Saint Matthew Island Blue King Crab Stock Assesssment 2020

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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 1978-2019 NMFS trawl survey mean biomass is 5,605 t with the 2019 value being the 15th lowest (3,170 t; the tenth lowest since 2000). This 2019 biomass of $\geq$ 90 mm carapace length (CL) male crab is 57% of the long term mean at 6.99 million pounds (with a CV of 34%), and an 83% increase from the 2018 biomass. The most recent 3-year average of the NMFS survey is 40% 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 2019 value is substantially larger than the two previous years (3,170 t compared to 1,731 t in 2018 and 1,794 t in 2017). Due to cancellation of the 2020 bottom trawl surveys there is no additional abundance data in the model for 2020. The ADFG pot survey last occured 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). The assessment model estimates temper this increase and suggest that the stock (in survey biomass units) is presently at about 26% of the long term model-predicted survey biomass average, similar to 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 2019 trawl-survey area-swept estimate of 0.403 million male SMBKC in this size class is the twelfth lowest in the 42 years since 1978 and follows two of the lowest previously observed values in 2017 and 2018. The recent six-year (2014 - 2019) average recruitment is only 47% 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

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

bycatch mortality in the groundfish fisheries. Based on the reference model for SMBKC, the estimate 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 55% 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 reference model.

Year	MSST	Biomass (MMB_{mating})	TAC	Retained catch	Total male catch	OFL	ABC
2016/17	1.97	2.23	0.00	0.00	0.001	0.14	0.11
2017/18	1.85	2.05	0.00	0.00	0.003	0.12	0.10
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		1.12				0.05	0.04

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

Year	MSST	Biomass (MMB_{mating})	TAC	Retained catch	Total male catch	OFL	ABC
2016/17	4.3	4.91	0.000	0.000	0.002	0.31	0.25
2017/18	4.1	2.85	0.000	0.000	0.007	0.27	0.22
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		2.48				0.112	0.08

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 ≥ 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 - 2019) as the default reference period.

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

Year	Tier	B_{MSY}	Biomass (MMB_{mating})	B/B_{MSY}	F_{OFL}		Basis for B_{MSY}	Natural mortality
2016/17	4b	3.67	2.23	0.61	0.09	1	1978-2016	0.18
2017/18	4b	3.86	2.05	0.53	0.08	1	1978-2017	0.18
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	1.12	0.34	0.047	1	1978-2019	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. This assessment includes no new survey data points due to the cancellation of the 2020 NMFS trawl-survey. The triennial ADF&G pot surveys were last conducted in 2018, and are back on a triennial cycle, with the next survey planned for 2021. Due to the lack of bycatch in other crab fisheries and new survey data there is no new size compositon data. The assessment was updated with 2010-2019 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 uses the General Model for Alaska Crab Stocks (GMACS) framework. 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 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 decline over the past few years. The "reference" model is that which was selected for use in 2019. The base model presented here is the reference model with updated groundfish bycatch data for the 2019/20 crab season (model 16.0 base). One additional model is presented for consideration, which is a small variant of the base model, model 16.0a (**fixR**), which fixes recruitment in the most recent year to the average of the last seven years to avoid unrealistically high recruitment estimates. Additionally, retrospective analyses without the terminal year of survey data and runs with "fake" survey data were performed to assess the uncertainty in the 2020 biomass estimates and reference point calculations due to the lack of a 2020 survey; the methods and results are detailed in Appendix C.

In addition to the two models for considerations, one additional model is presented here to assess sensitivity of data inputs to the model, attempting to deal with the disparity between the two survey time series (**no pot**). The **no pot** configuration runs the base model 16.0 without the ADF&G pot survey data, therefore only having the NMFS trawl survey as the abundance index.

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. *add the ability to conduct retrospective analyses*

   Retrospective runs/simulations are presented here in Appendix C as part of the analyses done to assess uncertainty in the model output (Figure 28). The ability to automate these in GMACS is still under developement but the author was able to do them by manually editing the data files.

2. *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 16). We did not address models without the natural mortality spike. These have been considered previously.

Comment: *Regarding potential model scenarios for Sept. 2020, the SSC and CPT requests are:*

1. *Explore model without ADf&G pot survey data*

   Model 20.1 explores this sensitivity to the data inputs and is shown here in the model scenarios.

2. *Random walk or exploration of catchability*

   The intial model of time blocks for Q did not show much potential for this in May 2020, therefore it was not a focus for the Sept. 2020 runs. More coding work is needed to make a true random walk for catchability GMACS and this will be added to GMACS model development, hopefully during the Jan 2021 modeling workshop.

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)*

Limited progress due to time availability and current world events. This will be a large focus on upcoming work on this model as the scenario without the ADF&G pot survey data (20.1) shows the differences in the current status of the stock between the two abundance surveys (Figure 13).

Comment: *Explore May 2020 model with VAST estimates*

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: *Please use the correct model number (e.g., if 19.0 is the same model as was first adopted in 16.0 then it is still 16.0.)*

Completed. Base model is 16.0.

C. Introduction

Scientific Name

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

Distribution

Blue king crab are sporadically distributed throughout the North Pacific Ocean from Hokkaido, Japan, to southeastern Alaska (Figure 1). In the eastern Bering Sea small populations are distributed around St. Matthew Island, the Pribilof Islands, St. Lawrence Island, and Nunivak Island. Isolated populations also exist in some other cold water areas of the Gulf of Alaska (NPFMC 1998). The St. Matthew Island Section for blue king crab is within Area Q2 (Figure 2), which is the Northern District of the Bering Sea king crab registration area and includes the waters north of 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 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 scheduled in fall and early winter to reduce the potential for bycatch mortality of vulnerable molting and mating crab.

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

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. The only new data in the 2020 assessment model is updated bycatch estimates, no new survey or size composition data were added. The assessment uses updated 1993-2019 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 is 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 (1978-2019; Table 8); results from the ADF&G SMBKC pot survey (every third year during 1995-2013, then 2015-2018; Table 9); mean somatic mass given 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 (1992/93-2019/20; 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

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

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.

Model Selection and Evaluation

Two models are presented with the reference model being the same configuration as approved last year (Palof et al. 2019), one sensitivity is considered which excludes the ADF&G pot survey data. In addition to this sensitivty, we evaluated the impacts of adding new data (here just groundfish bycatch) to the reference model. In summary, the following lists the models presented and the naming convention used:

1. **16.0 - 2019 Model**: 2019 accepted model
2. **16.0 - 2020 Reference Model**: updated with 2019/20 groudfish bycatch
3. **16.0a - 2020 Reference Model with fixed terminal year recruitment**: terminal year recruitment fixed as the average of the last seven years
4. **20.1 - no ADF&G pot survey data**: model 16.0 - excludes ADF&G pot survey data - abundace and length comps

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

There is no new survey data for the September 2020 model runs, the only additional data is groundfish bycatch data for the 2019/20 crab season. Additionally, the groundfish bycatch data was 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 2020 reference model is compared here to the 2019 accepted model, which is shown in Figures 6 and 7 with recruitment and spawning biomass shown in Figures 8 and 9, respectively. The 2019 accepted model and the 2020 base model have identical fits to the survey data, as well as identical estimates of SSB and recruitment. This is expected since there are no new influential data in the 2020 model. As has been noted in the past, the reference model 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 16. Currently the SDNR and MAR are not outputting correctly for the survey data in GMACS. This is on the list to address at the Januaury 2021 modeling workshop. In Sept. 2019 the SDNR for the trawl survey was acceptable at 1.66 in the reference 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 0.60 to 0.68 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 each of the GMACS scenarios are summarized in Tables 12, 13, and 14. These parameter estimates are compared in Table 15. Negative log-likelihood values and management measures for each of the model configurations are compared in Tables 4 and 17.

There are differences in parameter estimates among models as reflected in the log-likelihood components and the management quantities. The parameter estimates in the "no pot" scenario differ greatly from the reference model, as expected, due to the removal of recent ADF&G pot survey data points that pulled the MMB trend downward (Table 15). Also, the size composition residuals are smaller for the trawl survey in the **nopot** model, presumably because they are allowed to fit these size compositions better due to the removal of the size composition data from the ADF&G pot survey.

Selectivity estimates for the directed fishery show some variability between models (Figure 10). Estimated recruitment is similar in both models until the mid-2000s when the **no pot** model (20.1) has consistently higher recruitment, contributing to higher MMB for this model in recent years (Figure 11). Estimated mature male biomass on 15 February also is considerably higher in the **no pot** model (Figure 13). The **no pot** model has a better fit to recent years of the NMFS trawl survey data, fitting most of the post-2010 data ranges (fit line encompasses the error bars), compared to the reference model that only fits three of the last 10 years. The improved fit of the trawl survey corresponds to increased MMB estimates in the last 10 years. Not surprisingly this time frame also corresponds to sharp declines in the ADF&G pot survey abundance estimates that started in the post-2010 data.

Estimated natural mortality in each year (M_t) is presented in Figure 14, showing the mortality event in the late 90s. Estimates of fishing morality, from the reference model (16.0), are shown to assist with the rebuilding and reference point time frame discussions (Figure 26). Fishing mortality can not be ruled out as being an influential factor in the current stock status.

d. Evaluation of the fit to the data.

The reference model fit to total male ($\geq$ 90 mm CL) 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 15). 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 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 15).

The reference or 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 low points (Figure 16).

For the trawl survey the standardized residuals are more balanced in model 20.1 (**no pot**), without the ADF&G pot survey data, especially in recent years. The reference model has a clear residual pattern in the last 15 years, continually under predicting the observed data points (Figure 17). The standardized residuals for the ADF&G pot survey have similar patterns to past reference model iterations (Figure 18).

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 19, 20, and 21) for both scenarios. Representative residual plots of the composition data generally have a poor fit to the three composition data sources (Figures 22, 23 and 24). 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 25).

e. Retrospective and historical analyses

This is the fourth year GMACS has been used for this stock. As such, retrospective patterns and historical analyses of GMACS assessments are limited. However, completion of a retrospective analysis, for the base model, was completed (Figure 28) and is presented in detail in Appendix C.

f. Uncertainty and sensitivity analyses.

Estimated standard deviations of parameters and selected management measures for the models are summarized for each individual model in Tables 12, 13, 14, and compiled in Table 15. Model estimates of mature male biomass and OFL in 2020 are presented in Section F.

Uncertainty surrounding the lack of a 2020 trawl survey data point was examined using two approaches and the results are contained in Appendix C. Overall, the authors did not find much additional uncertainty for the reference model due to the lack of a 2020 data point. The current trajectory of the stock (MMB and recruitment) suggests a low status (below B_{MSY}) that would not change even with the addition of hypothetical 2020 data point (Approach 3, Appendix C). Appendix C goes into more detail for these analyses and a more thourough discussion of the authors recommendations.

g. Comparison of alternative model scenarios.

The estimates of mature male biomass (Figure 13) for the **no pot** model differs from the reference model (16.0) due to the removal of the pot survey abundance and size composition data. This abundance time series contrasts with the NMFS trawl survey and when present tends to lower the scale of the population estimate. This difference is greatest in the last 10 years, recognizing the contrast between these abundance time series and the influence of the ADF&G pot survey on the current population status.

In summary, the **no pot** model scenario was provided to explore the sensitivity of this model. Currently, the reference model is still the most appropriate model for settting reference points and model specifications. Research on alternative model specifications that may address the disparities between the trawl and pot survey data are ongoing, as is proposed spatial analyses of these data sets. 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 two reference models presented here, 16.0 and 16.0a, only differ in the estimation of 2019 recruitment. Model 16.0a fixes the 2019 recruitment to be the average of the last seven years of the model, effectively limiting the model's ability to estimate unreasonably high recruitment in the lack of a 2020 data point. However, fixing terminal year recruitment has a minimal effect on the status of the stock, projected MMB, or the resulting OFL for 2020 (Table 4). The recommended model for 2020 would be the reference model (16.0) to maintain consistency for this stock during the rebuilding time frame and with the lack of a 2020 data point for the trawl survey.

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 as B itself 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 - 2019, 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 2019 for all scenarios 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 model scenarios. Biomass and OFL are in tons.

Component	Ref	fixR	nopot
MMB_{2020}	1060.665	1065.996	3707.925
B_{MSY}	3335.710	3391.948	3548.160
MMB/B_{MSY}	0.337	0.334	1.171
F_{OFL}	0.047	0.047	0.180
OFL_{2020}	50.674	48.819	618.969
ABC_{2020}	38.005	36.614	464.226

G. Rebuilding Analysis

This stock was declared overfished in fall of 2018 and a rebuilding plan went before the Council for final review in June 2020. The most updated rebuilding plan can be found on the NPFMC website for the June 2020 meeting.

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 55% of what it would have been in the absence of fishing (Figure 27, supporting the hypothesis that fishing pressure is not the sole contributer 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 - 2018/19			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	5.842
2018	0.001	1.140
2019	0.030	1.038

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				

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: R. Foy, 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

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 in 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

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	

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

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.573	0.138
$\log(\bar{R})$	13.899	0.200
$\log(n^0_1)$	14.950	0.175
$\log(n^0_2)$	14.509	0.211
$\log(n^0_3)$	14.326	0.207
q_{pot}	3.838	0.253
$\log(\bar{F}^{\mathrm{df}})$	-2.125	0.052
$\log(\bar{F}^{\mathrm{tb}})$	-9.470	0.073
$\log(\bar{F}^{\mathrm{fb}})$	-8.093	0.073
log Stage-1 directed pot selectivity 1978-2008	-0.819	0.179
log Stage-2 directed pot selectivity 1978-2008	-0.452	0.129
log Stage-1 directed pot selectivity 2009-2017	-0.483	0.162
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.320	0.066
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.725	0.126
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.040	0.007
OFL	50.674	17.412

Table 13: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the reference model with fixed terminal year recruitment 'fixR' (16.0a).

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.573	0.138
$\log(\bar{R})$	13.870	0.198
$\log(n^0_1)$	14.950	0.175
$\log(n^0_2)$	14.508	0.211
$\log(n^0_3)$	14.326	0.207
q_{pot}	3.833	0.253
$\log(\bar{F}^{\mathrm{df}})$	-2.126	0.052
$\log(\bar{F}^{\mathrm{tb}})$	-9.472	0.073
$\log(\bar{F}^{\mathrm{fb}})$	-8.094	0.073
log Stage-1 directed pot selectivity 1978-2008	-0.820	0.179
log Stage-2 directed pot selectivity 1978-2008	-0.452	0.129
log Stage-1 directed pot selectivity 2009-2017	-0.484	0.162
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.320	0.066
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.727	0.125
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.047	0.007
OFL	48.819	9.115

Table 14: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the 'no pot' (20.1) model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.829	0.235
$\log(\bar{R})$	14.225	0.203
$\log(n^0_1)$	14.945	0.174
$\log(n^0_2)$	14.459	0.211
$\log(n^0_3)$	14.290	0.205
$\log(\bar{F}^{\mathrm{df}})$	-2.319	0.056
$\log(\bar{F}^{\mathrm{tb}})$	-9.716	0.079
$\log(\bar{F}^{\mathrm{fb}})$	-8.341	0.079
log Stage-1 directed pot selectivity 1978-2008	-0.817	0.178
log Stage-2 directed pot selectivity 1978-2008	-0.482	0.133
log Stage-1 directed pot selectivity 2009-2017	-0.982	0.182
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.376	0.062
log Stage-2 NMFS trawl selectivity	-0.000	0.000
F_{OFL}	0.047	0.000
OFL	618.969	144.208

Table 15: Comparisons of parameter estimates for the model scenarios.

Parameter	Ref	fixR	nopot
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.573	1.573	1.829
$\log(\bar{R})$	13.899	13.870	14.225
$\log(n^0_1)$	14.950	14.950	14.945
$\log(n^0_2)$	14.509	14.508	14.459
$\log(n^0_3)$	14.326	14.326	14.290
q_{pot}	3.838	3.833	-
$\log(\bar{F}^{\mathrm{df}})$	-2.125	-2.126	-2.319
$\log(\bar{F}^{\mathrm{tb}})$	-9.470	-9.472	-9.716
$\log(\bar{F}^{\mathrm{fb}})$	-8.093	-8.094	-8.341
log Stage-1 directed pot selectivity 1978-2008	-0.819	-0.820	-0.817
log Stage-2 directed pot selectivity 1978-2008	-0.452	-0.452	-0.482
log Stage-1 directed pot selectivity 2009-2017	-0.483	-0.484	-0.982
log Stage-2 directed pot selectivity 2009-2017	-0.000	-0.000	-0.000
log Stage-1 NMFS trawl selectivity	-0.320	-0.320	-0.376
log Stage-2 NMFS trawl selectivity	-0.000	-0.000	-0.000
log Stage-1 ADF&G pot selectivity	-0.725	-0.727	-
log Stage-2 ADF&G pot selectivity	-0.000	-0.000	-
F_{OFL}	0.047	0.047	0.180
OFL	50.674	48.819	618.969

Table 16: Comparisons of data weights, SDNR and MAR (standard deviation of normalized residuals and median absolute residual) values for the model scenarios.

Component	Ref	fixR	nopot
NMFS trawl survey weight	1.00	1.00	1.00
ADF&G pot survey weight	1.00	1.00	
Directed pot LF weight	1.00	1.00	1.00
NMFS trawl survey LF weight	1.00	1.00	1.00
ADF&G pot survey LF weight	1.00	1.00	
SDNR NMFS trawl survey	0.00	0.00	0.00
SDNR ADF&G pot survey	0.00	0.00	
SDNR directed pot LF	0.70	0.70	0.77
SDNR NMFS trawl survey LF	1.30	1.30	1.23
SDNR ADF&G pot survey LF	0.95	0.95	
MAR NMFS trawl survey	0.00	0.00	0.00
MAR ADF&G pot survey	0.00	0.00	
MAR directed pot LF	0.52	0.52	0.46
MAR NMFS trawl survey LF	0.60	0.60	0.78
MAR ADF&G pot survey LF	0.68	0.68	

Table 17: Comparisons of negative log-likelihood values for the selected model scenarios. It is important to note that comparisons among models may be limited since the number of parameters between models changes (e.g., **nopot** model).

Component	Ref	fixR	nopot
Pot Retained Catch	-68.50	-68.51	-56.27
Pot Discarded Catch	4.89	4.89	6.29
Trawl bycatch Discarded Catch	-7.99	-7.99	6.11
Fixed bycatch Discarded Catch	-7.95	-7.95	4.84
NMFS Trawl Survey	8.84	8.62	-4.42
ADF&G Pot Survey CPUE	84.62	84.93	
Directed Pot LF	-103.99	-103.99	-102.34
NMFS Trawl LF	-252.91	-252.93	-256.22
ADF&G Pot LF	-91.02	-91.05	
Recruitment deviations	59.56	60.01	59.37
F penalty	9.66	9.66	9.66
M penalty	6.46	6.46	6.45
Prior	13.71	13.71	12.11
Total	-344.61	-344.12	-314.40
Total estimated parameters	147.00	146.00	144.00

Table 18: 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 2019**.

Year	n_1	n_2	n_3	MMB	CV MMB
1978	3109715	2000299	1666848	4550	0.178
1979	4376763	2355384	2282776	6433	0.124
1980	3779544	3257707	3463738	10256	0.083
1981	1439955	3221560	4866873	10705	0.062
1982	1618361	1833987	4894696	7604	0.072
1983	811849	1447417	3468928	4537	0.099
1984	662337	858825	1983059	3022	0.124
1985	928011	622498	1406806	2656	0.144
1986	1366392	705833	1186990	2600	0.140
1987	1330701	989214	1278483	3074	0.129
1988	1241066	1061590	1484711	3360	0.126
1989	2898487	1033510	1638093	3849	0.121
1990	1877184	1956744	1939926	4970	0.094
1991	1938968	1673531	2420850	4992	0.095
1992	2099715	1593816	2382018	5175	0.085
1993	2372747	1673953	2494925	5427	0.077
1994	1608587	1844929	2573586	5200	0.070
1995	1749039	1461936	2471794	5073	0.073
1996	1780265	1429663	2364609	4775	0.075
1997	912655	1434576	2265018	4155	0.094
1998	603985	936010	1844896	2740	0.110
1999	369997	310550	711971	1680	0.102
2000	408474	312747	786233	1822	0.084
2001	372448	335395	853220	1973	0.076
2002	129931	322415	917072	2077	0.070
2003	290682	180441	940677	1961	0.071
2004	187364	224669	903940	1943	0.071
2005	468821	180737	886078	1860	0.072
2006	702839	325974	875801	2003	0.072
2007	403315	506459	961977	2337	0.069
2008	835694	391131	1082101	2461	0.060
2009	682211	603380	1179630	2497	0.054
2010	624238	577600	1251605	2110	0.057
2011	496132	520319	1099028	1528	0.070
2012	228196	415162	788179	998	0.108
2013	251502	235864	506691	1158	0.097
2014	204364	220853	566085	1090	0.103
2015	162705	185039	537244	1070	0.105
2016	169495	152401	534064	1116	0.102
2017	131331	146586	538681	1116	0.101
2018	141883	122799	535054	1085	0.100
2019	250747	121140	521618	1022	0.103

Table 19: 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 2020 reference model.

Year	n_1	n_2	n_3	MMB	CV MMB
1978	3151217	2048032	1704813	4676	0.176
1979	4405644	2394327	2341979	6576	0.122
1980	3774514	3287008	3535569	10427	0.083
1981	1435061	3228410	4941160	10851	0.062
1982	1622665	1833539	4959495	7725	0.072
1983	826815	1449709	3522402	4646	0.099
1984	673504	867978	2029459	3119	0.123
1985	940551	631919	1451162	2759	0.143
1986	1398609	716293	1230084	2694	0.139
1987	1351732	1011045	1322901	3183	0.127
1988	1256200	1080852	1534825	3474	0.123
1989	2919885	1048636	1691144	3969	0.119
1990	1888479	1974231	1993985	5088	0.093
1991	1953255	1686052	2476052	5111	0.094
1992	2112699	1606335	2435840	5290	0.085
1993	2392964	1685630	2547439	5543	0.077
1994	1638537	1860336	2625259	5314	0.070
1995	1766633	1483754	2525427	5201	0.073
1996	1804613	1446768	2421768	4904	0.075
1997	941521	1454055	2323563	4296	0.094
1998	618296	958642	1906137	2860	0.109
1999	381326	315898	737767	1735	0.102
2000	421648	320952	811560	1879	0.084
2001	383990	345593	879772	2034	0.076
2002	134380	332345	945496	2142	0.071
2003	302039	186255	969851	2022	0.072
2004	191454	233042	932326	2006	0.072
2005	479484	185831	914401	1919	0.072
2006	718464	333716	903047	2062	0.072
2007	409910	517899	990132	2402	0.069
2008	844891	398703	1112005	2526	0.061
2009	692584	611117	1209302	2557	0.055
2010	634017	586098	1281337	2168	0.058
2011	509421	528796	1129162	1588	0.072
2012	239665	425751	819051	1062	0.109
2013	264030	246289	539320	1227	0.098
2014	216047	231419	599794	1160	0.104
2015	171673	195187	571890	1140	0.106
2016	178308	160859	568985	1187	0.103
2017	138175	154391	572956	1186	0.101
2018	147990	129272	568274	1151	0.101
2019	262671	126752	553209	1081	0.103

Figures

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

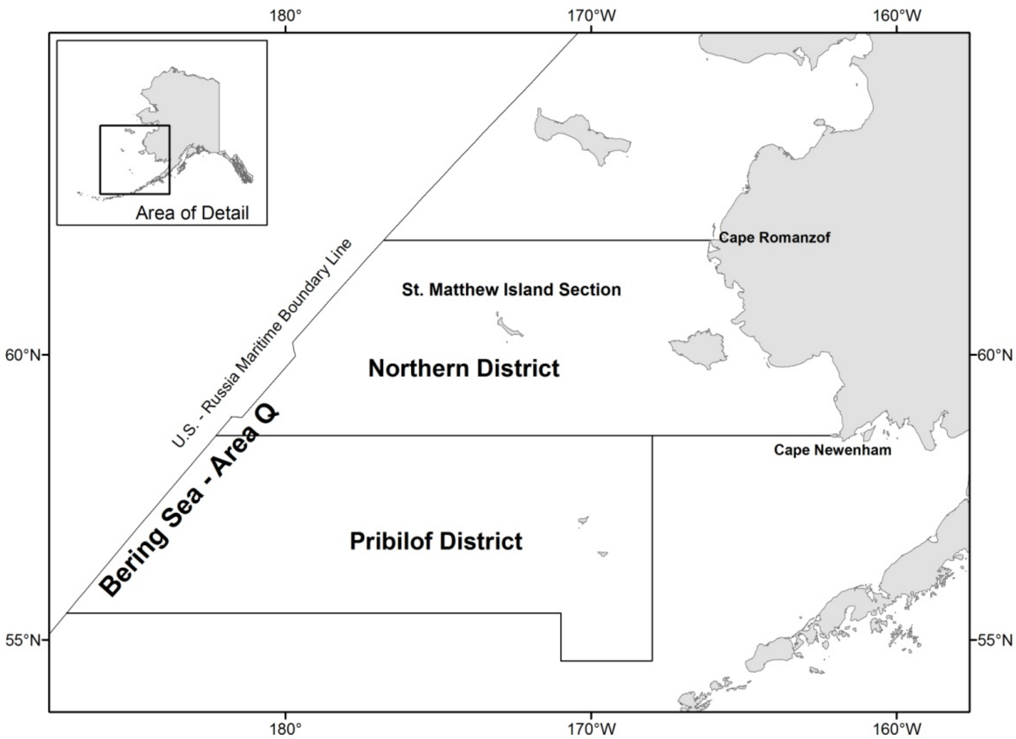

Figure 2: Blue king crab Registration Area Q (Bering Sea)

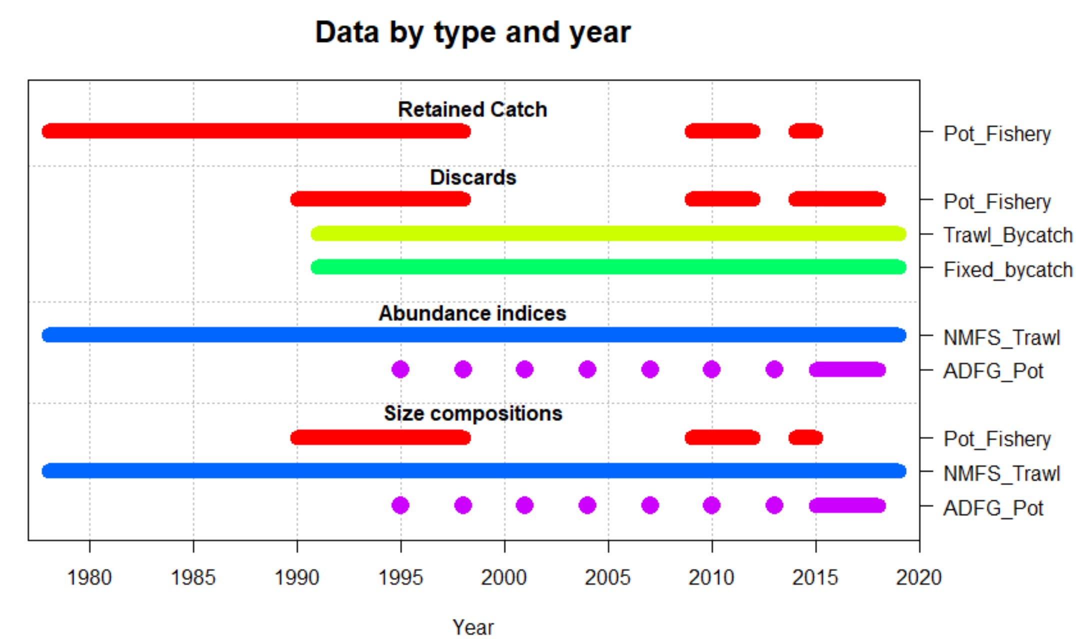

Figure 3: Data extent for the SMBKC assessment.

