Saint Matthew Island Blue King Crab Stock Assessment 2016

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September 2016

Executive Summary

1. **Stock**: Blue king crab, *Paralithodes platypus*, Saint Matthew Island (SMBKC), Alaska.
2. **Catches**: Peak historical harvest was 4288 tonnes (9.454 million pounds) in 1983/84[1]. The fishery was closed for 10 years after the stock was declared overfished in 1999. Fishing resumed in 2009/10 with a fishery-reported retained catch of 209 tonnes (0.461 million pounds), less than half the 529.3 tonne (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 tonnes (0.655 million pounds), but the fishery performance was relatively poor with a retained catch of 140 tonnes (0.309 million pounds).
3. **Stock biomass**: Following a period of low numbers (below 30% of the 1978-2016 mean of 5,865 t) after the stock was declared overfished in 1999, trawl-survey indices of SMBKC stock abundance and biomass generally increased to well above average from 2007-2012. In 2013 the survey biomass estimate was low (~40% of the mean value) but was followed by average biomass estimates in 2014 and 2015 (with sampling CVs of 77% and 45%, respectively). The 2016 biomass estimate was 3,500 t (7.7 million lbs with a CV of 39%). This value represents about 60% of the long term mean with the most recent 3-year average surveys at 87% of the mean value. This suggests a general decline in biomass compared to the recent peak survey estimate of nearly twice the average. The assessment model estimates moderate the interannual variability observed in the survey biomass substantially and suggest that the stock (in survey biomass units) is stable but only at about 45% of the long term model-predicted survey biomass average.
4. **Recruitment**: Because little information about the abundance of small crab is available for this stock, recruitment has been assessed in terms of the number of male crab within the 90-104 mm carapace length (CL) size class in each year. The 2013 trawl-survey area-swept estimate of 0.335 million male SMBKC in this size class marked a three-year decline and was the lowest since 2005. That decline did not continue as the 2014 survey estimate is 0.723 million. The survey recruitment is 0.992 million in 2015, but the majority of this survey estimate is from one tow with a great deal of uncertainty.
5. **Management performance**: In recent assessments, estimated total male catch has been determined as the sum of fishery-reported retained catch, estimated male discard mortality in the directed fishery, and estimated male bycatch mortality in the groundfish fisheries, as these have been the only sources of non-negligible fishing mortality to consider. The stock was above the minimum stock-size threshold (MSST) in 2014/15 and is hence not overfished. Overfishing did not occur in 2014/15 (Table 1).

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

Table 1: Status and catch specifications (1000 tonnes) (scenario 1).

Year	MSST	Biomass (MMB_{mating})	TAC	Retained catch	Total male catch	OFL	ABC
2011/12	1.50	5.03	1.15	0.85	0.95	1.70	1.54
2012/13	1.80	2.85	0.74	0.73	0.82	1.02	0.92
2013/14	1.50	3.01	0.00	0.00	0.00	0.56	0.45
2014/15	1.86	2.48	0.30	0.14	0.15	0.43	0.34
2015/16		2.45				0.28	0.22
2016/17							

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 2).

Table 2: Basis for the OFL (1000 tonnes) (scenario 1).

Year	Tier	B_{MSY}	Biomass (MMB_{mating})	B/B_{MSY}	F_{OFL}	γ	Basis for B_{MSY}	Natural mortality
2011/12	4a	3.11	7.17	2.31	0.18	1	1989-2010	0.18
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					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

All of the time series used in this assessment have been updated to include the most recent fishery and survey results. This assessment makes use of an updated trawl-survey time series supplied by R. Foy in August 2016, updated groundfish bycatch estimates based on 1999-2015 NMFS AKRO data also supplied by R. Foy, and the ADF&G pot survey data in 2016.

Changes in Assessment Methodology

This assessment is done using Gmacs. The model is based upon the 3-stage length-based assessment model first presented in May 2011 by Bill Gaeuman and accepted by the CPT in May 2012. There are several differences between the Gmacs assessment model and the previous model. One of the major differences being that natural and fishing mortality are continuous within 5 discrete seasons (using the "correct" catch equation rather than being applied as a pulse). Season length in Gmacs is controlled by changing the proportion of natural mortality that is applied during each season. A detailed outline of the Gmacs implementation of the SMBKC model is provided in Appendix A.

Changes in Assessment Results

One of the Gmacs model scenarios (**Gmacs match**) attempts to match the 2015 assessment as closely as possible by specifying the same (or similar) dynamics and some of the same (fixed) parameter values. There are some minor differences between the 2015 model and the **Gmacs match** model, but given that Gmacs and the 2015 model have different underpinning population dynamics, these differences should be of little concern. Four other Gmacs scenarios are presented as well, each providing a slightly different fit to the data.

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. *1-year projection for calculating Tier 3 or 4 OFLs*
2. *specify catchability as a fixed or estimated parameter or use the analytic calculation for the MLE*
3. *specify priors (e.g., gamma) using mean and variance/standard deviation for all parameters to ease specifying priors*
4. *include an option to calculate dynamic* B_{MSY}
5. *add the ability to "jitter" initial parameter values*
6. *add the ability to conduct retrospective analyses*
7. *add ability to estimate bycatch fishing mortality rates when observer data are missing but effort data is available*
8. *allow different phases for "rec_ini", "rec_dev" estimation*

Response:

1. Done
2. Done
3. Not yet implemented
4. Not yet implemented
5. Not yet implemented
6. Not yet implemented
7. Not yet implemented
8. Done

Comment: *Andre Punt pointed out the need to use a fixed-iteration Newton's method to calculate OFL, not bisection, to keep the calculation differentiable so that OFL can be reported as an sdreport variable.*

Response: This has been done and the F_{OFL} and OFL have both been reported as an sdreport variables in this document.

CPT and SSC Comments Specific to the SMBKC Stock Assessment

Comment: *the CPT requests that some evaluation should also be included in the September report to the CPT which compares against the previous assessment model corrected for the error.*

Response: The error in the 2015 was fixed and this model was run again. Comparisons between the Gmacs models and the 2015 model are presented throughout this document. One of the Gmacs model scenarios (**Gmacs match**) attempts to match the 2015 assessment as closely as possible by specifying the same (or similar) dynamics and some of the same (fixed) parameter values.

Comment: *The SSC and CPT requested the following models for review at the spring 2016 meeting:*

1. *Base: try to match 2015 model but prevent dome shaped selectivity*

2. *Base + add CV for both surveys*
3. *Above + Francis re-weighting*
4. *Above + remove M spike*

Response: Models 1, 3, and 4 are all included and evaluated in this document as the **Gmacs base**, **Gmacs Francis**, and **Gmacs M** scenarios. Model 2 was not included in this document for two reasons. Firstly, if doing Francis iterative re-weighting then additional CV should not be added as well (as the two methods basically do the same thing). Secondly, the SSC recommended against the model runs with additional CV (see the comment from the SSC below).

Comment: *The SSC is not convinced that the model runs with extra CV are very informative. The inclusion of extra CV seems to be rather arbitrary based on the numbers of points that fall within confidence intervals estimated from trawl surveys. The SSC recommends coming up with some alternative way to consider extra variability, which could be informed by simulation testing.*

Response: All model runs that estimate additional CV were dropped from this document. Instead we provide three model runs that use the Francis iterative re-weighting method to re-weight the length-frequency data relative to the abundance indices. These runs are the **Gmacs Francis**, **Gmacs M**, and **Gmacs force** scenarios. The final Gmacs scenario (**Gmacs force**) is an exploratory model run that upweights both the trawl-survey and pot survey abundance indices (it upweights the pot survey more than the trawl survey).

Comment: *The descriptions of seasons in the model is confusing and currently reads as if M differs among seasons. More justification is needed on how seasons are defined and how they were selected, as well as clarification on M during these seasons.*

Response: This description has been updated and justification provided in Appendix A.

Comment: *During the presentation to the SSC, uncertainty was expressed about the origins of the growth transition matrix, but page 7 of the report indicates that the matrix was derived by Otto and Cummiskey (1990). As this matrix is critical to the model, the origin and integrity of the growth transition matrix should be carefully explained in the assessment for fall 2016. In some other models, the transition matrix can be estimated. If there are doubts about the veracity of the transition matrix, perhaps this can be explored in the modeling framework.*

Response: The report is correct, the growth matrix was derived by Otto and Cummiskey (1990) and used in this assessment. PERHAPS JIE CAN HELP OUT WITH SOME MORE DETAIL HERE?

Comment: *The selectivities were constrained so that they do not exceed 1.0, but the tables of log-transformed parameter estimates do not indicate that this upper bound was approached. This should be clarified.*

Response: After fixing the error in the 2015 SMBKC model code, it was found that the NMFS trawl survey selectivity does exceed 1 for stage-2 crab. The **Gmacs match** scenario does allow selectivity to be greater than 1 (it uses the same fixed selectvity values as the 2015 model). At the request of the CPT an upper bound of 1 was specified for the remaining Gmacs scenarios. Tables 13, 14, 15, and 16 all show that this upper bound was approached in all of these scenarios.

Comment: *It would be helpful to include a table of NMFS trawl survey CPUE by crab stage, just as was provided for the ADF&G pot survey (Table 1).*

Response: This table has been added.

Comment: *Page 10 refers to a table of observed and estimated sample size, but no such table was provided.*

Response: This table has been added.

Comment: *As with the 2015 model, GMACS consistently overestimates trawl survey estimates of male biomass in the last decade, whereas GMACS tends to underestimate the last couple of pot survey estimates (Figure 9, 12). This is also reflected in patterns in residuals, and the proportions of stage-3 crab tend to be overestimated in recent years (Figure 14). These patterns should be discussed in the assessment.*

Response:

Comment: *The report contains very little description and interpretation of results. Moreover, not all figures are cited in the document. The document should highlight the major features of the results and offer some explanation, as well.*

Response:

Comment: *A brief explanation was provided about the future outlook (page 12) that indicated a declining stock. However, stock trends shown in Figure 24 generally suggest population growth since 1993. Closer examination of Tables 9-11 suggest that trends depend somewhat on model run and life stage. Statements about future outlook should be qualified and refer to figures and tables and explain any differences in outcomes.*

Response:

Comment: *The SSC discussed the possibility that these patterns could be indicative of spatial patterns in stock distribution. The trawl survey covers a much larger geographic distribution than the pot survey (Figure 4). Crab distribution may vary with sex (females tend to be found close to shore) and life stage. Thus, the trawl and pot surveys may sample the crab stock differentially. Moreover, the geographic distributions of these stages may vary with stock density and temperature. It could be informative to conduct some spatial analyses, which could include: (1) estimation of survey catchability as a function of temperature, (2) a stock assessment model run that includes pot surveys and only those trawl stations that fall within the pot survey distribution as a comparison the runs that include the full trawl survey data, and (3) analysis of the spatial distribution of surveyed crabs by stage at high and low biomass and during warm and cold years.*

Response:

C. Introduction

Scientific Name

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

Distribution

Blue king crab are sporadically distributed throughout the North Pacific Ocean from Hokkaido, Japan, to southeastern Alaska (Figure 1). In the eastern Bering Sea small populations are distributed around St. Matthew Island, the Pribilof Islands, St. Lawrence Island, and Nunivak Island. Isolated populations also exist in some other cold water areas of the Gulf of Alaska (NPFMC 1998). The St. Matthew Island Section for blue king crab is within Area Q2 (Figure 2), which is the Northern District of the Bering Sea king crab registration area and includes the waters north of Cape Newenham (58°39' N. lat.) and south of Cape Romanzof (61°49' N. lat.).

Stock Structure

The Alaska Department of Fish and Game (ADF&G) Gene Conservation Laboratory division has detected regional population differences between blue king crab collected from St. Matthew Island and the Pribilof Islands[2]. 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.

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

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

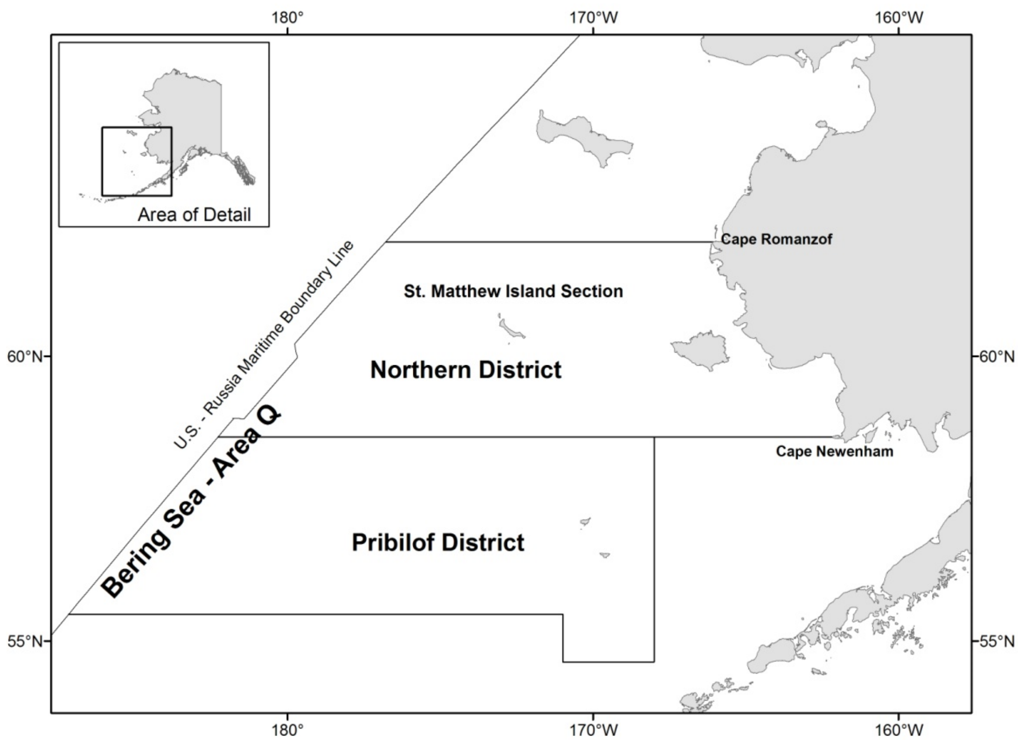

Figure 2: King crab Registration Area Q (Bering Sea).

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 (cf. Jensen and Armstrong 1989) and mature crab seasonally migrate inshore where they molt and mate. Unlike red king crab, juvenile blue king crab do not form pods, but instead rely on cryptic coloration for protection from predators and require suitable habitat such as cobble and shell hash. Somerton and MacIntosh (1983) estimated SMBKC male size at sexual maturity to be 77 mm carapace length (CL). Paul et al. (1991) found that spermatophores were present in the vas deferens of 50% of the St. Matthew Island blue king crab males examined with sizes of 40-49 mm CL and in 100% of the males at least 100 mm CL. Spermataphore diameter also increased with increasing CL with an asymptote at ~ 100 mm CL. They noted, however, that although spermataphore presence indicates physiological sexual maturity, it may not be an indicator of functional sexual maturity. For purposes of management of the St. Matthew Island blue king crab fishery, the State of Alaska uses 105 mm CL to define the lower size bound of functionally mature males (Pengilly and Schmidt 1995). Otto and Cummiskey (1990) report an average growth increment of 14.1 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 tonnes (1.202 million pounds) in 1977, and harvests peaked in 1983 when 164 vessels landed 4288 tonnes (9.454 million pounds) (Fitch et al. 2012; Table 3).

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 4990 tonnes (11.0 million pounds) as defined by the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner crabs (NPFMC 1999). Zheng and Kruse (2002) hypothesized a high level of SMBKC natural mortality from 1998 to 1999 as an explanation for the low catch per unit effort (CPUE) in the 1998/99 commercial fishery and the low numbers across all male crab size groups caught in the annual NMFS eastern Bering Sea trawl survey from 1999 to 2005 (Table 7). 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 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 tonnes (1.167 million pounds), closing again by regulation on 1 February 2010. Seven participating vessels landed a catch of 209 tonnes (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, prompting ADF&G to close the fishery again for the 2013/14 season. Due to an abundance above thresholds, the fishery was reopened for the 2014/15 season with a low TAC of 297 tonnes (0.655 million pounds) and in 2015/16 the TAC was further reduced to 186 tonnes (0.411 million pounds).

Though historical observer data are limited due to very limited sampling, 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 4), with total male discard mortality in the 2012/13

Table 3: The 1978/79 to 2014/15 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.

