

Saint Matthew Island Blue King Crab Stock Assessment 2017

James Ianelli¹, D'Arcy Webber², Jie Zheng³, and Alathea Letaw⁴

¹NOAA, jim.ianelli@noaa.gov

²Quantifish, darcy@quantifish.co.nz

³Alaska Department of Fish and Game, jie.zheng@alaska.gov

⁴NOAA, alathea.letaw@noaa.gov

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Executive Summary

1. **Stock:** Blue king crab, *Paralithodes platypus*, Saint Matthew Island (SMBKC), Alaska.
2. **Catches:** Peak historical harvest was 4288 t (9.454 million pounds) in 1983/84¹. 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 in 2016/2017 the fishery was closed.
3. **Stock biomass:** The 1978-2017 NMFS trawl survey mean biomass is 5,762 t with the 8th lowest value occurring in 2017 (the fourth lowest since 2000) with a biomass of \geq 90 mm carapace length (CL) and larger male crab of just under 1,800 t (~31% of the long term mean; 6.12 million lbs with a CV of 60%). The most recent 3-year average of the NMFS survey is 65% of the mean value, suggesting a general decline in biomass compared to the survey estimates in 2010 and 2011 that were nearly twice the current average. The assessment model estimates dampen the interannual variability observed in the survey biomass and suggest that the stock (in survey biomass units) is presently at about 45% of the long term model-predicted survey biomass average. The trend from these values suggests a slight decline.
4. **Recruitment:** Recruitment is based on estimated number of male crab within the 90-104 mm CL size class in each year. The 2017 trawl-survey area-swept estimate of 0.073 million male SMBKC in this size class is the lowest in the 40 years since 1978 and caps a six-year (2012 - 2017) average recruitment that is only 54% of this 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).
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 stock was above the minimum stock-size threshold (MSST) in 2016/17 and is hence not overfished. Overfishing did not occur in this year as the directed fishery was closed (Tables 1 and 2). Nonetheless, the low survey values and paucity of crabs in the region, as indicated by the surveys, remains a concern.

¹1983/84 refers to a fishing year that extends from 1 July 1983 to 30 June 1984.

Table 1: Status and catch specifications (1000 t) for the reference model. Notes: A - calculated from the assessment reviewed by the Crab Plan Team in September 2013, B - calculated from the assessment reviewed by the Crab Plan Team in September 2014, C - calculated from the assessment reviewed by the Crab Plan Team in September 2015, D - calculated from the assessment reviewed by the Crab Plan Team in September 2016, E - calculated from the assessment reviewed by the Crab Plan Team in September 2017.

| Year | MSST | Biomass (MMB_{mating}) | TAC | Retained catch | Total male catch | OFL | ABC |
|---------|-------------------|-------------------------------|------|-------------------|---------------------|------|------|
| 2012/13 | 1.80 ^A | 2.85 ^A | 0.74 | 0.73 | 0.82 | 1.02 | 0.92 |
| 2013/14 | 1.50 ^B | 3.01 ^B | 0.00 | 0.00 | 0.00 | 0.56 | 0.45 |
| 2014/15 | 1.86 ^C | 2.48 ^C | 0.30 | 0.14 | 0.15 | 0.43 | 0.34 |
| 2015/16 | 1.84 ^D | 2.11 ^D | 0.19 | 0.05 | 0.05 | 0.28 | 0.22 |
| 2016/17 | 1.97 ^E | 2.12 ^E | 0.00 | 0.00 | 0.05 | 0.28 | 0.22 |
| 2017/18 | | 2.18 ^E | | | | 0.12 | 0.1 |

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 |
|---------|------------------|-------------------------------|-------|-------------------|---------------------|------|------|
| 2012/13 | 4.0 ^A | 6.29 ^A | 1.630 | 1.616 | 1.81 | 2.24 | 2.02 |
| 2013/14 | 3.4 ^B | 6.64 ^B | 0.000 | 0.000 | 0.0006 | 1.24 | 0.99 |
| 2014/15 | 4.1 ^C | 5.47 ^C | 0.655 | 0.309 | 0.329 | 0.94 | 0.75 |
| 2015/16 | 4.1 ^D | 4.65 ^D | 0.419 | 0.110 | 0.110 | 0.62 | 0.49 |
| 2016/17 | 4.3 ^E | 4.68 ^E | 0.41 | 0.000 | 0.000 | 0.62 | 0.49 |
| 2017/18 | | 4.81 ^E | | | | 0.27 | 0.22 |

6. **Basis for the OFL:** Estimated mature-male biomass (MMB) on 15 February is used as the measure of biomass for this Tier 4 stock, with males measuring 105 mm CL or more considered mature. The B_{MSY} proxy is obtained by averaging estimated MMB over a specific reference time period, and current CPT/SSC guidance recommends using the full assessment time frame as the default reference period (Table 3).

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 |
|---------|------|-----------|-------------------------------|-------------|-----------|----------|---------------------|-------------------|
| 2012/13 | 4a | 3.56 | 5.63 | 1.56 | 0.18 | 1 | 1978-2012 | 0.18 |
| 2013/14 | 4b | 3.06 | 3.01 | 0.98 | 0.18 | 1 | 1978-2013 | 0.18 |
| 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 | 3.93 | 2.18 | 0.55 | 0.09 | 1 | 1978-2016 | 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 makes use of two new survey data points including the 2017 NMFS trawl-survey estimate of abundance, and the 2017 ADF&G pot survey CPUE. Both of these surveys have associated size composition data. The assessment also uses updated 2010-2016 groundfish and fixed gear bycatch estimates based on NMFS Alaska Regional Office (AKRO) data. There was no directed fishery data due to the 2016/17 closure.

Changes in Assessment Methodology

As with 2016, this assessment is done using the General model for Alaskans crab stocks (Gmacs) framework. The model is configured to track three stages of length categories and was first presented in May 2011 by Bill Gaeuman and accepted by the CPT in May 2012. A difference from the original approach and that used here is that natural and fishing mortality are continuous within 5 discrete seasons (using the appropriate catch equation rather than assuming an applied pulse removal). Season length in Gmacs is controlled by changing the proportion of natural mortality that is applied each season. An added diagnostic output is provided to include estimates of the “dynamic B_0 .” This simply computes the ratio of the spawning biomass as estimated relative to the spawning biomass that would have occurred had there been no historical fishing mortality. Details of this implementation are provided in Appendix A.

Changes in Assessment Results

Both surveys indicate a decline over the past few years. The “reference” model is that selected for use in 2016. The addition of new data introduced this year area are presented sequentially. Two alternative models are presented for sensitivity. One involves a re-analysis of the NMFS trawl survey data using a spatio-temporal Delta-GLMM approach (VAST model, Thorson and Barnett 2017) and the other configuration (named “Fit survey”) simply adds emphasis on the survey data (assumes a lower input variance). In all cases, the model tends to moderate the declines observed in the surveys.

B. Responses to SSC and CPT Comments

CPT and SSC Comments on Assessments in General

Comment: *Regarding general code development, the CPT had the following requests:*

1. *specify priors (e.g., gamma) using mean and variance/standard deviation for all parameters to ease specifying priors*

This was completed.

2. *include an option to calculate dynamic B_{MSY}*

This was completed.

3. *add the ability to “jitter” initial parameter values*

The framework for conducting this research has been added but has yet to be fully tested.

4. *add the ability to conduct retrospective analyses*

Incomplete.

5. add ability to estimate bycatch fishing mortality rates when observer data are missing but effort data is available

This was completed.

6. 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 introduced an alternative time-series estimated from the NMFS trawl survey using the VAST spatio-temporal Delta GLMM model and continued with the iterative re-weighting for composition data.

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 ($58^{\circ}39'$ N. lat.) and south of Cape Romanzof ($61^{\circ}49'$ N. lat.).

Stock Structure

The Alaska Department of Fish and Game (ADF&G) Gene Conservation Laboratory division, has detected regional population differences between blue king crab collected from St. Matthew Island and the Pribilof Islands². 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

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

CL. Spermatophore diameter also increased with increasing CL with an asymptote at ~ 100 mm CL. They noted, however, that although spermatophore 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 4288 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 (460,859 pounds) with a reported effort of 10,697 pot lifts and an estimated CPUE of 9.9 retained individual crab per pot lift. The fishery remained open the next three years with modest harvests and similar CPUE, but large declines in the NMFS trawl-survey estimate of stock abundance raised concerns about the health of the stock. This prompted ADF&G to close the fishery again for the 2013/14 season. The fishery was reopened for the 2014/15 season with a low TAC of 297 t (0.655 million pounds) and in 2015/16 the TAC was further reduced to 186 t (0.411 million pounds) then completely closed during 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 2009/10³. 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. NMFS observer data suggest that variable but mostly limited SMBKC bycatch has also occurred in the eastern Bering Sea groundfish fisheries (Table 6).

³D. Pengilly, ADF&G, pers. comm.

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 makes use of two new survey data points including the 2017 NMFS trawl-survey estimate of abundance, and the 2017 ADF&G pot survey CPUE. Both of these surveys have associated size composition data. The assessment also uses updated 1993-2016 groundfish and fixed gear bycatch estimates based on AKRO data. The fishery was closed in 2016/17 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 (1978-2017; Table 8); results from the ADF&G SMBKC pot survey (every third year during 1995-2013, then 2015-2017; 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 NMFS groundfish-observer bycatch biomass estimates (1992/93-2016/17; 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 NMFS Bering Sea reporting areas 521 and 524 (Figure 6).

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 (Zheng et al. 1997). The four-stage CSA is similar to a full length-based analysis, the major difference being coarser length groups, which are more suited to a small stock with consistently low survey catches. In this approach, the abundance of male crab with a CL \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 5.5in 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 ≥ 90 mm in CL, but combined stages 3 and 4 of the earlier model resulting in just three stages (male size classes) determined 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 were presented in the previous assessment. This year, four models are presented with the reference model being the same configuration as last year, three sensitivities are considered, one with a different treatment of NMFS bottom trawl survey (BTS) data using a geo-spatial model (VAST; Thorson and Barnett 2017), another which weights the survey data more heavily, and a third which weights the size composition data according to Francis' (2011) approach. In addition to these sensitivities, we also evaluated the impact of adding new data to the reference model. In summary, the following lists the models presented and the naming convention used:

1. **2016 Model:** the 2016 recommended model without any new data
2. **BTS:** adds in the 2017 bottom trawl survey (BTS) data
3. **BTS and pot:** as with previous but including the 2017 ADFG pot survey data (Model 16.0 or “reference case”)
4. **VAST:** applies a geo-spatial delta-GLMM model (Thorson and Barnett 2017) to the BTS data which provides a different BTS index. See appendix B for details and diagnostics. This is a preliminary examination as more work is needed to ensure options for the BTS CPUE data were specified appropriately.
5. **Fit survey:** an exploratory scenario that's the same as the reference model except the NMFS trawl survey is up-weighted by $\lambda^{\text{NMFS}} = 1.5$ and the ADF&G pot survey is up-weighted by $\lambda^{\text{ADFG}} = 2$.
6. **Francis weights:** is similar to the reference model except that it also uses the Francis iterative re-weighting method (Francis 2011), to re-weight the size-composition data relative to the abundance indices. The trawl survey and pot survey weights were unchanged. In this scenario the multinomial distribution was used instead as the theory underpinning the Francis weighting method is based on this distribution.

Note that SSC convention would label these (item 3 above) as model 16.0 (the model used last year). Since so few models are presented here, for simplicity model 16.0 is labeled “reference” and for the others, the naming convention above was used to make it easier to remember the main characteristic of the model configuration.

Results

a. Sensitivity to new data

Results for scenarios are provided with comparisons to the 2016 model and sensitivity new data are shown in Figures 7 and 8 with recruitment and spawning biomass shown in Figures 9 and 10, respectively. The fits to survey CPUEs and spawning biomass show that the addition of new data results in more of a decline than in the 2016 assessment, especially with the addition of the pot survey. The model with all new data is henceforth referred to as the “reference model.”

b. Alternative NMFS bottom-trawl survey index

Results comparing model fits between the “VAST” spatio-temporal index and the reference case show different time-series of data and a different model fit (Figure 11). The effect on spawning biomass suggests estimates were consistently higher since 1990 compared to the reference model (Figure 12).

c. 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 mean absolute residual (MAR) are presented in Table 17. The SDNR for the trawl survey is acceptable at 1.45 in the reference model, and improves to 1.36 in the **Francis weight** model (since size composition data are re-weighted). The SDNRs for the pot surveys show much the same pattern between each of the scenarios, but are much higher values (ranging from 3.72 to 5.45). These values are very high, and whilst they can be improved by down-weighting the pot survey, we chose to retain the values as the pot survey considered important to include (down-weighting the data further would effectively exclude the signal from this series). The MAR for the trawl and pot surveys shows the same pattern among each of the scenarios as the SDNR. The SDNR (and MAR) values for the trawl survey and pot survey size compositions were excellent, ranging from 0.49 to 0.78. The SDNRs for the directed pot fishery and other size compositions were all acceptable.

d. Parameter estimates

Model parameter estimates for each of the Gmacs scenarios are summarized in Tables 12, 13, 15, and 16. These parameter estimates are compared in Table 16. Negative log-likelihood values and management measures for each of the model configurations are compared in Tables 4 through 18.

There are some differences in parameter estimates among models as reflected in the log-likelihood components and the management quantities. The parameter estimates in the “fit survey” scenario differ the most, as expected, particularly the estimate of the ADF&G pot survey catchability (q) (see Table 16).

c. Graphs of estimates.

Selectivity estimates show some variability between models (Figure 13). Estimated recruitment is variable over time for all models and in recent years is well below average (Figure 14). Estimated mature male biomass on 15 February also fluctuates considerably (Figure 15). Estimated natural mortality each year (M_t) is presented in Figure 16.

d. Evaluation of the fit to the data.

The model fits to total male (≥ 90 mm CL) trawl survey biomass tend to miss the recent peak around 2010 and is slightly above the 2017 value for the key sensitivities (Figures 17). All of the models fit the pot survey

CPUE poorly (Figure 18). For both surveys the standardized residuals tend to have similar patterns with some improvement (generally) for the VAST model (Figures 19 and 20).

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 21, 22, and 23) for all scenarios. Representative residual plots of the composition data fits are generally poor (Figures 24 and 25). 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 26).

The contrast between the reference model and the “Francis weighted” model show minor differences (Figures 17 and 18). Unsurprisingly, the **fit surveys** model configuration fits the NMFS survey biomass and ADF&G pot survey CPUE data better but still has a similar residual pattern (note that this scenario was only included for exploratory purposes and forcing these weights resulted in worse SDNR and MAR values for the two abundance indices).

e. Retrospective and historic analyses.

The ability to conduct retrospective analyses with this software remains under development.

f. Uncertainty and sensitivity analyses.

Estimated standard deviations of parameters and selected management measures for the four models are summarized in Tables 12, 13, 14, and 15 (and compiled together in Table 16). Probabilities for mature male biomass and OFL in 2017 are presented in Section F.

g. Comparison of alternative model scenarios.

The estimates of mature male biomass (Figure 15), for the **fit surveys** sensitivity stands out as being quite different from the other models due to a low value for pot survey catchability being estimated (which tends to scale the population). This scenario results in a lower MMB from the mid-1980s through to the late-1990s, and is again lower in the most recent 5 years. This scenario upweights both the trawl survey and the pot survey abundance indices (it upweights the pot survey more than the trawl survey) and represents a model run that places greater trust in the abundance indices, particularly the pot survey, than other data sources.

In summary, the use of the reference model for management purposes is preferred since it provides the best fit to the data and is consistent with previous model specifications. Research on alternative model specifications (e.g., natural mortality variability) was limited this year. The model using the “VAST” time series may take better account of spatial processes but requires more research to ensure it has been appropriately applied and the assumptions are reasonable. Consequently, the reference model appears reasonable and appropriate for ACL and OFL determinations for this stock in 2017. Nonetheless, the **Fit surveys** model, while difficult to statistically justify, portends a more dire stock status (see below) and should highlight the caution needed in managing this resource.

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 (2013 SAFE), 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

$$F_{OFL} = \begin{cases} F_{MSY}, & \text{when } B/B_{MSY} > 1 \\ F_{MSY} \frac{(B/B_{MSY} - \alpha)}{(1-\alpha)}, & \text{when } \beta < B/B_{MSY} \leq 1 \\ F_{OFL} < F_{MSY} \text{ with directed fishery } F = 0 \text{ when } B/B_{MSY} \leq \beta \end{cases} \quad (1)$$

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- 2016, to define a B_{MSY} proxy in terms of average estimated MMB and to set $\gamma = 1.0$ with assumed stock natural mortality $M = 0.18 \text{ yr}^{-1}$ 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 2017 for all scenarios are summarized in Table 4. ABC is 80% of the OFL.