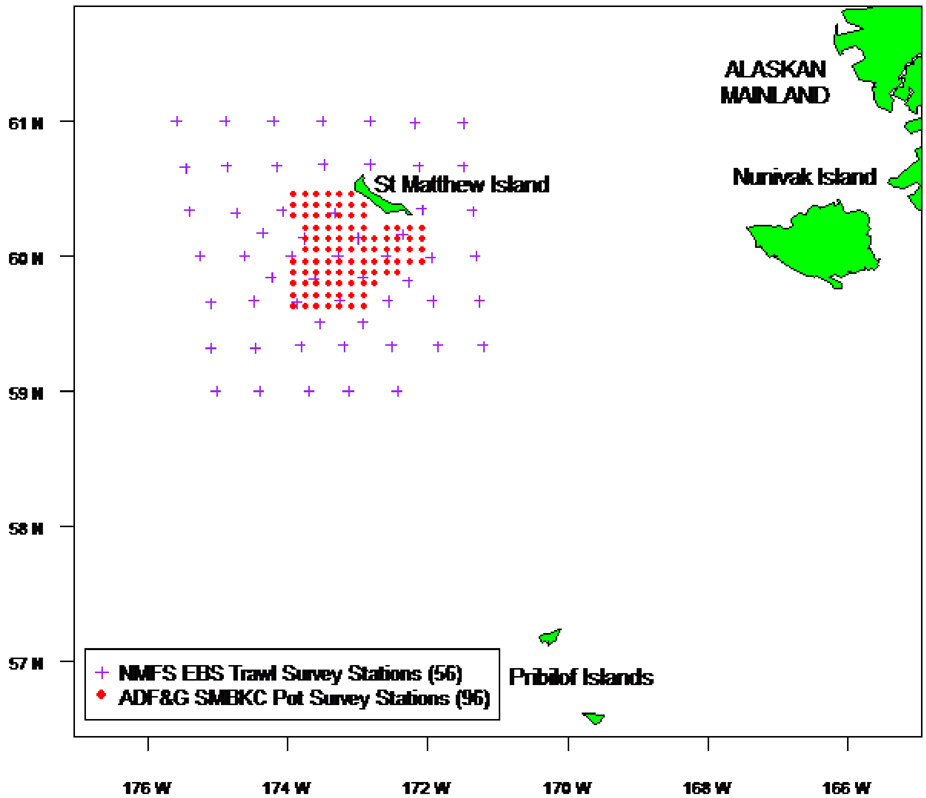

Figure 4: Trawl and pot-survey stations used in the SMBKC stock assessment.

Figure 5: Catches (in numbers) of male blue king crab > 90mm CL from the 2011-2019 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock.

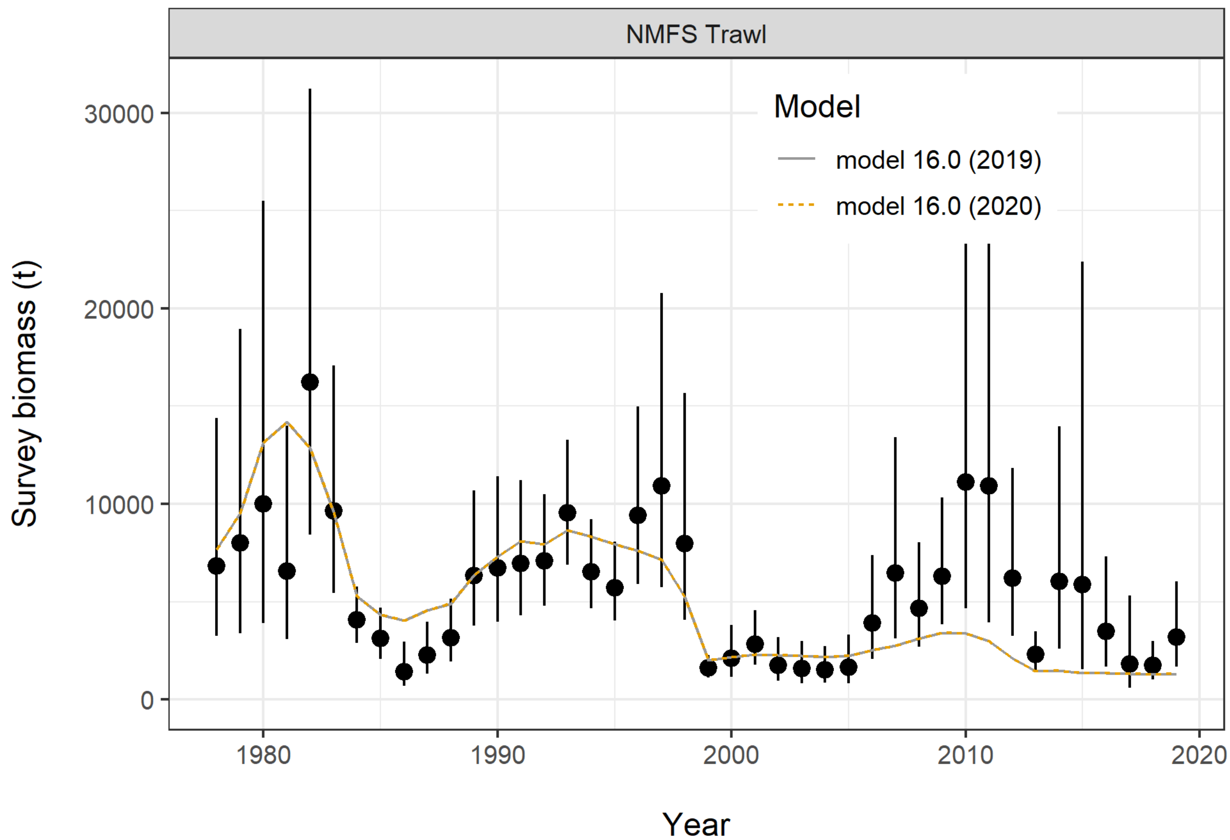

Figure 6: Fits to NMFS area-swept trawl estimates of total (> 90mm) male survey biomass for the reference model only (16.0 ref for 2020 and 16.0 2019 accepted model). Error bars are plus and minus 2 standard deviations.

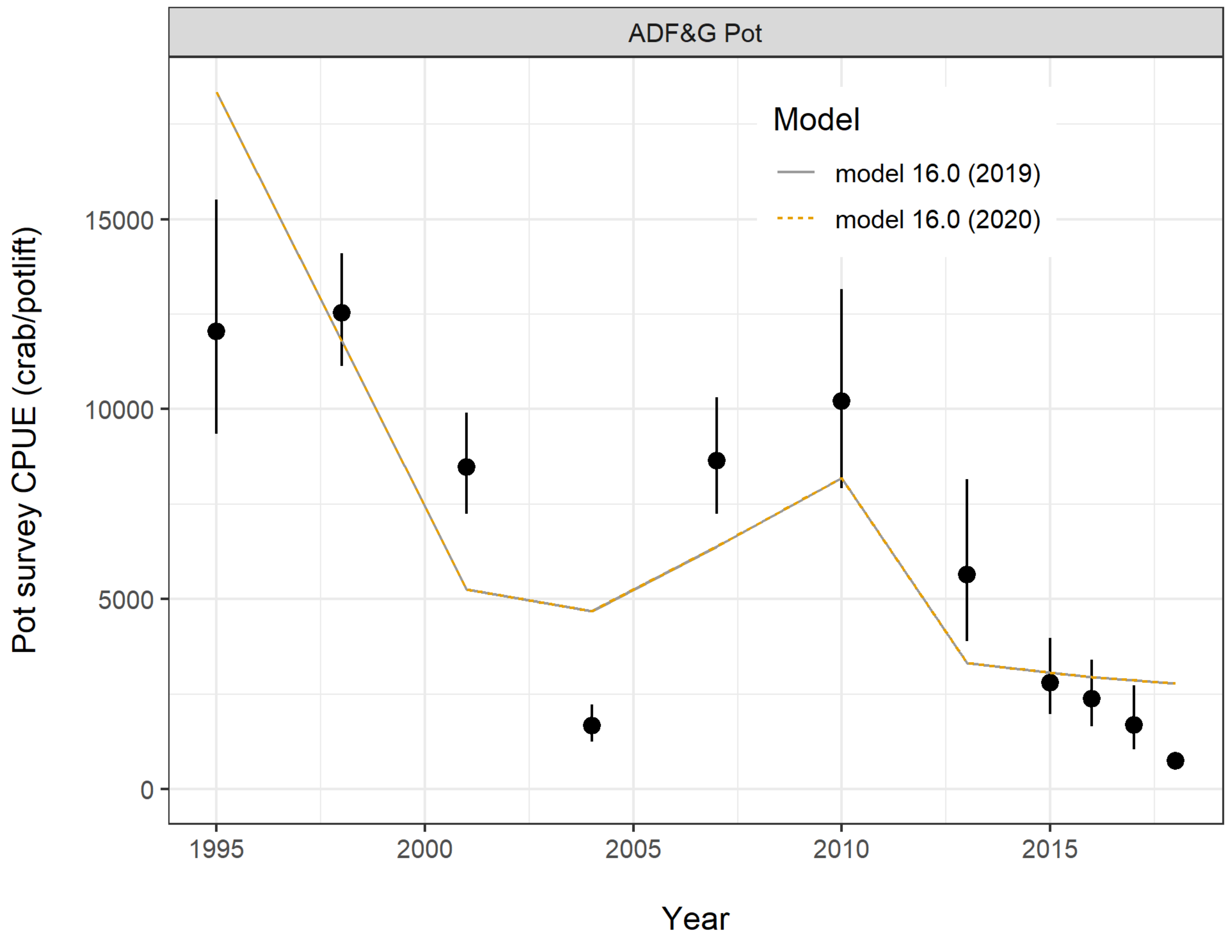

Figure 7: Comparisons of fits to CPUE from the ADFG pot surveys for the reference model 16.0 reference model in 2019 and 2020. Error bars are plus and minus 2 standard deviations.

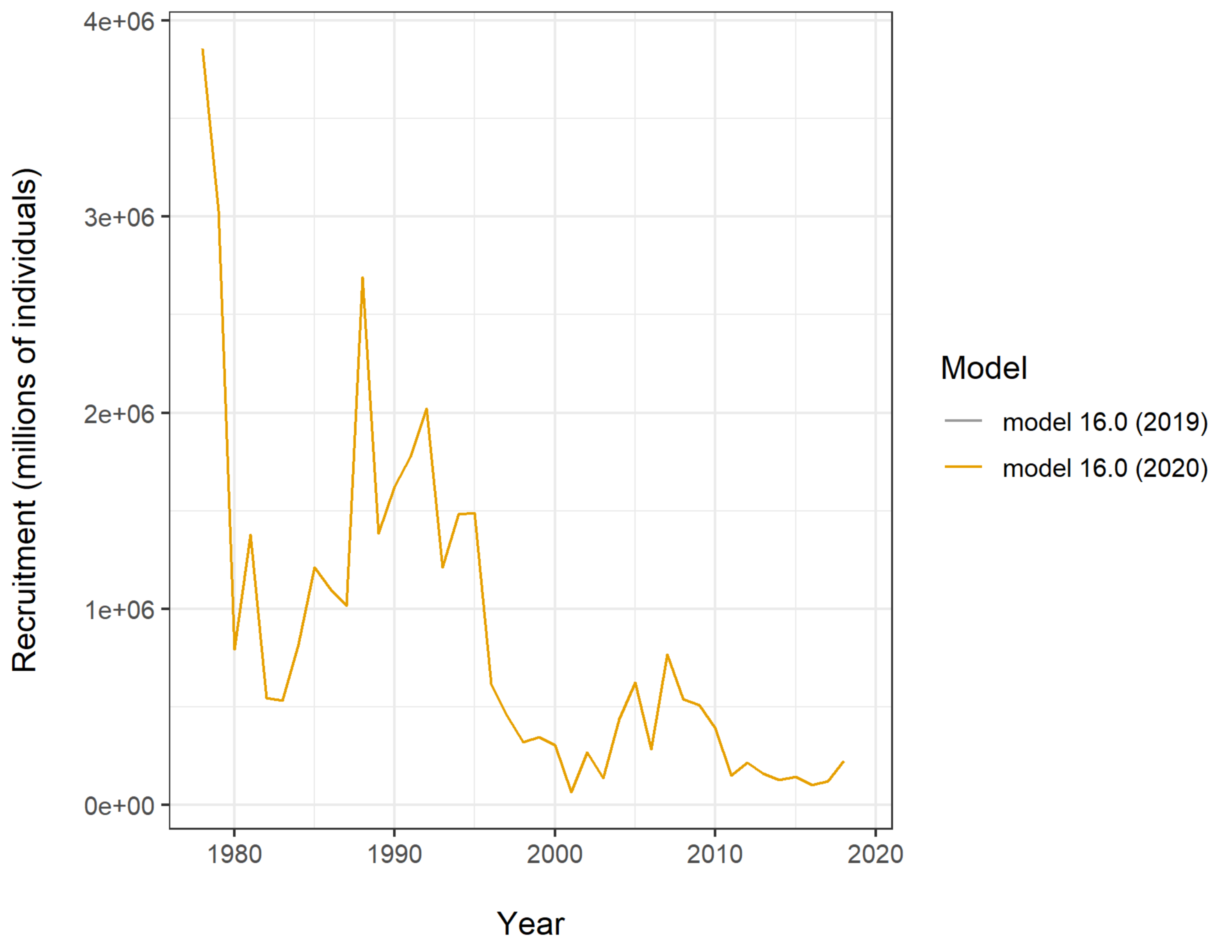

Figure 8: Reference model estimated recruitment (2019 and 2020) for comparison from 1978-2018, does not show recent recruitment, i.e. 2019.

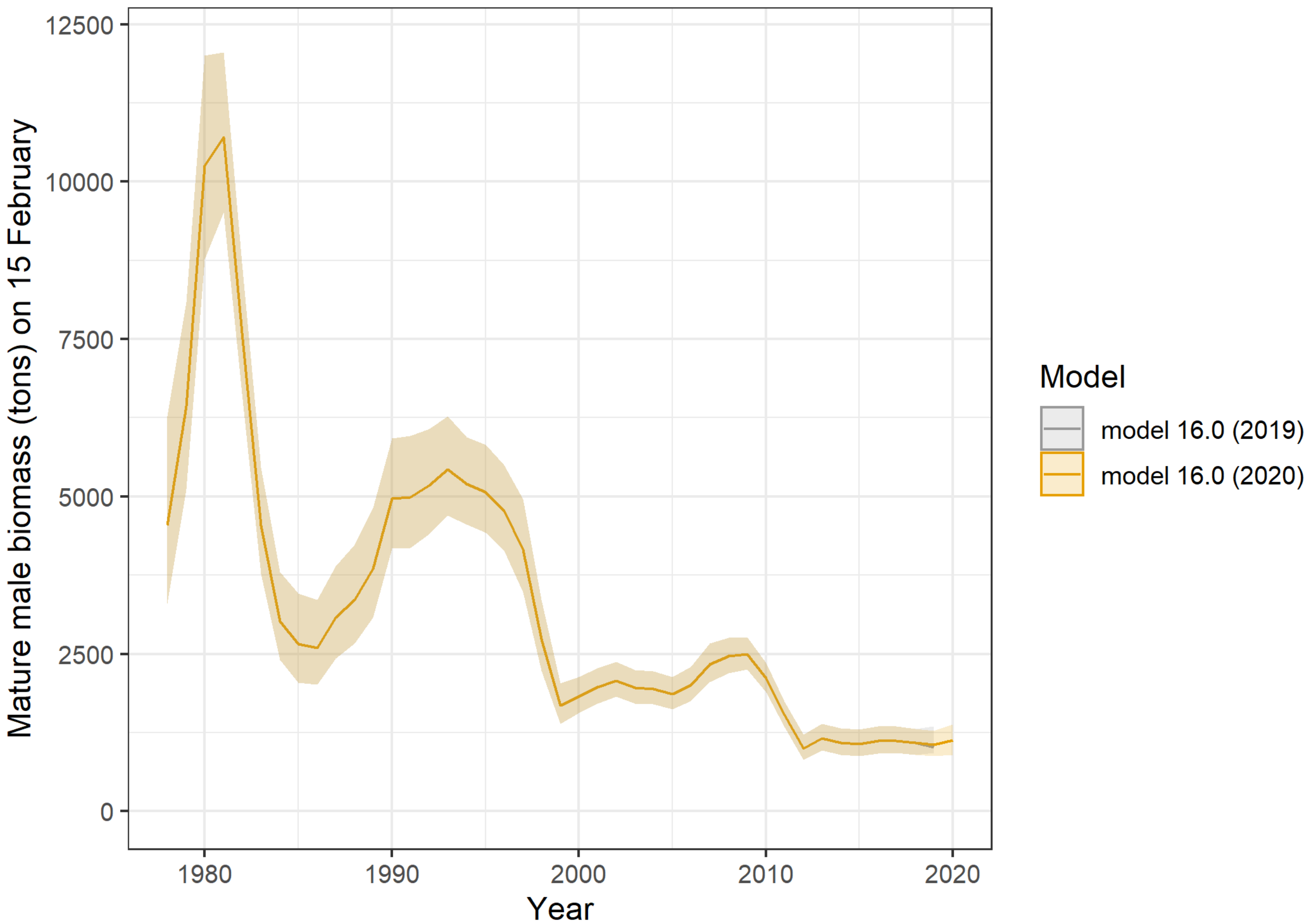

Figure 9: Sensitivity of new data in 2020 on estimated mature male biomass (MMB); 1978-2020.

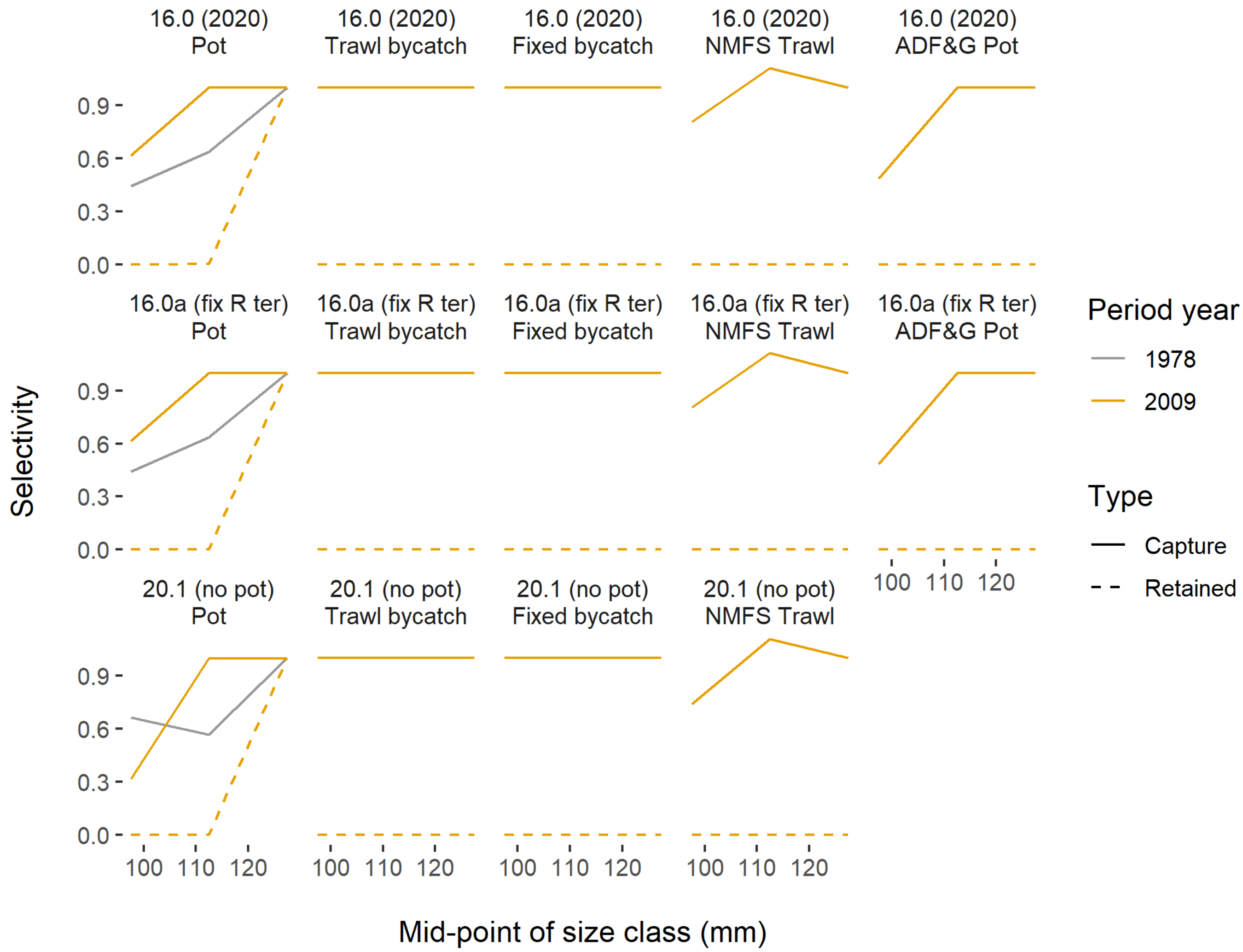

Figure 10: Comparisons of the estimated stage-1 and stage-2 selectivities for the different model scenarios (the stage-3 selectivities are all fixed at 1). Estimated selectivities are shown for the directed pot fishery, the trawl bycatch fishery, the fixed bycatch fishery, the NMFS trawl survey, and the ADFG pot survey. Two selectivity periods are estimated in the directed pot fishery, from 1978-2008 and 2009-2019.

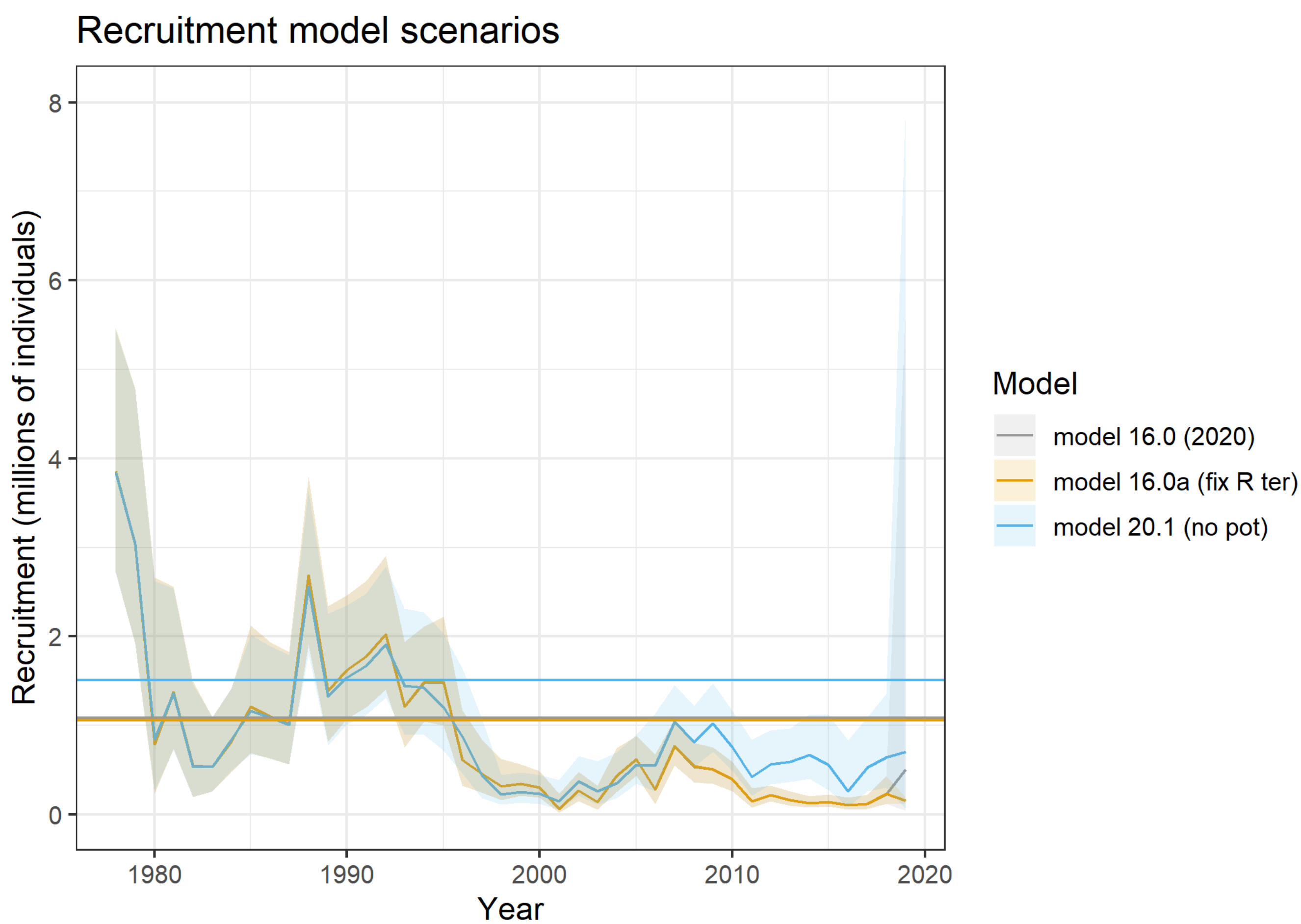

Figure 11: Estimated recruitment 1979-2019 comparing model alternatives. The solid horizontal lines in the background represent the estimate of the average recruitment parameter ($\bar{R}$) in each model scenario. Note the high uncertainty in recruitment in both the ref and the nopot model due to the lack of 2020 data.