			Harvest					
Year	Dates	GHL/TAC	Crab	Pounds	Pot lifts	CPUE	avg wt	avg CL
1978/79	07/15 - 09/03		436,126	1,984,251	43,754	10	4.5	132.2
1979/80	07/15 - 08/24		52,966	210,819	9,877	5	4.0	128.8
1980/81	07/15 - 09/03			CONFIDENTIAL				
1981/82	07/15 - 08/21		1,045,619	4,627,761	58,550	18	4.4	NA
1982/83	08/01 - 08/16		1,935,886	8,844,789	165,618	12	4.6	135.1
1983/84	08/20 - 09/06	8.0	1,931,990	9,454,323	133,944	14	4.9	137.2
1984/85	09/01 - 09/08	2.0-4.0	841,017	3,764,592	73,320	11	4.5	135.5
1985/86	09/01 - 09/06	0.9-1.9	436,021	2,175,087	46,988	9	5.0	139.0
1986/87	09/01 - 09/06	0.2-0.5	219,548	1,003,162	22,073	10	4.6	134.3
1987/88	09/01 - 09/05	0.6-1.3	227,447	1,039,779	28,230	8	4.6	134.1
1988/89	09/01 - 09/05	0.7-1.5	280,401	1,236,462	21,678	13	4.4	133.3
1989/90	09/01 - 09/04	1.7	247,641	1,166,258	30,803	8	4.7	134.6
1990/91	09/01 - 09/07	1.9	391,405	1,725,349	26,264	15	4.4	134.3
1991/92	09/16 - 09/20	3.2	726,519	3,372,066	37,104	20	4.6	134.1
1992/93	09/04 - 09/07	3.1	545,222	2,475,916	56,630	10	4.5	134.1
1993/94	09/15 - 09/21	4.4	630,353	3,003,089	58,647	11	4.8	135.4
1994/95	09/15 - 09/22	3.0	827,015	3,764,262	60,860	14	4.9	133.3
1995/96	09/15 - 09/20	2.4	666,905	3,166,093	48,560	14	4.7	135.0
1996/97	09/15 - 09/23	4.3	660,665	3,078,959	91,085	7	4.7	134.6
1997/98	09/15 - 09/22	5.0	939,822	4,649,660	81,117	12	4.9	139.5
1998/99	09/15 - 09/26	4.0	635,370	2,968,573	91,826	7	4.7	135.8
1999/00 - 2008/09				FISHERY CLOSED				
2009/10	10/15 - 02/01	1.17	103,376	460,859	10,697	10	4.5	134.9
2010/11	10/15 - 02/01	1.60	298,669	1,263,982	29,344	10	4.2	129.3
2011/12	10/15 - 02/01	2.54	437,862	1,881,322	48,554	9	4.3	130.0
2012/13	10/15 - 02/01	1.63	379,386	1,616,054	37,065	10	4.3	129.8
2013/14				FISHERY CLOSED				
2014/15	10/15 - 02/05	0.66	69,109	308,582	10,133	7	4.5	132.3
2015/16								

directed fishery estimated at about 12% (88 tonnes or 0.193 million pounds) of the reported retained catch weight, assuming 20% handling mortality.

On the other hand, these same data suggest a significant reduction in the bycatch of females, which may be attributable to the later timing of the contemporary fishery and the more offshore distribution of fishery effort since reopening in 2009/10[3]. Some bycatch of discarded blue king crab has also been observed historically in the eastern Bering Sea snow crab fishery, but in recent years it has generally been negligible, and observers recorded no bycatch of blue king crab in sampled pot lifts during 2013/14. 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 5).

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

Table 4: 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						

D. Data

Summary of New Information

Data used in this assessment have been updated to include the most recently available fishery and survey numbers. In addition, this assessment makes use of an updated trawl-survey time series provided by R. Foy in August 2016, as well as updated 1993-2015 groundfish bycatch estimates based on AKRO data also supplied by R. Foy. 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 3); results from the annual NMFS eastern Bering Sea trawl survey (1978-2016; Table 7); results from the triennial ADF&G SMBKC pot survey (every third year during 1995-2013), the 2015 pot survey, and the 2016 pot survey (Table 6); size-frequency information from ADF&G crab-observer pot-lift sampling (1990/91-1998/99, 2009/10-2012/13, and 2014/15-2015/16; Table 4); and NMFS groundfish-observer bycatch biomass estimates (1992/93-2015/16; Table 5).

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 where the other is not represented (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). Note that for this assessment the newly available NMFS groundfish observer data reported by ADF&G statistical area was not used.

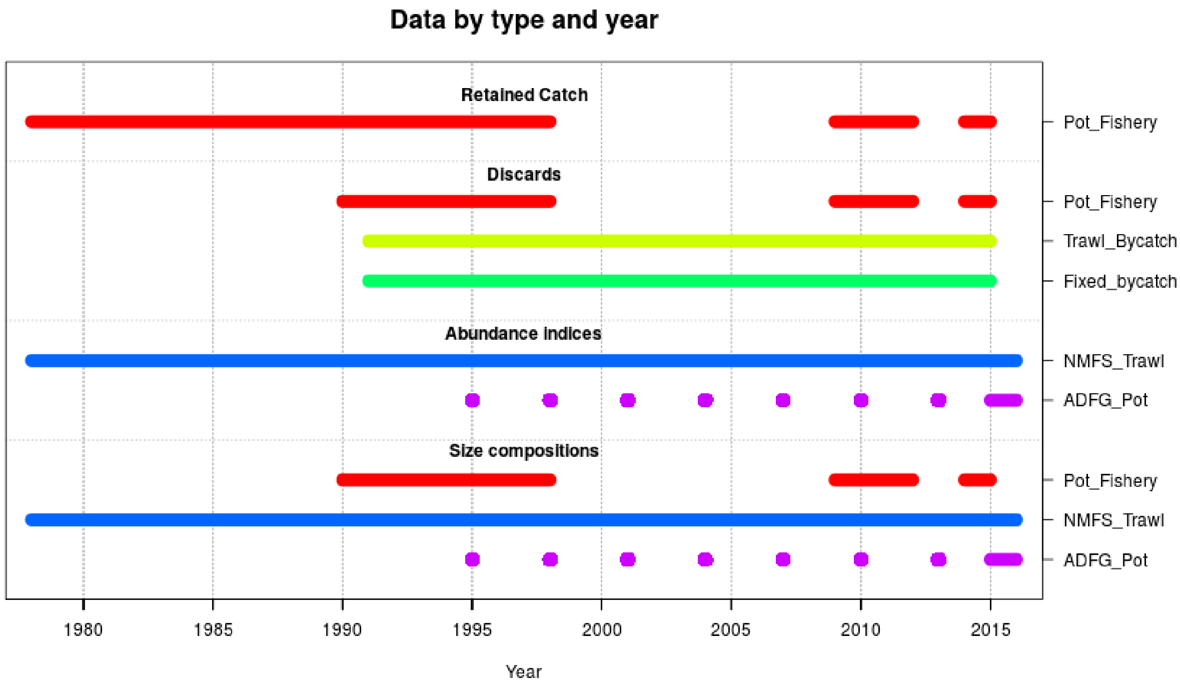

Figure 3: Data extent for the SMBKC assessment.

Other Data Sources

Recent model configurations developed for SMBKC makes use of a growth transition matrix based on Otto and Cummiskey (1990), the same growth transition matrix is used in this assessment. 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.

Excluded Data Sources

Groundfish bycatch size-frequency data are available for selected years. These data were used in model-based assessments prior to 2011. However, they have since been excluded because these data tend to be severely limited: for example, 2012/13 data include a total of just 4 90 mm+ CL male blue king crab from reporting areas 521 and 524.

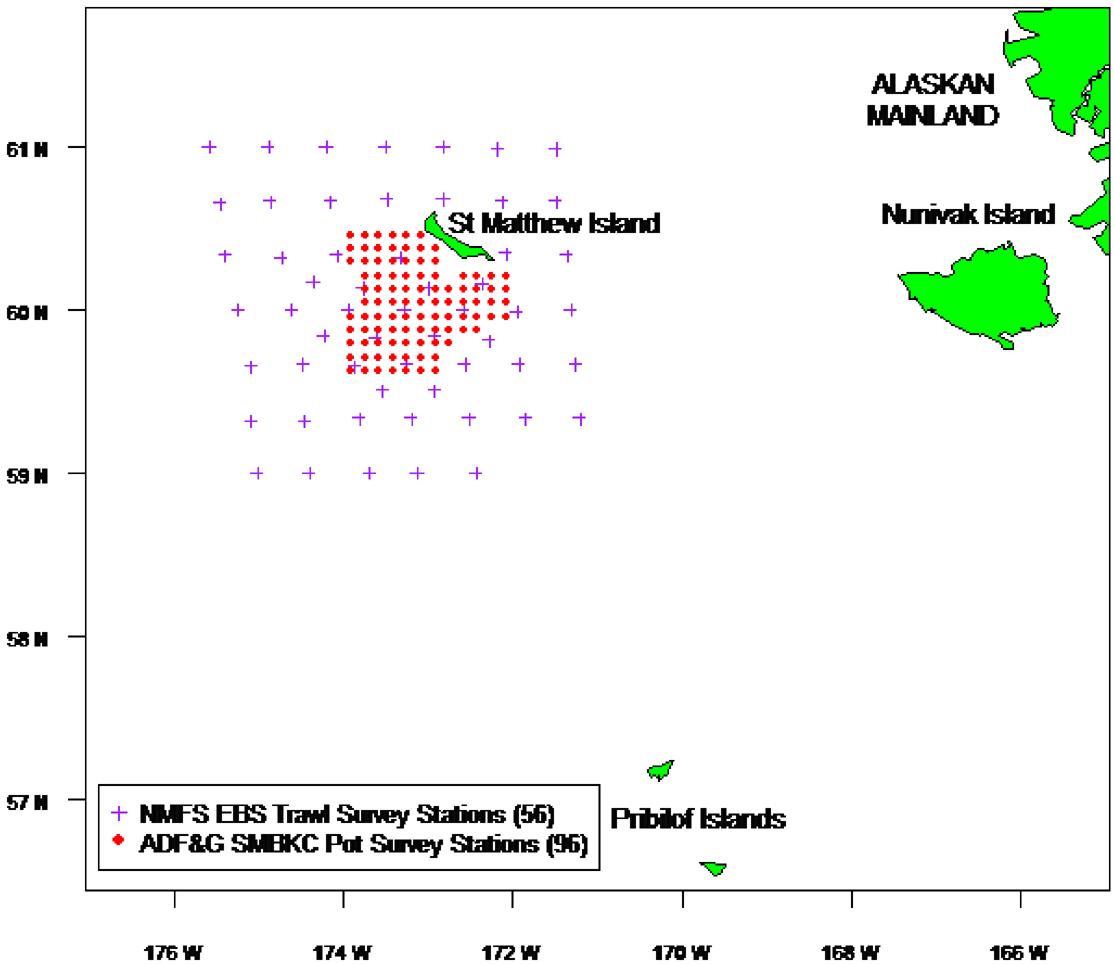

Figure 4: Trawl and pot-survey stations used in the SMBKC stock assessment.

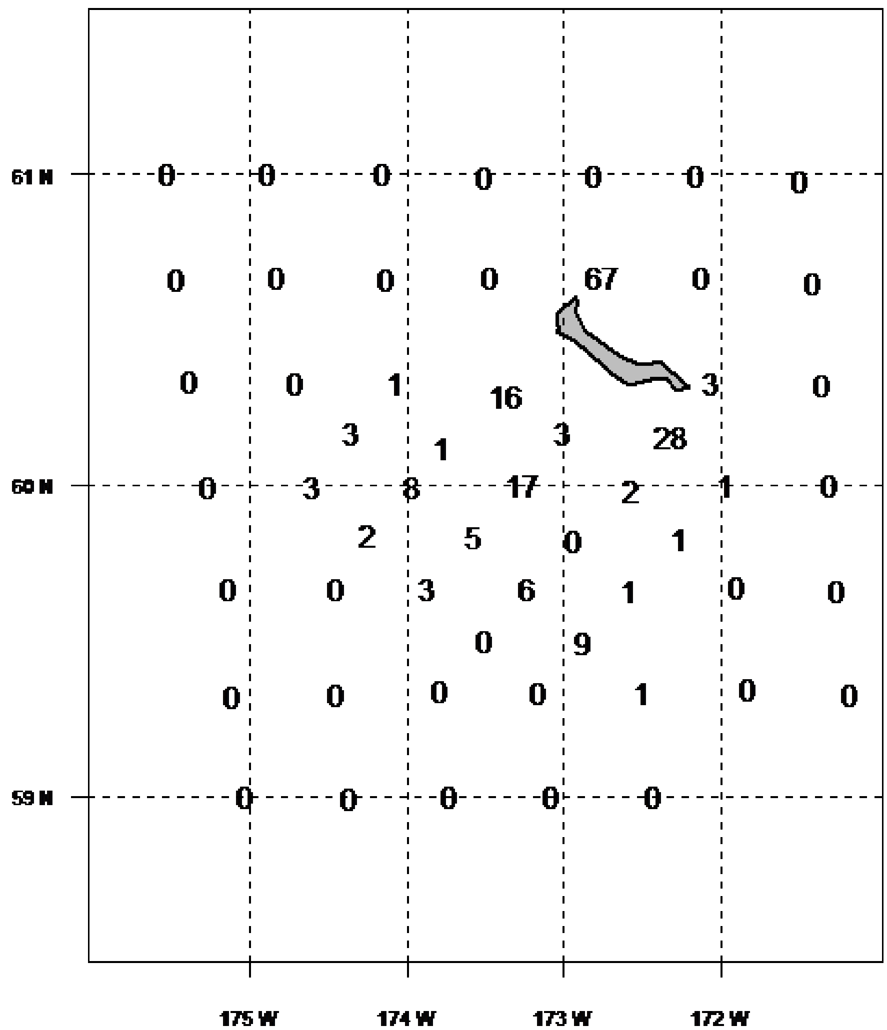

Figure 5: Catches of 181 male blue king crab measuring at least 90 mm CL from the 2014 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock. Note that the area north of St. Matthew Island, which includes the large catch of 67 crab at station R-24, is not represented in the ADF&G pot-survey data used in the assessment.

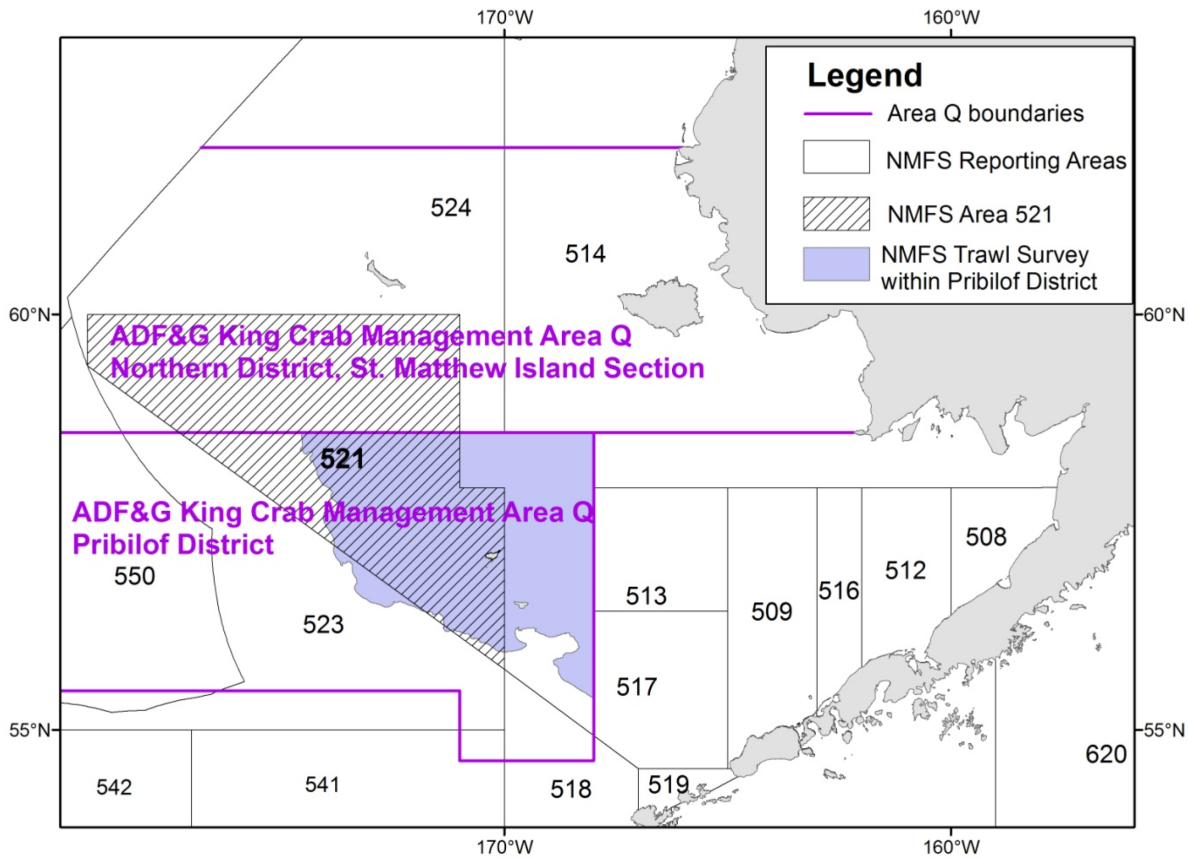

Figure 6: NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.

Table 5: Groundfish SMBKC male bycatch biomass (tonnes) 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. AKRO estimates used after 2008/09.

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	0.000
1994	0.318	0.091
1995	0.635	0.136
1996	0.000	0.045
1997	0.000	0.181
1998	0.000	0.907
1999	0.000	1.361
2000	0.000	0.000
2001	0.000	0.862
2002	0.726	0.408
2003	0.998	1.134
2004	0.091	0.635
2005	0.000	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	0.590
2012	0.000	0.590
2013	0.181	0.272
2014	0.000	0.272
2015	0.000	0.635

Table 6: 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 seven triennial ADF&G SMBKC pot surveys and the 2015 and 2016 surveys. Source: D. Pengilly and R. Gish, ADF&G.