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

| Component | Reference | VAST | Fit surveys | Francis weights |
|--------------|-----------|----------|-------------|-----------------|
| MMB_{2017} | 2179.720 | 3010.644 | 5674.035 | 2085.382 |
| B_{MSY} | 3930.576 | 4360.343 | 9828.733 | 3861.300 |
| F_{OFL} | 0.079 | 0.103 | 0.083 | 0.076 |
| OFL_{2017} | 123.613 | 220.403 | 367.946 | 117.651 |
| ABC_{2017} | 98.891 | 176.323 | 294.357 | 94.121 |

G. Rebuilding Analysis

This stock is not currently subject to a rebuilding plan.

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. Temporal changes in spatial distributions near the island.
4. Natural mortality.

I. Projections and Future Outlook

The outlook for recruitment looks relatively pessimistic. The dynamic- B_0 analysis, which removes historical fishing and projects the population based on estimated recruitments, indicates that the effect of fishing has reduced the stock to about 68%. The other aspects of depletion (ignoring stock-recruit relationship) may reflect variable survival rates due to environmental conditions and range shifts.

J. Acknowledgements

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K. References

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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 | | | 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 | 0.635 | 7.530 |
| 2010 | 0.363 | 9.571 |
| 2011 | 0.181 | 1.800 |
| 2012 | 0.100 | 1.600 |
| 2013 | 0.400 | 0.800 |
| 2014 | 0.100 | 1.100 |
| 2015 | 0.100 | 1.600 |
| 2016 | 0.500 | 3.600 |

Table 7: 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 omitted.

| Year | Dates | GHL/TAC | Harvest | | | | | |
|-------------------|---------------|---------|-----------|----------------|-----------|------|--------|--------|
| | | | 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 | | | | |

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

| Year | Abundance | | | Biomass | | | Number of crabs | |
|------|------------------------|-------------------------|----------------------|---------|-------|----------------------|-----------------|-----|
| | Stage-1 (90-104 mm) | Stage-2 (105-119 mm) | Stage-3 (120+ mm) | Total | CV | Total (90+ mm CL) | CV | |
| 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 |

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 | Stage-2 | Stage-3 | Total CPUE | CV | Number of crabs |
|------|-------------|--------------|-----------|------------|------|-----------------|
| | (90-104 mm) | (105-119 mm) | (120+ mm) | | | |
| 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 |

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 |

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.

| Year | Number measured | | | Input sample sizes | | |
|------|-----------------|------------|-----------|--------------------|------------|-----------|
| | 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 | | 50 | 100 |

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

| Parameter | Estimate | SD |
|--|----------|--------|
| Natural mortality deviation in 1998/99 (δ_{1998}^M) | 1.652 | 0.127 |
| $\log(\bar{R})$ | 14.064 | 0.060 |
| $\log(n_1^0)$ | 14.922 | 0.171 |
| $\log(n_2^0)$ | 14.551 | 0.201 |
| $\log(n_3^0)$ | 14.360 | 0.206 |
| q_{pot} | 3.644 | 0.280 |
| $\log(\bar{F}^{df})$ | -1.923 | 0.053 |
| $\log(\bar{F}^{tb})$ | -9.019 | 0.082 |
| $\log(\bar{F}^{fb})$ | -8.217 | 0.082 |
| log Stage-1 directed pot selectivity 1978-2008 | -0.654 | 0.174 |
| log Stage-2 directed pot selectivity 1978-2008 | -0.315 | 0.126 |
| log Stage-1 directed pot selectivity 2009-2017 | -0.463 | 0.154 |
| log Stage-2 directed pot selectivity 2009-2017 | -0.000 | 0.000 |
| log Stage-1 NMFS trawl selectivity | -0.243 | 0.066 |
| log Stage-2 NMFS trawl selectivity | -0.000 | 0.000 |
| log Stage-1 ADF&G pot selectivity | -0.852 | 0.127 |
| log Stage-2 ADF&G pot selectivity | -0.026 | 0.078 |
| F_{OFL} | 0.079 | 0.010 |
| OFL | 123.610 | 28.638 |

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

| Parameter | Estimate | SD |
|--|----------|--------|
| Natural mortality deviation in 1998/99 (δ_{1998}^M) | 1.710 | 0.108 |
| $\log(\bar{R})$ | 14.205 | 0.050 |
| $\log(n_1^0)$ | 14.952 | 0.168 |
| $\log(n_2^0)$ | 14.592 | 0.193 |
| $\log(n_3^0)$ | 14.424 | 0.192 |
| q_{pot} | 2.926 | 0.166 |
| $\log(\bar{F}^{df})$ | -2.037 | 0.042 |
| $\log(\bar{F}^{tb})$ | -9.220 | 0.070 |
| $\log(\bar{F}^{fb})$ | -8.419 | 0.070 |
| log Stage-1 directed pot selectivity 1978-2008 | -0.701 | 0.171 |
| log Stage-2 directed pot selectivity 1978-2008 | -0.331 | 0.124 |
| log Stage-1 directed pot selectivity 2009-2017 | -0.319 | 0.145 |
| log Stage-2 directed pot selectivity 2009-2017 | -0.000 | 0.000 |
| log Stage-1 NMFS trawl selectivity | -0.241 | 0.062 |
| log Stage-2 NMFS trawl selectivity | -0.000 | 0.000 |
| log Stage-1 ADF&G pot selectivity | -0.798 | 0.123 |
| log Stage-2 ADF&G pot selectivity | -0.000 | 0.000 |
| F_{OFL} | 0.103 | 0.009 |
| OFL | 220.400 | 32.463 |

Table 14: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the "Fit survey" model.

| Parameter | Estimate | SD |
|--|----------|--------|
| Natural mortality deviation in 1998/99 (δ_{1998}^M) | 2.160 | 0.107 |
| $\log(\bar{R})$ | 14.583 | 0.065 |
| $\log(n_1^0)$ | 15.456 | 0.417 |
| $\log(n_2^0)$ | 15.288 | 0.438 |
| $\log(n_3^0)$ | 15.120 | 0.418 |
| q_{pot} | 1.010 | 0.052 |
| $\log(\bar{F}^{df})$ | -2.901 | 0.045 |
| $\log(\bar{F}^{tb})$ | -10.043 | 0.071 |
| $\log(\bar{F}^{fb})$ | -9.243 | 0.071 |
| log Stage-1 directed pot selectivity 1978-2008 | -0.343 | 0.141 |
| log Stage-2 directed pot selectivity 1978-2008 | -0.082 | 0.119 |
| log Stage-1 directed pot selectivity 2009-2017 | -0.000 | 0.000 |
| log Stage-2 directed pot selectivity 2009-2017 | -0.000 | 0.000 |
| log Stage-1 NMFS trawl selectivity | -0.000 | 0.000 |
| log Stage-2 NMFS trawl selectivity | -0.000 | 0.000 |
| log Stage-1 ADF&G pot selectivity | -0.000 | 0.000 |
| log Stage-2 ADF&G pot selectivity | -0.000 | 0.000 |
| F_{OFL} | 0.083 | 0.006 |
| OFL | 367.950 | 44.694 |

Table 15: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the "Francis weights" model.

| Parameter | Estimate | SD |
|--|----------|--------|
| Natural mortality deviation in 1998/99 (δ_{1998}^M) | 1.634 | 0.136 |
| $\log(\bar{R})$ | 14.033 | 0.064 |
| $\log(n_1^0)$ | 14.885 | 0.285 |
| $\log(n_2^0)$ | 14.561 | 0.318 |
| $\log(n_3^0)$ | 14.361 | 0.317 |
| q_{pot} | 3.526 | 0.248 |
| $\log(\bar{F}^{df})$ | -1.884 | 0.060 |
| $\log(\bar{F}^{tb})$ | -9.044 | 0.081 |
| $\log(\bar{F}^{fb})$ | -8.243 | 0.081 |
| log Stage-1 directed pot selectivity 1978-2008 | -0.514 | 0.157 |
| log Stage-2 directed pot selectivity 1978-2008 | -0.319 | 0.128 |
| log Stage-1 directed pot selectivity 2009-2017 | -0.420 | 0.141 |
| log Stage-2 directed pot selectivity 2009-2017 | -0.000 | 0.000 |
| log Stage-1 NMFS trawl selectivity | -0.181 | 0.083 |
| log Stage-2 NMFS trawl selectivity | -0.000 | 0.000 |
| log Stage-1 ADF&G pot selectivity | -0.799 | 0.092 |
| log Stage-2 ADF&G pot selectivity | -0.000 | 0.000 |
| F_{OFL} | 0.076 | 0.010 |
| OFL | 117.650 | 26.963 |

Table 16: Comparisons of parameter estimates for the four model scenarios.

| Parameter | Ref | VAST | FitSurvey | Francis |
|--|---------|---------|-----------|---------|
| $\log(\bar{F}^{\text{df}})$ | -1.923 | -2.037 | -2.901 | -1.884 |
| $\log(\bar{F}^{\text{fb}})$ | -8.217 | -8.419 | -9.243 | -8.243 |
| $\log(\bar{F}^{\text{tb}})$ | -9.019 | -9.220 | -10.043 | -9.044 |
| $\log(\bar{R})$ | 14.064 | 14.205 | 14.583 | 14.033 |
| $\log(n_1^0)$ | 14.922 | 14.952 | 15.456 | 14.885 |
| $\log(n_2^0)$ | 14.551 | 14.592 | 15.288 | 14.561 |
| $\log(n_3^0)$ | 14.360 | 14.424 | 15.120 | 14.361 |
| F_{OFL} | 0.079 | 0.103 | 0.083 | 0.076 |
| q_{pot} | 0.004 | 0.003 | 0.001 | 0.004 |
| log Stage-1 ADF&G pot selectivity | -0.852 | -0.798 | -0.000 | -0.799 |
| log Stage-1 directed pot selectivity 1978-2008 | -0.654 | -0.701 | -0.343 | -0.514 |
| log Stage-1 directed pot selectivity 2009-2017 | -0.463 | -0.319 | -0.000 | -0.420 |
| log Stage-1 NMFS trawl selectivity | -0.243 | -0.241 | -0.000 | -0.181 |
| log Stage-2 ADF&G pot selectivity | -0.026 | -0.000 | -0.000 | -0.000 |
| log Stage-2 directed pot selectivity 1978-2008 | -0.315 | -0.331 | -0.082 | -0.319 |
| log Stage-2 directed pot selectivity 2009-2017 | -0.000 | -0.000 | -0.000 | -0.000 |
| log Stage-2 NMFS trawl selectivity | -0.000 | -0.000 | -0.000 | -0.000 |
| Natural mortality deviation in 1998/99 (δ_{1998}^M) | 1.652 | 1.710 | 2.160 | 1.634 |
| OFL | 123.610 | 220.400 | 367.950 | 117.650 |

Table 17: Comparisons of data weights, Francis LF weights (i.e. the new weights that should be applied to the LFs), SDNR values, and MAR values for the four model scenarios.

| Component | Reference | VAST | Fit survey | Francis |
|---|-----------|------|------------|---------|
| NMFS trawl survey weight | 1.00 | 1.00 | 1.50 | 1.00 |
| ADF&G pot survey weight | 1.00 | 1.00 | 2.00 | 1.00 |
| Directed pot LF weight | 1.00 | 1.00 | 1.95 | 1.61 |
| NMFS trawl survey LF weight | 1.00 | 1.00 | 0.22 | 0.50 |
| ADF&G pot survey LF weight | 1.00 | 1.00 | 0.10 | 3.72 |
| Francis weight for directed pot LF | 1.69 | 1.57 | 1.96 | 1.55 |
| Francis weight for NMFS trawl survey LF | 0.57 | 0.53 | 0.22 | 0.50 |
| Francis weight for ADF&G pot survey LF | 2.08 | 1.20 | 0.10 | 4.13 |
| SDNR NMFS trawl survey | 1.45 | 1.85 | 1.83 | 1.36 |
| SDNR ADF&G pot survey | 3.78 | 3.88 | 5.45 | 3.72 |
| SDNR directed pot LF | 0.71 | 0.78 | 1.39 | 0.91 |
| SDNR NMFS trawl survey LF | 1.23 | 1.28 | 1.06 | 0.94 |
| SDNR ADF&G pot survey LF | 0.80 | 0.92 | 0.96 | 1.01 |
| MAR NMFS trawl survey | 1.18 | 1.13 | 1.52 | 1.12 |
| MAR ADF&G pot survey | 2.96 | 2.63 | 4.57 | 2.97 |
| MAR directed pot LF | 0.59 | 0.66 | 0.66 | 0.76 |
| MAR NMFS trawl survey LF | 0.52 | 0.62 | 0.69 | 0.53 |
| MAR ADF&G pot survey LF | 0.49 | 0.78 | 0.55 | 0.59 |

Table 18: Comparisons of negative log-likelihood values for the four model scenarios. It is important to note that some of these models cannot be compared since the input sample size (or variances) are modified by re-weighting (e.g., **Francis** model).

| Component | Ref | VAST | FitSurvey | Francis |
|-------------------------------|--------|--------|-----------|---------|
| Pot Retained Catch | -71.53 | -71.15 | -70.53 | -71.50 |
| Pot Discarded Catch | 8.98 | 11.73 | 43.00 | 12.74 |
| Trawl bycatch Discarded Catch | -7.16 | -7.16 | -7.16 | -7.16 |
| Fixed bycatch Discarded Catch | -7.13 | -7.14 | -7.15 | -7.14 |
| NMFS Trawl Survey | -3.93 | 2.28 | 6.96 | -8.93 |
| ADF&G Pot Survey CPUE | 57.07 | 62.32 | 130.07 | 54.50 |
| Directed Pot LF | -11.31 | -9.15 | 22.78 | 9.96 |
| NMFS Trawl LF | 18.24 | 26.27 | 92.24 | 55.53 |
| ADF&G Pot LF | -7.40 | -4.61 | 32.83 | -6.46 |
| Recruitment deviations | 52.94 | 51.61 | 59.96 | 53.48 |
| F penalty | 14.49 | 14.49 | 14.49 | 14.49 |
| M penalty | 6.47 | 6.47 | 6.49 | 6.47 |
| Prior | 12.66 | 12.62 | 13.61 | 12.66 |
| Total | 62.39 | 88.59 | 337.59 | 118.65 |
| Total estimated parameters | 138.00 | 138.00 | 138.00 | 138.00 |

Table 19: Population abundances (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 **2016 model**.

| Year | n_1 | n_2 | n_3 | MMB |
|------|---------|---------|---------|-------|
| 1978 | 2816497 | 1960202 | 1444270 | 4173 |
| 1979 | 4054755 | 2248354 | 2097572 | 6008 |
| 1980 | 3581771 | 3047062 | 3228875 | 9573 |
| 1981 | 1366446 | 3042808 | 4547965 | 10026 |
| 1982 | 1495157 | 1783152 | 4587146 | 7110 |
| 1983 | 767497 | 1439252 | 3248511 | 4291 |
| 1984 | 639352 | 912111 | 1887891 | 2987 |
| 1985 | 880391 | 664957 | 1390828 | 2716 |
| 1986 | 1321656 | 720083 | 1212765 | 2692 |
| 1987 | 1279302 | 988951 | 1316950 | 3180 |
| 1988 | 1176369 | 1053889 | 1528925 | 3471 |
| 1989 | 2659962 | 1016938 | 1684431 | 3951 |
| 1990 | 1669442 | 1847273 | 1965108 | 4964 |
| 1991 | 1760684 | 1559550 | 2402885 | 4938 |
| 1992 | 1877628 | 1515489 | 2346712 | 5093 |
| 1993 | 2138081 | 1567357 | 2441780 | 5294 |
| 1994 | 1523681 | 1732752 | 2499174 | 5062 |
| 1995 | 1713019 | 1438756 | 2407204 | 5007 |
| 1996 | 1594900 | 1448944 | 2338286 | 4834 |
| 1997 | 890940 | 1385339 | 2278762 | 4267 |
| 1998 | 638656 | 964438 | 1894686 | 2951 |
| 1999 | 384630 | 309673 | 705797 | 1668 |
| 2000 | 423856 | 320841 | 782180 | 1824 |
| 2001 | 387023 | 346925 | 855630 | 1991 |
| 2002 | 136630 | 334576 | 926440 | 2109 |
| 2003 | 323258 | 188283 | 955265 | 1997 |
| 2004 | 215940 | 245764 | 923187 | 2003 |
| 2005 | 507624 | 203958 | 915516 | 1941 |
| 2006 | 763229 | 355768 | 915955 | 2111 |
| 2007 | 485177 | 550620 | 1016300 | 2489 |
| 2008 | 938121 | 451958 | 1157900 | 2672 |
| 2009 | 785462 | 681685 | 1283392 | 2784 |
| 2010 | 753813 | 670916 | 1398376 | 2516 |
| 2011 | 648139 | 649192 | 1313310 | 2130 |
| 2012 | 376523 | 582847 | 1099116 | 1794 |
| 2013 | 469549 | 406668 | 913357 | 2067 |
| 2014 | 426762 | 401241 | 1012730 | 2079 |
| 2015 | 356241 | 375162 | 1028792 | 2119 |
| 2016 | 355336 | 326462 | 1061000 | 2244 |

