermediate, and advanced) of statistical analyses for monitoring the indicator suite listed in the previous section. The beginning stage is a relatively simple evaluation by traffic light scoring. This evaluates the current year trends relative to the mean of the whole time series, and provides a historical perspective on the utility of the whole indicator suite. The intermediate stage uses importance methods related to a stock assessment variable of interest (e.g., recruitment, biomass, catchability). These regression techniques provide a simple predictive performance for the variable of interest and are run separate from the stock assessment model. They provide the direction, magnitude, uncertainty of the effect, and an estimate of inclusion probability. The advanced stage is used for testing a research ecosystem linked model and output can be compared with the current operational model to understand information on retrospective patterns, prediction performance, and comparisons of other model output such as terminal spawning stock biomass or mean recruitment. This stage provides an on-ramp for introducing an alternative ecosystem linked stock assessment model to the current operational stock assessment model and can be used to understand the potential reduction in uncertainty by including the ecosystem information.

Beginning Stage: Traffic Light Test

We use a simple scoring calculation for this beginning stage traffic light evaluation. Indicator status is evaluated based on being greater than (“high”), less than (“low”), or within (“neutral”) one standard deviation of the long-term mean. A sign based on the anticipated relationship between the ecosystem indicators and the stock (generally shown in Figure 1a and specifically by indicator in the Indicator Suite, Ecosystem Indicators section) is also assigned to the indicator where possible. If a high value of an indicator generates good conditions for the stock and is also greater than one standard deviation above the mean, then that value receives a ‘+1’ score. If a high value generates poor conditions for the stock and is greater than one standard deviation above the mean, then that value receives a ‘-1’ score. All values less than or equal to one standard deviation from the long-term mean are average and receive a ‘0’ score. The scores are summed by the three organizational categories within the ecosystem (physical, lower trophic, and upper trophic) or socioeconomic (fishery performance, economic, and community) indicators and divided by the total number of indicators available in that category for a given year. The scores over time allow for comparison of the indicator performance and the history of stock productivity (Figure 3). We also provide five year indicator status tables with a color or text code for the relationship with the stock (Tables 1a,b) and evaluate the current year status in the historical indicator time series graphic (Figures 2a,b) for each ecosystem and socioeconomic indicator. Socioeconomic indicators representing the target fishery are reported, by calendar year, through 2015 (noting that virtually all active harvest activity occurs prior to January), the last year that the fishery was open (corresponding to the 2015-2016 crab season), and incidental catch is reported for the most recent full calendar year (2021).

We evaluate the status and trends of the ecosystem and socioeconomic indicators to understand the pressures on the SMBKC stock regarding recruitment, stock productivity, and stock health. We start with the physical indicators and proceed through the increasing trophic levels for the ecosystem indicators then evaluate the fishery performance and economic indicators as listed above. Here, we concentrate on updates since the last ESP. Overall, the physical indicators scored below average for 2022, while the lower trophic indicators were above average, and the upper trophic indicators were average (Figure 3). The fishery performance indicators scored below average for 2021, but this is based solely on one indicator (incidental catch of SMBKC biomass in EBS groundfish fisheries). There is no new information for the remaining socioeconomic indicators associated with the target SMBKC fishery, which has remained closed since the 2015-2016 season. Compared to the previously available data points, these scores reflect a further decrease from below-average for the physical indicators, an increase from average for the lower trophic indicators, an increase from below-average for the upper trophic indicators, and a decrease for the fishery performance indicator.

Overall, trends in physical ecosystem indicators indicate a return to near-normal conditions near St. Matthew Island, with average bottom temperatures nearly 2.5°C colder than 2018-2019 heat conditions. Continued declines in pH are approaching a critical threshold for many Bering Sea crustacean stocks, although blue king crab may be capable of acclimating to acidic bottom waters at or around 7.8 (Long et al., 2017). A fairly large cold pool in 2022 suggests that SMBKC larvae likely hatched in mid-April, coinciding with average peak spring bloom in the Bering Sea (Stevens, 2006). Likewise, above-average chlorophyll-*a* biomass in the St. Matthew Island management area indicates suitable primary production conditions for larval survival. Higher spring and summer surface winds in 2022 may have compromised prey encounter rates and SMBKC larval first-feeding success, although more research is needed to understand early life history processes of blue king crab.

