Saint Matthew Island Blue King Crab Stock Assessment 2016

D'Arcy Webber
Jie Zheng
James Ianelli

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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 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 after the stock was declared overfished in 1999, trawl-survey indices of SMBKC stock abundance and biomass generally increased in subsequent years, with survey estimated mature male biomass reaching 9516 tonnes (20.98 million pounds; CV = 0.55) in 2011, the second highest in the 39-year time series used in this assessment. Survey mature male biomass then declined to 5652 tonnes (12.46 million pounds; CV = 0.33) in 2012 and to 2202 tonnes (4.459 million pounds; CV = 0.22) in 2013 before going back up to 5472 tonnes (12.06 million pounds; CV = 0.44) in 2014 and 5134 tonnes (11.32 million pounds; CV = 0.76) in 2015.

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).

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).

[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							

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 full trawl-survey time series supplied by R. Foy in August 2015, updated groundfish bycatch estimates based on 1999-2014 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 and the previous model. One of the major differences being that natural and fishing mortality are continuous within 5 discrete seasons. Season length in Gmacs is controlled by changing the proportion of natural mortality that is applied during each season.

Changes in Assessment Results

Changes in assessment results depend on model scenario. The Gmacs match model scenario attempts to match the 2015 assessment by specifying the same (or similar) dynamics and the same (fixed) parameter values. However, a different Gmacs scenario (Gmacs selex) provides a much better match to the 2015 model assessment.

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. XXX
4. XXX
5. XXX
6. XXX
7. XXX
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 with the Gmacs models and the 2015 model are presented throughout this document.

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. 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 weight the length-frequency data relative to the abundance indices. These runs are the **Gmacs Francis**, **Gmacs M**, and **Gmacs force** scenarios.

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.

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:

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:

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.

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

[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).

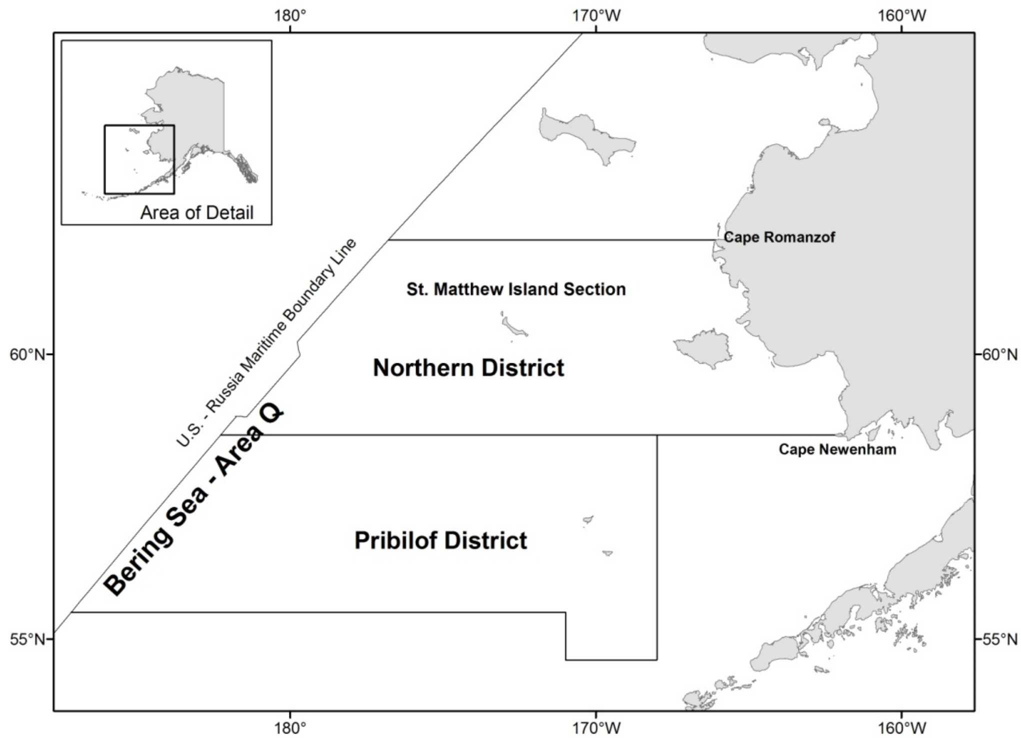

Figure 2: King crab Registration Area Q (Bering Sea).

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).

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								

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 XX2a). 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 directed fishery estimated at about 12% (88 tonnes or 0.193 million pounds) of the reported retained catch weight, assuming 20% handling mortality.

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						

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

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

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).

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
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

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 2015, as well as updated 1993-2014 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 2XX); 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,

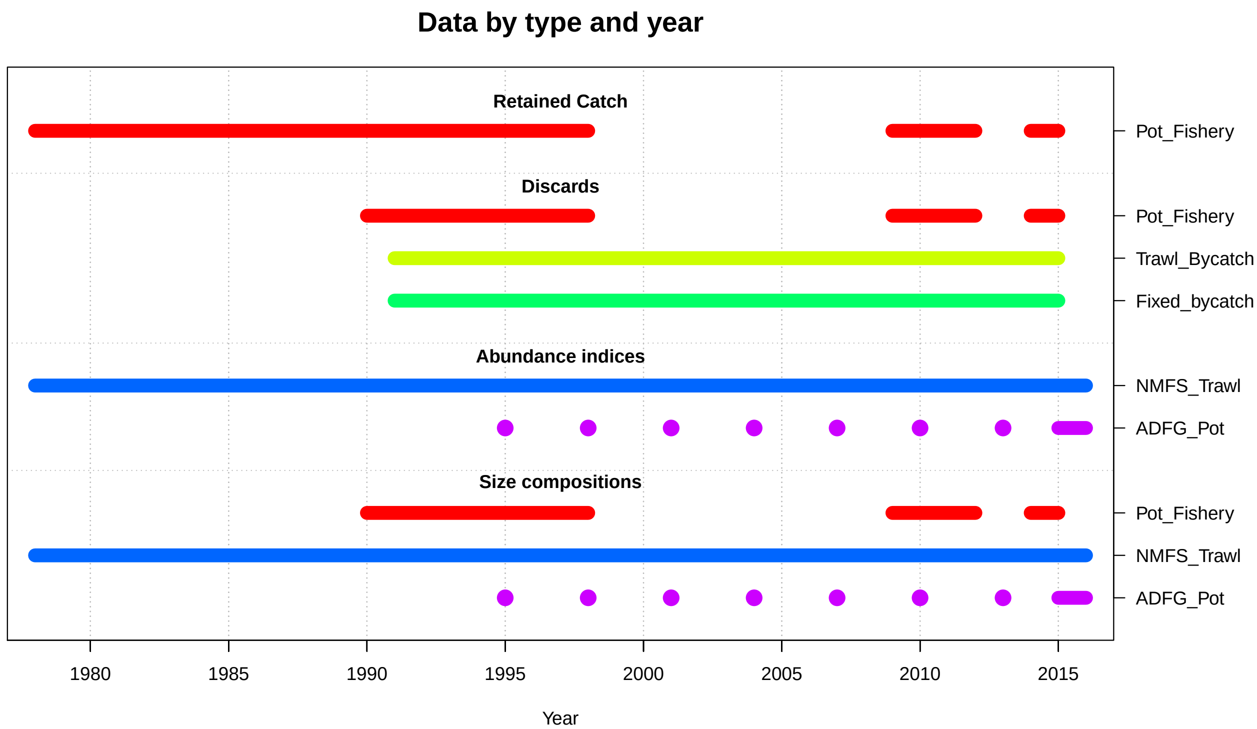

Figure 3: Data extent for the SMBKC assessment.

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.

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.

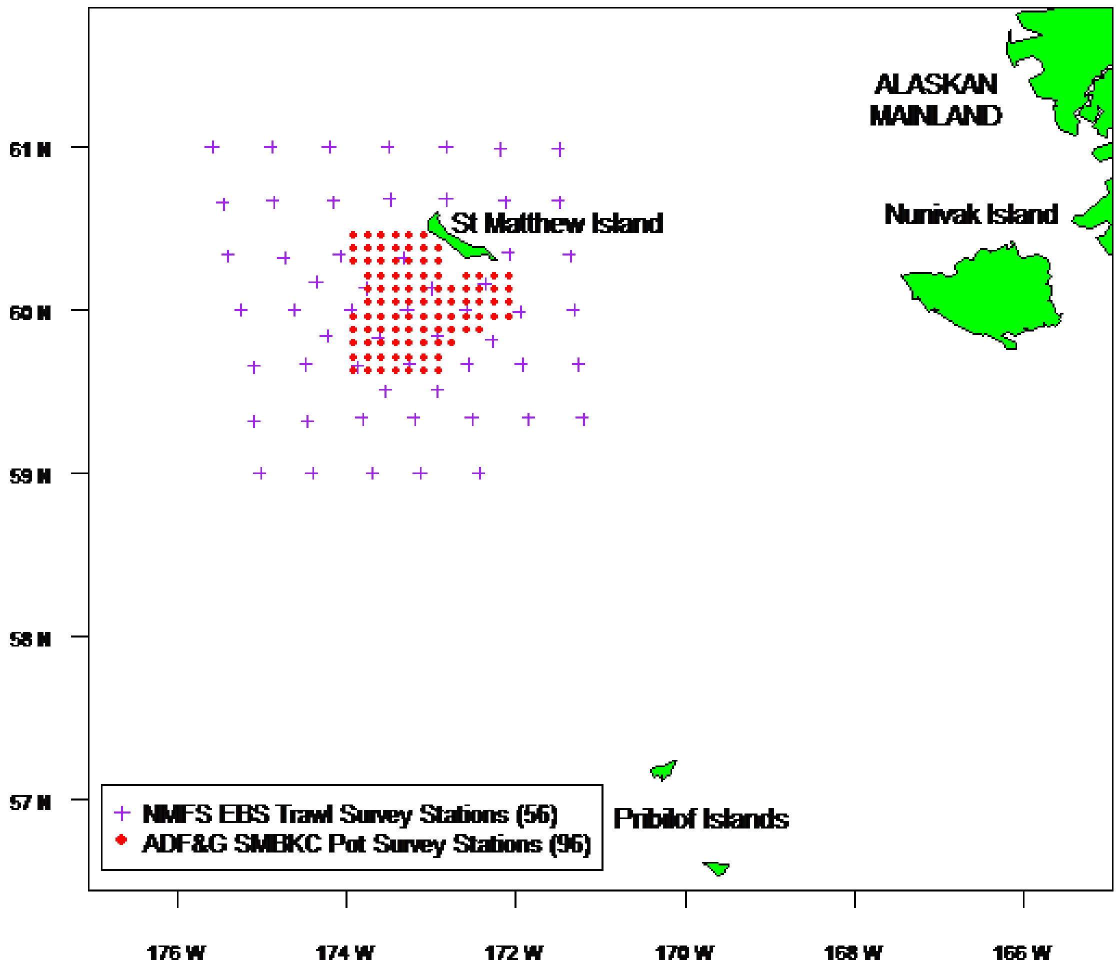

Figure 4: Trawl and pot-survey stations used in the SMBKC stock assessment.

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						

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:

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 in 1998 (M_{1998}), and the fishing mortalities for the directed pot fishery, the trawl bycatch fishery, and the fixed bycatch fishery.
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.
4. **Gmacs Francis**: uses the Francis iterative re-weighting method (Francis 2011) as well as estimating the directed pot, NMFS trawl survey and ADF&G pot survey selectivities for stage-1 and stage-2 crab. These selectivities are bounded so that they cannot be greater than 1.
5. **Gmacs M**: natural mortality (M) is fixed at 0.18 yr^{-1} during all years as well as using the Francis iterative re-weighting method and estimating the directed pot, NMFS trawl survey and ADF&G pot survey selectivities for stage-1 and stage-2 crab. These selectivities are bounded so that they cannot be greater than 1.
6. **Gmacs force**:

Table 7 outlines the major features of each of the models.

Table 7: Description of the five different Gmacs scenarios.

Scenario	Selectivity estimated	Use Francis 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 the Gmacs configuration are provided here with comparisons to the 2015 model.

a. Effective sample sizes and weighting factors.

Observed and estimated effective sample sizes are compared in Table 10. Effective sample sizes are also shown on size-frequency plots (Figures XX).

[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);`‘.

b. Tables of estimates.

Model parameter estimates are summarized in Tables 11, 12, 13, and 14. Negative log likelihood values and management measures for the five Gmacs scenarios are compared in Table 17. Estimated abundances by stage and mature male biomasses for three of the scenarios are listed in Tables 19, **??**, and **??**.

The scenarios that estimated stage-1 and stage-2 selectivities fit the data better. The scenario with additional CV for the pot survey CPUE fit the trawl survey data better and resulted in higher abundance and biomass estimates in the most recent years. Estimated directed pot and trawl survey selectivities > 1.0 for stage-2 crab are troublesome.

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 Figure 8, and the fits to pot survey CPUE are compared in Figure 10. Standardized residuals of total male trawl survey biomass and pot survey CPUE are plotted in Figure **??**. 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 in Figures **??**, 18, and 20 for the Gmacs base model. Fits to retained catch biomass and bycatch death biomass are shown for all Gmacs scenarios in Figure 22. Estimated recruitment and mature male biomass are compared in Figures 23 and 24, respectively.

d. Graphic evaluation of the fit to the data.

