Saint Matthew Island Blue King Crab Stock Assessment 2017

James Ianelli[1], D'Arcy Webber[2], Jie Zheng[3], and Alathea Letaw[4]
[1]NOAA, jim.ianelli@noaa.gov
[2]Quantifish, darcy@quantifish.co.nz
[3]Alaska Department of Fish and Game, jie.zheng@alaska.gov
[4]NOAA, alathea.letaw@noaa.gov

September 2017

Executive Summary

1. **Stock**: Blue king crab, *Paralithodes platypus*, Saint Matthew Island (SMBKC), Alaska.

2. **Catches**: Peak historical harvest was 4288 t (9.454 million pounds) in 1983/84[1]. The fishery was closed for 10 years after the stock was declared overfished in 1999. Fishing resumed in 2009/10 with a fishery-reported retained catch of 209 t (0.461 million pounds), less than half the 529.3 t (1.167 million pound) TAC. Following three more years of modest harvests supported by a fishery catch per unit effort (CPUE) of around 10 crab per pot lift, the fishery was again closed in 2013/14 due to declining trawl-survey estimates of abundance and concerns about the health of the stock. The directed fishery resumed again in 2014/15 with a TAC of 300 t (0.655 million pounds), but the fishery performance was relatively poor with a retained catch of 140 t (0.309 million pounds). The retained catch in 2015/16 was even lower at 48 t (0.105 million pounds) and in 2016/2017 the fishery was closed.

3. **Stock biomass**: The 1978-2017 NMFS trawl survey mean biomass is 5,762 t with the 8th lowest value occurring in 2017 (the fourth lowest since 2000) with a biomass of 90mm and larger male crab of just under 1,800 t (~31% of the long term mean; 6.12 million lbs with a CV of 60%). The most recent 3-year average of the NMFS survey is 65% of the mean value suggesting a general decline in biomass compared to the survey estimates in 2010 and 2011 that were nearly twice the current average. The assessment model estimates dampen the interannual variability observed in the survey biomass and suggest that the stock (in survey biomass units) is presently at about 45% of the long term model-predicted survey biomass average. The trend from these values suggest a slight decline.

4. **Recruitment**: Recruitment is based on estimated number of male crab within the 90-104 mm carapace length (CL) size class in each year. The 2017 trawl-survey area-swept estimate of 0.073 million male SMBKC in this size class is the lowest in the 40 years since 1978 and caps a six-year (2012 - 2017) average recruitment that is only 54% of this mean. In the pot-survey, the abundance of this size group in 2017 was also the second-lowest in the time series relatively low (22% of the mean for the available pot-survey data).

5. **Management performance**: In this assessment estimated total male catch is the sum of fishery-reported retained catch, estimated male discard mortality in the directed fishery, and estimated male bycatch mortality in the groundfish fisheries. Based on the reference model for SMBKC, the stock was above the minimum stock-size threshold (MSST) in 2016/17 and is hence not overfished. Overfishing did not occur in this year as the directed fishery was closed (Tables 1 and 2). Nonetheless, the low survey values and paucity of crabs in the region, as indicated by the surveys, remains a concern.

[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 t) for the reference model. Notes: A - calculated from the assessment reviewed by the Crab Plan Team in September 2013, B - calculated from the assessment reviewed by the Crab Plan Team in September 2014, C - calculated from the assessment reviewed by the Crab Plan Team in September 2015, D - calculated from the assessment reviewed by the Crab Plan Team in September 2016, E - calculated from the assessment reviewed by the Crab Plan Team in September 2017.

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

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

Year	MSST	Biomass (MMB_{mating})	TAC	Retained catch	Total male catch	OFL	ABC
2012/13	4.0^A	6.29^A	1.630	1.616	1.81	2.24	2.02
2013/14	3.4^B	6.64^B	0.000	0.000	0.0006	1.24	0.99
2014/15	4.1^C	5.47^C	0.655	0.309	0.329	0.94	0.75
2015/16	4.06^D	4.65^D	0.419	0.110	0.110	0.62	0.49
2016/17	4.3^E	4.68^E	0.41	0.000	0.000	0.62	0.49
2017/18		4.81^E				0.27	0.22

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

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

Year	Tier	B_{MSY}	Biomass (MMB_{mating})	B/B_{MSY}	F_{OFL}	γ	Basis for B_{MSY}	Natural mortality
2012/13	4a	3.56	5.63	1.56	0.18	1	1978-2012	0.18
2013/14	4b	3.06	3.01	0.98	0.18	1	1978-2013	0.18
2014/15	4b	3.28	2.71	0.82	0.14	1	1978-2014	0.18
2015/16	4b	3.71	2.45	0.66	0.11	1	1978-2015	0.18
2016/17	4b	3.67	2.23	0.61	0.09	1	1978-2016	0.18
2017/18	4b	3.93	2.18	0.55	0.09	1	1978-2016	0.18

A. Summary of Major Changes

Changes in Management of the Fishery

There are no new changes in management of the fishery.