While current-year updates for upper trophic level Pacific cod and benthic invertebrate indicators are not yet available following the conclusion of the 2022 EBS bottom trawl survey, both indicators were near-average in 2021. SMBKC recruitment still remains below the long-term average, although increased population abundances noted on the 2022 EBS bottom trawl survey coinciding with cold-water conditions may point to enhanced productivity in years with near-normal thermal conditions (Zacher et al., *in review*).

Intermediate Stage: Importance Test

We plan to update the second stage indicator analysis in 2024 and are exploring additional importance methods for SMBKC.

Advanced Stage: Research Model Test

At this time we do not have any ecosystem research models to report for SMBKC.

Data Gaps and Future Research Priorities

Additional data on BKC life history characteristics (i.e. growth-per-molt data and molting probabilities) as well as estimates for natural mortality would aid in a better understanding of stage-specific vulnerabilities for the metric panel. In addition, process-based studies are necessary in order to identify links between larval survival, recruitment and environmental factors. Specifically, future laboratory and field research should focus on clarifying the range of optimal conditions for larval survival and successful larval retention and settlement in juvenile nursery areas. Examining larval drift patterns and spatial distributions of mature female BKC around St. Matthew Island in relation to habitat characteristics will help to inform essential fish habitat models and support the future development of a settlement success indicator. Developing a proxy for habitat quality in and around St. Matthew Island should also be prioritized, as metric assessment results highlighted several vulnerabilities related to habitat. Furthermore, given the prevalence of corrosive bottom water conditions in the SMBKC management area, continued research efforts should focus on the potential impacts of ocean acidification on BKC physiology and the role pH levels may play in determining habitat use and spatial distributions of the stock.

In most socioeconomic dimensions, SMBKC fishery is relatively data rich in many respects. In the context of the ESP, however, the intermittent nature of the fishery and reliance on fishery-dependent socioeconomic data limits the available socioeconomic information to years when the fishery has opened. This complicates the depiction and/or interpretation of long-term averages for most socioeconomic indicators and suggests the need for development of indicators that are informative of social and economic factors relevant to the purposes of the ESP, but function on a continuous basis, including during years when the fishery is closed. Potential examples include estimation of current value of PSMFC QS assets, calculation of revenue share metrics for SMBKC processors and vessels identified with the SMBKC fishery on the basis of more continuous association than participation in the fishery during a particular year. Substantial improvements over the indicators reported above are feasible, however, are largely dependent on further development of clear objectives for the inclusion of social and economic indicators within the ESP framework.

SMBKC ESP developments for 2024 include: 1) updating the intermediate stage indicator analysis, 2) producing a Request for Indicators in January 2024 to highlight data gaps and propose new indicator contributions, 3) developing a habitat quality indicator using EFH and Fishing Effects model output, and 4) updating ecosystem and socioeconomic indicators and considerations prior to the 2024 Crab Plan Team meeting to inform SMBKC management and rebuilding.

We plan to further evaluate the information provided in the Economic SAFE and ACEPO report to determine what socioeconomic indicators could be provided in the ESP that are not redundant with those reports and related directly to stock health. This may result in a transition of socioeconomic indicators currently reported in this ESP to a different series of indicators in future ESPs. Additional consideration of the timing of the economic and community reports, which are delayed by 1-2 years (depending on the data source) from the annual stock assessment cycle, should also be undertaken. The Scientific and Statistical Committee (SSC) recently recommended that local knowledge, traditional knowledge, and subsistence information may be helpful for understanding recent fluctuations in stock health, shifts in stock distributions, or changes in size or condition of species in the fishery. We could include this information as supportive evidence and perspective on many indicators monitored within the ESP.

As indicators are improved or updated, they may replace those in the current set of indicators to allow for refinement of the BAS model and potential evaluation of performance and risk within the operational stock assessment model. The annual request for indicators (RFI) for the SMBKC ESP will include these data gaps and research priorities along with a list of potential new indicators that could be developed for the next full ESP assessment.

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Tables

Table 1a. First stage ecosystem indicator analysis for SMBKC, including indicator title and the indicator status of the last five available years. The indicator status is designated with text, (greater than = "high", less than = "low", or within 1 standard deviation = "neutral" of time series mean). Fill color of the cell is based on the sign of the anticipated relationship between the indicator and the stock (blue or italicized text = good conditions for the stock, red or bold text = poor conditions, white = average conditions). A gray fill and text = "NA" will appear if there were no data for that year.