Model estimated relative survey biomasses are different in each of the scenarios. The Gmacs base model has a comparatively low biomass in the early years compared with the other scenarios, including the 2015 model (Figure 8). The Gmacs CV scenario that includes additional CV for the pot survey CPUE results in much higher biomass estimates in recent years (Figure 8). Estimated pot survey CPUEs are also dependent on scenarios, and the difference among scenarios are very similar to the relative survey biomasses (Figure 10).

Estimated recruitment to the model is variable over time (Figure 23). 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 24).

e. Retrospective and historic analyses.

Gmacs retrospective analyses under development.

f. Uncertainty and sensitivity analyses.

Estimated standard deviations of parameters for the five Gmacs scenarios are summarized in Tables 11, 12, 13, and 14. Probabilities for mature male biomass and OFL in 2016 are illustrated in section F.

g. Comparison of alternative model scenarios.

Discussion to come.

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, and MMB in 2016 for all scenarios are summarized in Table XXX. ABC is 80% of the OFL.

OFL, ABC, retained catch and bycatches for 2016 are summarized for all scenarios in Table 8.

Table 8: Summary of the OFL, ABC, retained catch and bycatches for the five different Gmacs scenarios.

Scenario	OFL	ABC	Retained catch	Pot male bycatch	Groundfish bycatch
Gmacs match					
Gmacs base					
Gmacs Francis					
Gmacs M					
Gmacs force					

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.

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Table 9: 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 10: 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	100

Table 11: 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
$\log(N_1)$	14.894	0.169
$\log(N_2)$	14.477	0.194
$\log(N_3)$	14.285	0.200
$\log(\bar{F}_{\text{pot}})$	-1.519	0.045
$\log(\bar{F}_{\text{trawl bycatch}})$	-12.228	0.068
$\log(\bar{F}_{\text{fixed bycatch}})$	-9.130	0.068
F_{OFL}	0.088	0.009
OFL	826.120	152.500

Table 12: 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
$\log(N_1)$	14.861	0.171
$\log(N_2)$	14.509	0.197
$\log(N_3)$	14.213	0.210
ADF&G pot survey catchability ($q \times 1000$)	3.834	0.293
$\log(\bar{F}_{\text{pot}})$	-1.517	0.054
$\log(\bar{F}_{\text{trawl bycatch}})$	-12.258	0.082
$\log(\bar{F}_{\text{fixed bycatch}})$	-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 13: 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
$\log(N_1)$	14.836	0.205
$\log(N_2)$	14.538	0.227
$\log(N_3)$	14.231	0.236
ADF&G pot survey catchability ($q \times 1000$)	3.767	0.274
$\log(\bar{F}_{\text{pot}})$	-1.488	0.057
$\log(\bar{F}_{\text{trawl bycatch}})$	-12.253	0.082
$\log(\bar{F}_{\text{fixed bycatch}})$	-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 14: 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
$\log(N_1)$	14.836	0.207
$\log(N_2)$	14.601	0.224
$\log(N_3)$	14.275	0.236
ADF&G pot survey catchability ($q \times 1000$)	4.522	0.298
$\log(\bar{F}_{\text{pot}})$	-1.421	0.056
$\log(\bar{F}_{\text{trawl bycatch}})$	-12.158	0.080
$\log(\bar{F}_{\text{fixed bycatch}})$	-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 15: 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
$\log(N_1)$	14.788	0.206
$\log(N_2)$	14.588	0.218
$\log(N_3)$	14.248	0.228
ADF&G pot survey catchability ($q \times 1000$)	4.006	0.193
$\log(\bar{F}_{\text{pot}})$	-1.337	0.044
$\log(\bar{F}_{\text{trawl bycatch}})$	-12.175	0.070
$\log(\bar{F}_{\text{fixed bycatch}})$	-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 16: Comparisons of model parameter estimates for the five Gmacs model scenarios.

Parameter	Base	Force	Francis	M	Match
ADF&G pot survey catchability (q)	0.004	0.004	0.004	0.005	-1.519
$\log(\bar{F}_{\text{fixed bycatch}})$	-9.160	-9.076	-9.155	-9.060	-
$\log(\bar{F}_{\text{pot}})$	-1.517	-1.337	-1.488	-1.421	-12.228
$\log(\bar{F}_{\text{trawl bycatch}})$	-12.258	-12.175	-12.253	-12.158	-9.130
$\log(\bar{R})$	13.373	13.096	13.376	13.227	13.360
$\log(N_1)$	14.861	14.788	14.836	14.836	14.894
$\log(N_2)$	14.509	14.588	14.538	14.601	14.477
$\log(N_3)$	14.213	14.248	14.231	14.275	14.285
log Stage-1 ADF&G pot selectivity	-0.750	-0.283	-0.792	-0.747	-
log Stage-1 directed pot selectivity 1978-2008	-0.709	-0.635	-0.621	-0.509	-
log Stage-1 directed pot selectivity 2009-2015	-0.611	-0.228	-0.498	-0.500	-
log Stage-1 NMFS trawl selectivity	-0.222	-0.029	-0.150	-0.071	-
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	-0.502	-0.417	-0.394	-
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 (M) deviation in 1998/99	1.659	-	1.668	-	1.667

Table 17: Comparisons of negative log-likelihood values, SDNR values, and MAR 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
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
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
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

Table 18: 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

Table 19: Population abundances (N) by crab stage in numbers of crab and mature male biomass (MMB) at survey in tonnes on 15 February for the **2015 model**. All abundances are at time of survey (season 3).

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
2016				

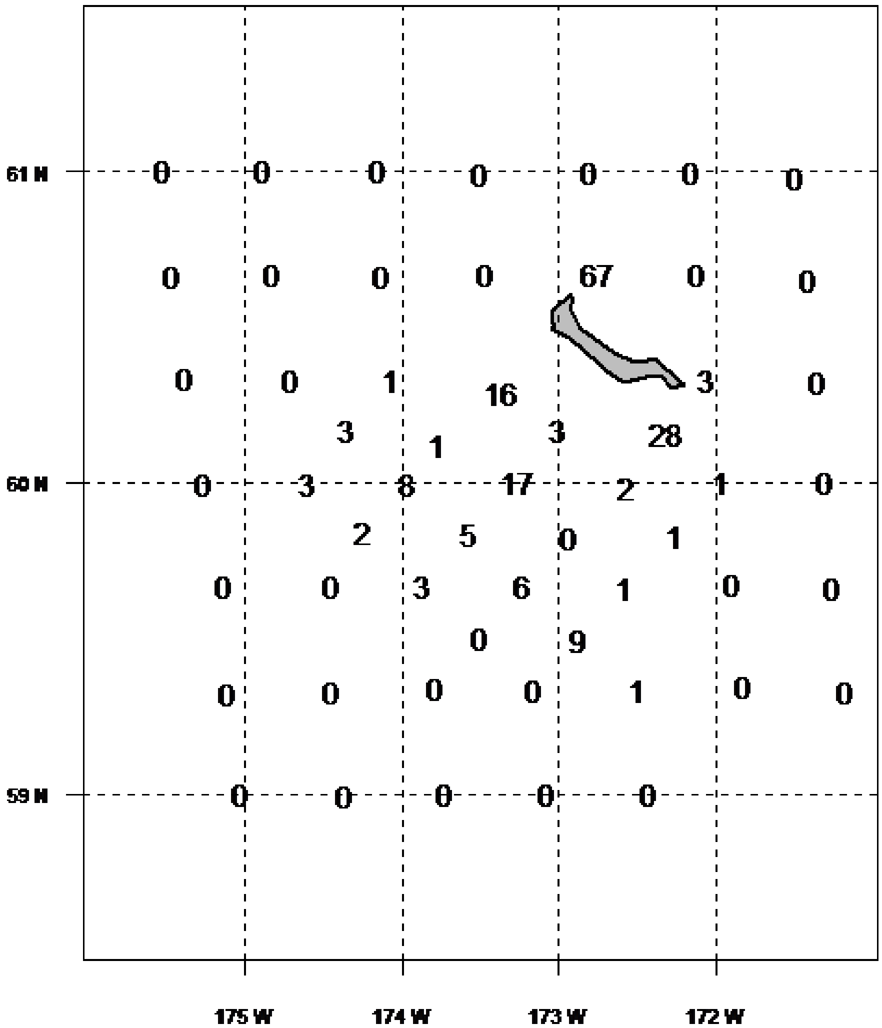


Figure 5: Catches of 181 male blue king crab measuring at least 90 mm CL from the 2014 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock. Note that the area north of St. Matthew Island, which includes the large catch of 67 crab at station R-24, is not represented in the ADF&G pot-survey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

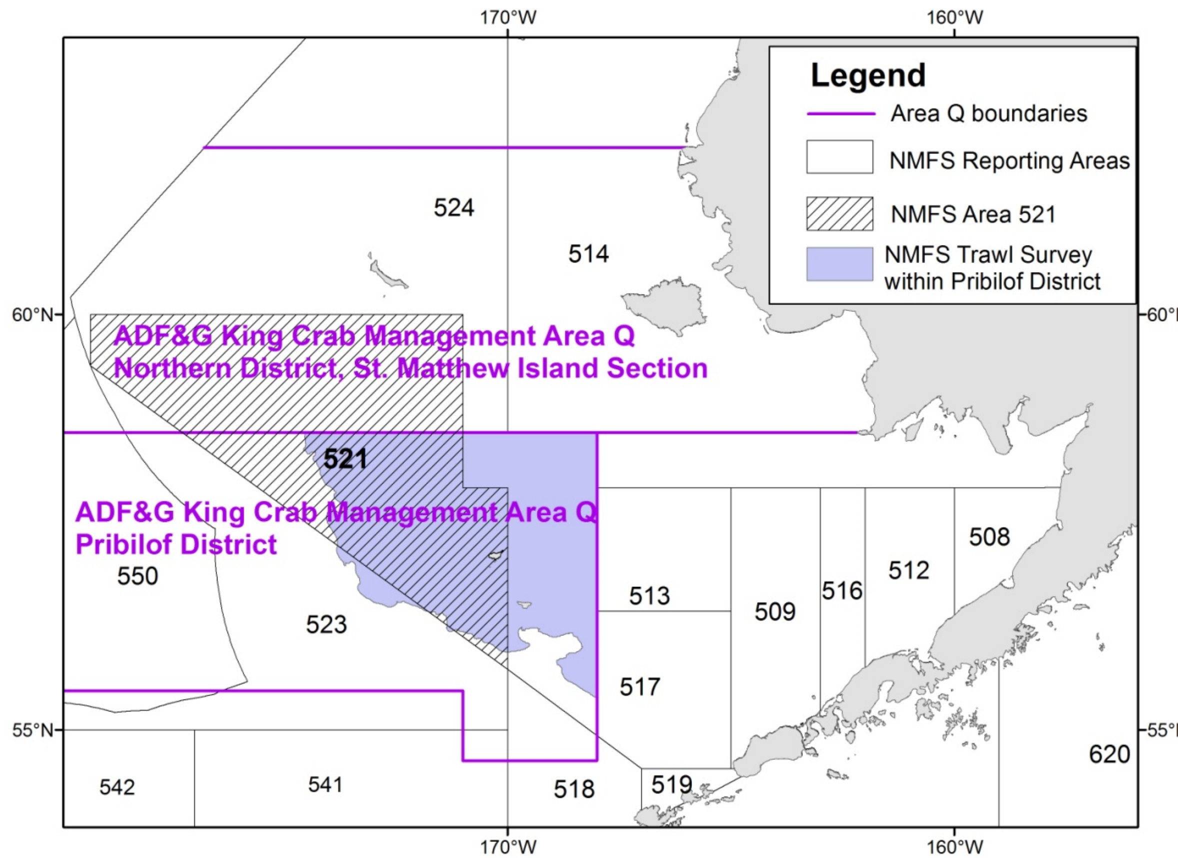


Figure 6: NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.