Changes to the Input Data

Data used in this assessment have been updated to include the most recently available fishery and survey numbers. This assessment makes use of two new survey data points including the 2017 NMFS trawl-survey estimate of abudance, and the 2017 ADF&G pot survey CPUE. Both of these surveys have associated size compositon data. The assessment also uses updated 2010-2016 groundfish and fixed gear bycatch estimates based on AKRO data. There was no directed fishery data due to 2016/17 closure.

Changes in Assessment Methodology

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

Changes in Assessment Results

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

B. Responses to SSC and CPT Comments

CPT and SSC Comments on Assessments in General

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

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

   This was completed.

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

   This was completed.

3. *add the ability to "jitter" initial parameter values*

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

4. *add the ability to conduct retrospective analyses*

   Incomplete.

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

   This was completed.

6. *Continued exploration of data weighting (Francis and other approaches) and evaluation of models with and without the 1998 natural mortality spike. The authors are encouraged to bring other models forward for CPT and SSC consideration*

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

C. Introduction

Scientific Name

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

Distribution

Blue king crab are sporadically distributed throughout the North Pacific Ocean from Hokkaido, Japan, to southeastern Alaska (Figure 1). In the eastern Bering Sea small populations are distributed around St. Matthew Island, the Pribilof Islands, St. Lawrence Island, and Nunivak Island. Isolated populations also exist in some other cold water areas of the Gulf of Alaska (NPFMC 1998). The St. Matthew Island Section for blue king crab is within Area Q2 (Figure 2), which is the Northern District of the Bering Sea king crab registration area and includes the waters north of Cape Newenham (58°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 crab fishery, the State of Alaska uses 105 mm CL to define the lower size bound of functionally mature males

[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).

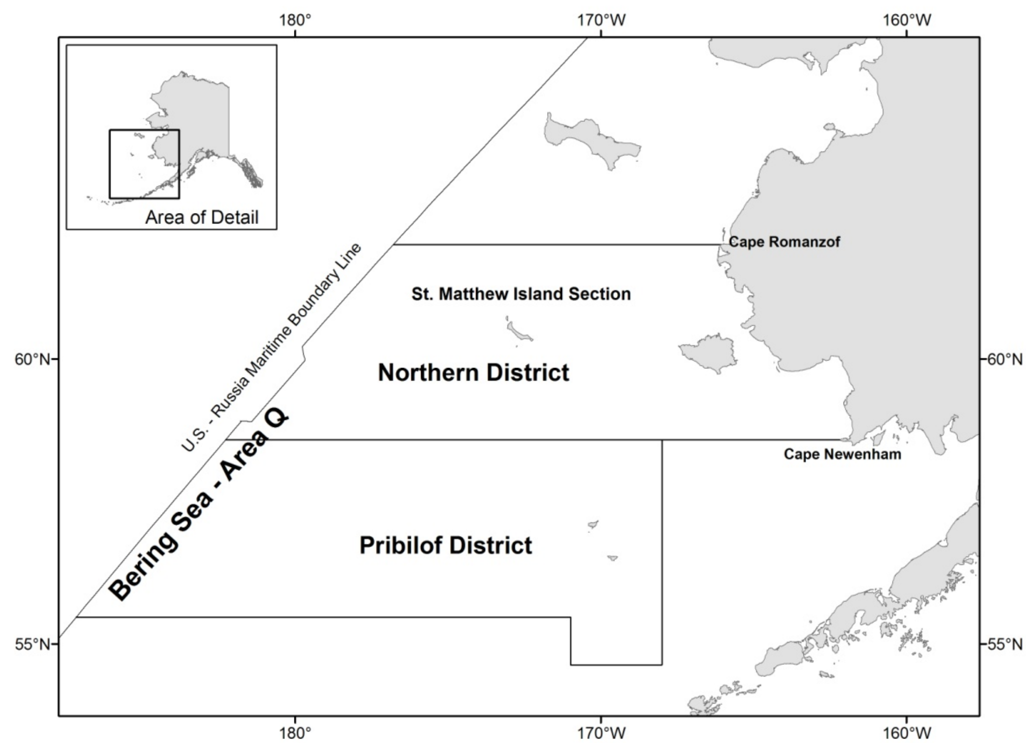

Figure 2: King crab Registration Area Q (Bering Sea).

