Saint Matthew Island Blue King Crab Stock Assesssment May 2020 draft

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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). The ADFG pot survey did not occur in 2019, but in 2018 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 two 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.

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

5. **Management performance**: In this assessment, estimated total male catch is the sum of fishery-reported retained catch, estimated male discard mortality in the directed fishery, and estimated male bycatch mortality in the groundfish fisheries. Based on the reference model for SMBKC, the estimate for mature male biomass was below the minimum stock-size threshold (MSST) in 2018/19 and is in an "overfished" condition, despite fishery closures in the last three years (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 51% 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
2015/16	1.84	2.11	0.19	0.05	0.053	0.28	0.22
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		1.08	0.00	0.00		0.04	0.03
2020/21							

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
2015/16	4.1	4.65	0.419	0.110	0.117	0.62	0.49
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		2.25	0.000	0.000		0.087	0.07
2020/21							

6. **Basis for the OFL**: Estimated mature-male biomass (MMB) on 15 February is used as the measure of biomass for this Tier 4 stock, with males measuring $\geq$ 105 mm CL considered mature. The B_{MSY} proxy is obtained by averaging estimated MMB over a specific reference period, and current CPT/SSC guidance recommends using the full assessment time frame as the default reference period. Both the full time frame and the current regime are presented here for consideration for 2019/20.

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

Year	Tier	B_{MSY}	Biomass (MMB_{mating})	B/B_{MSY}	F_{OFL}	γ	Basis for B_{MSY}	Natural mortality
2014/15	4b	3.28	2.71	0.82	0.14	1	1978-2014	0.18
2015/16	4b	3.71	2.45	0.66	0.11	1	1978-2015	0.18
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	4c	3.39	1.08	0.3	0.04	1	1978-2018	0.18
2020/21						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 and survey numbers. This assessment plans to include one new survey data point - the 2020 NMFS trawl-survey estimate of abudance. The triennial ADF&G pot surveys were last conducted in 2018, and are back on a triennial cycle, with the next survey in 2021. The NMFS trawl-surveys have associated size compositon data. The assessment will also use updated 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. In fall of 2020 there will be only one new data set to be included so this becomes the updated reference model (model 16.0 ref). One alternative model is presented to explore the use of VAST on estimates of the time series of NOAA trawl survey data (**VAST**).

The other three model alternatives are presented to assess sensitivity to the model, attempting to deal with the disparity between the two survey time series. The **add CV pot** configuration estimates an additional CV on the pot survey data, which in turn allows the model to fit the trawl-survey estimates better. The **add CV both** configuration estimates an additional CV on both survey data sets as a sensitivity run to see if these results differ much from the **add CV pot** run. The last alternative model presented **q time block pot** attempts to address CPT and SSC concerns over ADF&G pot survey catchability by creating two time blocks for this survey. The time blocks (1995 - 2013, 2015-2018) were an initial attempt to deal with the idea of a random walk for survey catchability. Other sensitivities were explored, including estimating both the trawl survey and pot survey catchability, but are not reported here due to insignificant findings.

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*

   Underway but progress was limited in implementing this feature. We plan to conduct a retrospective analysis of at least the base model for the final assessment in September 2020.

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

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

1. *Extra CV for both surveys*

   Model 19.3 has an extra CV for both surveys, for comparison to Model 19.2 with only an additional CV on the pot survey.

2. *Random walk or exploration of catchability*

   Model 19.4 has an initial attempt at dealing with pot survey catchability by applying time blocks to q for the pot survey. More work is most likely needed on this but progress was limited due to unexpected world events.

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 data availability (ADF&G), current plan is to have progress update in Sept. 2020

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.

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

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

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 numbers. This assessment will use one new survey data point, which is the 2020 NMFS trawl-survey estimate of abudance, and its associated size compositon data. The assessment also uses updated 1993-2018 groundfish and fixed gear bycatch estimates based on AKRO data. The fishery was closed in 2018/19, and is also closed in 2019/20, so no directed fishery catch data were 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 (1992/93-2018/19; Table 6).

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

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

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 (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

Five models are presented with the reference model being the same configuration as approved last year (Palof et al. 2019), three sensitivities are considered, one that adds an additional CV on the ADF&G pot survey data, one that adds an additional CV on both surveys (for comparison), and one that has time blocks for the ADF&G survey catchability (q). In addition to these sensitivities, there is a model presented that includes VAST estimates for the NOAA trawl survey time series. We will also evaluate the impacts of adding new data to the reference model, once 2020 data is obtained. All models below do NOT include any new data from the 2019 accepted model and SAFE report. In summary, the following lists the models presented and the naming convention used:

1. **16.0 - 2019 Reference Model**: updated with Jan 2020 updates to GMACS
2. **19.1 - VAST NMFS trawl data**: model 16.0 with VAST data output for the NMFS trawl survey time series
3. **19.2 - add CV pot**: model 16.0 + an estimated additional CV on the ADF&G pot survey
4. **19.3 - add CV both**: model 16.0 + an estimated additional CV on the ADF&G pot survey and the NOAA trawl survey
5. **19.4 - q time block pot**: time block estimated q's for ADF&G pot survey. 2 time blocks: 1995 to 2013 and 2015 to 2018.

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 data from the September 2019 model runs, therefore sesults for scenarios are provided with comparisons to the 2019 model, which is shown in Figures 6 and 8 with recruitment and spawning biomass shown in Figures 9 and 10, respectively. The 2019 fits to survey CPUEs and spawning biomass show that the addition of new data results in a slight increase compared to the 2018 assessment. However, in the past few years the reference model 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 18. Currently the SDNR and MAR are not outputting correctly for the survey data in GMACS. This will be fixed before the Sept. 2020 meeting. 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 this year.
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 relatively good, 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, 14, 15, and 16. These parameter estimates are compared in Table 17. Negative log-likelihood values and management measures for each of the model configurations are compared in Tables 4 and 19.

There are differences in parameter estimates among models as reflected in the log-likelihood components and the management quantities. The parameter estimates in the "add CV pot" and "add CV both" scenarios differ the most, as expected, particularly the estimate of the ADF&G pot survey catchability (q) (see Table

17). Also, the residuals for recruitment in the first size group are large for these model runs, presumably because higher estimates of recruits in some years are required by the model to match the observed biomass trends.

Selectivity estimates show some variability between models (Figure 11 and 12). Estimated recruitment is variable over time for all models and in recent years is well below average (Figure 13). Models that include an extra CV for the pot survey (Models 19.2 and 19.3) estimate higher recent recruitment than the others, more closely following the trends in the NOAA trawl survey. Estimated mature male biomass on 15 February also fluctuates considerably (Figure 15). Also here the models that include an extra CV for the pot survey have much higher recent mature male biomass estimates. Model 19.1, which uses the VAST estimates of the NOAA trawl survey data, generally follows the same trends as the base model but has a greater magnitude of mmb since the 1990s, this is also reflected in larger overall recruitment. Estimated natural mortality in each year (M_t) is presented in Figure 17, 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 35). 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 model fits to total male ($\geq$ 90 mm CL) trawl survey biomass tend to miss the recent peak around 2010 and fits recent survey data points on the lower end of their error bars (Figures 18). These fits are most likely being pulled down by the recent decline in the ADF&G pot survey data points, since the **add CV pot** and the **add CV both** models captures the upward error bars for these data points when it is allowed to fit the ADF&G pot survey data very poorly. However, these two models tend to overfit the recent trawl survey data points (Figure 20).

The VAST model estimates tend to be higher than the traditional trawl surey estimates, but also miss the up tick around 2010; however, this model tends to fit the recent survey years more fairly (Figure 19 and 7). The reference model is biased low in recent years, while the additional CV models are biased high.

All of the models fit the pot survey CPUE poorly (Figure 21), with the **add CV pot** and **add CV both** models having the worst fit due to the addition of variability (Figure 22).

For the trawl survey the standardized residuals have similar patterns with the exception of recent years for the **add CV pot** and **add CV both** models (19.2, 19.3), generally poor fit to the last 15 years of data (Figure 23). The standardized residuals for the ADF&G pot survey have similar patterns but are much larger for the additional CV models than the others, for obvious reasons (Figure 25).

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 26, 27, and 28) for all scenarios. Representative residual plots of the composition data fits are generally poor (Figures 29, 30, 31, 32, and 33). 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 34).

e. Retrospective and historical analyses

This is only the third year GMACS has been used for this stock. As such, retrospective patterns and historical analyses of GMACS assessments are limited. Completion of a retrospective analysis, for at least the base model, is anticipated to be presented in Sept. 2020.

f. Uncertainty and sensitivity analyses.

Estimated standard deviations of parameters and selected management measures for the models are summarized in Tables 12, 13, 14, 15, and 16, (compiled in Table 17). Model estimates of mature male biomass and OFL in 2019 are presented in Section F.

g. Comparison of alternative model scenarios.

The estimates of mature male biomass (Figure 15) for the additional CV models differ from the other models due to a low value for pot survey catchability being estimated (which tends to scale the population estimate). Difference in the mature male biomass since 2010 in the these models (19.2 and 19.3) are due to the model overfitting the trajectory of the trawl survey and downweighting the declines in the pot survey (Figure 20. The **VAST** scenario generally has high mature male biomass estimates since the early 90s, which would be expected since the trawl survey biomass estimates generated from VAST are larger in the 90s and 2000s (Figure 19). The VAST model trawl survey biomass fit also captures the 90s survey data more closey than the reference model. The **q block pot** fits the mature male biomass very similarly to the reference model, which is expected since they both fit the survey data similarly. The addition of a time block for recent years of the pot survey does not appear to improve model fit to this survey or change the fit overall.

The VAST model (19.1) may be an option to consider for model spefications this fall, if the CPT finds the VAST data to be appropriate for model options. In general this model fits the trawl survey data at higher biomasses throughout time, specifically higher in the late 90s (Figure 7 and 19), however it tends to fit the survey data better than the reference model (Figure 24). Additionally, recruitment estimates for the VAST model trend similarly to the reference model, only at a higher magnitude (Figure 14). As stated above mature male biomass for the VAST model are also generally higher than the reference model, but tend to display a similar trend (Figure 16). The 2019 model MMB for the VAST model is still less than 50% of the B_{MSY} and therefore the stock would remain in overfished status.

In summary, these model scenarios, with the exception of the VAST model, were 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 resolute is found to deal with the trawl and pot survey data fit issues.

F. Calculation of the OFL and ABC

The overfishing level (OFL) is the fishery-related mortality biomass associated with fishing mortality F_{OFL}. The SMBKC stock is currently managed as Tier 4, 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 model geometric mean values over years for which there are data-based estimates of bycatch-mortality biomass.

The currently recommended Tier 4 convention is to use the full assessment period, currently 1978- 2018, 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 ABC is 80% of the OFL.

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

Component	Ref	VAST	addCVpot	addCVboth	qBlock
MMB_{2019}	1085.076	2074.537	3187.204	3500.926	1147.464
B_{MSY}	3391.188	4383.451	3588.097	3931.963	3392.544
MMB/B_{MSY}	0.301	0.426	0.806	0.813	0.330
F_{OFL}	0.040	0.065	0.141	0.142	0.046
OFL_{2019}	39.684	118.146	383.413	424.846	48.215
ABC_{2019}	31.747	94.517	306.730	339.877	38.572

G. Rebuilding Analysis

This stock was declared overfished in fall of 2018 and a rebuilding plan was under initial review by the NPFMC in December 2019. The rebuilding plan is scheduled for final review during the June 2020 NPFMC meeting. The most updated rebuilding plan can be found on the NPFMC website for the upcoming 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 51% of what it would have been in the absence of fishing (Figure 36). Supporting the hypothesis that fishing pressure has not substantially contributed to the decline of this stock compared to other contributors. 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	1.633
2017	0.052	6.032
2018	0.001	1.281

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 ($\geq$ 90 mm CL) biomass (10^6 lbs). Total number of captured male crab $\geq$ 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

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
$\log(\bar{F}^{\text{df}})$	-2.125	0.052
$\log(\bar{F}^{\text{tb}})$	-9.425	0.073
$\log(\bar{F}^{\text{fb}})$	-8.122	0.074
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}	0.042	0.005
OFL	43.736	9.254

Table 13: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the 'VAST' (19.1) model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.744	0.106
$\log(\bar{R})$	14.161	0.199
$\log(n^0_1)$	15.075	0.172
$\log(n^0_2)$	14.714	0.200
$\log(n^0_3)$	14.553	0.192
q_{pot}	2.542	0.144
$\log(\bar{F}^{\text{df}})$	-2.440	0.043
$\log(\bar{F}^{\text{tb}})$	-9.801	0.068
$\log(\bar{F}^{\text{fb}})$	-8.499	0.068
log Stage-1 directed pot selectivity 1978-2008	-0.799	0.175
log Stage-2 directed pot selectivity 1978-2008	-0.388	0.125
log Stage-1 directed pot selectivity 2009-2017	-0.279	0.153
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.252	0.065
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.579	0.126
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.065	0.000
OFL	118.146	0.175

Table 14: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the 'add CV pot' (19.2) model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.848	0.211
$\log(\bar{R})$	14.202	0.202
$\log(n^0_1)$	14.948	0.174
$\log(n^0_2)$	14.461	0.212
$\log(n^0_3)$	14.293	0.205
q_{pot}	2.253	0.466
$\log(\bar{F}^{\mathrm{df}})$	-2.320	0.055
$\log(\bar{F}^{\mathrm{tb}})$	-9.614	0.078
$\log(\bar{F}^{\mathrm{fb}})$	-8.314	0.079
log Stage-1 directed pot selectivity 1978-2008	-0.795	0.180
log Stage-2 directed pot selectivity 1978-2008	-0.438	0.130
log Stage-1 directed pot selectivity 2009-2017	-0.905	0.178
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.377	0.063
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-1.067	0.122
log Stage-2 ADF&G pot selectivity	-0.140	0.074
log add CV_{pot}	-0.361	0.145
F_{OFL}	0.141	0.018
OFL	383.413	99.801

Table 15: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the 'add CV both' (19.3) model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.984	0.249
$\log(\bar{R})$	14.244	0.209
$\log(n^0_1)$	15.009	0.177
$\log(n^0_2)$	14.548	0.216
$\log(n^0_3)$	14.369	0.211
q_{pot}	2.237	0.510
$\log(\bar{F}^{\mathrm{df}})$	-2.448	0.078
$\log(\bar{F}^{\mathrm{tb}})$	-9.611	0.101
$\log(\bar{F}^{\mathrm{fb}})$	-8.310	0.101
log Stage-1 directed pot selectivity 1978-2008	-0.663	0.183
log Stage-2 directed pot selectivity 1978-2008	-0.323	0.137
log Stage-1 directed pot selectivity 2009-2017	-0.994	0.183
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.343	0.064
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-1.122	0.125
log Stage-2 ADF&G pot selectivity	-0.157	0.076
log add CV_{trawl}	-0.956	0.217
log add CV_{pot}	-0.321	0.143
F_{OFL}	0.142	0.018
OFL	424.846	99.801

Table 16: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the 'q time block pot' (19.4) model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.552	0.141
$\log(\bar{R})$	13.913	0.200
$\log(n^0_1)$	14.951	0.174
$\log(n^0_2)$	14.496	0.211
$\log(n^0_3)$	14.318	0.206
q_{pot1}	3.784	0.244
q_{pot2}	4.000	1.000
$\log(\bar{F}^{\text{df}})$	-2.139	0.052
$\log(\bar{F}^{\text{tb}})$	-9.430	0.073
$\log(\bar{F}^{\text{fb}})$	-8.127	0.073
log Stage-1 directed pot selectivity 1978-2008	-0.805	0.179
log Stage-2 directed pot selectivity 1978-2008	-0.448	0.129
log Stage-1 directed pot selectivity 2009-2017	-0.514	0.163
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.336	0.065
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.505	0.147
log Stage-2 ADF&G pot selectivity	-0.000	0.000
log add CV_{trawl}	-1.268	0.269
log add CV_{pot}	-0.097	0.134
F_{OFL}	0.046	0.018
OFL	48.215	99.801

Table 17: Comparisons of parameter estimates for the model scenarios.

Parameter	Ref	VAST	addCVpot	addCVboth	qBlock
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.573	1.744	1.848	1.984	1.552
$\log(\bar{R})$	13.899	14.161	14.202	14.244	13.913
$\log(n^0_1)$	14.950	15.075	14.948	15.009	14.951
$\log(n^0_2)$	14.509	14.714	14.461	14.548	14.496
$\log(n^0_3)$	14.326	14.553	14.293	14.369	14.318
q_{pot}	3.838	2.542	2.253	2.236	-
q_{pot1}	-	-	-	-	3.784
q_{pot2}	-	-	-	-	4.000
$\log(\bar{F}^{\text{df}})$	-2.125	-2.440	-2.320	-2.448	-2.139
$\log(\bar{F}^{\text{fb}})$	-8.122	-8.499	-8.314	-8.310	-8.127
$\log(\bar{F}^{\text{tb}})$	-9.425	-9.801	-9.614	-9.611	-9.430
log Stage-1 directed pot selectivity 1978-2008	-0.819	-0.799	-0.795	-0.663	-0.805
log Stage-2 directed pot selectivity 1978-2008	-0.452	-0.388	-0.438	-0.323	-0.448
log Stage-1 directed pot selectivity 2009-2017	-0.483	-0.279	-0.905	-0.994	-0.514
log Stage-2 directed pot selectivity 2009-2017	-0.000	-0.000	-0.000	-0.000	-0.000
log Stage-1 NMFS trawl selectivity	-0.320	-0.252	-0.377	-0.343	-0.336
log Stage-2 NMFS trawl selectivity	-0.000	-0.000	-0.000	-0.000	-0.000
log Stage-1 ADF&G pot selectivity	-0.725	-0.579	-1.067	-1.122	-
log Stage-1 ADF&G pot1 selectivity	-	-	-	-	-0.505
log Stage-1 ADF&G pot2 selectivity	-	-	-	-	-1.268
log Stage-2 ADF&G pot selectivity	-0.000	-0.000	-0.140	-0.157	-
log Stage-2 ADF&G pot1 selectivity	-	-	-	-	-0.000
log Stage-2 ADF&G pot2 selectivity	-	-	-	-	-0.097
F_{OFL}	0.040	0.065	0.141	0.142	0.046
OFL	39.684	118.146	383.413	424.846	48.215

Table 18: Comparisons of data weights, SDNR and MAR (standard deviation of normalized residuals and median absolute residual) values for the model scenarios.