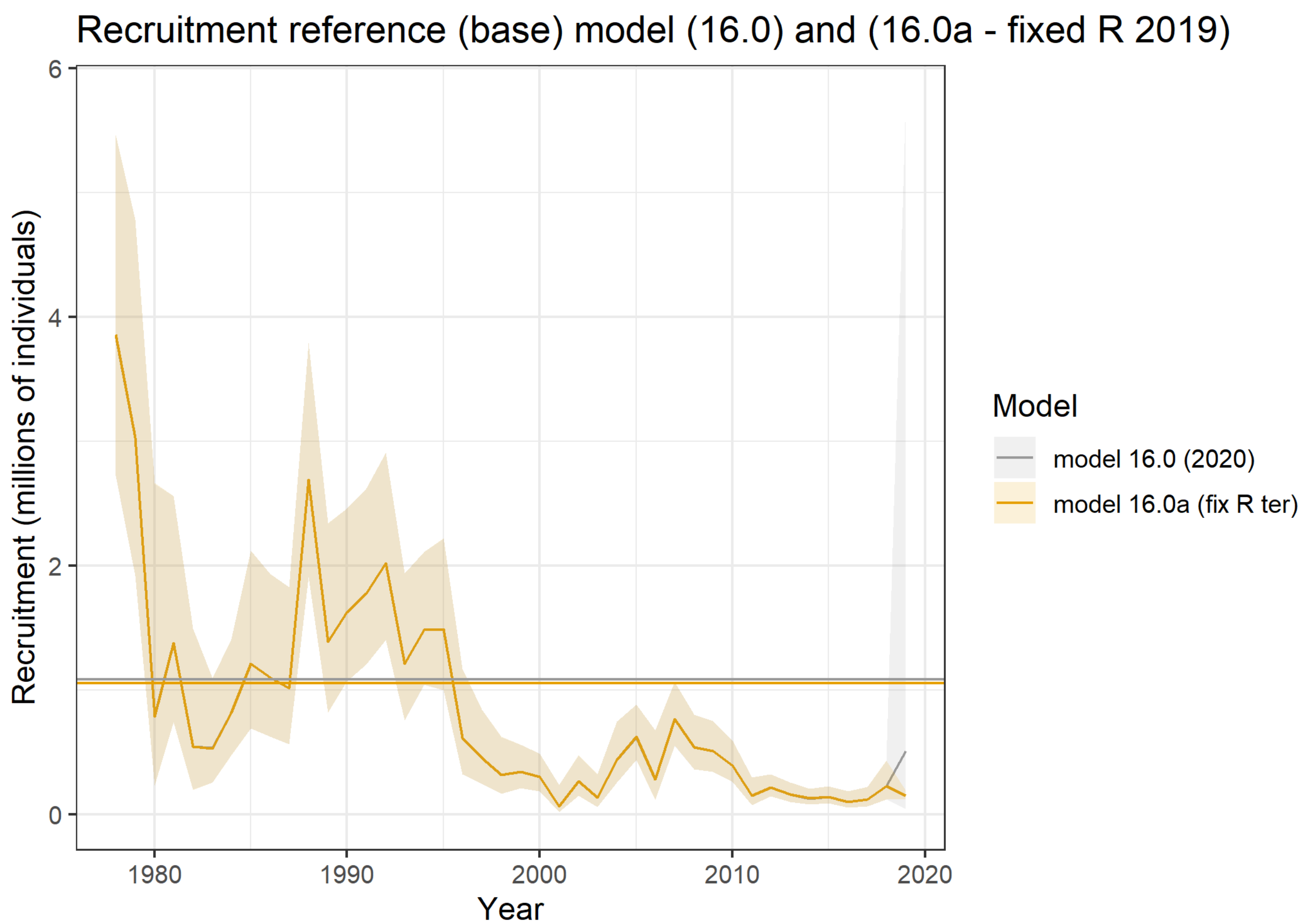

Figure 12: Estimated recruitment 1979-2019 comparing ref model (16.0) and model with fixed recruitment in the terminal year (16.0a). The solid horizontal lines in the background represent the estimate of the average recruitment parameter ($\bar{R}$) in each model scenario.

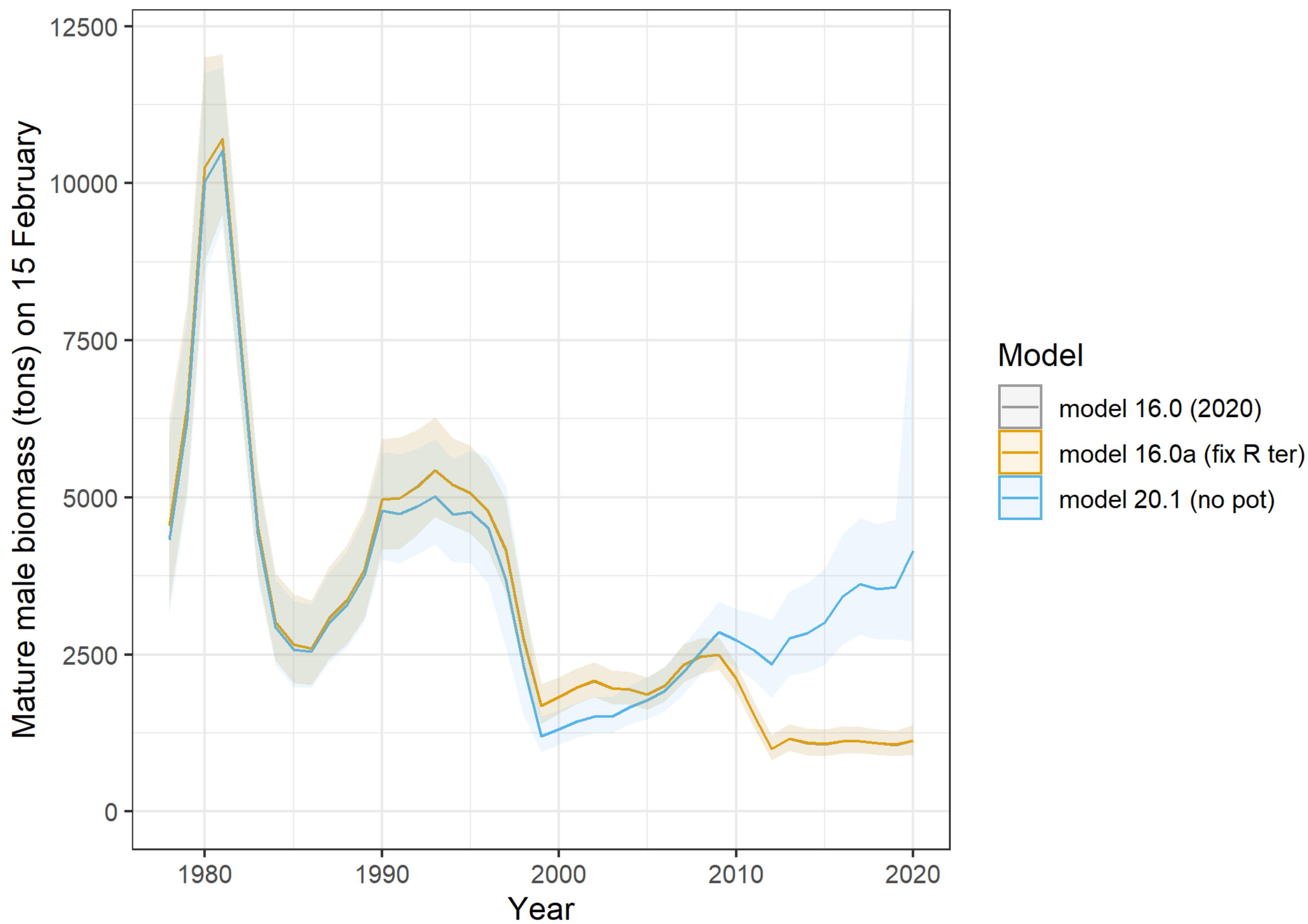

Figure 13: Comparisons of estimated mature male biomass (MMB) time series on 15 February during 1978-2020 for each of the model scenarios.

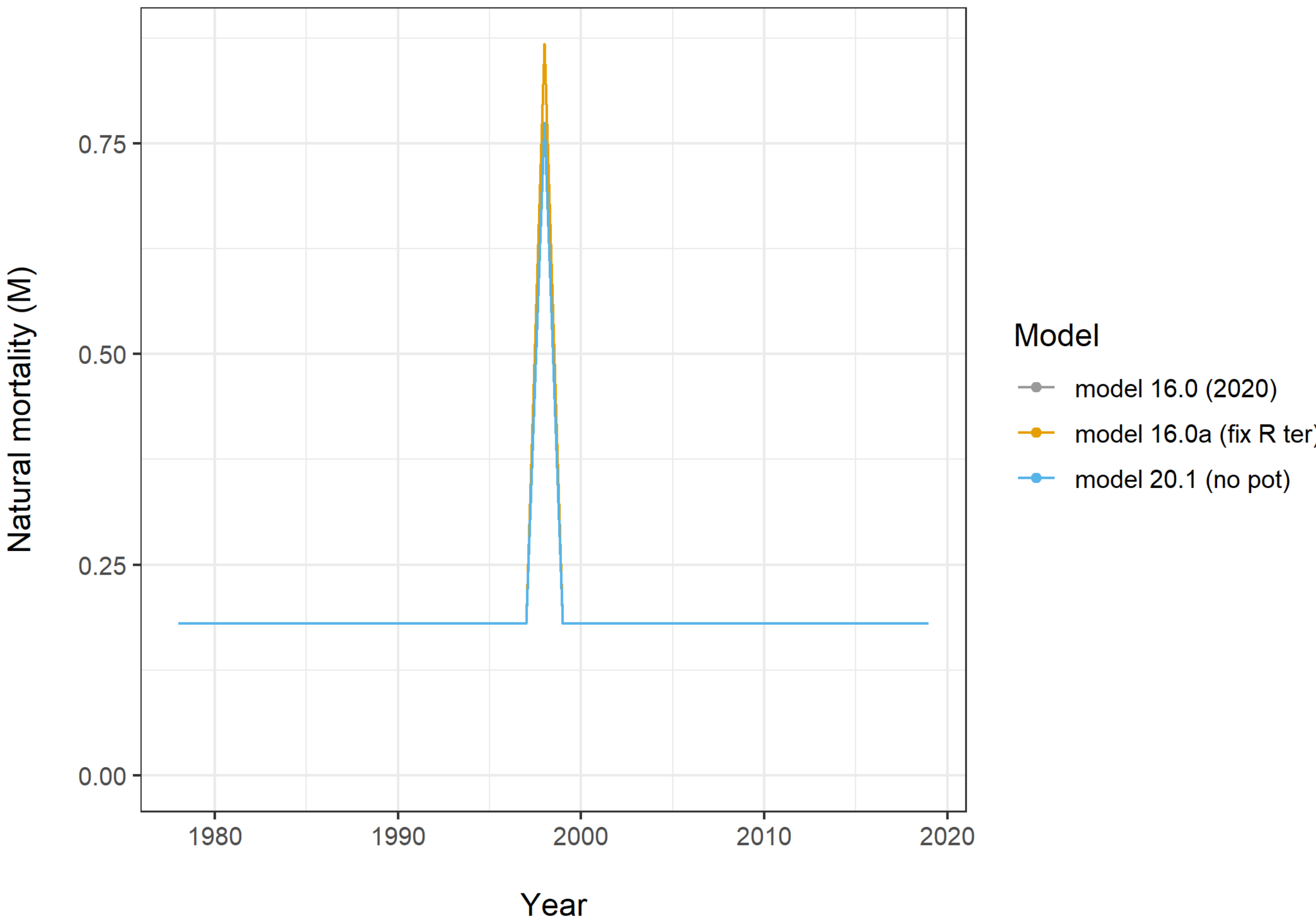

Figure 14: Time-varying natural mortality (M_t). Estimated pulse period occurs in 1998/99 (i.e. M_{1998}).

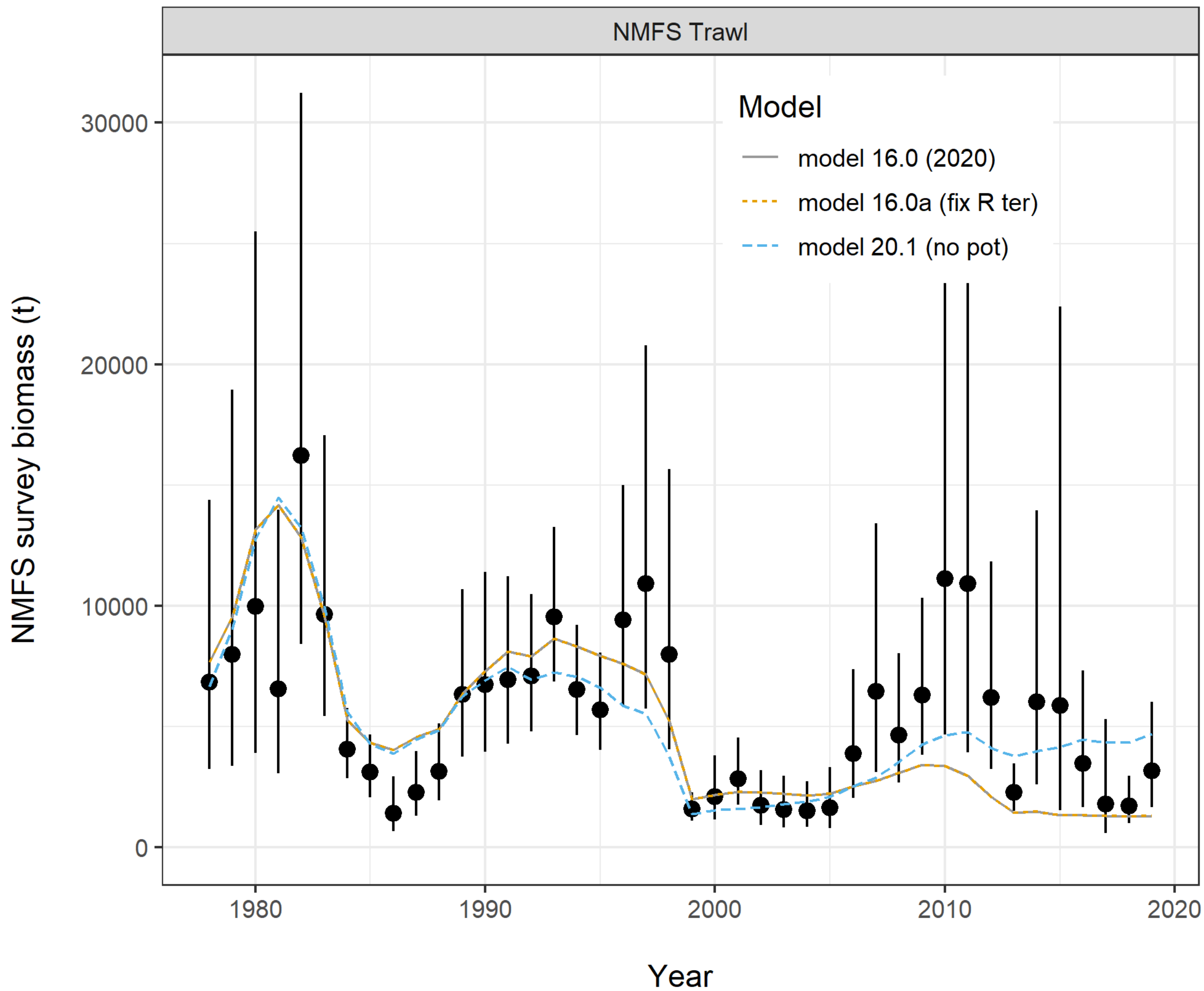

Figure 15: Comparisons of area-swept estimates of total (90+ mm CL) male survey biomass (tons) and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

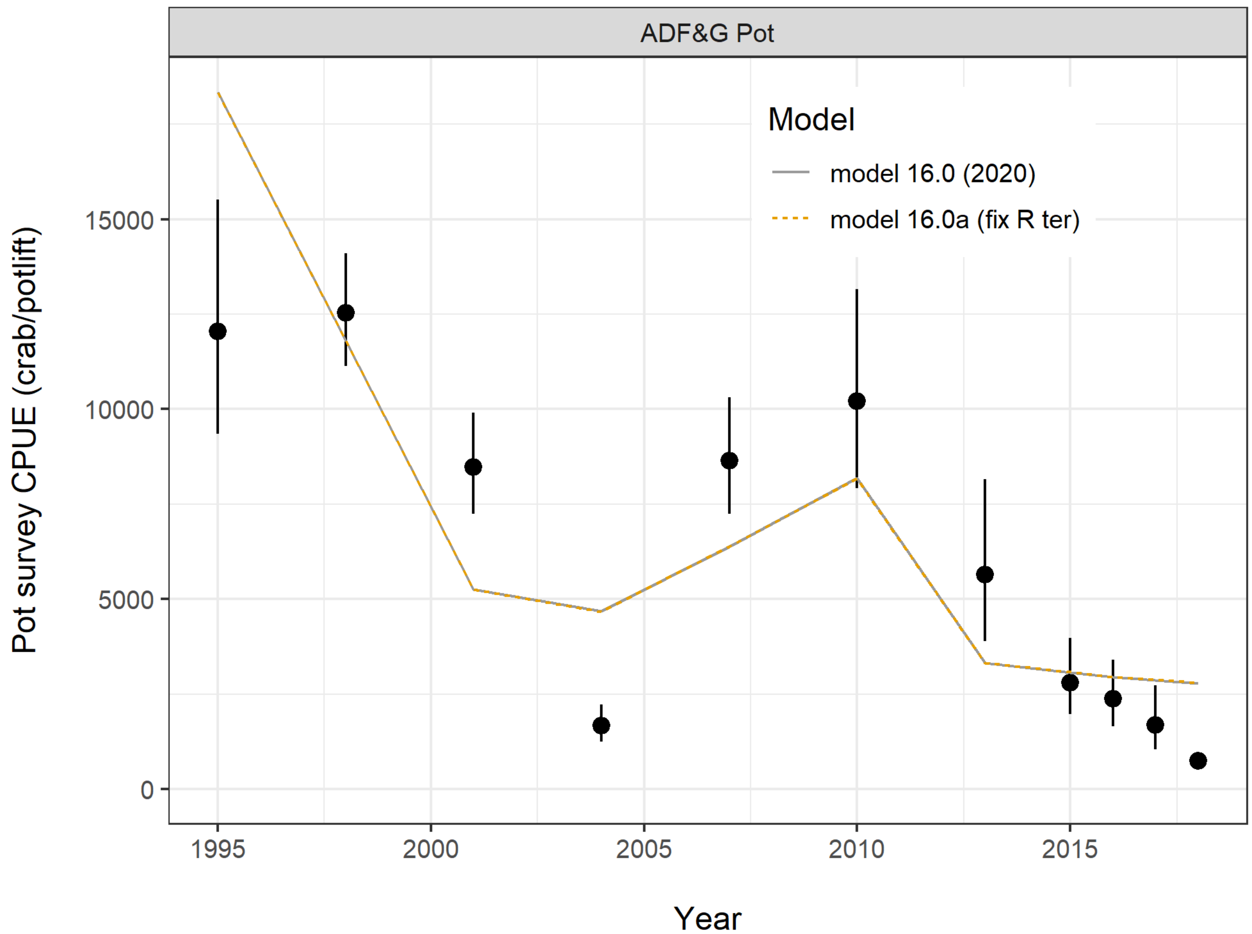

Figure 16: Comparisons of total (90+ mm CL) male pot survey CPUEs and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

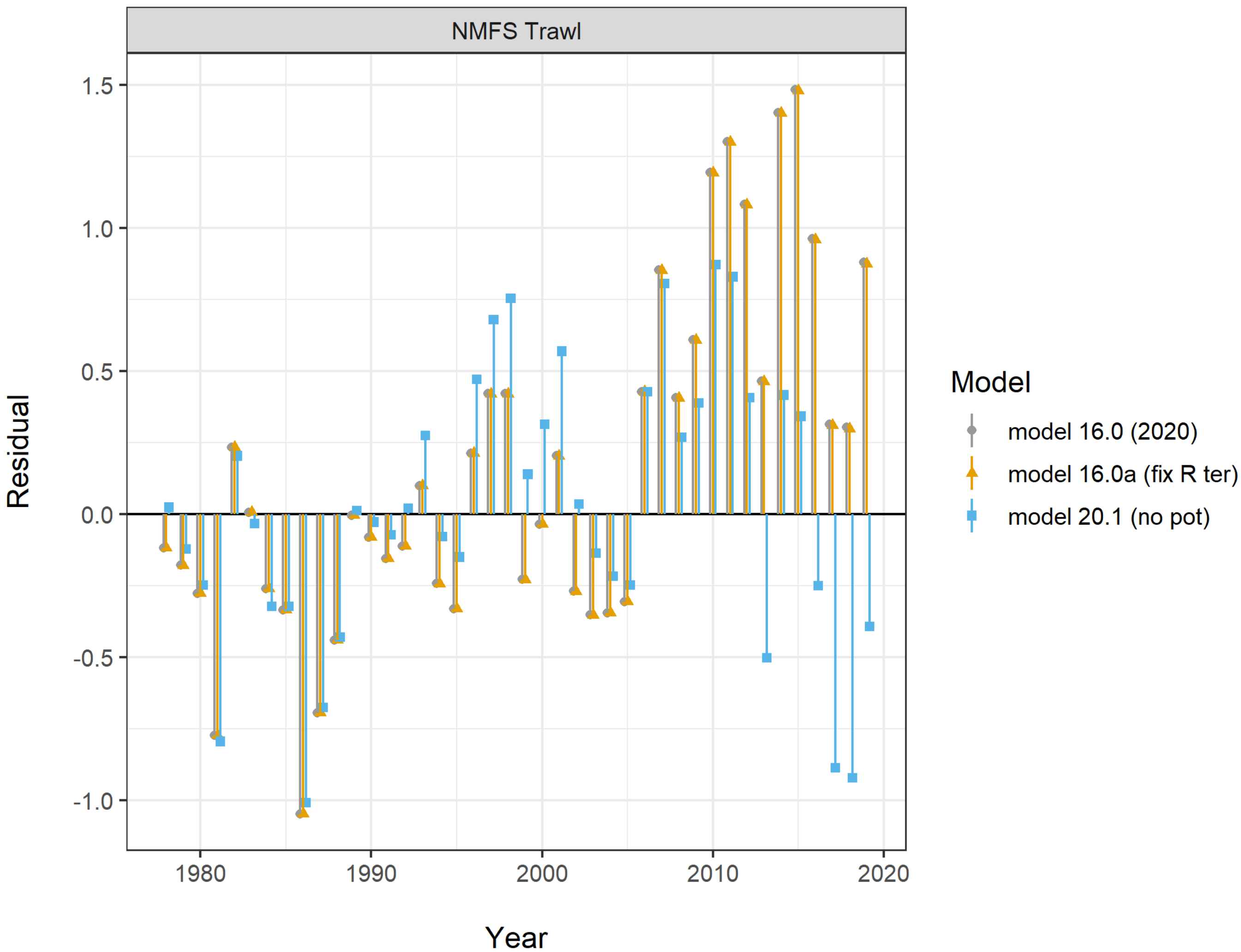

Figure 17: Standardized residuals for area-swept estimates of total male survey biomass for the model scenarios.

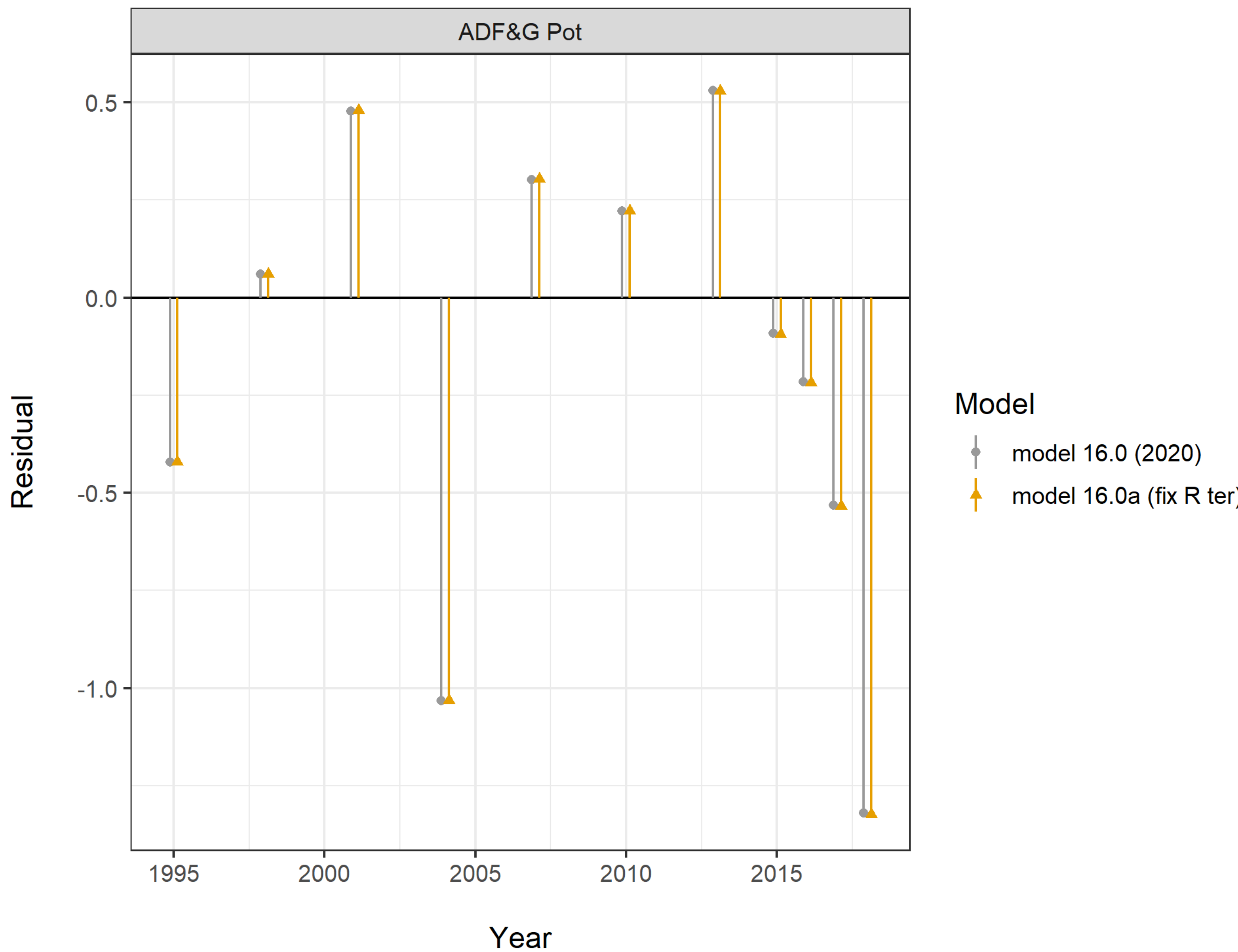

Figure 18: Standardized residuals for total male pot survey CPUEs for each of the GMACS model scenarios.

Figure 19: Observed and model estimated size-frequencies of SMBKC by year retained in the directed pot fishery for the model scenarios.

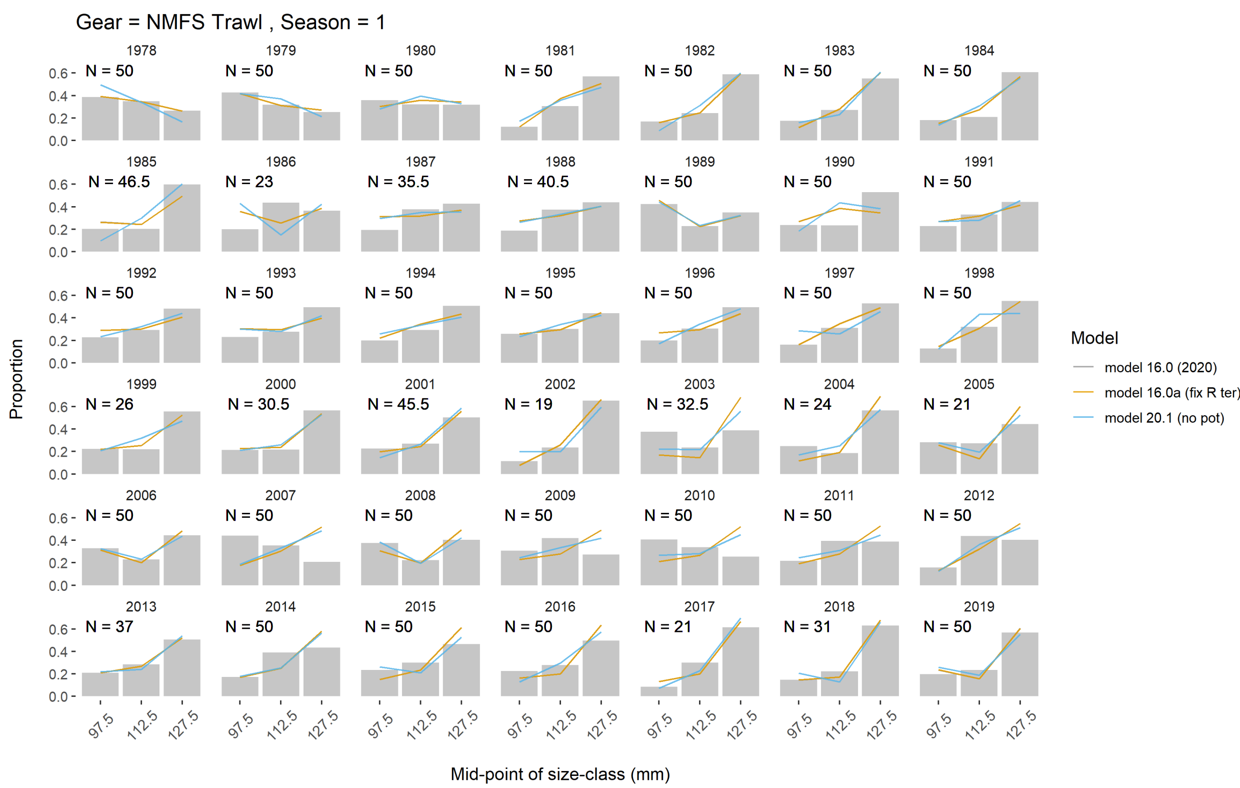

Figure 20: Observed and model estimated size-frequencies of discarded male SMBKC by year in the NMFS trawl survey for the model scenarios.