(Pengilly and Schmidt 1995). Otto and Cummiskey (1990) report an average growth increment of 14.1 mm CL for adult SMBKC males.

Management History

The SMBKC fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990). Ten U.S. vessels harvested 545 t (1.202 million pounds) in 1977, and harvests peaked in 1983 when 164 vessels landed 4288 t (9.454 million pounds) (Fitch et al. 2012; Table 4).

Table 4: The 1978/79 to 2015/16 directed St. Matthew Island blue king crab pot fishery. The Guideline Harvest Level (GHL) and Total Allowable Catch (TAC) are in millions of pounds. Harvest includes deadloss. Catch per unit effort (CPUE) in this table is simply the harvest number / pot lifts. The average weight is the harvest weight / harvest number in pounds. The average CL is the average of retained crab in mm from dockside sampling of delivered crab. Source: Fitch et al 2012; ADF&G Dutch Harbor staff, pers. comm. Note that management (GHL) units are in pounds, for conserving space, convertion to tons is ommitted.

			Harvest					
Year	Dates	GHL/TAC	Crab	Pounds	Pot lifts	CPUE	avg wt	avg CL
1978/79	07/15 - 09/03		436,126	1,984,251	43,754	10	4.5	132.2
1979/80	07/15 - 08/24		52,966	210,819	9,877	5	4.0	128.8
1980/81	07/15 - 09/03			CONFIDENTIAL				
1981/82	07/15 - 08/21		1,045,619	4,627,761	58,550	18	4.4	NA
1982/83	08/01 - 08/16		1,935,886	8,844,789	165,618	12	4.6	135.1
1983/84	08/20 - 09/06	8.0	1,931,990	9,454,323	133,944	14	4.9	137.2
1984/85	09/01 - 09/08	2.0-4.0	841,017	3,764,592	73,320	11	4.5	135.5
1985/86	09/01 - 09/06	0.9-1.9	436,021	2,175,087	46,988	9	5.0	139.0
1986/87	09/01 - 09/06	0.2-0.5	219,548	1,003,162	22,073	10	4.6	134.3
1987/88	09/01 - 09/05	0.6-1.3	227,447	1,039,779	28,230	8	4.6	134.1
1988/89	09/01 - 09/05	0.7-1.5	280,401	1,236,462	21,678	13	4.4	133.3
1989/90	09/01 - 09/04	1.7	247,641	1,166,258	30,803	8	4.7	134.6
1990/91	09/01 - 09/07	1.9	391,405	1,725,349	26,264	15	4.4	134.3
1991/92	09/16 - 09/20	3.2	726,519	3,372,066	37,104	20	4.6	134.1
1992/93	09/04 - 09/07	3.1	545,222	2,475,916	56,630	10	4.5	134.1
1993/94	09/15 - 09/21	4.4	630,353	3,003,089	58,647	11	4.8	135.4
1994/95	09/15 - 09/22	3.0	827,015	3,764,262	60,860	14	4.9	133.3
1995/96	09/15 - 09/20	2.4	666,905	3,166,093	48,560	14	4.7	135.0
1996/97	09/15 - 09/23	4.3	660,665	3,078,959	91,085	7	4.7	134.6
1997/98	09/15 - 09/22	5.0	939,822	4,649,660	81,117	12	4.9	139.5
1998/99	09/15 - 09/26	4.0	635,370	2,968,573	91,826	7	4.7	135.8
1999/00 - 2008/09				FISHERY CLOSED				
2009/10	10/15 - 02/01	1.17	103,376	460,859	10,697	10	4.5	134.9
2010/11	10/15 - 02/01	1.60	298,669	1,263,982	29,344	10	4.2	129.3
2011/12	10/15 - 02/01	2.54	437,862	1,881,322	48,554	9	4.3	130.0
2012/13	10/15 - 02/01	1.63	379,386	1,616,054	37,065	10	4.3	129.8
2013/14				FISHERY CLOSED				
2014/15	10/15 - 02/05	0.66	69,109	308,582	10,133	7	4.5	132.3
2015/16	10/19 - 11/28	0.41	24,076	105,010	5,475	4	4.4	132.6
2016/17				FISHERY CLOSED				