Component	Ref	VAST	addCVpot	addCVboth	qBlock
NMFS trawl survey weight	1.00	1.00	1.00	1.00	1.00
ADF&G pot survey weight	1.00	1.00	1.00	1.00	1.00
Directed pot LF weight	1.00	1.00	1.00	1.00	1.00
NMFS trawl survey LF weight	1.00	1.00	1.00	1.00	1.00
ADF&G pot survey LF weight	1.00	1.00	1.00	1.00	1.00
SDNR NMFS trawl survey	0.00	0.00	0.00	0.00	0.00
SDNR ADF&G pot survey	0.00	0.00	0.00	0.00	0.00
SDNR directed pot LF	0.70	0.80	0.64	0.63	0.00
SDNR NMFS trawl survey LF	1.30	1.38	1.04	0.92	0.69
SDNR ADF&G pot survey LF	0.95	1.07	0.67	0.63	1.30
MAR NMFS trawl survey	0.00	0.00	0.00	0.00	1.02
MAR ADF&G pot survey	0.00	0.00	0.00	0.00	0.00
MAR directed pot LF	0.52	0.57	0.36	0.46	0.00
MAR NMFS trawl survey LF	0.60	0.73	0.51	0.47	0.00
MAR ADF&G pot survey LF	0.68	0.83	0.58	0.57	0.56

Table 19: 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., **add CV** models).

Component	Ref	VAST	addCVpot	addCVboth	qBlock
Pot Retained Catch	-68.50	-67.82	-69.56	-69.72	-68.54
Pot Discarded Catch	4.89	9.40	3.07	2.45	4.29
Trawl bycatch Discarded Catch	-7.71	-7.71	-7.71	-7.71	-7.71
Fixed bycatch Discarded Catch	-7.67	-7.69	-7.70	-7.71	-7.67
NMFS Trawl Survey	8.84	9.18	-8.95	-7.08	8.01
ADF&G Pot Survey CPUE	84.62	107.07	6.06	7.01	83.31
Directed Pot LF	-103.99	-101.26	-105.39	-105.61	-104.22
NMFS Trawl LF	-252.91	-241.56	-276.25	-286.42	-254.74
ADF&G Pot LF	-91.02	-87.83	-97.33	-98.09	-89.45
Recruitment deviations	58.44	55.34	52.50	52.74	57.96
F penalty	9.66	9.66	9.66	9.66	9.66
M penalty	6.46	6.46	6.46	6.46	6.46
Prior	13.71	13.71	16.11	16.21	0.15
Total	-345.18	-303.05	-479.03	-487.82	-362.50
Total estimated parameters	144.00	144.00	145.00	146.00	147.00

Table 20: 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	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).

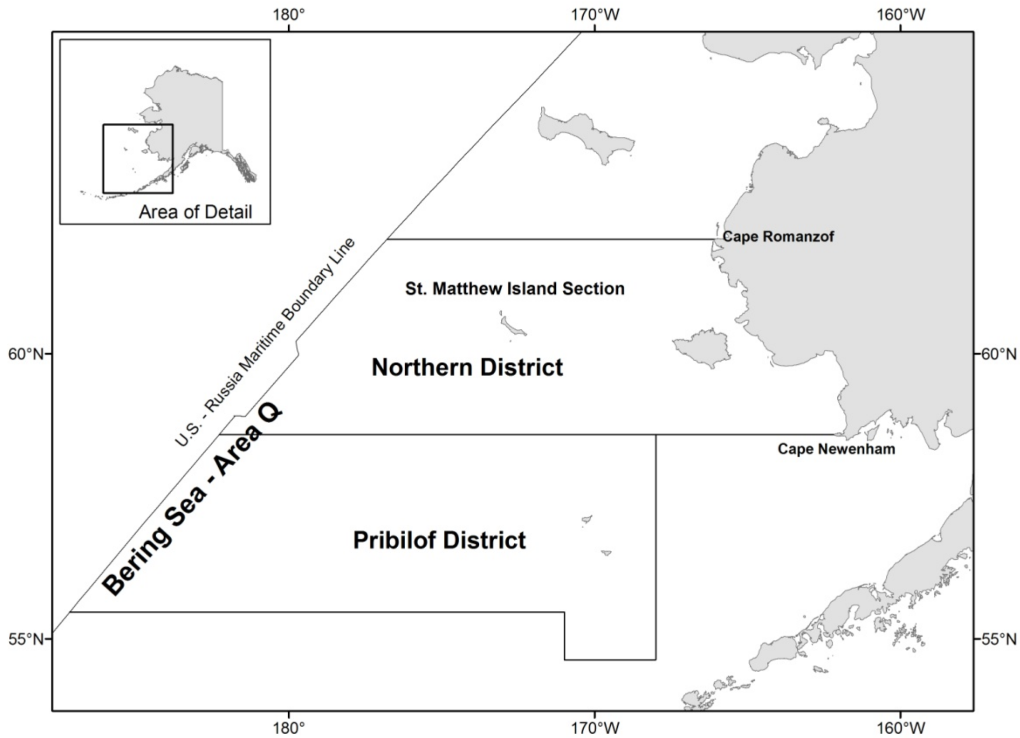

Figure 2: Blue king crab Registration Area Q (Bering Sea)

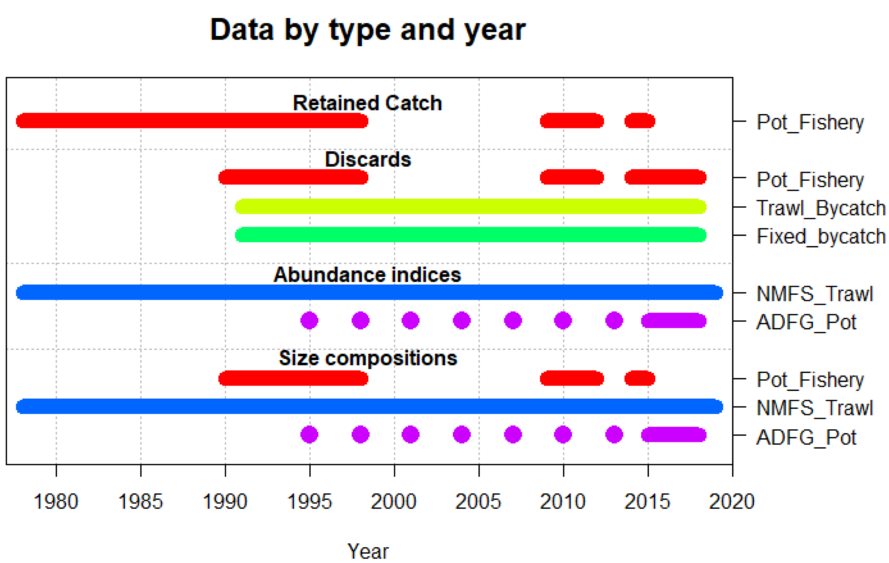

Figure 3: Data extent for the SMBKC assessment.

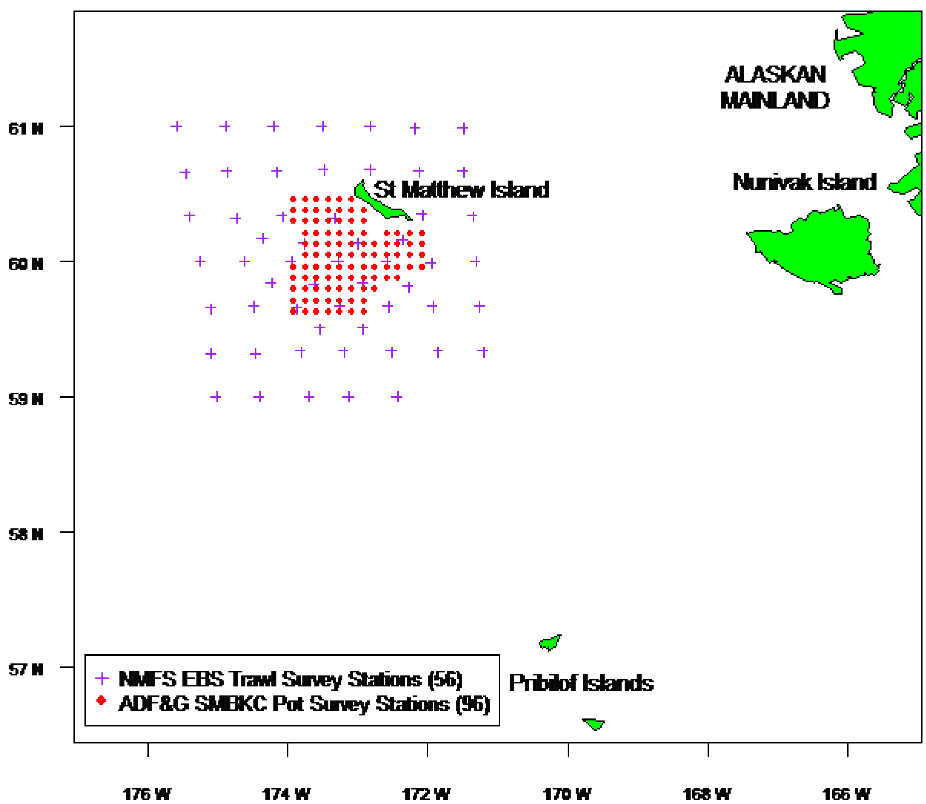

Figure 4: Trawl and pot-survey stations used in the SMBKC stock assessment.

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.

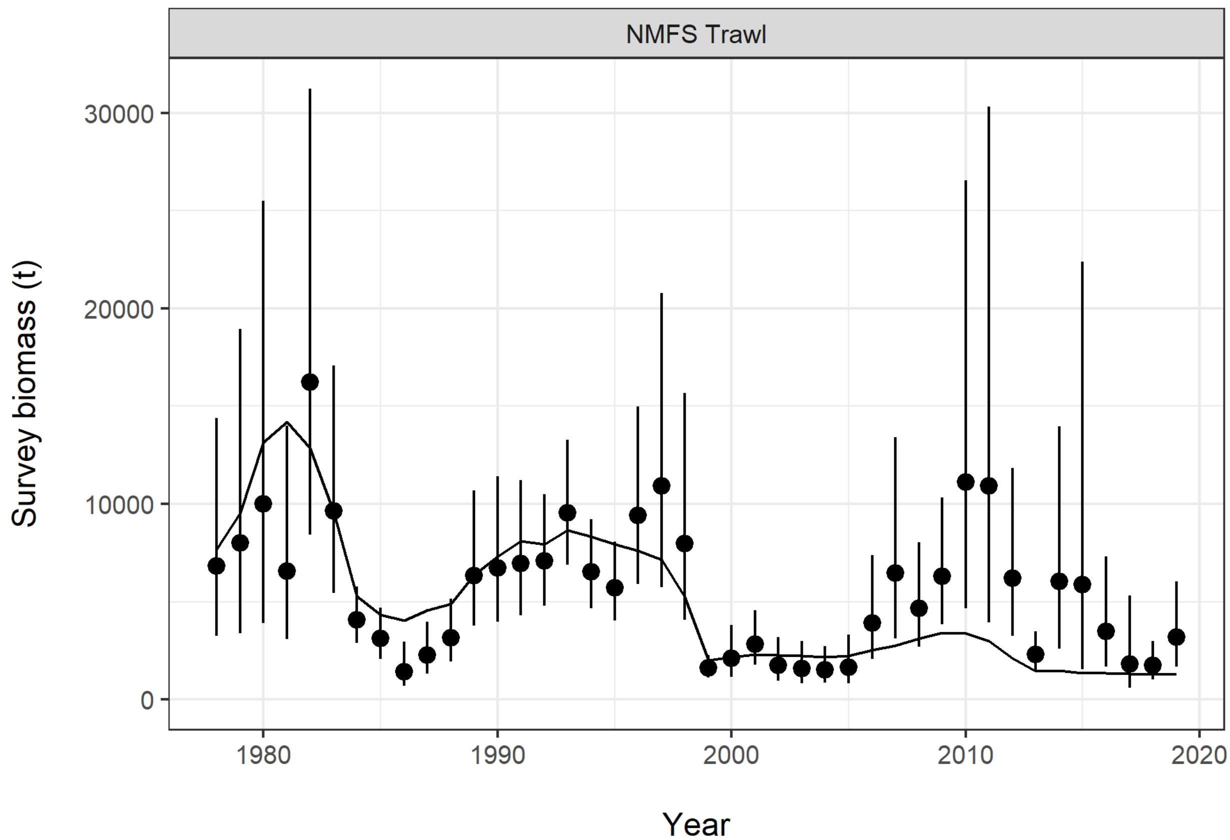

Figure 6: Fits to NMFS area-swept trawl estimates of total (> 90mm) male survey biomass for the reference model only (will show 16.0 ref with new data and 16.0 as last year's accepted model). Error bars are plus and minus 2 standard deviations.

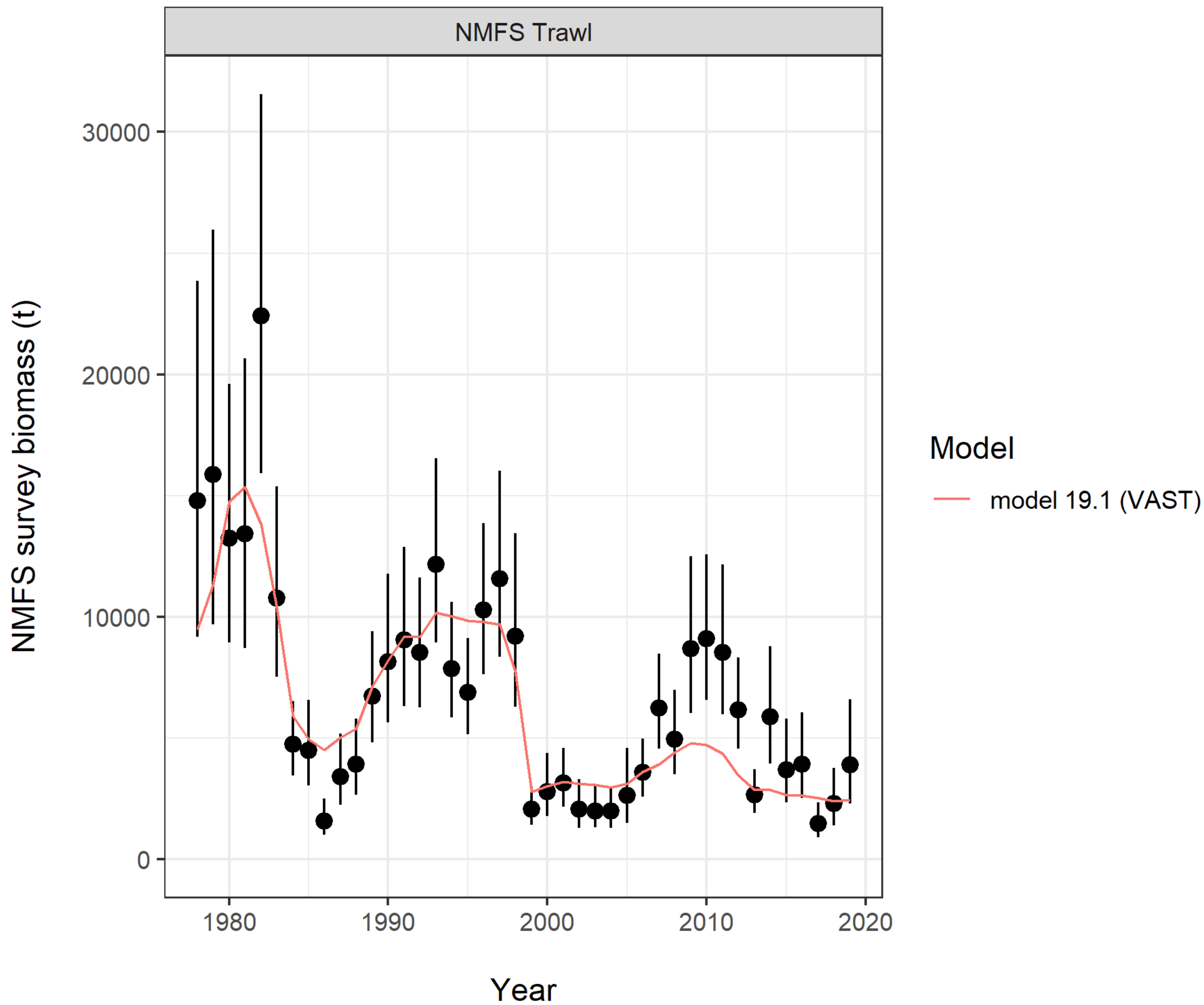

Figure 7: Fits to NMFS VAST trawl estimates of total (> 90mm) male survey biomass for the VAST model only. Error bars are plus and minus 2 standard deviations.