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

Table 7: NMFS EBS trawl-survey area-swept estimates of male crab abundance (10^6 crab) and of mature male biomass (10^6 lbs). Total number of captured male crab $\geq$ 90 mm CL is alos given. Source: R. Foy, NMFS. The "+" refer to plus group.

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

E. Analytic Approach

History of Modeling Approaches for this Stock

A four-stage catch-survey-analysis (CSA) assessment model was used before 2011 to estimate abundance and biomass and prescribe fishery quotas for the SMBKC stock (2010 SAFE; Zheng et al. 1997). The four-stage CSA is similar to a full length-based analysis, the major difference being coarser length groups, which are more suited to a small stock with consistently low survey catches. In this approach, the abundance of male crab with a CL of 90 mm or above is modeled in terms of four crab stages: stage 1: 90-104 mm CL; stage 2: 105-119 mm CL; stage 3: newshell 120-133 mm CL; and stage 4: oldshell $\geq$ 120 mm CL and newshell $\geq$ 134 mm CL. Motivation for these stage definitions comes from the fact that for management of the SMBKC stock, male crab measuring at least 105 mm CL are considered mature, whereas 120 mm CL is considered a proxy for the legal size of 5.5 in carapace width, including spines. Additional motivation for these stage definitions 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 was requested to proceed with a survey-based approach for the Fall 2011 assessment. In May 2012 the CPT approved a slightly revised and better documented version of the alternative model for assessment.

The 2015 SMBKC stock assessment model, first used in Fall 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 at least 90 mm in CL, but it 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.

Assessment Methodology

The 2016 SMBKC assessment model makes use of the modeling framework Gmacs. The aim when developing this model was to first provide a fit to the data that best matched the 2015 SMBKC stock assessment model. A detailed description of the Gmacs model and its implementation is presented in Appendix A.

Model Selection and Evaluation

Five different Gmacs model scenarios were considered, in this document results from these models and the 2015 model are compared. The models inlcude:

1. **2015 Model**: the 2015 provided by Jie. Note that an error was found in the 2015 model code[4]. This error was fixed before making comparisons. Fixing this error caused the NMFS trawl survey selectivity to exceed 1 for stage-2 crab.
2. **Gmacs match**: tries to match as closely as possible with the 2015 Model by fixing the stage-1 and stage-2 selectivity parameters and the catchability coefficient (q) for the ADF&G pot survey at those values estimated in the 2015 model (and allows the NMFS trawl survey selectivity to exceed 1 for stage-2 crab). The parameters that are estimated in this model include the average recruitment ($\bar{R}$), the recruitment deviations (δ_y^R), the initial numbers in each stage ($\boldsymbol{n}^0$), the natural mortality deviation

[4]The error in the 2015 model code was in the population dynamics function where the growth transition matrix is applied to the numbers at length to calculate the numbers during the following time-step, specifically `N(t+1,3)=TM(2,3)*NN(2)+NN(3);` which should be `N(t+1,3)=TM(1,3)*NN(1)+TM(2,3)*NN(2)+NN(3);`.

1998 (δ^M_{1998}), and the fishing mortalities for the directed pot fishery, the trawl bycatch fishery, and the fixed bycatch fishery ($\bar{F}^{\text{df}}$, $\bar{F}^{\text{tb}}$, $\bar{F}^{\text{fb}}$, $\delta^{\text{df}}_{t,y}$, $\delta^{\text{tb}}_{t,y}$, $\delta^{\text{fb}}_{t,y}$).

3. **Gmacs base**: directed pot, NMFS trawl survey and ADF&G pot survey selectivities are estimated for stage-1 and stage-2 crab (and fixed at 1 for stage-3 crab). These selectivities are bounded so that they cannot be greater than 1. This model also estimates the catchability coefficient (q) for the ADF&G pot survey as well as the average recruitment ($\bar{R}$), the recruitment deviations (δ^R_y), the initial numbers in each stage ($\boldsymbol{n}^0$), the natural mortality deviation 1998 (δ^M_{1998}), and the fishing mortalities for the directed pot fishery, the trawl bycatch fishery, and the fixed bycatch fishery ($\bar{F}^{\text{df}}$, $\bar{F}^{\text{tb}}$, $\bar{F}^{\text{fb}}$, $\delta^{\text{df}}_{t,y}$, $\delta^{\text{tb}}_{t,y}$, $\delta^{\text{fb}}_{t,y}$).
4. **Gmacs Francis**: is the same as above 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 left as is (i.e. a weight of 1) because upweighting these series resulted in worse standard deviation of the normalised residual (SDNR) and median of the absolute residual (MAR) values for each of the surveys. Down-weighting the two surveys actually improved the SDNR and MAR values, but it would be unwise to down-weight both of these series.
5. **Gmacs M**: is the same as above except that natural mortality (M) is fixed at 0.18 yr^{-1} during all years. The Francis weights for each of the size-compostitons were recalculated and applied again in this model.
6. **Gmacs force**: is an exploratory scenario that the same as above except the NMFS trawl survey is up-weighted by $\lambda^{\text{NMFS}} = 1.5$ and the ADF&G pot survey is up-weighted by $\lambda^{\text{ADFG}} = 2$. After this, the Francis weights for each of the size-compostitons were recalculated and applied again in this model. This scenario should not be used for overfishing determination as it upweights the trawl and pot survey abundance indices to force a better fit to each of these data sets and provide some contrast among the Gmacs model runs. This scenario forces a better fit to the trawl and pot surveys at the expense of the SDNR (and MAR) for each of these series.

Table 8 outlines the major features of each of the models.

Table 8: Outline of the major features of the five different Gmacs scenarios.

Scenario	Selectivity estimated	Use Francis LF weighting	Estimate M_{1998}
Gmacs match	No	No	Yes
Gmacs base	Yes	No	Yes
Gmacs Francis	Yes	Yes	Yes
Gmacs M	Yes	Yes	No
Gmacs force	Yes	Yes	No

Results

Results for all Gmacs scenarios are provided with comparisons to the 2015 model. We recommend scenario XXX to be used for the overfishing determination in 2016, based on the fit to the data and the plausibility of parameter estimates.

a. Effective sample sizes and weighting factors.

Observed and estimated effective sample sizes are compared in Table 11. Effective sample sizes are also shown on size-composition plots (Figures 14, 15, and 16).

Data weighting factors, SDNRs, and MARs are presented in Table 18. The SDNR for the trawl survey is acceptable at 1.44 in the **Gmacs match** scenario, and improves to 1.41 and 1.36 in the **Gmacs base** and **Gmacs Francis** scenarios. In the **Gmacs M** model the SDNR of the trawl survey is slightly worse at 1.54, and is much worse in the exploratory **Gmacs force** scenario at 2.26. The SDNRs for the pot surveys show much the same pattern between each of the scenarios, but are much higher values (ranging from 3.77 to 5.94). These values are very high, and whilst they can be improved by down-weighting the pot survey, it is recommended that they be left as they are as the pot survey is one of the most important data series in this model. 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 0.79 to 1.35 (except for in the **Gmacs force** scenario where the weights were a little high). The SDNRs for the directed pot fishery size compositions are a little low, ranging from 0.65 to 0.8. However, the SDNRs (and MARs) were not used when weighting the size composition data set. Instead, the Francis size composition weights were used (Francis 2011). In all model scenarios, the Francis weights match the weights that were actually applied to each of the size composition data sets.

b. Tables of estimates.

Model parameter estimates for each of the Gmacs scenarios are summarized in Tables 12, 13, 14, 15, and 16. These parameter estimates are compared in Table 17. Negative log-likelihood values and management measures for each of the Gmacs scenarios are compared in Tables 19 and 9.

There is little difference in the parameter estimates within the **Gmacs match** and **Gmacs base** scenarios. This is reflected in the log-likelihood components and the management quantities.

c. Graphs of estimates.

Estimated (and fixed) selectivities are compared in Figure 7.

The various model fits to total male (> 89 mm CL) trawl survey biomass are compared in Figures 8 and 9. The fits to pot survey CPUE are compared in Figures 10 and 11. Standardized residuals of total male trawl survey biomass and pot survey CPUE are plotted in Figures 12 and 13.

Fits to stage compositions for trawl survey, pot survey, and commercial observer data are shown in Figures 14, 15, and 16 for the all scenarios. Bubble plots of stage composition residuals for trawl survey, pot survey, and commercial observer data are shown for the **Gmacs base**, **Gmacs Francis**, **Gmacs M**, and **Gmacs force** scenarios in Figures 17, 18, 19, and 20, respectively.

Fits to retained catch numbers and bycatch biomass are shown for all Gmacs scenarios in Figure 21.

Estimated recruitment is compared in Figure 22. Estimated abundances by stage and mature male biomasses for all scenarios (including the 2015 model) are shown in Figures 26 and 23. Estimated natural mortality each year (M_t) is presented in Figure 27.

d. Graphic evaluation of the fit to the data.

There is little difference between model estimated survey biomass in the gmacs scenarios when compared with the 2015 model (Figures 8 and 10). Looking at the model fits to the NMFS trawl survey biomass (Figure 8), the **Gmacs match** scenario is the most similar to the 2015 model, and the **Gmacs base** model is very similar as well. In all scenarios, Gmacs produces a better fit during the mid-late 1980s. However, since about 2010 Gmacs estimates a slighly lower survey biomass than the 2015 model in an attempt to better fit the ADF&G pot survey CPUE (Figure 10). The two Gmacs scenarios that do not attempt to estimate natural mortality in 1998/99 (**Gmacs M** and **Gmacs force**) predict lower survey biomass from 1992 to 1998 than the other scenarios and the 2015 model. These same two runs also predict a lower survey biomass in recent years (since about 2010). While these two models may result in slightly worse fits to the data, they do not risk over-fitting the data in the same way the other scenarios do. As exptected the model that upweights the NMFS survey biomass and ADF&G pot survey CPUE (**Gmacs force**) provides a better fit to the survey biomass during the mid-late 1980s and a much better fit to the pot survey CPUE in the most recent two years (Figures 8, 9, 10, and 11). Keep in mind 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.

Estimated recruitment to the model is variable over time (Figure 22). Estimated recruitment during recent years is generally low in all scenarios. Estimated mature male biomass on 15 February also fluctuates strongly over time. The high biomass estimates in recent years for the Gmacs CV scenario is quite different to the other scenarios (Figure 23).

e. Retrospective and historic analyses.

Gmacs retrospective analyses under development.

f. Uncertainty and sensitivity analyses.

Estimated standard deviations of parameters and selected management measures for the five Gmacs scenarios are summarized in Tables 12, 13, 14, 15, and 16. Probabilities for mature male biomass and OFL in 2016 are illustrated in Section F.

g. Comparison of alternative model scenarios.

Looking at the plot of mature male biomass (Figure 23), the **Gmacs force** scenario stands out as being quite different to the other models (including the 2015 model). This scenario results in a lower MMB from the mid-1908s 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, we recommend that scenario XXX be used for overfishing determination for this stock in 2016.

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

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

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

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

The currently recommended Tier 4 convention is to use the full assessment period, currently 1978-2016, to define a B_{MSY} proxy in terms of average estimated MMB and to set $\gamma = 1.0$ with assumed stock natural mortality $M = 0.18$ 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 2016 for all scenarios are summarized in Table 9. ABC is 80% of the OFL.

Table 9: Comparisons of management measures for the five Gmacs model scenarios. Biomass and OFL are in tonnes.

Component	Gmacs match	Gmacs base	Gmacs Francis	Gmacs M	Gmacs force
MMB_{2016}	2225.552	2229.252	2205.083	1803.586	1447.430
B_{MSY}	3681.508	3692.217	3614.103	3462.258	3335.423
F_{OFL}	0.088	0.088	0.089	0.073	0.058
OFL_{2016}	826.123	826.770	833.788	564.369	355.853
ABC_{2016}	660.898	661.416	667.030	451.495	284.682

G. Rebuilding Analysis

This stock is not currently subject to a rebuilding plan.

H. Data Gaps and Research Priorities

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

With the decline of estimated population biomass during recent years, outlook for this stock is not promising. If the decline continues, the stock will fall to depleted status soon.

J. Acknowledgements

We thank the Crab Plan Team, Doug Pengilly for reviewing the earlier draft of this manuscript. Some materials in the report are from the SAFE report prepared by Bill Gaeuman in 2014. We thank Andre Punt for his input into the Gmacs model and for finding the error in the old SMBKC model code.

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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

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

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

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

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.667	0.116
$\log(\bar{R})$	13.360	0.048
$\log(n^0_1)$	14.894	0.169
$\log(n^0_2)$	14.477	0.194
$\log(n^0_3)$	14.285	0.200
$\log(\bar{F}^{\mathrm{df}})$	-1.519	0.045
$\log(\bar{F}^{\mathrm{tb}})$	-12.228	0.068
$\log(\bar{F}^{\mathrm{fb}})$	-9.130	0.068
F_{OFL}	0.088	0.009
OFL	826.120	152.500

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

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.659	0.128
$\log(\bar{R})$	13.373	0.059
$\log(n^0_1)$	14.861	0.171
$\log(n^0_2)$	14.509	0.197
$\log(n^0_3)$	14.213	0.210
ADF&G pot survey catchability ($q \times 1000$)	3.834	0.293
$\log(\bar{F}^{\mathrm{df}})$	-1.517	0.054
$\log(\bar{F}^{\mathrm{tb}})$	-12.258	0.082
$\log(\bar{F}^{\mathrm{fb}})$	-9.160	0.082
log Stage-1 directed pot selectivity 1978-2008	-0.709	0.175
log Stage-2 directed pot selectivity 1978-2008	-0.399	0.126
log Stage-1 directed pot selectivity 2009-2016	-0.611	0.164
log Stage-2 directed pot selectivity 2009-2016	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.222	0.066
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.750	0.136
log Stage-2 ADF&G pot selectivity	-0.062	0.083
F_{OFL}	0.088	0.011
OFL	826.770	191.960

Table 14: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the **Gmacs Francis** model.

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.668	0.136
$\log(\bar{R})$	13.376	0.059
$\log(n^0_1)$	14.836	0.205
$\log(n^0_2)$	14.538	0.227
$\log(n^0_3)$	14.231	0.236
ADF&G pot survey catchability ($q \times 1000$)	3.767	0.274
$\log(\bar{F}^{\mathrm{df}})$	-1.488	0.057
$\log(\bar{F}^{\mathrm{tb}})$	-12.253	0.082
$\log(\bar{F}^{\mathrm{fb}})$	-9.155	0.082
log Stage-1 directed pot selectivity 1978-2008	-0.621	0.183
log Stage-2 directed pot selectivity 1978-2008	-0.417	0.149
log Stage-1 directed pot selectivity 2009-2016	-0.498	0.174
log Stage-2 directed pot selectivity 2009-2016	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.150	0.062
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.792	0.136
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.089	0.011
OFL	833.790	193.920

Table 15: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the **Gmacs M** model.

Parameter	Estimate	SD
$\log(\bar{R})$	13.227	0.054
$\log(n^0_1)$	14.836	0.207
$\log(n^0_2)$	14.601	0.224
$\log(n^0_3)$	14.275	0.236
ADF&G pot survey catchability ($q \times 1000$)	4.522	0.298
$\log(\bar{F}^{\mathrm{df}})$	-1.421	0.056
$\log(\bar{F}^{\mathrm{tb}})$	-12.158	0.080
$\log(\bar{F}^{\mathrm{fb}})$	-9.060	0.080
log Stage-1 directed pot selectivity 1978-2008	-0.509	0.183
log Stage-2 directed pot selectivity 1978-2008	-0.394	0.150
log Stage-1 directed pot selectivity 2009-2016	-0.500	0.175
log Stage-2 directed pot selectivity 2009-2016	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.071	0.061
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.747	0.136
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.073	0.010
OFL	564.370	132.530

Table 16: Model parameter estimates, selected derived quantities, and their standard deviations (SD) for the **Gmacs force** model.