The fishing seasons were generally short, often lasting only a few days. The fishery was declared overfished and closed in 1999 when the stock biomass estimate was below the minimum stock-size threshold (MSST) of 4,990 t (11.0 million pounds) as defined by the Fishery Management Plan (FMP) for the Bering Sea/Aleutian Islands King and Tanner crabs (NPFMC 1999). Zheng and Kruse (2002) hypothesized a high level of SMBKC natural mortality from 1998 to 1999 as an explanation for the low catch per unit effort (CPUE) in the 1998/99 commercial fishery and the low numbers across all male crab size groups caught in the annual NMFS eastern Bering Sea trawl survey from 1999 to 2005 (see survey data in next section). In November 2000, Amendment 15 to the FMP for Bering Sea/Aleutian Islands king and Tanner crabs was approved to implement a rebuilding plan for the SMBKC stock (NPFMC 2000). The rebuilding plan included a regulatory harvest strategy (5 AAC 34.917), area closures, and gear modifications. In addition, commercial crab fisheries near St. Matthew Island were scheduled in fall and early winter to reduce the potential for bycatch mortality of vulnerable molting and mating crab.

NMFS declared the stock rebuilt on 21 September 2009, and the fishery was reopened after a 10-year closure on 15 October 2009 with a TAC of 529 t (1.167 million pounds), closing again by regulation on 1 February 2010. Seven participating vessels landed a catch of 209 t (460,859 pounds) with a reported effort of 10,697 pot lifts and an estimated CPUE of 9.9 retained individual crab per pot lift. The fishery remained open the next three years with modest harvests and similar CPUE, but large declines in the NMFS trawl-survey estimate of stock abundance raised concerns about the health of the stock. This prompted ADF&G to close the fishery again for the 2013/14 season. The fishery was reopened for the 2014/15 season with a low TAC of 297 t (0.655 million pounds) and in 2015/16 the TAC was further reduced to 186 t (0.411 million pounds) then completely closed during the 2016/17 season.

Although historical observer data are limited due to low sampling effort, bycatch of female and sublegal male crab from the directed blue king crab fishery off St. Matthew Island was relatively high historically, with estimated total bycatch in terms of number of crab captured sometimes more than twice as high as the catch of legal crab (Moore et al. 2000; ADF&G Crab Observer Database). Pot-lift sampling by ADF&G crab observers (Gaeuman 2013; ADF&G Crab Observer Database) indicates similar bycatch rates of discarded male crab since the reopening of the fishery (Table 5), with total male discard mortality in the 2012/13 directed fishery estimated at about 12% (88 t or 0.193 million pounds) of the reported retained catch weight, assuming 20% handling mortality.

These data suggest a reduction in the bycatch of females, which may be attributable to the later timing of the contemporary fishery and the more offshore distribution of fishery effort since reopening in 2009/10[3]. Some bycatch of discarded blue king crab has also been observed historically in the eastern Bering Sea snow crab fishery, but in recent years it has generally been negligible. The St. Matthew Island golden king crab fishery, the third commercial crab fishery to have taken place in the area, typically occurred in areas with depths exceeding blue king crab distribution. NMFS observer data suggest that variable but mostly limited SMBKC bycatch has also occurred in the eastern Bering Sea groundfish fisheries (Table 6).

D. Data

Summary of New Information

Data used in this assessment were updated to include the most recently available fishery and survey numbers. This assessment makes use of two new survey data points including the 2017 NMFS trawl-survey estimate of abudance, and the 2017 ADF&G pot survey CPUE. Both of these surveys have associated size compositon data. The assessment also uses updated 1993-2016 groundfish and fixed gear bycatch estimates based on AKRO data. The fishery was closed in 2016/17 so no directed fishery catch data were available. The data used in each of the new models is shown in Figure 3.

Major Data Sources

Major data sources used in this assessment include annual directed-fishery retained-catch statistics from fish tickets (1978/79-1998/99, 2009/10-2012/13, and 2014/15-2015/16; Table 4); results from the annual

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

Table 5: Observed proportion of crab by size class during the ADF&G crab observer pot-lift sampling. Source: ADF&G Crab Observer Database.

Year	Total pot lifts	Pot lifts sampled	Number of crab (90 mm+ CL)	Stage 1	Stage 2	Stage 3
1990/91	26,264	10	150	0.113	0.393	0.493
1991/92	37,104	125	3,393	0.133	0.177	0.690
1992/93	56,630	71	1,606	0.191	0.268	0.542
1993/94	58,647	84	2,241	0.281	0.210	0.510
1994/95	60,860	203	4,735	0.294	0.271	0.434
1995/96	48,560	47	663	0.148	0.212	0.640
1996/97	91,085	96	489	0.160	0.223	0.618
1997/98	81,117	133	3,195	0.182	0.205	0.613
1998/99	91,826	135	1.322	0.193	0.216	0.591
1999/00 - 2008/09			FISHERY CLOSED			
2009/10	10,484	989	19,802	0.141	0.324	0.535
2010/11	29,356	2,419	45,466	0.131	0.315	0.553
2011/12	48,554	3,359	58,666	0.131	0.305	0.564
2012/13	37,065	2,841	57,298	0.141	0.318	0.541
2013/14			FISHERY CLOSED			
2014/15	10,133	895	9,906	0.094	0.228	0.679
2015/16	5,475	419	3,248	0.115	0.252	0.633
2016/17			FISHERY CLOSED			