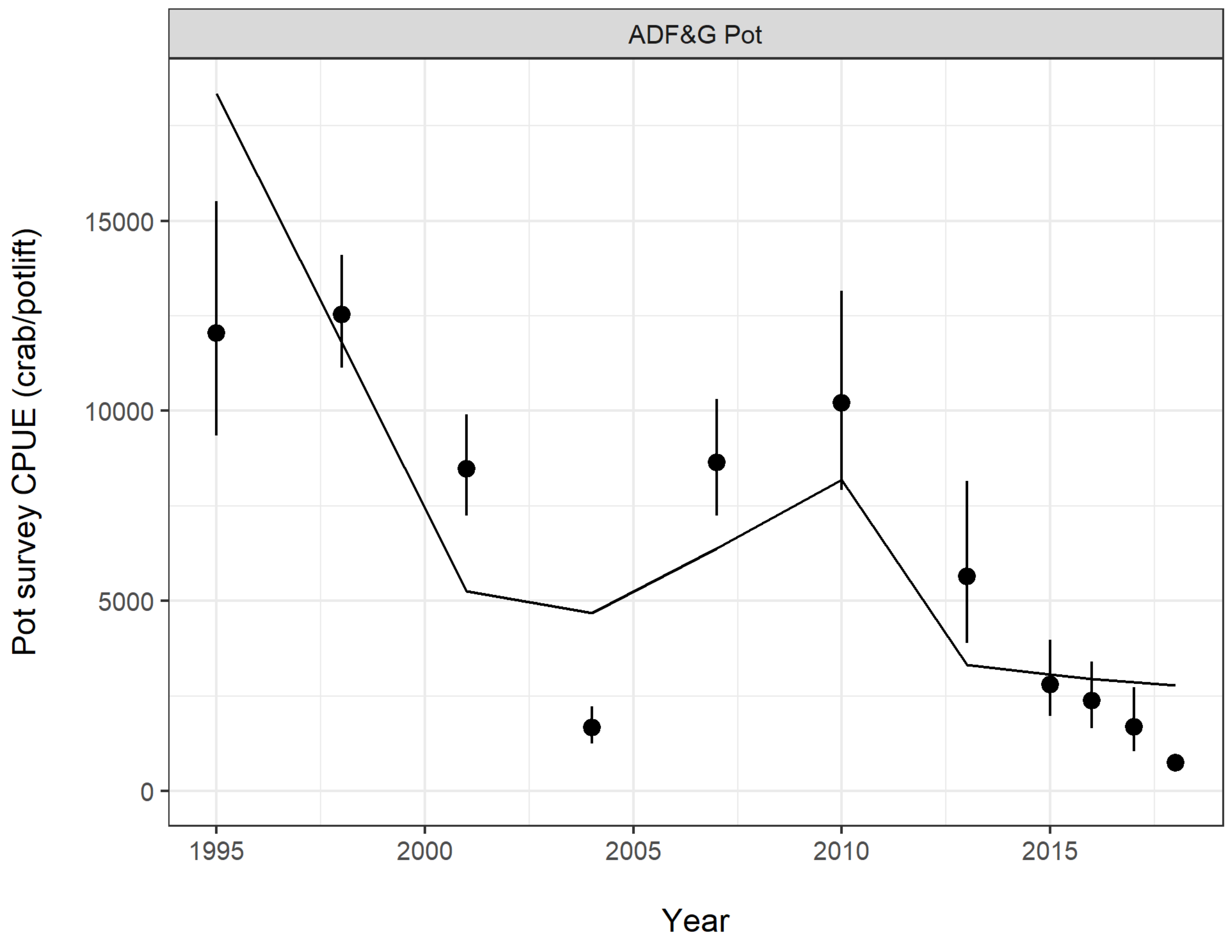

Figure 8: Comparisons of fits to CPUE from the ADFG pot surveys for the reference model 16.0 ref (note that there is no new pot data for 2019). Error bars are plus and minus 2 standard deviations.

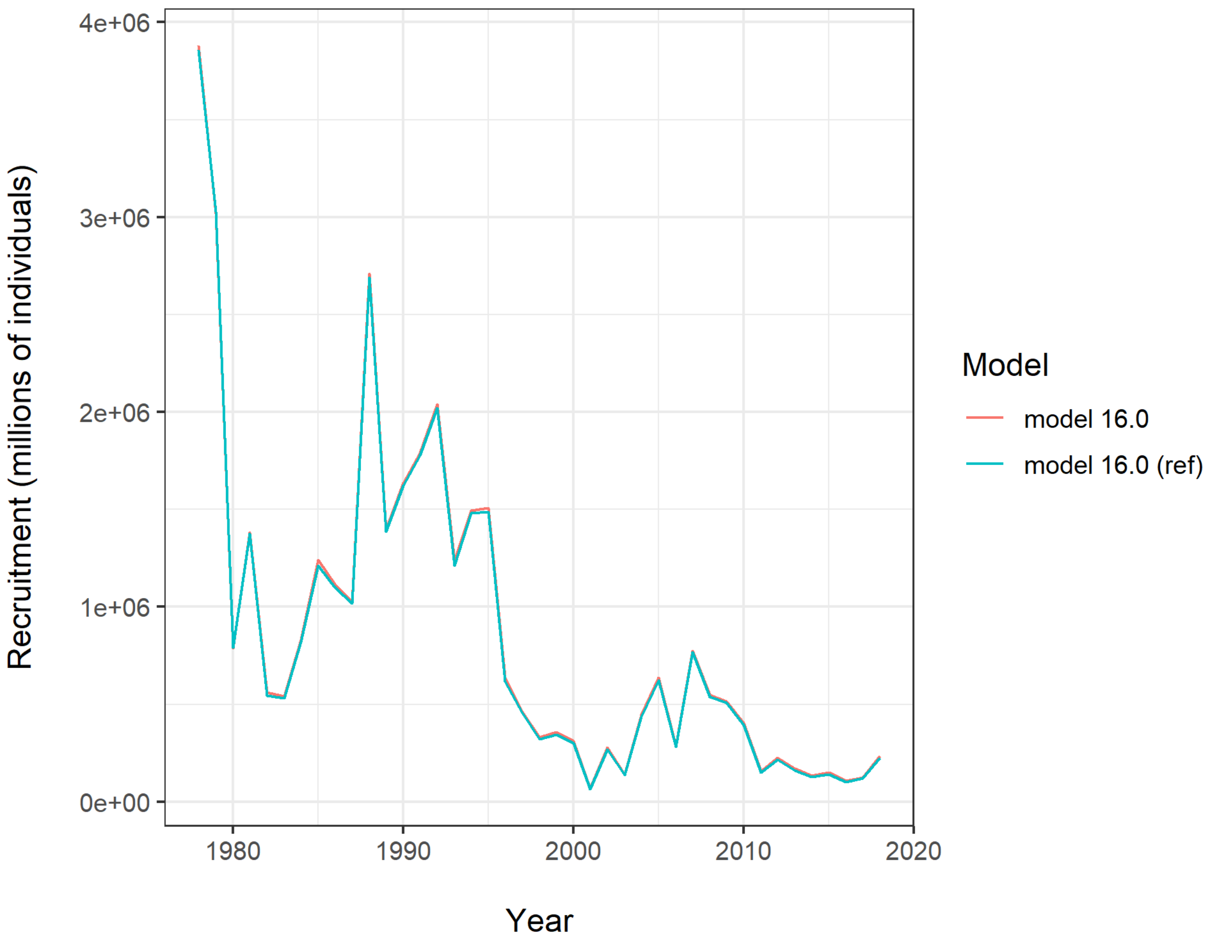

Figure 9: Set up to show sensitivity of new data in 2020 on estimated recruitment ; 1978-2018.

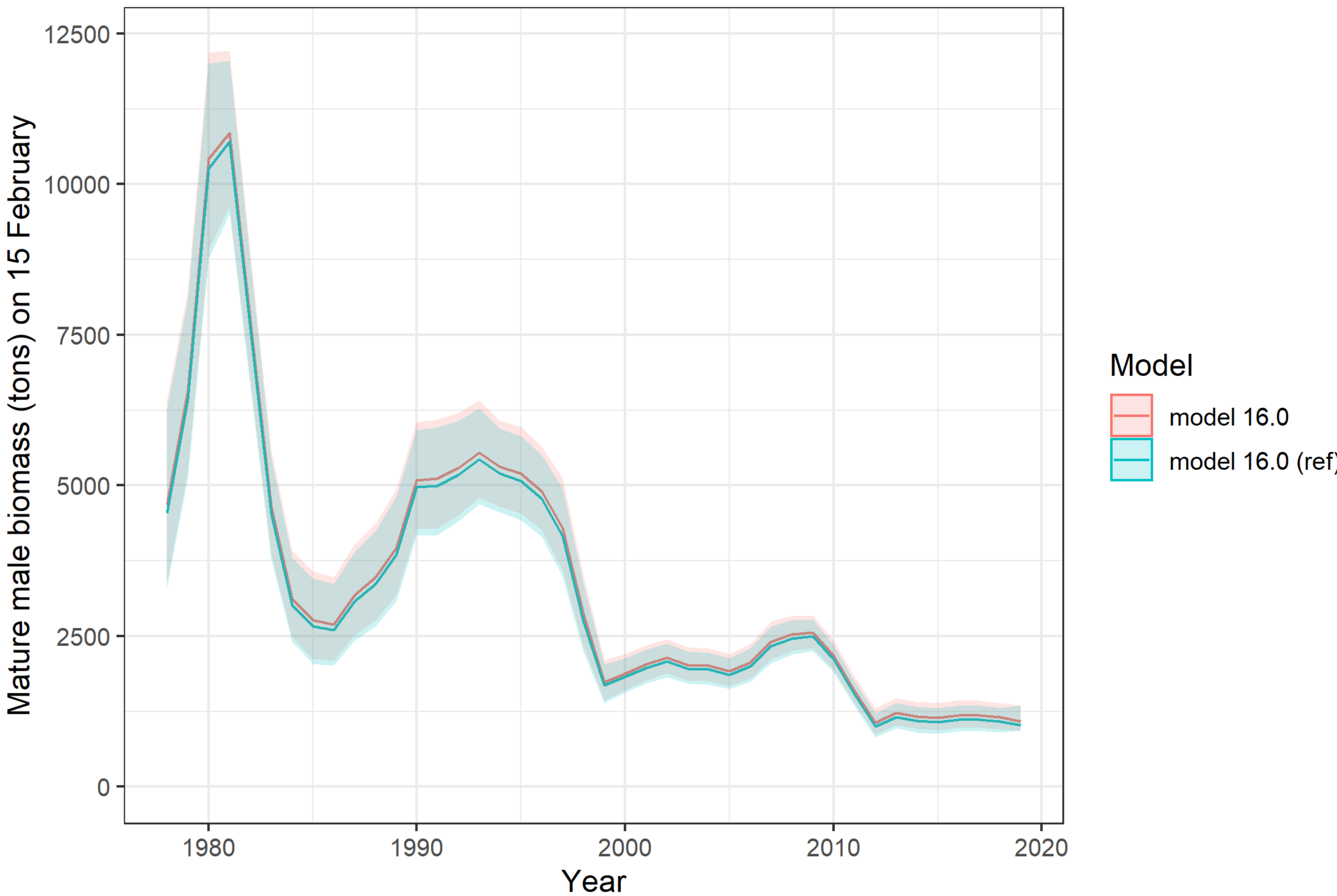

Figure 10: Sensitivity of new data in 2019 on estimated mature male biomass (MMB); 1978-2019.

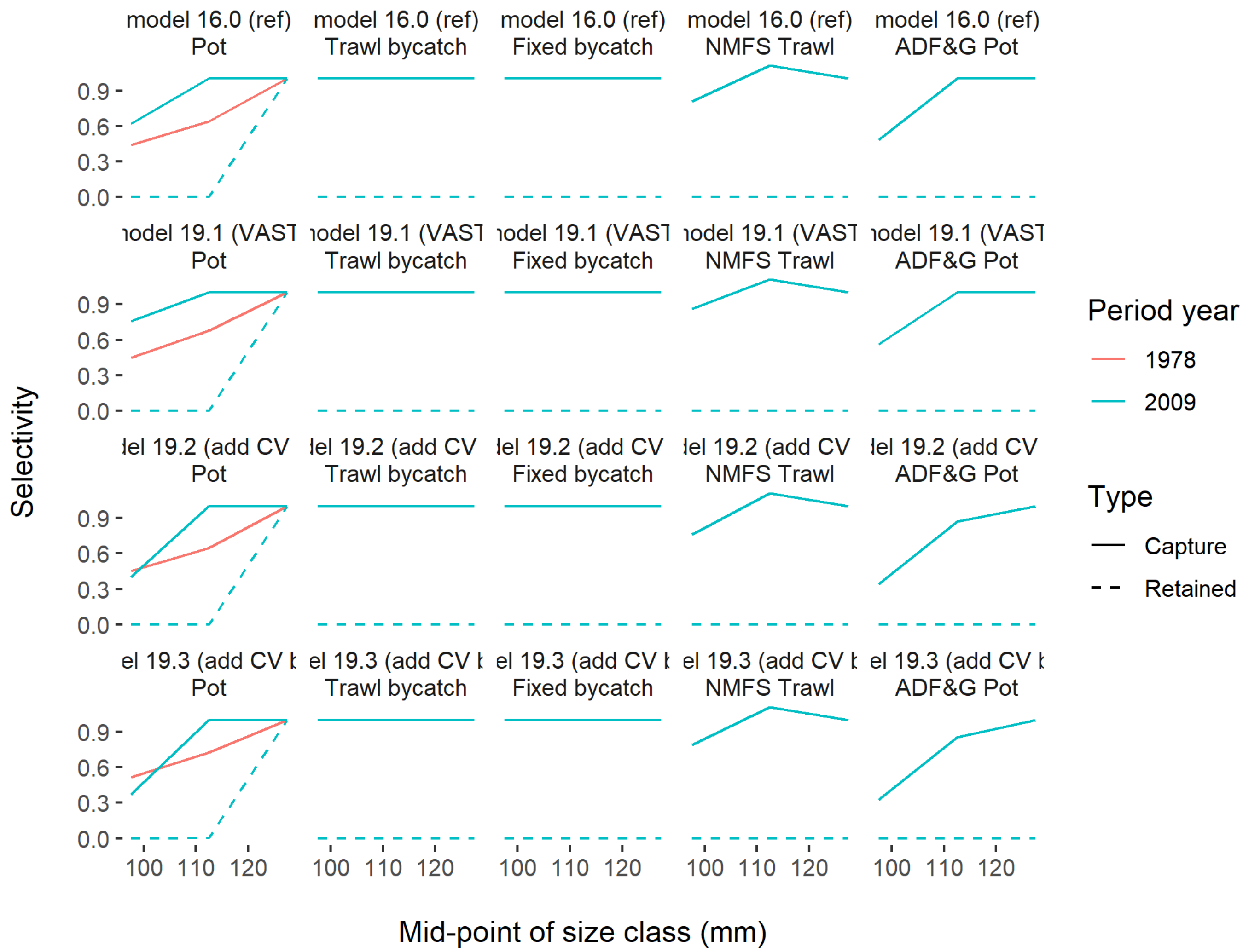

Figure 11: Comparisons of the estimated stage-1 and stage-2 selectivities for the different model scenarios (the stage-3 selectivities are all fixed at 1). Estimated selectivities are shown for the directed pot fishery, the trawl bycatch fishery, the fixed bycatch fishery, the NMFS trawl survey, and the ADFG pot survey. Two selectivity periods are estimated in the directed pot fishery, from 1978-2008 and 2009-2018.

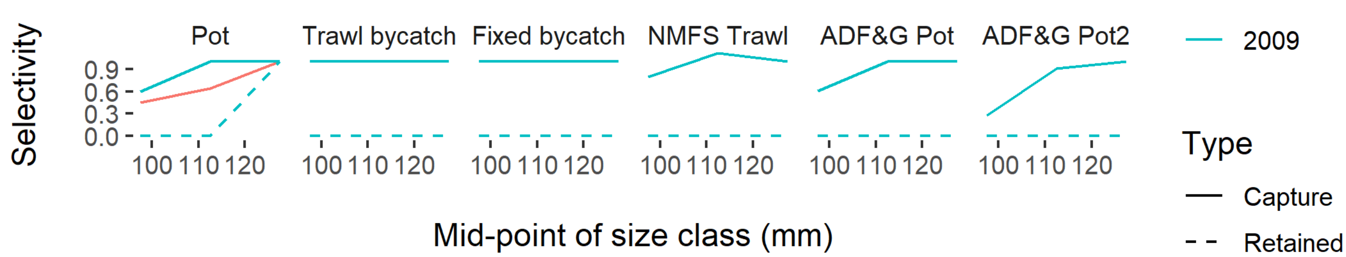

Figure 12: Comparisons of the estimated stage-1 and stage-2 selectivities for the q time block pot model scenario (the stage-3 selectivities are all fixed at 1). Estimated selectivities are shown for the directed pot fishery, the trawl bycatch fishery, the fixed bycatch fishery, the NMFS trawl survey, and the ADFG pot survey. Two selectivity periods are estimated in the directed pot fishery, from 1978-2008 and 2009-2018.

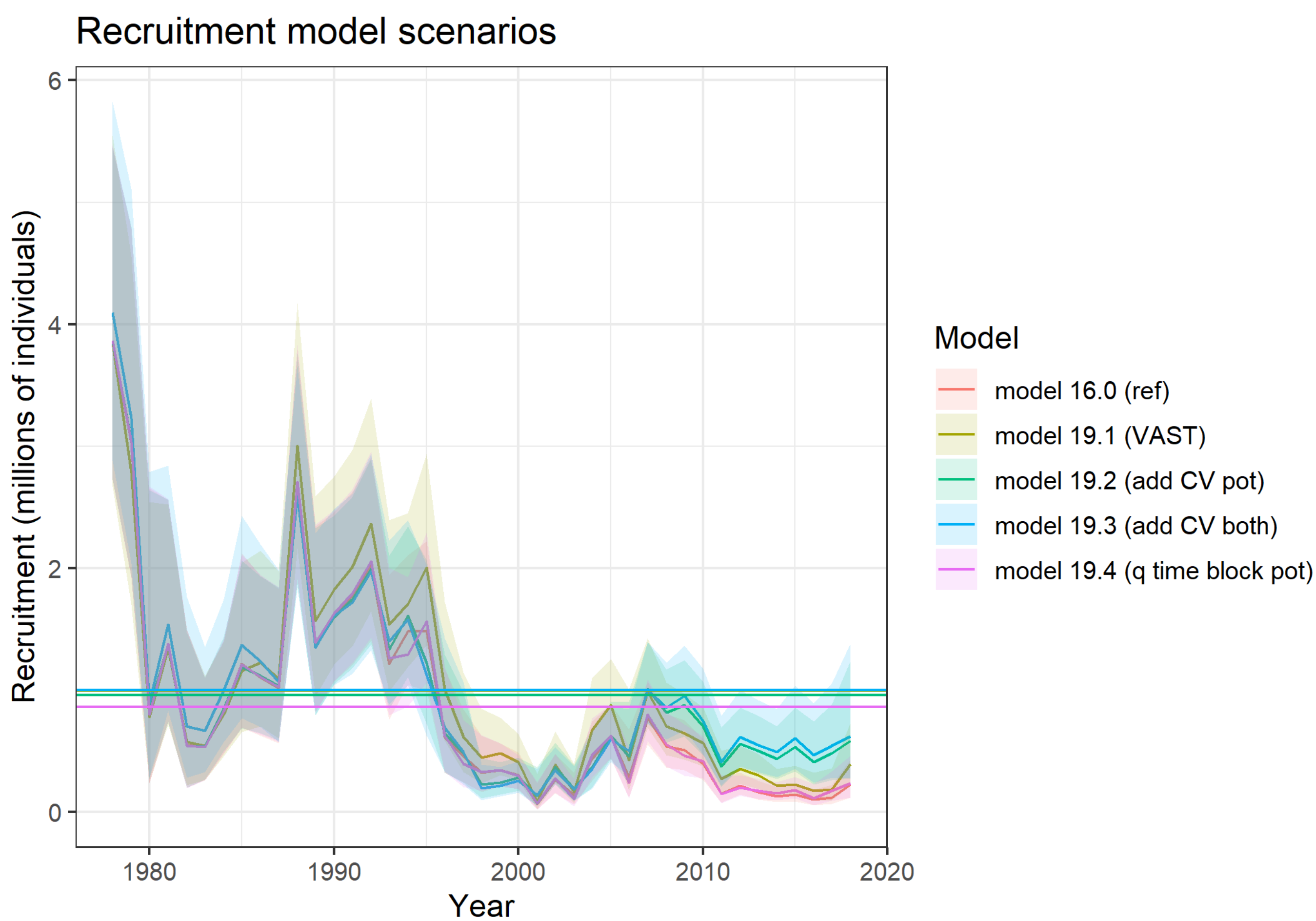

Figure 13: Estimated recruitment 1979-2018 comparing model alternatives. The solid horizontal lines in the background represent the estimate of the average recruitment parameter ($\bar{R}$) in each model scenario.