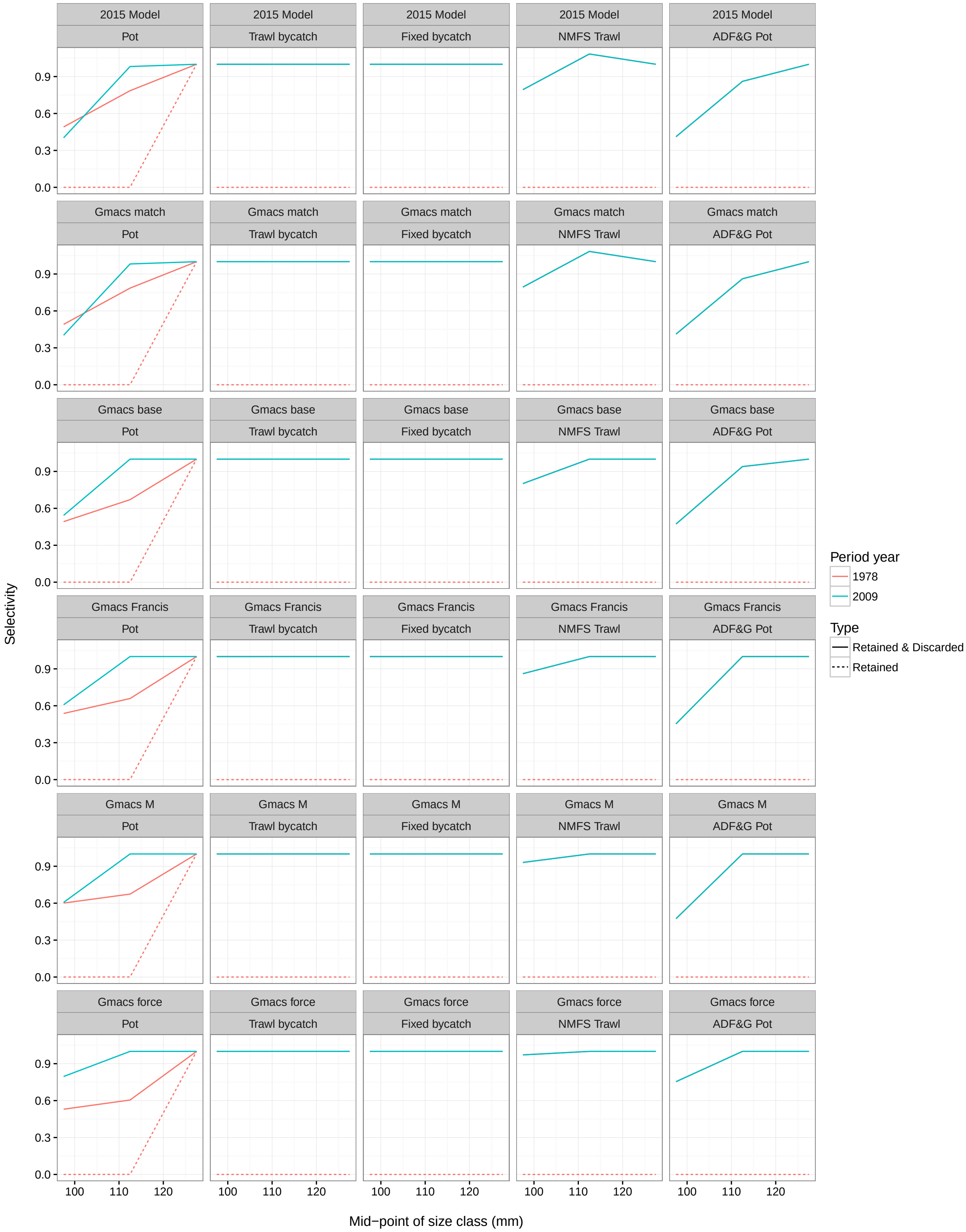


Figure 7: Comparisons of the estimated (and fixed to match the 2015 model selectivities in the Gmacs base scenario) stage-1 and stage-2 selectivities for each of the different model scenarios (the stage-3 selectivities are all fixed at 1). Estimated selectivities are shown for the directed pot fishery,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

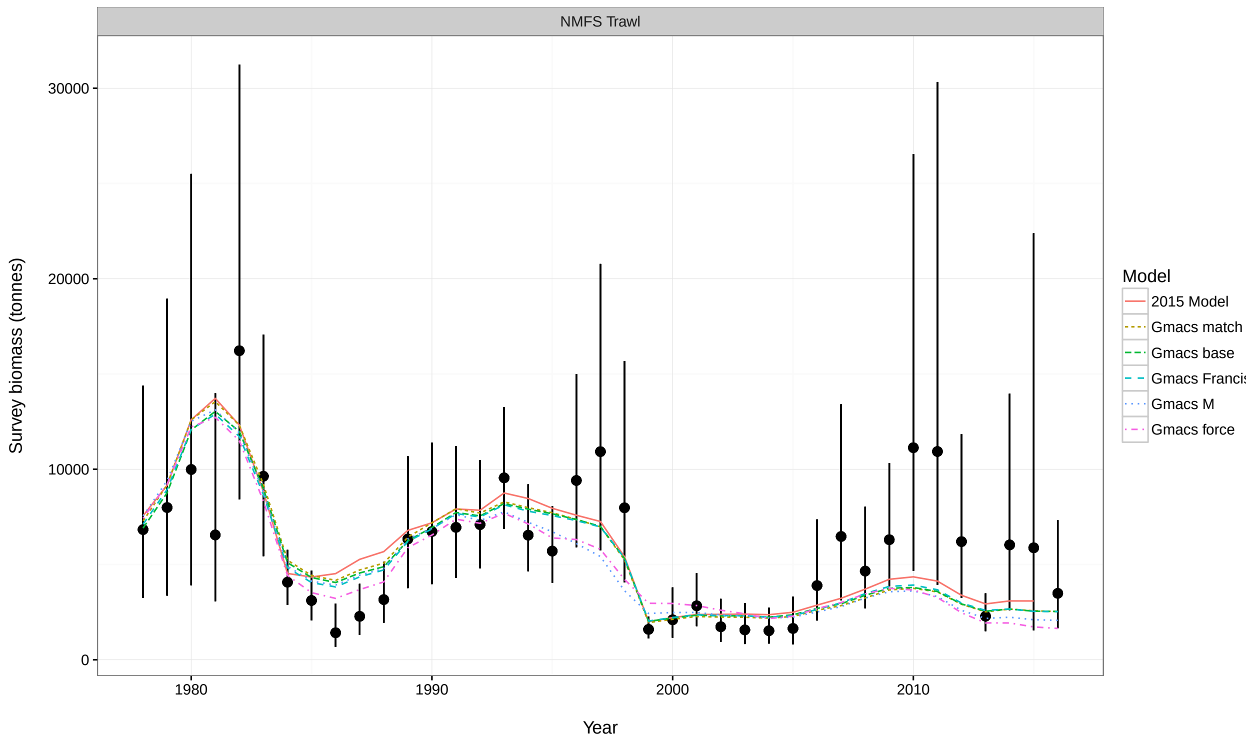


Figure 8: Comparisons of area-swept estimates of total male survey biomass (tonnes) and model predictions for the 2015 model and each of the Gmacs model scenarios. The error bars are plus and minus 2 standard deviations.

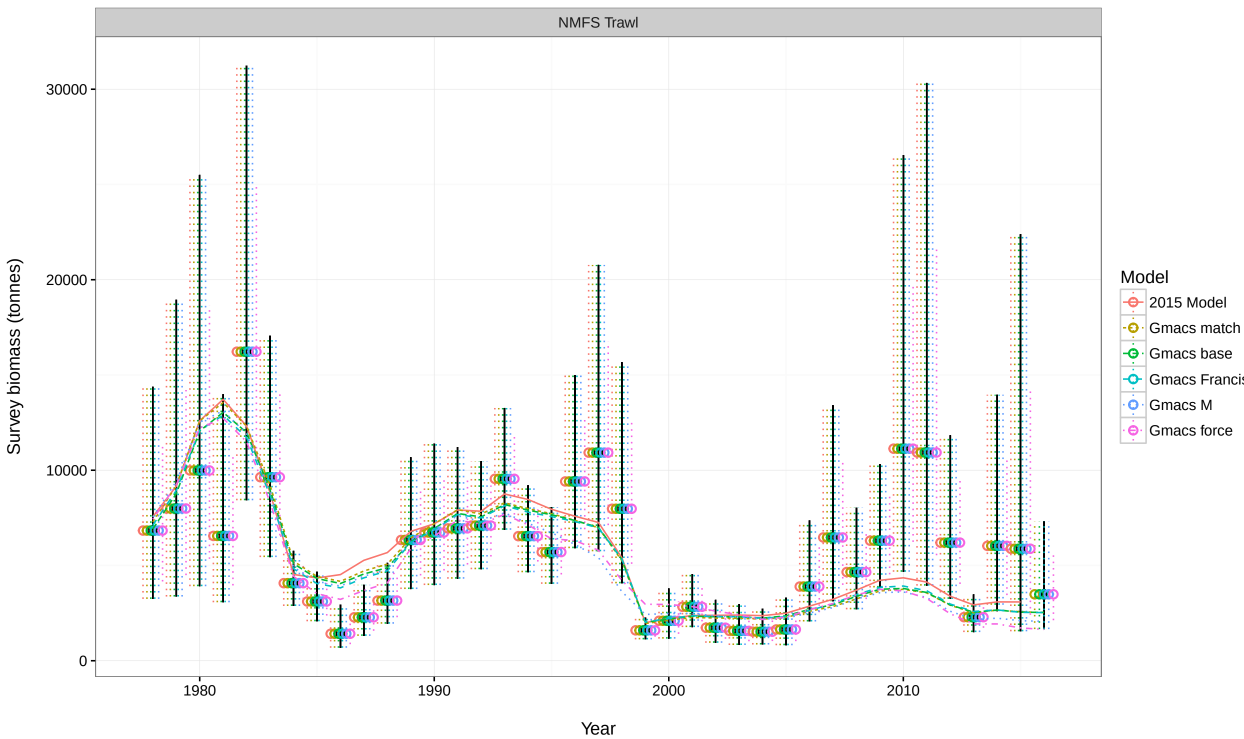


Figure 9: Comparisons of area-swept estimates of total male survey biomass (tonnes) and model predictions for the 2015 model and each of the Gmacs model scenarios. The solid black error bars are plus and minus 2 standard deviations derived using the original survey CVs. The dotted error bars are plus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

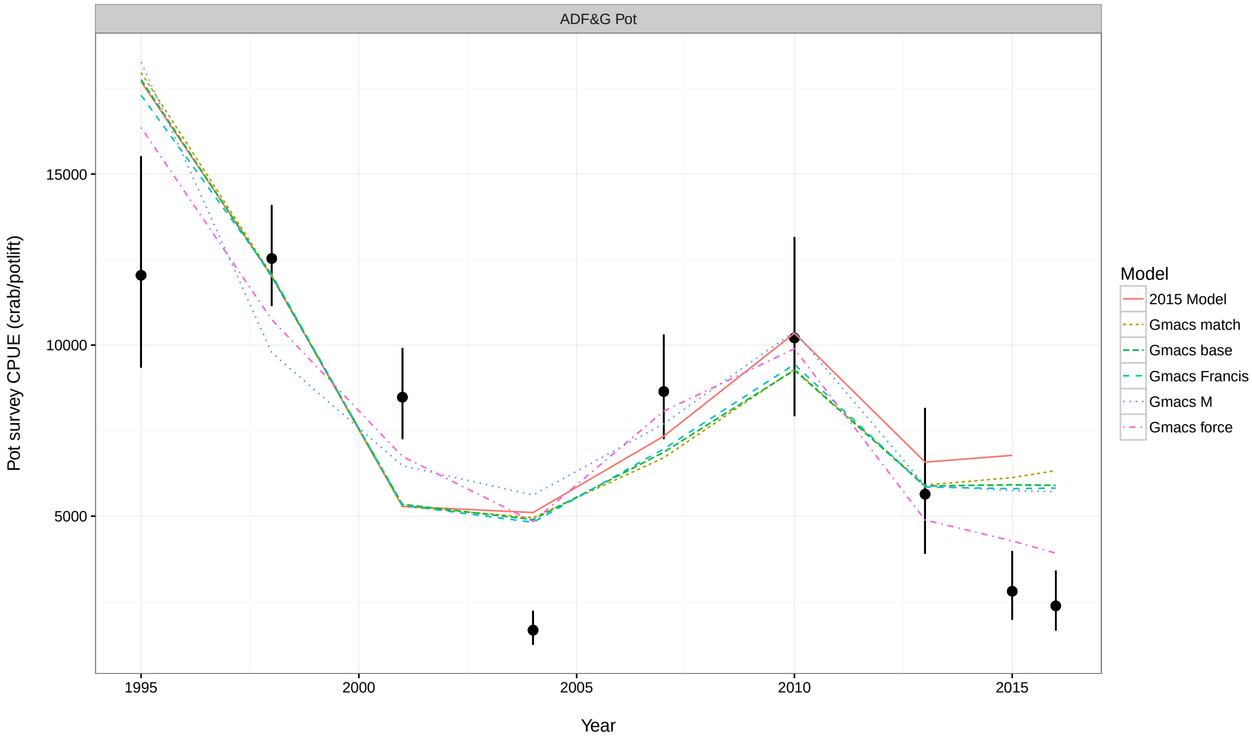


Figure 10: Comparisons of total male pot survey CPUEs and model predictions for the 2015 model and each of the Gmacs model scenarios. The error bars are plus and minus 2 standard deviations.