NMFS eastern Bering Sea trawl survey (1978-2017; Table 8); results from the ADF&G SMBKC pot survey (every third year during 1995-2013, then 2015-2017; Table 7); size-frequency information from ADF&G crab-observer pot-lift sampling (1990/91-1998/99, 2009/10-2012/13, and 2014/15-2016/17; Table 5); and NMFS groundfish-observer bycatch biomass estimates (1992/93-2016/17; Table 6).

Figure 4 maps stations from which SMBKC trawl-survey and pot-survey data were obtained. Further information concerning the NMFS trawl survey as it relates to commercial crab species is available in Daly et al. (2014); see Gish et al. (2012) for a description of ADF&G SMBKC pot-survey methods. It should be noted that the two surveys cover different geographic regions and that each has in some years encountered proportionally large numbers of male blue king crab in areas not covered by the other survey (Figure 5). Crab-observer sampling protocols are detailed in the crab-observer training manual (ADF&G 2013). Groundfish SMBKC bycatch data come from NMFS Bering Sea reporting areas 521 and 524 (Figure 6).

Other Data Sources

The growth transition matrix used is based on Otto and Cummiskey (1990), as in the past. Other relevant data sources, including assumed population and fishery parameters, are presented in Appendix A, which also provides a detailed description of the model configuration used for this assessment.

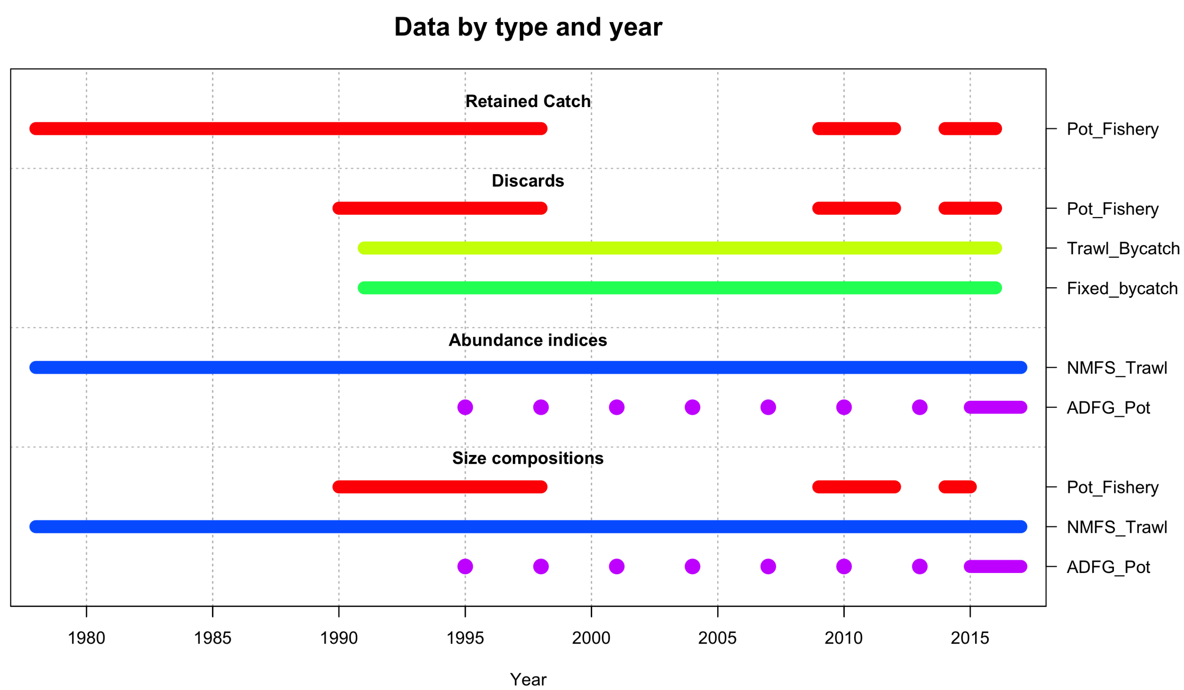

Figure 3: Data extent for the SMBKC assessment (with the 2017 Pot survey included).