Indicator category	Indicator	2018 Status	2019 Status	2020 Status	2021 Status	2022 Status
Physical	Summer Cold Pool- SEBS Survey	**low**	**low**	NA	**low**	neutral
	Summer Temperature Bottom- SEBS Survey	*high*	*high*	NA	*high*	neutral
	Spring pH SMBKC- Model	**low**	**low**	**low**	**low**	**low**
	Summer Wind Stress SMBKC- Satellite	**high**	neutral	neutral	neutral	**high**
Lower Trophic	Spring Chlorophyll-*a* Biomass- Satellite	neutral	neutral	neutral	neutral	*high*
Upper Trophic	Summer Pacific Cod Density- SEBS Survey	neutral	neutral	NA	neutral	NA
	Summer Benthic Invertebrate Density- SEBS Survey	neutral	*high*	NA	neutral	NA
	Annual Blue King Crab Recruit Abundance- SEBS Survey	**low**	neutral	NA	**low**	neutral

Table 1b. First stage socioeconomic indicator analysis for SMBKC, including indicator title and the indicator status of the last five available years. The indicator status is designated with text, (greater than = “high”, less than = “low”, or within 1 standard deviation = “neutral” of time series mean). A gray fill and text = “NA” will appear if there were no data for that year.

Indicator category	Indicator	2017 Status	2018 Status	2019 Status	2020 Status	2021 Status
Fishery Performance	Annual Blue King Crab CPUE SMBKC Fishery	NA	NA	NA	NA	NA
	Annual Blue King Crab Total Potlift SMBKC Fishery	NA	NA	NA	NA	NA
	Annual Blue King Crab Active Vessels SMBKC Fishery	NA	NA	NA	NA	NA
	Annual Blue King Crab Incidental Catch EBS Fishery	high	neutral	neutral	neutral	low
Economic	Annual Blue King Crab TAC Utilization SMBKC Fishery	NA	NA	NA	NA	NA
	Annual Blue King Crab Exvessel Value SMBKC Fishery	NA	NA	NA	NA	NA
	Annual Blue King Crab Exvessel Price SMBKC Fishery	NA	NA	NA	NA	NA
	Annual Blue King Crab Exvessel Revenue Share SMBKC Fishery	NA	NA	NA	NA	NA