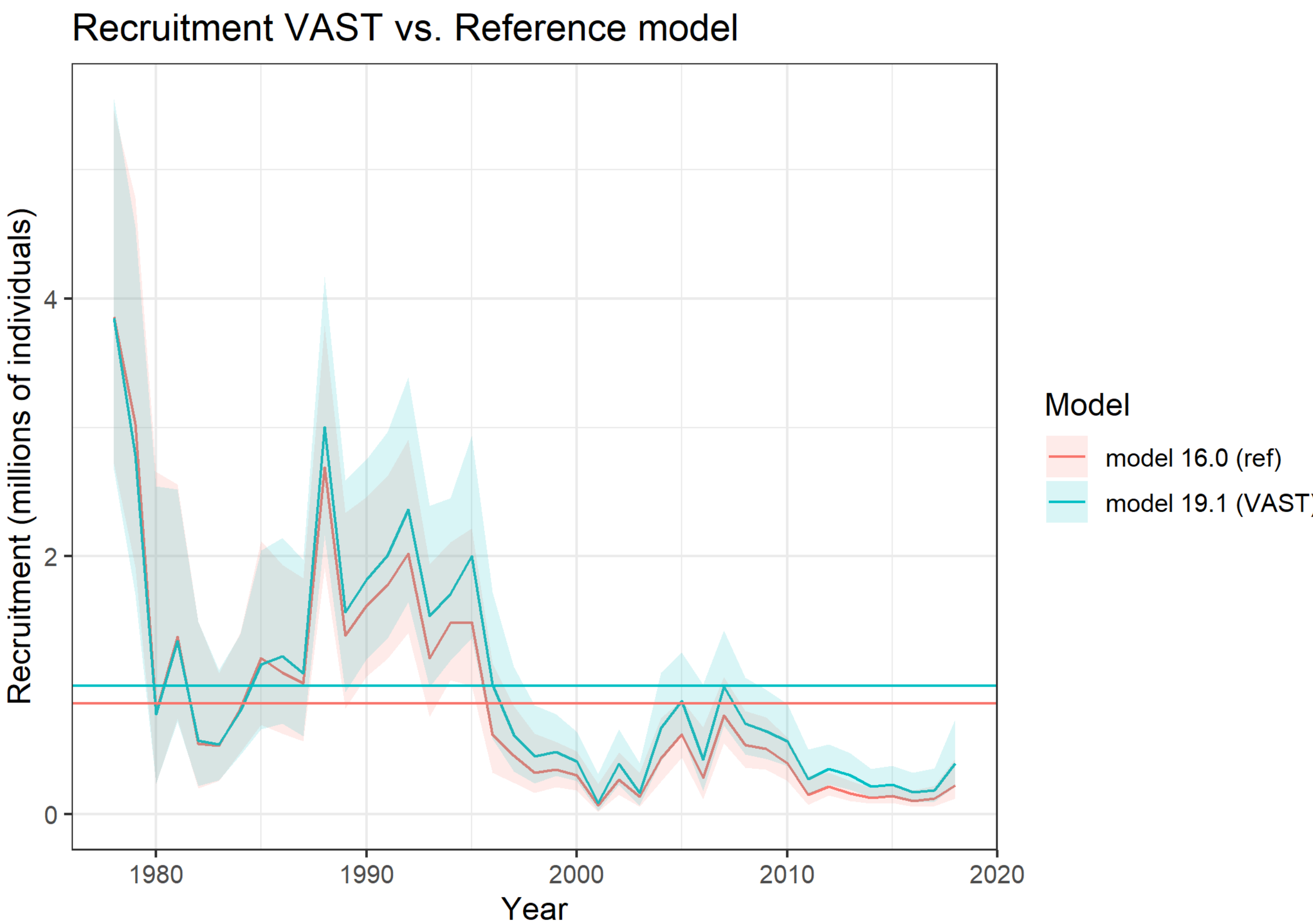

Figure 14: Estimated recruitment 1979-2018 comparing the VAST (19.1) and Reference model (16.0). The solid horizontal lines in the background represent the estimate of the average recruitment parameter ($\bar{R}$) in each model scenario.

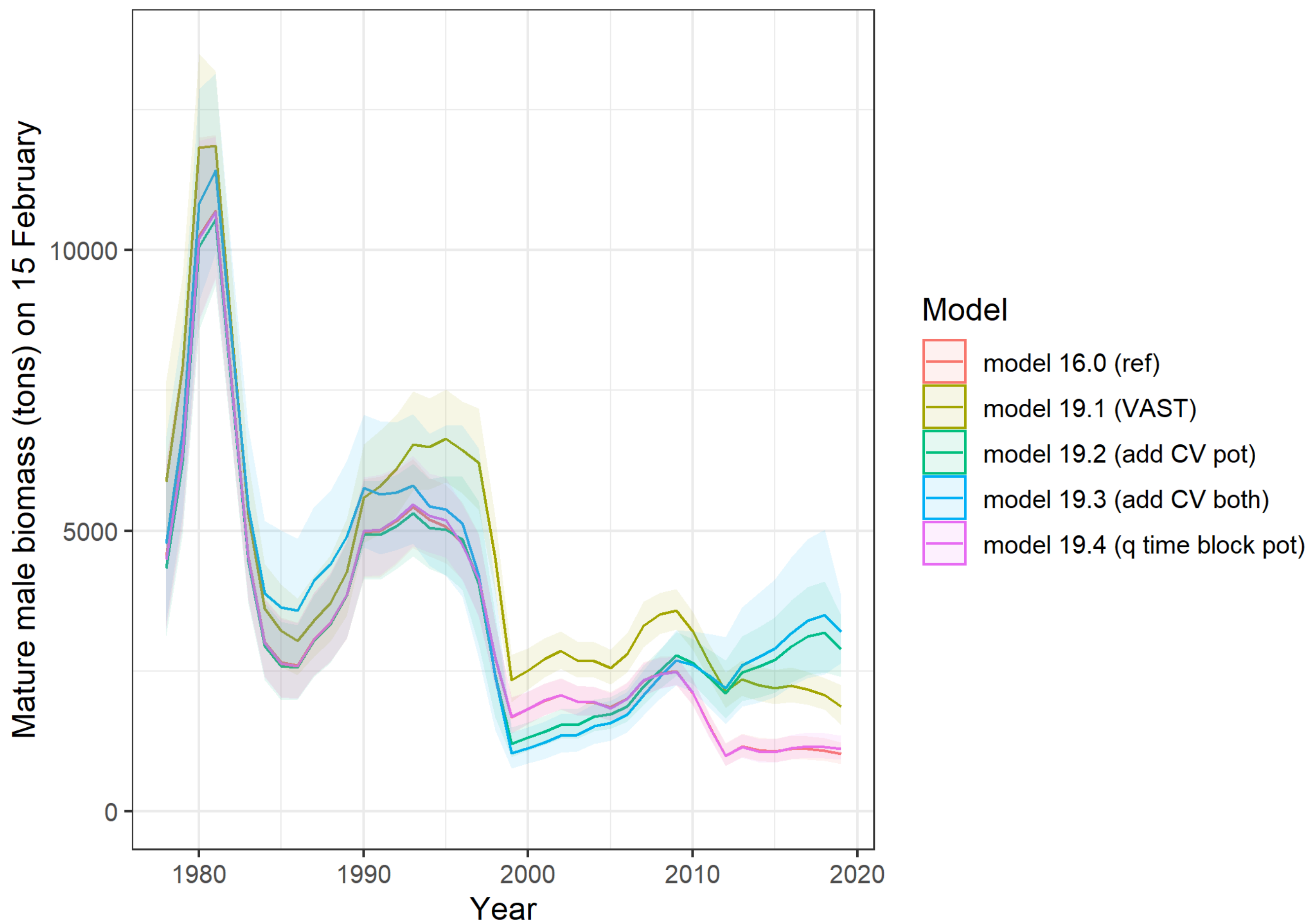

Figure 15: Comparisons of estimated mature male biomass (MMB) time series on 15 February during 1978-2019 for each of the model scenarios.

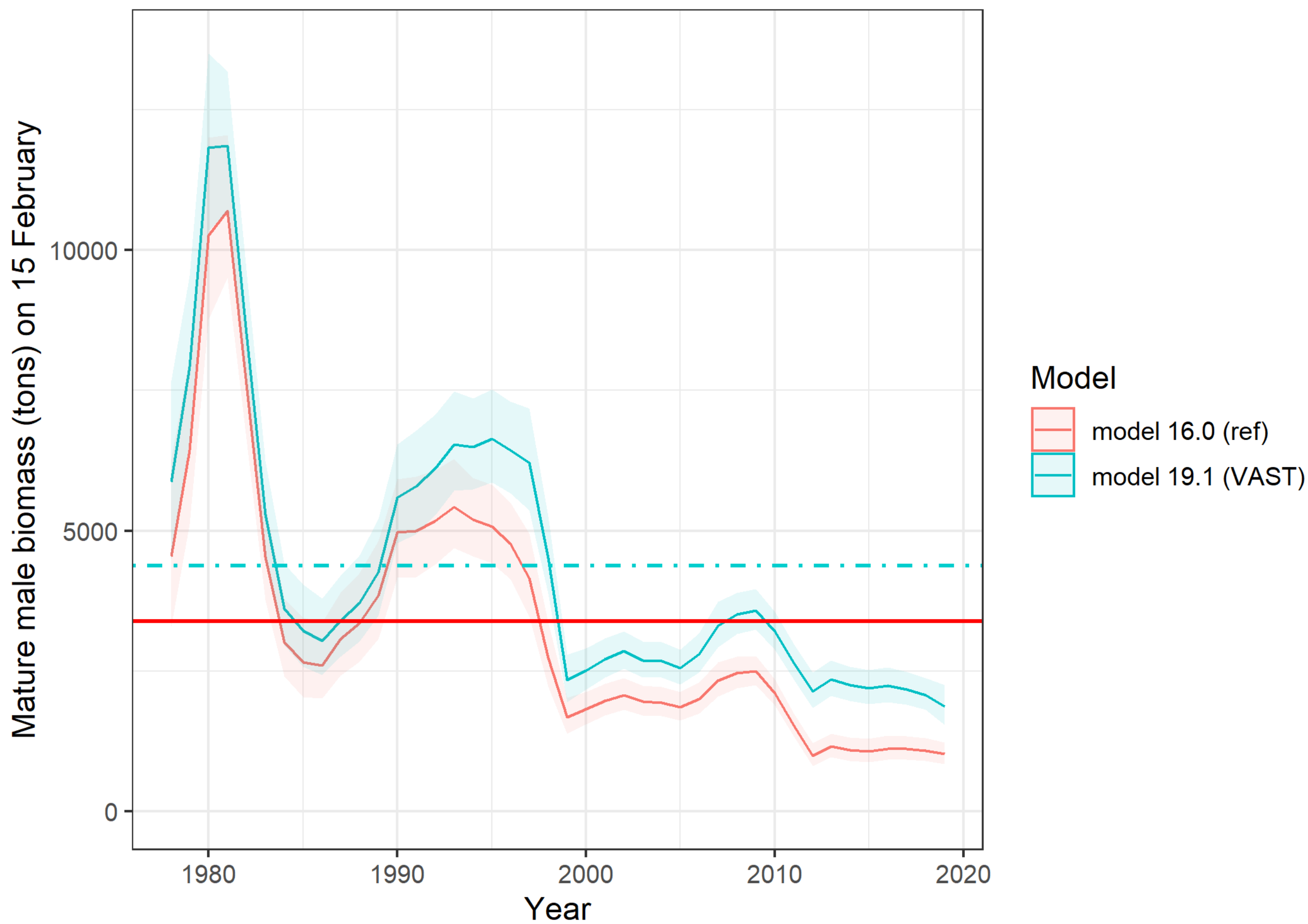

Figure 16: Comparisons of estimated mature male biomass (MMB) time series on 15 February during 1978-2019 for the reference (16.0) and VAST (19.1) model scenarios. Horizontal lines are average mmb from 1978 - 2018 (Bmsy proxy)

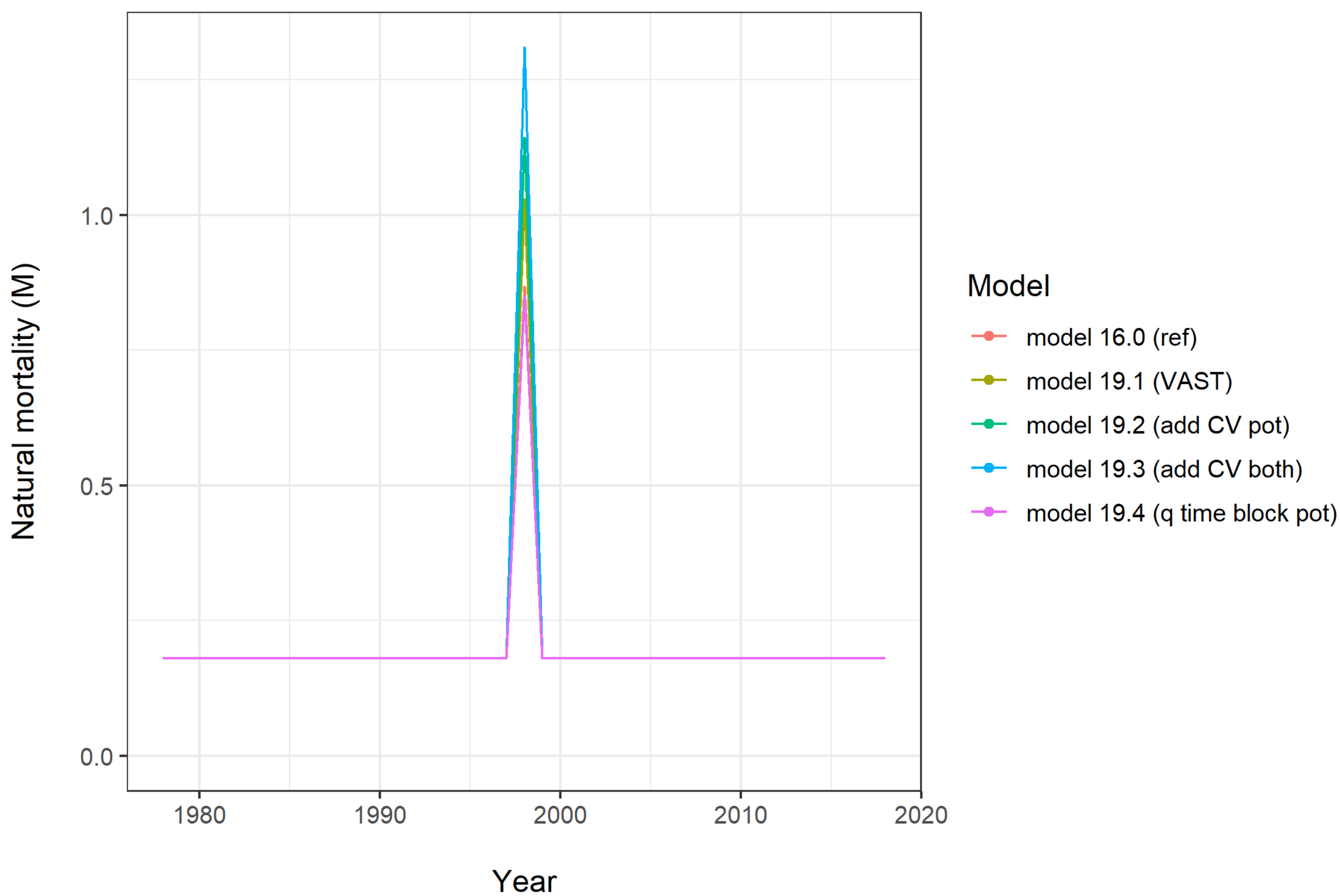

Figure 17: Time-varying natural mortality (M_t). Estimated pulse period occurs in 1998/99 (i.e. M_{1998}).