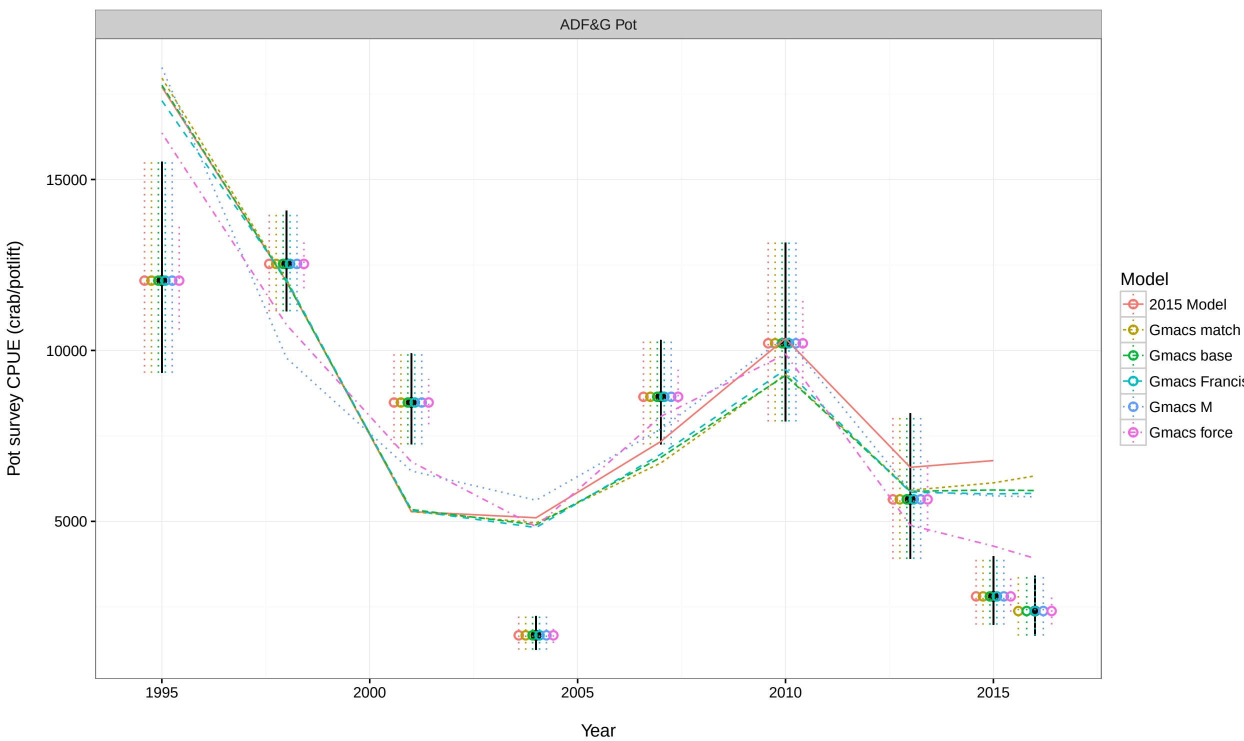


Figure 11: Comparisons of total male pot survey CPUEs and model predictions for the 2015 model and each of the Gmacs model scenarios. The solid black error bars are plus and minus 2 standard deviations derived using the original survey CVs. The dotted error bars are plus and minus 2 standard deviations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

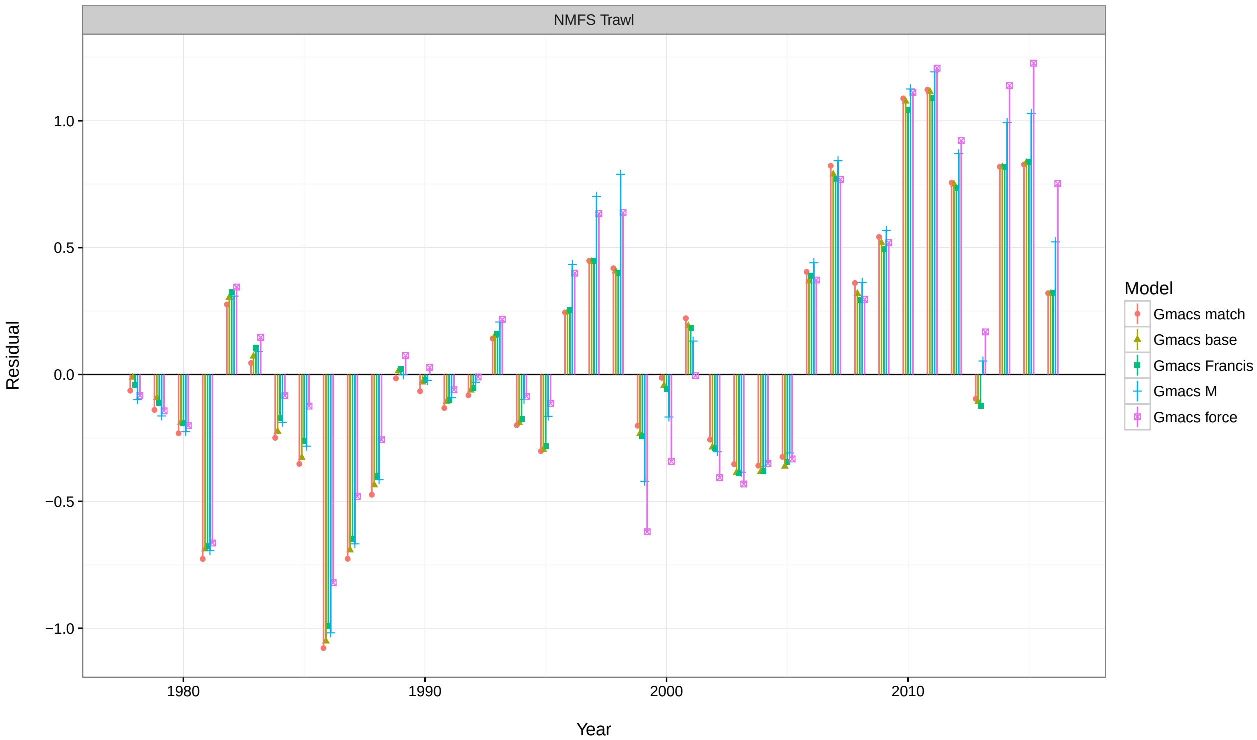


Figure 12: Standardized residuals for area-swept estimates of total male survey biomass for each of the Gmacs model scenarios.

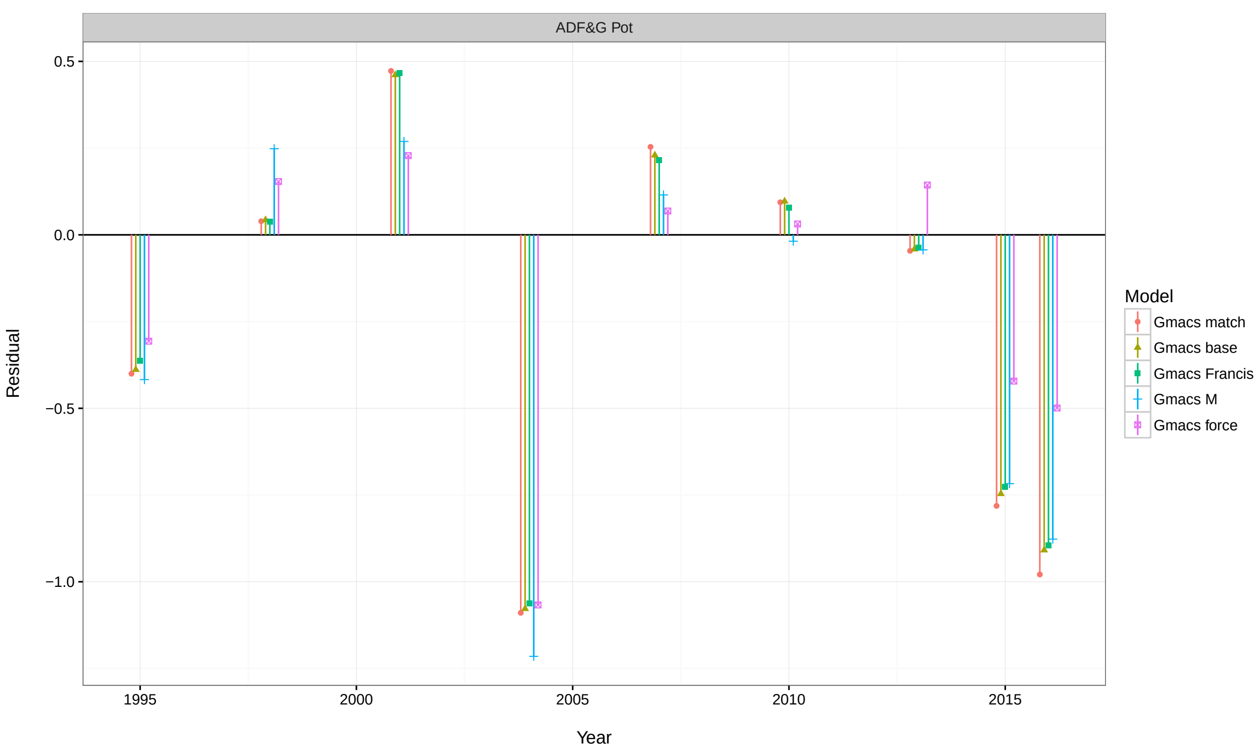


Figure 13: Standardized residuals for total male pot survey CPUEs for each of the Gmacs model scenarios.

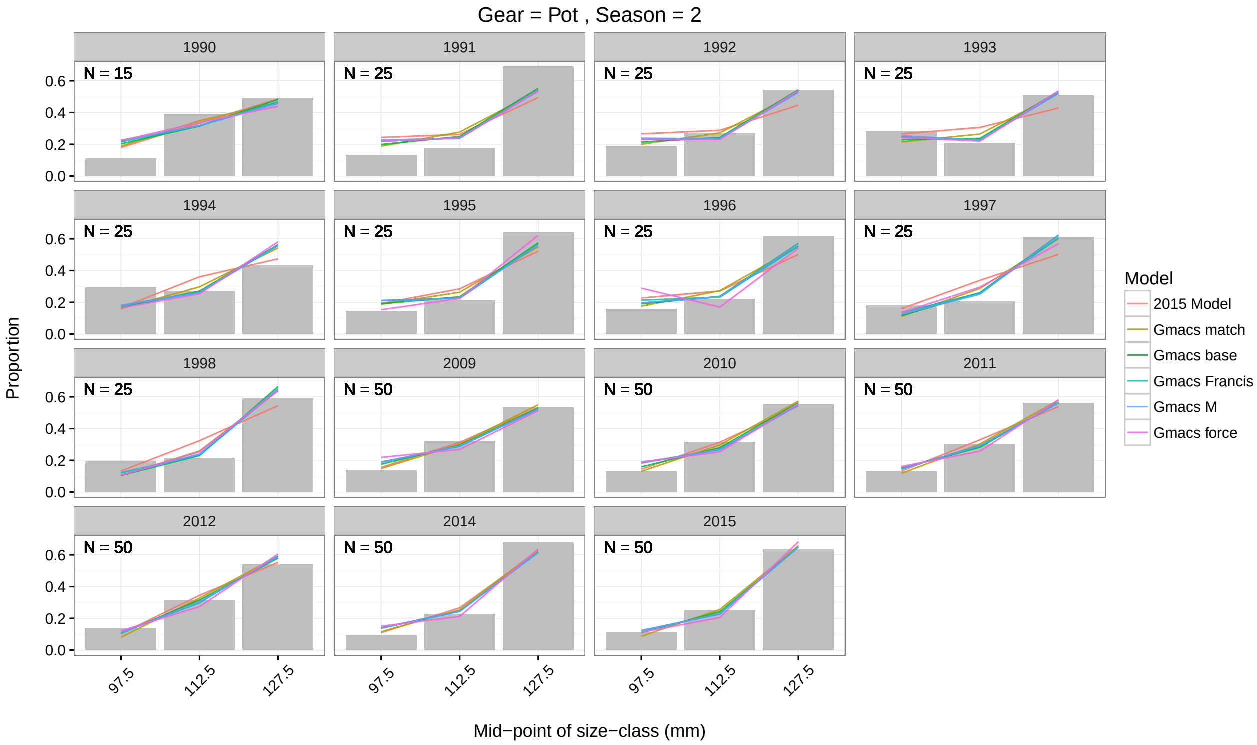


Figure 14: Observed and model estimated size-frequencies of SMBKC by year retained in the directed pot fishery for the 2015 model and each of the Gmacs model scenarios. Note that there is no model estimated size-frequency for the 2015 model during the 2015 year.

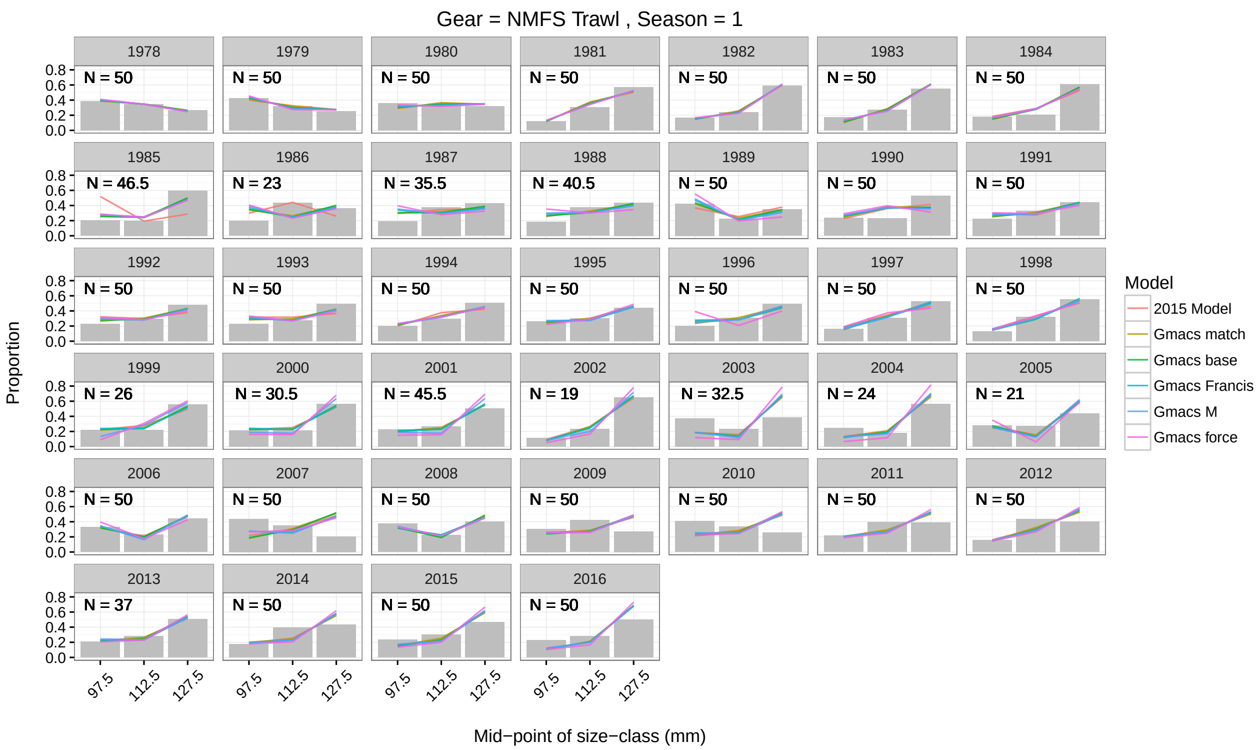


Figure 15: Observed and model estimated size-frequencies of discarded male SMBKC by year in the NMFS trawl survey for the 2015 model and each of the Gmacs model scenarios. Note that there is no model estimated size-frequency for the 2015 model during the 2016 year.