Figures

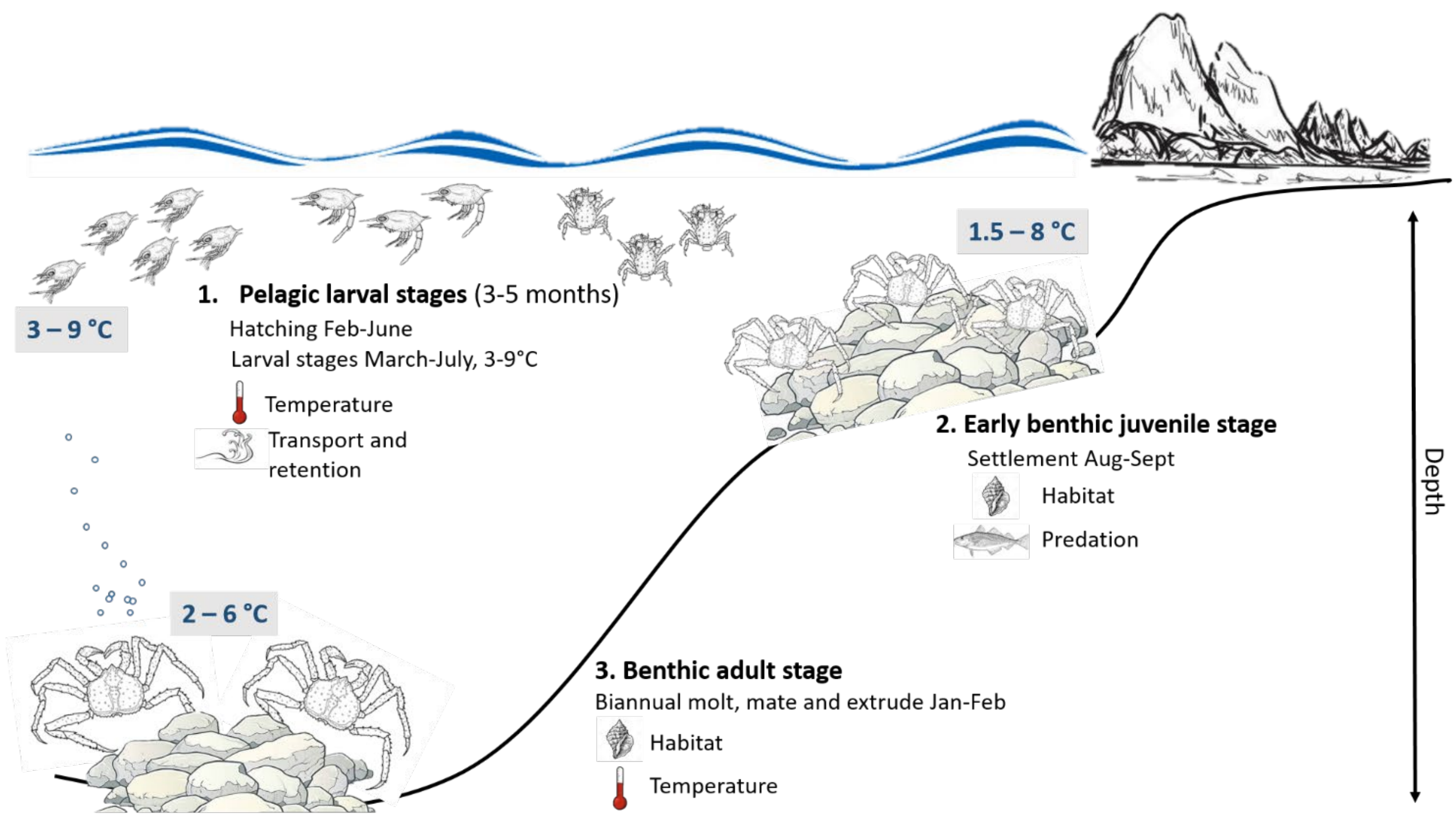

Figure 1a: Life history conceptual model for SMBKC summarizing ecological information and key ecosystem processes affecting survival by life history stage. Thermal requirements by life history stage were determined from BKC laboratory studies. Red text means increases in process negatively affect survival, while blue text means increases in process positively affect survival.