Table 6: Groundfish SMBKC male bycatch biomass (t) estimates. Trawl includes pelagic trawl and non-pelagic trawl types. Source: J. Zheng, ADF&G, and author estimates based on data from R. Foy, NMFS. Estimates used after 2008/09 are from NMFS Alaska Regional Office.

Year	Trawl bycatch	Fixed gear bycatch
1978	0.000	0.000
1979	0.000	0.000
1980	0.000	0.000
1981	0.000	0.000
1982	0.000	0.000
1983	0.000	0.000
1984	0.000	0.000
1985	0.000	0.000
1986	0.000	0.000
1987	0.000	0.000
1988	0.000	0.000
1989	0.000	0.000
1990	0.000	0.000
1991	3.538	0.045
1992	1.996	2.268
1993	1.542	0.500
1994	0.318	0.091
1995	0.635	0.136
1996	0.500	0.045
1997	0.500	0.181
1998	0.500	0.907
1999	0.500	1.361
2000	0.500	0.500
2001	0.500	0.862
2002	0.726	0.408
2003	0.998	1.134
2004	0.091	0.635
2005	0.500	0.590
2006	2.812	1.451
2007	0.045	69.717
2008	0.272	6.622
2009	0.635	7.530
2010	0.363	9.571
2011	0.181	1.800
2012	0.100	1.600
2013	0.400	0.800
2014	0.100	1.100
2015	0.100	1.600
2016	0.500	3.600

Table 7: Size-class and total CPUE (90+ mm CL) with estimated CV and total number of captured crab (90+ mm CL) from the 96 common stations surveyed during the ADF&G SMBKC pot surveys. Source: ADF&G.

Year	Stage-1 (90-104 mm)	Stage-2 (105-119 mm)	Stage-3 (120+ mm)	Total CPUE	CV	Number of crabs
1995	1.919	3.198	6.922	12.042	0.13	4624
1998	0.964	2.763	8.804	12.531	0.06	4812
2001	1.266	1.737	5.487	8.477	0.08	3255
2004	0.112	0.414	1.141	1.667	0.15	640
2007	1.086	2.721	4.836	8.643	0.09	3319
2010	1.326	3.276	5.607	10.209	0.13	3920
2013	0.878	1.398	3.367	5.643	0.19	2167
2015	0.198	0.682	1.924	2.805	0.18	1077
2016	0.198	0.456	1.724	2.378	0.19	777
2017	0.177	0.429	1.083	1.689	0.25	643