Table 20: Population abundances (n) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tons on 15 February for the reference model.

| Year | n_1 | n_2 | n_3 | MMB |
|------|---------|---------|---------|-------|
| 1978 | 3024941 | 2086744 | 1724025 | 4852 |
| 1979 | 4239965 | 2408632 | 2414987 | 6724 |
| 1980 | 3596344 | 3205302 | 3592526 | 10446 |
| 1981 | 1349025 | 3103464 | 4932899 | 10813 |
| 1982 | 1475780 | 1793338 | 4937657 | 7792 |
| 1983 | 781016 | 1431623 | 3544534 | 4882 |
| 1984 | 666738 | 917278 | 2131823 | 3448 |
| 1985 | 933667 | 682228 | 1599710 | 3167 |
| 1986 | 1410067 | 756061 | 1401082 | 3088 |
| 1987 | 1349409 | 1051073 | 1500841 | 3599 |
| 1988 | 1231932 | 1114269 | 1720553 | 3889 |
| 1989 | 2800176 | 1068482 | 1880245 | 4391 |
| 1990 | 1751534 | 1943967 | 2168052 | 5444 |
| 1991 | 1814448 | 1638180 | 2629043 | 5458 |
| 1992 | 1939805 | 1572076 | 2580522 | 5597 |
| 1993 | 2184235 | 1621426 | 2671609 | 5805 |
| 1994 | 1553370 | 1776820 | 2722837 | 5530 |
| 1995 | 1770998 | 1470210 | 2619081 | 5455 |
| 1996 | 1600408 | 1492289 | 2536543 | 5262 |
| 1997 | 912973 | 1402738 | 2466495 | 4667 |
| 1998 | 660074 | 982653 | 2061868 | 3267 |
| 1999 | 394430 | 327571 | 798265 | 1861 |
| 2000 | 442239 | 332277 | 869216 | 1999 |
| 2001 | 405731 | 361052 | 935595 | 2156 |
| 2002 | 144740 | 349823 | 1001982 | 2267 |
| 2003 | 341000 | 197937 | 1026826 | 2142 |
| 2004 | 227177 | 259039 | 989524 | 2142 |
| 2005 | 505715 | 214734 | 978693 | 2071 |
| 2006 | 763531 | 358196 | 973818 | 2222 |
| 2007 | 521970 | 551619 | 1065877 | 2583 |
| 2008 | 935990 | 473156 | 1203369 | 2781 |
| 2009 | 760273 | 687508 | 1331849 | 2875 |
| 2010 | 729826 | 658570 | 1439363 | 2570 |
| 2011 | 600893 | 631520 | 1338699 | 2152 |
| 2012 | 345261 | 550063 | 1105742 | 1768 |
| 2013 | 442426 | 377975 | 898271 | 2009 |
| 2014 | 367920 | 376271 | 982889 | 1999 |
| 2015 | 352930 | 333413 | 985388 | 1999 |
| 2016 | 379414 | 310688 | 1003127 | 2122 |
| 2017 | 186468 | 318041 | 1029878 | 2180 |

Table 21: Population abundances (n) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tons on 15 February for the Francis weights model.

| Year | n_1 | n_2 | n_3 | MMB |
|------|---------|---------|---------|-------|
| 1978 | 2914158 | 2107534 | 1724626 | 4878 |
| 1979 | 4110549 | 2352595 | 2415404 | 6660 |
| 1980 | 3272000 | 3113252 | 3552247 | 10263 |
| 1981 | 1255767 | 2888789 | 4821836 | 10358 |
| 1982 | 1252747 | 1669317 | 4727728 | 7247 |
| 1983 | 752019 | 1263907 | 3284909 | 4156 |
| 1984 | 589896 | 845294 | 1824879 | 2791 |
| 1985 | 797309 | 614749 | 1298973 | 2469 |
| 1986 | 1195843 | 656276 | 1102745 | 2411 |
| 1987 | 1416960 | 896378 | 1180842 | 2818 |
| 1988 | 1481565 | 1101427 | 1381697 | 3256 |
| 1989 | 3404588 | 1206002 | 1614487 | 4029 |
| 1990 | 1438930 | 2332738 | 2073038 | 5713 |
| 1991 | 1815552 | 1589318 | 2715817 | 5567 |
| 1992 | 2022514 | 1556550 | 2627746 | 5667 |
| 1993 | 2472885 | 1663260 | 2710930 | 5929 |
| 1994 | 1478514 | 1954580 | 2804465 | 5885 |
| 1995 | 1775538 | 1486535 | 2770349 | 5768 |
| 1996 | 1693651 | 1500281 | 2671388 | 5530 |
| 1997 | 769965 | 1458341 | 2592267 | 4987 |
| 1998 | 664628 | 919851 | 2182322 | 3417 |
| 1999 | 413378 | 324515 | 845070 | 1945 |
| 2000 | 389302 | 342029 | 908581 | 2084 |
| 2001 | 464065 | 334225 | 968329 | 2187 |
| 2002 | 151330 | 374068 | 1021377 | 2331 |
| 2003 | 403096 | 209704 | 1055881 | 2209 |
| 2004 | 204945 | 298185 | 1025667 | 2254 |
| 2005 | 428497 | 215067 | 1026496 | 2161 |
| 2006 | 847860 | 314466 | 1006528 | 2234 |
| 2007 | 564417 | 585018 | 1079224 | 2646 |
| 2008 | 889231 | 508147 | 1235657 | 2881 |
| 2009 | 860820 | 672564 | 1371981 | 2929 |
| 2010 | 707726 | 710694 | 1475014 | 2687 |
| 2011 | 538185 | 636243 | 1393311 | 2249 |
| 2012 | 344859 | 516030 | 1147911 | 1801 |
| 2013 | 471797 | 366494 | 915902 | 2028 |
| 2014 | 369039 | 389149 | 994635 | 2033 |
| 2015 | 286665 | 338310 | 1001843 | 2033 |
| 2016 | 297822 | 274688 | 1012976 | 2101 |
| 2017 | 175628 | 259829 | 1012138 | 2085 |

Table 22: Population abundances (n) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tons on 15 February for the model that uses the VAST BTS index.

| Year | n_1 | n_2 | n_3 | MMB |
|------|---------|---------|---------|-------|
| 1978 | 3115215 | 2172899 | 1838086 | 5169 |
| 1979 | 4165349 | 2488423 | 2562202 | 7061 |
| 1980 | 3502187 | 3189337 | 3748592 | 10724 |
| 1981 | 1366561 | 3044705 | 5046205 | 10957 |
| 1982 | 1475664 | 1783853 | 5004687 | 7901 |
| 1983 | 742837 | 1428422 | 3591786 | 4964 |
| 1984 | 631179 | 894542 | 2161933 | 3474 |
| 1985 | 858312 | 654510 | 1608409 | 3152 |
| 1986 | 1248013 | 704090 | 1386589 | 3002 |
| 1987 | 1360239 | 941837 | 1447079 | 3373 |
| 1988 | 1246057 | 1084264 | 1621642 | 3675 |
| 1989 | 2985149 | 1066574 | 1783972 | 4201 |
| 1990 | 1870987 | 2048386 | 2104422 | 5447 |
| 1991 | 1939133 | 1740581 | 2640145 | 5596 |
| 1992 | 2122333 | 1676762 | 2653809 | 5854 |
| 1993 | 2412369 | 1759724 | 2803232 | 6218 |
| 1994 | 1718543 | 1952155 | 2924306 | 6104 |
| 1995 | 1977307 | 1622056 | 2891334 | 6157 |
| 1996 | 1908447 | 1659726 | 2859846 | 6069 |
| 1997 | 1131105 | 1633109 | 2850023 | 5704 |
| 1998 | 803062 | 1182797 | 2518291 | 4178 |
| 1999 | 464910 | 375024 | 972746 | 2241 |
| 2000 | 511519 | 388018 | 1045620 | 2392 |
| 2001 | 473002 | 418852 | 1117669 | 2561 |
| 2002 | 165752 | 407162 | 1189639 | 2683 |
| 2003 | 401411 | 228852 | 1214492 | 2527 |
| 2004 | 269011 | 303583 | 1167639 | 2525 |
| 2005 | 715254 | 253240 | 1153927 | 2442 |
| 2006 | 979145 | 489934 | 1159636 | 2718 |
| 2007 | 703674 | 717650 | 1308132 | 3224 |
| 2008 | 1182362 | 631080 | 1507167 | 3527 |
| 2009 | 919542 | 879699 | 1688787 | 3706 |
| 2010 | 874752 | 812665 | 1849739 | 3416 |
| 2011 | 738581 | 764892 | 1772676 | 3022 |
| 2012 | 445923 | 672431 | 1546550 | 2629 |
| 2013 | 551092 | 475675 | 1334636 | 2893 |
| 2014 | 473134 | 470339 | 1407020 | 2842 |
| 2015 | 447580 | 424314 | 1396981 | 2801 |
| 2016 | 547678 | 394543 | 1401765 | 2924 |
| 2017 | 311774 | 441360 | 1421219 | 3011 |

Table 23: Population abundances (n) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tons on 15 February for the **fit surveys** model.

| Year | n_1 | n_2 | n_3 | MMB |
|------|---------|---------|---------|-------|
| 1978 | 5159537 | 4361084 | 3687283 | 11213 |
| 1979 | 6210267 | 4373769 | 5405672 | 13986 |
| 1980 | 3673747 | 4974775 | 7269812 | 19463 |
| 1981 | 1540288 | 3733146 | 8904090 | 18930 |
| 1982 | 1435675 | 2110417 | 8589692 | 15134 |
| 1983 | 924987 | 1513838 | 6744725 | 11444 |
| 1984 | 759383 | 1026332 | 4845730 | 8627 |
| 1985 | 888512 | 770974 | 3926869 | 8069 |
| 1986 | 1169500 | 759806 | 3384557 | 6842 |
| 1987 | 2073978 | 915706 | 3136254 | 6538 |
| 1988 | 3432758 | 1480998 | 3087326 | 6799 |
| 1989 | 7016427 | 2439826 | 3416727 | 8943 |
| 1990 | 2176388 | 4792406 | 4545548 | 13018 |
| 1991 | 3012152 | 2822327 | 6091388 | 13390 |
| 1992 | 3410492 | 2644416 | 6181631 | 13578 |
| 1993 | 4658345 | 2811786 | 6359402 | 14361 |
| 1994 | 3595317 | 3576027 | 6638067 | 14873 |
| 1995 | 2415186 | 3225465 | 6988280 | 15949 |
| 1996 | 3767773 | 2439220 | 7129303 | 15116 |
| 1997 | 3507563 | 2947152 | 6984231 | 15576 |
| 1998 | 2577269 | 2967449 | 6856068 | 11783 |
| 1999 | 935872 | 614530 | 1723836 | 3915 |
| 2000 | 1680050 | 734770 | 1838776 | 4266 |
| 2001 | 2898966 | 1197252 | 2066729 | 5214 |
| 2002 | 560274 | 2042480 | 2606795 | 7177 |
| 2003 | 183891 | 994184 | 3260530 | 7216 |
| 2004 | 104651 | 433447 | 3241730 | 6549 |
| 2005 | 981856 | 202910 | 2936121 | 5717 |
| 2006 | 1923313 | 624740 | 2648339 | 5653 |
| 2007 | 3575445 | 1298593 | 2709815 | 6506 |
| 2008 | 1607754 | 2450926 | 3247373 | 8834 |
| 2009 | 1497545 | 1723791 | 4100573 | 8829 |
| 2010 | 1772043 | 1420514 | 4344790 | 8209 |
| 2011 | 1093878 | 1475839 | 4248690 | 7957 |
| 2012 | 687238 | 1109613 | 4006465 | 7204 |
| 2013 | 763979 | 757501 | 3630856 | 7292 |
| 2014 | 799080 | 684574 | 3487434 | 6713 |
| 2015 | 589916 | 680368 | 3273389 | 6284 |
| 2016 | 429463 | 560172 | 3111618 | 6152 |
| 2017 | 190561 | 429189 | 2921581 | 5674 |

Figures

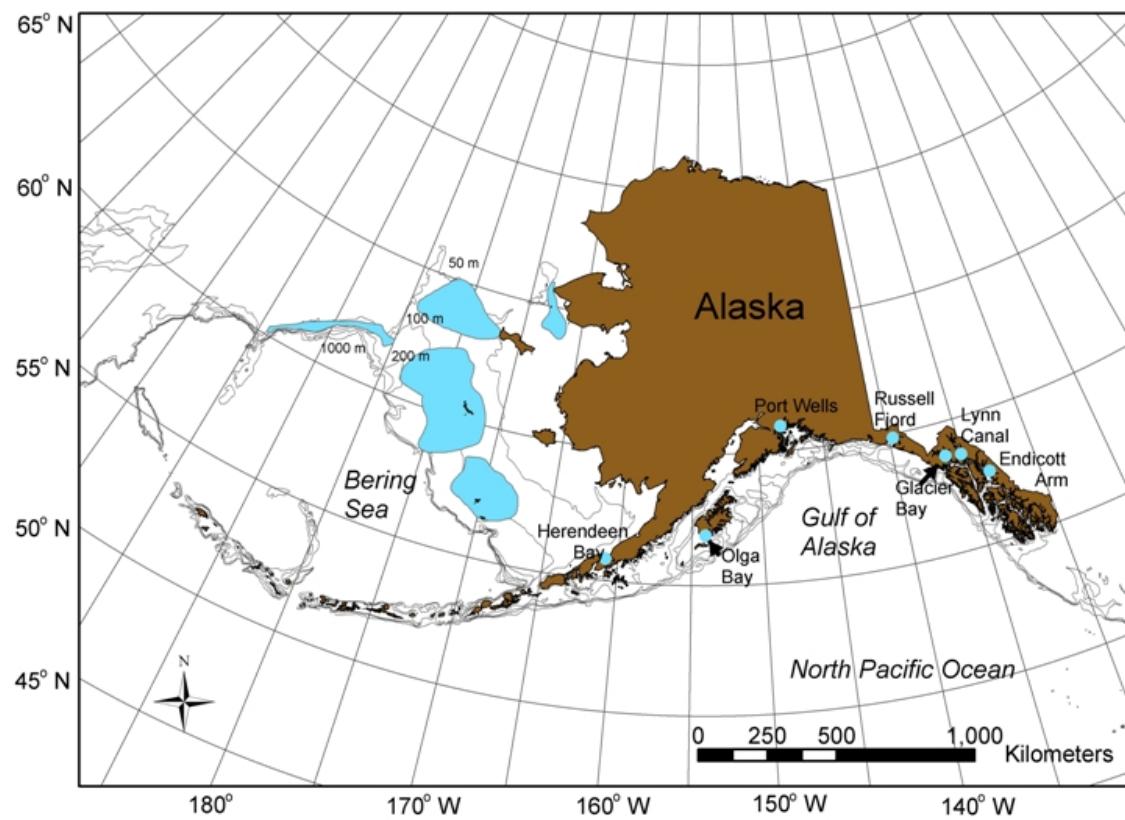


Figure 1: Distribution of blue king crab (*Paralithodes platypus*) in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters (shown in blue).

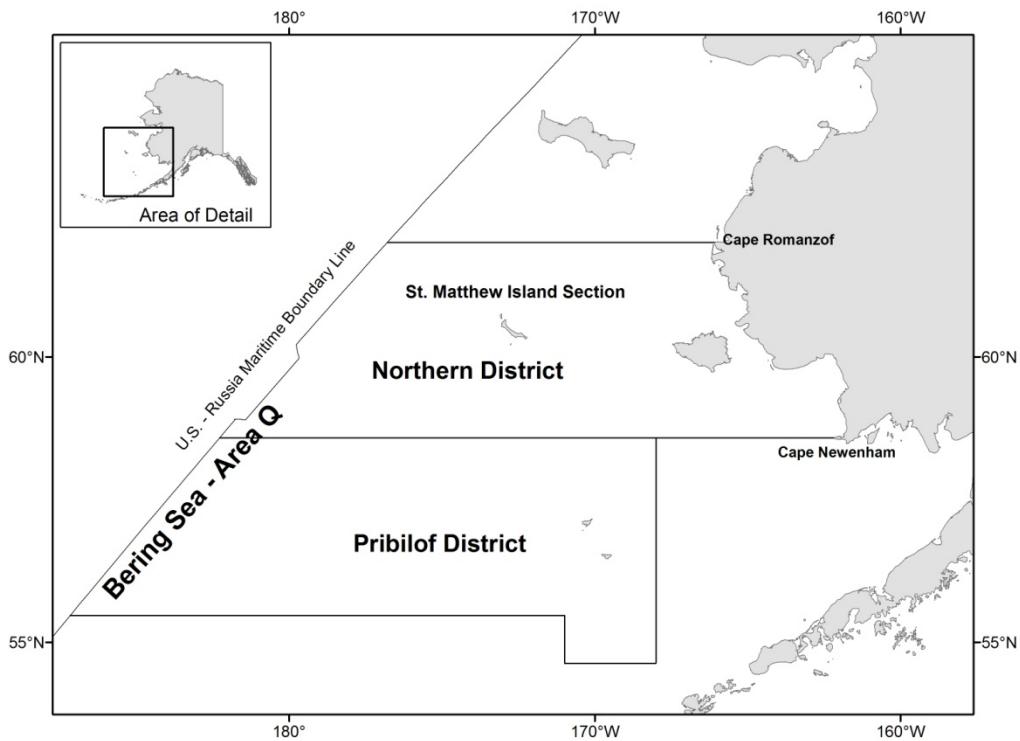


Figure 2: King crab Registration Area Q (Bering Sea).