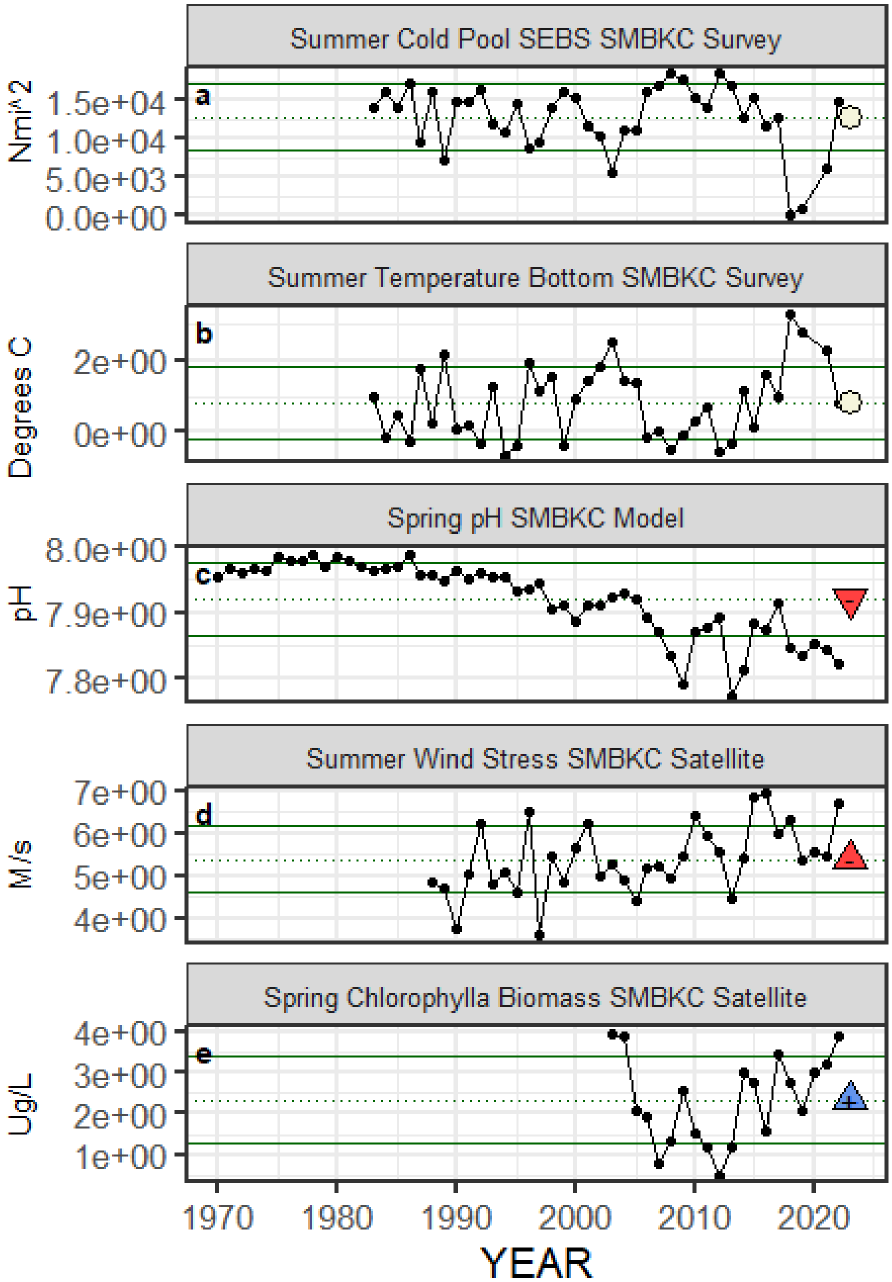

Figure 2a. Selected ecosystem indicators for SMBKC with time series ranging from 1970 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color represents proposed relationship for stock, white circle for neutral).