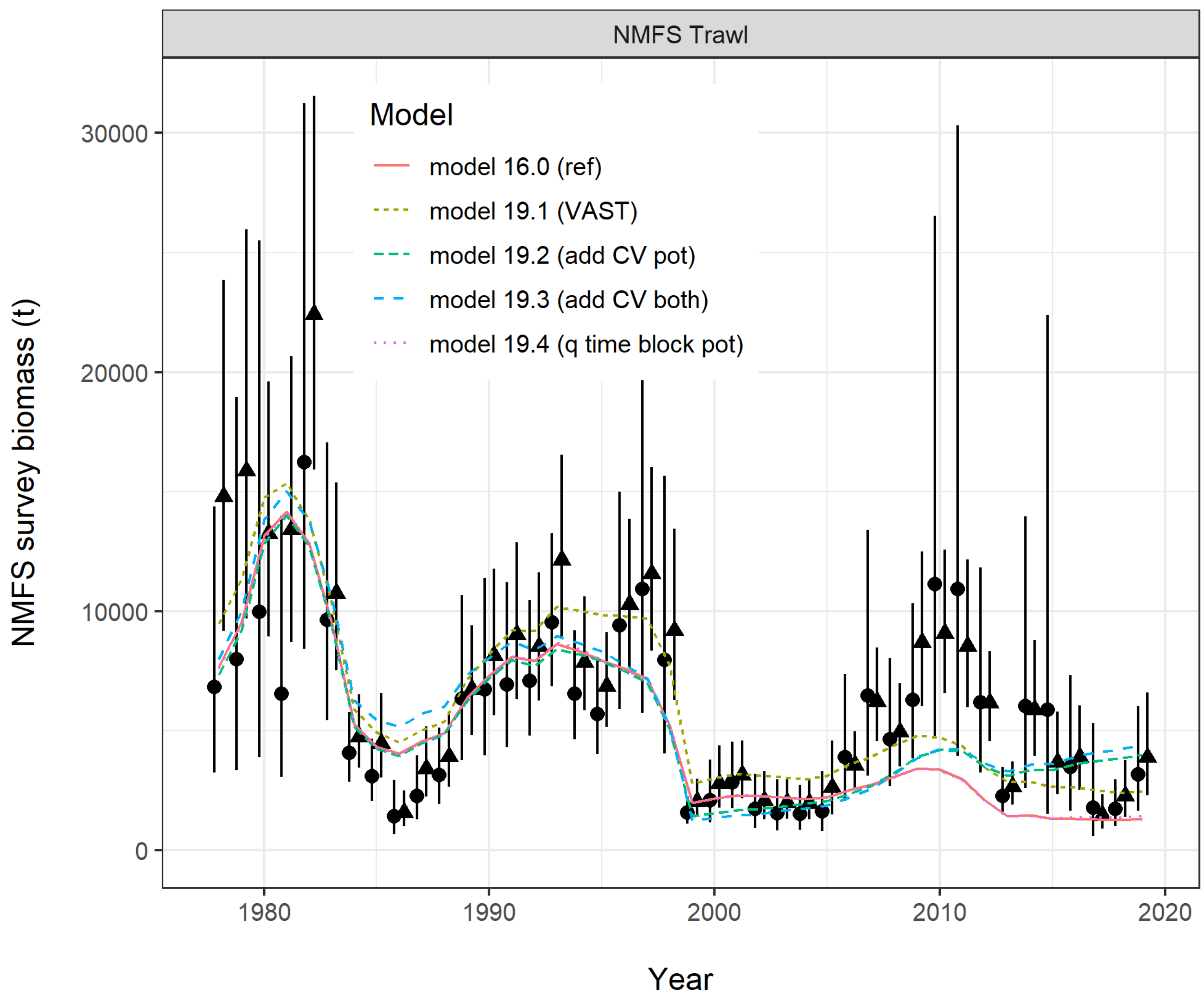

Figure 18: Comparisons of area-swept estimates of total (90+ mm CL) male survey biomass (tons) and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations. Triangles represent VAST survey estimtaes.

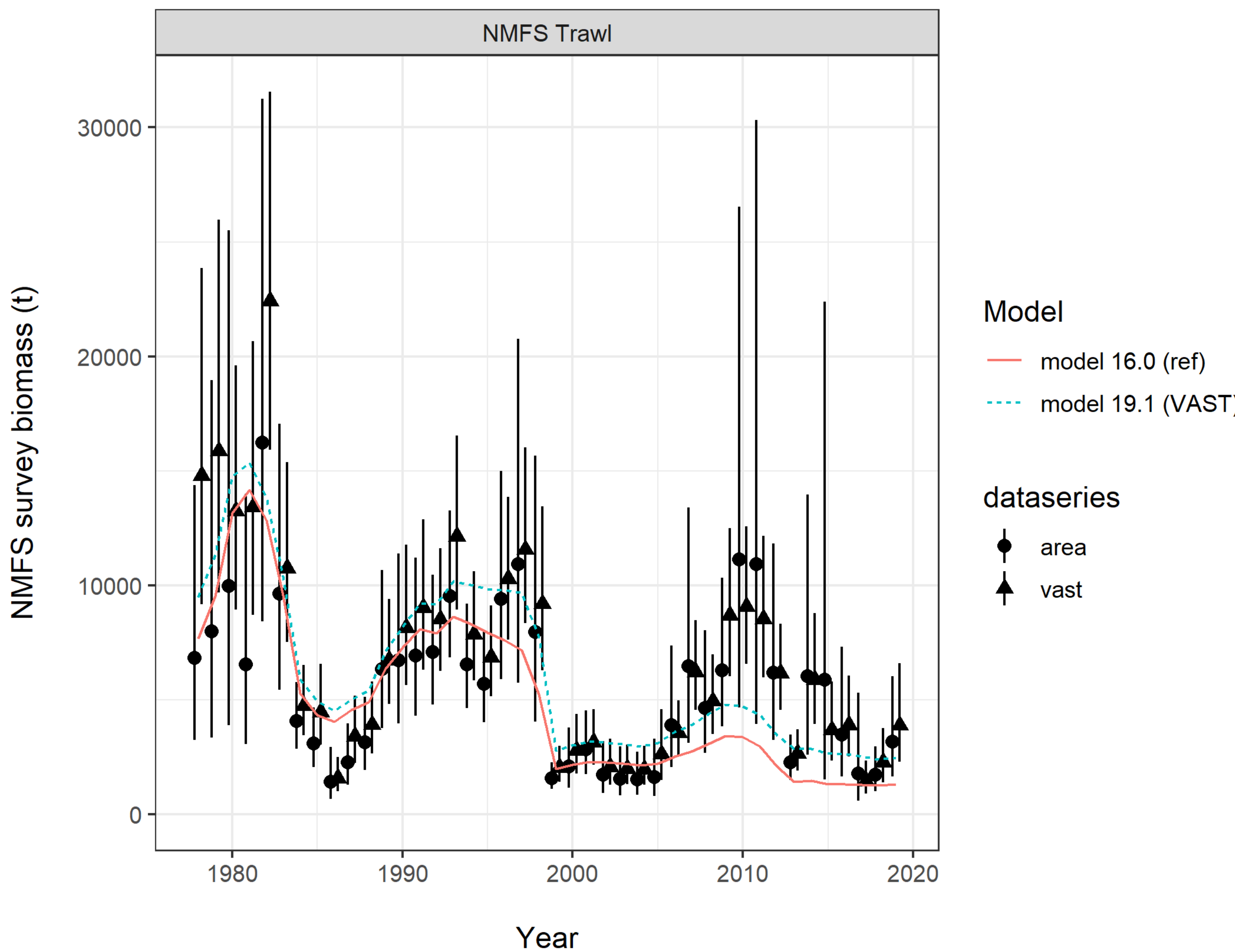

Figure 19: Comparisons of estimates of total (90+ mm CL) male survey biomass (tons) and model predictions for the reference (area-swept) model and the VAST model. The error bars are plus and minus 2 standard deviations. Triangles represent VAST survey estimtaes.

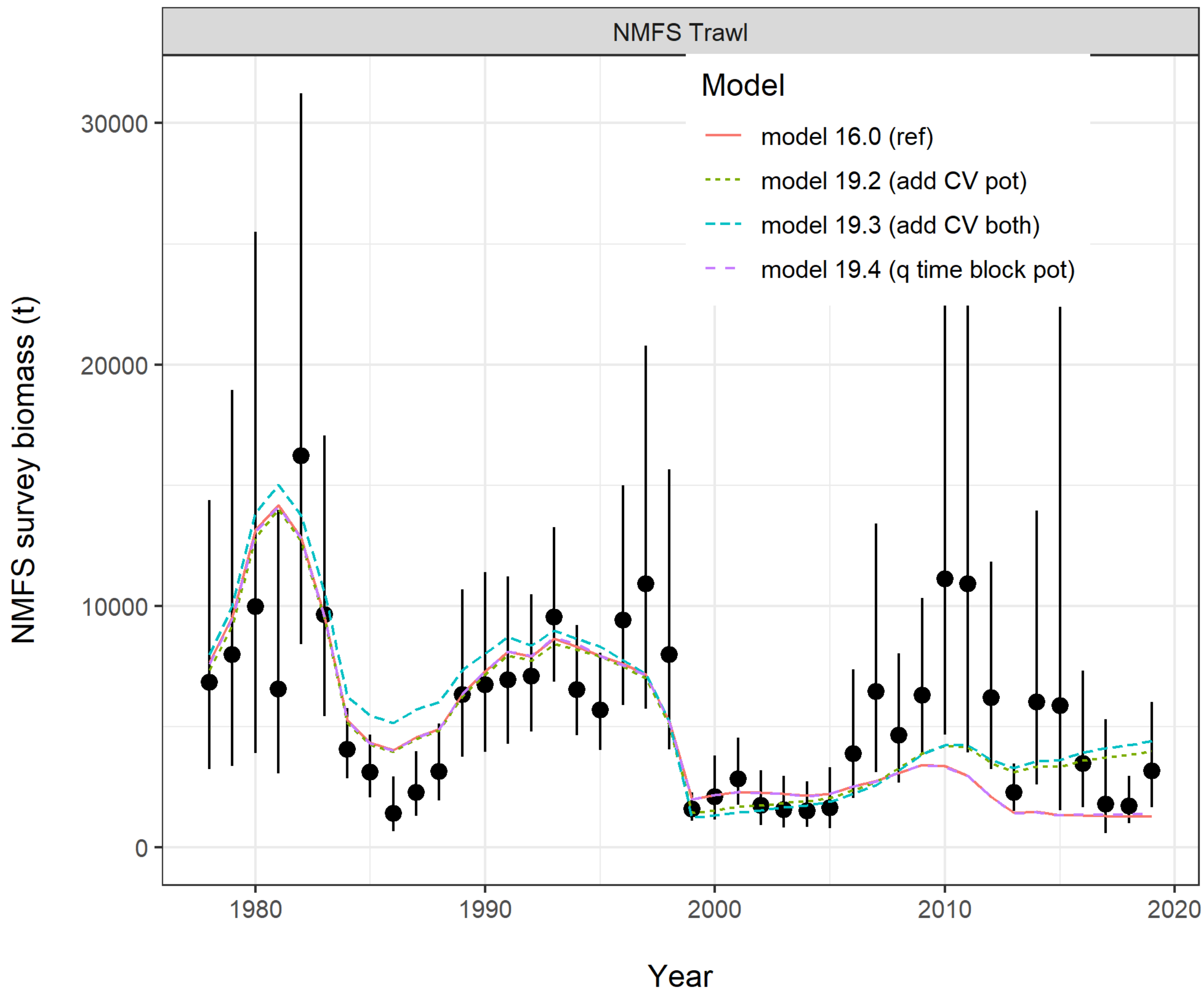

Figure 20: Comparisons of area-swept estimates of total (90+ mm CL) male survey biomass (tons) and model predictions model scenarios excluding the VAST model. The error bars are plus and minus 2 standard deviations.

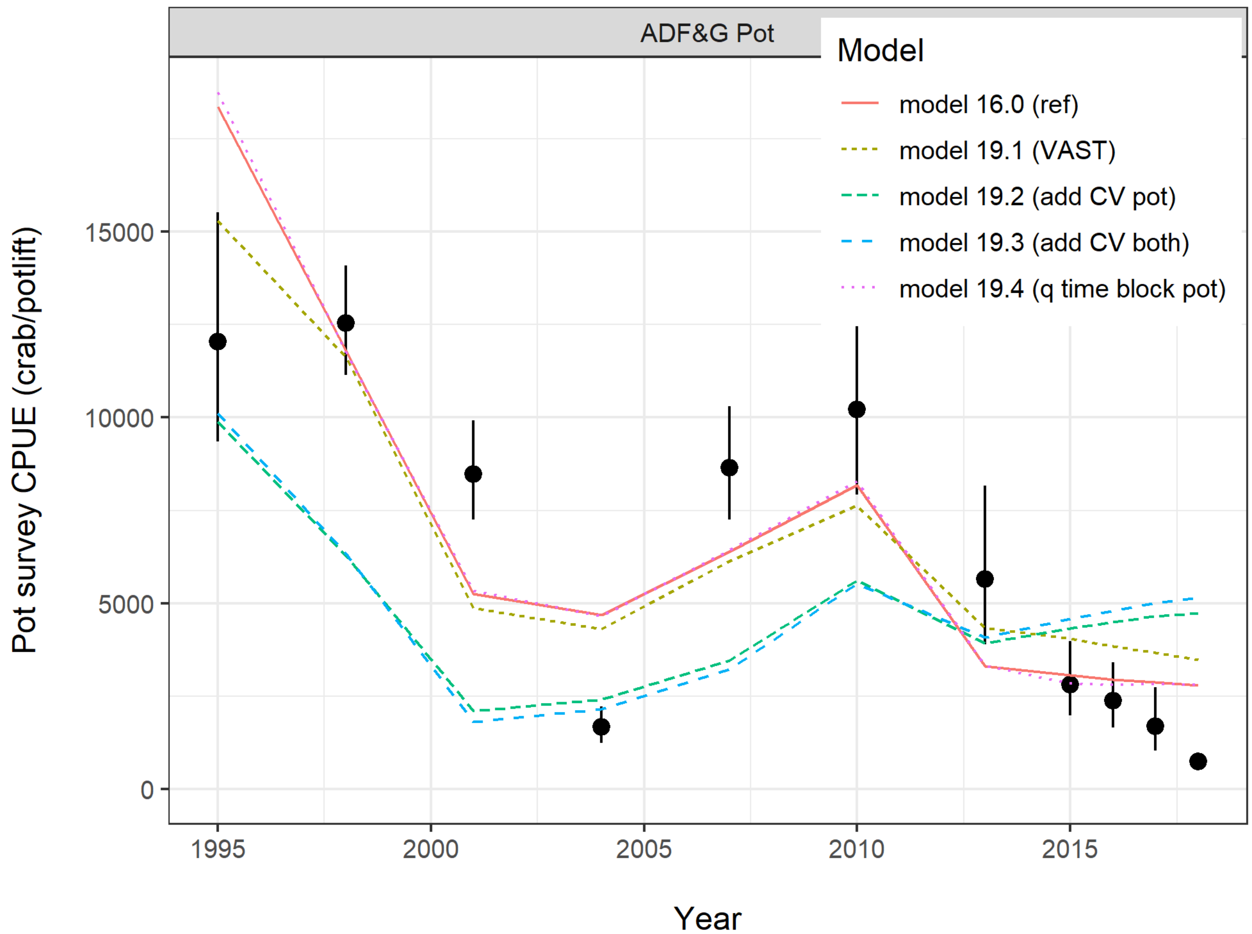

Figure 21: Comparisons of total (90+ mm CL) male pot survey CPUEs and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

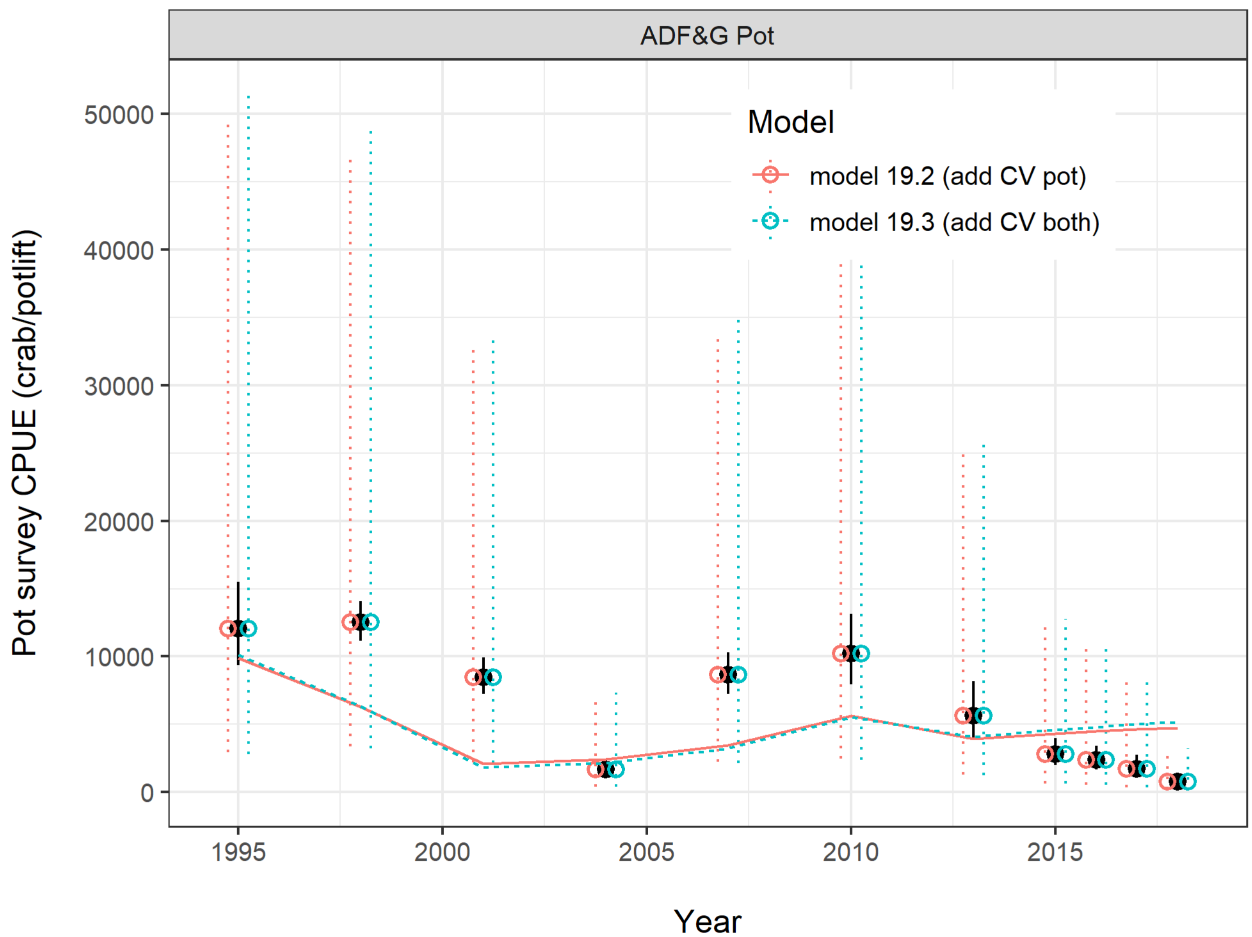

Figure 22: Comparisons of total (90+ mm CL) male pot survey CPUEs and model predictions for the 'add CV pot' (Model 19.2) and 'add CV both' (Model 19.3) scenarios. The black error bars are plus and minus 2 standard deviations, while the red/blue ones incorporate the additional variability.