Data by type and year

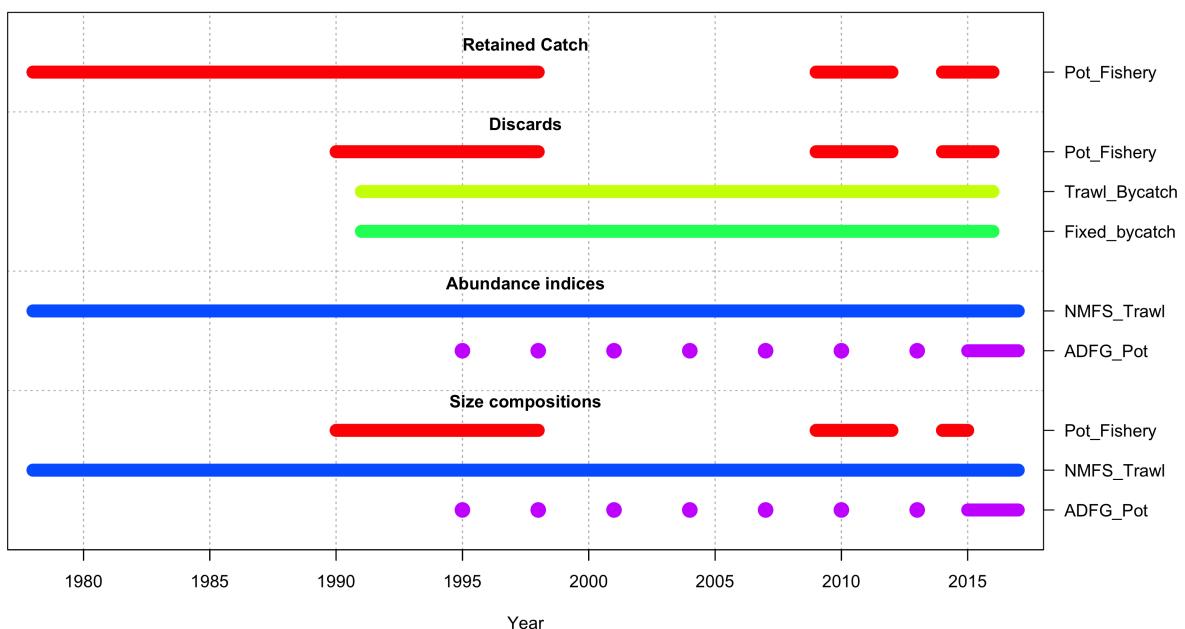


Figure 3: Data extent for the SMBKC assessment (with the 2017 Pot survey included).

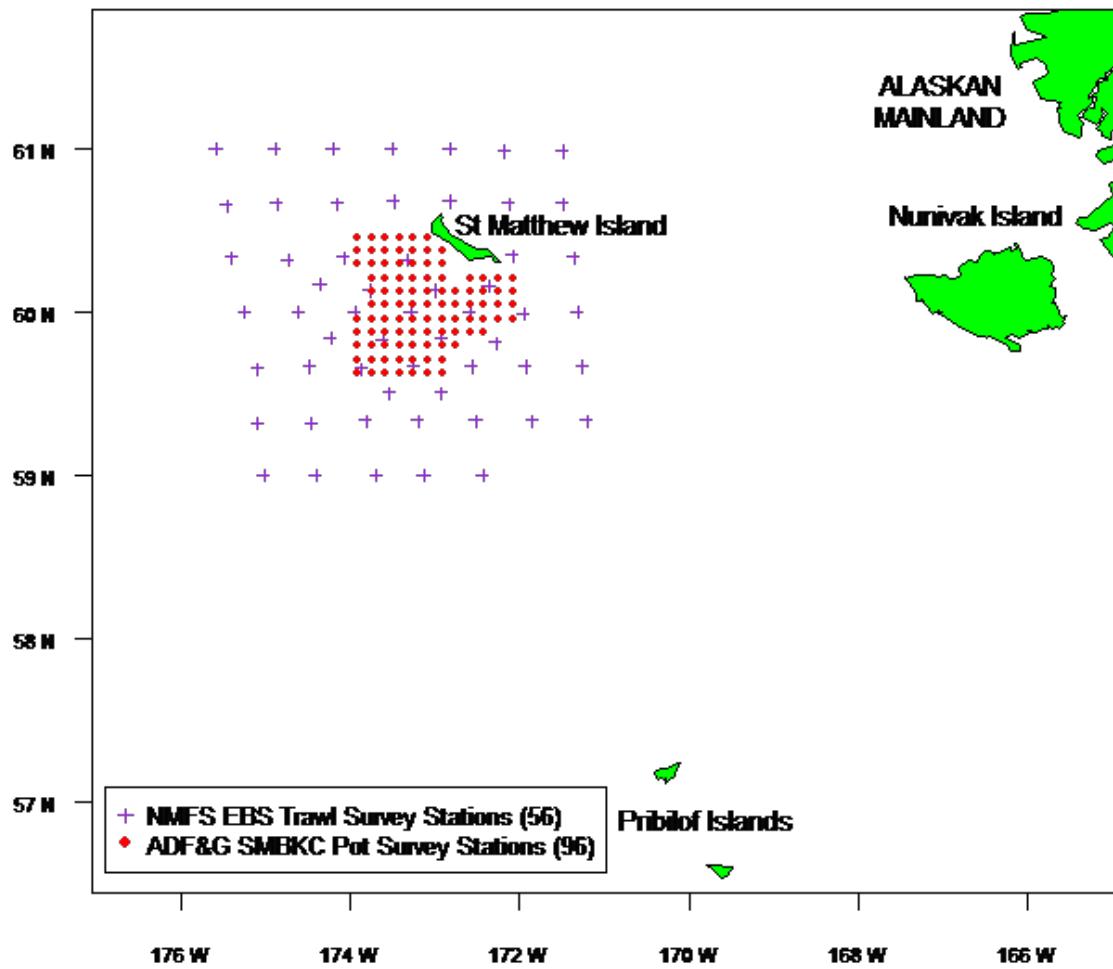


Figure 4: Trawl and pot-survey stations used in the SMBKC stock assessment.

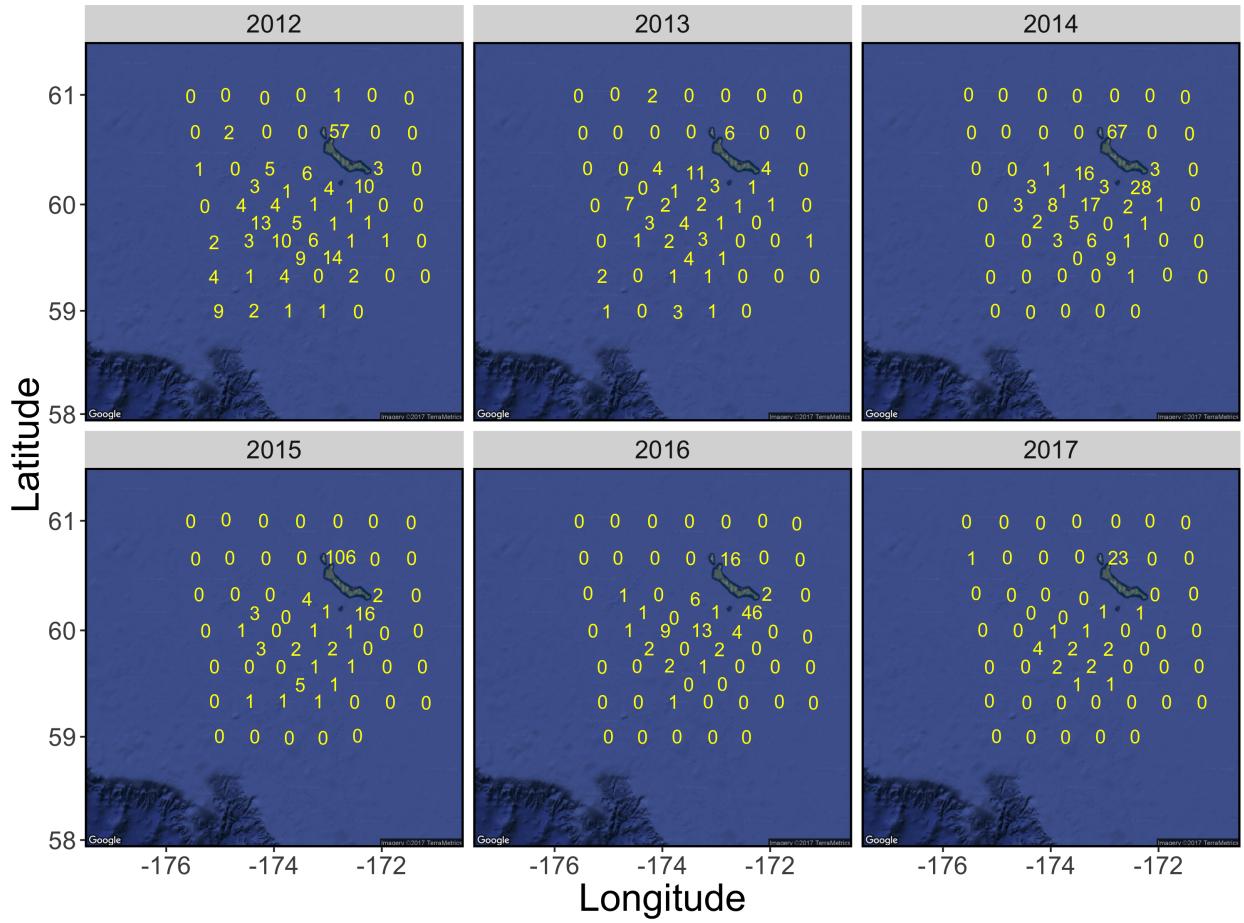


Figure 5: Catches (in numbers) of male blue king crab measuring 90 mm CL from the 2012-2017 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock. Note that the area north of St. Matthew Island, which often shows large catches of crab at station R-24 is not covered in the ADF&G pot-survey data used in the assessment.

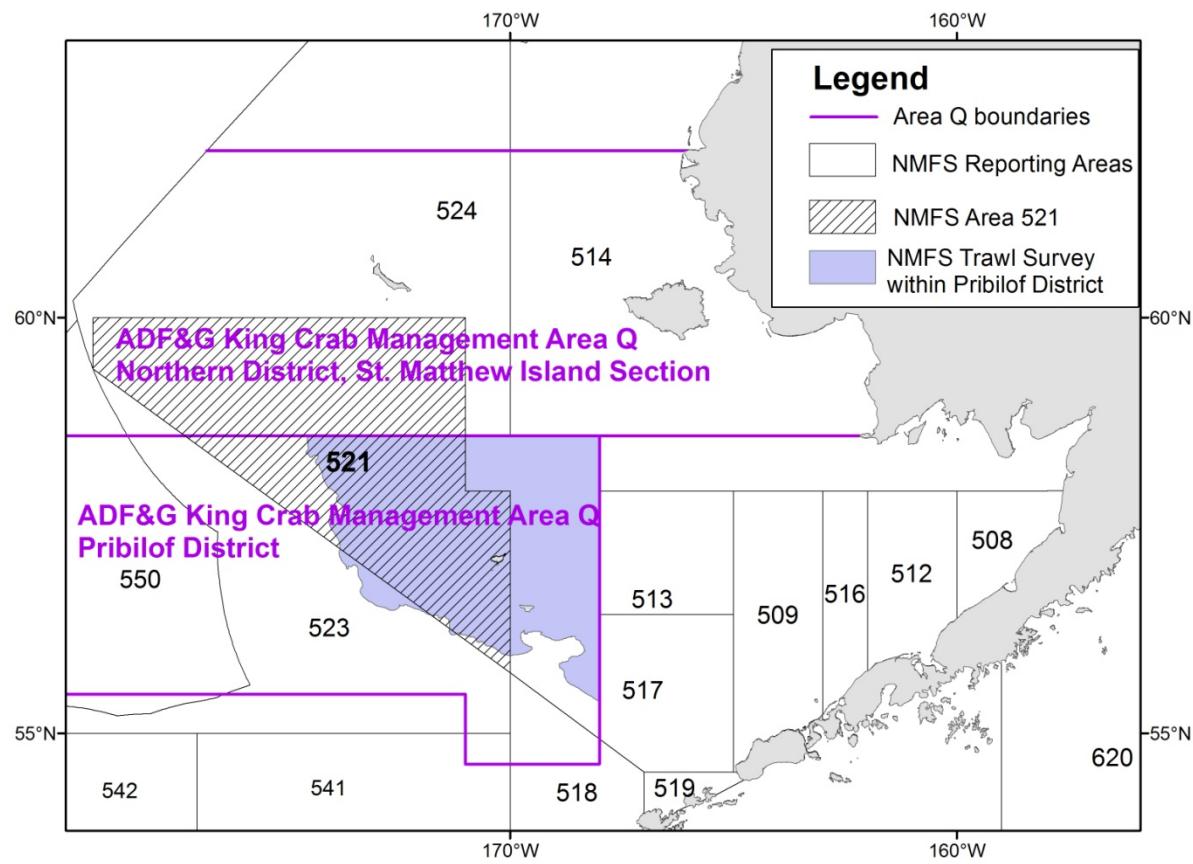


Figure 6: NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.

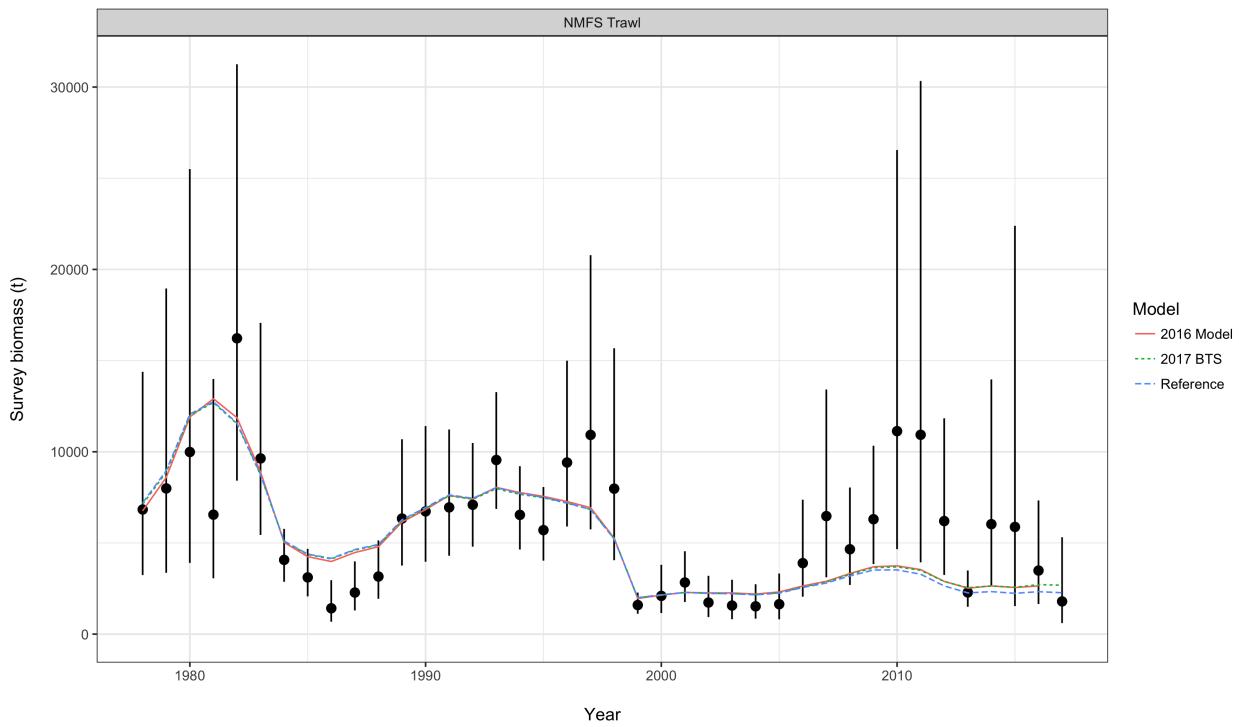


Figure 7: Fits to NMFS area-swept trawl estimates of total (>90mm) male survey biomass with the addition of new data. Error bars are plus and minus 2 standard deviations.