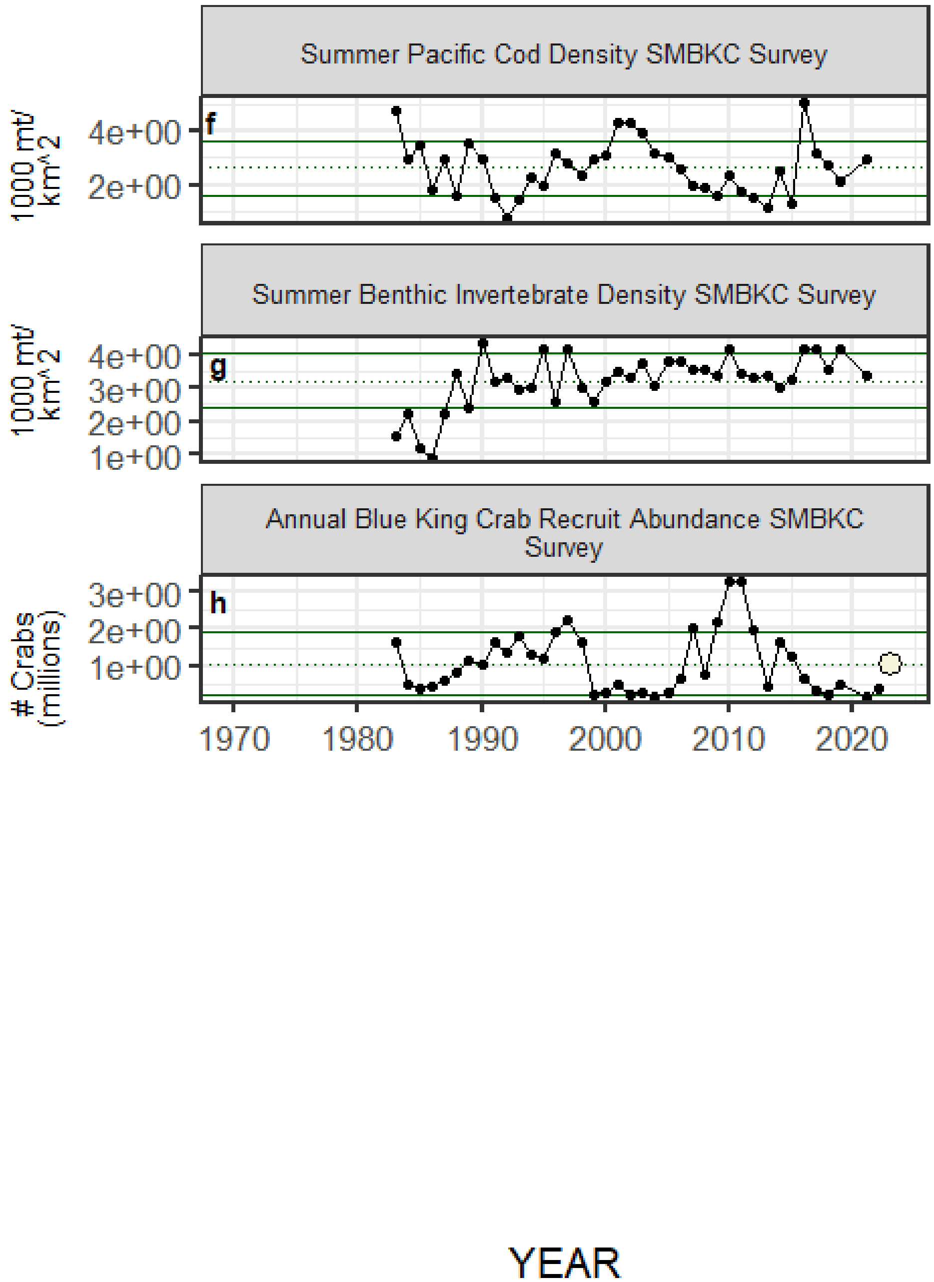

Figure 2a (cont.). Selected ecosystem indicators for SMBKC with time series ranging from 1970 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation of the time series mean, color represents proposed relationship for stock, white circle for neutral).

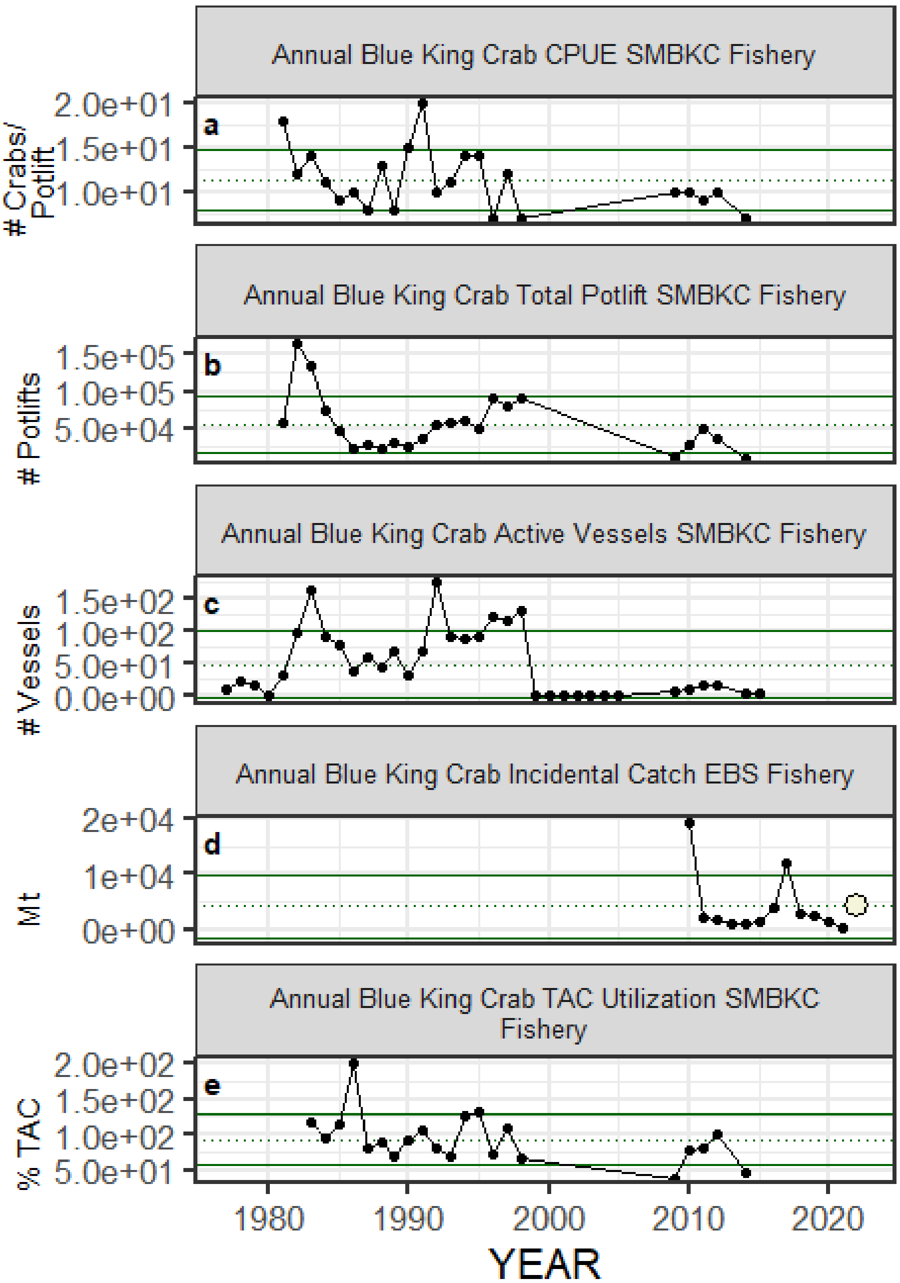

Figure 2b. Selected socioeconomic indicators for SMBKC with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation from the time series mean, color represents proposed relationship for stock, white circle for neutral).