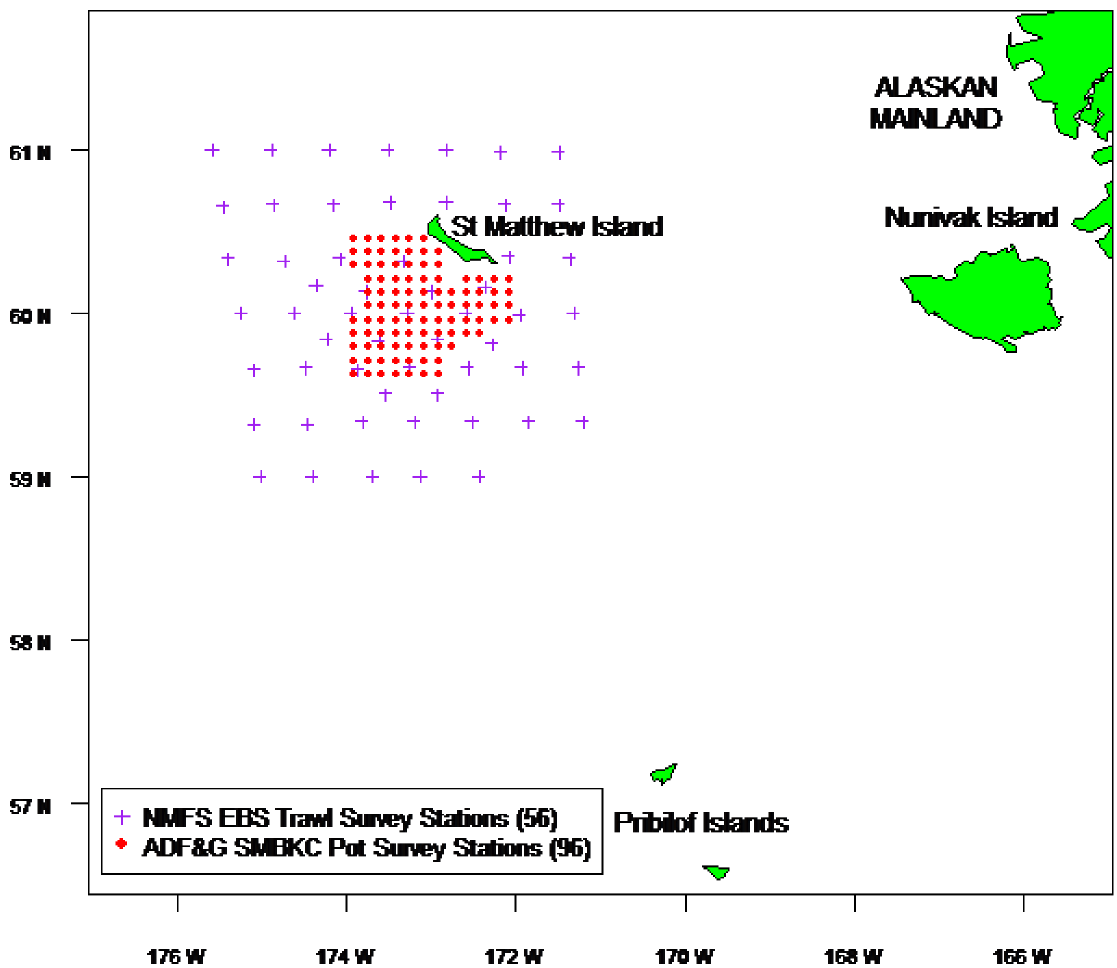

Figure 4: Trawl and pot-survey stations used in the SMBKC stock assessment.

Table 8: 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 also given. Source: R. Foy, NMFS. The "+" refer to plus group.

	Abundance					Biomass		
Year	Stage-1 (90-104 mm)	Stage-2 (105-119 mm)	Stage-3 (120+ mm)	Total	CV	Total (90+ mm CL)	CV	Number of crabs
1978	2.213	1.991	1.521	5.726	0.411	15.064	0.394	157
1979	3.061	2.281	1.808	7.150	0.472	17.615	0.463	178
1980	2.856	2.563	2.541	7.959	0.572	22.017	0.507	185
1981	0.483	1.213	2.263	3.960	0.368	14.443	0.402	140
1982	1.669	2.431	5.884	9.984	0.401	35.763	0.344	271
1983	1.061	1.651	3.345	6.057	0.332	21.240	0.298	231
1984	0.435	0.497	1.452	2.383	0.175	8.976	0.179	105
1985	0.379	0.376	1.117	1.872	0.216	6.858	0.210	93
1986	0.203	0.447	0.374	1.025	0.428	3.124	0.388	46
1987	0.325	0.631	0.715	1.671	0.302	5.024	0.291	71
1988	0.410	0.816	0.957	2.183	0.285	6.963	0.252	81
1989	2.169	1.154	1.786	5.109	0.314	13.974	0.271	208
1990	1.053	1.031	2.338	4.422	0.302	14.837	0.274	170
1991	1.147	1.665	2.233	5.046	0.259	15.318	0.248	197
1992	1.074	1.382	2.291	4.746	0.206	15.638	0.201	220
1993	1.521	1.828	3.276	6.626	0.185	21.051	0.169	324
1994	0.883	1.298	2.257	4.438	0.187	14.416	0.176	211
1995	1.025	1.188	1.741	3.953	0.187	12.574	0.178	178
1996	1.238	1.891	3.064	6.193	0.263	20.746	0.241	285
1997	1.165	2.228	3.789	7.182	0.367	24.084	0.337	296
1998	0.660	1.661	2.849	5.170	0.373	17.586	0.355	243
1998	0.223	0.222	0.558	1.003	0.192	3.515	0.182	52
2000	0.282	0.285	0.740	1.307	0.303	4.623	0.310	61
2001	0.419	0.502	0.938	1.859	0.243	6.242	0.245	91
2002	0.111	0.230	0.640	0.981	0.311	3.820	0.320	38
2003	0.449	0.280	0.465	1.194	0.399	3.454	0.336	65
2004	0.247	0.184	0.562	0.993	0.369	3.360	0.305	48
2005	0.319	0.310	0.501	1.130	0.403	3.620	0.371	42
2006	0.917	0.642	1.240	2.798	0.339	8.585	0.334	126
2007	2.518	2.020	1.193	5.730	0.420	14.266	0.385	250
2008	1.352	0.801	1.457	3.609	0.289	10.261	0.284	167
2009	1.573	2.161	1.410	5.144	0.263	13.892	0.256	251
2010	3.937	3.253	2.458	9.648	0.544	24.539	0.466	388
2011	1.800	3.255	3.207	8.263	0.587	24.099	0.558	318
2012	0.705	1.970	1.808	4.483	0.361	13.669	0.339	193
2013	0.335	0.452	0.807	1.593	0.215	5.043	0.217	74
2014	0.723	1.627	1.809	4.160	0.503	13.292	0.449	181
2015	0.992	1.269	1.979	4.240	0.774	12.958	0.770	153
2016	0.535	0.660	1.178	2.373	0.447	7.685	0.393	108
2017	0.091	0.323	0.663	1.077	0.657	3.955	0.600	42