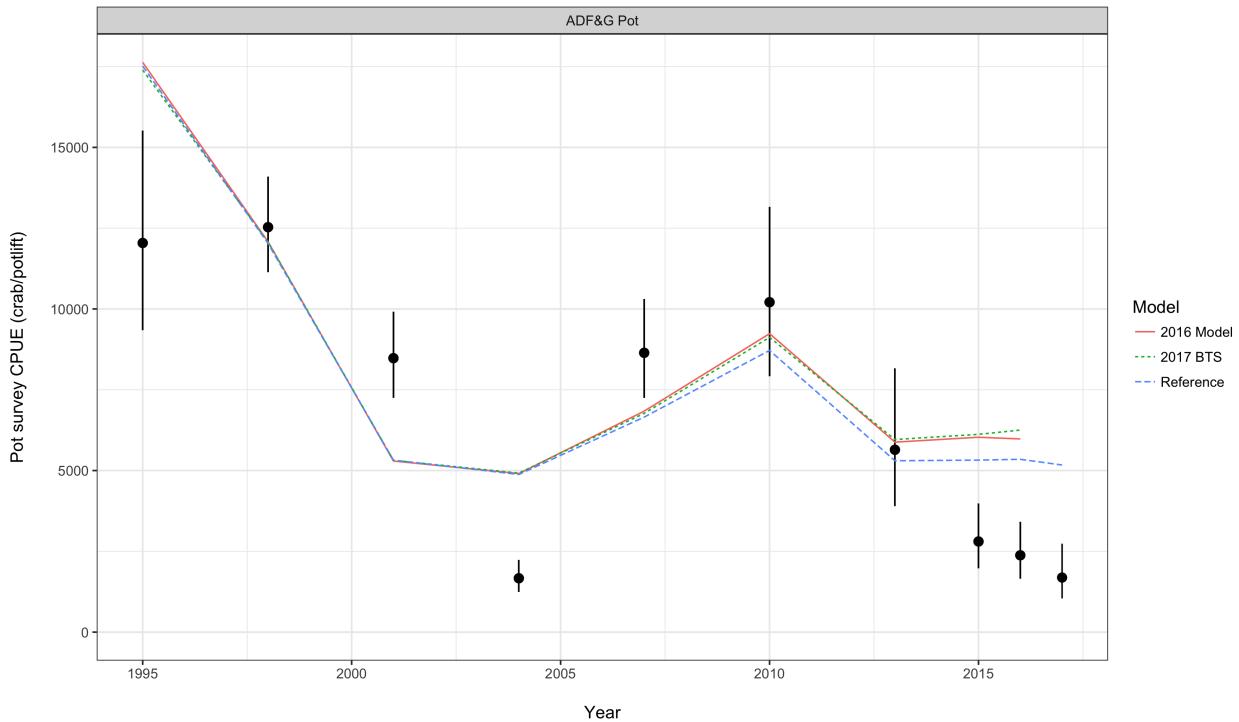


Figure 8: Comparisons of fits to CPUE from the ADF&G pot surveys with the addition of new data. Error bars are plus and minus 2 standard deviations.

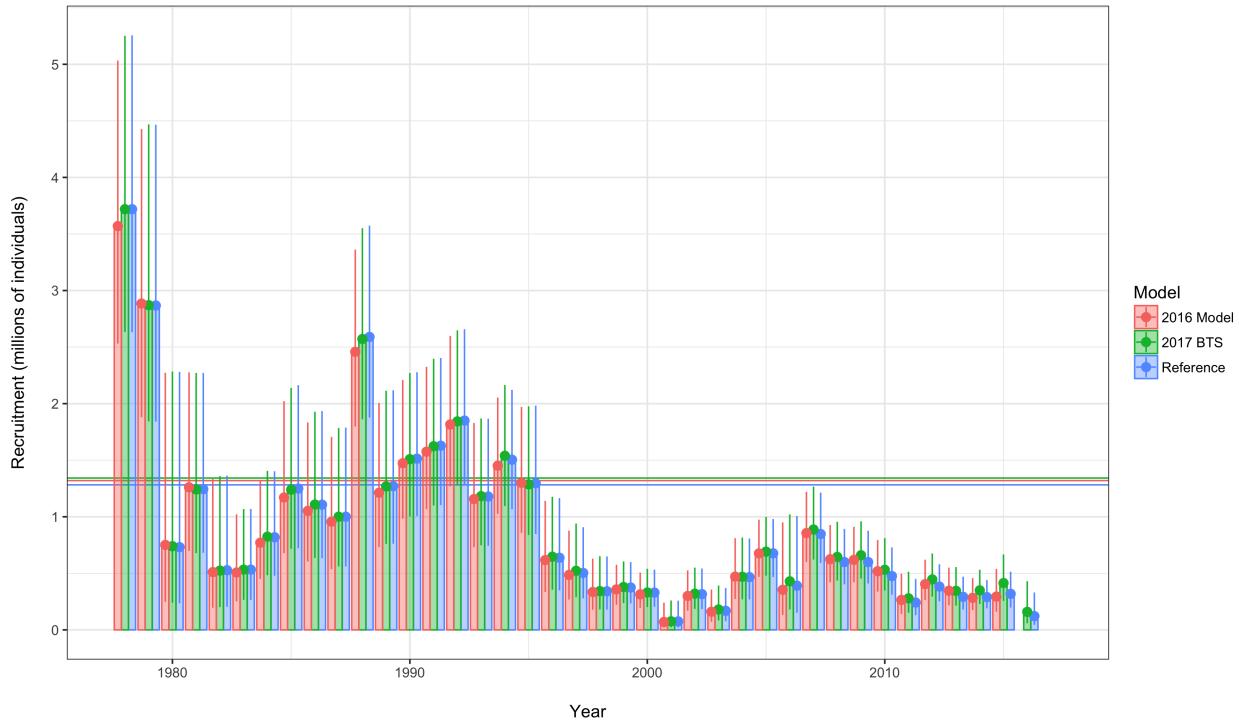


Figure 9: Sensitivity of new data in 2017 on estimated recruitment ; 1978-2017.

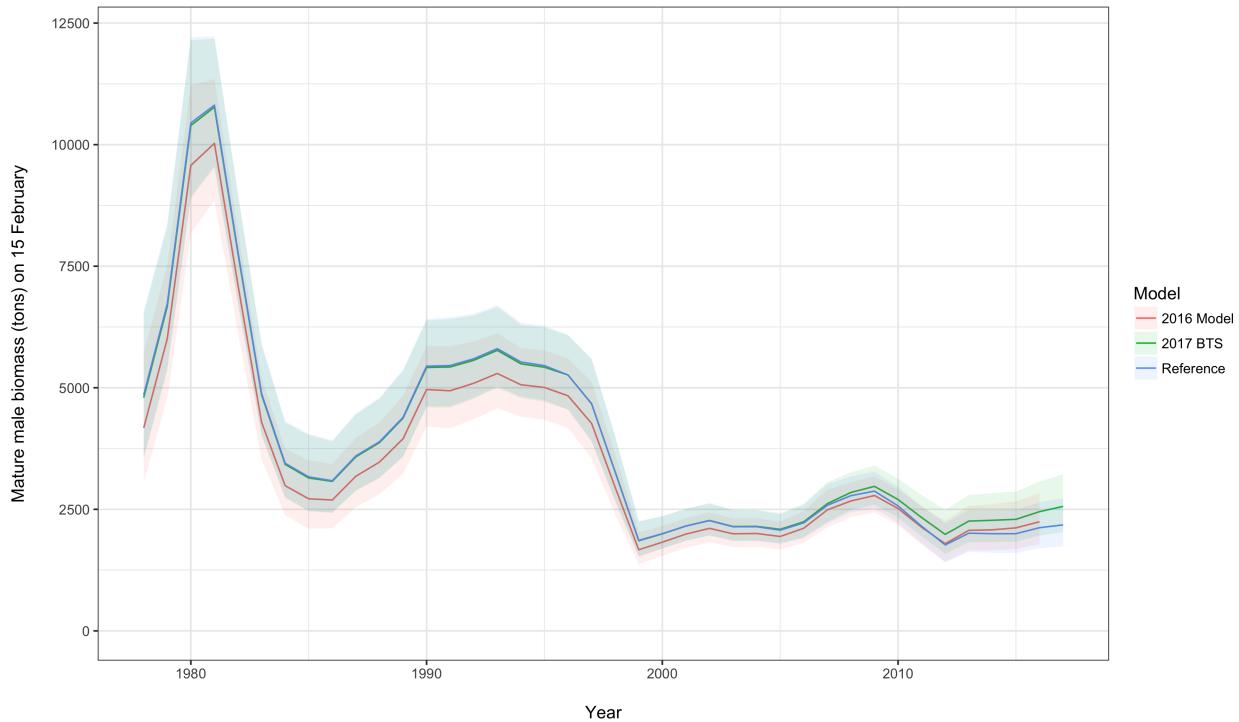


Figure 10: Sensitivity of new data in 2017 on estimated mature male biomass (MMB); 1978-2017.

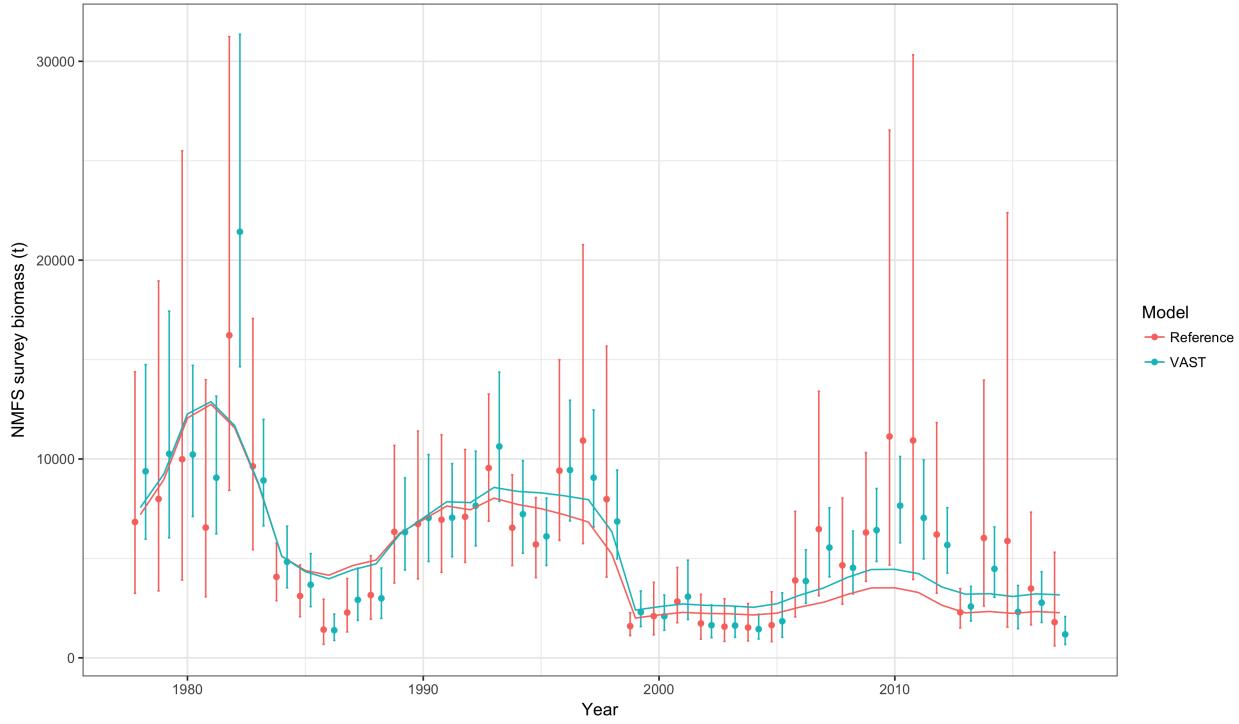


Figure 11: Comparisons of fits to area-swept estimates of total ($>90\text{mm}$) male survey biomass (t) for the standard design-based estimate and for estimates derived from the VAST spatio-temporal model of Thorson and Barnett (2017). Error bars are plus and minus 2 standard deviations.

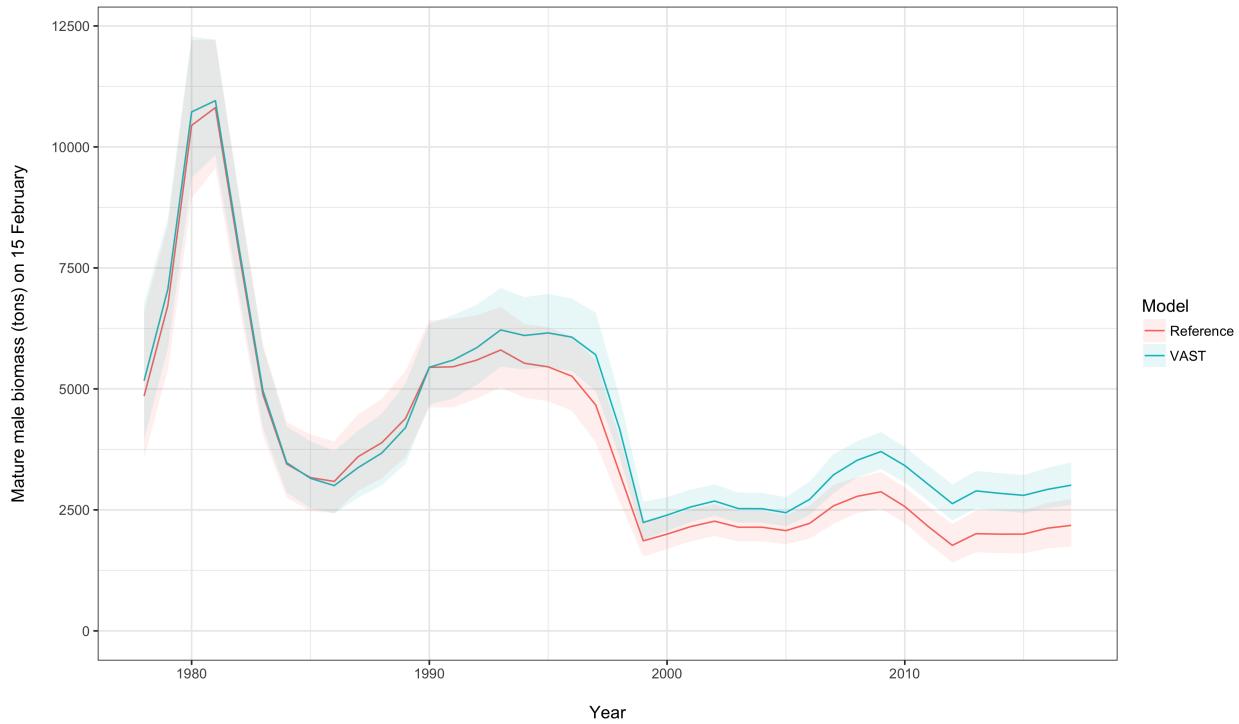


Figure 12: Sensitivity of new data in 2017 on estimated mature male biomass (MMB); 1978-2017 comparing the reference model with that fitted to the VAST BTS estimates.