Parameter	Estimate	SD
$\log(\bar{R})$	13.096	0.049
$\log(n_1^0)$	14.788	0.206
$\log(n_2^0)$	14.588	0.218
$\log(n_3^0)$	14.248	0.228
ADF&G pot survey catchability ($q \times 1000$)	4.006	0.193
$\log(\bar{F}^{\mathrm{df}})$	-1.337	0.044
$\log(\bar{F}^{\mathrm{tb}})$	-12.175	0.070
$\log(\bar{F}^{\mathrm{fb}})$	-9.076	0.070
log Stage-1 directed pot selectivity 1978-2008	-0.635	0.178
log Stage-2 directed pot selectivity 1978-2008	-0.502	0.147
log Stage-1 directed pot selectivity 2009-2016	-0.228	0.169
log Stage-2 directed pot selectivity 2009-2016	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.029	0.059
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.283	0.175
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.057	0.005
OFL	355.850	50.454

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

Parameter	Match	Base	Francis	M	Force
ADF&G pot survey catchability (q)	-	3.834	3.767	4.522	4.006
$\log(\bar{F}^{\mathrm{df}})$	-1.519	-1.517	-1.488	-1.421	-1.337
$\log(\bar{F}^{\mathrm{fb}})$	-9.130	-9.160	-9.155	-9.060	-9.076
$\log(\bar{F}^{\mathrm{tb}})$	-12.228	-12.258	-12.253	-12.158	-12.175
$\log(\bar{R})$	13.360	13.373	13.376	13.227	13.096
$\log(n_1^0)$	14.894	14.861	14.836	14.836	14.788
$\log(n_2^0)$	14.477	14.509	14.538	14.601	14.588
$\log(n_3^0)$	14.285	14.213	14.231	14.275	14.248
log Stage-1 ADF&G pot selectivity	-	-0.750	-0.792	-0.747	-0.283
log Stage-1 directed pot selectivity 1978-2008	-	-0.709	-0.621	-0.509	-0.635
log Stage-1 directed pot selectivity 2009-2015	-	-0.611	-0.498	-0.500	-0.228
log Stage-1 NMFS trawl selectivity	-	-0.222	-0.150	-0.071	-0.029
log Stage-2 ADF&G pot selectivity	-	-0.062	-0.000	-0.000	-0.000
log Stage-2 directed pot selectivity 1978-2008	-	-0.399	-0.417	-0.394	-0.502
log Stage-2 directed pot selectivity 2009-2015	-	-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})	1.667	1.659	1.668	-	-

Table 18: Comparisons of data weights, Francis LF weights, SDNR values, and MAR values for the five Gmacs model scenarios.

Component	Match	Base	Francis	M	Force
NMFS trawl survey weight	1.00	1.00	1.00	1.00	1.50
ADF&G pot survey weight	1.00	1.00	1.00	1.00	2.00
Directed pot LF weight	1.00	1.00	1.72	1.61	1.40
NMFS trawl survey LF weight	1.00	1.00	0.50	0.51	0.26
ADF&G pot survey LF weight	1.00	1.00	1.70	1.21	0.38
Francis weight for directed pot LF	1.71	1.71	1.72	1.61	1.40
Francis weight for NMFS trawl survey LF	0.49	0.47	0.50	0.51	0.26
Francis weight for ADF&G pot survey LF	1.96	2.24	1.70	1.21	0.38
SDNR NMFS trawl survey	1.44	1.41	1.36	1.54	2.26
SDNR ADF&G pot survey	3.97	3.83	3.77	3.79	5.94
SDNR directed pot LF	0.68	0.65	0.67	0.68	0.80
SDNR NMFS trawl survey LF	1.25	1.32	1.31	1.35	1.79
SDNR ADF&G pot survey LF	0.79	0.83	0.96	1.00	1.67
MAR NMFS trawl survey	1.06	1.15	1.14	1.25	1.69
MAR ADF&G pot survey	3.03	2.94	2.74	3.41	4.70
MAR directed pot LF	0.47	0.43	0.55	0.49	0.60
MAR NMFS trawl survey LF	0.55	0.53	0.68	0.70	1.01
MAR ADF&G pot survey LF	0.56	0.43	0.57	0.62	0.92

Table 19: Comparisons of negative log-likelihood values for the five Gmacs model scenarios.

Component	Match	Base	Francis	M	Force
Pot Retained Catch	-69.05	-69.21	-69.25	-69.07	-67.37
Pot Discarded Catch	6.58	6.21	6.33	5.71	8.22
Trawl bycatch Discarded Catch	-6.88	-6.88	-6.88	-6.88	-6.88
Fixed bycatch Discarded Catch	-6.85	-6.86	-6.86	-6.87	-6.86
NMFS Trawl Survey	-6.12	-7.93	-10.40	1.53	41.59
ADF&G Pot Survey CPUE	57.08	52.01	49.68	52.73	145.40
Directed Pot LF	-12.03	-12.84	11.42	11.66	14.56
NMFS Trawl LF	20.24	26.65	54.72	58.11	97.49
ADF&G Pot LF	-6.70	-6.00	1.50	2.01	14.92
Recruitment deviations	58.13	58.05	57.67	58.67	63.07
F penalty	14.49	14.49	14.49	14.49	14.49
M penalty	6.47	6.47	6.47	0.00	0.00
Prior	13.72	13.71	13.71	13.71	13.71
Total	69.09	67.87	122.60	135.81	332.34
Total estimated parameters	282.00	291.00	291.00	289.00	289.00

Table 20: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey and mature male biomass (MMB) in tonnes on 15 February for the **2015 model**.

Year	n_1	n_2	n_3	MMB
1978	3018380	1953510	1597980	4075
1979	3919060	2341120	2147490	5802
1980	3467980	3064710	3243990	9074
1981	1395090	3047670	4504000	9239
1982	1368260	1777680	4466940	6370
1983	707216	1318650	3036760	3355
1984	683165	782950	1543430	1990
1985	2244990	616447	986160	1686
1986	1338560	1445520	916977	2727
1987	1432180	1228070	1383660	3375
1988	1306640	1222920	1677970	3723
1989	2279000	1148700	1865710	4245
1990	1445840	1690250	2098040	4744
1991	2024880	1377550	2361620	4400
1992	2321500	1583990	2169580	4531
1993	2514290	1829500	2290170	4977
1994	1465290	2012460	2447020	4912
1995	1572620	1462710	2400370	4768
1996	1807950	1360970	2267560	4351
1997	1086810	1459480	2125050	3718
1998	684461	1059430	1727860	1804
1999	373686	342335	653347	1560
2000	412027	332743	748221	1725
2001	380490	352080	826139	1889
2002	169056	340032	898096	2008
2003	336657	212374	934340	1942
2004	235762	267626	914402	1963
2005	525625	227222	917421	1927
2006	799432	383194	923952	2099
2007	590277	594788	1029430	2455
2008	1019370	530589	1177800	2720
2009	928263	772468	1333420	2992
2010	873520	791923	1475900	2755
2011	723104	753585	1409700	2350
2012	458036	646078	1187950	1959
2013	532334	461243	984254	2294
2014	466341	465305	1097620	2327
2015	389087	424535	1123020	2511

Table 21: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tonnes on 15 February for the **Gmacs match** model.

Year	n_1	n_2	n_3	MMB
1978	2941585	1937720	1599772	4444
1979	4216672	2367256	2186694	6294
1980	3531048	3256382	3320597	9988
1981	1336736	3152551	4672641	10386
1982	1423808	1834747	4718156	7422
1983	702293	1445331	3355105	4516
1984	627126	893317	1961479	3103
1985	932572	665063	1431682	2801
1986	1338278	767439	1238753	2795
1987	1329469	1038871	1345663	3291
1988	1225243	1124399	1563686	3615
1989	2675719	1092046	1735519	4136
1990	1665478	1929310	2011602	5143
1991	1762008	1618330	2456977	5109
1992	1851527	1570220	2396213	5249
1993	2090721	1606531	2481532	5417
1994	1515031	1758826	2518060	5129
1995	1675608	1473294	2412458	5058
1996	1511563	1471761	2332612	4851
1997	853145	1375441	2255566	4211
1998	613470	958236	1853171	2886
1999	363033	313112	694175	1650
2000	410012	316768	766798	1791
2001	375271	345567	833483	1948
2002	131799	334810	900542	2061
2003	328214	188860	930665	1952
2004	211583	254848	898868	1968
2005	467527	208824	896029	1910
2006	745727	343091	892017	2052
2007	436387	550029	978201	2417
2008	922399	433052	1114047	2569
2009	820113	683273	1223285	2680
2010	758308	706917	1340251	2458
2011	645443	678495	1272045	2092
2012	364556	603925	1069157	1767
2013	458796	414823	891416	2037
2014	451957	406806	990675	2046
2015	332783	400146	1008828	2112
2016	161958	328223	1049423	2226

Table 22: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tonnes on 15 February for the **Gmacs base** model.

Year	n_1	n_2	n_3	MMB
1978	2843771	2000058	1488550	4304
1979	4122346	2330897	2116812	6136
1980	3537209	3189084	3236124	9750
1981	1342409	3133670	4568870	10170
1982	1470682	1831773	4622273	7233
1983	747654	1471765	3276722	4385
1984	636580	928690	1912428	3052
1985	898018	682415	1408955	2774
1986	1333940	753038	1225494	2753
1987	1296467	1031526	1326976	3248
1988	1191214	1102653	1541602	3550
1989	2678975	1064889	1703278	4042
1990	1685755	1922145	1971279	5061
1991	1772684	1627801	2421151	5050
1992	1898496	1579630	2371316	5212
1993	2162676	1637135	2469020	5426
1994	1515953	1811126	2528531	5206
1995	1659808	1491322	2447005	5144
1996	1608209	1468561	2368434	4914
1997	872193	1430893	2291382	4345
1998	615694	987916	1911999	3018
1999	388807	320782	729328	1725
2000	418788	334399	802158	1877
2001	395152	356589	872587	2033
2002	139623	350117	940389	2152
2003	328623	198548	972273	2040
2004	204086	258328	938510	2046
2005	537967	205606	930257	1971
2006	771017	383198	924879	2159
2007	467004	578215	1027861	2542
2008	971096	460403	1172442	2709
2009	787704	720883	1289837	2838
2010	733816	700576	1412144	2571
2011	653903	662113	1327160	2169
2012	371014	603405	1108353	1833
2013	456411	418428	925047	2101
2014	423318	406617	1020373	2098
2015	321751	383340	1031210	2132
2016	164208	316160	1058780	2229

Table 23: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tonnes on 15 February for the **Gmacs Francis** model.

Year	n_1	n_2	n_3	MMB
1978	2774283	2059548	1515496	4424
1979	4016380	2310143	2163327	6189
1980	3418573	3120192	3255724	9708
1981	1267164	3041287	4540805	10012
1982	1332183	1756915	4546289	7001
1983	791306	1365781	3164130	4033
1984	619689	918809	1767785	2770
1985	865856	669231	1281477	2495
1986	1273459	729824	1109673	2508
1987	1310984	988406	1213551	2984
1988	1192536	1096734	1426464	3333
1989	2737905	1063683	1604214	3848
1990	1623754	1956196	1892775	4956
1991	1776670	1602924	2367416	4919
1992	1865399	1573640	2314175	5098
1993	2124679	1615777	2415454	5297
1994	1476891	1781772	2469828	5063
1995	1666352	1458676	2379661	4976
1996	1646799	1461478	2296196	4768
1997	929209	1451089	2230525	4242
1998	661305	1027996	1875229	2990
1999	387597	336491	719855	1725
2000	423420	338939	802017	1882
2001	388414	360814	875131	2043
2002	140337	347590	944068	2156
2003	310065	198122	974139	2043
2004	206743	247340	938303	2033
2005	451776	203487	924800	1958
2006	759568	332100	912057	2077
2007	670710	554456	990590	2447
2008	920035	570315	1147025	2785
2009	784539	727753	1319410	2897
2010	803842	701034	1440061	2619
2011	587432	703179	1357078	2264
2012	349246	578263	1148754	1872
2013	468834	397308	943747	2111
2014	383509	406824	1026446	2109
2015	324559	360134	1033061	2110
2016	186107	310049	1048920	2205

Table 24: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tonnes on 15 February for the **Gmacs M** model.

Year	n_1	n_2	n_3	MMB
1978	2774458	2194195	1583741	4709
1979	4017154	2355229	2287816	6449
1980	3384019	3135708	3382365	9967
1981	1228816	3026267	4651475	10200
1982	1323853	1729477	4628024	7127
1983	784751	1351746	3218128	4127
1984	608072	910290	1805560	2831
1985	843151	659594	1307977	2539
1986	1304252	713330	1125177	2518
1987	1302187	1000901	1220831	3012
1988	1168214	1095764	1438095	3353
1989	2731486	1049137	1611449	3845
1990	1550306	1947581	1891019	4943
1991	1666638	1557099	2355590	4845
1992	1709725	1494012	2272359	4929
1993	1882182	1498171	2327713	4993
1994	1252041	1600704	2317365	4573
1995	1334164	1266712	2142661	4297
1996	1139476	1203115	1974566	3860
1997	594659	1068139	1790020	2915
1998	358775	704437	1287446	2003
1999	222849	444989	908530	2200
2000	319397	278895	1000210	2185
2001	316994	279932	1001895	2188
2002	125049	278822	1003446	2190
2003	288022	166218	987994	2033
2004	182738	223805	932042	1995
2005	396633	181591	905769	1898
2006	668771	292546	880582	1974
2007	587206	488188	936879	2272
2008	867006	499706	1061924	2546
2009	718315	673151	1208518	2644
2010	719495	644067	1314560	2350
2011	514497	634829	1216877	1956
2012	295124	512779	991945	1541
2013	386708	343780	776150	1755
2014	314908	340921	852771	1734
2015	260752	298004	849235	1729
2016	153412	251984	858908	1804

Table 25: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey (1 July, season 1) and mature male biomass (MMB) in tonnes on 15 February for the **Gmacs M** model.

Year	n_1	n_2	n_3	MMB
1978	2644960	2166052	1541405	4596
1979	3869223	2270118	2227533	6251
1980	3300292	3020778	3277002	9634
1981	1172066	2938914	4498876	9817
1982	1262008	1667120	4452920	6723
1983	697588	1294763	3036968	3694
1984	512777	840297	1618486	2402
1985	686910	580491	1108729	2038
1986	1057351	595548	906041	1971
1987	1200387	817188	958287	2307
1988	1177636	974864	1118476	2633
1989	2934433	1014253	1285087	3170
1990	1547454	2054584	1618097	4568
1991	1689676	1591174	2181362	4553
1992	1729748	1518829	2146420	4721
1993	1919837	1518145	2236846	4836
1994	1206759	1629386	2254082	4486
1995	974147	1249820	2099831	4204
1996	1920056	987004	1904111	3490
1997	760671	1452346	1691657	3161
1998	445287	929830	1416978	2480
1999	170573	570867	1125939	2748
2000	302193	290398	1240518	2647
2001	269330	273716	1206945	2565
2002	78691	248887	1167618	2463
2003	172356	129127	1106242	2212
2004	83591	143834	1002541	2036
2005	561556	96919	916291	1822
2006	827033	360678	860716	2014
2007	587897	603391	967683	2459
2008	854451	538514	1145255	2746
2009	694456	678812	1296505	2804
2010	595159	632056	1388801	2457
2011	439020	558245	1260732	1938
2012	247527	443080	979379	1437
2013	271732	292672	722634	1604
2014	229682	256626	772852	1502
2015	152124	220013	732710	1445
2016	102106	162421	713329	1447

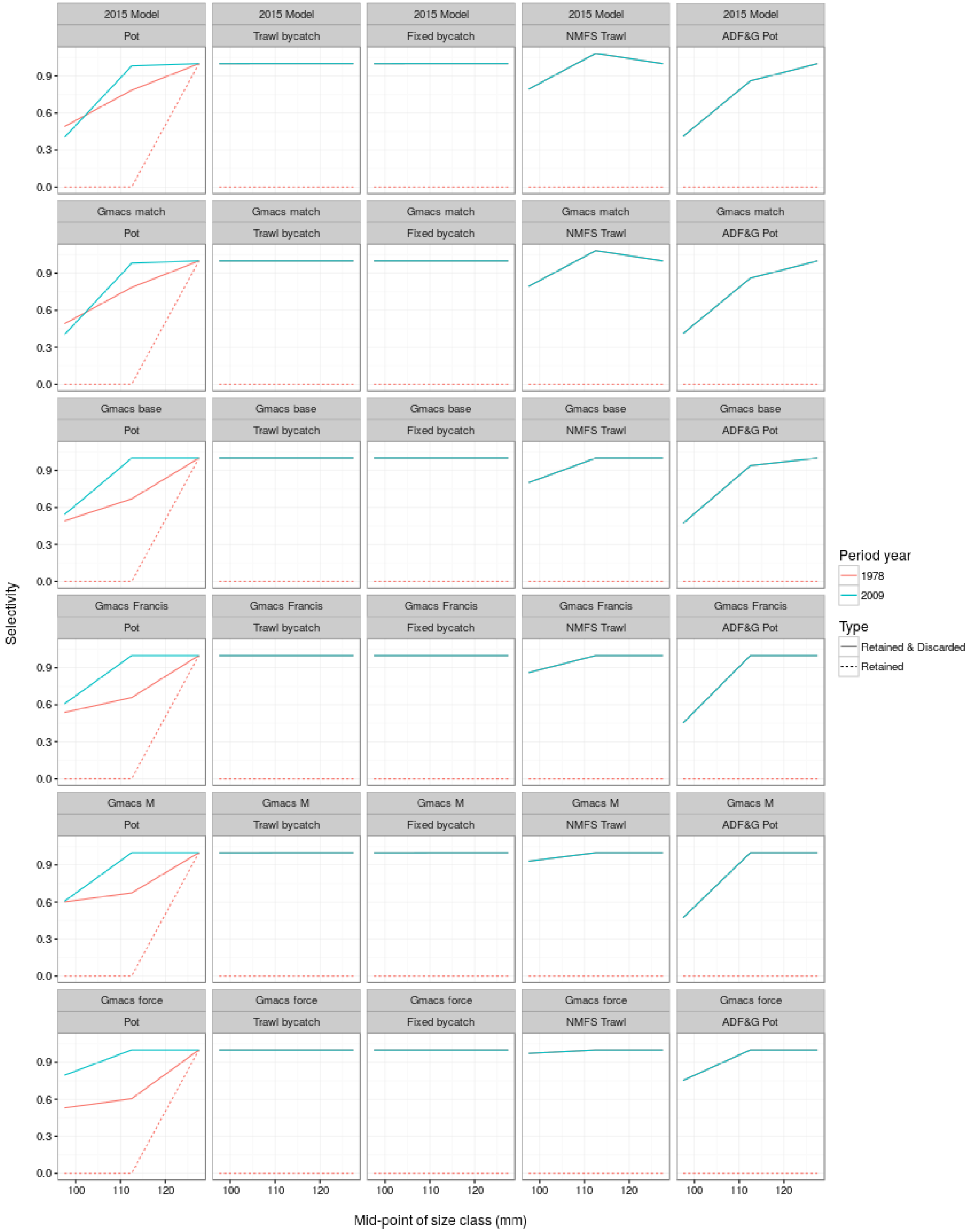

Figure 7: Comparisons of the estimated (and fixed to match the 2015 model selectivities in the Gmacs base scenario) stage-1 and stage-2 selectivities for each of the different model scenarios (the stage-3 selectivities are all fixed at 1). Estimated selectivities are shown for the directed pot fishery, 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 2009-2016.