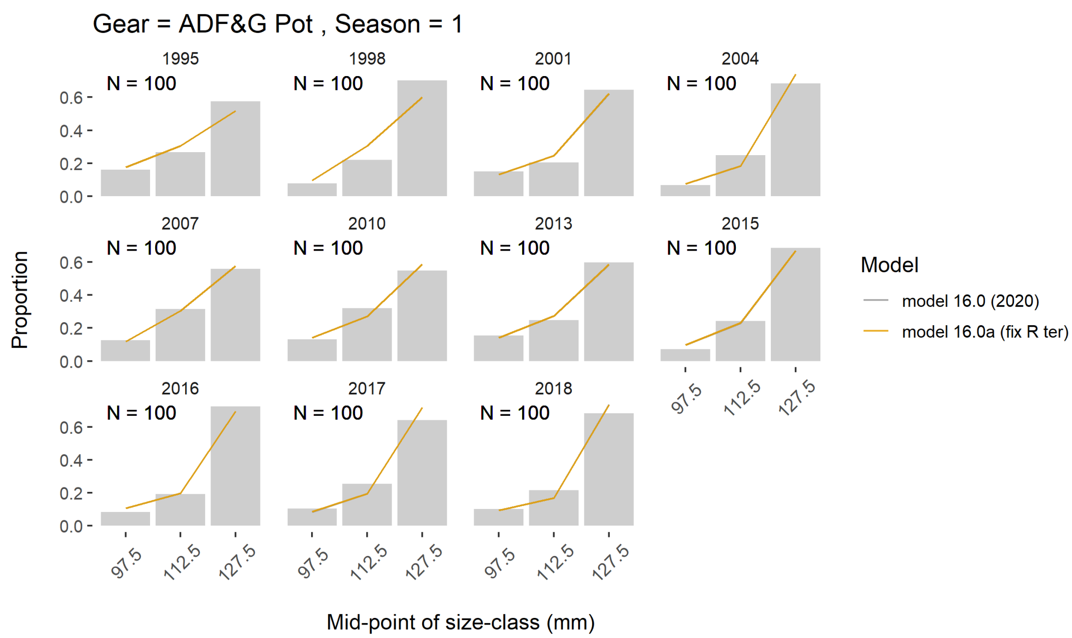

Figure 21: Observed and model estimated size-frequencies of discarded SMBKC by year in the ADFG pot survey for the model scenarios.

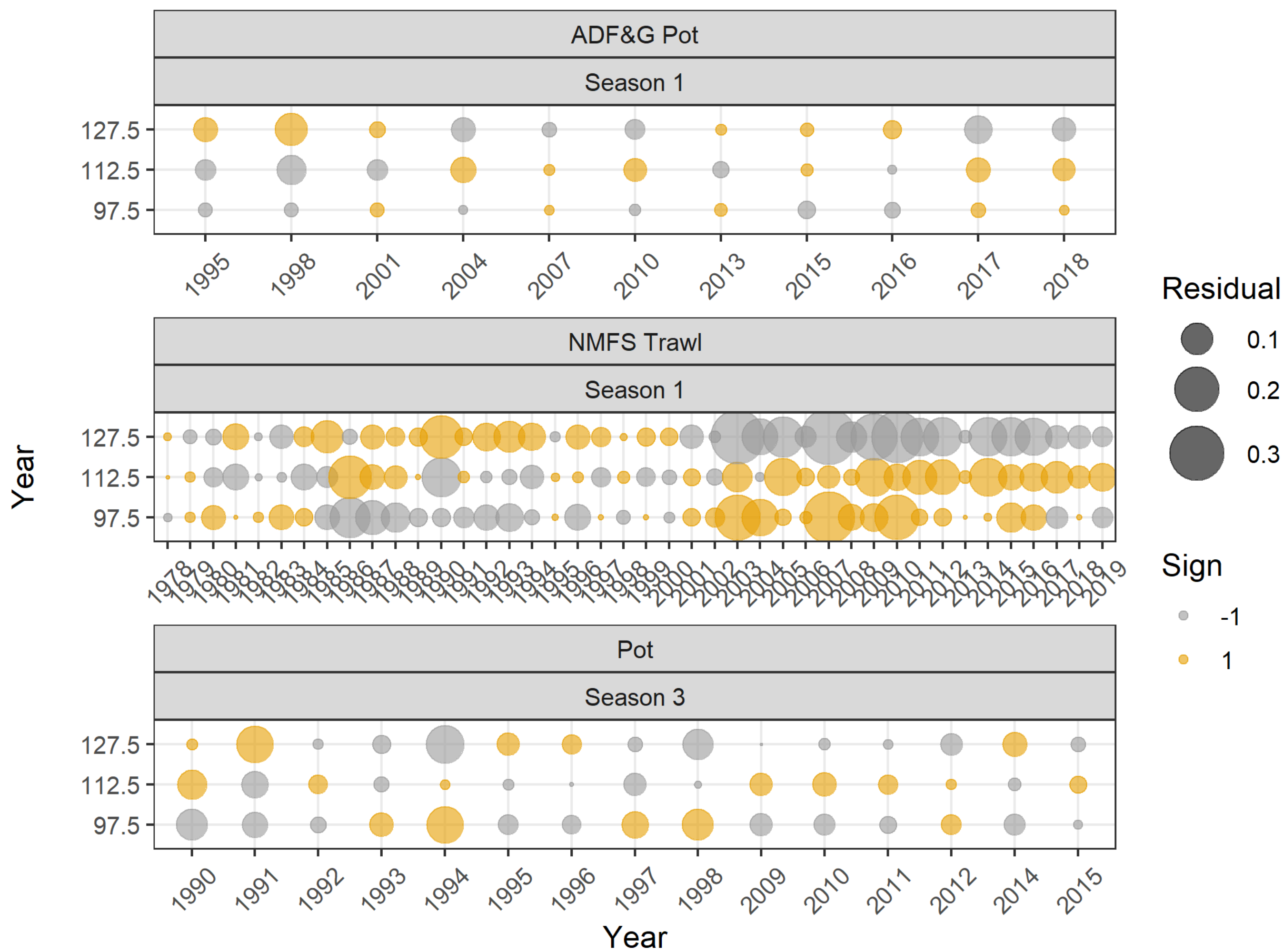

Figure 22: Bubble plots of residuals by stage and year for the all the size composition data sets (ADFG pot survey, NMFS trawl survey, and the directed pot fishery) for SMBKC in the 'reference' model (16.0).

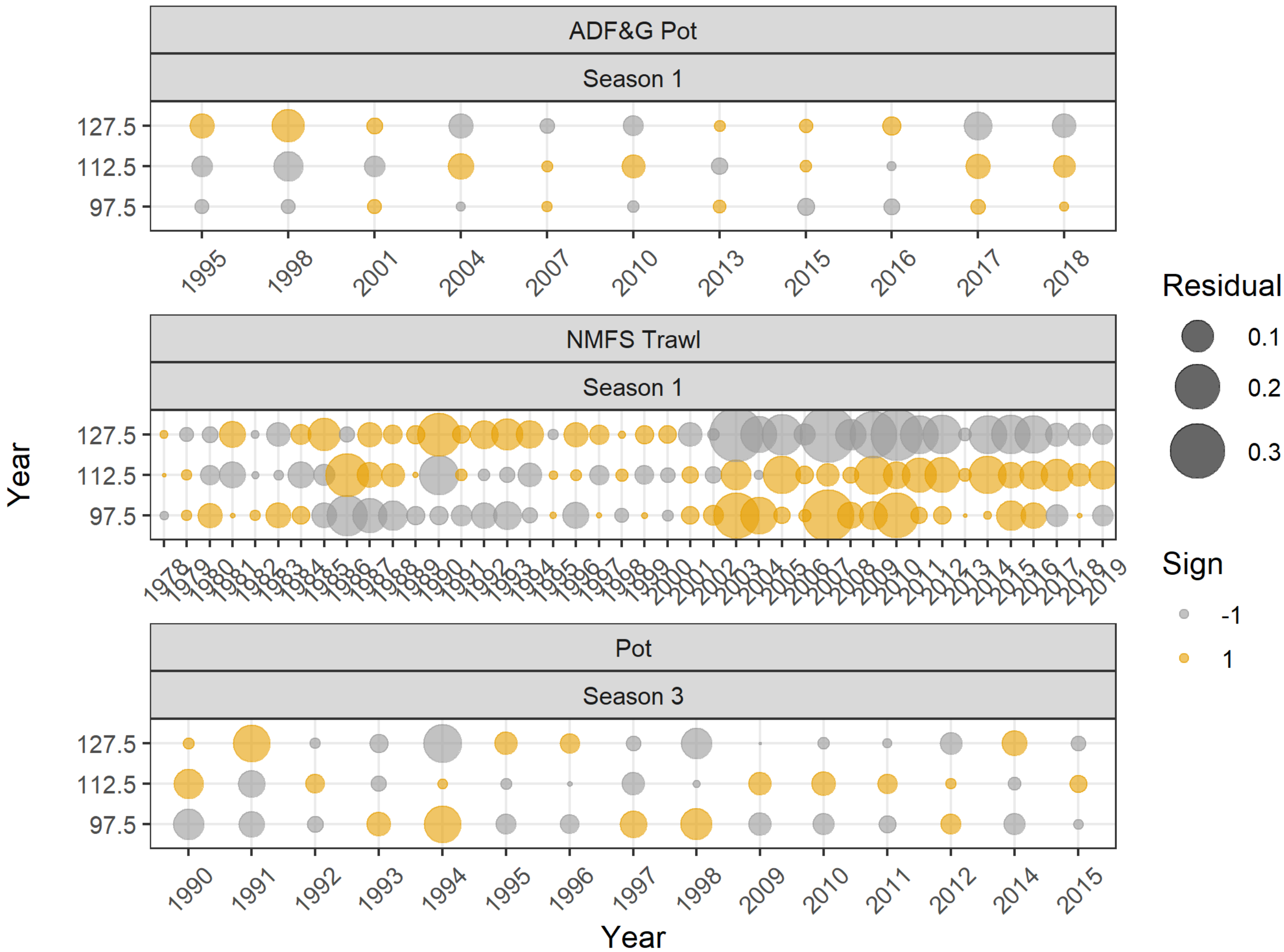

Figure 23: Bubble plots of residuals by stage and year for the all the size composition data sets (NMFS trawl survey, and the directed pot fishery) for SMBKC in the 'fixR' model (16.0a).

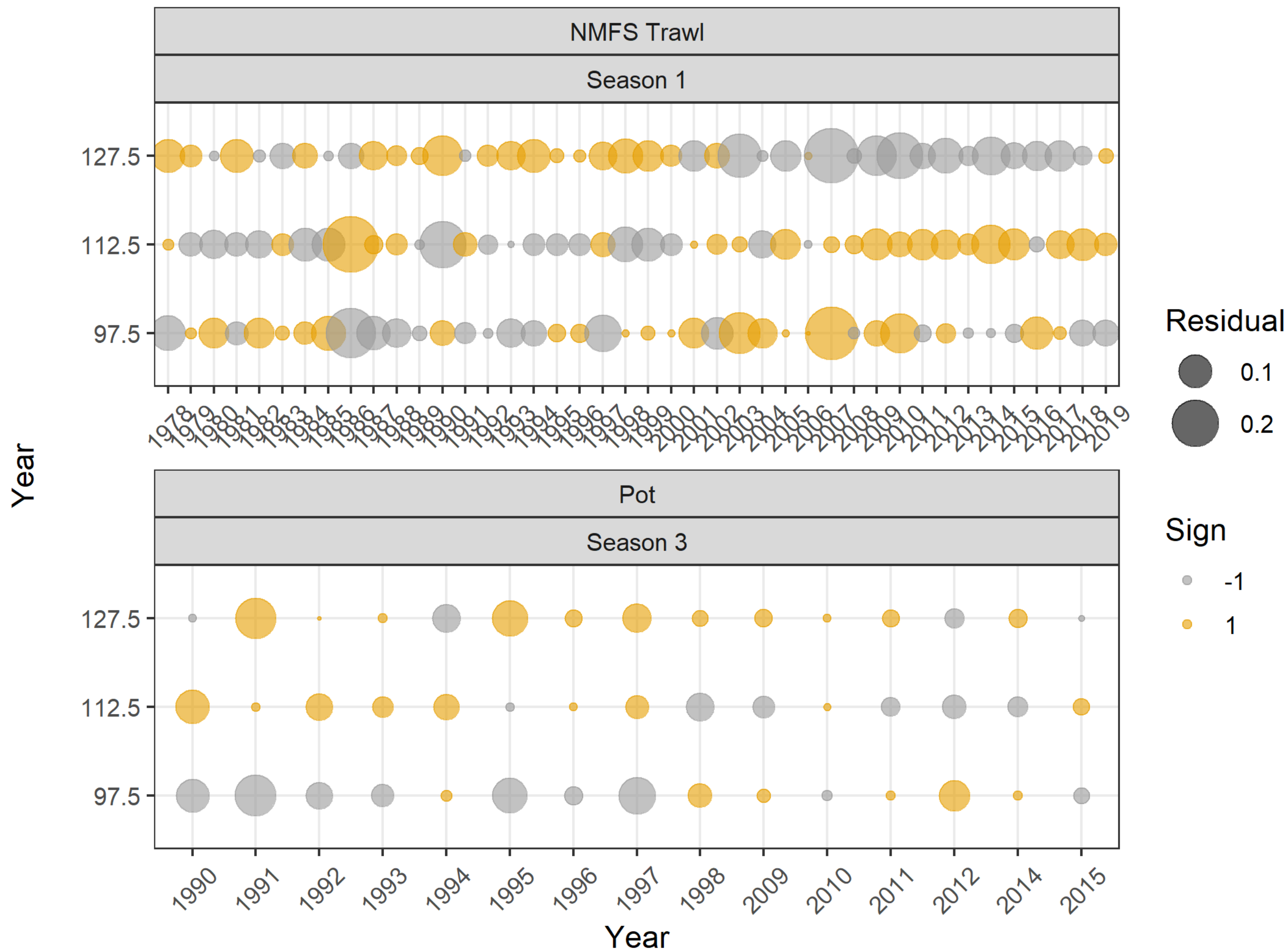

Figure 24: Bubble plots of residuals by stage and year for the all the size composition data sets (NMFS trawl survey, and the directed pot fishery) for SMBKC in the 'no pot' model (20.1).

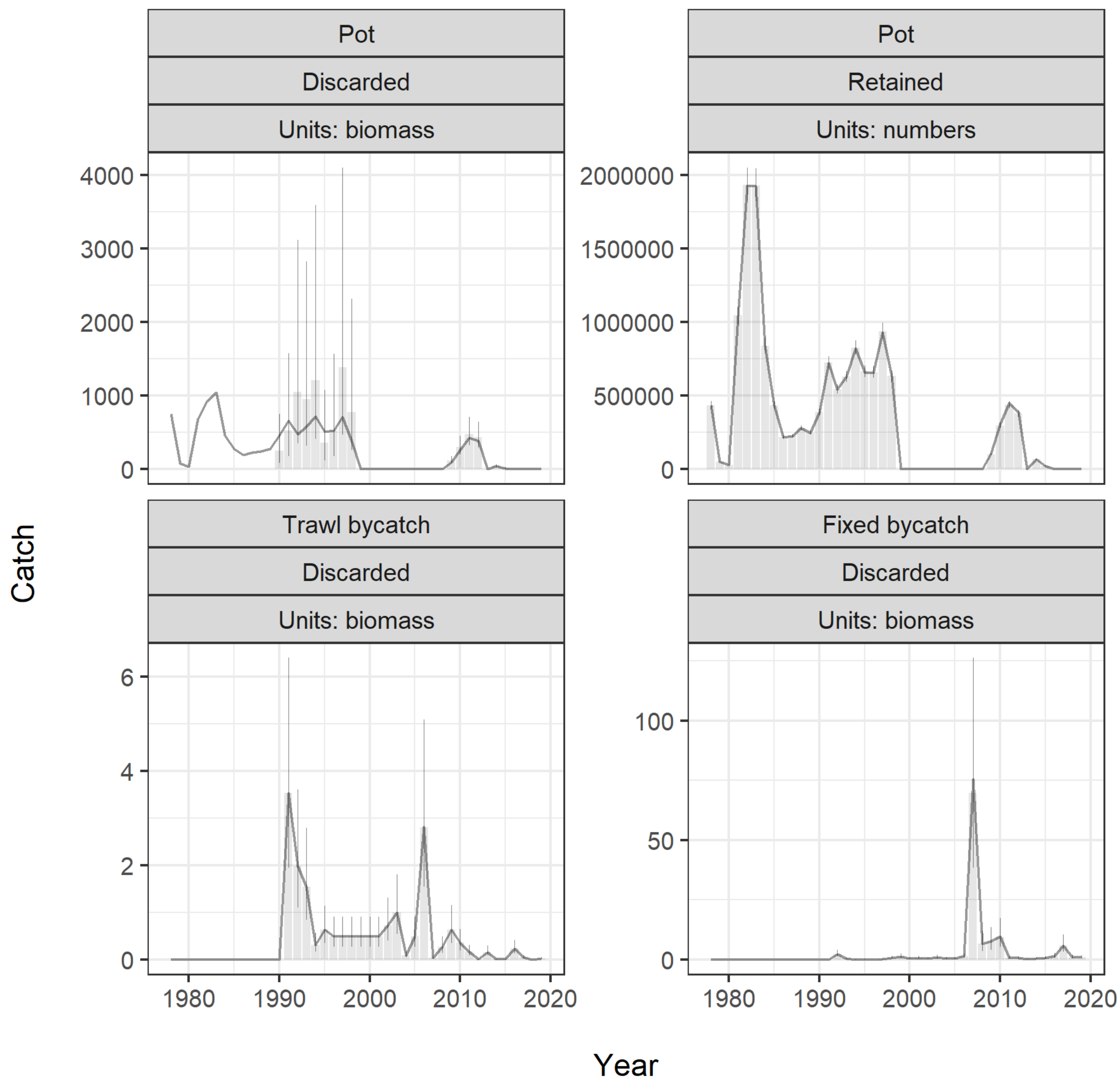

Figure 25: Comparison of observed and model predicted retained catch and bycatches in each of the GMACS models. Note that difference in units between each of the panels, some panels are expressed in numbers of crab, some as biomass (tons).

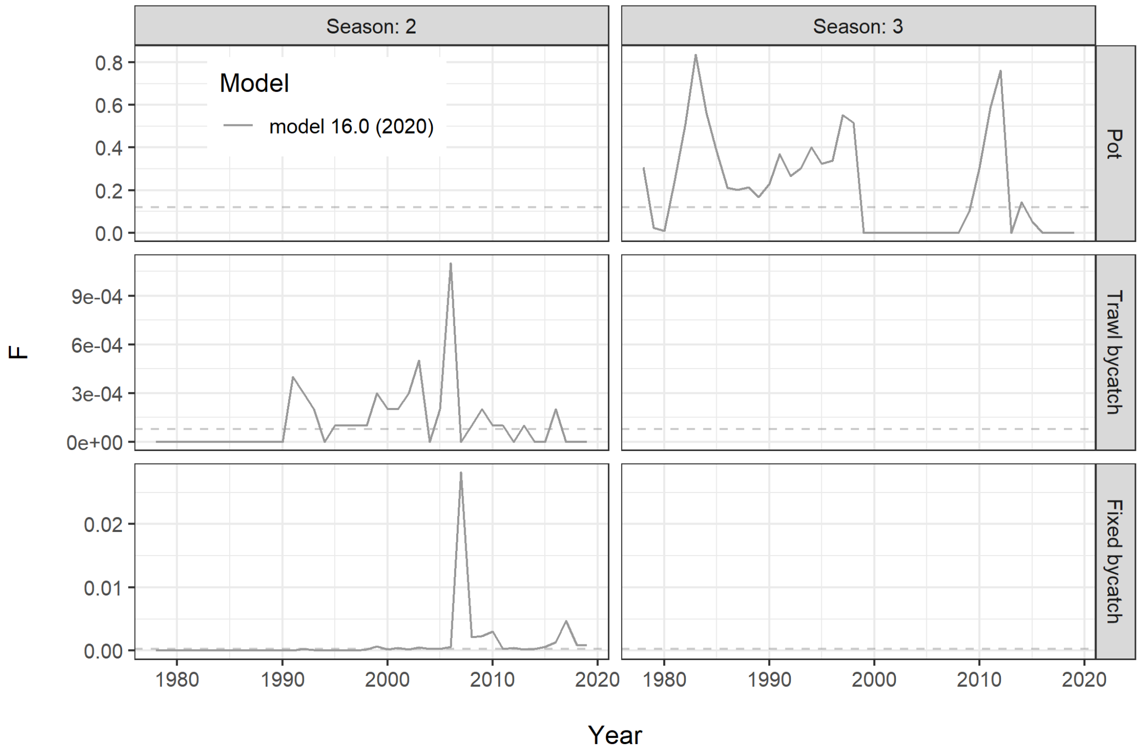

Figure 26: Fishing mortality estimates from the reference model (16.0) for directed and bycatch fleets

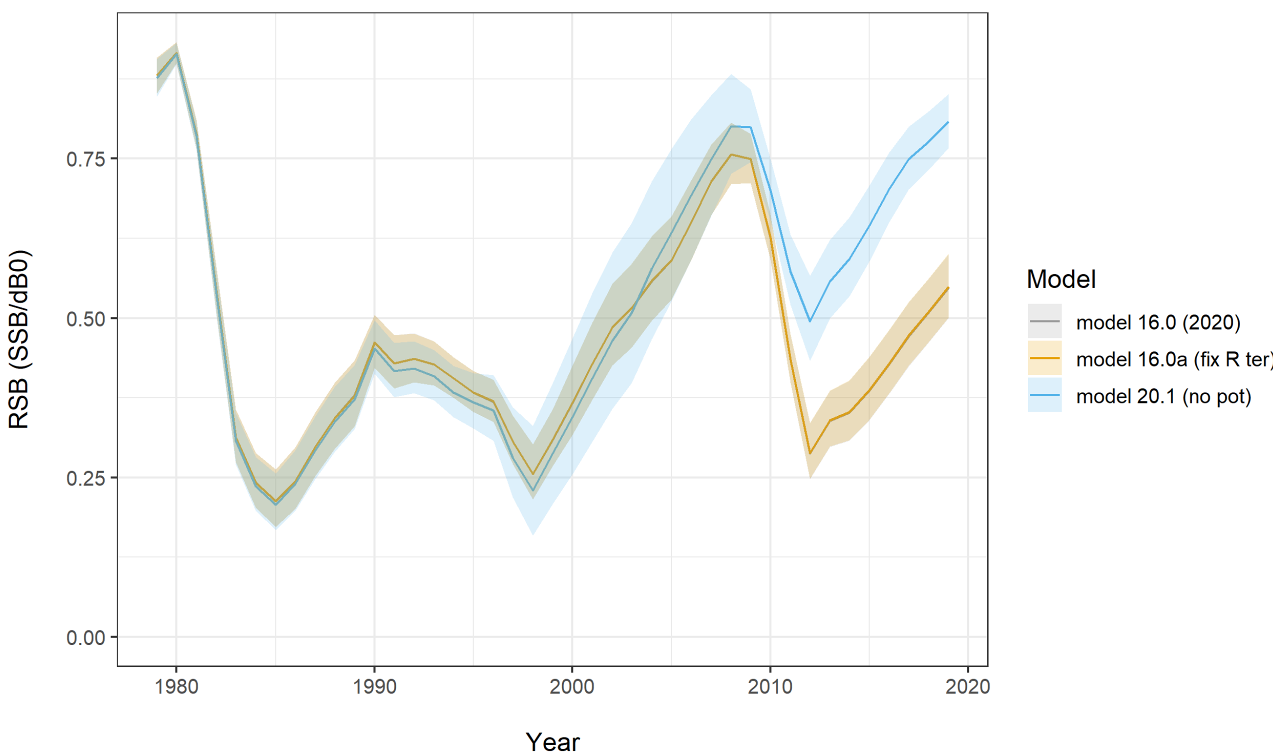

Figure 27: Comparison of mature male biomass relative to the dynamic B zero value, (15 February, 1978-2019) for each of the model scenarios.

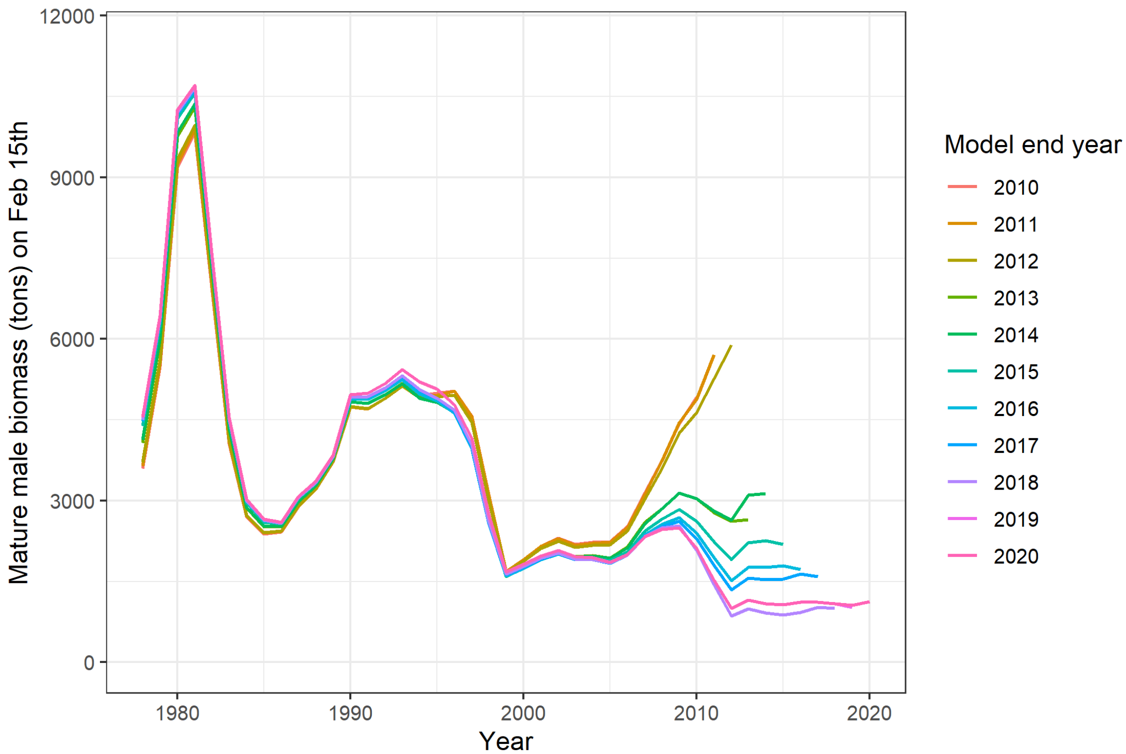

Figure 28: Retrospective pattern in mature male biomass (MMB (t)) for the reference (base) model (16.0), Mohn's rho = -0.346

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; see 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 20. 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

$$\boldsymbol{G} = \left[\begin{array}{ccc} 1 - \pi_{12} - \pi_{13} & \pi_{12} & \pi_{13} \\ 0 & 1 - \pi_{23} & \pi_{23} \\ 0 & 0 & 1 \end{array} \right], \tag{6}$$

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

$$\boldsymbol{S}_{t,y} = \left[\begin{array}{ccc} 1 - e^{-Z_{1,t,y}} & 0 & 0 \\ 0 & 1 - e^{-Z_{2,t,y}} & 0 \\ 0 & 0 & 1 - e^{-Z_{3,t,y}} \end{array} \right]. \tag{11}$$

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 21.