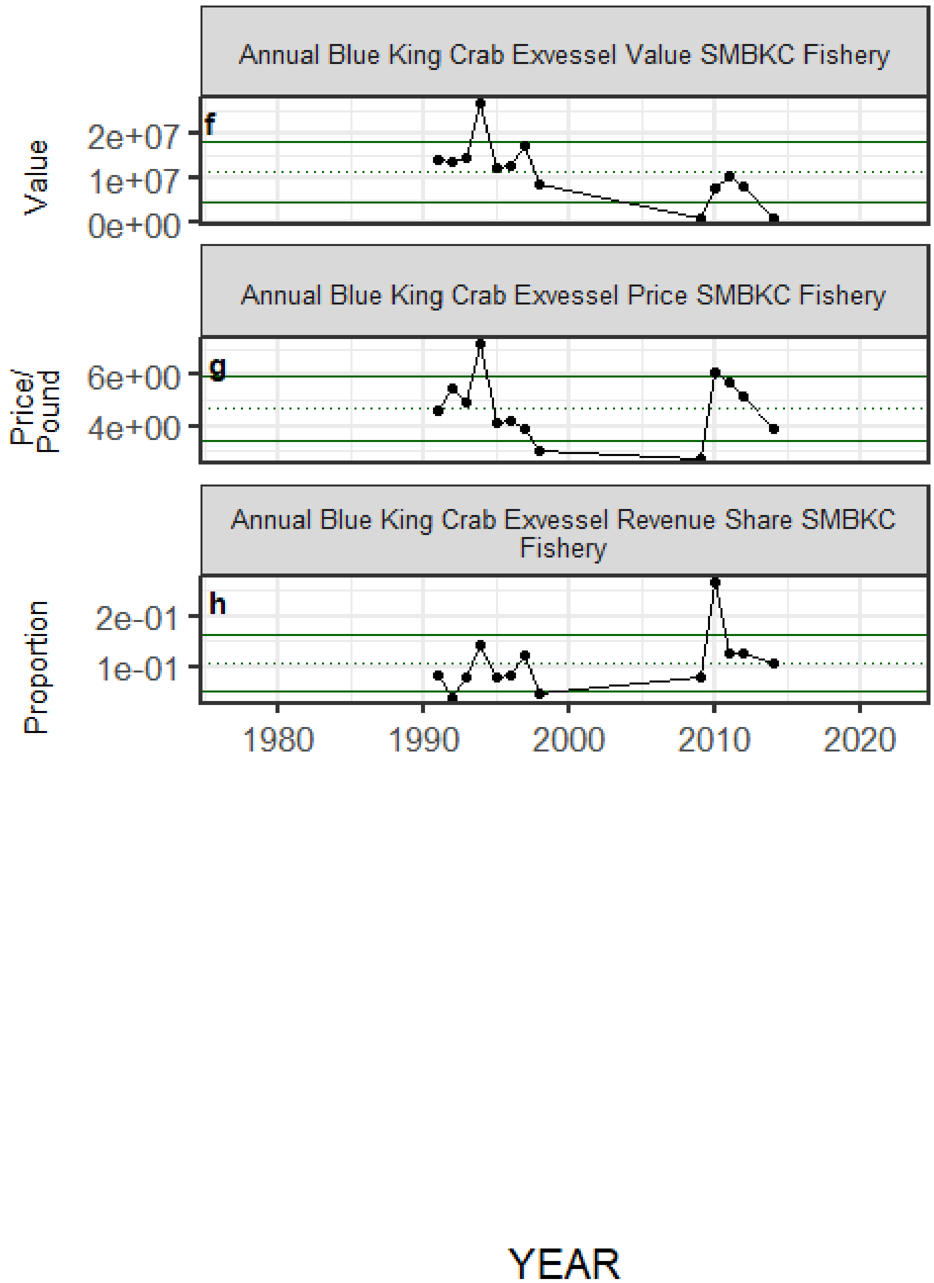

Figure 2b (cont.). Selected socioeconomic indicators for SMBKC with time series ranging from 1977 – present. Upper and lower solid green horizontal lines represent 1 standard deviation of the time series mean. Dotted green horizontal line is the mean of the time series. A symbol appears when current year data are available and follows the traffic light status table designations (triangle direction represents if above or below 1 standard deviation from the time series mean, color represents proposed relationship for stock, white circle for neutral).