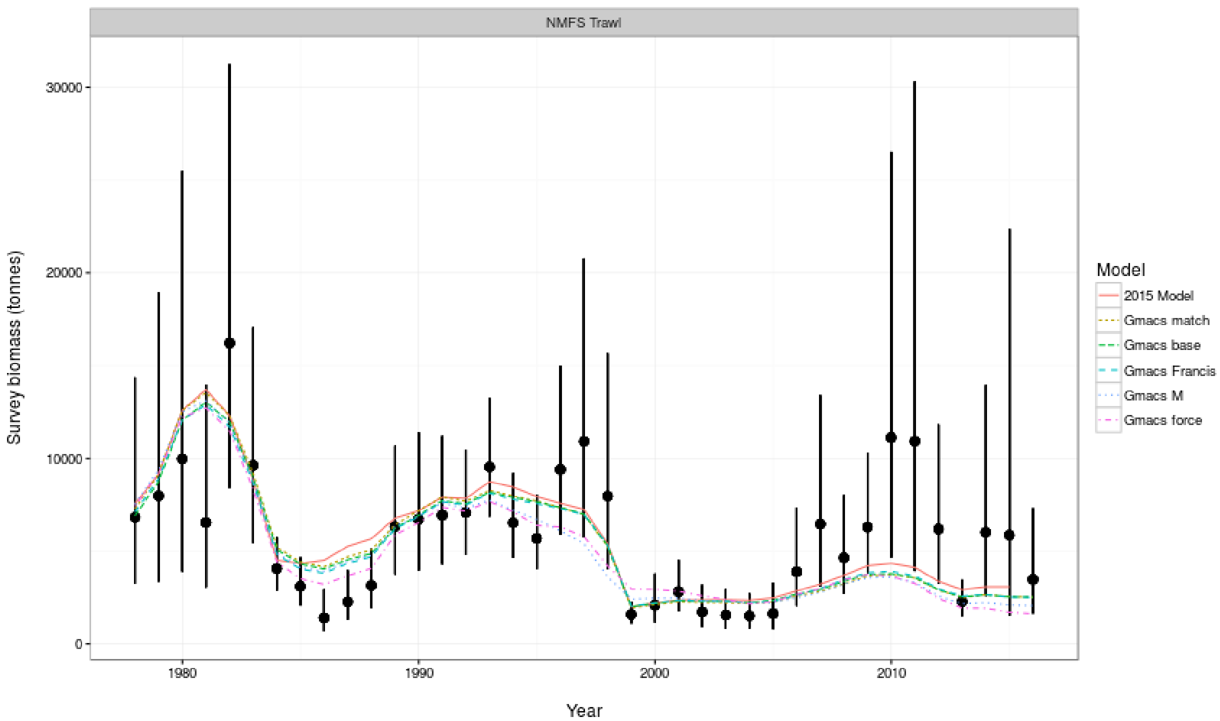

Figure 8: Comparisons of area-swept estimates of total male survey biomass (tonnes) and model predictions for the 2015 model and each of the Gmacs model scenarios. The error bars are plus and minus 2 standard deviations.

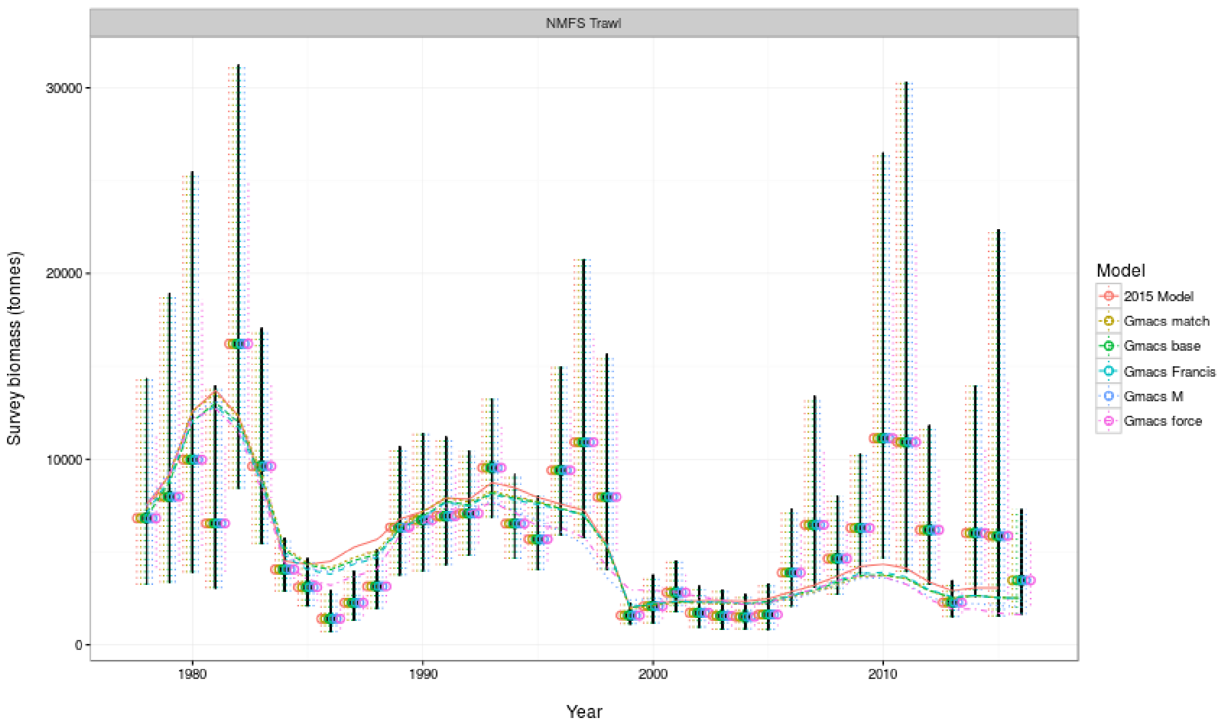

Figure 9: Comparisons of area-swept estimates of total male survey biomass (tonnes) and model predictions for the 2015 model and each of the Gmacs model scenarios. The solid black error bars are plus and minus 2 standard deviations derived using the original survey CVs. The dotted error bars are plus and minus 2 standard deviations but represent the weighted survey CVs.

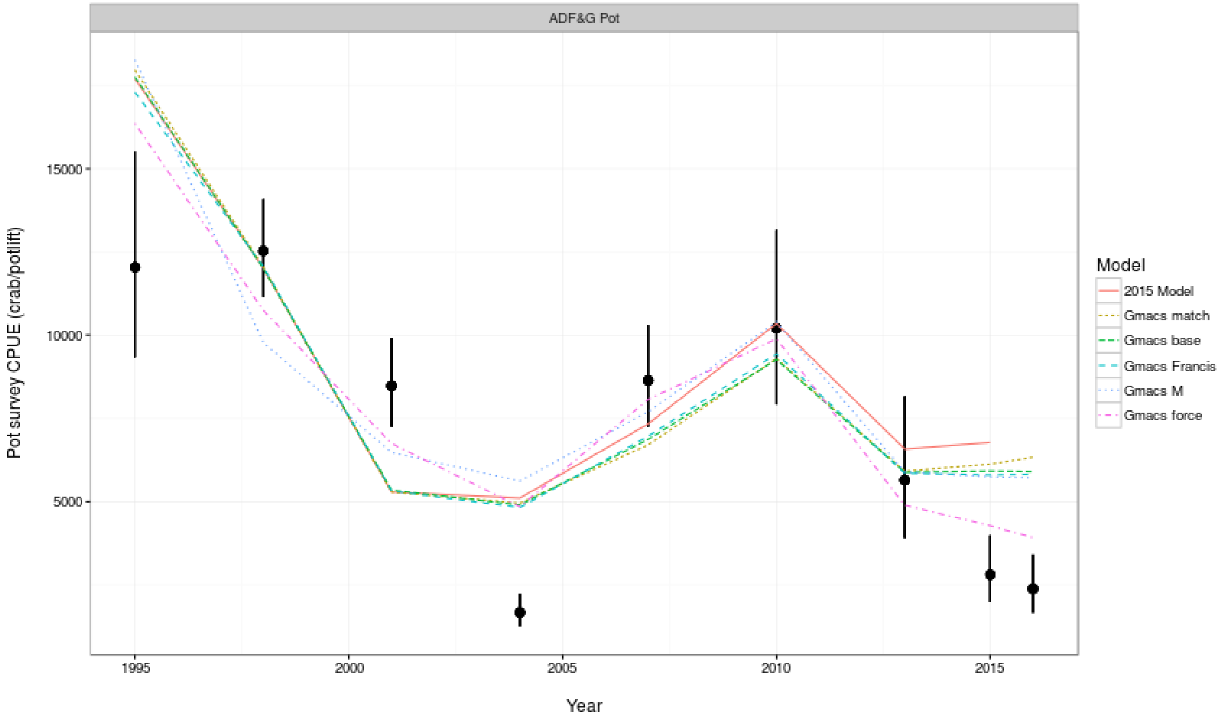

Figure 10: Comparisons of total male pot survey CPUEs and model predictions for the 2015 model and each of the Gmacs model scenarios. The error bars are plus and minus 2 standard deviations.

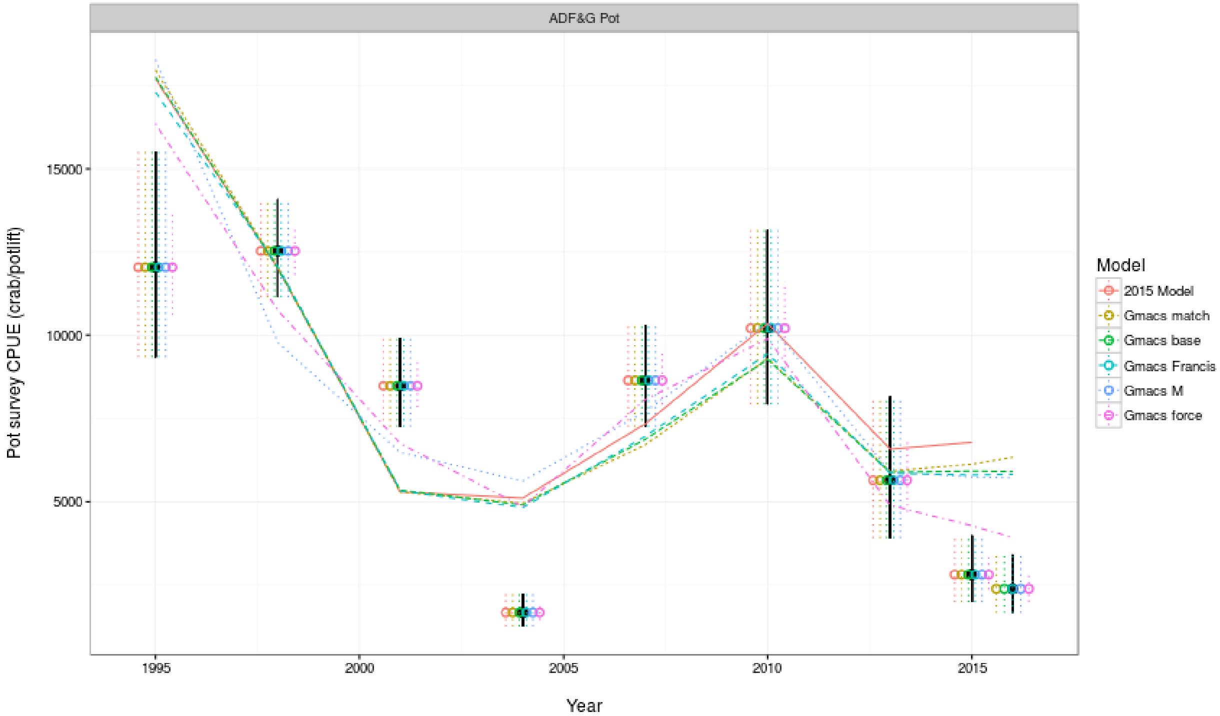

Figure 11: Comparisons of total male pot survey CPUEs and model predictions for the 2015 model and each of the Gmacs model scenarios. The solid black error bars are plus and minus 2 standard deviations derived using the original survey CVs. The dotted error bars are plus and minus 2 standard deviations but represent the weighted survey CVs.

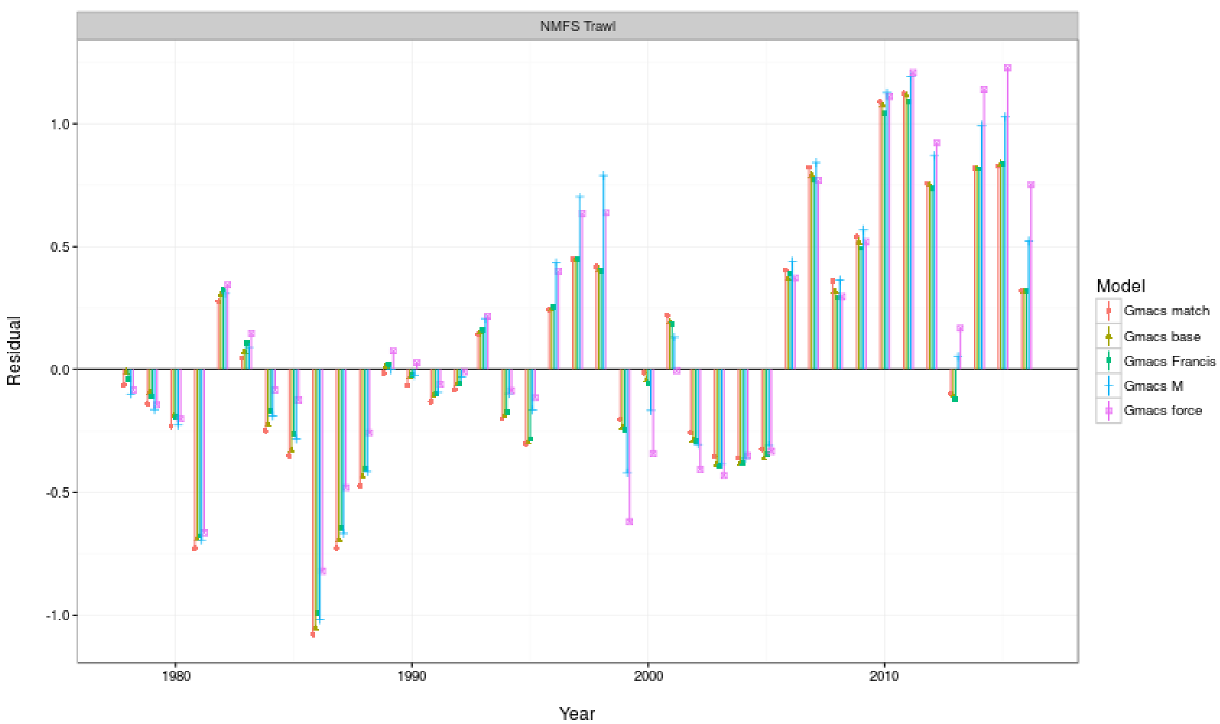

Figure 12: Standardized residuals for area-swept estimates of total male survey biomass for each of the Gmacs model scenarios.