4. Model Parameters

Table 22 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 23 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 17). 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 20: 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

Table 21: 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 22: 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 23: 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^M_{1998}	-3	0.0	3	Normal(0, σ^2_M)	4
Recruitment deviations δ^R_y	-7	0.0	7	Normal(0, σ^2_R)	3
Average directed fishery fishing mortality $\bar{F}^{\mathrm{df}}$	-	0.2	-	-	1
Average trawl bycatch fishing mortality $\bar{F}^{\mathrm{tb}}$	-	0.001	-	-	1
Average fixed gear bycatch fishing mortality $\bar{F}^{\mathrm{fb}}$	-	0.001	-	-	1

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

The reference model (16.0) data file for 2020

```
#======================================================================================================
# Gmacs Main  Data  File  Version 1.1:  SM20 Sept 2020 version.
# GEAR_INDEX  DESCRIPTION
#   1      : Pot fishery retained catch.
#   1      : Pot fishery with discarded catch.
#   2      : Trawl bycatch
#   3      : Fixed bycatch
#   4      : Trawl survey
#   5      : 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
2019  # 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
0.000   0.060   0.000   0.570   0.370
0.000   0.070   0.000   0.560   0.370
0.000   0.050   0.000   0.580   0.370
0.000   0.070   0.000   0.560   0.370
0.000   0.120   0.000   0.510   0.370
0.000   0.100   0.000   0.530   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.140   0.000   0.490   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.180   0.000   0.450   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
```

```
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000   0.440   0.000   0.190   0.370
0.000 0.440 0.000 0.190 0.370
0.000   0.440   0.000   0.190   0.370 # (updated)
#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 29  29 #(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)
#   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 )
#   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   5.842   0.31    2   1   1   0   0.5 # updates was 6.032
2018    2   3   1   1.140   0.31    2   1   1   0   0.5 # updated was 1.281
2019  2 3 1 1.038 0.31  2 1 1 0 0.5 # (updated - 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
##  Number  of  rows  in  each  index
53
# Survey data (abundance indices, units are mt for trawl survey and crab/potlift for pot survey)
#   Year,   Seas,   Fleet,  Sex,    Maturity,   Abundance,  CV  units
1   1978    1   4   1   0   6832.819    0.394   1
```

```
1   1979    1   4   1   0   7989.881    0.463   1
1   1980    1   4   1   0   9986.83 0.507   1
1   1981    1   4   1   0   6551.132    0.402   1
1   1982    1   4   1   0   16221.933   0.344   1
1   1983    1   4   1   0   9634.25 0.298   1
1   1984    1   4   1   0   4071.218    0.179   1
1   1985    1   4   1   0   3110.541    0.21    1
1   1986    1   4   1   0   1416.849    0.388   1
1   1987    1   4   1   0   2278.917    0.291   1
1   1988    1   4   1   0   3158.169    0.252   1
1   1989    1   4   1   0   6338.622    0.271   1
1   1990    1   4   1   0   6730.13 0.274   1
1   1991    1   4   1   0   6948.184    0.248   1
1   1992    1   4   1   0   7093.272    0.201   1
1   1993    1   4   1   0   9548.459    0.169   1
1   1994    1   4   1   0   6539.133    0.176   1
1   1995    1   4   1   0   5703.591    0.178   1
1   1996    1   4   1   0   9410.403    0.241   1
1   1997    1   4   1   0   10924.107   0.337   1
1   1998    1   4   1   0   7976.839    0.355   1
1   1999    1   4   1   0   1594.546    0.182   1
1   2000    1   4   1   0   2096.795    0.31    1
1   2001    1   4   1   0   2831.44 0.245   1
1   2002    1   4   1   0   1732.599    0.32    1
1   2003    1   4   1   0   1566.675    0.336   1
1   2004    1   4   1   0   1523.869    0.305   1
1   2005    1   4   1   0   1642.017    0.371   1
1   2006    1   4   1   0   3893.875    0.334   1
1   2007    1   4   1   0   6470.773    0.385   1
1   2008    1   4   1   0   4654.473    0.284   1
1   2009    1   4   1   0   6301.47 0.256   1
1   2010    1   4   1   0   11130.898   0.466   1
1   2011    1   4   1   0   10931.232   0.558   1
1   2012    1   4   1   0   6200.219    0.339   1
1   2013    1   4   1   0   2287.557    0.217   1
1   2014    1   4   1   0   6029.22 0.449   1
1   2015    1   4   1   0   5877.433    0.77    1
1   2016    1   4   1   0   3485.909    0.393   1
1   2017    1   4   1   0   1793.76 0.599   1
1   2018    1   4   1   0   1730.742    0.281   1
1   2019    1   4   1   0   3170.467    0.337   1   #   (updated    -   EBSsurvey_analysis.R)
2   1995    1   5   1   0   12042   0.13    2
2   1998    1   5   1   0   12531   0.06    2
2   2001    1   5   1   0   8477    0.08    2
2   2004    1   5   1   0   1667    0.15    2
2   2007    1   5   1   0   8643    0.09    2
2   2010    1   5   1   0   10209   0.13    2
2   2013    1   5   1   0   5643    0.19    2
2   2015    1   5   1   0   2805    0.18    2
2   2016    1   5   1   0   2378    0.186   2
2   2017    1   5   1   0   1689    0.25    2
2   2018    1   5   1   0   745 0.14    2   #   no  smbkc   pot survey  in  2019
##  Number  of  length  frequency matrices
3
##  Number  of  rows  in  each  matrix
15  42  11 # (updated)
##  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
  2019  1 4 1 0 0 0 50  0.1961  0.2346  0.5692 # no survey so not updated
  ##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 2020

```
## ============================================== updated for sept 2020 base model     ##
## LEADING PARAMETER CONTROLS                                                           ##
# Controls for leading parameter vector theta
# LEGEND FOR PRIOR:
#                 0 -> uniform #                 1 -> normal #                 2 -> lognormal
#                 3 -> beta
#                 4 -> gamma
# 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?)
# Proportion mature by sex
0 1 1
# Proportion legal by sex
0 0 1

## GROWTH PARAM CONTROLS                                                              ##
# Use custom transition matrix (0=no, 1=growth matrix, 2=transition matrix, i.e. growth and molting)
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
## 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
## ================================================================================== ##
# ival       lb       ub        phz  prior     p1      p2        # parameter         #
#  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                                                               ##
##     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, 1 = coefficients, 2 = logistic, 3 = logistic95,      ##
##               4 = double normal (NIY)                                              ##
##     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         3        3         0        0         # male selectivity type
```

```
   0        0       0        0       0        # within another gear
   0        0       0        0       0        # extra parameters
## Gear-1    Gear-2  Gear-3   Gear-4  Gear-5
   1        1       1        1       1        # Retention periods
   0        0       0        0       0        # sex specific retention
   3        6       6        6       6        # male retention type
   1        0       0        0       0        # male retention flag (0 -> no, 1 -> yes)
   0        0       0        0       0        # extra parameters
## gear  par   sel                                         phz    start  end        ##
## index index par sex  ival  lb    ub     prior p1     p2     mirror period period     ##
# 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   2019 # update end yr
   1     2     2   0    0.4    0.001 1.0    0       0      1    3     2009   2019 # update end yr
   1     3     3   0    1.0    0.001 2.0    0       0      1    -2     2009   2019 # update end yr
# Gear-2
   2     7     1   0    40      10.0  200    0      10    200   -3     1978   2019 # update end yr
   2     8     2   0    60      10.0  200    0      10    200   -3     1978   2019 # update end yr
# Gear-3
   3     9     1   0    40      10.0  200    0      10    200   -3     1978   2019 # update end yr
   3    10     2   0    60      10.0  200    0      10    200   -3     1978   2019 # update end yr
# Gear-4
   4     11    1   0    0.7     0.001 1.0    0       0      1   4     1978   2020 # update end yr
   4     12    2   0    0.8     0.001 1.0    0       0      1   4     1978   2020 # update end yr
   4     13    3   0    0.9     0.001 1.0    0       0      1   -5     1978   2020 # update end yr
# Gear-5
   5     14    1   0    0.4     0.001 1.0    0       0      1   4     1978   2020 # update end yr
   5     15    2   0    0.7     0.001 1.0    0       0      1   4     1978   2020 # update end yr
   5     16    3   0    1.0     0.001 2.0    0       0      1   -2     1978   2020 # update end yr
## Retained
# Gear-1
  -1     17    1   0    120        50 200    0      1    900    -7     1978   2019 # update end yr
  -1     18    2   0    123       110 200    0      1    900    -7     1978   2019 # update end yr
# Gear-2
  -2     19    1   0   595    1    999    0      1    999   -3     1978   2019 # update end yr
# Gear-3
  -3     20    1   0   595    1    999    0      1    999   -3     1978   2019 # update end yr
# Gear-4
  -4     21    1   0   595    1    999    0      1    999   -3     1978   2020 # update end yr
# Gear-5
  -5     22    1   0   595    1    999    0      1    999   -3     1978   2020 # 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                                        ##
## 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
## 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
## ================================================================================= ##

## ================================================================================= ##
## 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      0.00000001   10.0      -4    4         1.0     100   # NMFS (PHASE -4)
```

```
   0.0000001      0.00000001   10.0      -4    4         1.0     100   # ADF&G
## ================================================================================ ##

## ================================================================================ ##
## 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   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 = Time blocks
## ================================================================================ ##
## Type
6
## 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
## ================================================================================ ##

## ================================================================================ ##
```

```
## OTHER CONTROLS
## ==================================================================================== ##
1978       # First rec_dev
2019       # last rec_dev (updated annually)
   3       # Estimated rec_dev phase
  -3       # Estimated sex_ratio
 0.5       # initial sex-ratio
  -3       # Estimated rec_ini phase
   0       # 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
## ==================================================================================== ##
## EMPHASIS FACTORS (CATCH)
## ==================================================================================== ##
#Ret_POT Disc_POT Disc_trawl Disc_fixed
       1        1          1          1

## ==================================================================================== ##
## EMPHASIS FACTORS (Priors)
## ==================================================================================== ##
# Log_fdevs   meanF       Mdevs  Rec_devs Initial_devs Fst_dif_dev Mean_sex-Ratio
      10000       1           1         1            0           0              1             #(10000)
## EOF
9999
```

Appendix C. Assessing uncertainty in model output due to lack of terminal year survey data for St. Matthew blue king crab (SMBKC)

Introduction

NMFS trawl surveys during the summer of 2020 were cancelled due to logistic difficulties caused by the global pandemic COVID-19. Therefore, the crab assessment authors met to discuss approaches to address the potential of additional uncertainty in the current year models - specifically the projected mature male biomass and associated reference points. The objective of these approaches/simulations was to provide the crab plan team (CPT) and the scientific and statistical committee (SSC) a range of potential additional uncertainty that could be applied to the buffers used on the OFL calculations to produce an appropriate ABC for the 2020/21 crab season.

Objectives

```
1. Can we characterize the additional uncertainty in the current years estimates due to
the lack of terminal year survey data? If so, what does it look like?