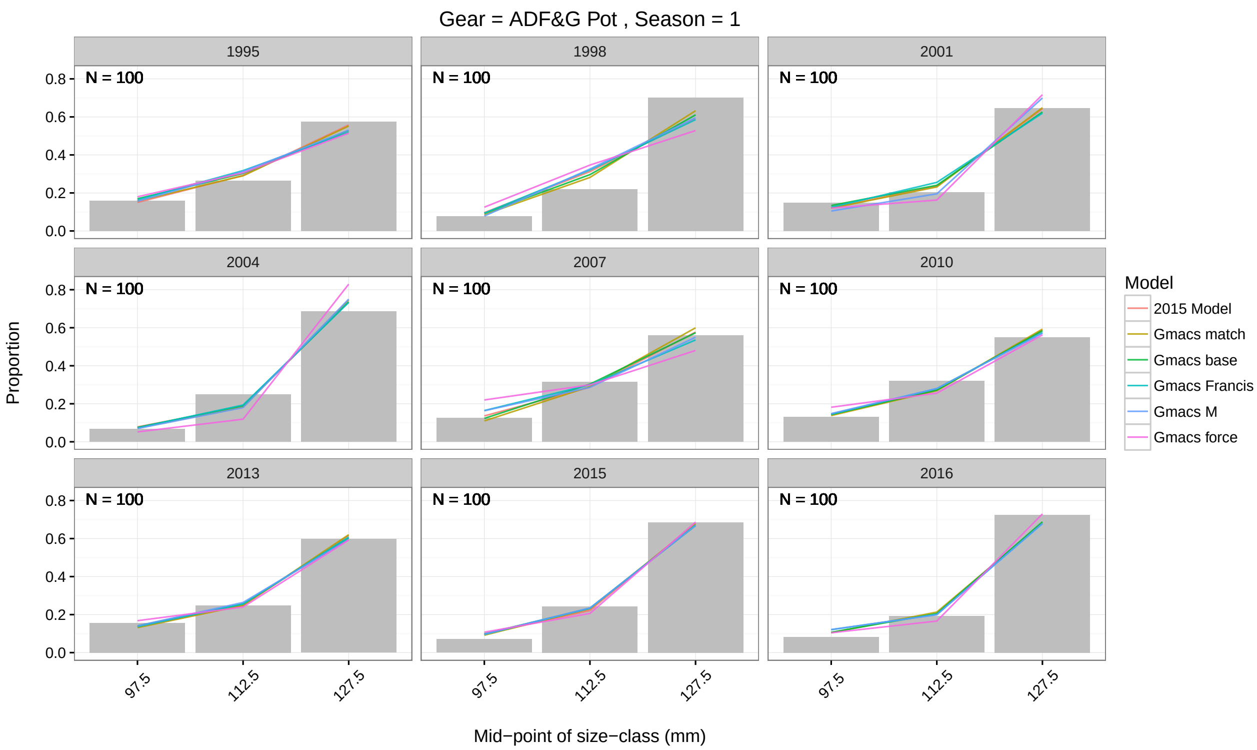
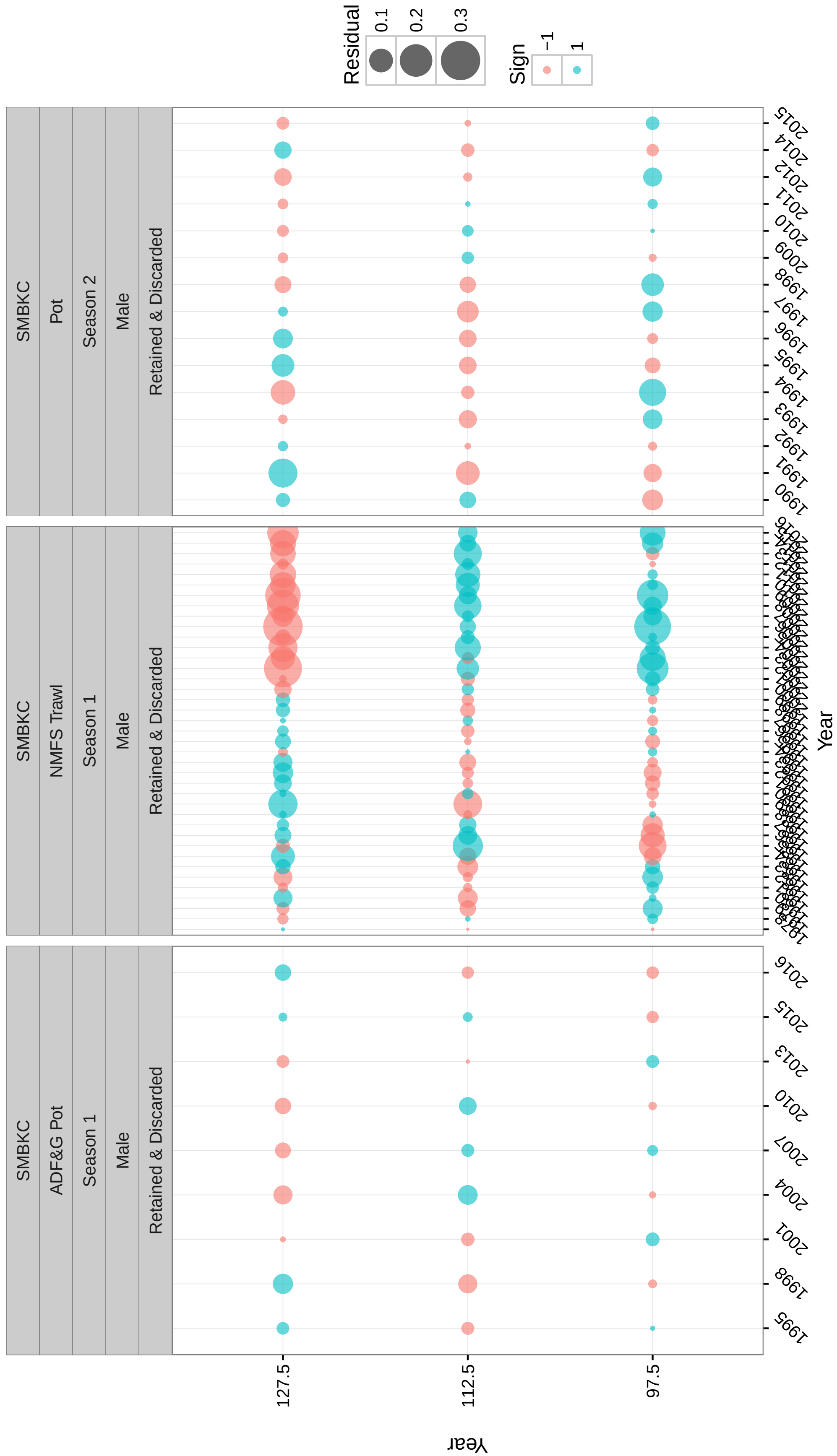


Figure 16: Observed and model estimated size-frequencies of discarded SMBKC by year in the ADF&G pot survey for the 2015 model and each of the Gmacs model scenarios. Note that there is no model estimated size-frequency for the 2015 model during the 2016 year.


SMBKC
ADF&G Pot
Season 1
Male
Retained & Discarded
SMBKC
NMFS Trawl
Season 1
Male
Retained & Discarded
SMBKC
Pot
Season 2
Male
Retained & Discarded
127.5
112.5
97.5
Year
Year
Residual
0.1
0.2
0.3
Sign
−1
1

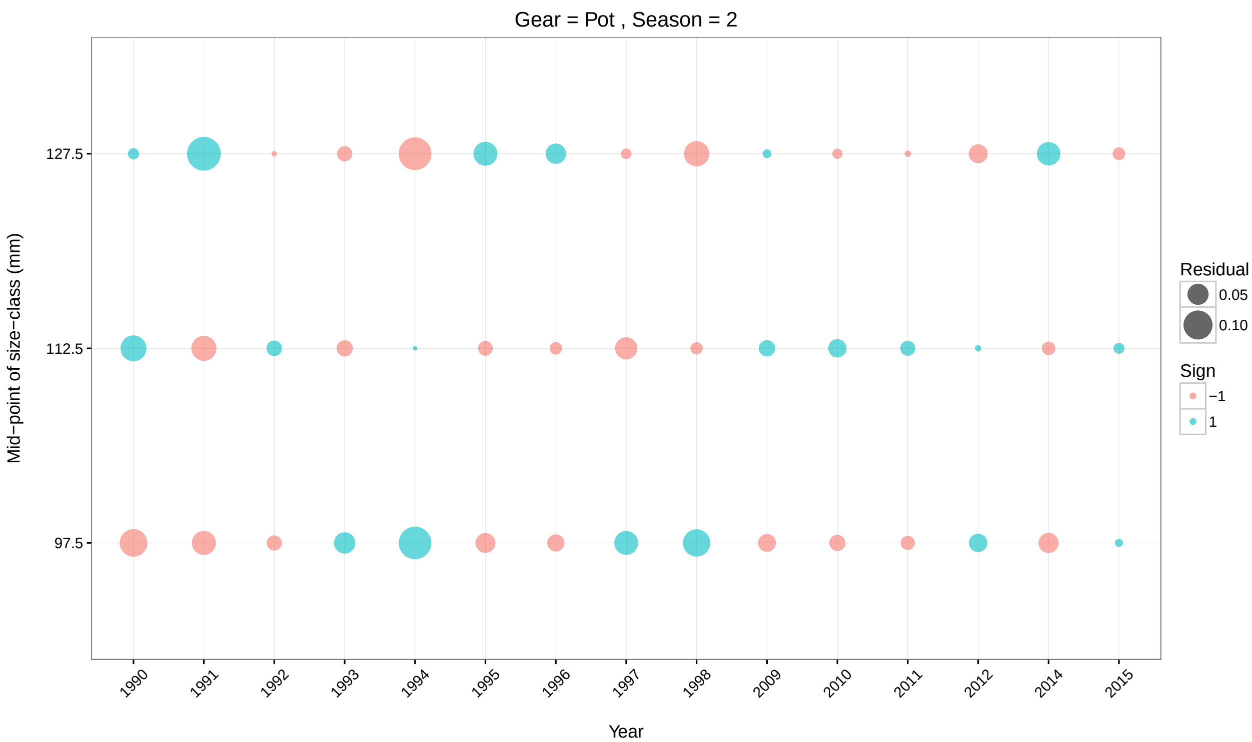


Figure 17: Bubble plots of residuals by stage and year for the directed pot fishery size composition data for St. Mathew Island blue king crab (SMBKC) in the **Gmacs base** model.