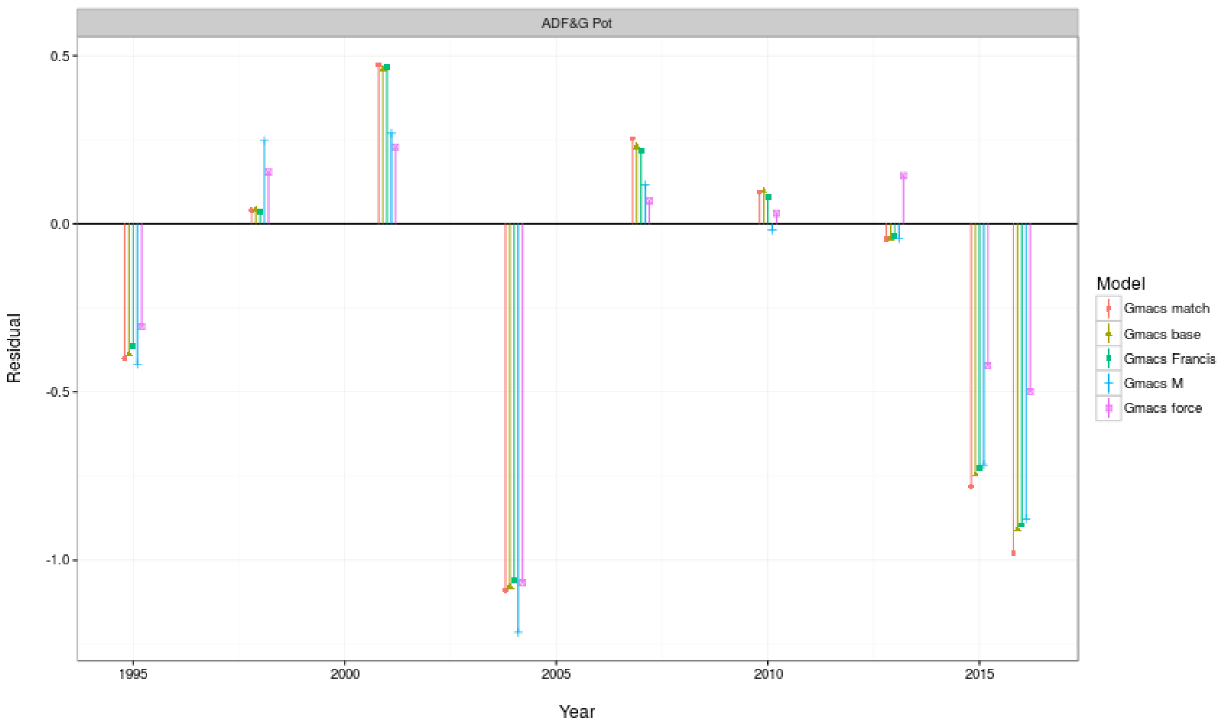

Figure 13: Standardized residuals for total male pot survey CPUEs for each of the Gmacs model scenarios.

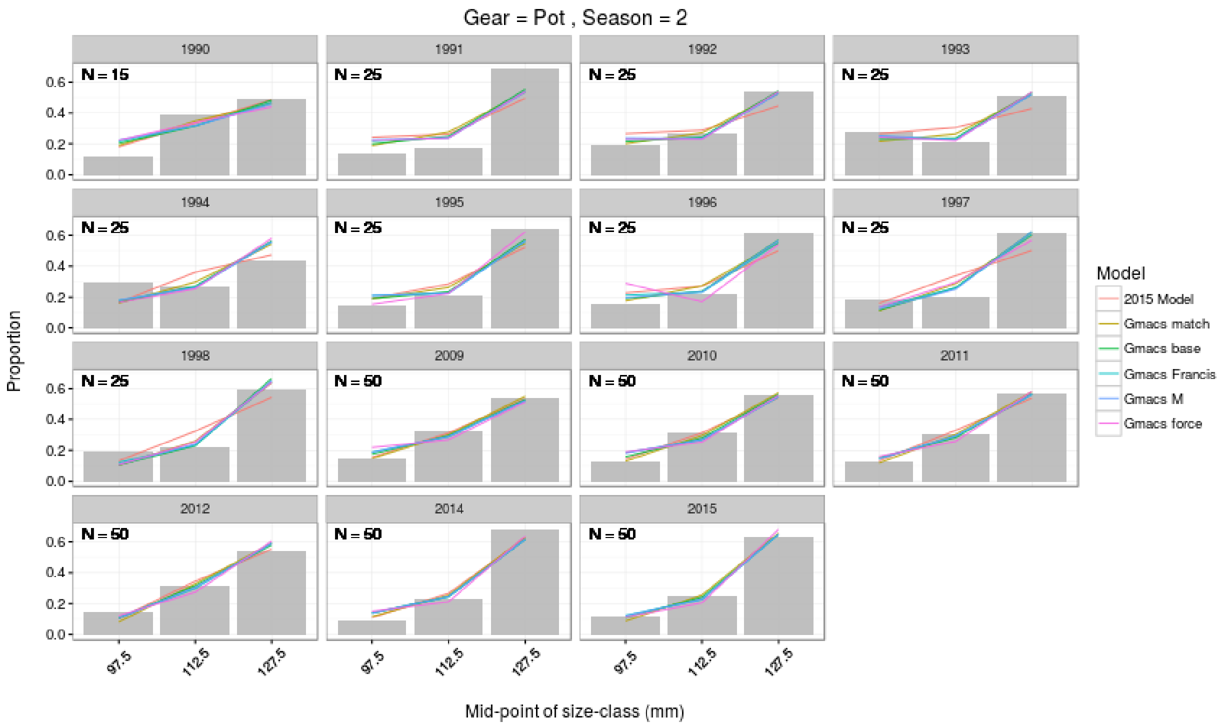

Figure 14: Observed and model estimated size-frequencies of SMBKC by year retained in the directed pot fishery for the 2015 model and each of the Gmacs model scenarios. Note that there is no model estimated size-frequency for the 2015 model during the 2015 year.

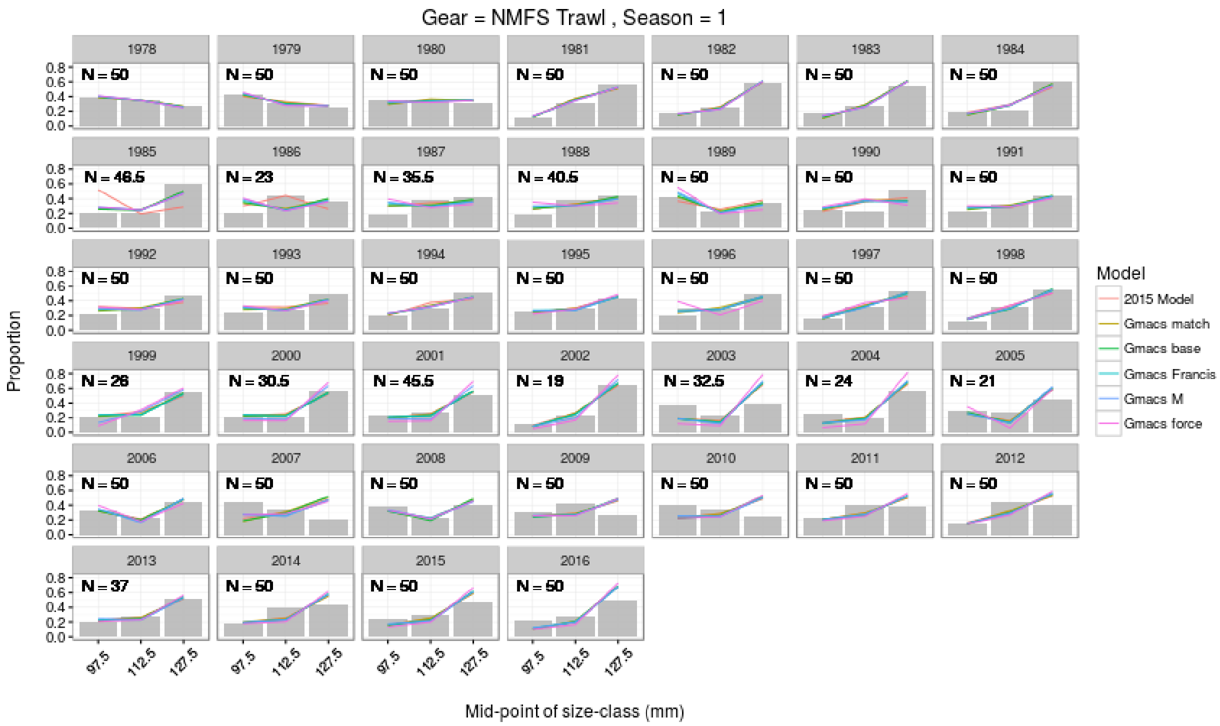

Figure 15: Observed and model estimated size-frequencies of discarded male SMBKC by year in the NMFS trawl survey for the 2015 model and each of the Gmacs model scenarios. Note that there is no model estimated size-frequency for the 2015 model during the 2016 year.

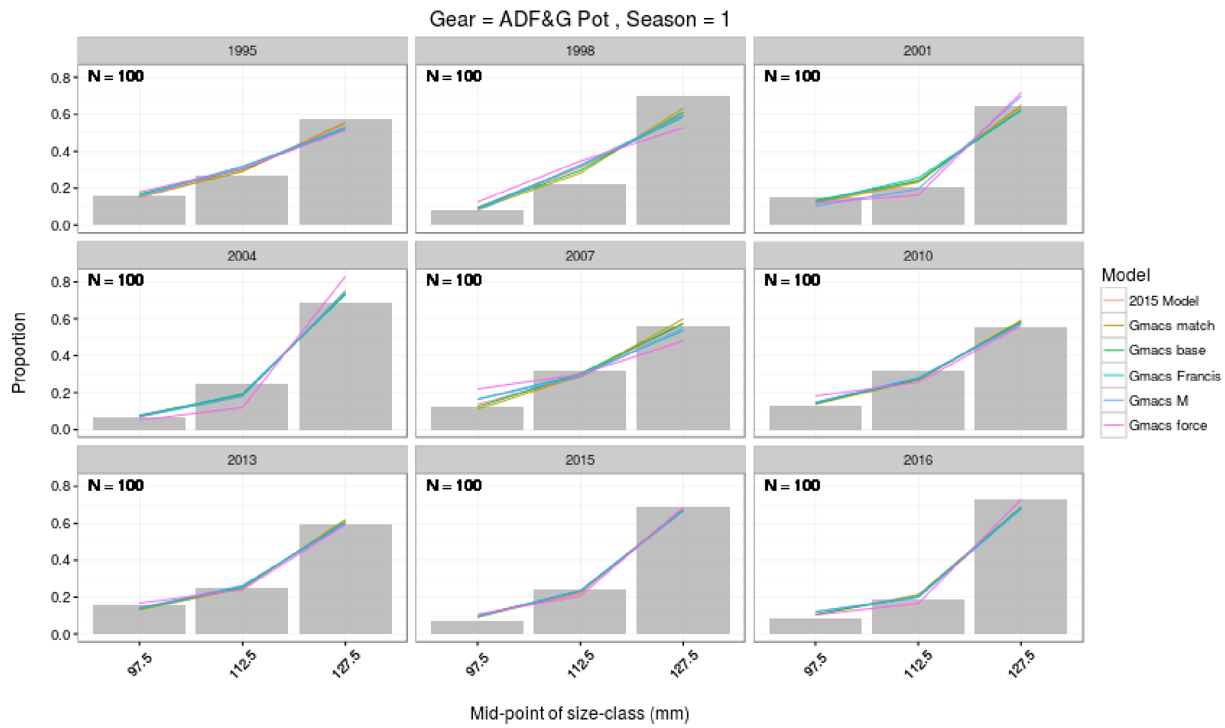

Figure 16: Observed and model estimated size-frequencies of discarded SMBKC by year in the ADF&G pot survey for the 2015 model and each of the Gmacs model scenarios. Note that there is no model estimated size-frequency for the 2015 model during the 2016 year.

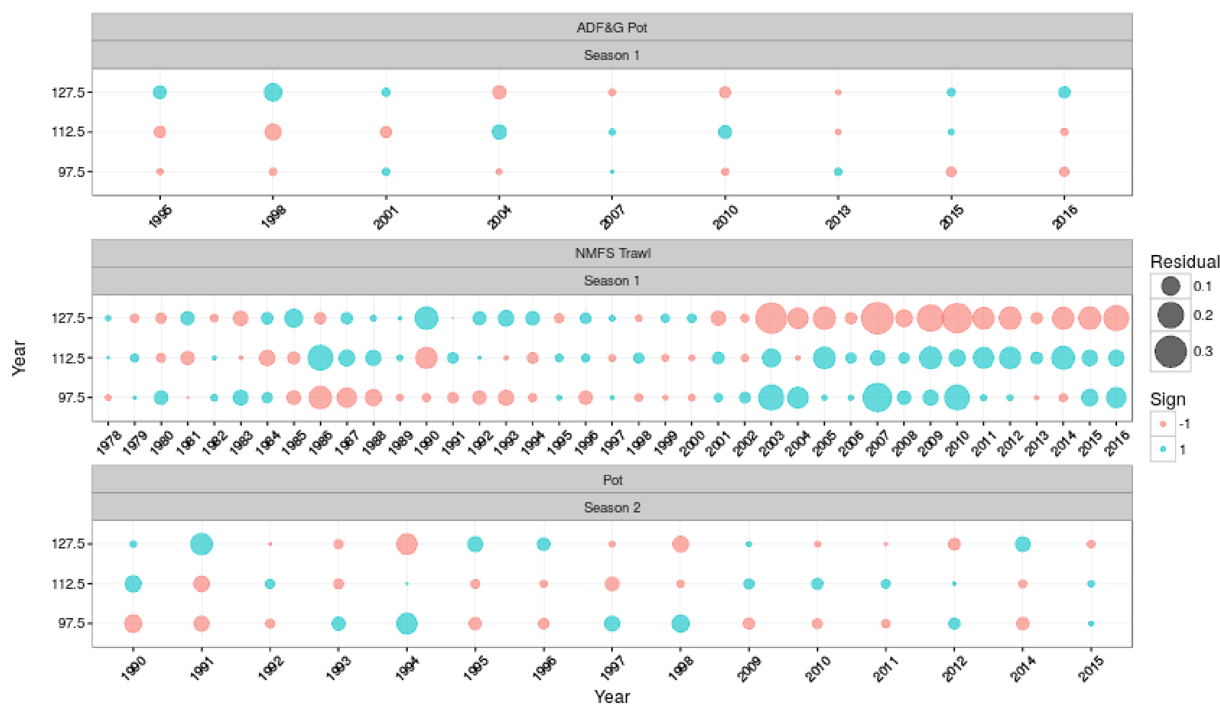

Figure 17: Bubble plots of residuals by stage and year for the directed pot fishery size composition data for St. Mathew Island blue king crab (SMBKC) in the **Gmacs base** model.

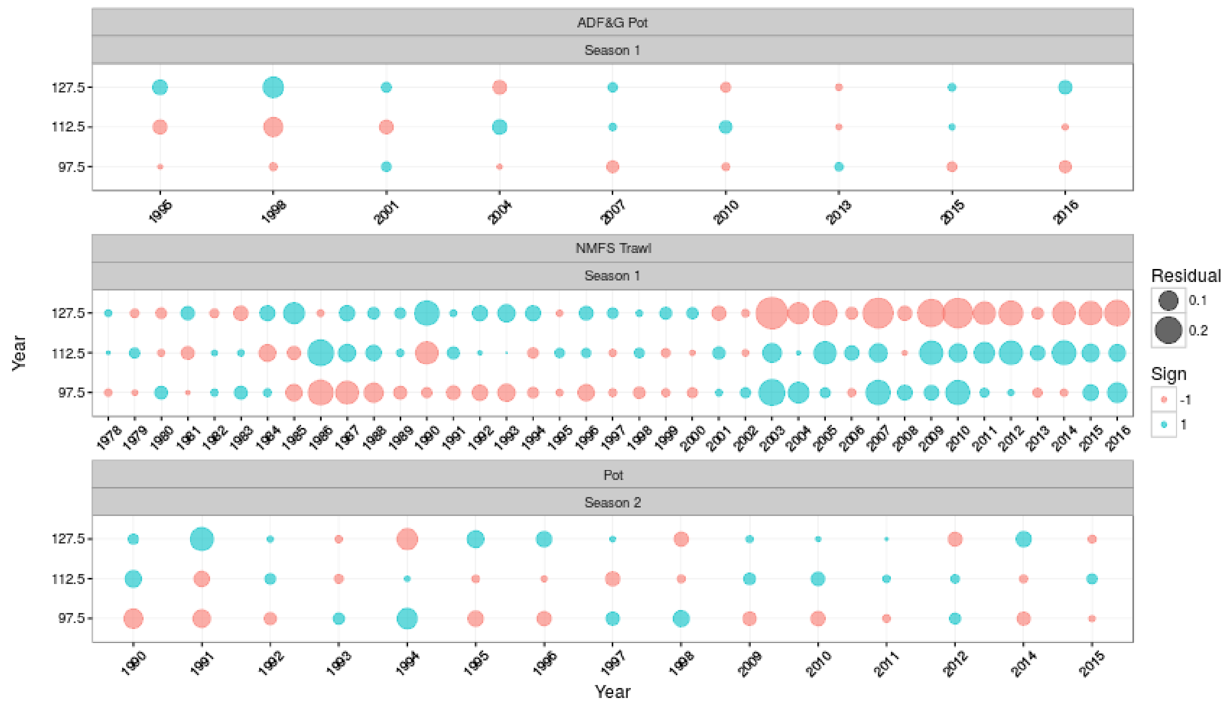

Figure 18: Bubble plots of residuals by stage and year for the NMFS trawl survey size composition data for St. Mathew Island blue king crab (SMBKC) in the **Gmacs Francis** model.