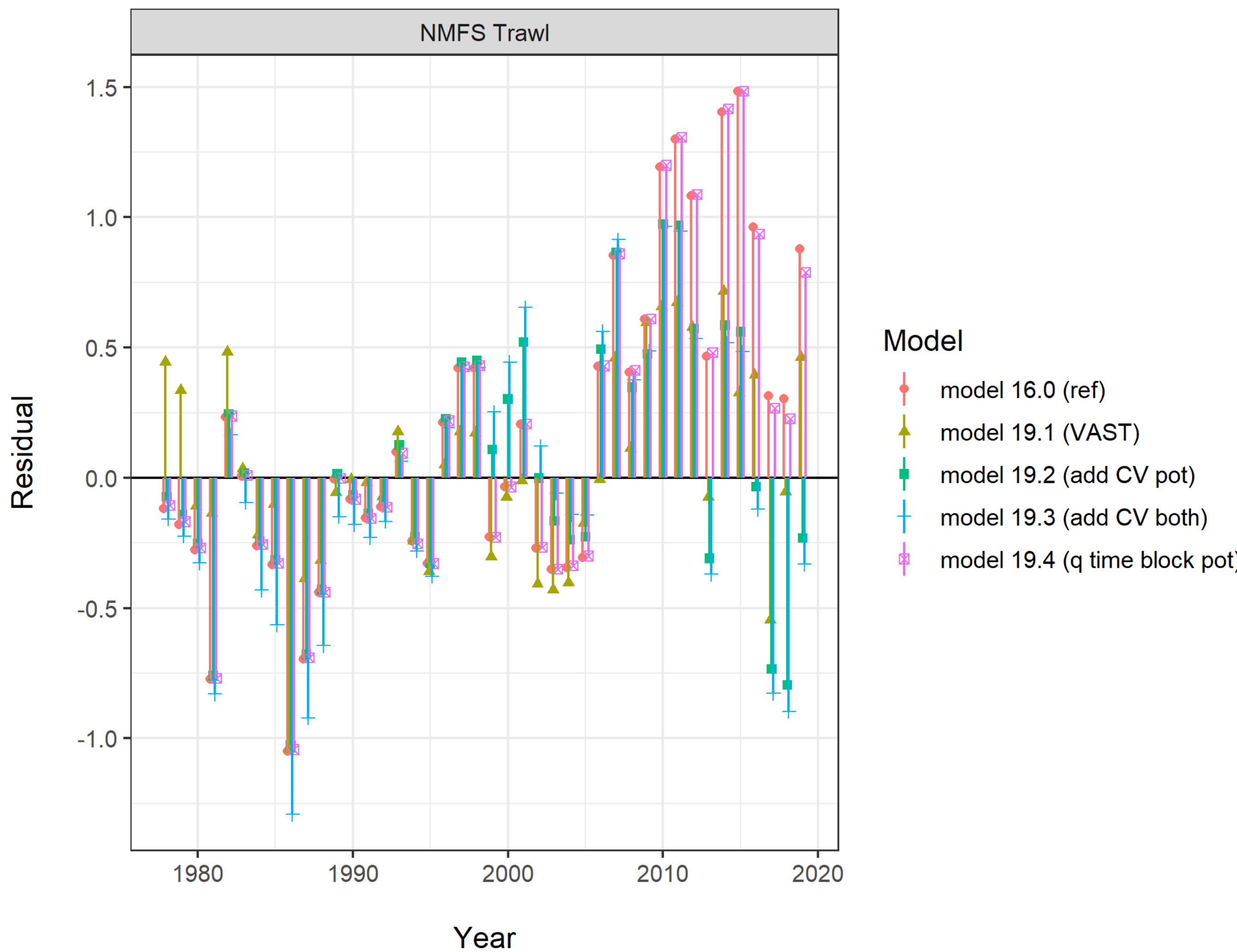

Figure 23: Standardized residuals for area-swept estimates of total male survey biomass for the model scenarios.

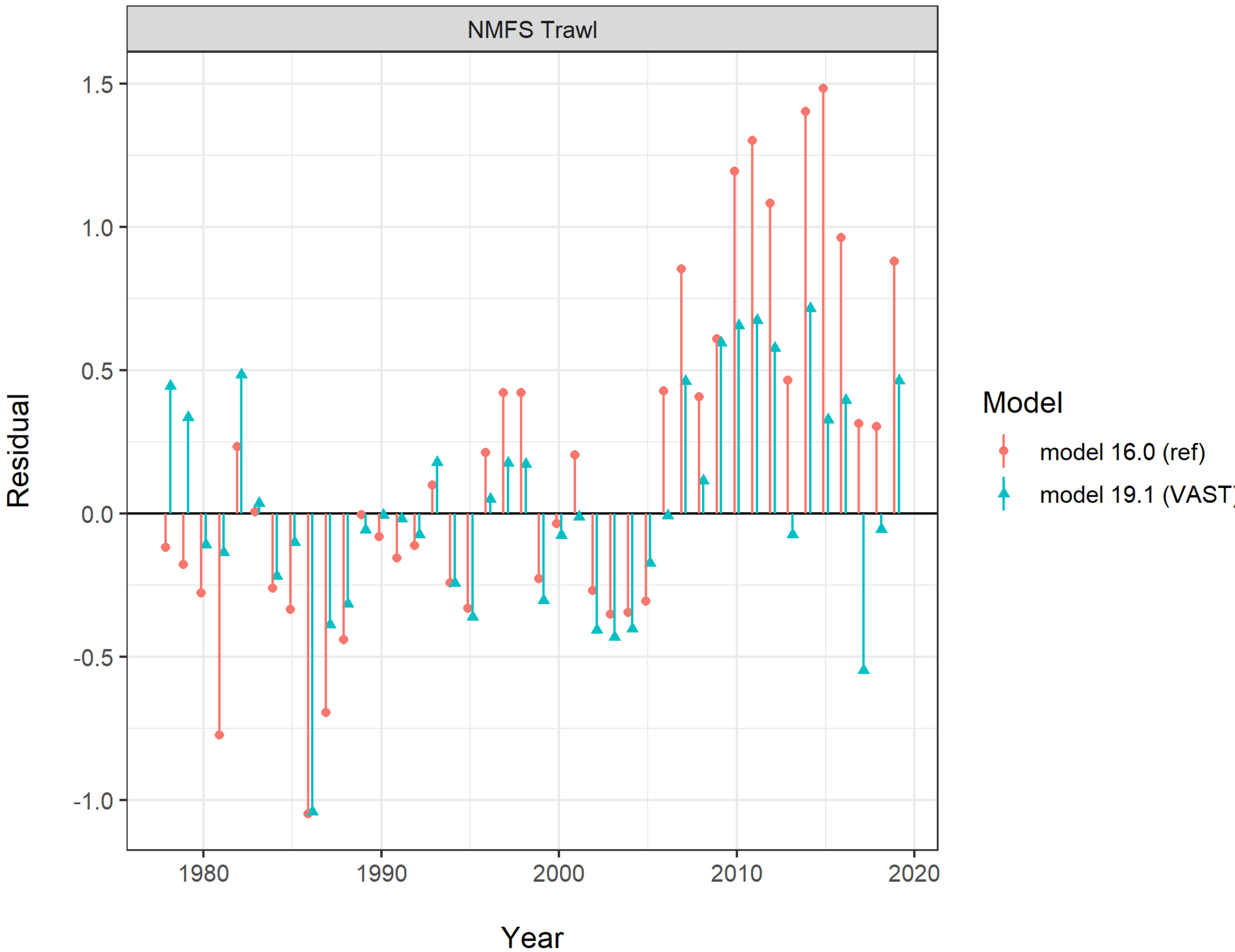

Figure 24: Standardized residuals for VAST vs area-swept estimates of total male survey biomass for the ref (16.0) and VAST (19.1) model scenarios.

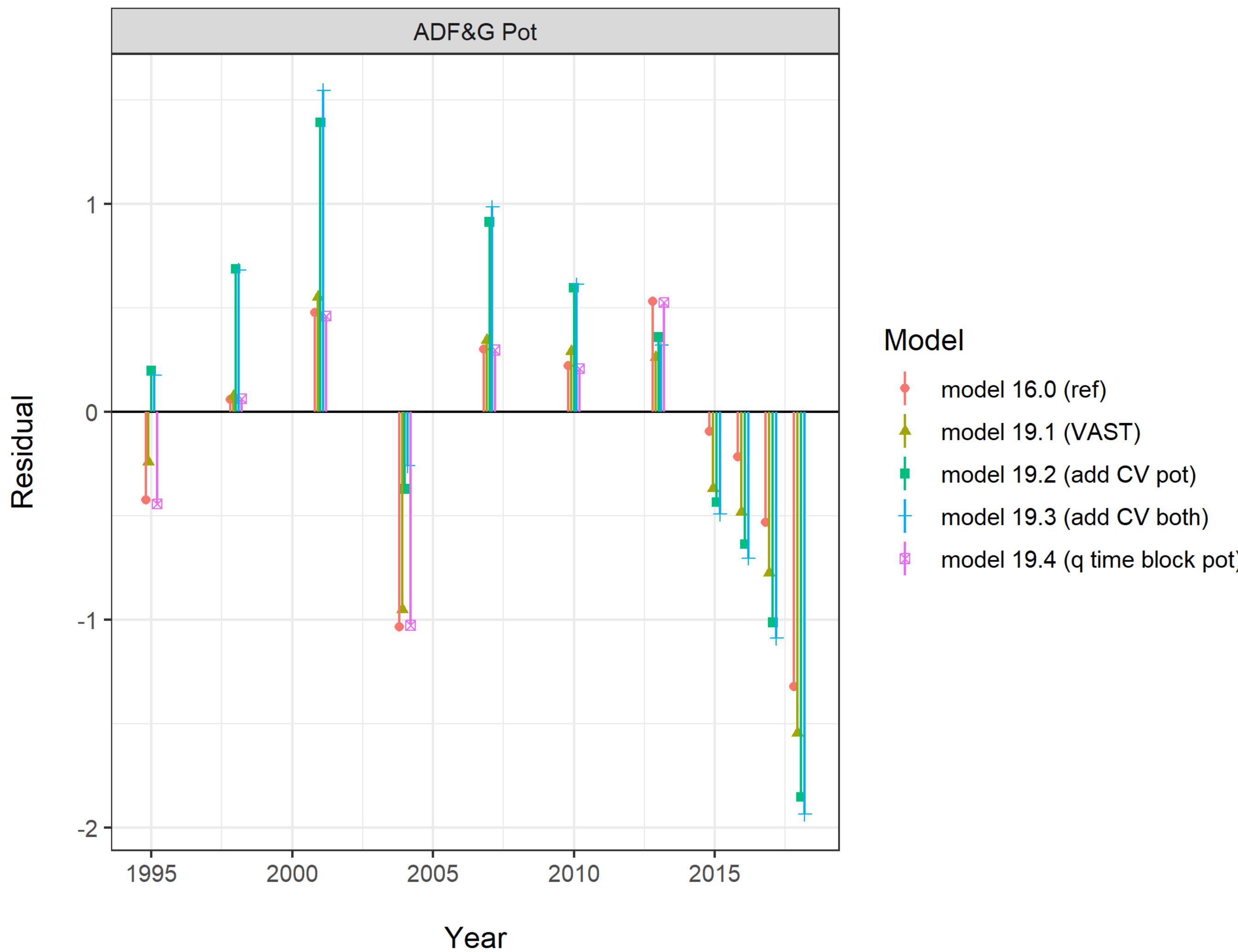

Figure 25: Standardized residuals for total male pot survey CPUEs for each of the GMACS model scenarios.

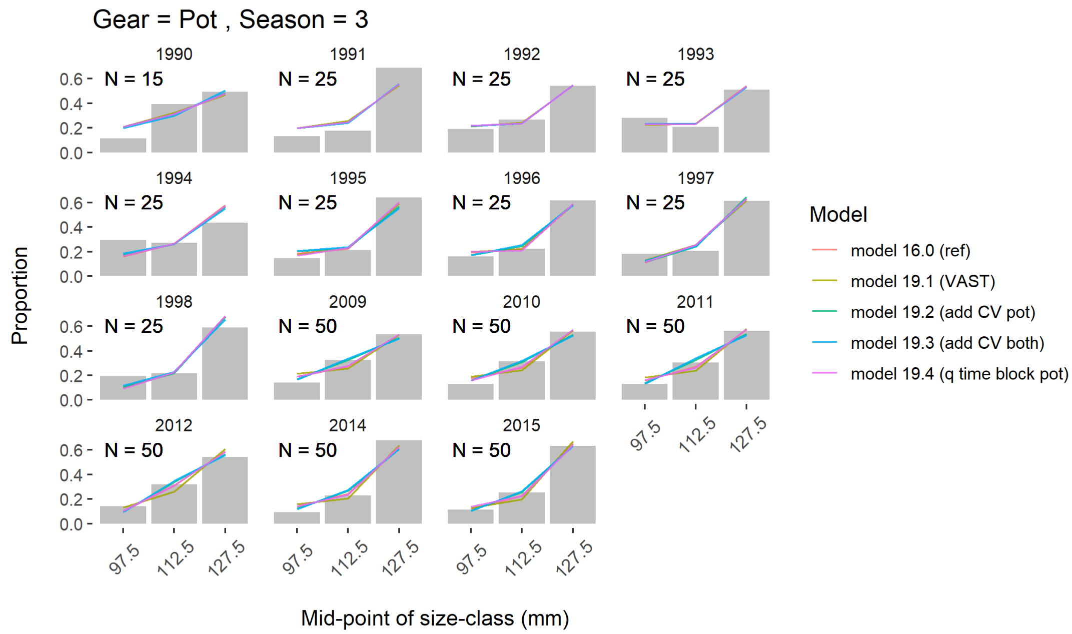

Figure 26: Observed and model estimated size-frequencies of SMBKC by year retained in the directed pot fishery for the model scenarios.

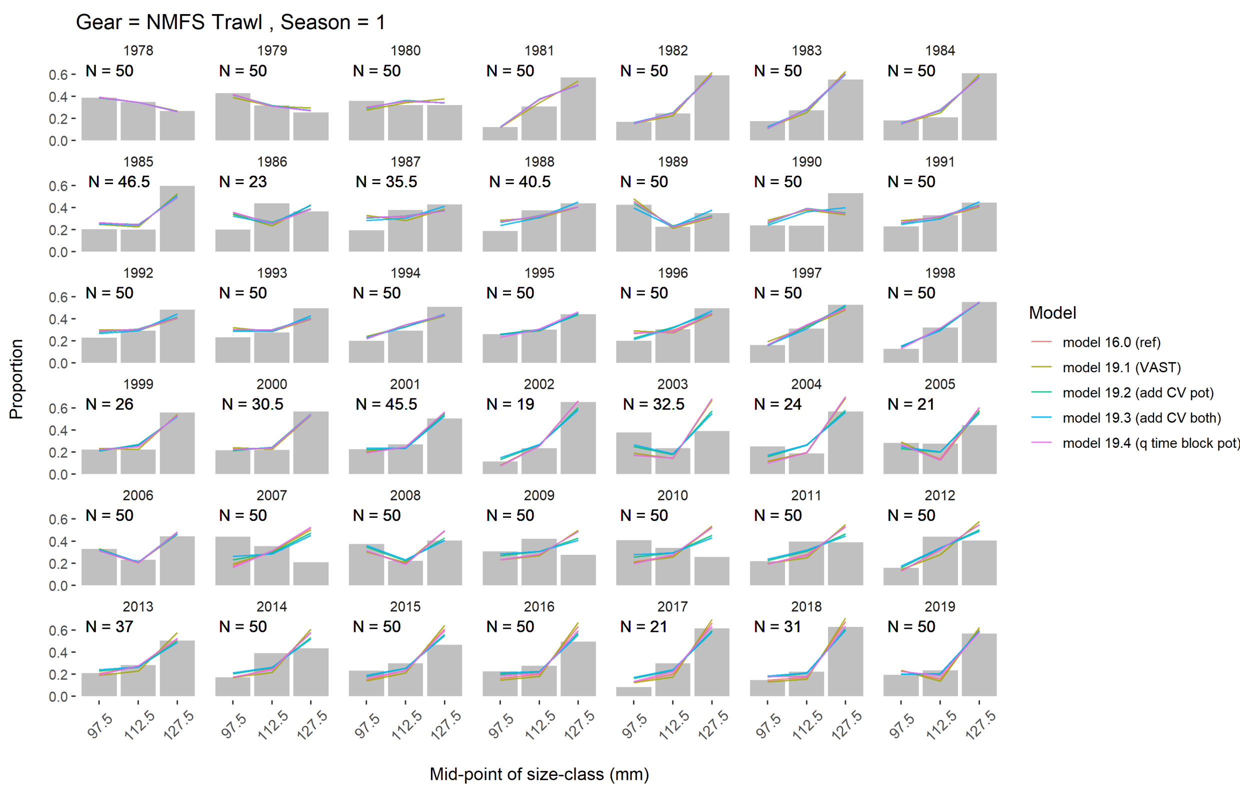

Figure 27: Observed and model estimated size-frequencies of discarded male SMBKC by year in the NMFS trawl survey for the model scenarios.