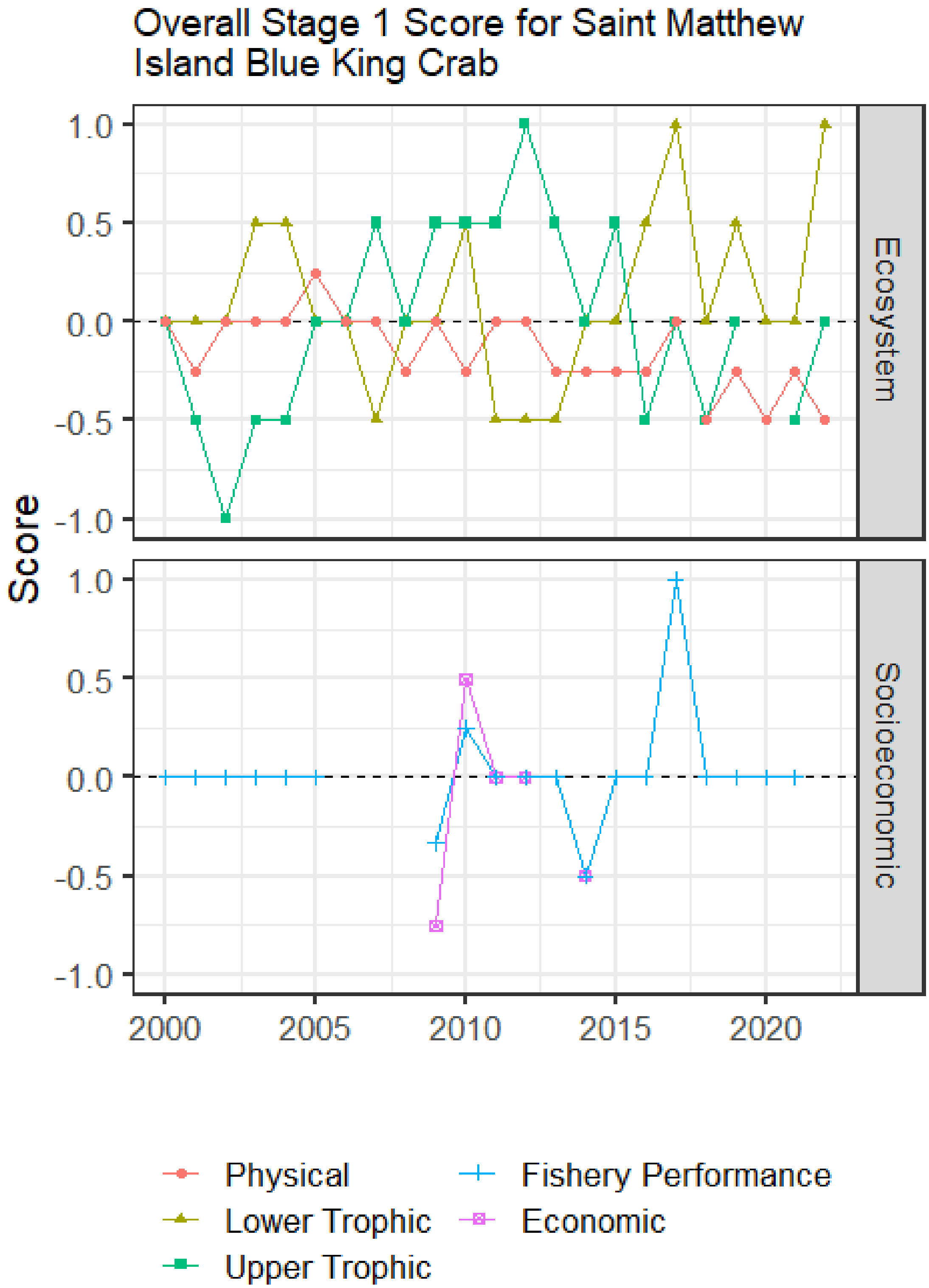

Figure 3: Simple summary traffic light score by category for ecosystem and socioeconomic indicators from 2000 to present.