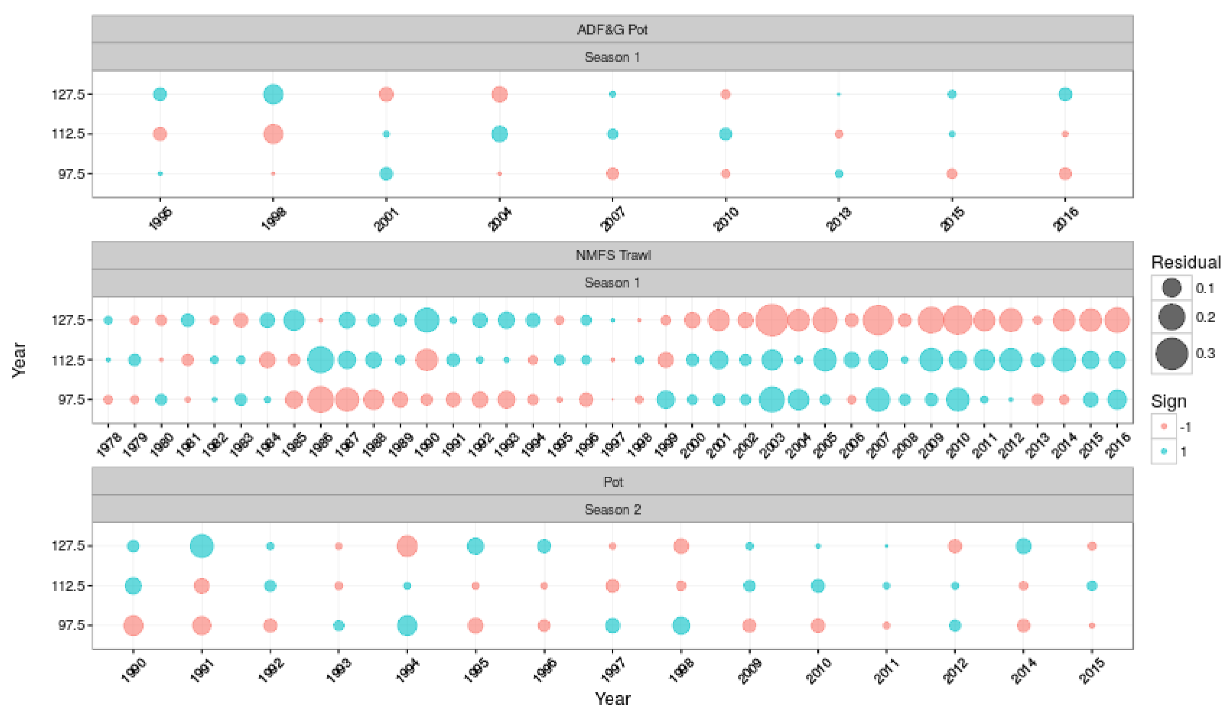

Figure 19: Bubble plots of residuals by stage and year for the NMFS trawl survey size composition data for St. Mathew Island blue king crab (SMBKC) in the **Gmacs M** model.

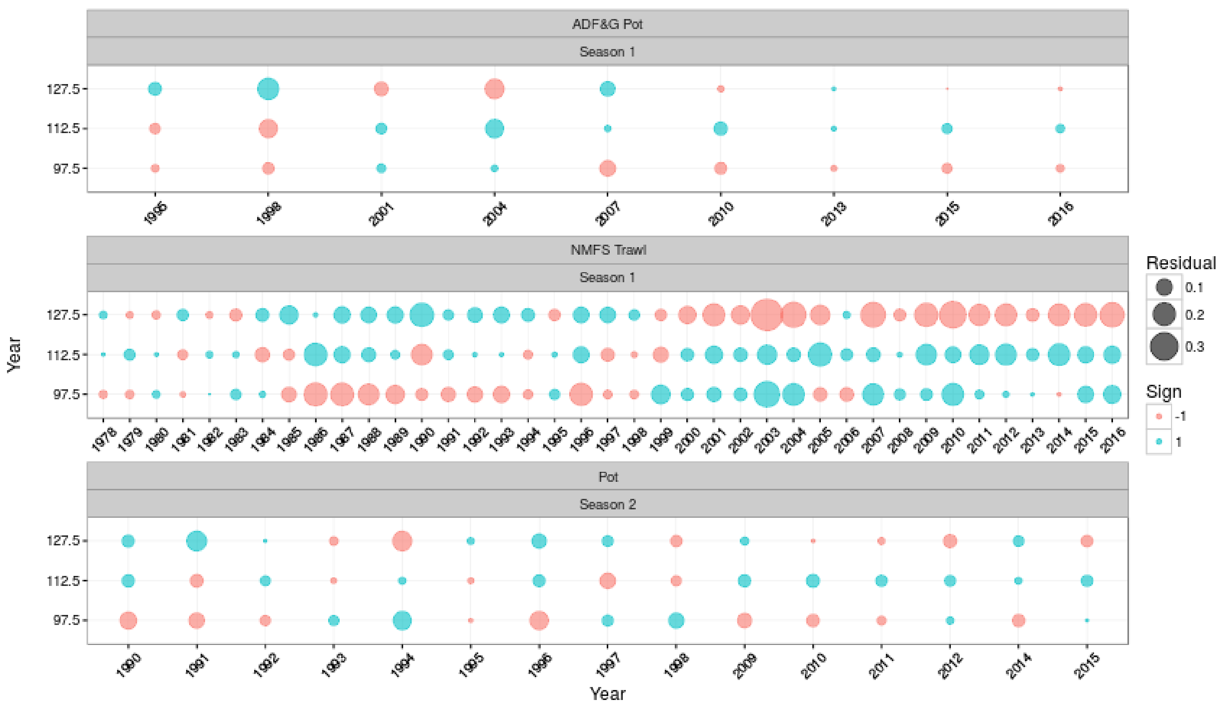

Figure 20: Bubble plots of residuals by stage and year for the ADF&G pot survey size composition data for St. Mathew Island blue king crab (SMBKC) in the **Gmacs force** model.

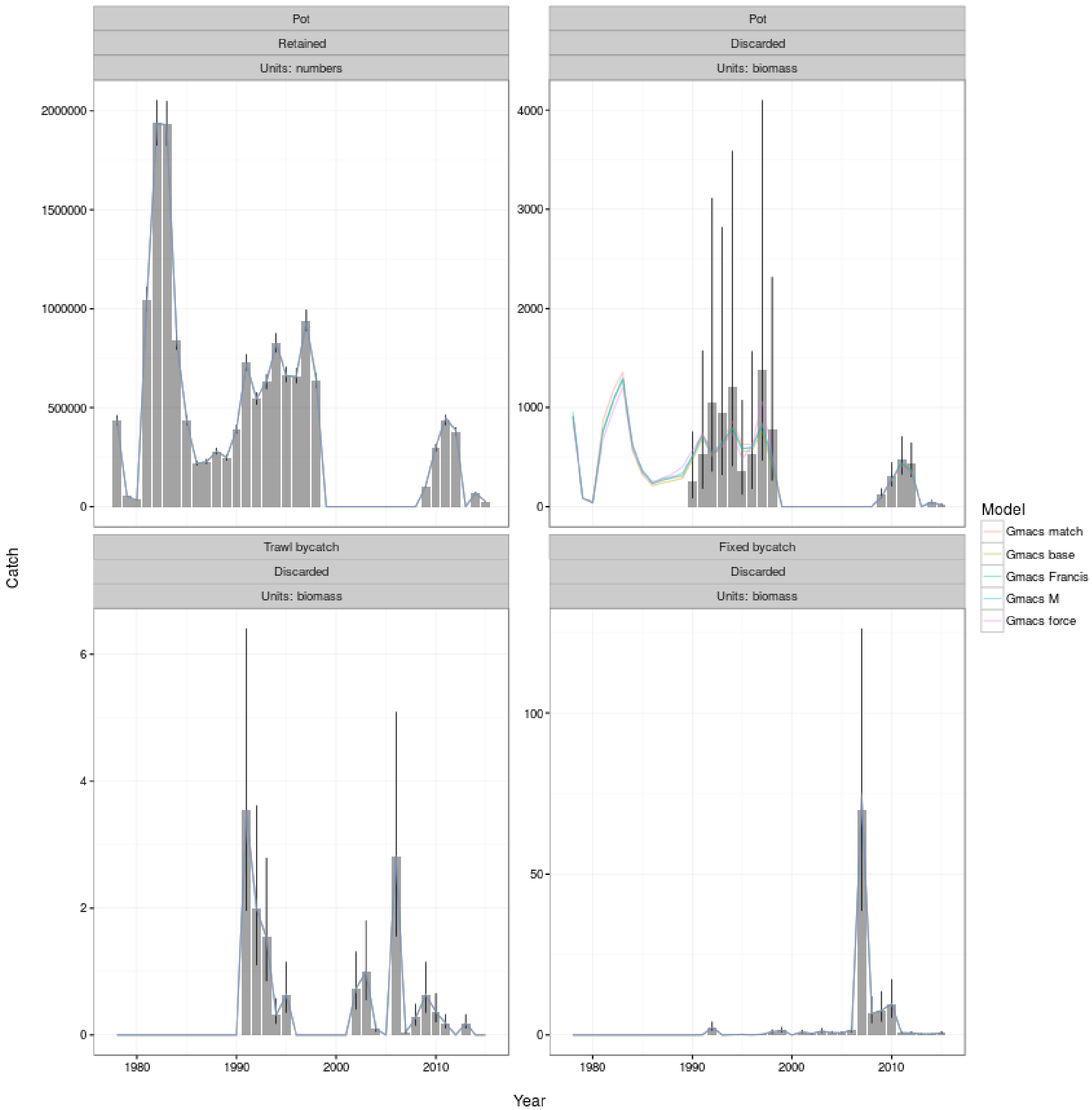

Figure 21: Comparison of observed and model predicted retained catch and bycatches in each of the Gmacs models. Note that difference in units between each of the panels, some panels are expressed in numbers of crab, some as biomass (tonnes).

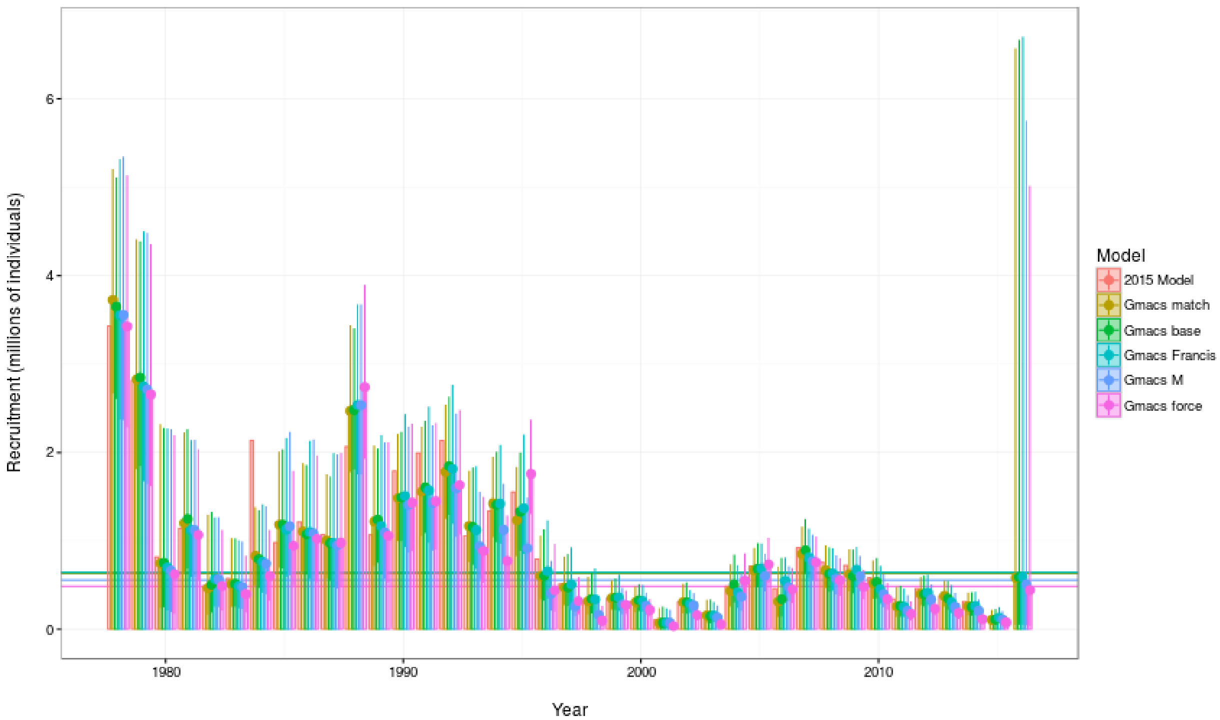

Figure 22: Comparisons of estimated recruitment time series during 1979-2016 in each of the scenarios. The solid horizontal lines in the background represent the estimate of the average recruitment parameter ($\bar{R}$) in each model scenario.

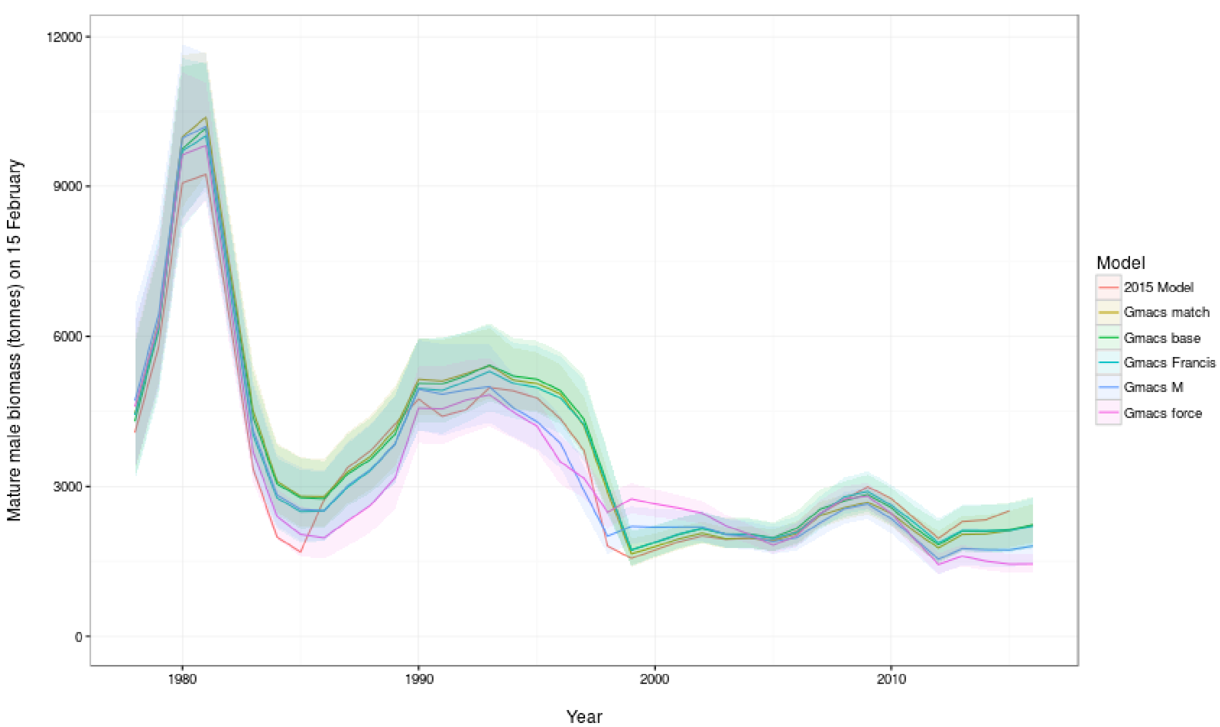

Figure 23: Comparisons of estimated mature male biomass (MMB) time series on 15 February during 1978-2016 for each of the model scenarios.

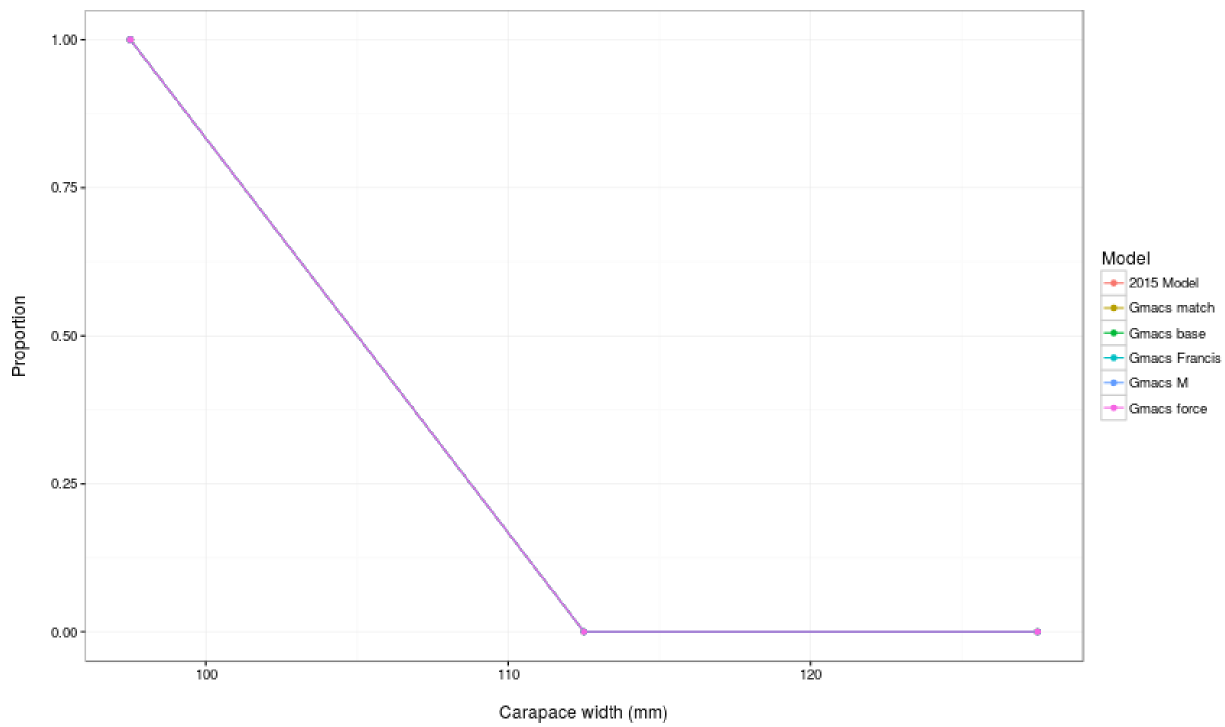

Figure 24: Distribution of carapace width (mm) at recruitment.