2. Is the model uncertainty characterized in objective #1 currently included in the ABC
buffer applied to this stock or do we need to apply additional uncertainty measures?
```

Approaches

Approach 1 (and 2): retrospective patterns with and without terminal survey data

Retrospective analysis are typically performed on models to characterize the tendencies of a model to over or under estimate current trends in biomass, recruitment, etc. Retrospective patterns are described as a clear tendency for a model to either over or under estimate. Approach 1 compares the output of retrospective models with the terminal year of survey data and ones where the terminal year of trawl survey data are removed (both abundance and size composition data). Approach 2 was to do this for the last year's model - 2019 - which is included in the analysis.

A number of key model outputs were compared for these retrospective runs. These include: average recruitment, B_{msy}, status of the stock, terminal year MMB, and reference point calculations (OFL).

Results

Retrospective analysis of the base model show a retrospective pattern that tends to overestimate mature male biomass (MMB) in the terminal year (Figure 1 and 2). Using a peel of the last 5 years estimates of MMB the estimated Mohn's ρ is -0.346, which suggests a retrospecive pattern in the MMB estimates for the base model. Since 2018 the MMB estimates have been relatively stable, however, they are the lowest in the model history and reflect a time of overfished declaration for the stock.

In general, models that lacked the terminal year of survey data performed similarly to models with the survey data for each model end year (Figure 3). In cases where the model outputs differed the model without the terminal year of survey data tended to have results similar to the previous years model. For the last 5 years of retrospective model runs the models with and without the terminal year of survey data performed very similarly. These results support the hypothesis that for SMBKC in the last few years no additional uncertainty is present in the mmb estimates with the lack of the terminal year survey data (Figure 4).

Figures 5 through 10 display the small differences between these model runs in each model end year. There are some small differences in the model with and without the terminal year of survey data, but most of these exist around between 2013 and 2015 where the population was transitioning from healthy levels to overfished. This is most evident in the terminal MMB, F_{OFL}, and OFL comparisons for 2013 (Figures 6, 9, and 10).

Hypothetically if the uncertainty about the quantities of interest increased due to the lack of a terminal year of survey data the resuling average CVs for the quantities would be larger in runs without the terminal year of survey data. Table 2 summarises the average CVs over all years for the "normal" retrospective runs and those without the terminal year of survey data. There are small differences in the average CVs, with those in the "missing survey" retrospective runs being slightly larger on average, but this difference is small and does not suggest increase uncertainty in the "missing survey" runs.

The average percent difference between these quantities was approximately 1% overall and was the highest in OFL comparisons at an average difference of 4% (Table 1). Most differences were small and even unnoticeable in years where the population trajectory was similar to the previous year. The underlying model processes (growth, mortality, selectivity, etc.) drive the current year's model estimates without the presence of new abundance or size data, and the uncertainty about these processes has not increased with the lack of one year of survey data.
Based on this analysis the author does not recommend additional uncertainty in the ABC buffer for SMBKC for the 2020 base model.

Approach 3: encompassing expected variability

This approach was designed to run models with "fake" 2020 data to determine how much a data point in 2020 could have potential influenced the model outcome. The same key model outputs were compared in this approach as in approach 1.

This approach evaluates the impact of different hypothetical 2020 survey outcomes, and is based on a SSC recommendation in its June minutes. Using the NMFS trawl survey time series fit in the proposed base or reference model the multiplicative residuals were calculated (predicted survey fit/observed survey data point) for each year. The 25th and 75th percentiles of the multiplicative residual distribution were obtained, which would represent a typical low and high value for the survey (Martin Dorn per comm.).

A predicted survey value was obtained for 2020 by running the base model with a hypothetical survey value with a very high CV (100), so that the model did not attempt to fit the observation. For SMBKC the hypothetical survey value was an average of the last 4 years of the survey to best estimate the hypothetical 2020 data point even though the CV for this data point was large. Once the base model was fit with this hypothetical data point the resulting estimate for the 2020 survey was used to complete two additional model runs. These runs multiplied the predicted 2020 survey data point by the 25th and 75th percentiles of the multiplicative residuals to simulate a "low" and "high" survey data point. The CV for these runs was set equal to the median survey CV. These two runs were evaluated along side the 2020 base model to determine the sensitivity of model output and management quantities on the 2020 survey data point.

Results

Overall, the model output and management quantities did not differ much between the base and the low and high hypothetical survey data runs for 2020 (Figure 11 and Table 3).

The estimated mature male biomass trend was the same, with little difference evident when viewing the entire time series (Figure 12). A detailed view of the last 10 years is provided for the MMB estimates in order to view the small difference in the three model estimates. The trends are all similar, with the only difference being the scale of the MMB estimate in the last 7 years (Figure 13). In reference to the base model the "high" run increased the MMB by a very small amount, where the "low" run decreased the MMB trend by about twice as much. All model estimates were very similar and within the typical range of uncertainty of the base model (Figure 14). Based on this analysis the author does not recommend additional uncertainty in the ABC buffer for SMBKC for the 2020 base model.

Recommendations on uncertainty

The analysis performed in this appendix, including the general retrospective analysis, suggest that no additional uncertainty is neccessary for SMBKC. Any additional variability in the model estimates from not having a survey data point in 2020 would like produce a small change in the calculated 2020 OFL. The current buffer of 20% includes the expected uncertainty in the model output that is observed in the retrospective analysis, adding to this uncertainty does not appear neccessary at this time.

The current status of the stock is still overfished, and the directed fishery is closed. The only harvest for this stock comes from bycatch in the groundfish and other crab fisheries which occurs at very low levels. While increasing the buffer on the ABC would not impact these fisheries, it also does not appear neccessary to keep the bycatch numbers well below the projected ABC.

Figures

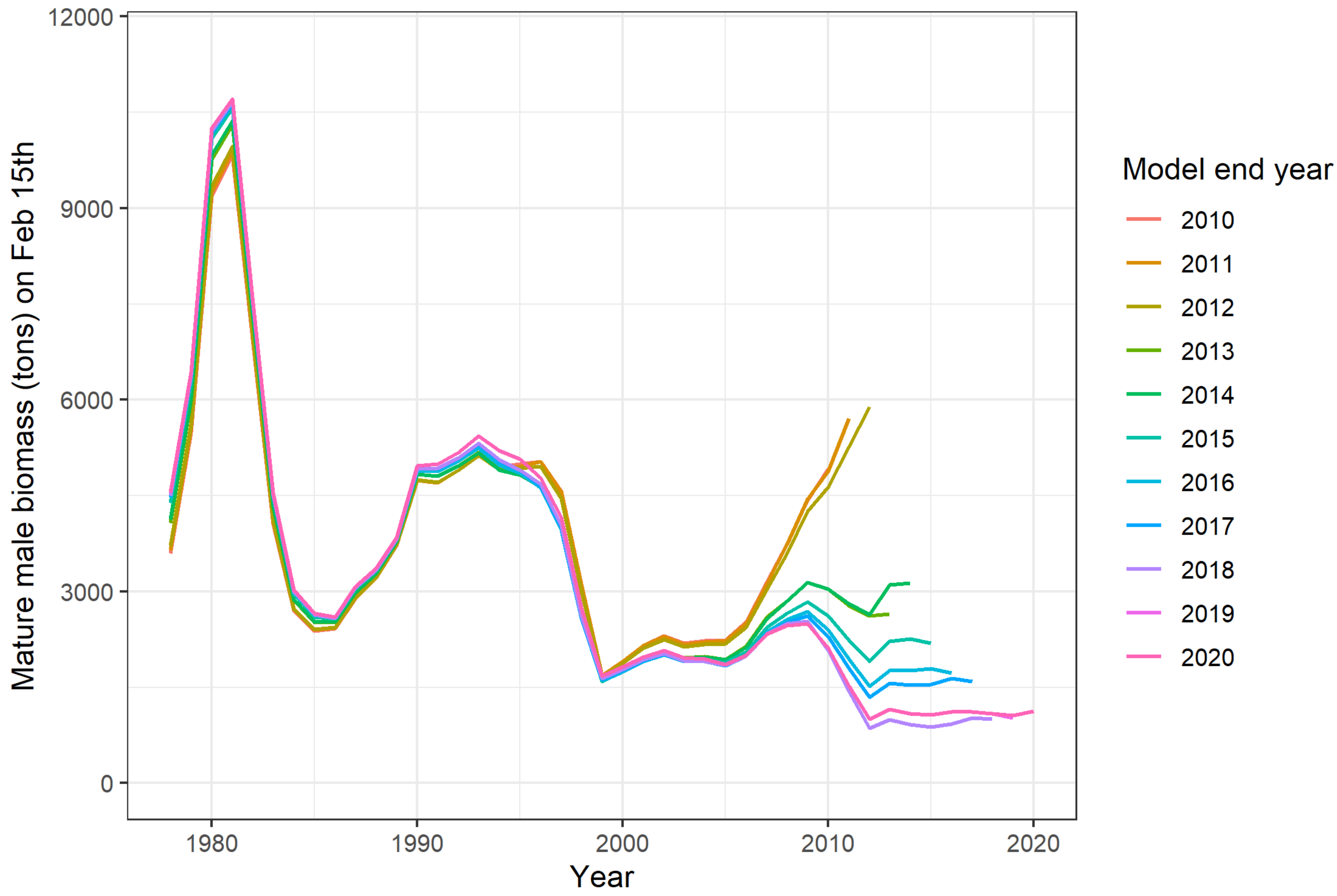

Figure 1: Retrospective run estimates of mature male biomass (mmb) for the SMBKC reference model (16.0) for the last 10 years.

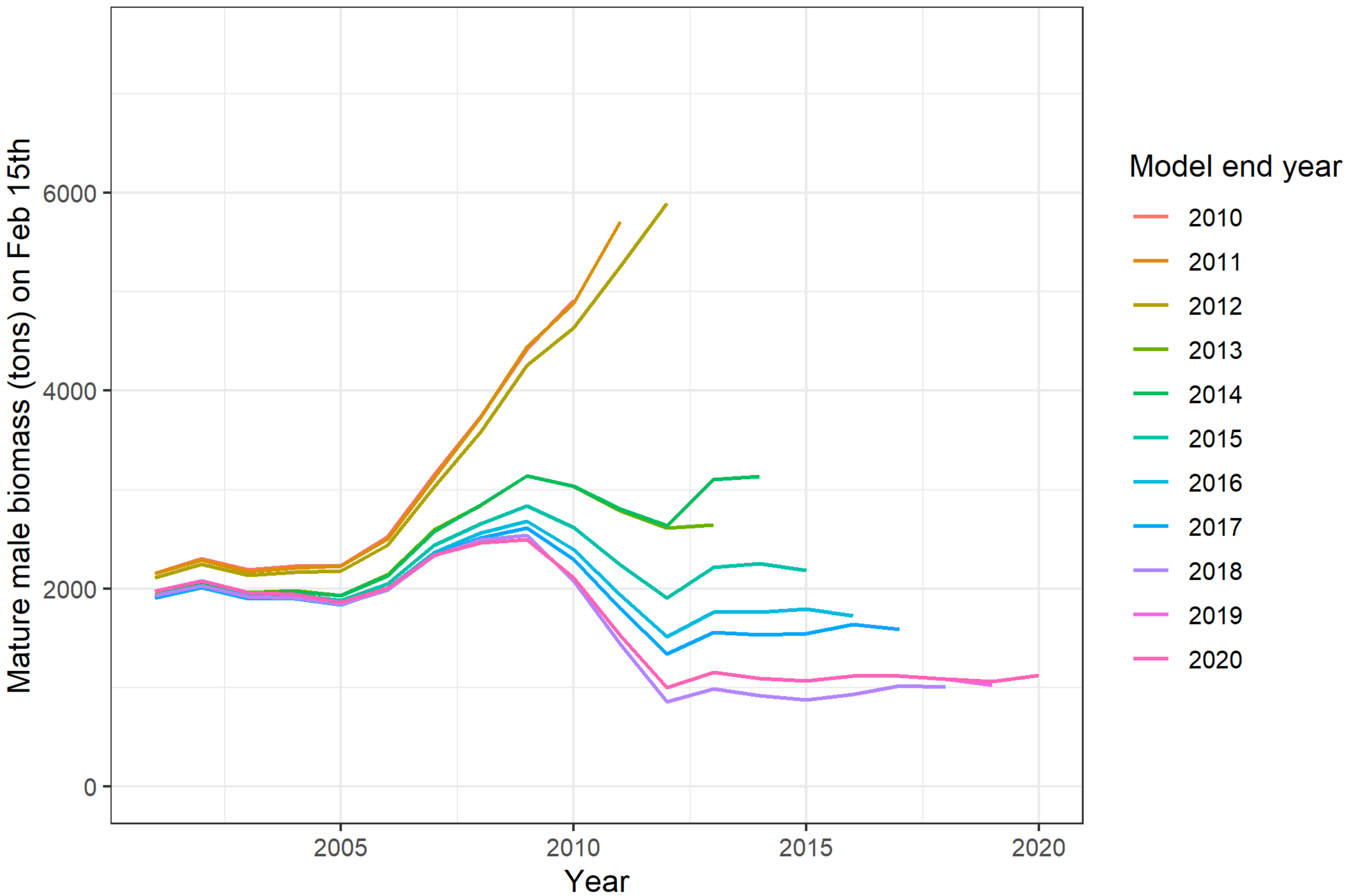

Figure 2: Retrospective run estimates of mature male biomass (mmb) for the SMBKC reference model (16.0) for the last 10 years, only showing the last 20 years for a detailed view.

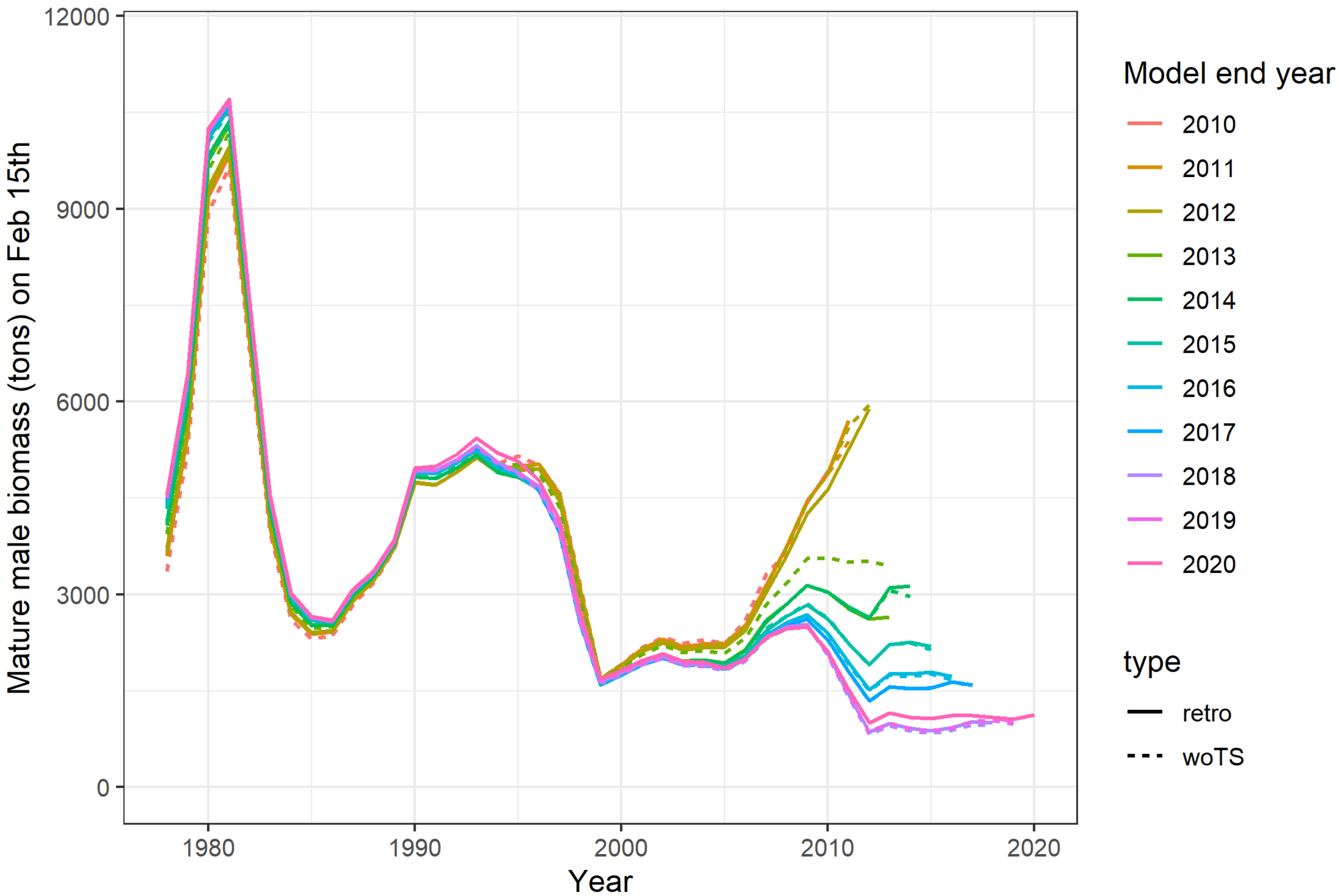

Figure 3: Retrospective run estimates of mature male biomass (mmb) for the SMBKC reference model (16.0) including models that eliminated the terminal year survey data.

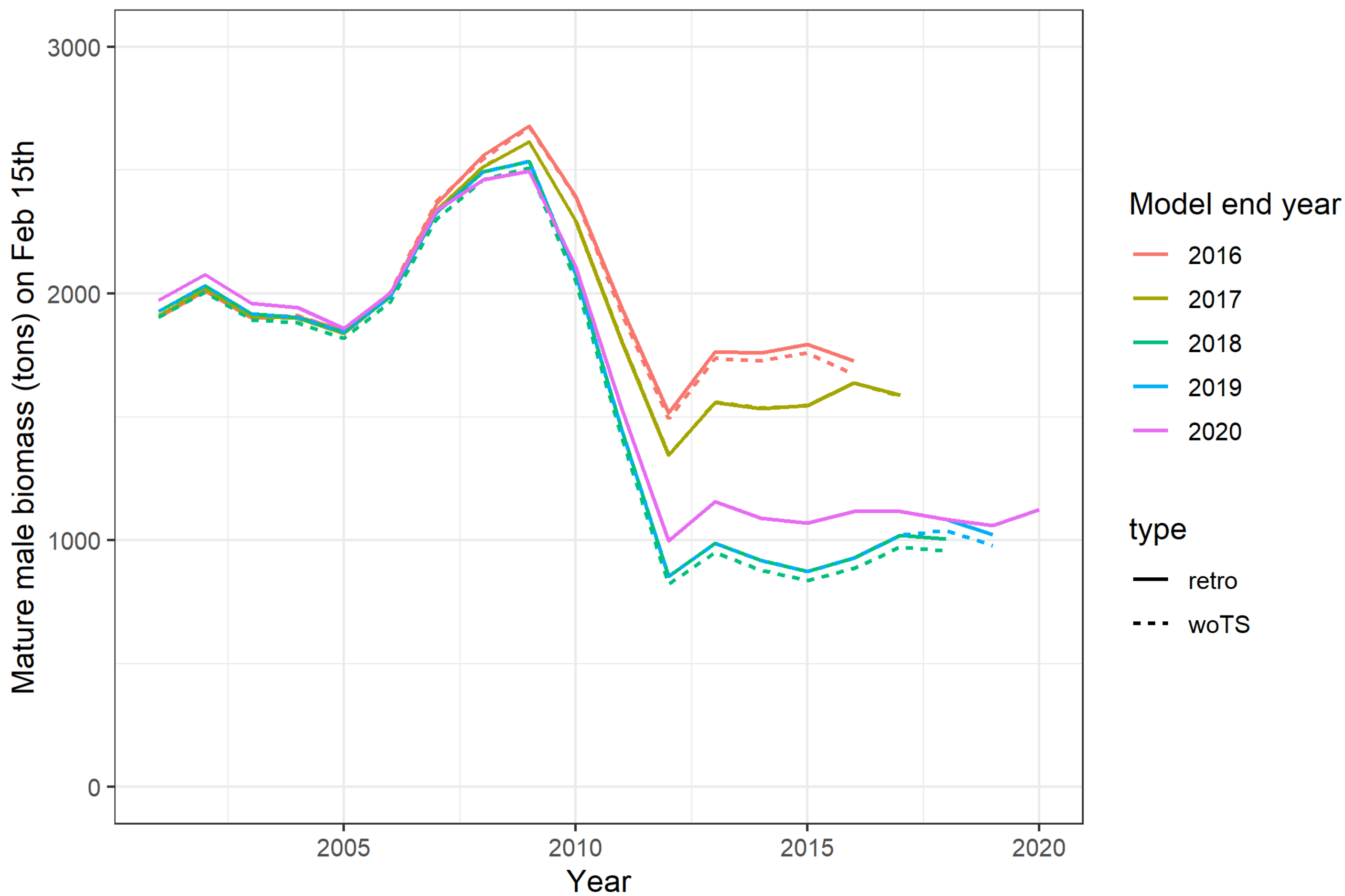

Figure 4: Retrospective run estimates of mature male biomass (mmb) for the SMBKC reference model (16.0) including models that eliminated the terminal year survey data for the last 5 model years. Highlighting the last 20 years for a more detailed view.

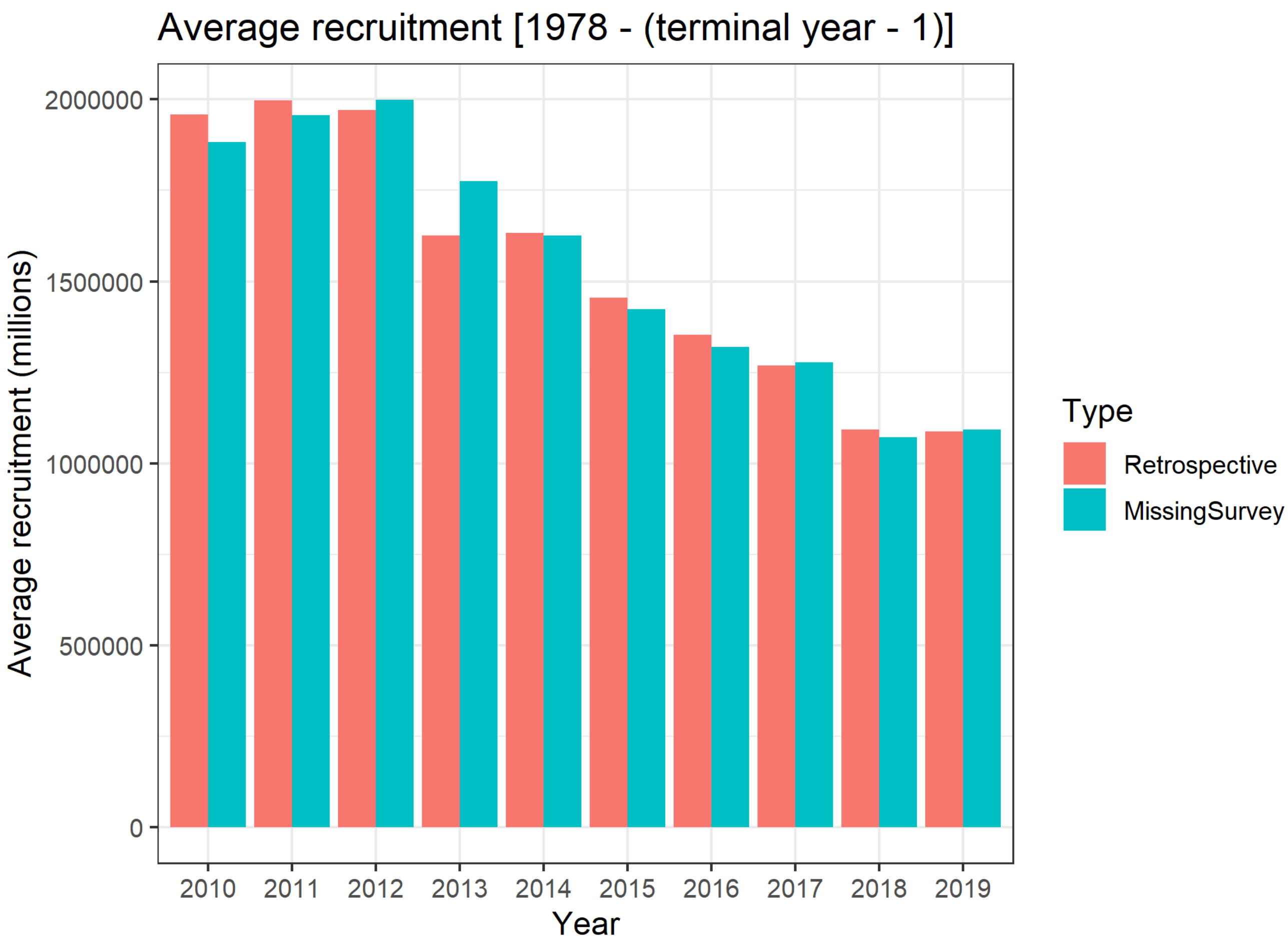

Figure 5: Comparison of average recruitment model estimates from 'normal' retrospective runs and those without the terminal year survey data.

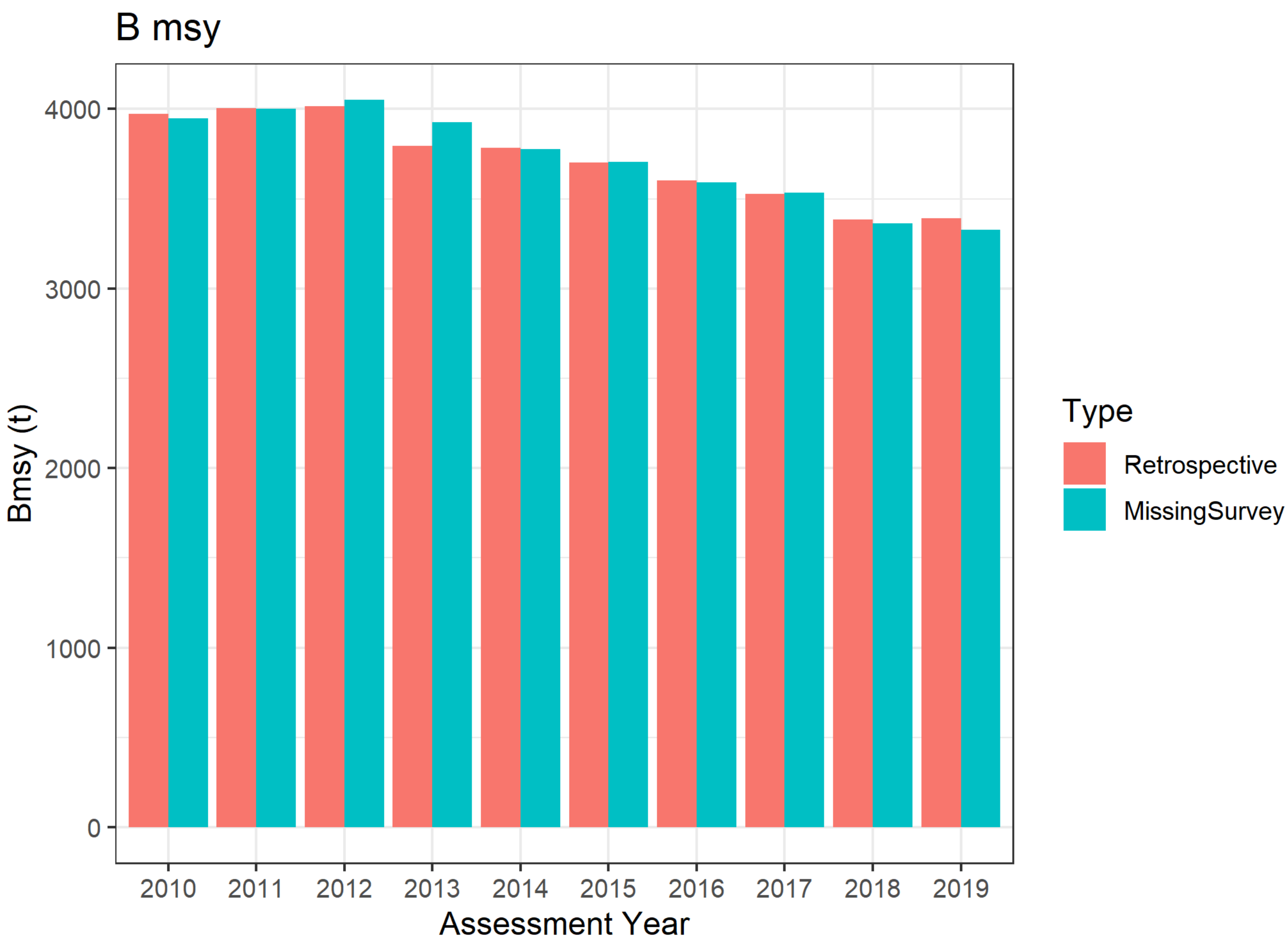

Figure 6: Comparison of Bmsy model estimates from 'normal' retrospective runs and those without the terminal year survey data.

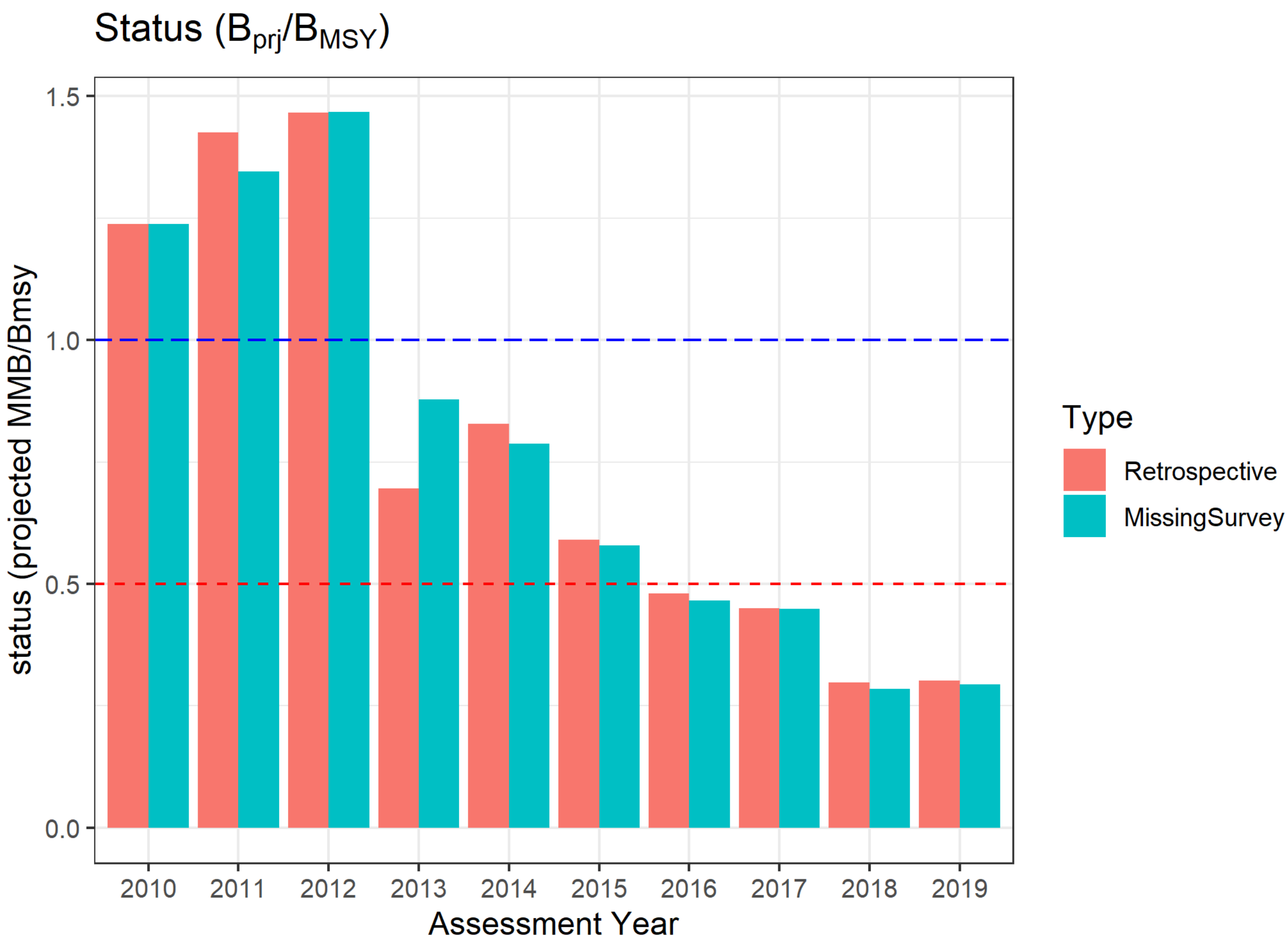

Figure 7: Comparison of the model estimate of 'status' (B/Bmsy) from 'normal' retrospective runs and those without the terminal year survey data.

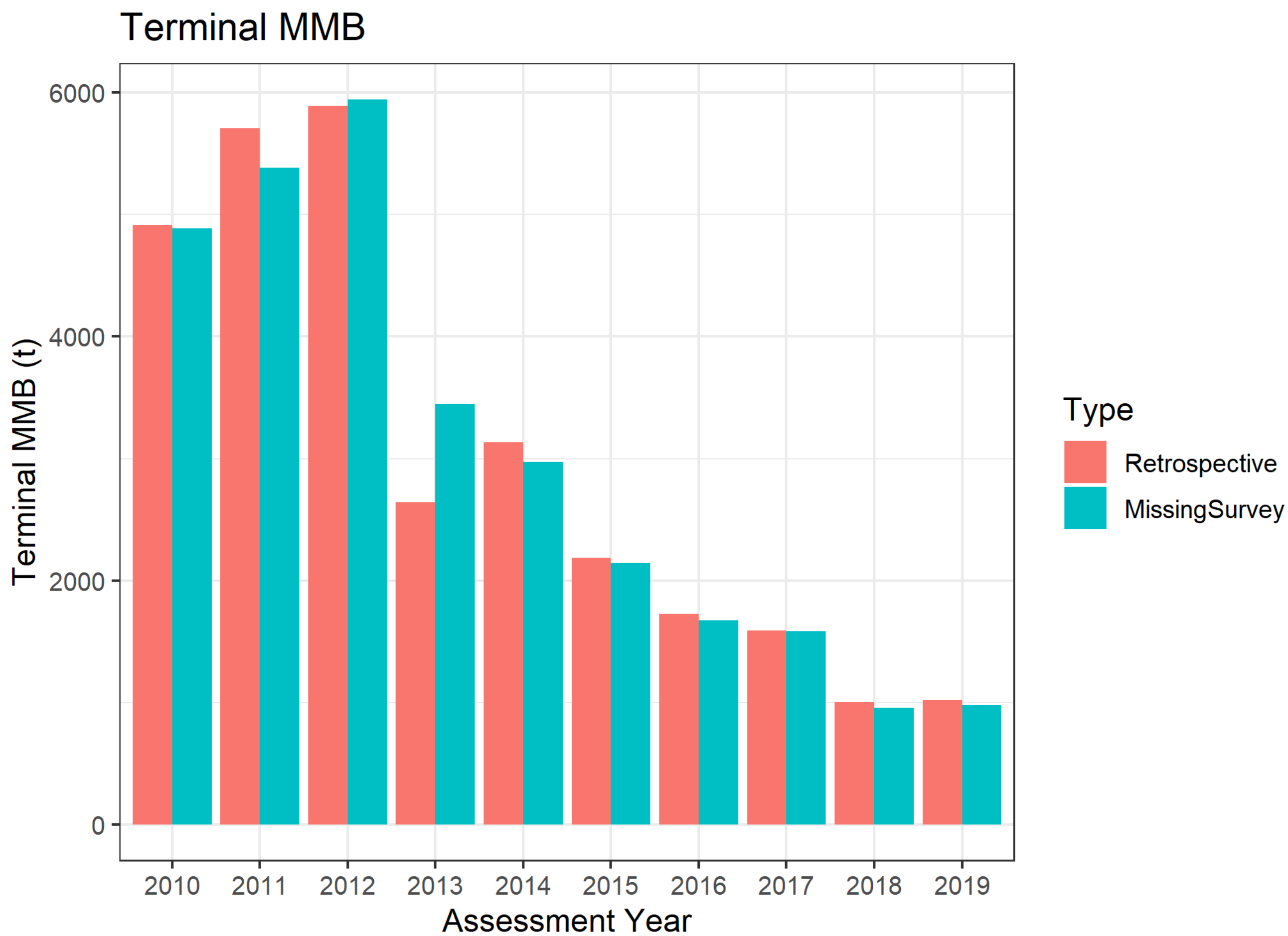

Figure 8: Comparison of the model estimate of terminal year mmb from 'normal' retrospective runs and those without the terminal year survey data.

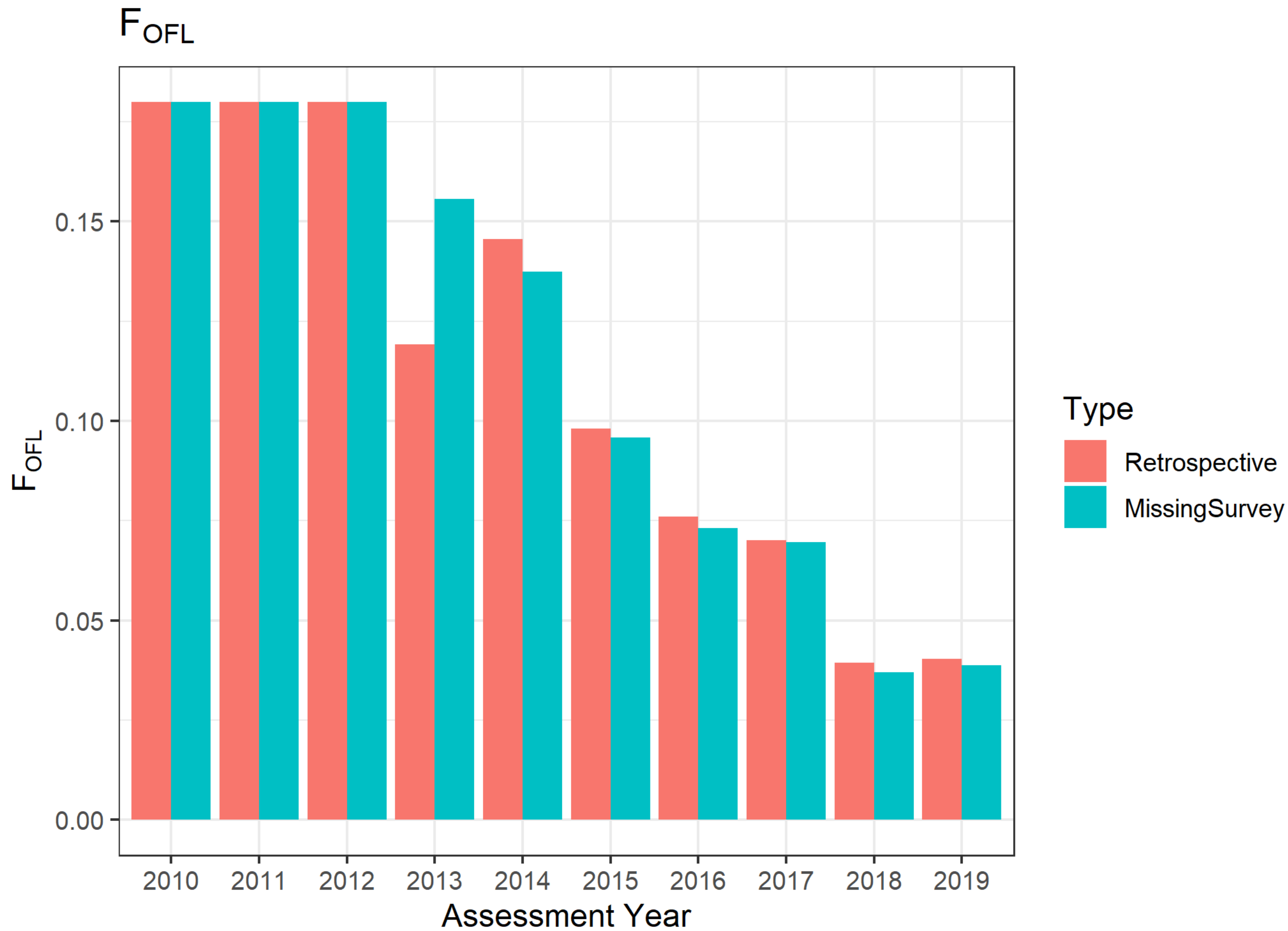

Figure 9: Comparison of the model estimate of fofl from 'normal' retrospective runs and those without the terminal year survey data.

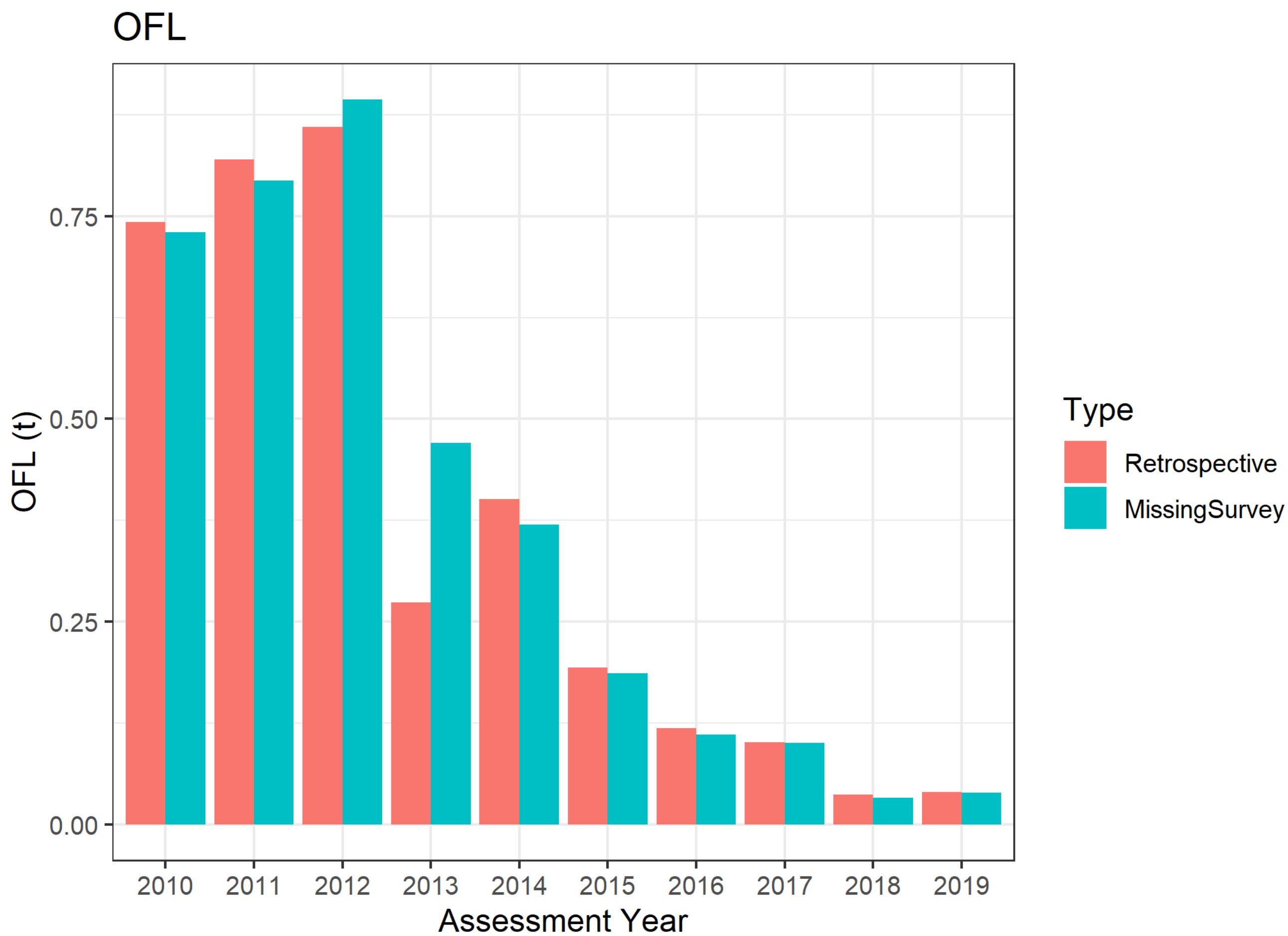

Figure 10: Comparison of the model estimate of OFL from 'normal' retrospective runs and those without the terminal year survey data.

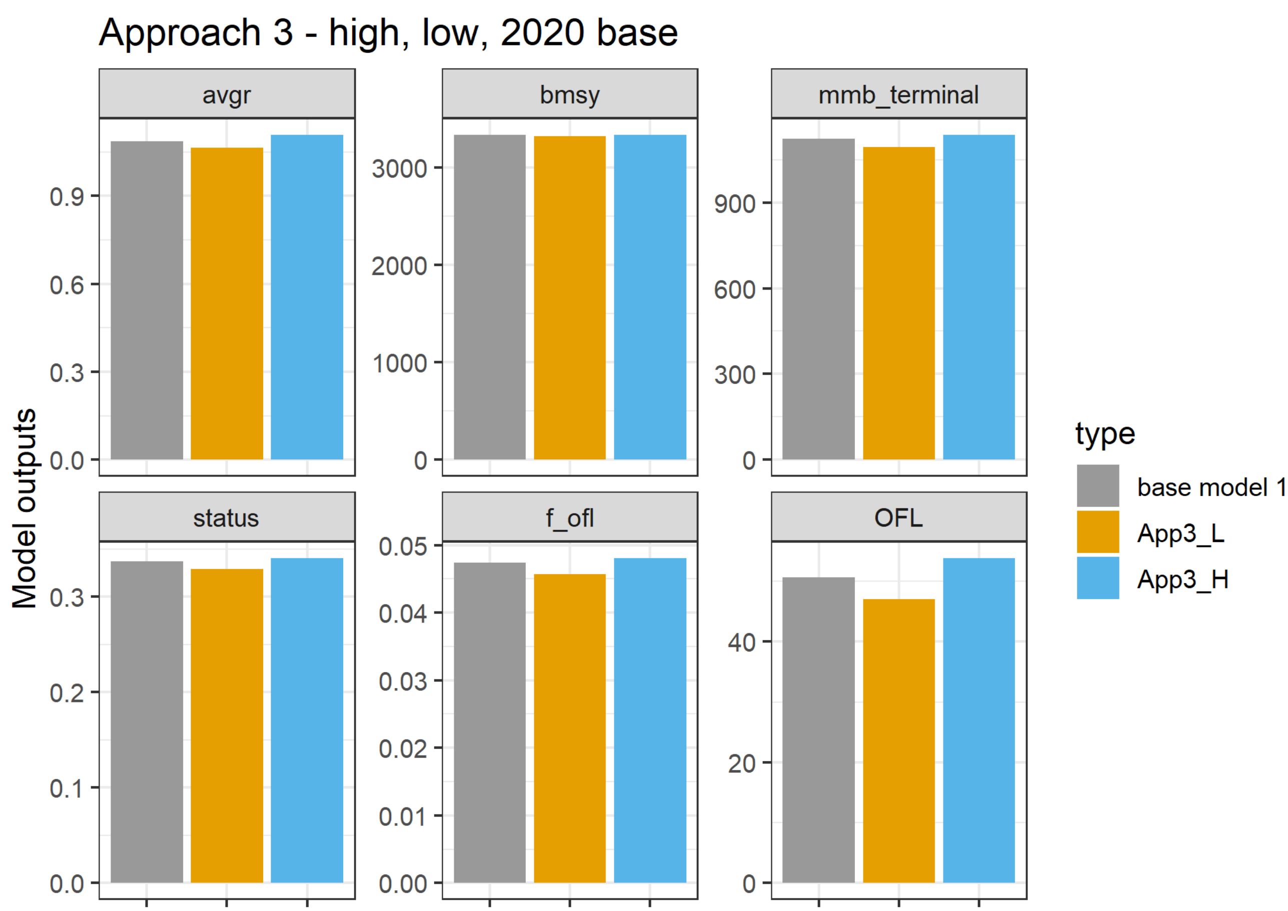

Figure 11: Model output and reference points from approach 3. Comparing the 2020 base model with a model that has a high 'fake' 2020 survey data point and one that has a low 'fake' survey data point.

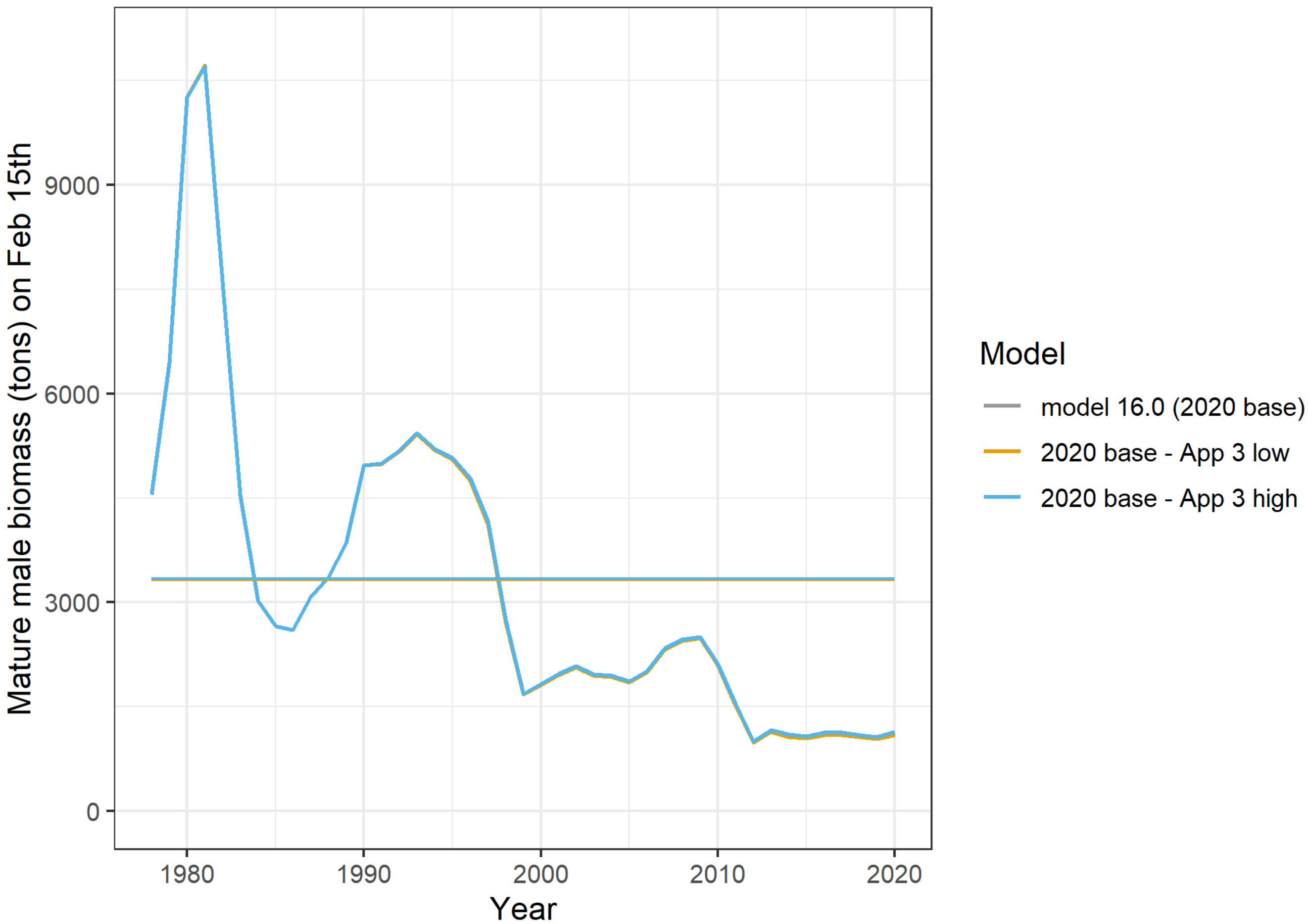

Figure 12: Mature male biomass estimates from approach 3. Comparing the 2020 base model with a model that has a high 'fake' 2020 survey data point and one that has a low 'fake' survey data point.

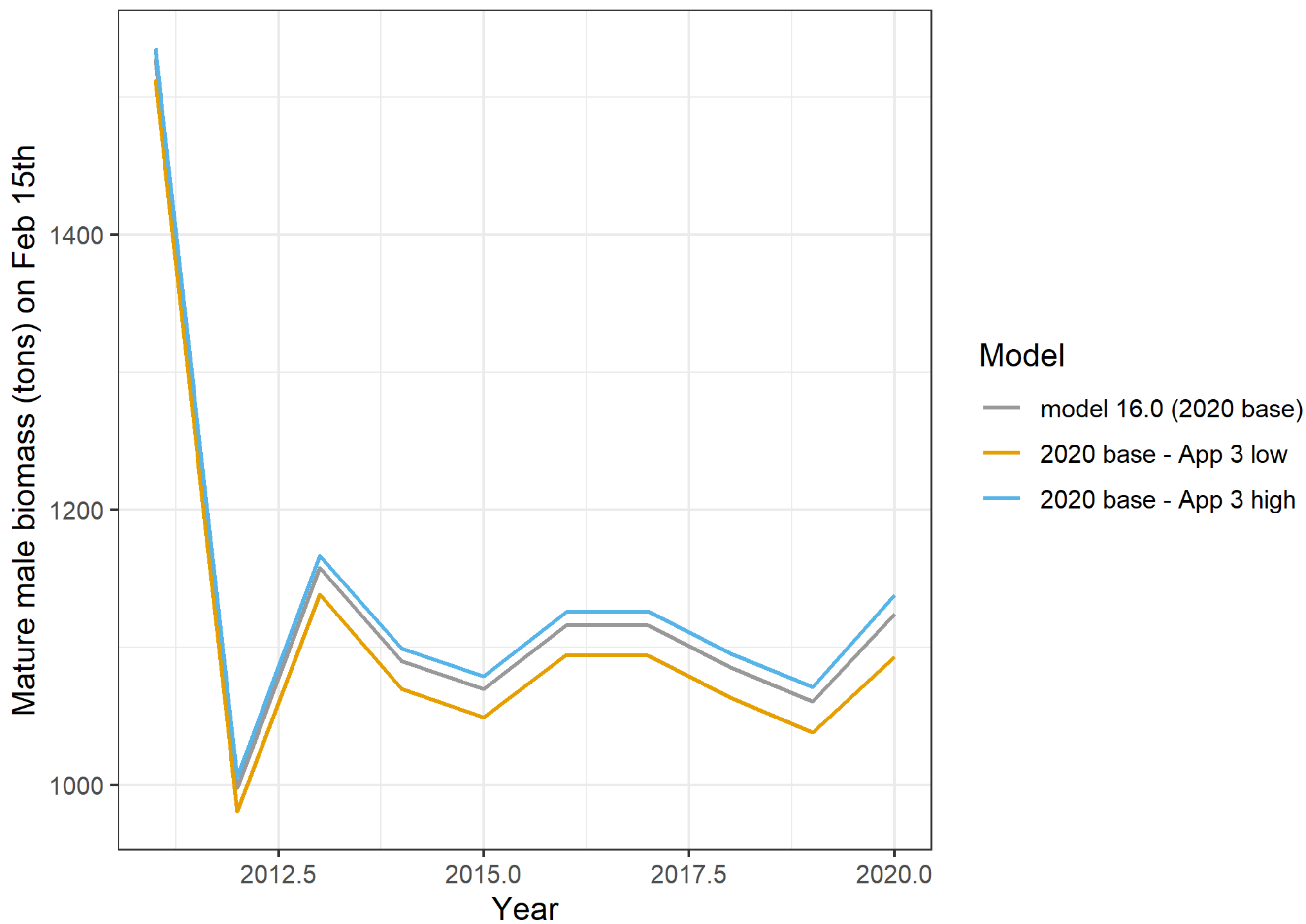

Figure 13: Mature male biomass estimates from approach 3. Comparing the 2020 base model with a model that has a high 'fake' 2020 survey data point and one that has a low 'fake' survey data point, only showing the last 10 years for detail on model differentiation.

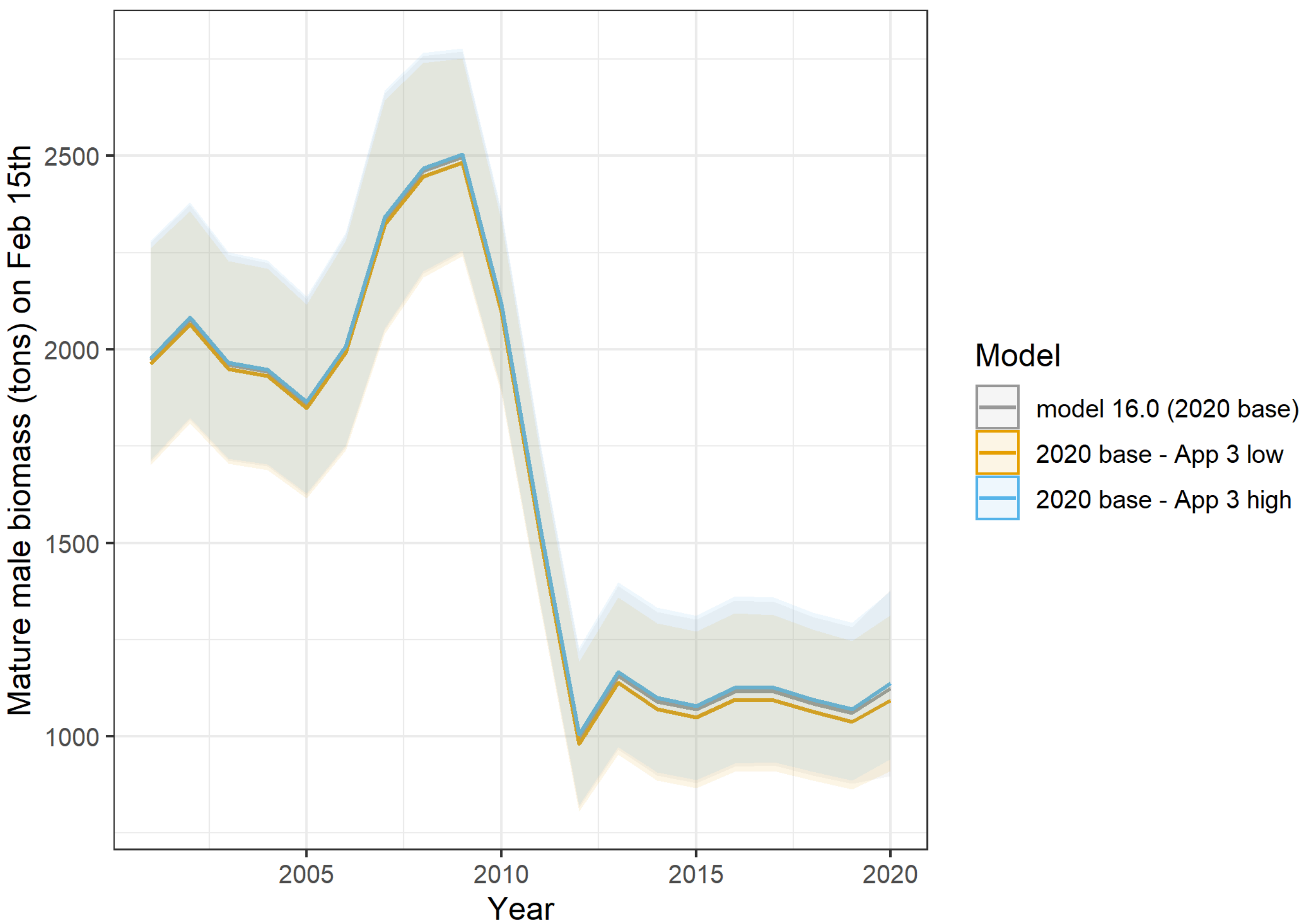

Figure 14: Mature male biomass estimates with associated variability from approach 3. Comparing the 2020 base model with a model that has a high 'fake' 2020 survey data point and one that has a low 'fake' survey data point, only showing the last 20 years for detail on model differentiation.

Tables

Table 1: Comparisons of the percent difference in parameter estimates for the retrospective models with and without the terminal year of survey data.

Year	AvgR	Bmsy	Terminal MMB	Status	Fofl	OFL
2010	-3.921	-0.606	-0.582	0.024	0.000	-1.692
2011	-1.980	-0.117	-5.674	-5.564	0.000	-3.183
2012	1.410	0.835	0.863	0.027	0.000	3.898
2013	9.199	3.471	30.491	26.113	30.537	72.124
2014	-0.399	-0.208	-5.101	-4.903	-5.563	-7.861
2015	-2.176	0.037	-1.912	-1.948	-2.345	-3.588
2016	-2.469	-0.256	-3.270	-3.021	-3.816	-6.579
2017	0.602	0.125	-0.364	-0.488	-0.713	-0.419
2018	-1.882	-0.630	-4.642	-4.038	-6.091	-10.343
2019	0.501	-1.927	-4.270	-2.389	-3.722	-2.330
RMS	3.479	1.318	10.214	8.787	10.173	23.368

Table 2: Average CV over all years (2010-2019) for normal retrospective runs and those missing the terminal year of survey data.

Type	CV-Bmsy	CV-OFL	CV-status	CV-temrinal-SSB
retro	4.32	20.19	11.12	11.77
missing-survey	4.36	21.42	11.71	12.51