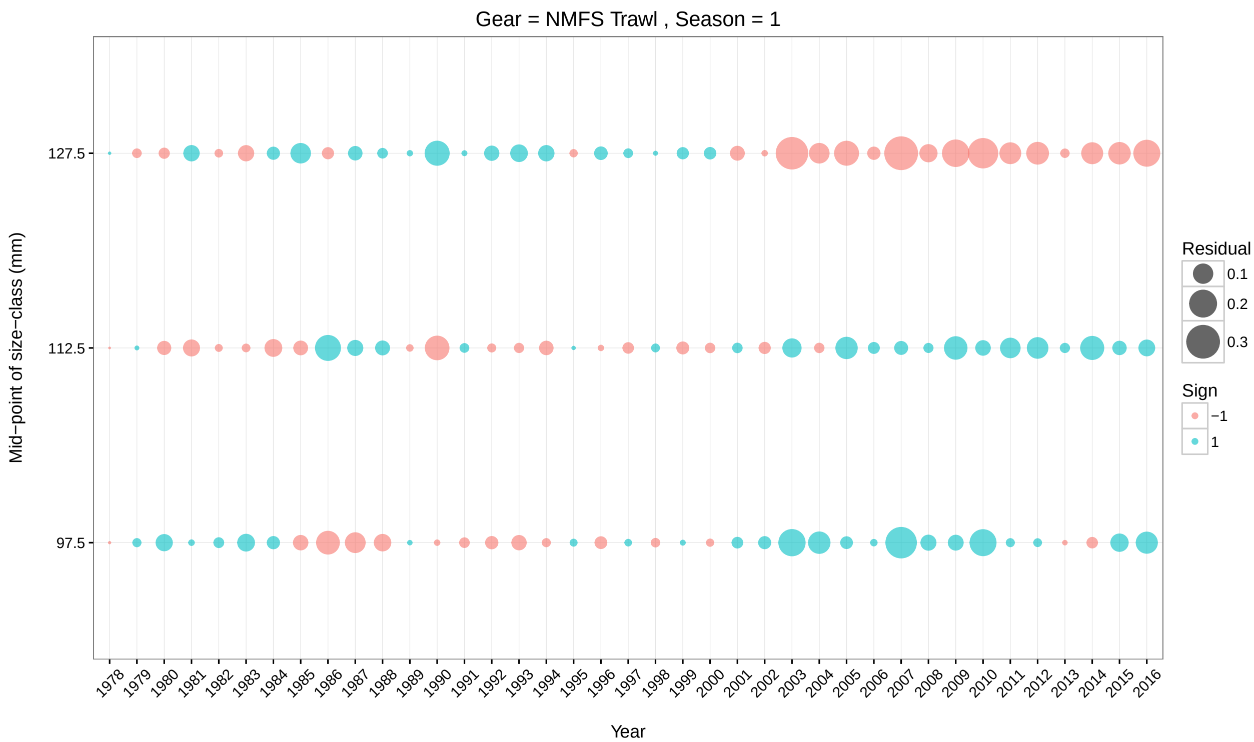


Figure 18: Bubble plots of residuals by stage and year for the NMFS trawl survey size composition data for St. Mathew Island blue king crab (SMBKC) in the **Gmacs base** model.

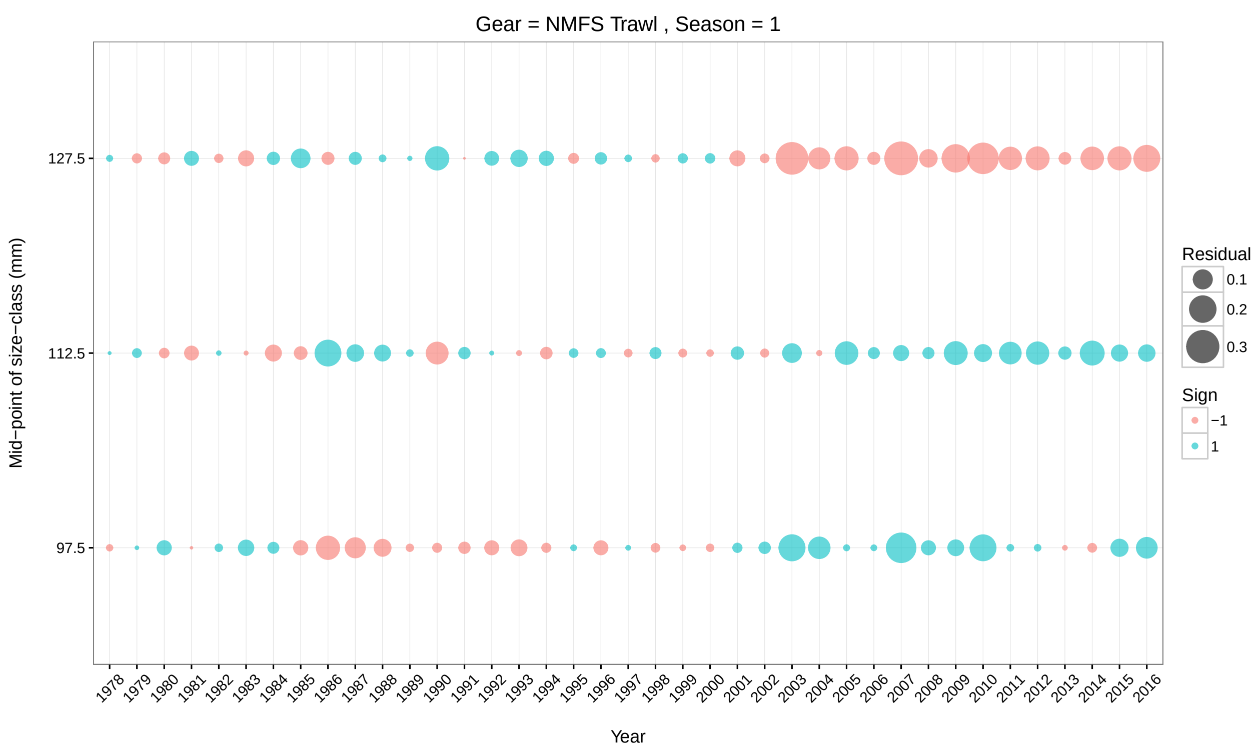


Figure 19: Bubble plots of residuals by stage and year for the NMFS trawl survey size composition data for St. Mathew Island blue king crab (SMBKC) in the **Gmacs selex** model.

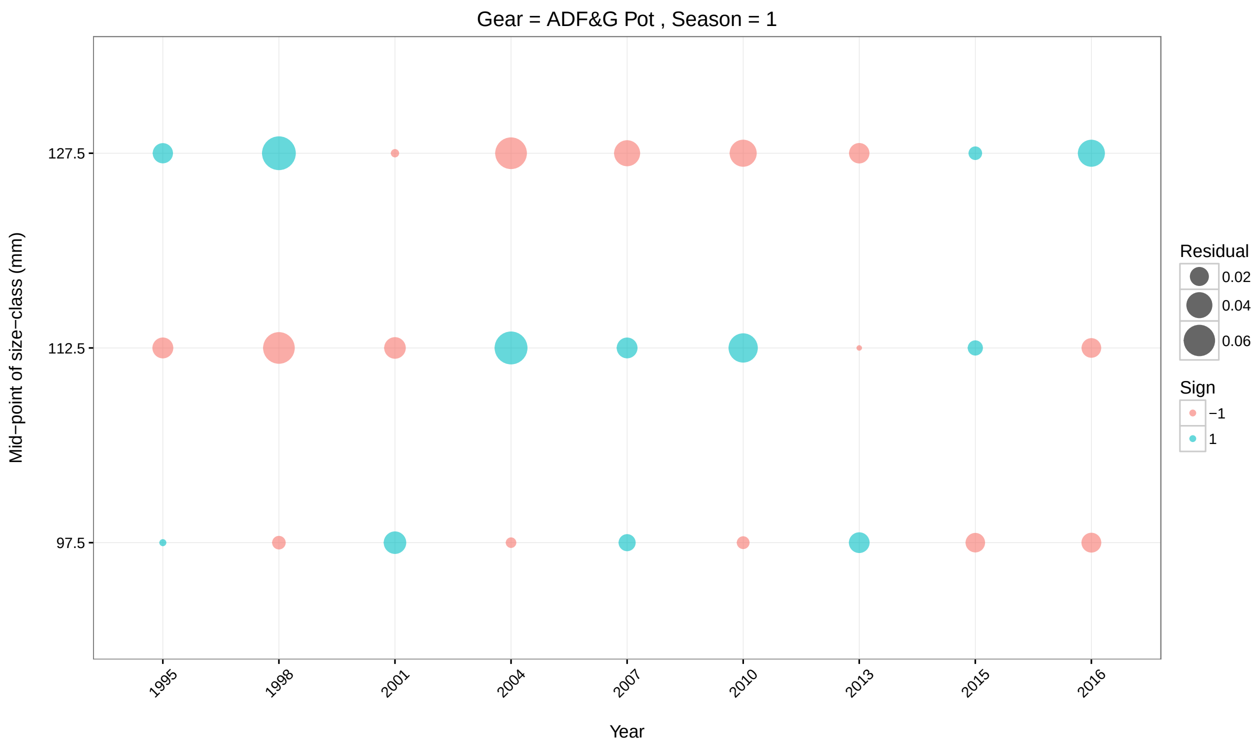


Figure 20: Bubble plots of residuals by stage and year for the ADF&G pot survey size composition data for St. Mathew Island blue king crab (SMBKC) in the **Gmacs base** model.

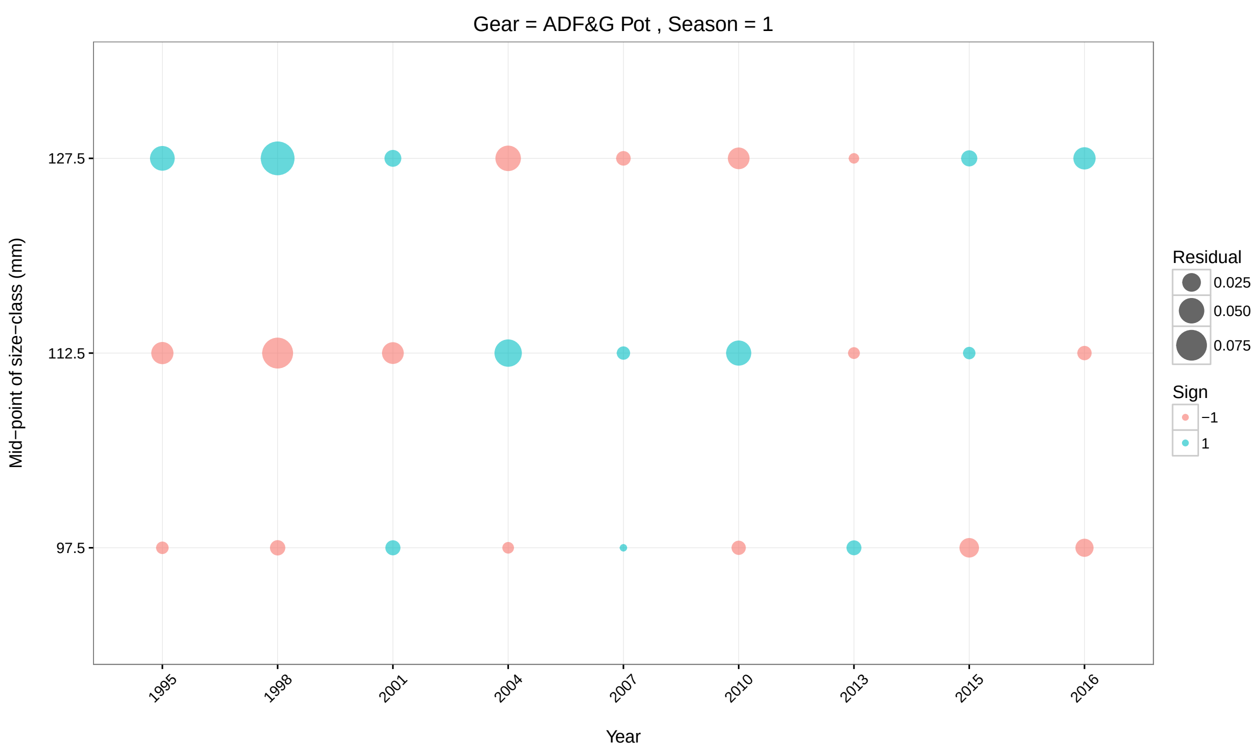


Figure 21: Bubble plots of residuals by stage and year for the ADF&G pot survey size composition data for St. Mathew Island blue king crab (SMBKC) in the **Gmacs selex** model.

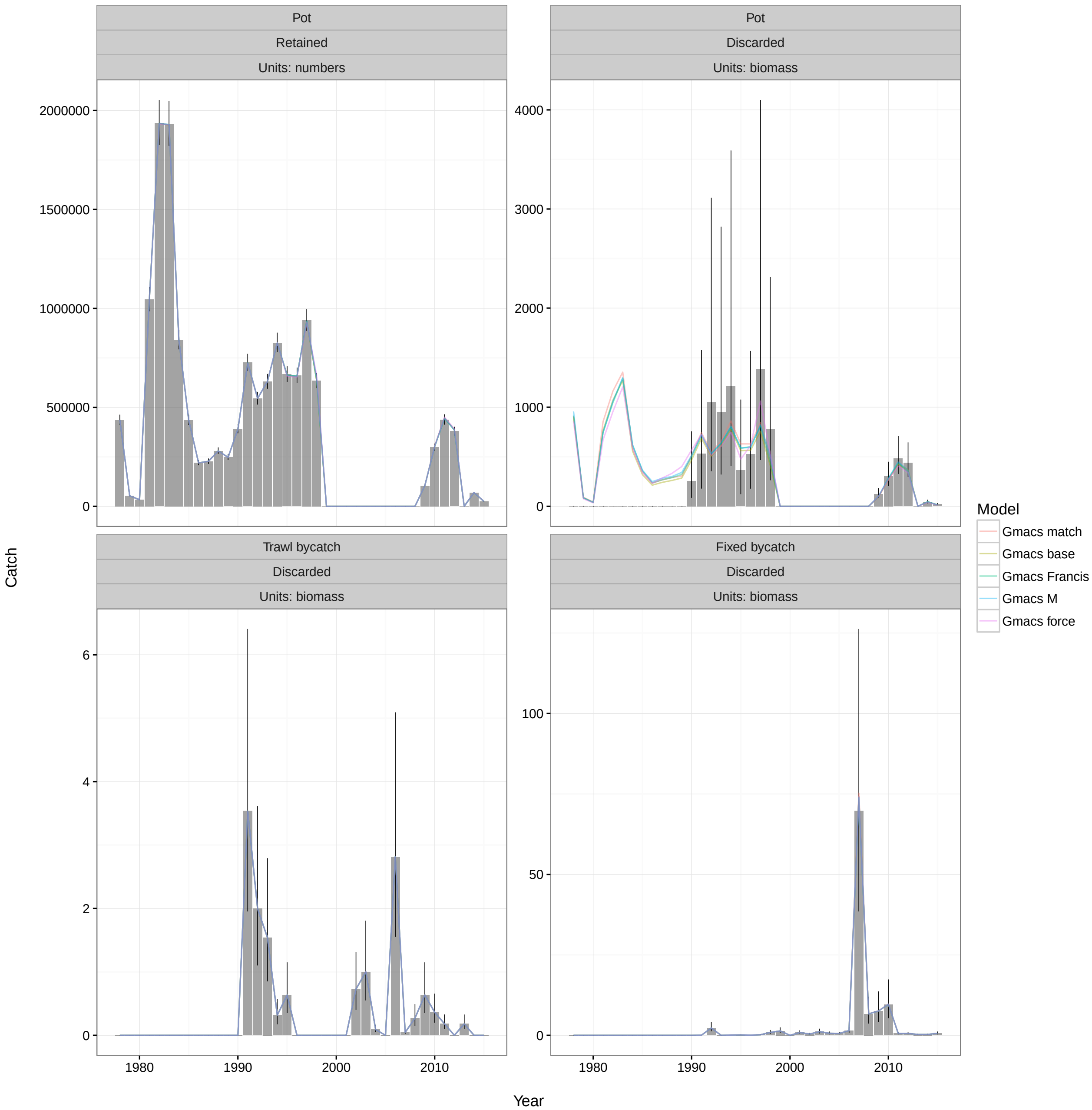


Figure 22: Comparison of observed and model predicted retained catch and bycatches in each of the Gmacs models. Note that difference in units between each of the panels, some panels are expressed in numbers of crab, some as biomass (tonnes).