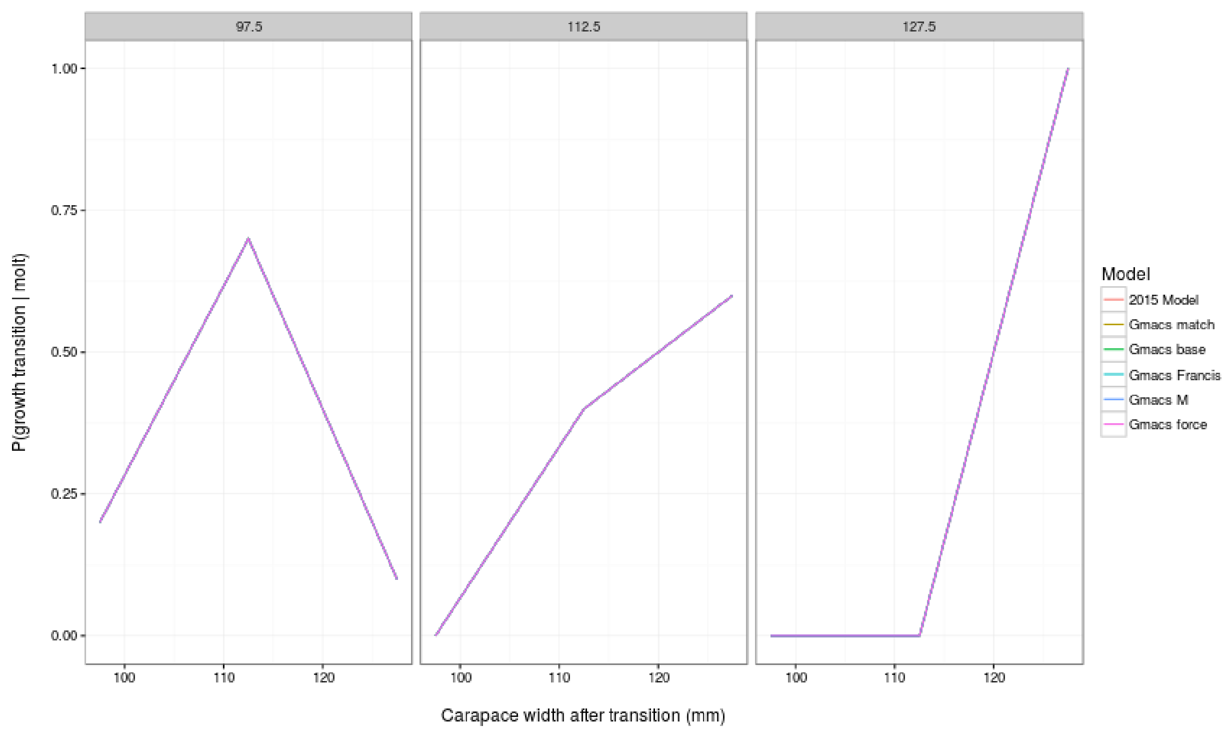

Figure 25: Probability of size transition by stage (i.e. the combination of the growth matrix and molting probabilities). Each of the panels represent the stage before a transition. The x-axes represent the stage after a transition. The size transition matrix was provided as an input directly to Gmacs (as it was during the 2015 SMBKC assessment).

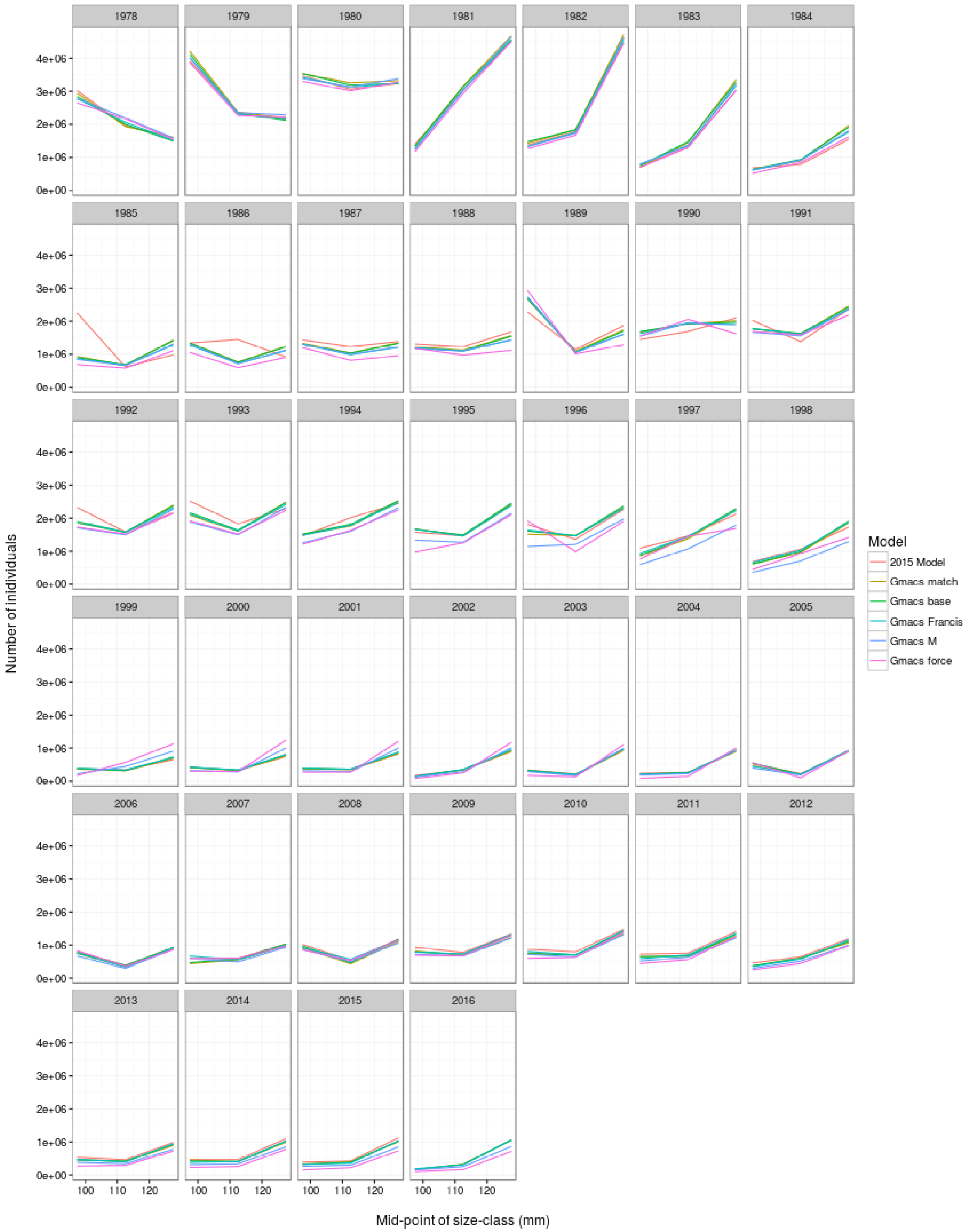

Figure 26: Numbers by stage each year (at the beginning of the model year, i.e. 1 July) in each of the models including the 2015 model.

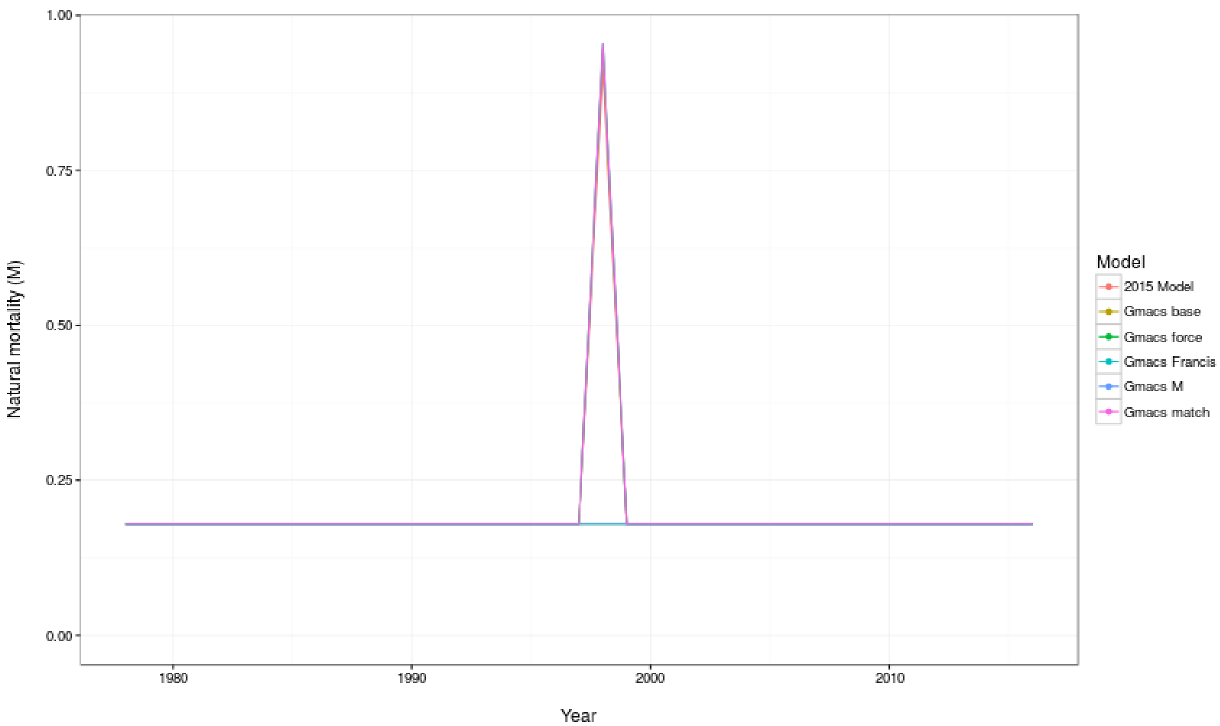

Figure 27: Time-varying natural mortality (M_t). Estimated pulse period occurs in 1998/99 (i.e. M_{1998}).

Appendix A: SMBKC Model Description

1. Introduction

The Gmacs model has been specified to account only for male crab at least 90 mm in carapace length (CL). These are partitioned into three stages (size-classes) determined by CL measurements of (1) 90-104 mm, (2) 105-119 mm, and (3) 120+ mm. For management of the St. Matthew Island blue king crab (SMBKC) fishery, 120 mm CL is used as the proxy value for the legal measurement of 5.5 mm in 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 measured 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) is applied in each of these seasons where $\sum_{t=1}^{t=5} \tau_t = 1$. Each model year consists of the following processes:

1. Season 1
    - Beginning of the SMBKC fishing year (1 July)
    - $\tau_1 = 0$
    - Surveys
2. Season 2
    - 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 3)
3. Season 3
    - $\tau_3 = 0$
    - Fishing mortality applied
4. Season 4
    - $\tau_4 = 0.63 - \sum_{i=1}^{i=4} \tau_i$
    - Calculate MMB (15 February)
5. Season 5
    - $\tau_5 = 0.37$
    - 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 26. 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 is different each year and thus τ_4 differs each year.

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

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

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

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

and the recruitment is

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

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

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

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

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

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

The natural mortality each season t and year y is

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

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

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

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

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

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

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

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

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

The basic population dynamics underlying Gmacs can thus be described as

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

Also add selectivity $s_{l,y}$, retension, discard mortality in here. Also catch $C_{t,y}$, CPUE $I_{t,y} = qB_{t,y}$. weight $w_{l,y}$. Biomass $B_{t,y} = \sum_l n_{l,t,y} w_{l,y} s_{l,y}$. MMB, LFs.

$\theta = \{\bar{R}, \boldsymbol{n}_0, q_{\text{pot}}, cv, \delta^M_{1998}, s^{\text{pot}}_{1,l=1}, s^{\text{pot}}_{1,l=2}, s^{\text{pot}}_{2,l=1}, s^{\text{pot}}_{2,l=2} s^{\text{NMFS}}_{l=1}, s^{\text{NMFS}}_{l=2}, s^{\text{ADFG}}_{l=1}, s^{\text{ADFG}}_{l=2}\}$

3. Model Data

Data inputs used in model estimation are listed in Table 27.

4. Model Parameters

Table 28 lists fixed (externally determined) parameters used in model computations. In all scenarios, the stage-transition matrix is

$$\boldsymbol{G} = \left[\begin{array}{ccc} 0.2 & 0.7 & 0.1 \\ 0 & 0.4 & 0.6 \\ 0 & 0 & 1 \end{array} \right] \tag{13}$$

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

Estimated parameters are listed in Table 29 and include an estimated natural mortality deviation parameter in 1998/99 (δ^M_{1998}) assuming an anomalous mortality event in that year, as hypothesized by Zheng and Kruse (2002), with natural mortality otherwise fixed at 0.18 yr^{-1}.

In any year with no directed fishery, and hence zero retained catch, F^{df}_t is set to zero rather than model estimated. Similarly, for years in which no groundfish bycatch data are available, F^{gf}_t and F^{gt}_t are imputed to be the geometric means of the estimates from years for which there are data.

Both surveys are assigned a nominal date of 1 July, the start of the crab year.

5. Model Objective Function and Weighting Scheme

The objective function consists of a sum of eight "negative log-likelihood" terms characterizing the hypothesized error structure of the principal data inputs with respect to their true, i.e., model-predicted, values and four "penalty" terms associated with year-to-year variation in model recruit abundance and fishing mortality in the directed fishery and groundfish trawl and fixed-gear fisheries (Table 30). See Table 6, where upper and lower case letters designate model-predicted and data-computed quantities, respectively, and boldface letters again indicate vector quantities. Sample sizes n_t (observed number of male SMBKC $\leq$ 90 mm CL) and estimated coefficients of variation $\widehat{cv}_t$ were used to develop appropriate variances for stage-proportion and abundance-index components. The weights λ_j appearing in the objective function component expressions in Table 6 play the role of "tuning" parameters in the modeling procedure.

$$\sigma_i = \frac{1}{\lambda}\sqrt{\log(1.0 + c_i^2)} \tag{14}$$

$$\delta_i = \frac{\log(obs_i/pred_i)}{\sigma_i} + 0.5\sigma_i \tag{15}$$

The standard deviation of the normalized (or standardized) residuals (SDNR) is calculated as

$$\text{SDNR} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\delta_i - \bar{\delta}\right)^2} \tag{16}$$

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.

MAR, Francis weighting (Francis 2011).

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 26: 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

Table 27: 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)
Groundfish trawl bycatch biomass	1992/93 - 2015/16	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93 - 2015/16	NMFS groundfish observer program
NMFS trawl-survey biomass index (area-swept estimate) and CV	1978-2016	NMFS EBS trawl survey
ADF&G pot-survey abundance index (CPUE) and CV	Triennial 1995-2016	ADF&G SMBKC pot survey
NMFS trawl-survey stage proportions and total number of measured crab	1978-2016	NMFS EBS trawl survey
ADF&G pot-survey stage proportions and total number of measured crab	Triennial 1995-2016	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)

Table 28: Fixed model parameters for all scenarios.

Parameter	Symbol	Value	Source/rationale
Trawl-survey catchability	q	1.0	Default
Natural mortality	M	0.18 yr^{-1}	NPFMC (2007)
Size transition matrix	$\boldsymbol{G}$	Equation 13	Otto and Cummiskey (1990)
Stage-1 and stage-2 mean weights	w_1, w_2	0.7, 1.2 kg	Length-weight equation (B. Foy, NMFS) applied to stage midpoints
Stage-3 mean weight	$w_{3,y}$	Depends on year 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 29: 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 2009-2015	0	0.4	1	Uniform(0,1)	3
Stage-2 directed fishery selectivity 2009-2015	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

Table 30: Log-likelihood and penalty components of base-model objective function. The λ_k are weights, described in text; the neff t are effective sample sizes, also described in text. All summations are with respect to years over each data series.

Component	Distribution	Form
Legal retained-catch biomass	Lognormal	$-0.5\sum\left(\log(c_t/C_t)^2/\log(1+cv_c^2)\right)$
Dis. Pot bycatch biomass	Lognormal	$-0.5\sum\left(\log(c_t/C_t)^2/\log(1+cv_c^2)\right)$