Table 3: Comparisons of the percent difference in parameter estimates for the low and high models in approach 3 compared to the 2020 base model (16.0).

Variable	Diff-Ltobase	Diff-Htobase
avgR	-2.176	2.020
Bmsy	-0.291	0.156
Terminal-MMB	-2.746	1.226
Status	-2.463	1.068
F-ofl	-3.586	1.477
OFL	-7.261	6.303

Appendix D. Ecosystem and Socioeconomic Profile of the Saint Matthew Blue King Crab Stock

Erin Fedewa, Brian Garber-Yonts and Kalei Shotwell

September 2020

With Contributions from:

Curry Cunningham, Kelly Kearny, Jens Nielsen, Katie Palof, Darren Pilcher, Jon Richar, Dale Robinson and Jordan Watson

Executive Summary

National initiative and NPFMC recommendations suggest a high priority for conducting an ecosystem and socioeconomic profile (ESP) for Saint Matthew blue king crab (SMBKC) due to the stock's current overfished status and poor recruitment in recent years. Scores for stock assessment prioritization, habitat prioritization, climate vulnerability assessment, and data classification analysis were moderate to high. Furthermore, in 2018 when the stock was declared overfished, the Crab Plan Team requested an evaluation of ecosystem factors to inform the stock rebuilding plan.

We follow the standardized template for conducting an ESP and present results of applying the ESP process through a metric and subsequent indicator assessment. We use information from a variety of data streams available for the SMBKC stock. Analysis of the ecosystem and socioeconomic processes for SMBKC by life history stage along with information from the literature identified a suite of indicators for testing and continued monitoring within the ESP. Results of the metric and indicator assessment are summarized below as ecosystem and socioeconomic considerations that can be used for evaluating concerns in the main stock assessment.

Please refer to the last full ESP document for further information regarding the ecosystem and socioeconomic linkages for this stock (Fedewa et al., 2019, available online within the SMBKC SAFE, Appendix E, pp. 99-120 at: https://meetings.npfmc.org/CommentReview/DownloadFile?p=6ffde3ce-67be-4139-b165-cbff9062da06.pdf&fileName=C4%206%20SMBKC%20SAFE%202019.pdf).

Summary of Changes in Assessment Inputs

Changes in the Metric or Indicator Data

The 2020 SMBKC ESP update includes a suite of new ecosystem indicators that were developed from remote sensing data and Bering10K ROMS model output hindcasts. The suite of socioeconomic indicators for SMBKC remain unchanged due to the continued closure of the fishery while the stock rebuilds.

Changes in the Indicator Analysis

We have included the addition of a Stage 2 Importance Test in the Indicator Analysis section of the 2020 SMBKC ESP update. Results from the analysis are outlined below.

Summary of Results

Important ecosystem and socioeconomic processes that may identify dominant pressures on the SMBKC stock were reviewed in the last full ESP document. We updated the suite of ecosystem indicators for SMBKC using these mechanistic linkages or hypothesized relationships. Specifically, the addition of spring bottom temperature, wind stress and chlorophyll *a* indicators likely represent environmental conditions and prey availability for BKC early life stages. Please reference the 2019 full SMBKC ESP document for complete descriptions of indicators that occurred in the last full ESP. Any changes in methodology for indicators developed in 2019 are outlined below, as well as full descriptions for new indicators.

Indicator Suite

<u>Ecosystem Indicators:</u>

1.) Physical Indicators
   - Cold Pool Index: Due to the cancelation of the 2020 EBS summer bottom trawl survey, the cold pool index was calculated from ROMS model output as the fraction of the EBS

survey area with bottom waters less than 2°C on July 1 of each year (Kearney et al., 2020).

- Summer Bottom Temperature: Due to the cancelation of the 2020 EBS summer bottom trawl survey, June-July bottom temperatures were averaged within the SMBKC management area from ROMS model output (Kearney et al., 2020).
- Spring Bottom Temperature: Average of Feb-March bottom temperatures within the SMBKC management boundary from ROMS model output (Kearney et al., 2020).
- Corrosivity Index: Percent of the SMBKC management area containing an average bottom aragonite saturation state of < 1 from Feb-April (D. Pilcher, *pers. commun.*, 2020)
- Chlorophyll *a* Biomass: April-June average chlorophyll-a biomass within the St. Matthew region of the Bering Sea; calculated with 8-day composite data from MODIS satellites (J. Nielsen, *pers. commun.*, 2020)
- Wind Stress: June ocean surface wind stress within the SMBKC management boundary. Product of NOAA blended winds and MetOp ASCAP sensors from multiple satellites (Zhang et al., 2006, NOAA/NESDIS, CoastWatch)

2.) Biological Indicators

- Pacific Cod Biomass: Pacific cod comprise the majority of total biomass in the Benthic Predator Biomass indicator developed for the 2019 full ESP document. As such, we refined a predation indicator to solely include pacific cod biomass within the SMBKC management area.
- Benthic Invert Biomass
- SMBKC Recruit Biomass (Palof, *pers. commun*, 2020)

<u>Socioeconomic Indicators:</u>

1.) Fishery Performance Indicators

- CPUE (mean no. of crabs per potlift): Fishing effort efficiency, as measured by estimated mean number of retained SMBKC per potlift.
- Total Potlifts: Fishing effort, as measured by estimated number of crab pots lifted by vessels during the SMBKC fishery.
- Vessels active in fishery: Annual count of crab vessels that delivered commercial landings of SMBKC to processors.
- SMBKC male bycatch biomass: Incidental bycatch biomass estimates of male BBRKC (tons) in trawl and fixed gear fisheries

2.) Economic Indicators

- TAC Utilization (%): Percentage of the annual SMBKC TAC (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing.
- SMBKC ex-vessel revenue share (% of total exvessel revenue): SMBKC ex-vessel revenue share as percentage of total calendar year ex-vessel revenue from all commercial landings in Alaska fisheries, mean value over all vessels active in SMBKC during the respective year.
- Ex-vessel price per pound: commercial value per unit (pound) of SMBKC landings (as adjusted by CFEC to account for post-season adjustments to ex-vessel settlements), measured as weighted average value over all ex-vessel sales reported.

3.) Community Indicators

- Processors active in fishery: Total number of crab processors that purchased landings of SMBKC from delivering vessels during the calendar year. This provides an indicator of the level of participation of buyers in the market for SMBKC landings.
- Local Quotient of SMBKC landed catch in Saint Paul: Ex-vessel value share of SMBKC landings to communities on St. Paul Island, as percentage of total value of commercial landings to St. Paul processors from all commercial Alaska fisheries, as aggregate

percentage over all landings during the respective year. St Paul represents the principal port of landing for the SMBKC fishery during the post-rationalization period, representing from 78% to 100% of all purchased landings in the fishery. The local quotient (LQ) represents the share of community landings attributed to SMBKC in relation to revenue from all other species landed in the community during years when the fishery was opened.

Indicator Analysis

We provide an update to the list and time-series of ecosystem and socioeconomic indicators (Tables 1-2, Figures 1-2) and then report the results of the first and second stage statistical tests for the indicator analysis with the inclusion of current-year data. The third stage has not yet been completed, and will require more indicator development and review of the ESP modeling applications.

Stage 1: Traffic Light Test

The first stage of the indicator analysis is a simple assessment of the most recent year relative value and a traffic-light evaluation of the most current year where available (Tables 1-2). Details of the analysis can be found in the 2019 full ESP document.

Current year trends suggest relatively average environmental conditions for the SMBKC stock in 2020, although SMBKC recruit biomass is still well below the long-term average (Figure 1). While summer bottom temperatures in the St. Matthew management area were 1-2°C below 2018-2019 temperatures, the region still experienced warmer than average conditions relative to the long-term mean. However, a larger fraction of bottom waters were < 2°C in 2020 compared to previous years. The addition of a corrosivity indicator suggests that SMBKC are exposed to significant interannual variability in the aragonite saturation state of bottom waters. All stations within the SMBKC management area contained under-saturated bottom waters ($\Omega arag < 1$) in spring 2020 which suggests potential consequences for shell formation following the spring molt, as well as reduced condition and survival of embryos and larval stages.

Chlorophyll *a* biomass was above the long-term average in 2020, suggesting a more intense spring bloom and good first-feeding conditions for BKC larvae. Likewise, June wind speeds around St. Matthew Island were near-average in 2020 and on a downward trend since 2015, which may promote increased larval encounter rates with diatom prey. Current-year data for benthic invertebrate and Pacific cod biomass indicators were not available due to the cancellation of the EBS bottom trawl survey. Benthic invertebrate biomass has remained high since the late 1980's (possibly coinciding with a 1989 regime shift in the North Pacific), while Pacific cod biomass has been on a downward trend after reaching an all-time high in 2016.

With the exception of SMBKC male bycatch, all socioeconomic indicators in Table 2 are derived from SMBKC fishery data reported from the most recent open season (2015/16), and thus are not updated in this report. Bycatch of SMBKC in the groundfish fisheries during 2019 was near the lower bound of the historical range, and was slightly reduced from 2018.

Stage 2: Importance Test

Bayesian adaptive sampling (BAS) was used for the second stage statistical test to quantify the association between hypothesized predictors and SMBKC mature male biomass (MMB), and to assess the strength of support for each hypothesis. BAS explores model space, or the full range of candidate combinations of predictor variables, to calculate marginal inclusion probabilities for each predictor, model weights for each combination of predictors, and generate Bayesian model averaged predictions for outcomes (Clyde et al., 2011). In this second test, the full set of indicators is first winnowed to the predictors that could directly relate to MMB, and have consistent temporal data coverage. We then provide the mean relationship between each predictor variable and log MMB over time (Figure 3a), with error bars describing the uncertainty (1 standard deviation) in each estimated effect and the marginal inclusion probabilities for each predictor variable (Figure 3b). A higher probability indicates that the variable is a better candidate predictor of SMBKC MMB. The highest ranked predictor variables (≥ 0.25 inclusion probability) were: SMBKC recruit biomass, summer bottom temperatures, and benthic invertebrate biomass. Unfortunately, due to the nature of the BAS model only being able to fit years with complete observations for each covariate, the final subset of covariates was quite small and creates a significant data gap. Despite this shortcoming, predictive performance of the BAS model appears to generally capture SMBKC MMB trends across the time series (Figure 3d).