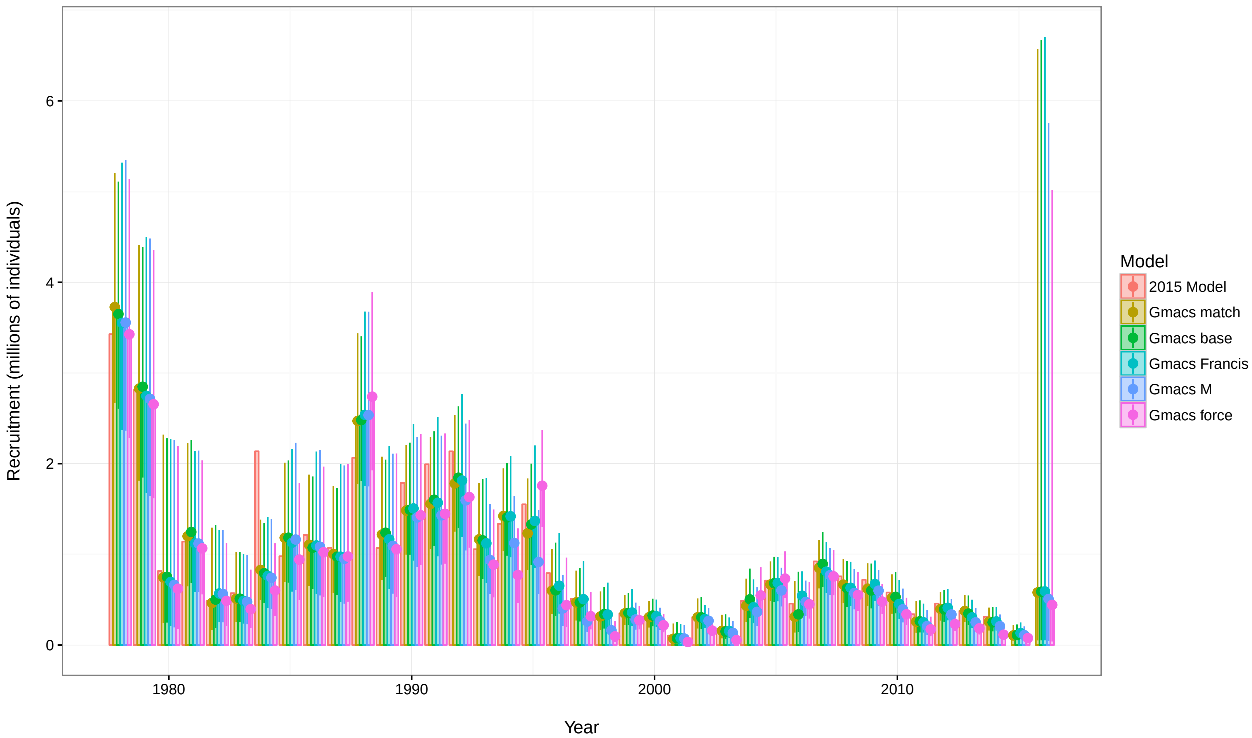


Figure 23: Comparisons of estimated recruitment time series during 1979-2016 in each of the scenarios.

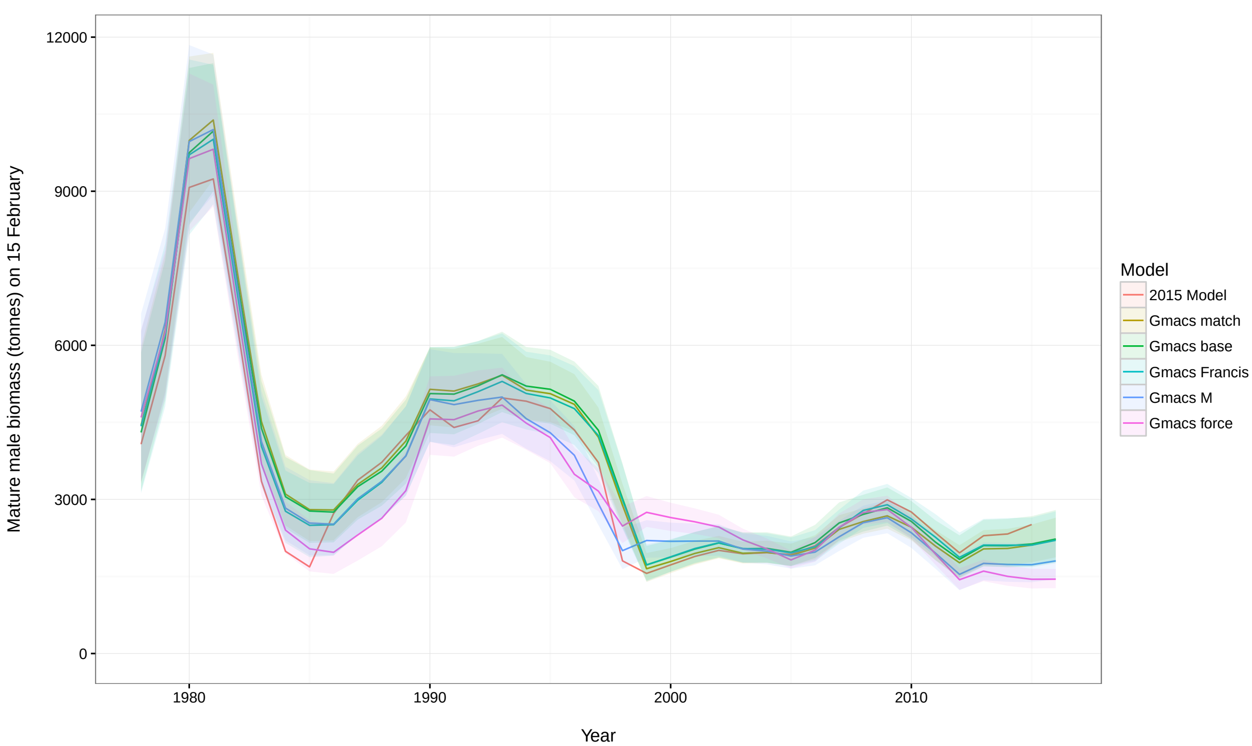


Figure 24: Comparisons of estimated mature male biomass (MMB) time series on 15 February during 1978-2016 for each of the model scenarios.

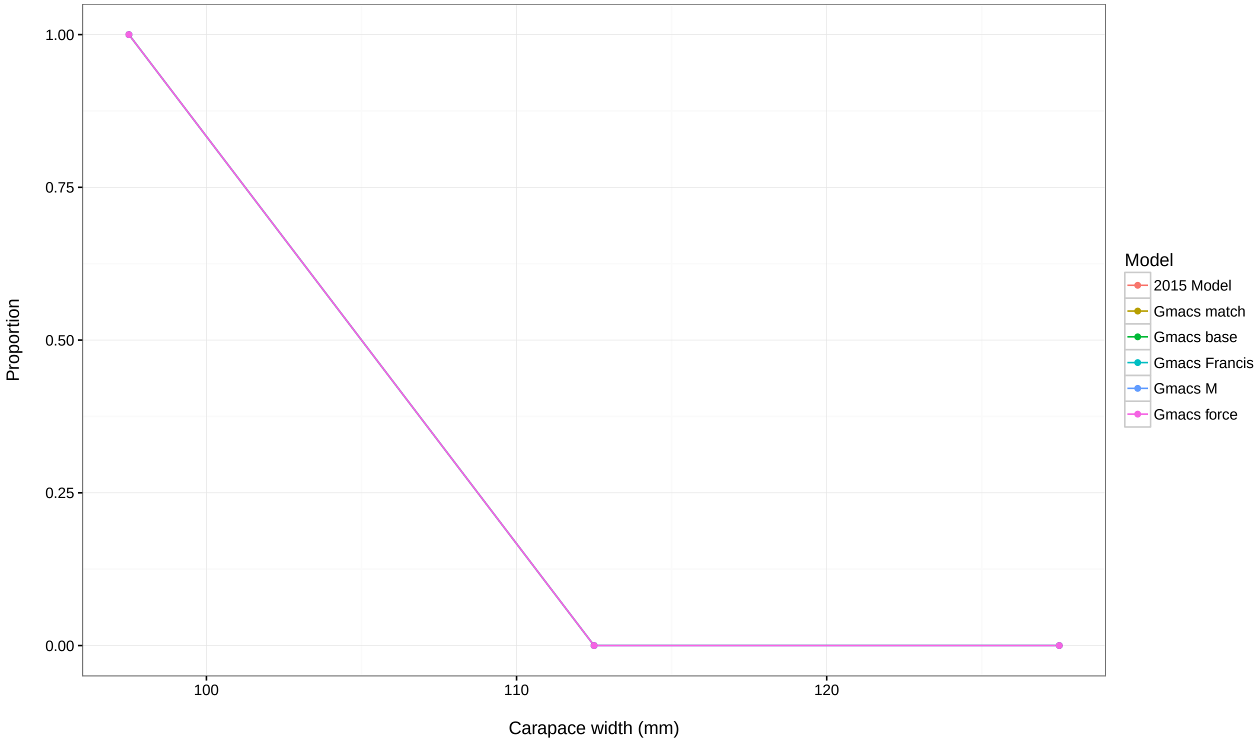


Figure 25: Distribution of carapace width (mm) at recruitment.

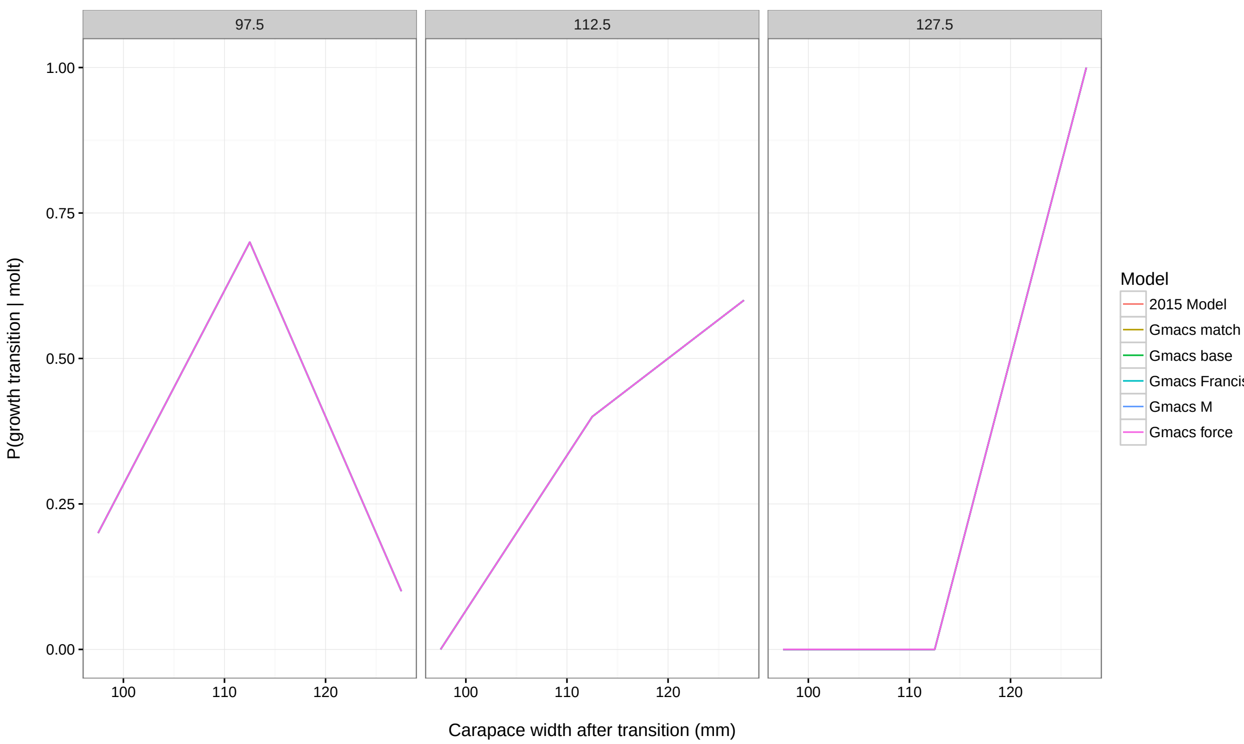


Figure 26: Probability of size transition by stage (i.e. the combination of the growth matrix and molting probabilities). Each of the panels represent the stage before a transition. The x-axes represent the stage after a transition. The size transition matrix was provided as an input directly to Gmacs (as it was during the 2015 SMBKC assessment).