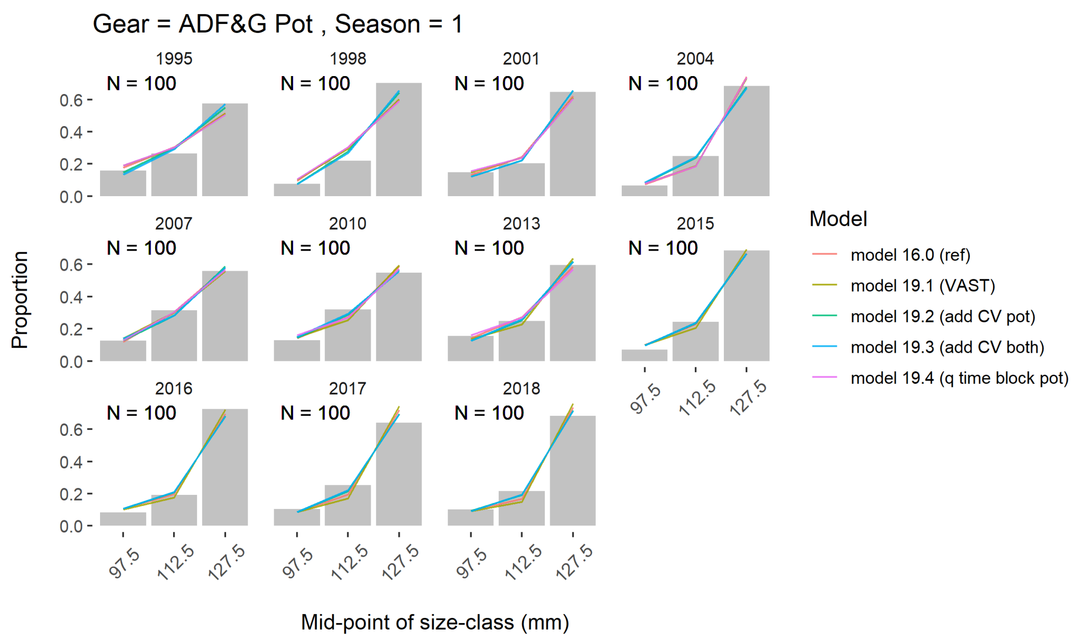

Figure 28: Observed and model estimated size-frequencies of discarded SMBKC by year in the ADFG pot survey for the model scenarios.

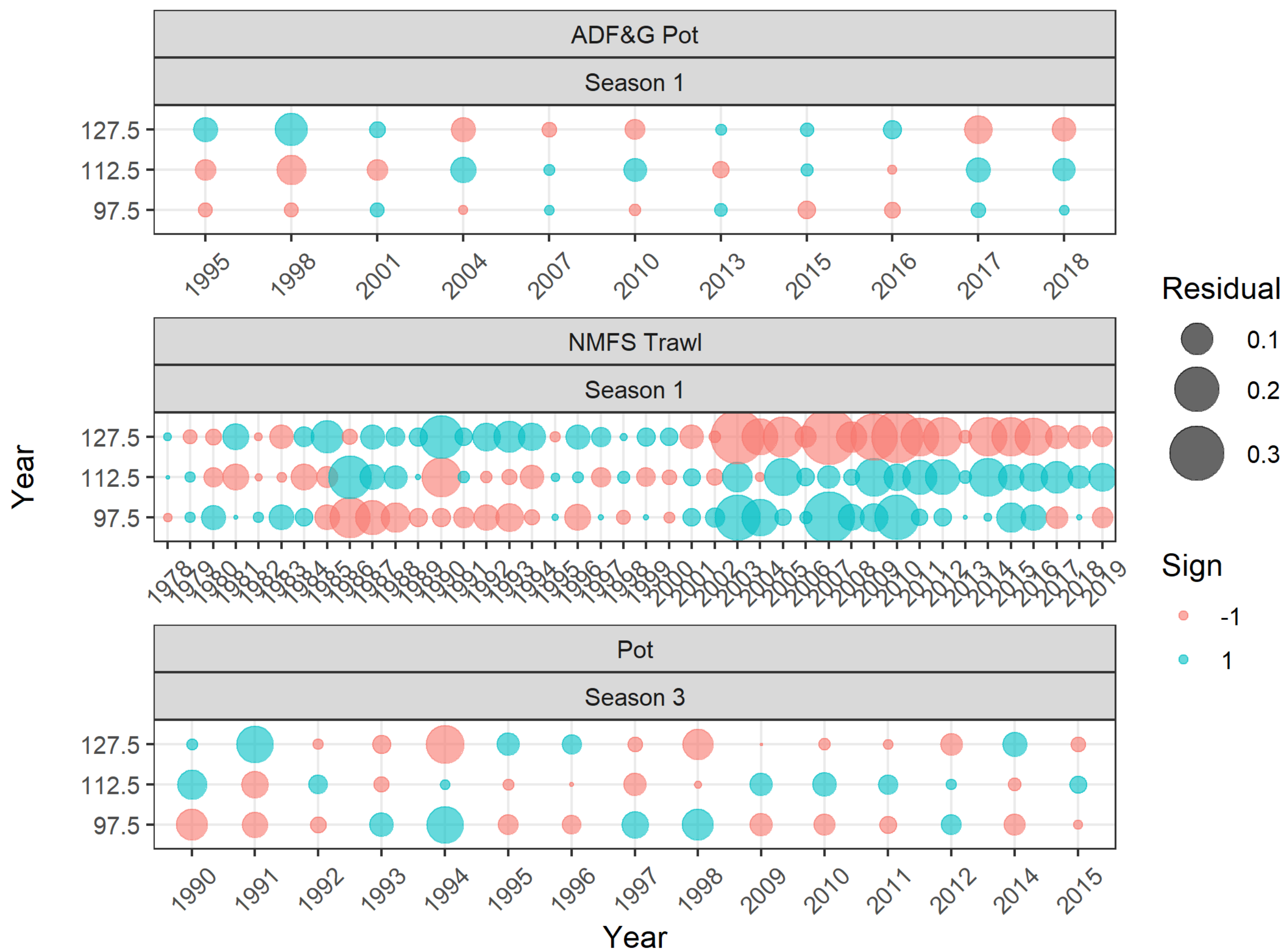

Figure 29: Bubble plots of residuals by stage and year for the all the size composition data sets (ADFG pot survey, NMFS trawl survey, and the directed pot fishery) for SMBKC in the 'reference' model (16.0).

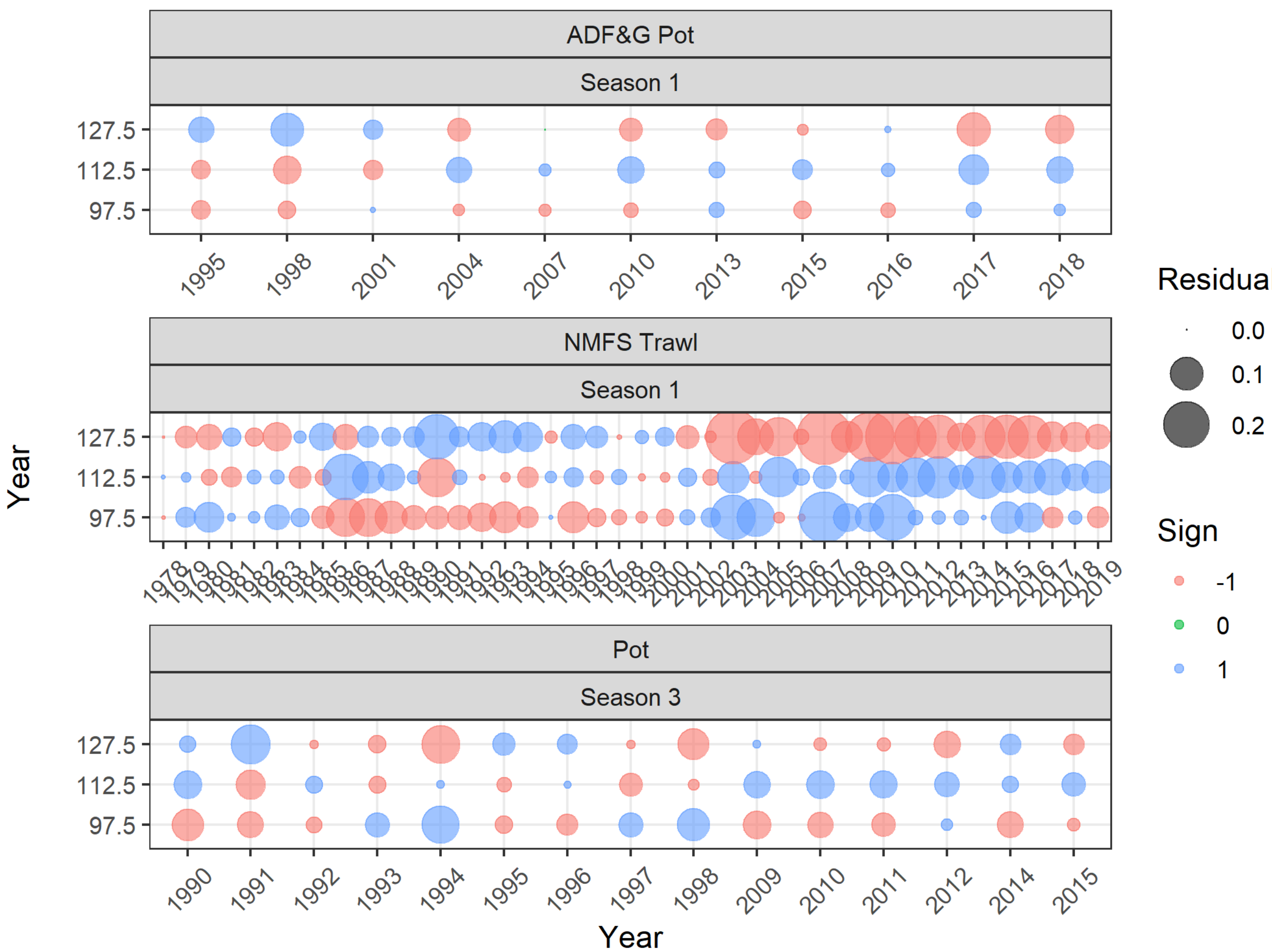

Figure 30: Bubble plots of residuals by stage and year for the all the size composition data sets (ADFG pot survey, NMFS trawl survey, and the directed pot fishery) for SMBKC in the 'VAST' model (19.1).

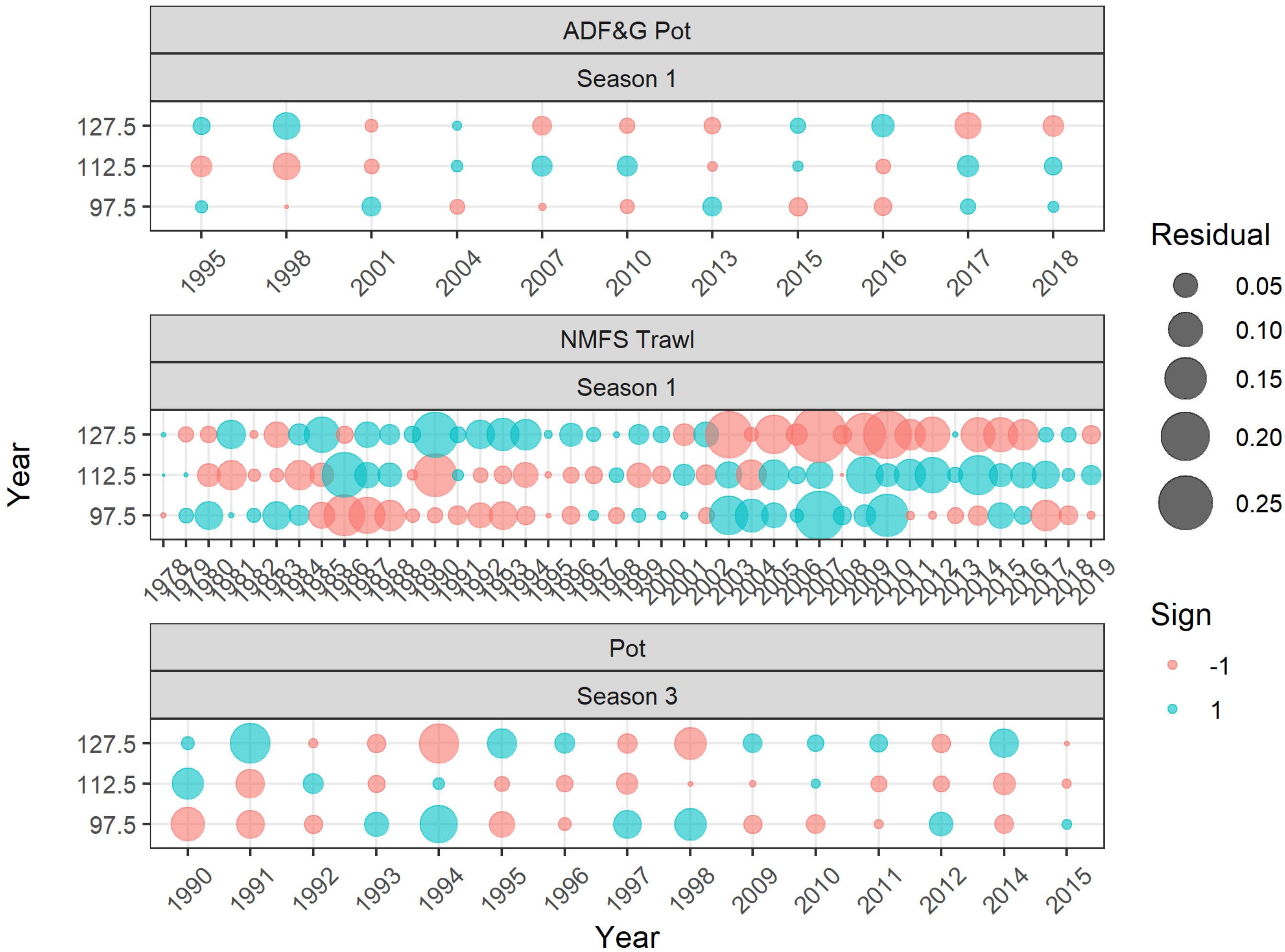

Figure 31: Bubble plots of residuals by stage and year for the all the size composition data sets (ADFG pot survey, NMFS trawl survey, and the directed pot fishery) for SMBKC in the 'add CV pot' model (19.2).

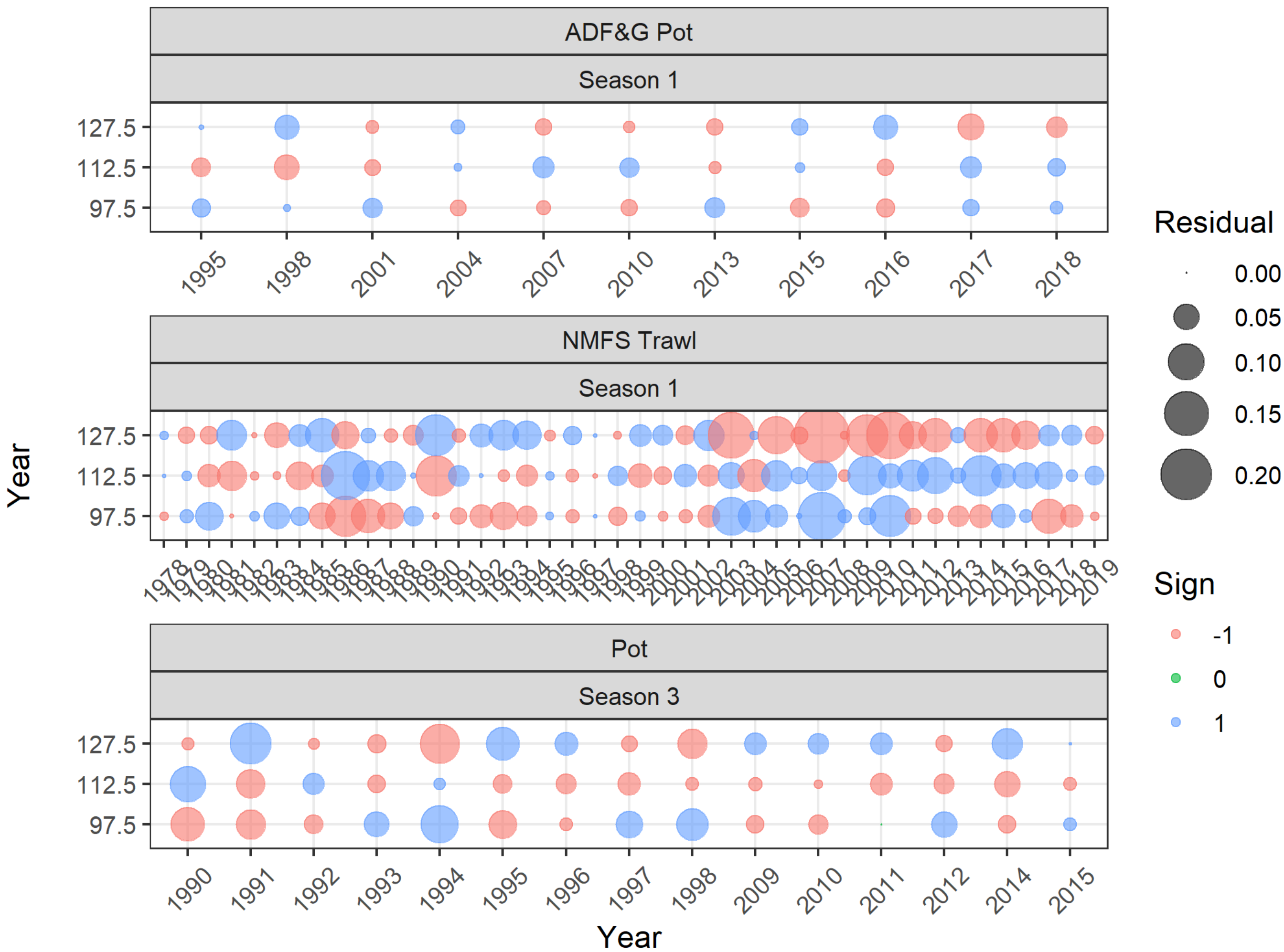

Figure 32: Bubble plots of residuals by stage and year for the all the size composition data sets (ADFG pot survey, NMFS trawl survey, and the directed pot fishery) for SMBKC in the 'add CV both' model (19.3).