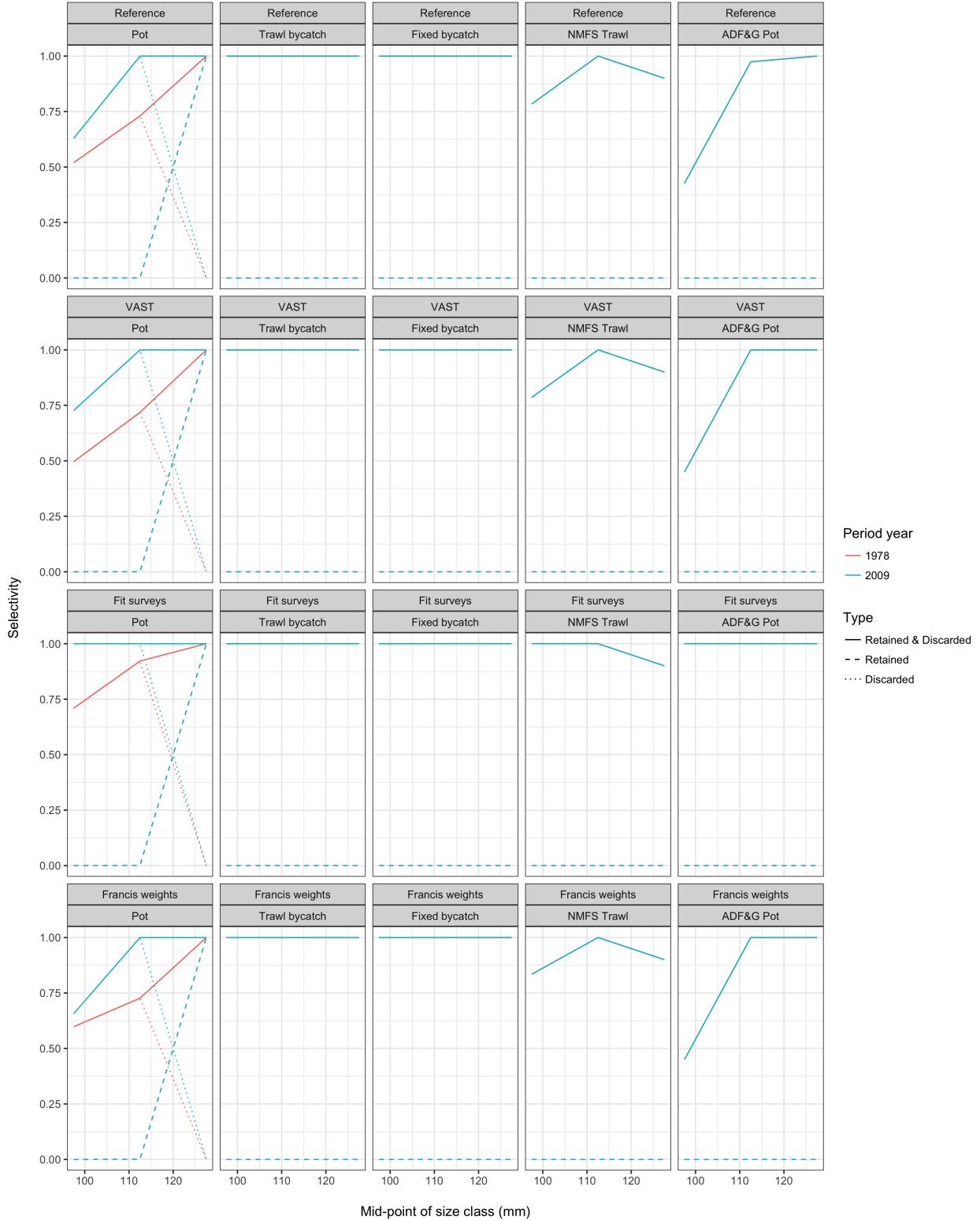


Figure 13: Comparisons of the estimated stage-1 and stage-2 selectivities for the different model scenarios (the stage-3 selectivities are all fixed at 1). Estimated selectivities are shown for the directed pot fishery, the trawl bycatch fishery, the fixed bycatch fishery, the NMFS trawl survey, and the ADF&G pot survey. Two selectivity periods are estimated in the directed pot fishery, from 1978-2008 and 2009-2017.

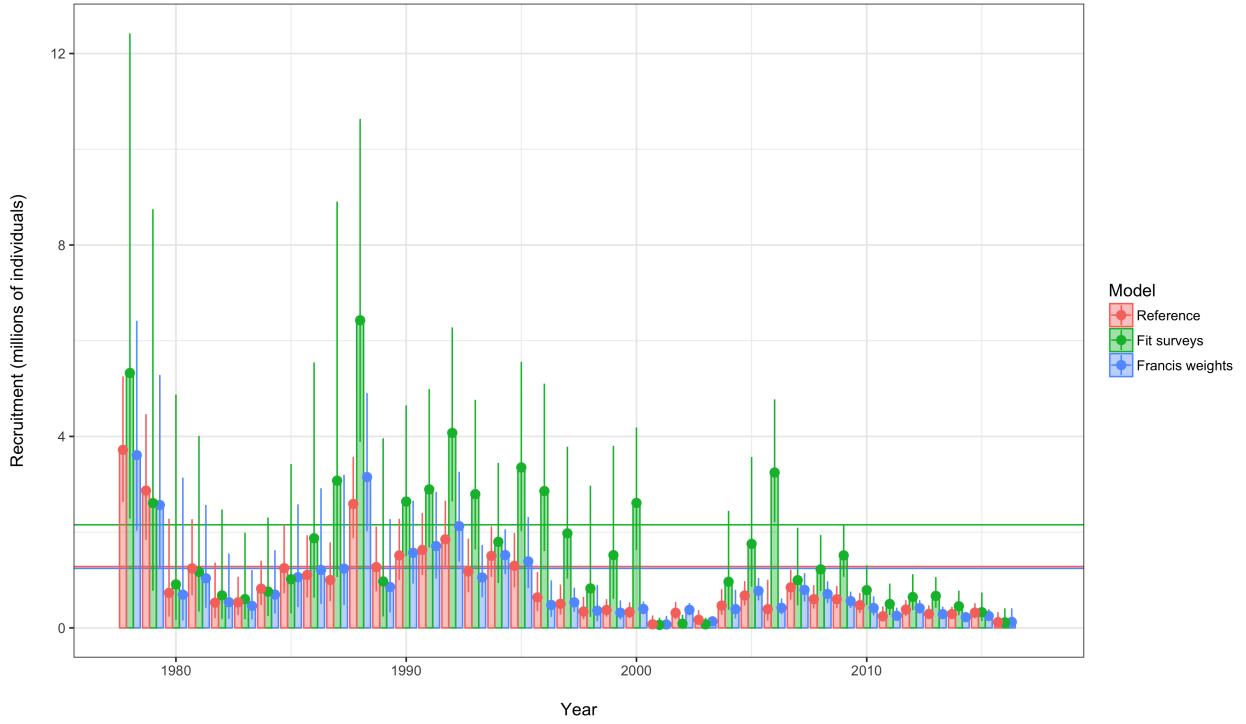


Figure 14: Estimated recruitment 1979-2017 comparing model alternatives. The solid horizontal lines in the background represent the estimate of the average recruitment parameter (\bar{R}) in each model scenario.

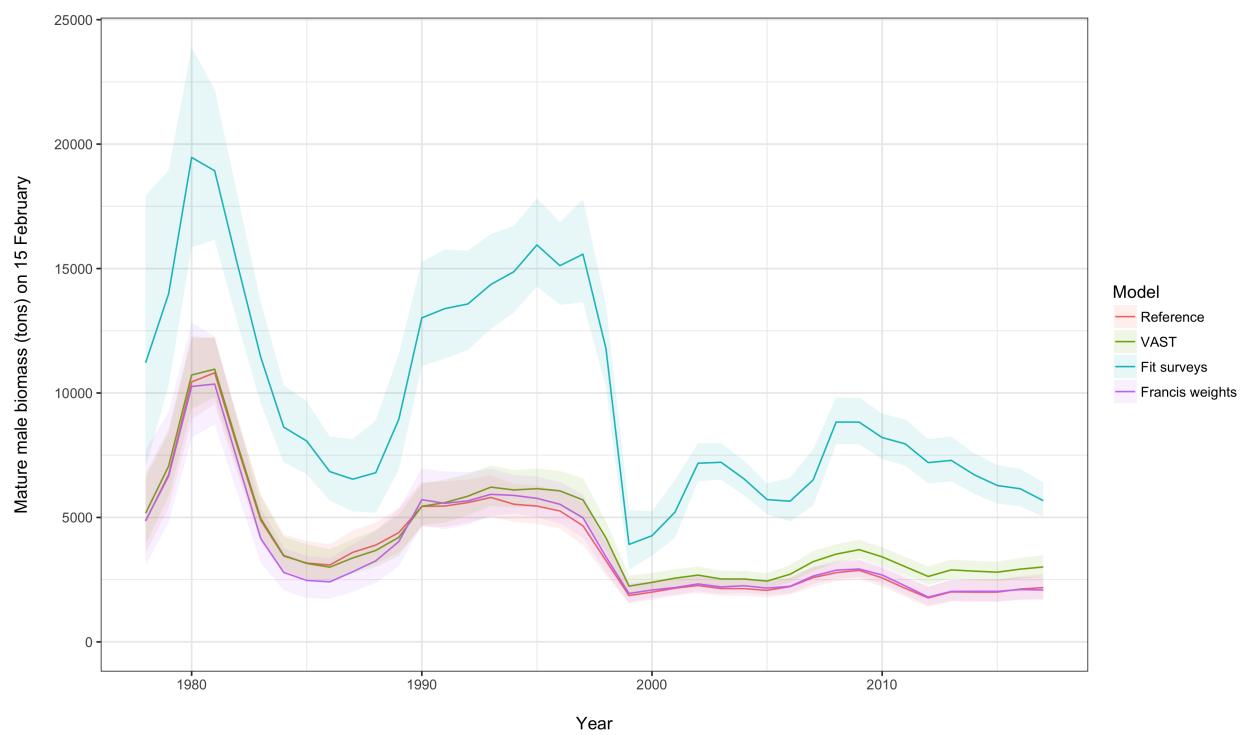


Figure 15: Comparisons of estimated mature male biomass (MMB) time series on 15 February during 1978-2017 for each of the model scenarios.

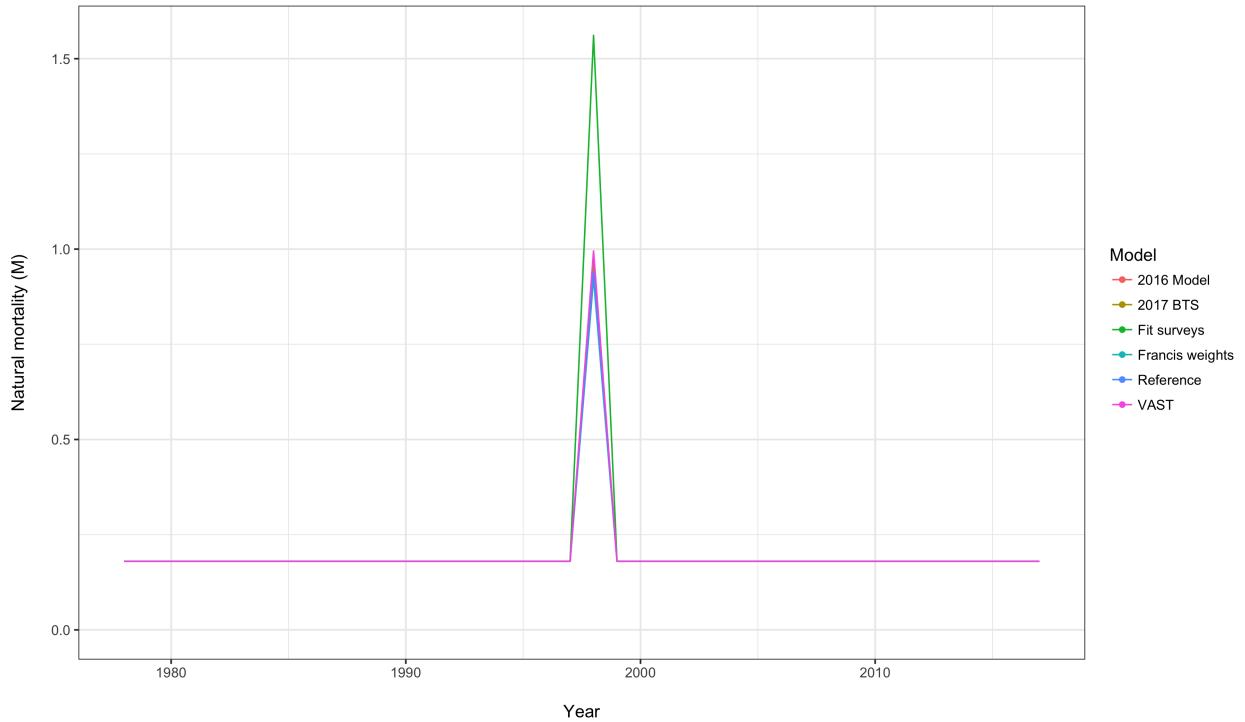


Figure 16: Time-varying natural mortality (M_t). Estimated pulse period occurs in 1998/99 (i.e. M_{1998}).

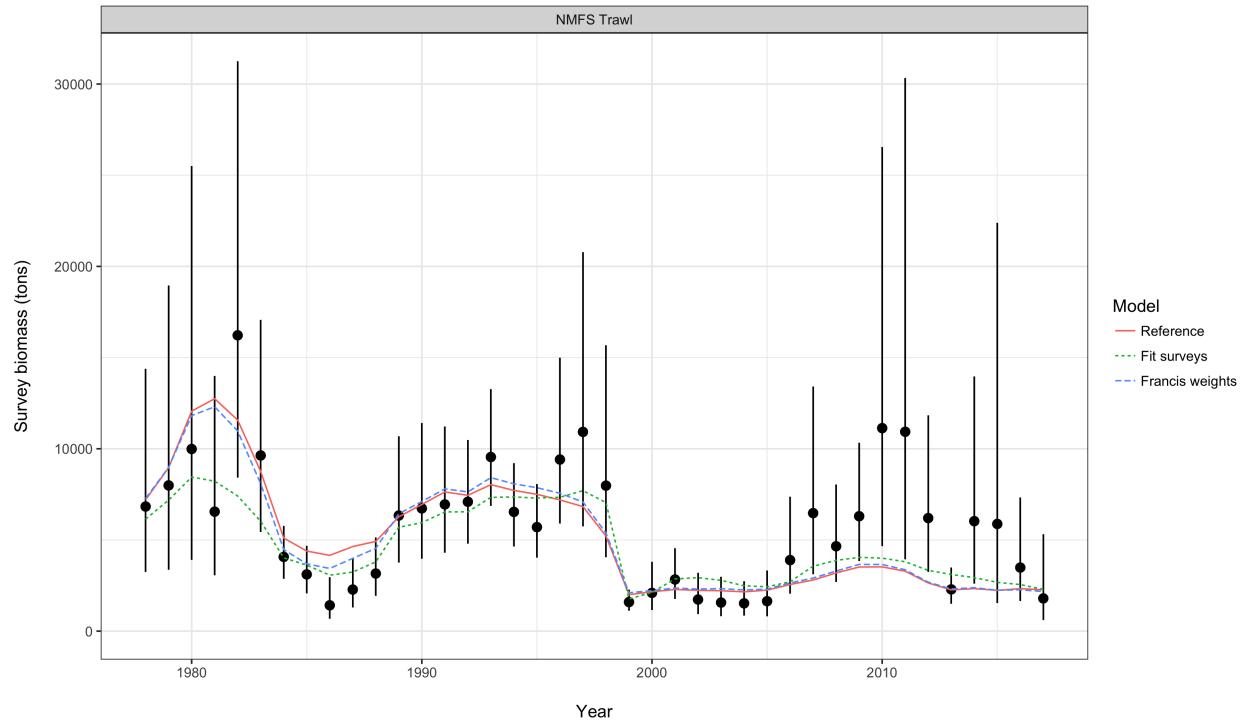


Figure 17: Comparisons of area-swept estimates of total (90+ mm CL) male survey biomass (tons) and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

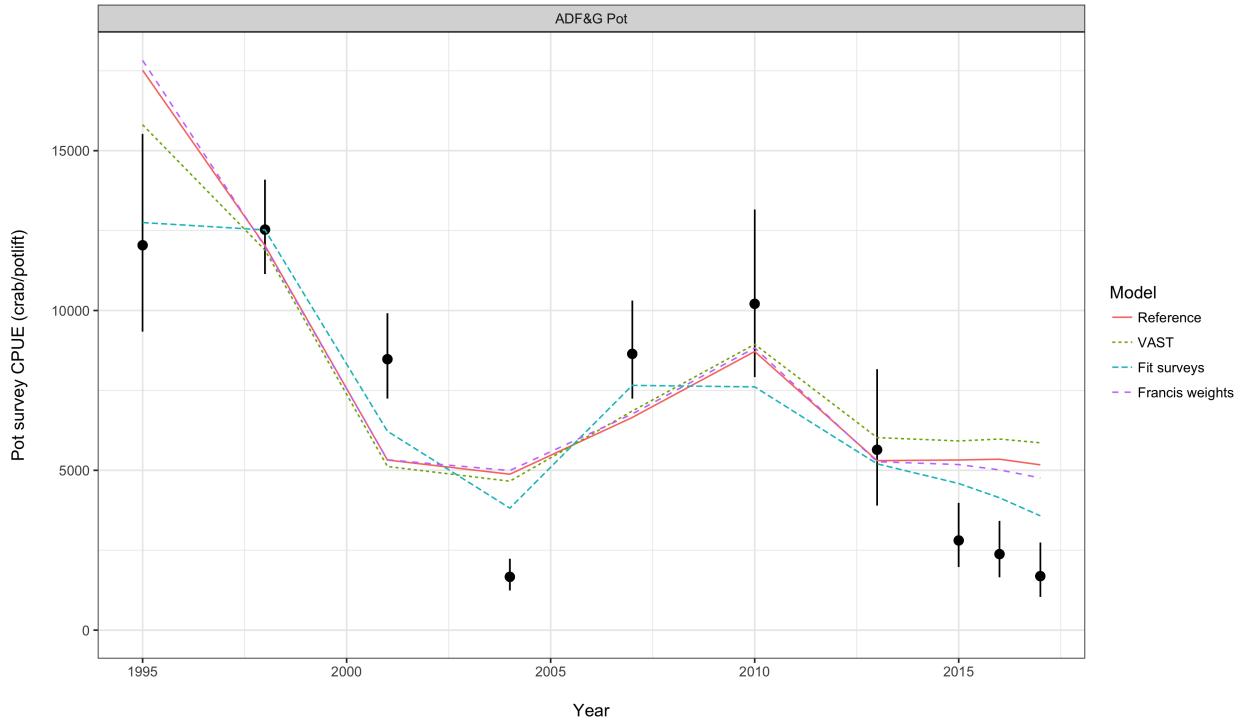


Figure 18: Comparisons of total (90+ mm CL) male pot survey CPUEs and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