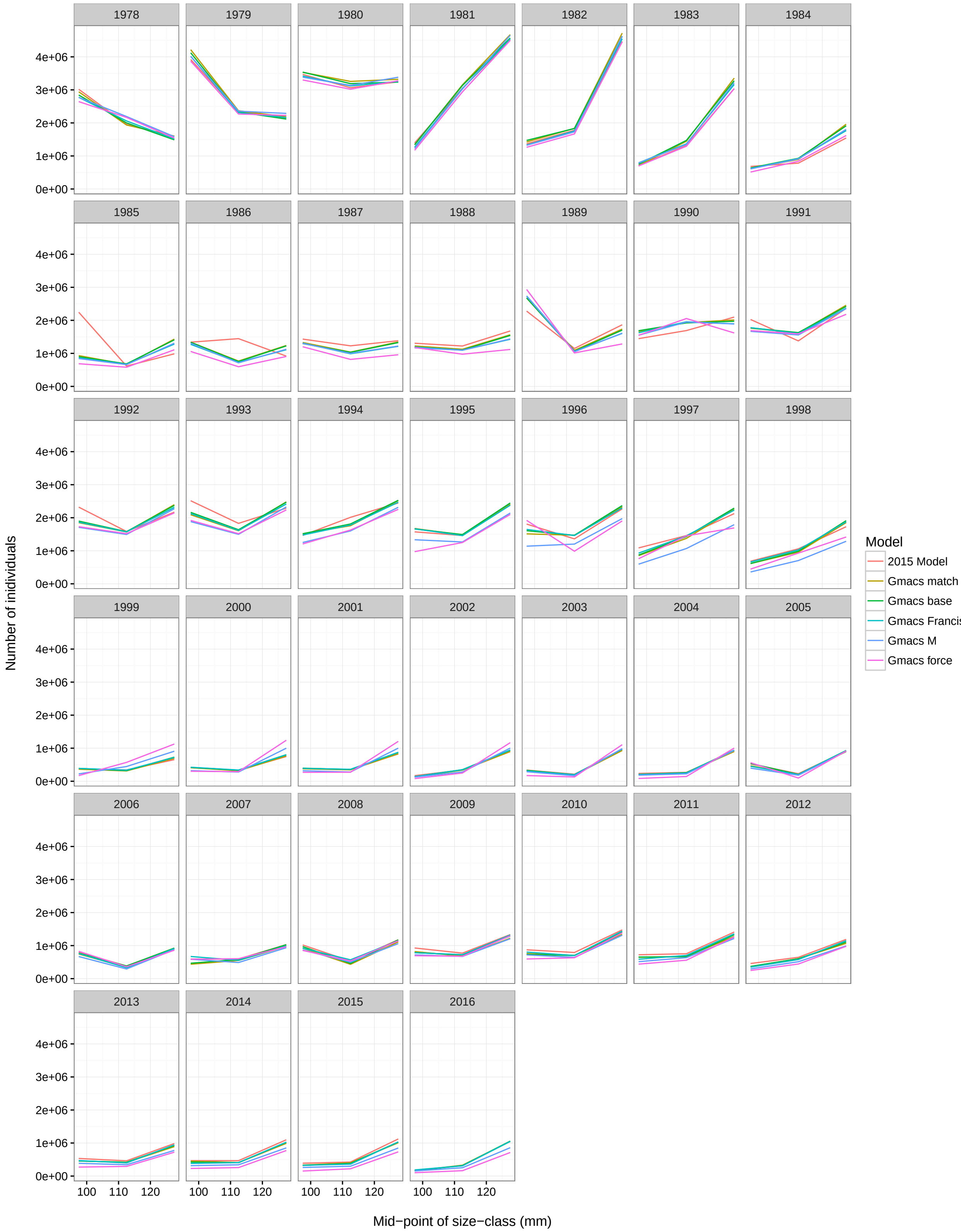


Figure 27: Numbers by stage each year (at the beginning of the model year, i.e. 1 July) in each of the models including the 2015 model.

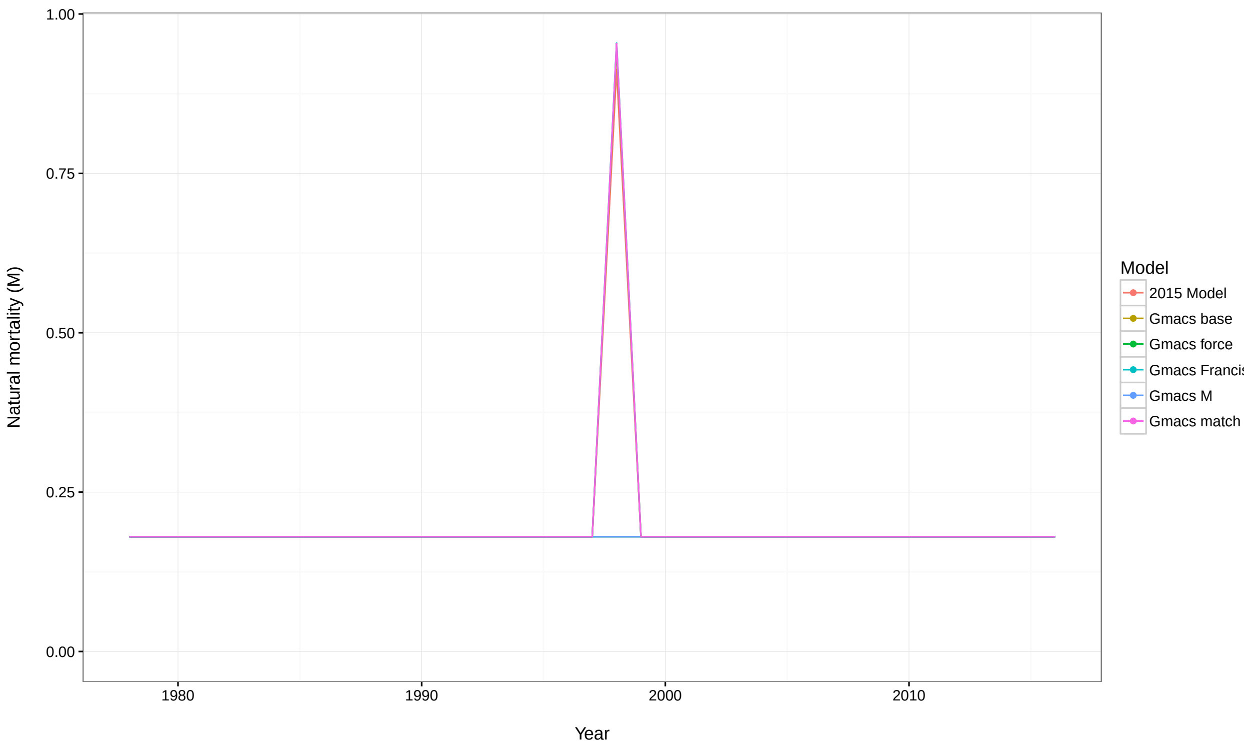


Figure 28: Time-varying natural mortality (M_t). Estimated pulse period occurs in 1998/99 (i.e. M_{1998}).

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 20. The beginning of the year (1 July) to the date that MMB is measured (15 February) is 63% of the year. Therefore 63% of the natural mortality must be applied before the MMB is calculated. Because the timing of the fishery is different each year τ_2 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

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

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

$$\boldsymbol{G} = \begin{bmatrix} 1-\pi_{12}-\pi_{13} & \pi_{12} & \pi_{13} \\ 0 & 1-\pi_{23} & \pi_{23} \\ 0 & 0 & 1 \end{bmatrix}, \tag{3}$$

with π_{jk} equal to the proportion of stage-j crab that molt and grow into stage-k within a season or year. Similarly, the survival matrix $\boldsymbol{S}_{t,y}$ during season t and year y is

$$\boldsymbol{S}_{t,y} = \begin{bmatrix} 1-e^{-Z_{1,t,y}} & 0 & 0 \\ 0 & 1-e^{-Z_{2,t,y}} & 0 \\ 0 & 0 & 1-e^{-Z_{3,t,y}} \end{bmatrix}, \tag{4}$$

where $Z_{l,t,y}$ represents the combination of natural mortality $M_{t,y}$ and fishing mortality $F_{t,y}$ during season t and year y

$$Z_{l,t,y} = M_{t,y} + F_{t,y}. \tag{5}$$

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

$$\boldsymbol{r}_{t,y} = \left[\bar{R}, 0, 0\right]^\top \quad \text{for} \quad t = 5, \tag{6}$$

where $\bar{R}$ is the average annual recruitment. The basic population dynamics underlying Gmacs can thus be described as

$$\begin{aligned} \boldsymbol{n}_{t+1,y} &= \boldsymbol{S}_{t,y}\boldsymbol{n}_{t,y}, && \text{if } t < 5 \\ \boldsymbol{n}_{t,y+1} &= \boldsymbol{G}\boldsymbol{S}_{t,y}\boldsymbol{n}_{t,y} + \boldsymbol{r}_{t,y}, && \text{if } t = 5 \end{aligned} \tag{7}$$

The natural mortality

$$M_{t,y} = \bar{M}\tau_t + \delta_y^M \text{ where } \delta_y^M \sim \mathcal{N}\left(0, \sigma_M^2\right) \tag{8}$$

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

$$F_{t,y} = F_{t,y}^{\text{df}} + F_{t,y}^{\text{tb}} + F_{t,y}^{\text{fb}} \tag{9}$$

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.

3. Model Data

Data inputs used in model estimation are listed in Table 21.

4. Model Parameters

Table 22 lists fixed (externally determined) parameters used in model computations. In all scenarios, the stage-transition matrix is

$$\boldsymbol{G} = \begin{bmatrix} 0.2 & 0.7 & 0.1 \\ 0 & 0.4 & 0.6 \\ 0 & 0 & 1 \end{bmatrix} \tag{10}$$

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

Estimated parameters are listed in Table 23 and include an estimated parameter for natural mortality (M) in 1998/99 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}.

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

Also Fs

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 24). 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.

$$\sigma_i = \frac{1}{\lambda}\sqrt{\log(1.0 + c_i^2)} \tag{11}$$

$$\delta_i = \frac{\log(obs_i/pred_i)}{\sigma_i} + 0.5\sigma_i \tag{12}$$

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

$$\text{SDNR} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\delta_i - \bar{\delta}\right)^2} \tag{13}$$

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

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

Table 21: Data inputs used in model estimation.

Data	Years	Source
Directed pot-fishery retained-catch number (not biomass)	1978/79 - 1998/99 2009/10 - 2015/16	Fish tickets (fishery closed 1999/00 - 2008/09)
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 22: Fixed model parameters for all scenarios.

Parameter	Symbol	Value	Source/rationale
Trawl-survey catchability	q	1.0	Default
Natural mortality	M	0.18 yr^{-1}	NPFMC (2007)
Size transition matrix	$\boldsymbol{G}$	Equation 10	Otto and Cummiskey (1990)
Stage-1 and stage-2 mean weights	w_1, w_2	0.7, 1.2 kg	Length-weight equation (B. Foy, NMFS) applied to stage midpoints
Stage-3 mean weight	$w_{3,y}$	Depends on year	Fishery reported average retained weight from fish tickets, or its average, and mean weights of legal males
Recruitment SD	σ_R	1.2	High value
Natural mortality SD	σ_M	10.0	High value (basically free parameter)
Directed fishery handling mortality		0.2	2010 Crab SAFE
Groundfish trawl handling mortality		0.8	2010 Crab SAFE
Groundfish fixed-gear handling mortality		0.5	2010 Crab SAFE

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

Parameter	LB	Initial value	UB	Prior	Phase
Average recruitment $\log(\bar{R})$	-7	10.0	20	Uniform(-7,20)	1
Stage-1 initial numbers $\log(N_1)$	5	14.5	20	Uniform(5,20)	1
Stage-2 initial numbers $\log(N_2)$	5	14.0	20	Uniform(5,20)	1
Stage-3 initial numbers $\log(N_3)$	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^M_{1998}	-3	0.0	3	Normal(δ^M_{1997}, σ^2_M)	4
Recruitment deviations δ^R_y	-7	0.0	7	Normal(0, σ^2_R)	3

Table 24: 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	$-0.5\sum\left(\log(c_t/C_t)^2/\log(1+cv_c^2)\right)$