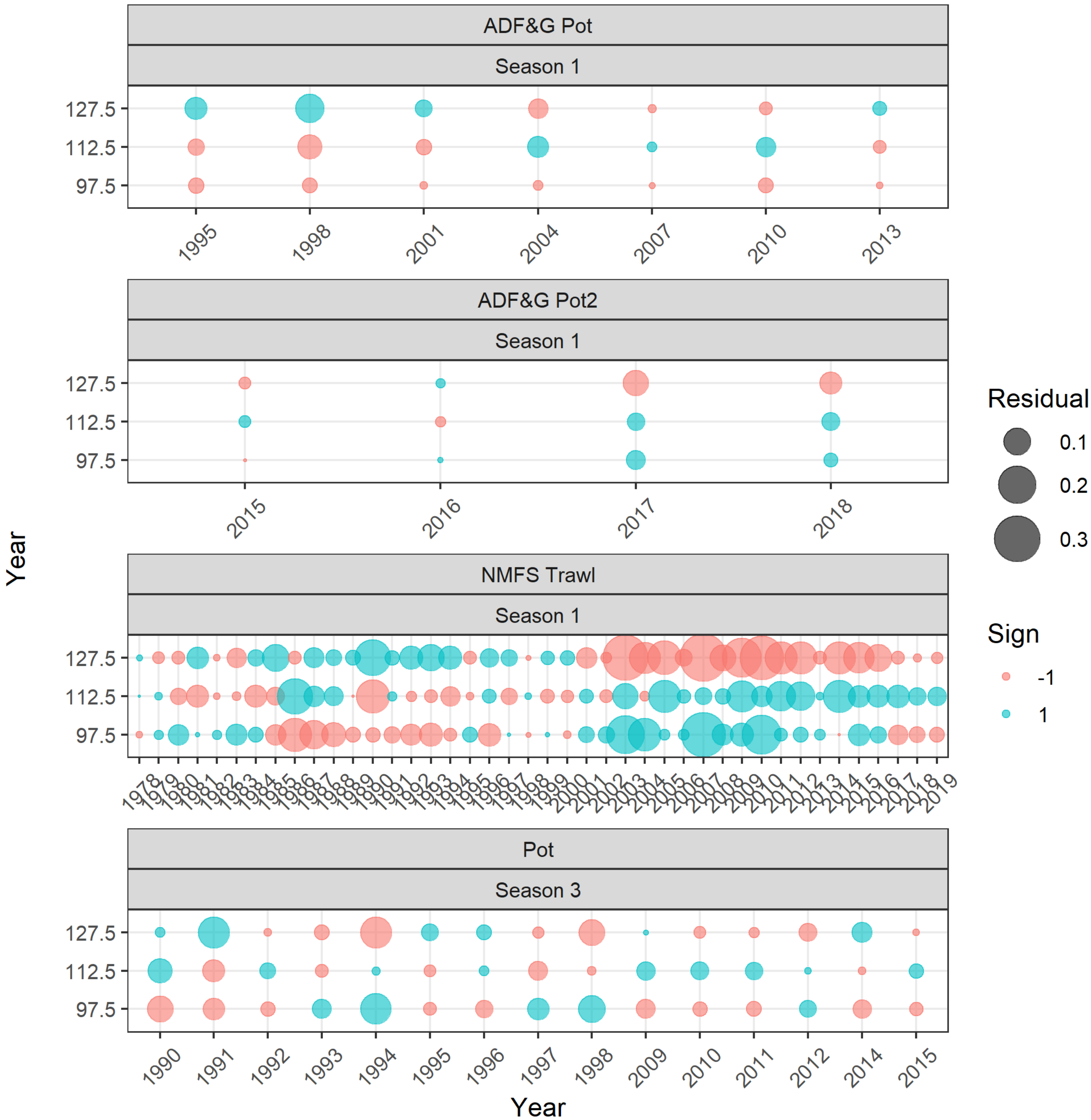

Figure 33: Bubble plots of residuals by stage and year for the all the size composition data sets (ADFG pot survey, NMFS trawl survey, and the directed pot fishery) for SMBKC in the 'q time block pot' model (19.4).

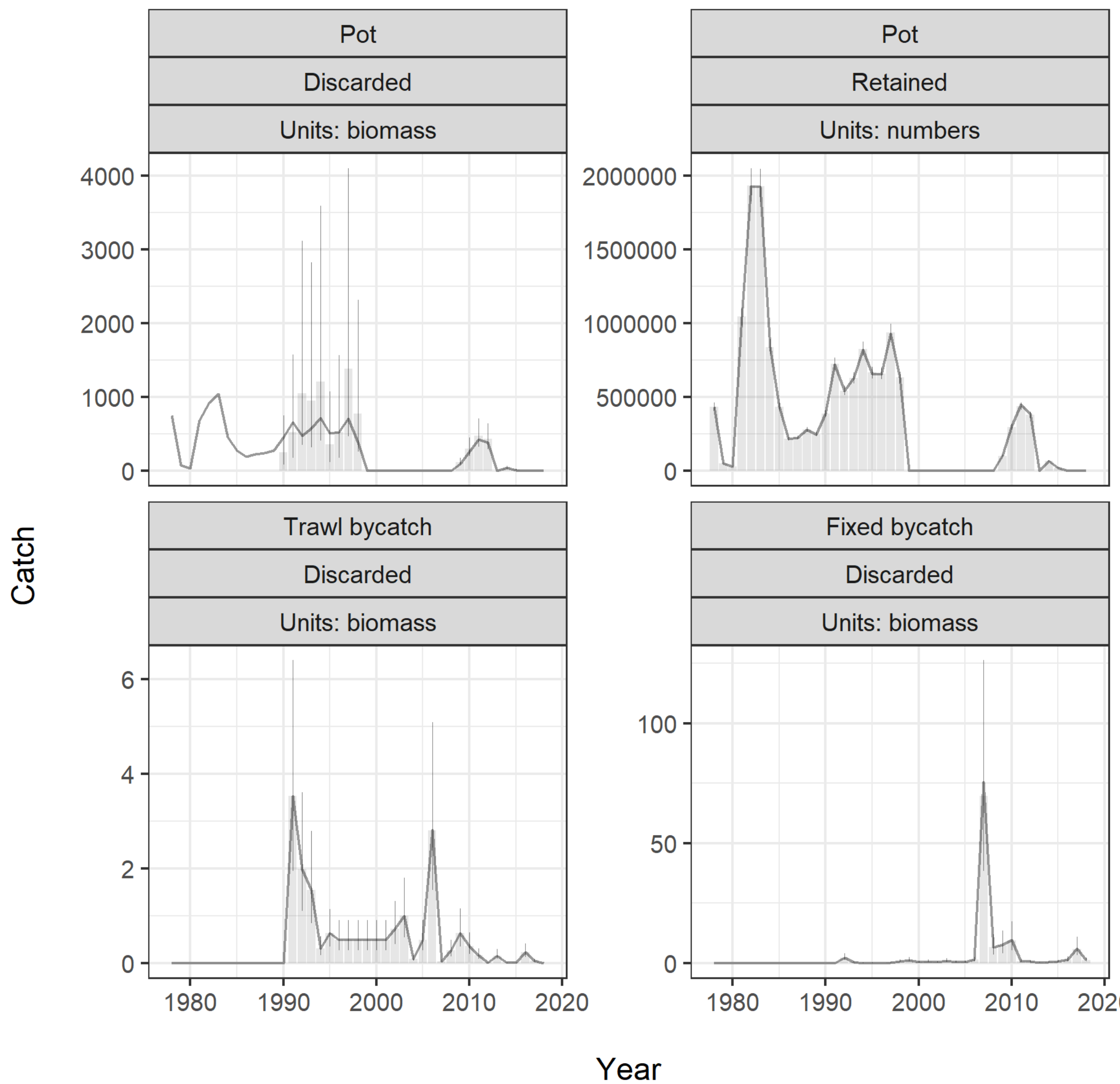

Figure 34: Comparison of observed and model predicted retained catch and bycatches in each of the GMACS models. Note that difference in units between each of the panels, some panels are expressed in numbers of crab, some as biomass (tons).

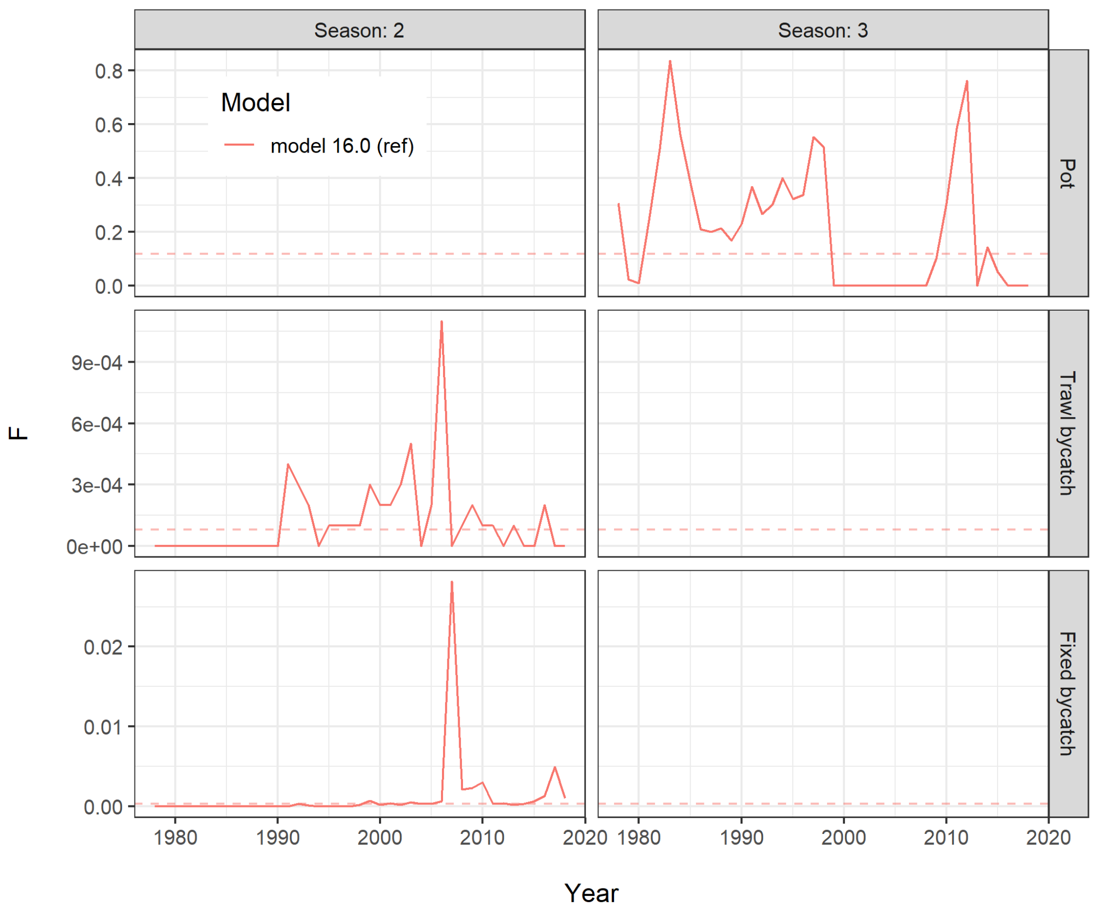

Figure 35: Fishing mortality estimates from the reference model (19.0) for directed and bycatch fleets

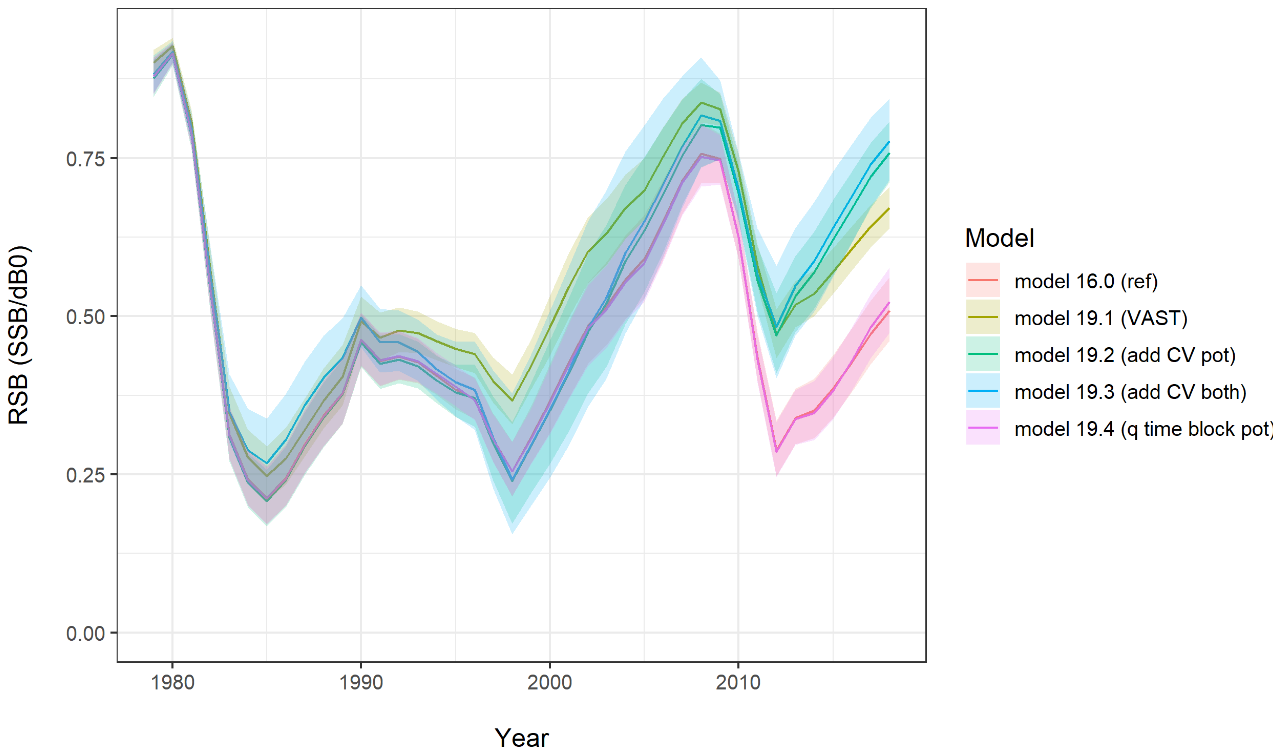

Figure 36: Comparison of mature male biomass relative to the dynamic B zero value, (15 February, 1978-2018) for each of the model scenarios.

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 21. 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 22.

4. Model Parameters

Table 23 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 24 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 19). 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 21: 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

Table 22: 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 23: 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 24: The lower bound (LB), upper bound (UB), initial value, prior, and estimation phase for each estimated model parameter.

Parameter	LB	Initial value	UB	Prior	Phase
Average recruitment $\log(\bar{R})$	-7	10.0	20	Uniform(-7,20)	1
Stage-1 initial numbers $\log(n_1^0)$	5	14.5	20	Uniform(5,20)	1
Stage-2 initial numbers $\log(n_2^0)$	5	14.0	20	Uniform(5,20)	1
Stage-3 initial numbers $\log(n_3^0)$	5	13.5	20	Uniform(5,20)	1
ADF&G pot survey catchability q	0	3.0	5	Uniform(0,5)	1
Stage-1 directed fishery selectivity 1978-2008	0	0.4	1	Uniform(0,1)	3
Stage-2 directed fishery selectivity 1978-2008	0	0.7	1	Uniform(0,1)	3
Stage-1 directed fishery selectivity 2009-2017	0	0.4	1	Uniform(0,1)	3
Stage-2 directed fishery selectivity 2009-2017	0	0.7	1	Uniform(0,1)	3
Stage-1 NMFS trawl survey selectivity	0	0.4	1	Uniform(0,1)	4
Stage-2 NMFS trawl survey selectivity	0	0.7	1	Uniform(0,1)	4
Stage-1 ADF&G pot survey selectivity	0	0.4	1	Uniform(0,1)	4
Stage-2 ADF&G pot survey selectivity	0	0.7	1	Uniform(0,1)	4
Natural mortality deviation during 1998 δ_{1998}^M	-3	0.0	3	Normal(0, σ_M^2)	4
Recruitment deviations δ_y^R	-7	0.0	7	Normal(0, σ_R^2)	3
Average directed fishery fishing mortality $\bar{F}^{\mathrm{df}}$	-	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 2019

```
#====================================================================================================
# Gmacs Main  Data  File  Version 1.1:  SM19 May 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
2018  # 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
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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 28  28 #(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
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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   0.052   0.31    2   1   1   0   0.8
2018    2   2   1   0.001   0.31    2   1   1   0   0.8 # (updated - data is 0 but small value for placeholder)
#   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   1.633   0.31    2   1   1   0   0.5
2017    2   3   1   6.032   0.31    2   1   1   0   0.5
2018    2   3   1   1.281   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
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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
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  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
  ##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
##  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 2019

```
## ==================================================================================== ##
## 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 # (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   2018
   1     2     2   0    0.4    0.001 1.0    0       0      1    3     2009   2018
   1     3     3   0    1.0    0.001 2.0    0       0      1    -2     2009   2018
# Gear-2
   2     7     1   0    40      10.0  200    0      10    200   -3     1978   2018
   2     8     2   0    60      10.0  200    0      10    200   -3     1978   2018
# Gear-3
   3     9     1   0    40      10.0  200    0      10    200   -3     1978   2018
   3    10     2   0    60      10.0  200    0      10    200   -3     1978   2018
# Gear-4
   4     11    1   0    0.7     0.001 1.0    0       0      1   4     1978   2019
   4     12    2   0    0.8     0.001 1.0    0       0      1   4     1978   2019
   4     13    3   0    0.9     0.001 1.0    0       0      1   -5     1978   2019
# Gear-5
   5     14    1   0    0.4     0.001 1.0    0       0      1   4     1978   2019
   5     15    2   0    0.7     0.001 1.0    0       0      1   4     1978   2019
   5     16    3   0    1.0     0.001 2.0    0       0      1   -2     1978   2019
## Retained
# Gear-1
  -1     17    1   0    120        50 200    0      1    900    -7     1978   2018
  -1     18    2   0    123       110 200    0      1    900    -7     1978   2018
# Gear-2
  -2     19    1   0   595    1    999    0      1    999   -3     1978   2018
# Gear-3
  -3     20    1   0   595    1    999    0      1    999   -3     1978   2018
# Gear-4
  -4     21    1   0   595    1    999    0      1    999   -3     1978   2019
# Gear-5
  -5     22    1   0   595    1    999    0      1    999   -3     1978   2019

# 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
2018       # last rec_dev
```

```
   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
```