Ecosystem Considerations

- Despite repeated fishery closures, SMBKC mature male biomass and recruitment estimates remain below-average following a 1989 regime shift in the Bering Sea, suggesting that environmental factors may be impeding recruitment success and stock recovery.
- Highly specific thermal optimums and habitat requirements of SMBKC likely limit mobility in response to warmer than average bottom temperatures and shifting predator distributions in the Bering Sea.
- Large catches of Pacific cod in the St. Matthew Island management boundary in 2016 preceded declines in BKC mature male biomass, recruitment, and the overfished declaration in 2018.
- Trend modeling for SMBKC ecosystem indicators revealed near-average conditions for SMBKC in 2020, although persistent, corrosive bottom waters surrounding St. Matthew Island suggest potential impacts on shell formation, growth and survival of BKC.

Socioeconomic Considerations

- Vessel engagement in the SMBKC fishery as measured by annual counts of active vessels during years that the fishery has opened, has declined relative to the pre-rationalization period reflecting consolidation of the crab fleet following rationalization.
- In the most recent open seasons, the active fleet has been reduced to 3-4 vessels, with TAC utilization also declining to 26% during the 2015/16 season.
- Ex-vessel revenue share and the Local Quotient for Saint Paul both reached high values during 2010, concurrent with a peak in ex-vessel price; large declines in both metrics over the subsequent open seasons, despite relatively high ex-vessel prices during the next four open SMBKC seasons indicate that both vessels and processors active during those years have shifted into other fisheries.

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 aide 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. Examining larval drift patterns and spatial distributions of mature 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 larval retention indicator. Developing an EFH habitat indicator for SMBKC 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.

Responses to SSC and Plan Team Comments on ESPs in General

"Regarding ESPs in general, the SSC recommends development of a method to aggregate indices into a score that could be estimated over time and compared to stock history. One potential pathway forward may be to normalize and use an unweighted sum of all the indicators where all time series overlap, or just assign +1 or -1 to each indicator so that a neutral environment would be zero." (SSC, February 2020, pg. 7)

A presentation on a scoring option for the indicator suite was provided in the ESP Model Workshop in March 2020. The score used a simple +1, 0, and -1 assignment to the indicator based on whether the current year was above, within, or below 1 standard deviation from the mean for the time series. Sablefish and GOA pollock were provided as case studies and scores were calculated historically for the past 15 years. The score timeline trajectory was also evaluated with respect to the general ecosystem and socioeconomic considerations provided in the ESP documents. We plan to provide this score in next year's ESPs for SMBKC and hope for feedback on the method.

Responses to SSC and Plan Team Comments Specific to this ESP

"*The SSC is very pleased to see the Ecosystem and Socioeconomic Profile for SMBKC. The conceptual model was appreciated especially by those that are less familiar with crab life history characteristics. The introduction of some new ecosystem indicators was a good start. It was noted that the stock showed a high vulnerability to ocean acidification (OA), so if there is a way to index OA in the ESP that might be a good addition."* (SSC, Oct, 2019, pg. 12)

In response to this recommendation, we updated the 2020 SMBKC ecosystem indicator suite to include a Corrosivity Index developed from Bering10K ROMS output. This index, representing the percent of SMBKC management area containing low pH bottom waters undersaturated in aragonite, will provide the means to highlight vulnerabilities across BKC life stages to acidified conditions.

"The SMBKC ESP provides a tool to track, for the first time, the socioeconomic context of a fishery that has not successfully provided for the continuous, sustained participation of fishing communities over time. The SSC recommends that the ESP be augmented to track indices of community engagement and dependency, by community or aggregations of communities, across the relevant vessel and processing sectors and, for the years following rationalization, quota share ownership by community by share type. Where data confidentiality constraints dictate, the analysts should consider the use of regional as well as local quotient indicators." (SSC, Oct, 2019, pg. 12)

This recommendation has not been accomplished in this update. AFSC is currently developing a dedicated annual report to accompany the Crab and Groundfish Economic SAFE reports, focused on providing comprehensive analysis and monitoring of community participation and engagement in groundfish and crab fisheries. The Annual Community Engagement and Participation Overview

(ACEPO) will provide detailed, community-level metrics of fishery participation, including income and employment, and ownership of vessel, plant, permit and quota share assets. Development of methods and indices for effectively capturing these and other dimensions of management effects on communities is currently concentrated on producing the ACEPO report. It is expected that this will provide the basis for identifying reduced-form indicators of community effects that will be suitable for incorporation in ESPs in the future.

Acknowledgements

We would like to thank all contributors and stock assessment authors for their timely response to requests and questions regarding data, report summaries, and manuscripts. We also thank all attendees and presenters at ESP Data workshops (May 2019 and March 2020) for their valuable insight on the development of the BBRKC ESP and future indicator development. Lastly, we thank the Crab Plan Team, North Pacific Fisheries Management Council, and AFSC for supporting the development of this report and future reports.

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Table 1. First stage ecosystem indicator analysis for St. Matthew blue king crab (SMBK), including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for SMBKC of the current year conditions relative to 1 standard deviation of the longterm mean (white = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
Cold Pool Index	Fraction of the EBS BT survey area with bottom water less than 2°C on 1 July of each year from Bering10K ROMS model output hindcasts	•
Summer Bottom Temperature	Average of June-July bottom temperatures (° C) within the SMBKC management boundary from the Bering 10K ROMS model output hindcasts	•
Corrosivity Index	Percent of the SMBKC management area containing an average bottom aragonite saturation state of < 1 from Feb-April	+
Spring Bottom Temperature	Average of Feb-March bottom temperatures (° C) within the SMBKC management boundary from the Bering 10K ROMS model output hindcasts	•
Wind Stress	June ocean surface wind stress within the SMBKC management boundary. Product of NOAA blended winds and MetOp ASCAP sensors from multiple satellites	•
Chlorophyll-a Biomass	April-June average chlorophyll-a biomass within the St. Matthew region; calculated with 8-day composite data from MODIS satellites	•
Pacific cod biomass	Biomass (1,000t) of Pacific cod within the SMBKC management boundary on the EBS bottom trawl survey	•
Benthic invertebrate biomass	Combined biomass (1,000t) of benthic invertebrates within the SMBKC management boundary on the EBS bottom trawl survey	+
SMBKC Pre-recruit Biomass	Model estimates for SMBKC recruitment. Includes male crab (90-104 mm CL) that will likely enter the fishery the following year.	•

Table 2. First stage socioeconomic indicator analysis for St. Matthew blue king crab (SMBK), including indicator title and short description. The most recent year relative value (greater than (+), less than (-) or within 1 standard deviation (•) of long-term mean) of the time series is provided. Fill color is based on a traffic light evaluation for SMBKC of the current year conditions relative to 1 standard deviation of the longterm mean (white = average, blue = good, red = poor, no fill = no current year data).

Title	Description	Recent
Vessels active in fishery	Annual count of crab vessels that delivered commercial landings of SMBKC to processors[1]	●
TAC Utilization	Percentage of the annual SMBKC TAC (GHL prior to 2005) that was harvested by active vessels, including deadloss discarded at landing.	●
Total Potlifts	Fishing effort, as measured by estimated number of crab pots lifted by vessels during the SMBKC fishery	+
CPUE	Fishing effort efficiency, as measured by estimated mean number of retained SMBKC per potlift	●
Ex-vessel price per pound	Commercial value per unit (pound) of SMBKC landings (as adjusted by CFEC to account for post-season adjustments to ex-vessel settlements), measured as weighted average value over all ex-vessel sales reported.	●
SMBKC ex-vessel revenue share	SMBKC ex-vessel revenue share as percentage of total calendar year ex-vessel revenue from all commercial landings in Alaska fisheries, mean value over all vessels active in SMBKC during the respective year.	●
Processors active in fishery	Total number of crab processors that purchased landings of SMBKC from delivering vessels during the calendar year.	-
Local Quotient of SMBKC landed catch in St. Paul	Ex-vessel value share of SMBKC landings to communities on St. Paul Island, as percentage of total value of commercial landings to St. Paul processors from all commercial Alaska fisheries, aggregate percentage over all landings during the respective year.	●
SMBKC Male Bycatch in Groundfish Fishery	Incidental bycatch biomass estimates of male SMBKC (tons) in trawl and fixed gear fisheries	●

[1]Includes crab catcher/processors that harvested and processed SMBKC catch on-board.

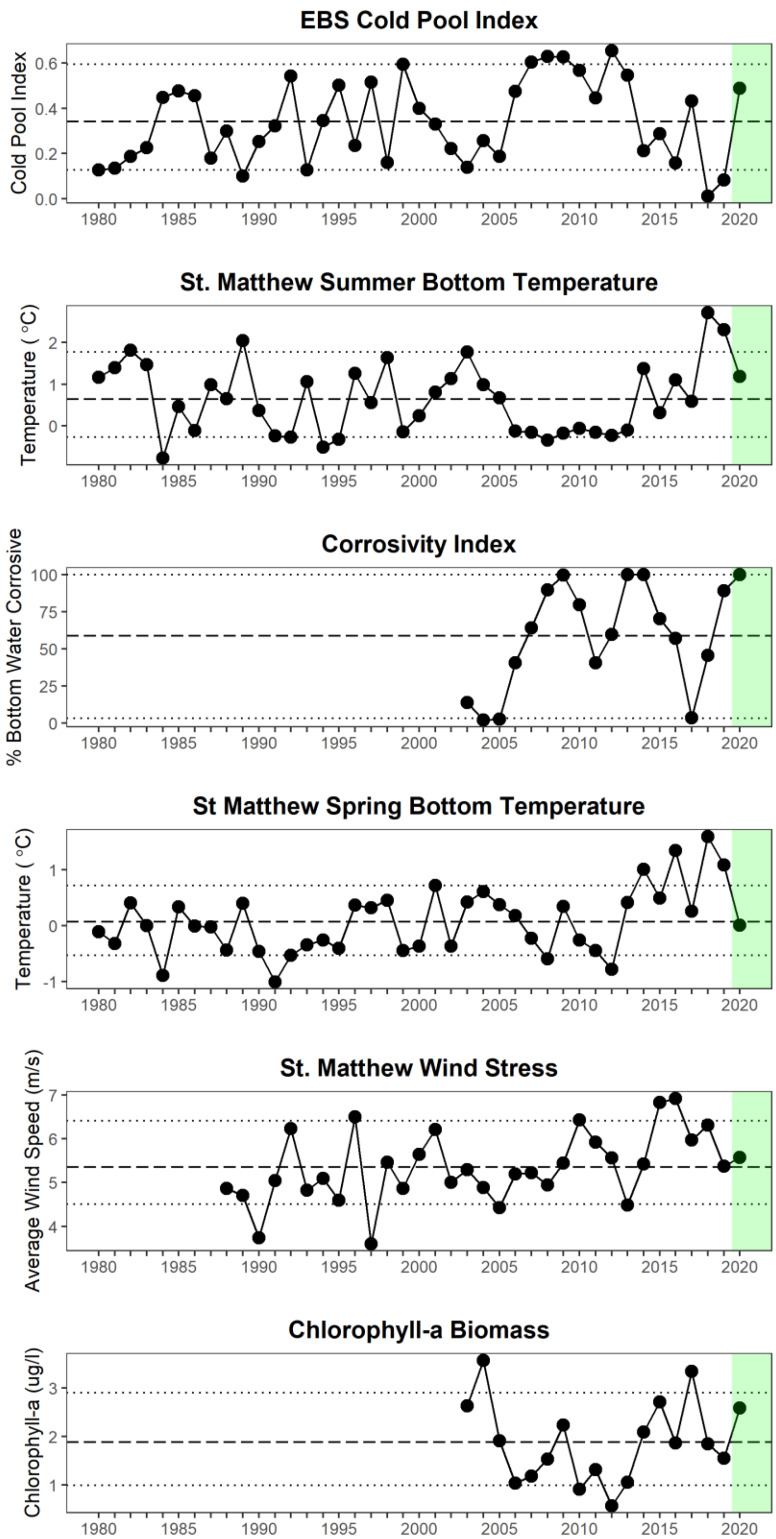

Figure 1. Selected ecosystem indicators for SMBKC with time series ranging from 1980 – 2020. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

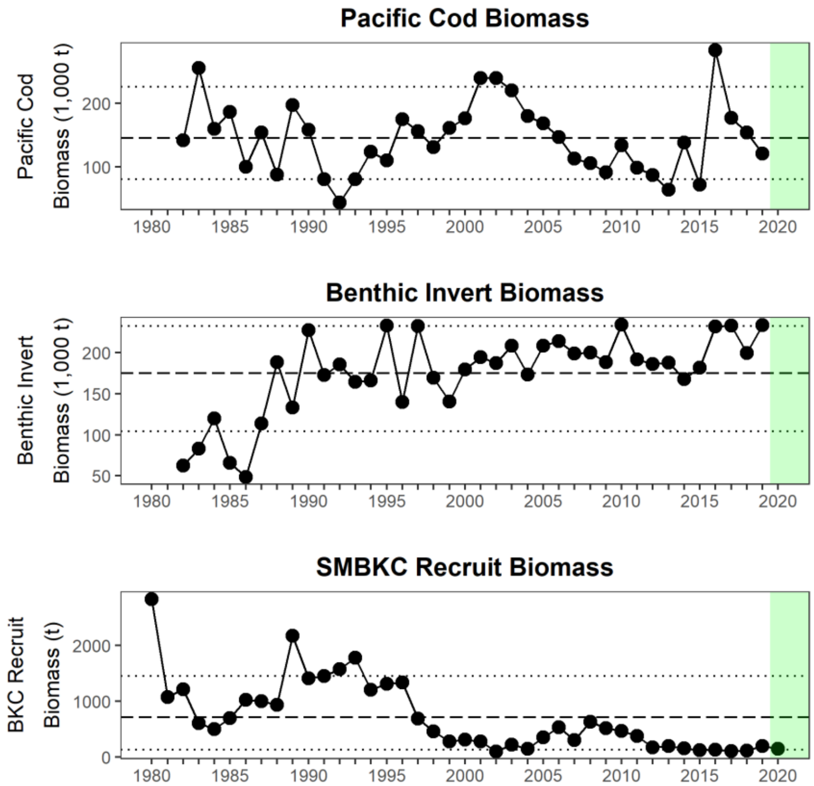

Figure 1. (cont.) Selected ecosystem indicators for SMBKC with time series ranging from 1980 – 2020. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

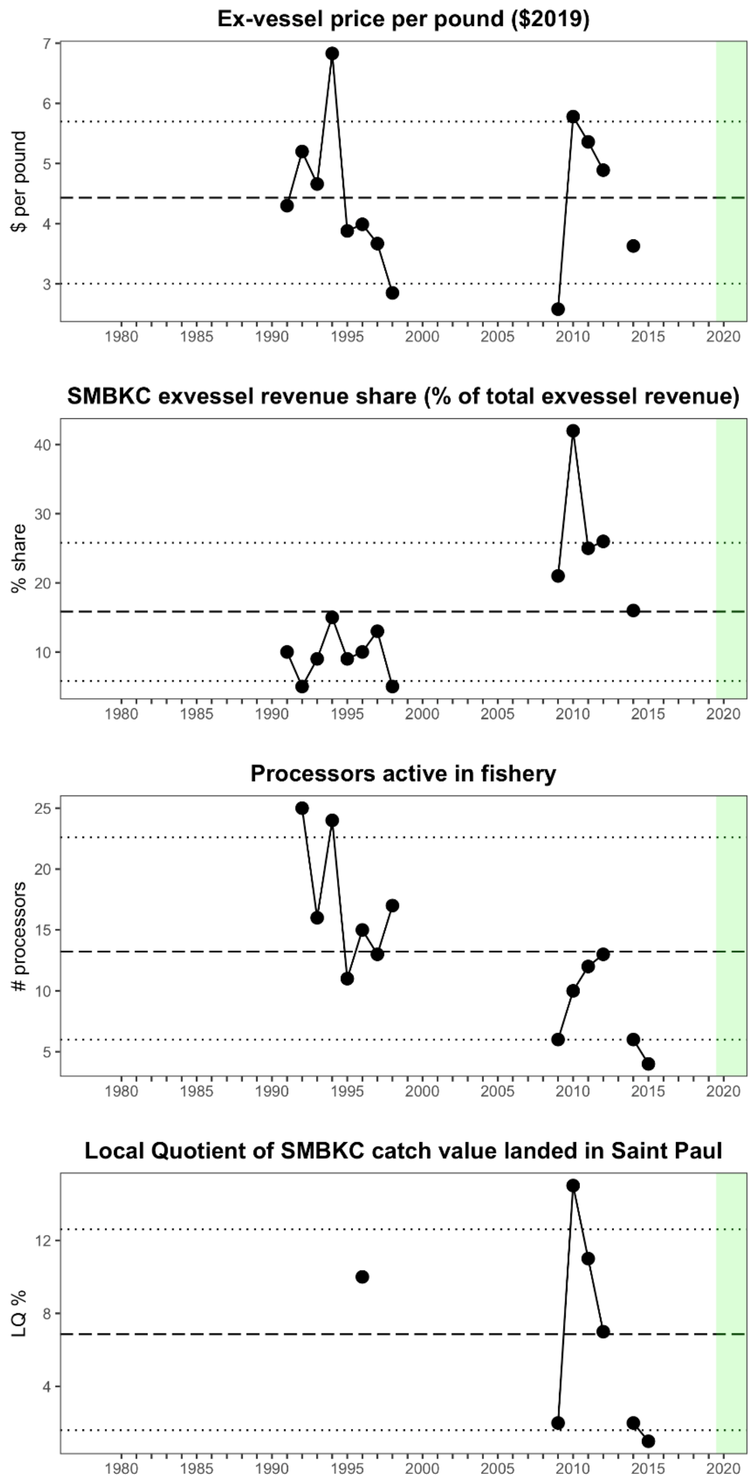

Figure 2. Selected socioeconomic indicators for SMBKC with time series ranging from 1980 – 2019. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

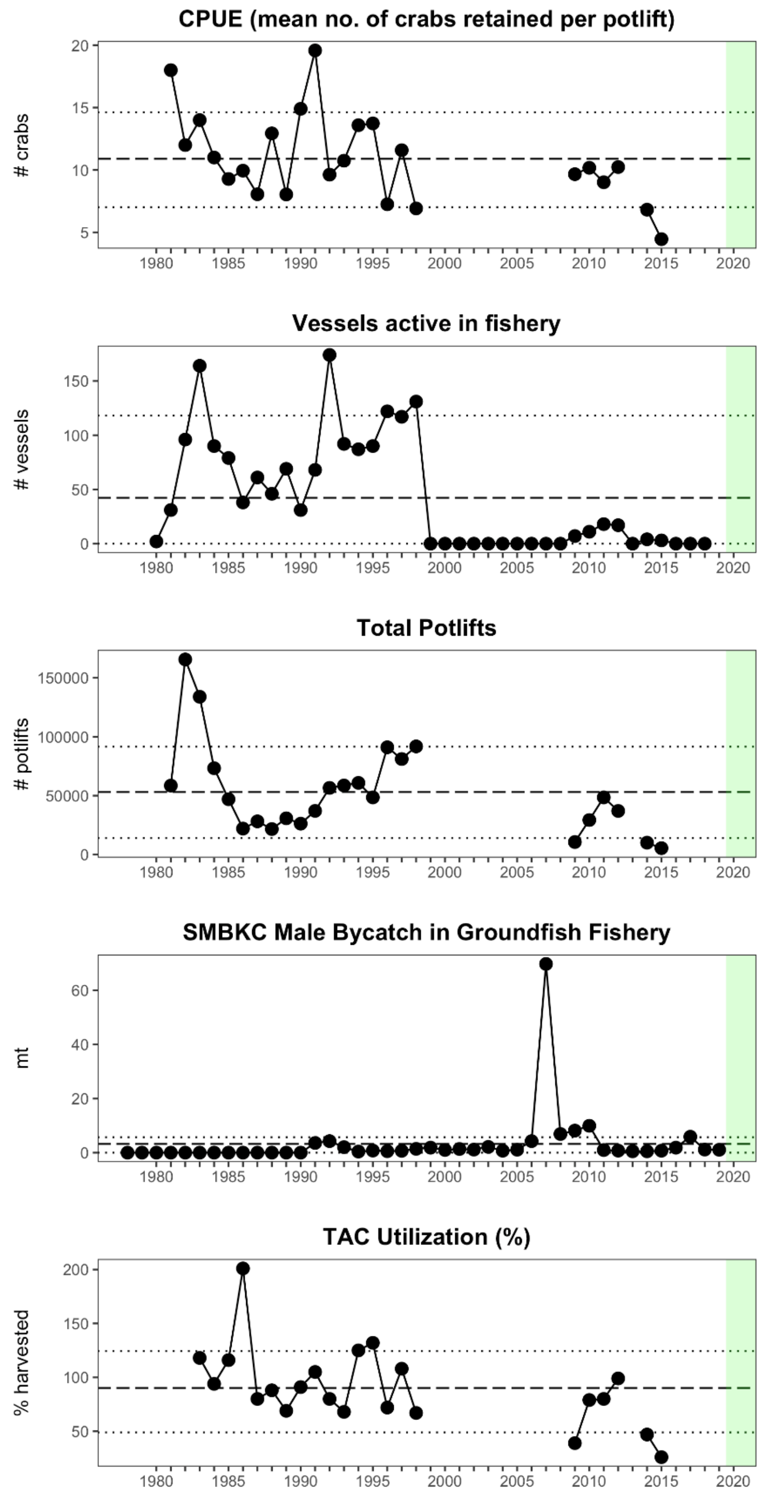

Figure 2. (cont.) Selected socioeconomic indicators for SMBKC with time series ranging from 1980 – 2019. Upper and lower dotted horizontal lines are 90th and 10th percentiles of time series. Dashed horizontal line is mean of time series. Light green shaded area represents most recent year data for traffic light analysis.

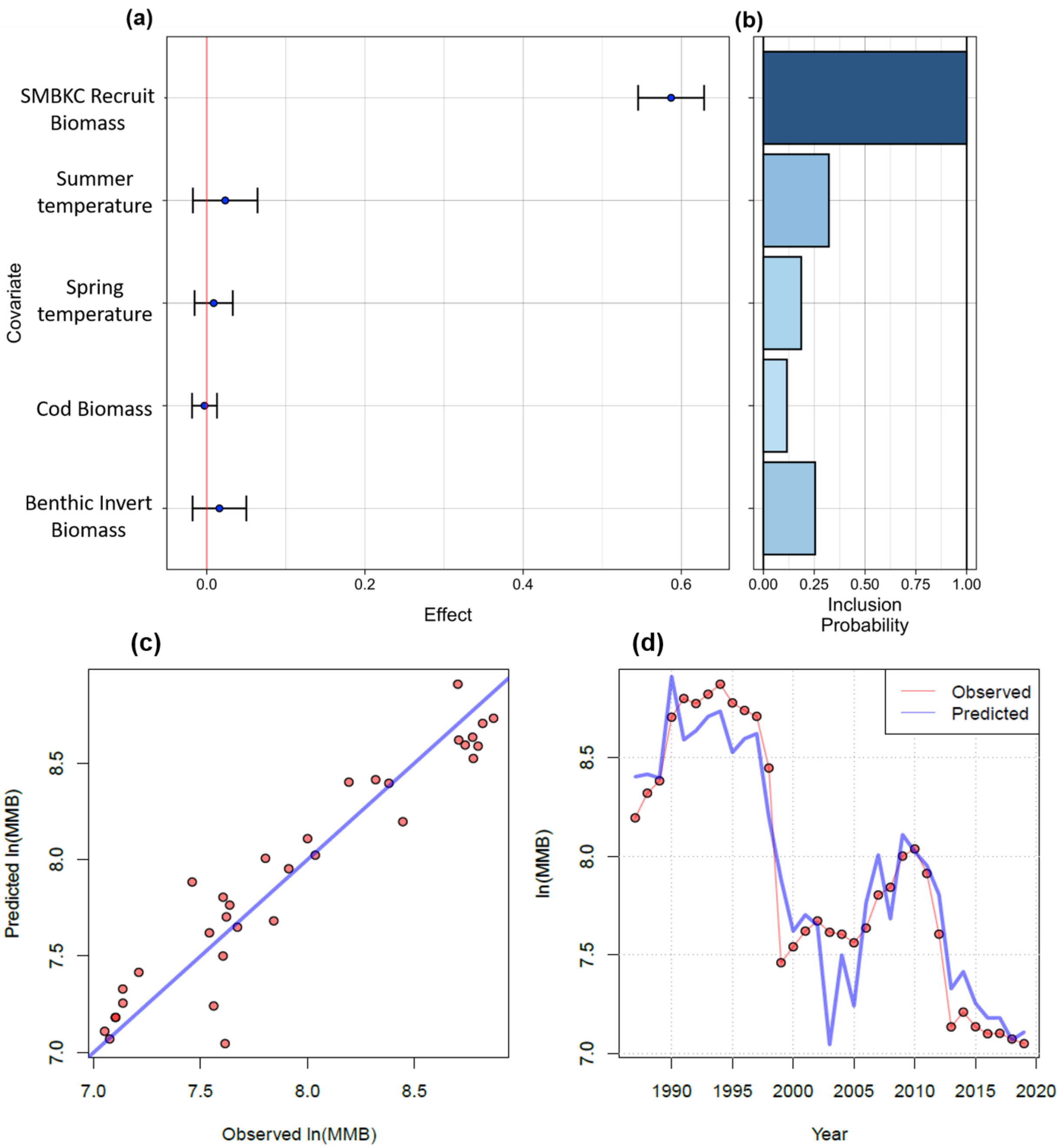

Figure 3. Bayesian adaptive sampling output showing the mean relationship and uncertainty (± 1 SD) with log-transformed St. Matthew blue king crab mature male biomass: a) the estimated effect and b) marginal inclusion probabilities for each predictor variable of the subsetted covariate ecosystem indicator dataset. Output also includes model c) predicted fit (1:1 line) and d) average fit across the MMB time series.