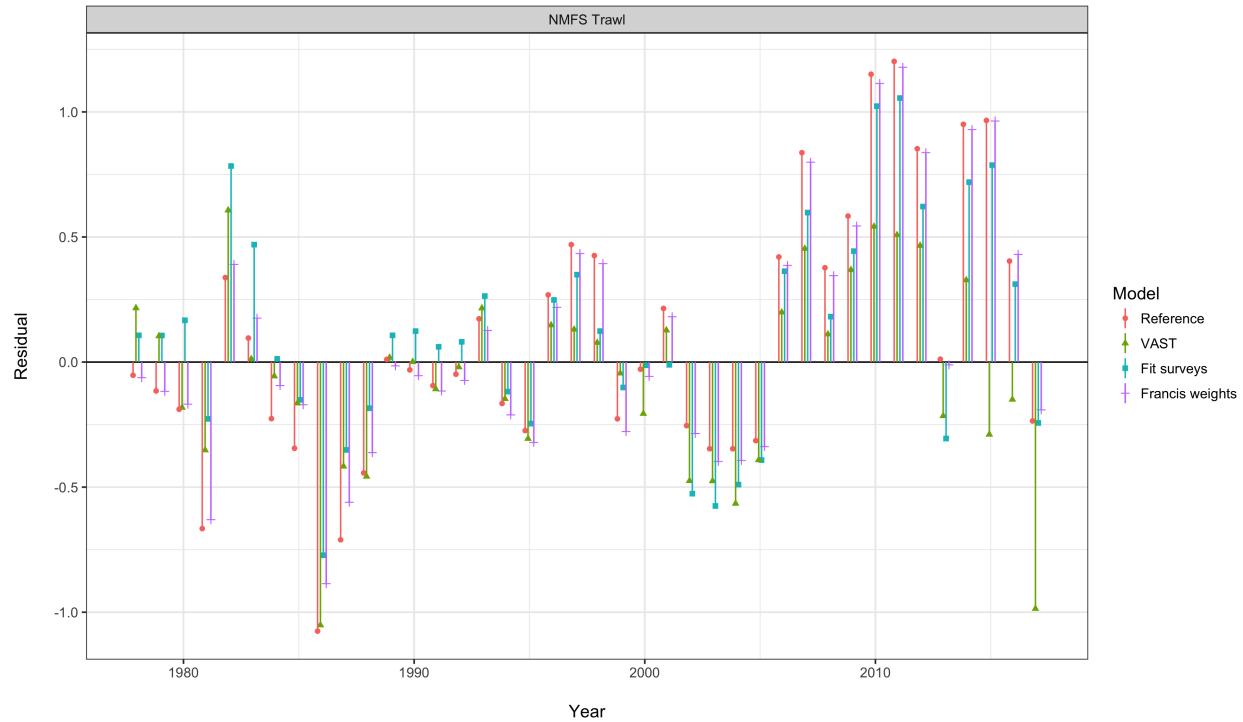


Figure 19: Standardized residuals for area-swept estimates of total male survey biomass for the model scenarios.

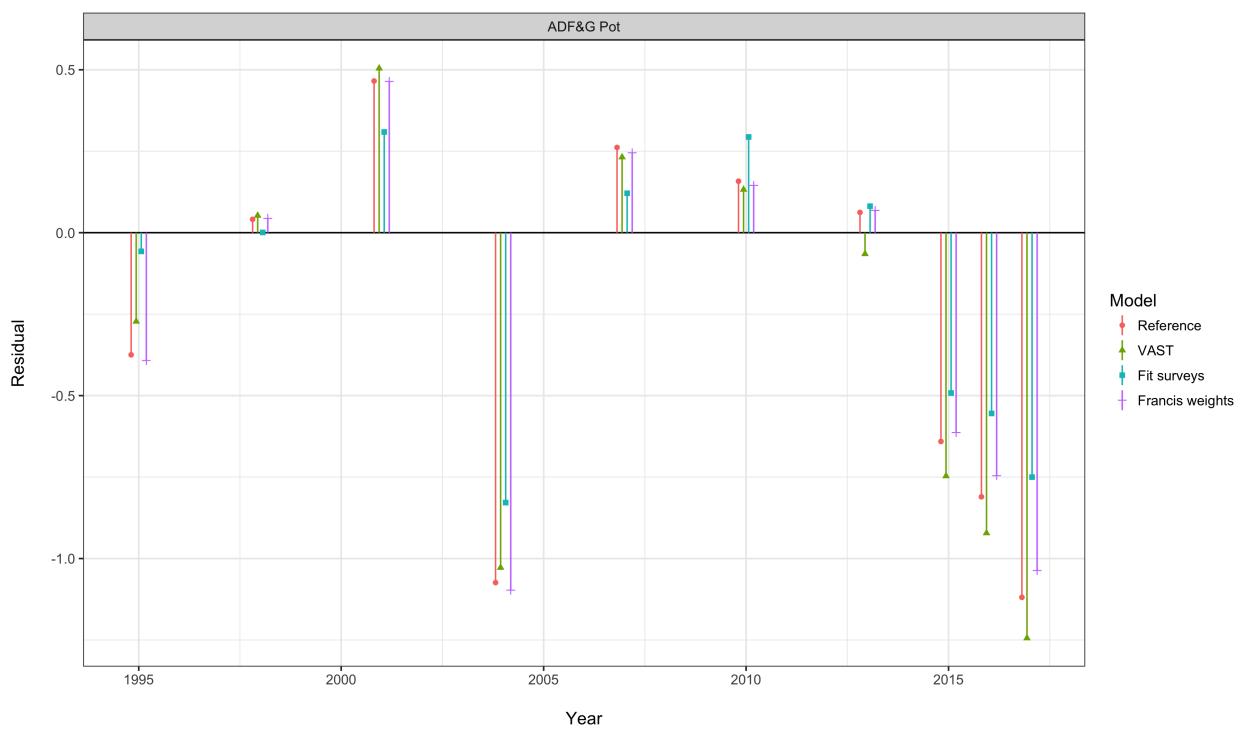


Figure 20: Standardized residuals for total male pot survey CPUEs for each of the Gmacs model scenarios.

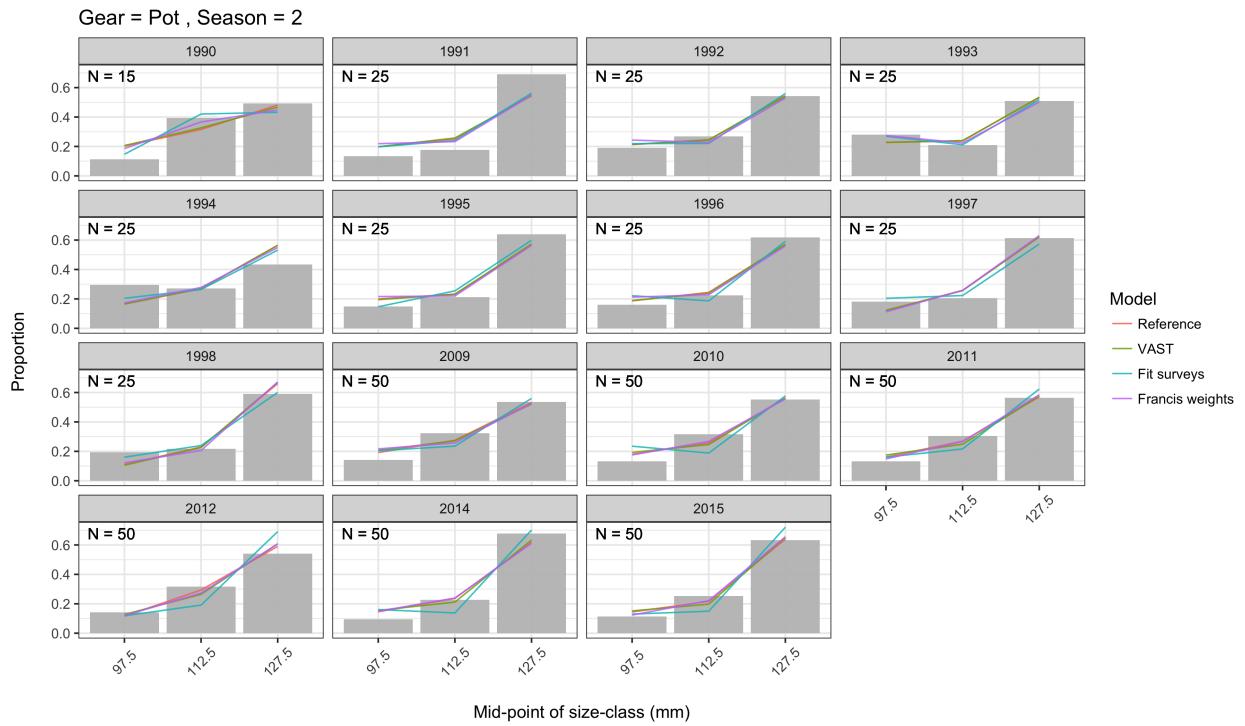


Figure 21: Observed and model estimated size-frequencies of SMBKC by year retained in the directed pot fishery for the model scenarios.

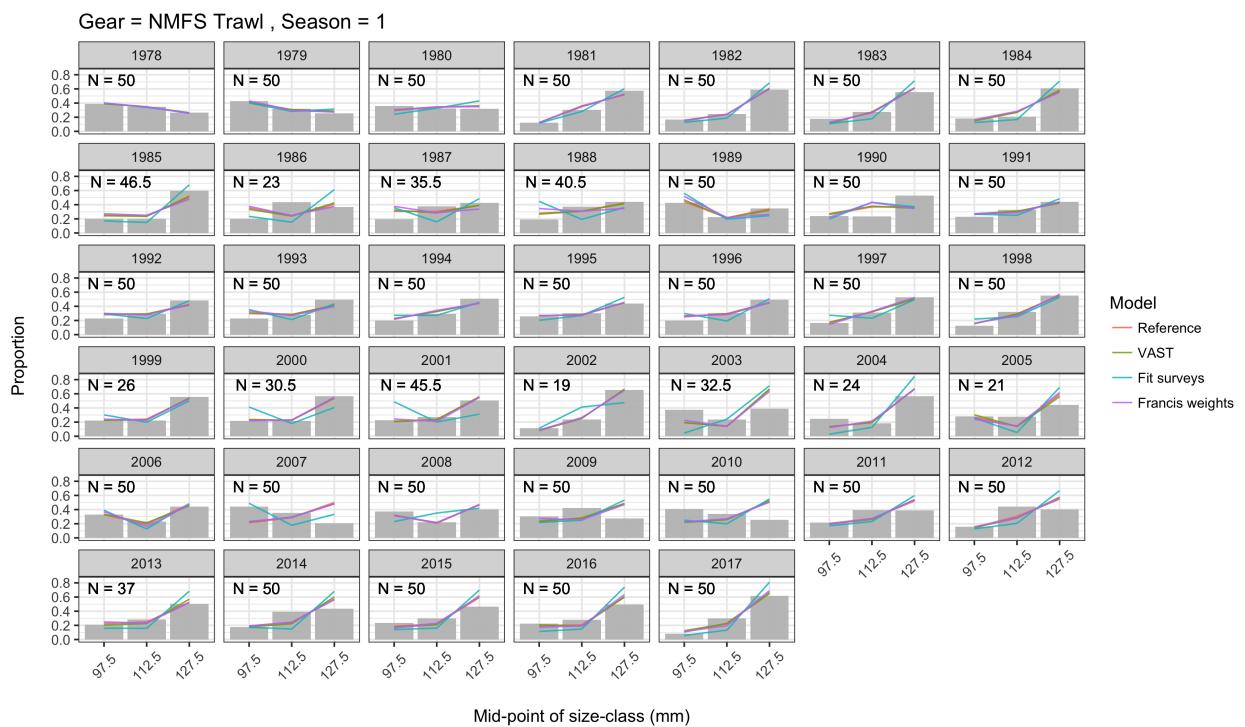


Figure 22: Observed and model estimated size-frequencies of discarded male SMBKC by year in the NMFS trawl survey for the model scenarios.

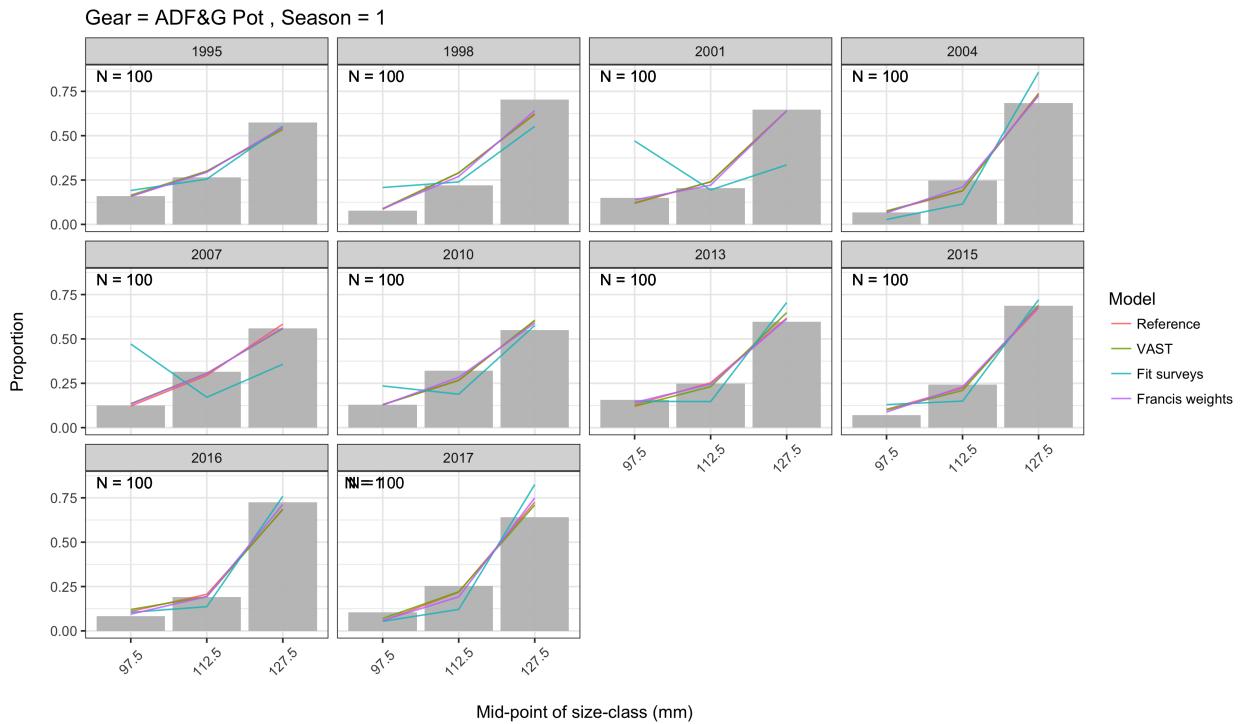


Figure 23: Observed and model estimated size-frequencies of discarded SMBKC by year in the ADF&G pot survey for the model scenarios.

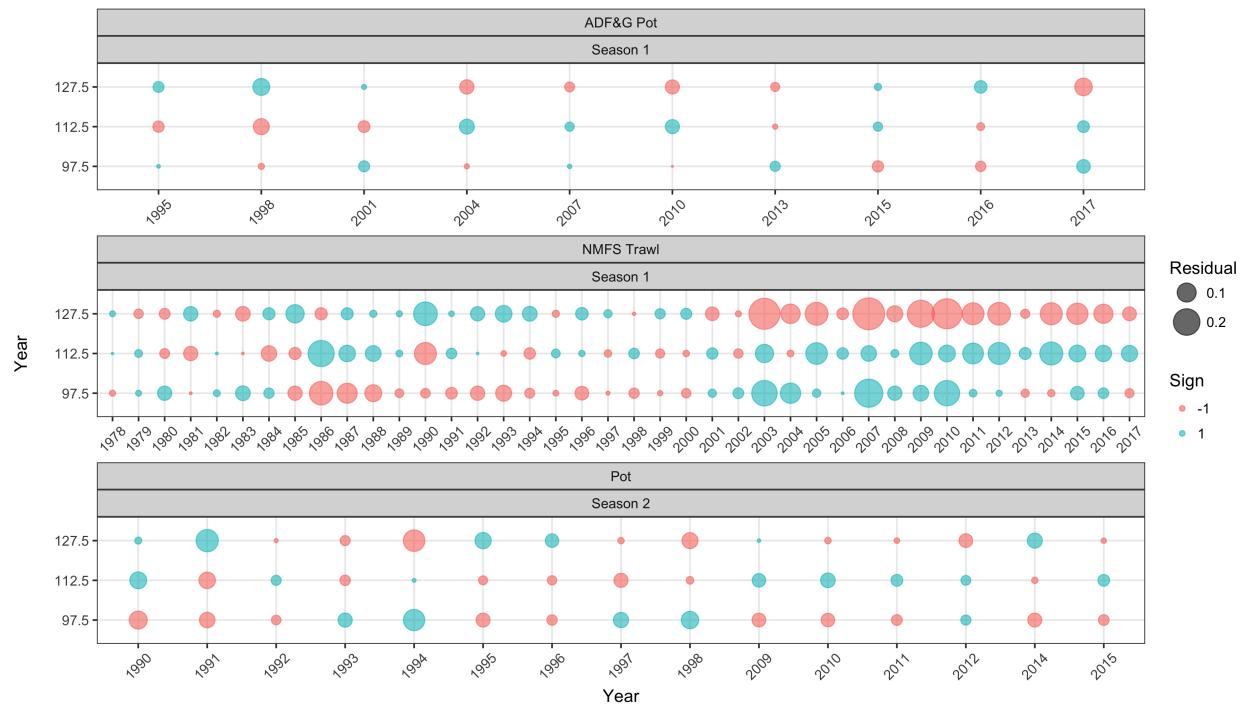


Figure 24: Bubble plots of residuals by stage and year for the directed pot fishery size composition data for SMBKC in the reference model.

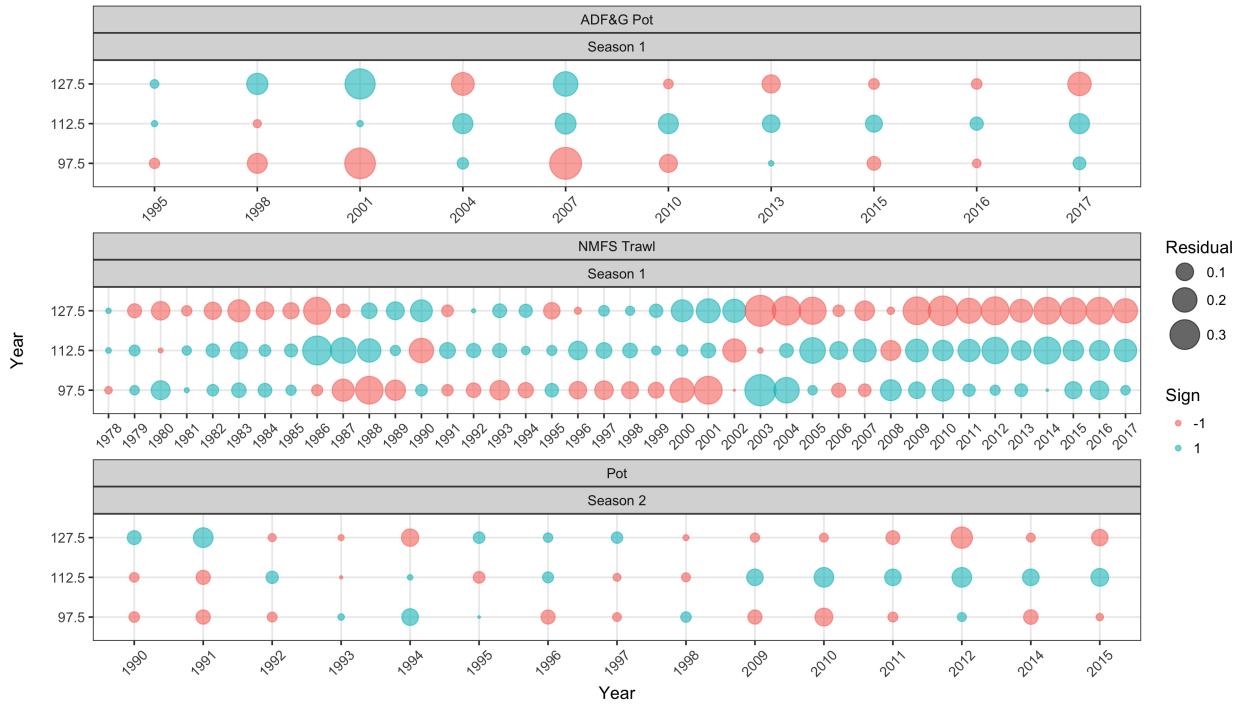


Figure 25: Bubble plots of residuals by stage and year for the ADF&G pot survey size composition data for SMBKC in the **fit surveys** model.

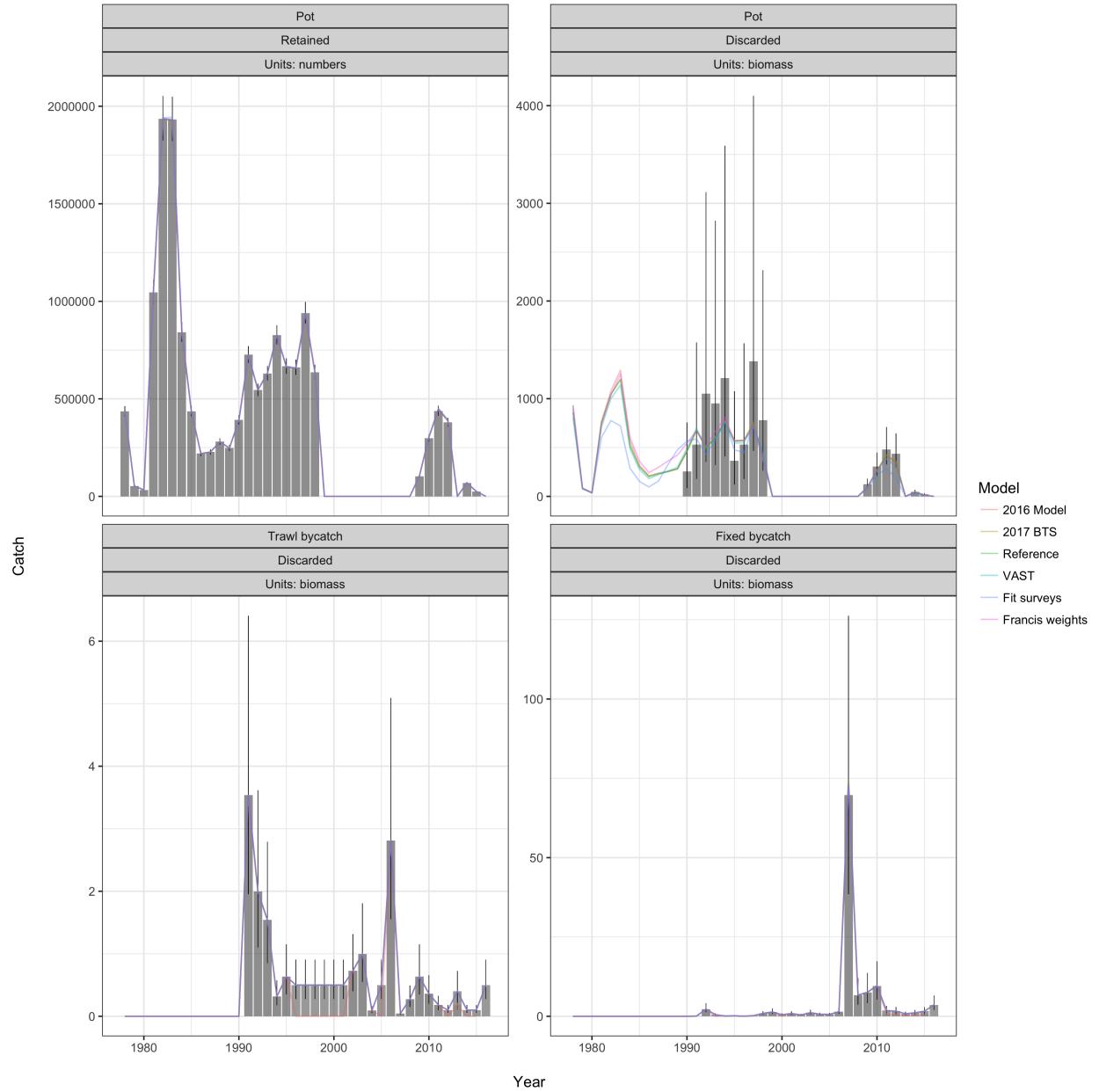


Figure 26: Comparison of observed and model predicted retained catch and bycatches in each of the Gmacs models. Note that difference in units between each of the panels, some panels are expressed in numbers of crab, some as biomass (tons).

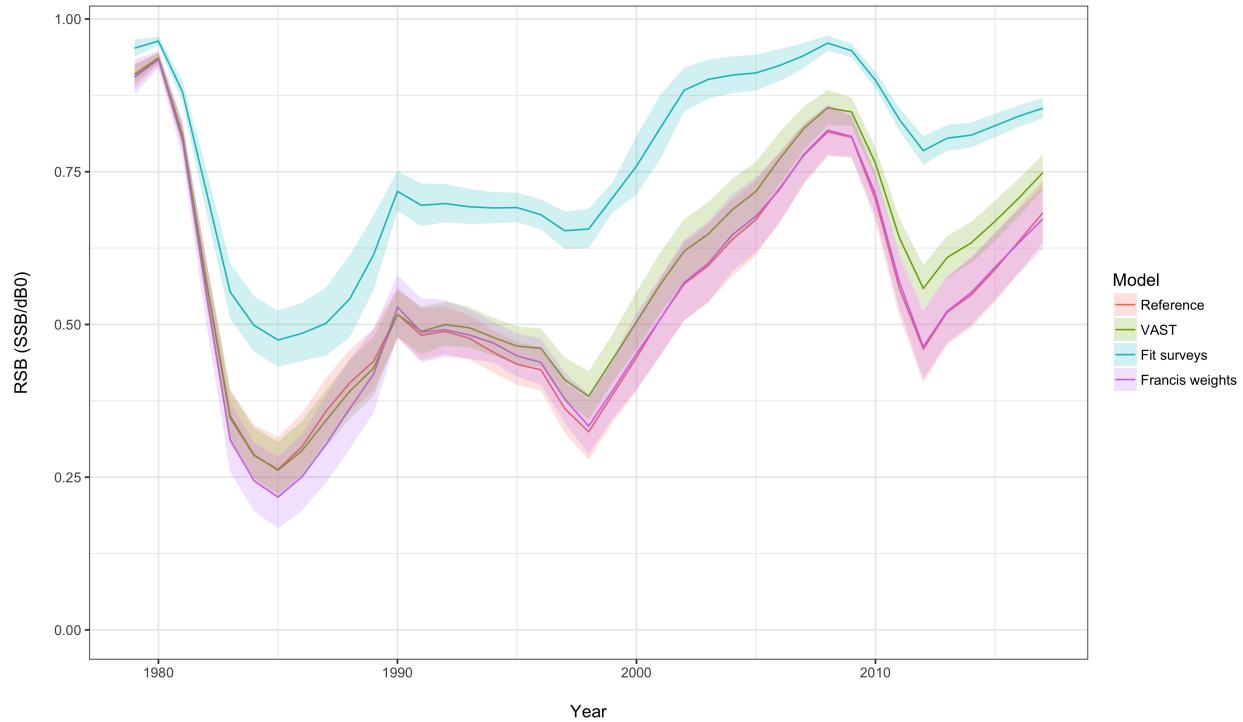


Figure 27: Comparisons of mature male biomass relative to the dynamic B_0 value, (15 February, 1978-2017) for each of the model scenarios.

Appendix A: SMBKC Model Description

1. Introduction

The Gmacs model has been specified to account only for male crab ≥ 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 5.5in carapace width (CW), whereas 105 mm CL is the management proxy for mature-male size (5 AAC 34.917 (d)). Accordingly, within the model only stage-3 crab are retained in the directed fishery, and stage-2 and stage-3 crab together comprise the collection of mature males. Some justification for the 105 mm value is presented in Pengilly and Schmidt (1995), who used it in developing the current regulatory SMBKC harvest strategy. The term “recruit” here designates recruits to the model, i.e., annual new stage-1 crab, rather than recruits to the fishery. The following description of model structure reflects the 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 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 7)
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 24. 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

$$\mathbf{n}_{t,y} = n_{l,t,y} = [n_{1,t,y}, n_{2,t,y}, n_{3,t,y}]^\top. \quad (2)$$

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

$$\phi_l = [1, 0, 0]^\top, \quad (3)$$

and the recruitment is

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

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

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

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

$$\mathbf{G} = \begin{bmatrix} 1 - \pi_{12} - \pi_{13} & \pi_{12} & \pi_{13} \\ 0 & 1 - \pi_{23} & \pi_{23} \\ 0 & 0 & 1 \end{bmatrix}, \quad (6)$$

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

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

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

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

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

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

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 , F^{df} , \bar{F}^{tb} , and \bar{F}^{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

$$Z_{t,y} = Z_{l,t,y} = M_{t,y} + F_{t,y}. \quad (10)$$

The survival matrix $S_{t,y}$ during season t and year y is

$$S_{t,y} = \begin{bmatrix} 1 - e^{-Z_{1,t,y}} & 0 & 0 \\ 0 & 1 - e^{-Z_{2,t,y}} & 0 \\ 0 & 0 & 1 - e^{-Z_{3,t,y}} \end{bmatrix}. \quad (11)$$

The basic population dynamics underlying Gmacs can thus be described as

$$\begin{aligned} \mathbf{n}_{t+1,y} &= S_{t,y} \mathbf{n}_{t,y}, & \text{if } t < 5 \\ \mathbf{n}_{t,y+1} &= \mathbf{G} S_{t,y} \mathbf{n}_{t,y} + \mathbf{r}_{t,y} & \text{if } t = 5. \end{aligned} \quad (12)$$

3. Model Data

Data inputs used in model estimation are listed in Table 25.

4. Model Parameters

Table 26 lists fixed (externally determined) parameters used in model computations. In all scenarios, the stage-transition matrix is

$$\mathbf{G} = \begin{bmatrix} 0.2 & 0.7 & 0.1 \\ 0 & 0.4 & 0.6 \\ 0 & 0 & 1 \end{bmatrix} \quad (13)$$

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

Estimated parameters are listed in Table 27 and include an estimated natural mortality deviation parameter in 1998/99 (δ_{1998}^M) 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 18). A lognormal distribution is assumed to characterize the catch data and is modelled as

$$\sigma_{t,y}^{\text{catch}} = \sqrt{\log \left(1 + \left(CV_{t,y}^{\text{catch}} \right)^2 \right)} \quad (14)$$

$$\delta_{t,y}^{\text{catch}} = \mathcal{N} \left(0, \left(\sigma_{t,y}^{\text{catch}} \right)^2 \right) \quad (15)$$

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

$$\sigma_{t,y}^I = \frac{1}{\lambda} \sqrt{\log \left(1 + \left(CV_{t,y}^I \right)^2 \right)} \quad (16)$$

$$\delta_{t,y}^I = \log \left(I^{\text{obs}} / I^{\text{pred}} \right) / \sigma_{t,y}^I + 0.5 \sigma_{t,y}^I \quad (17)$$

and the likelihood is

$$\sum \log (\delta_{t,y}^I) + \sum 0.5 (\sigma_{t,y}^I)^2 \quad (18)$$

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 adequate. 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 24: 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 |

Table 25: 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) |
| Groundfish trawl bycatch biomass | 1992/93 - 2016/17 | NMFS groundfish observer program |
| Groundfish fixed-gear bycatch biomass | 1992/93 - 2016/17 | NMFS groundfish observer program |
| NMFS trawl-survey biomass index (area-swept estimate) and CV | 1978-2017 | NMFS EBS trawl survey |
| ADF&G pot-survey abundance index (CPUE) and CV | 1995-2017 | ADF&G SMBKC pot survey |
| NMFS trawl-survey stage proportions and total number of measured crab | 1978-2017 | NMFS EBS trawl survey |
| ADF&G pot-survey stage proportions and total number of measured crab | 1995-2017 | 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) |

Table 26: 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 | \mathbf{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 Table 10 | 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 27: 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 | 4.0 | 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}^{df} | - | 0.2 | - | - | 1 |
| Average trawl bycatch fishing mortality \bar{F}^{tb} | - | 0.001 | - | - | 1 |
| Average fixed gear bycatch fishing mortality \bar{F}^{fb} | - | 0.001 | - | - | 1 |