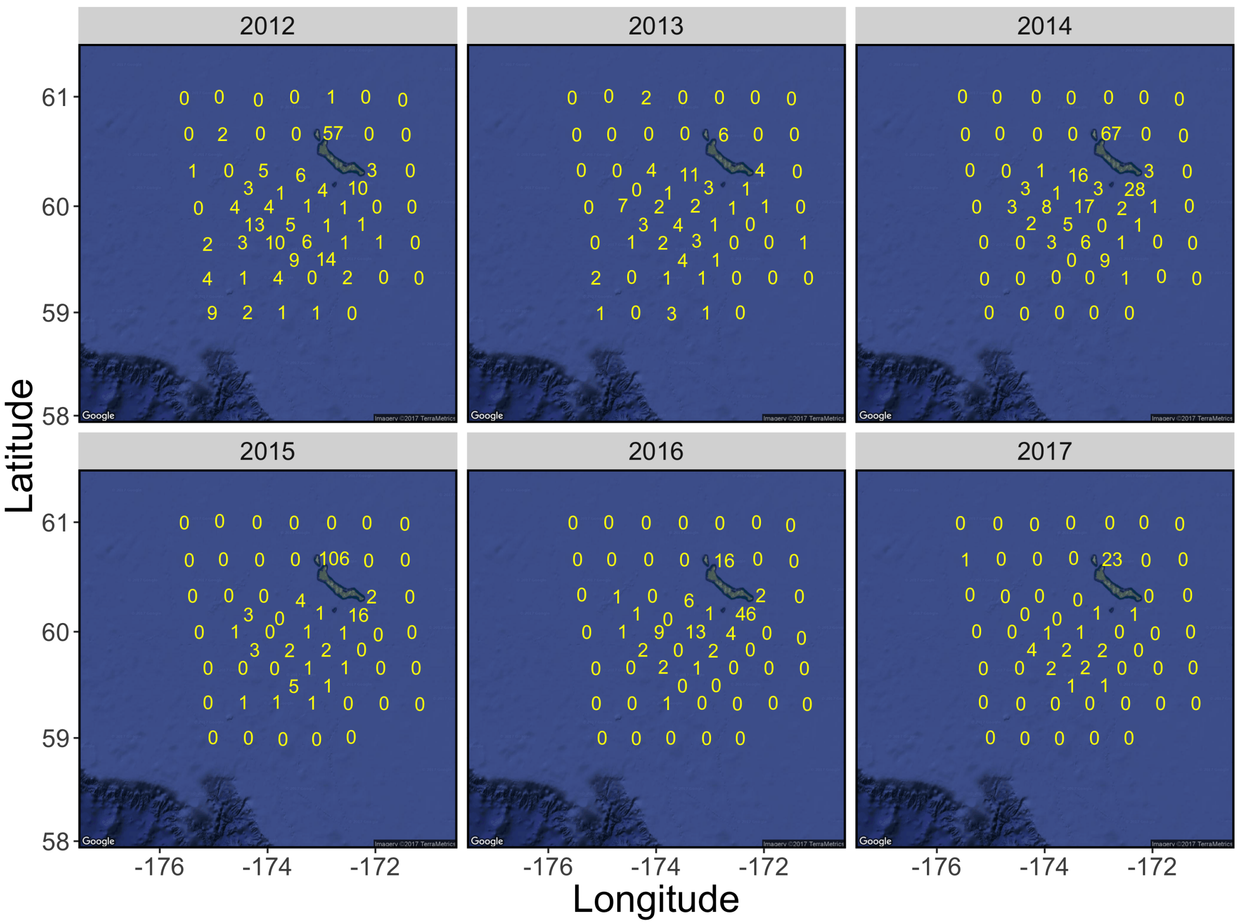

Figure 5: Catches (in numbers) of male blue king crab measuring at least 90 mm CL from the 2012-2017 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock. Note that the area north of St. Matthew Island, which often shows large catches crab at station R-24 is not covered in the ADF&G pot-survey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

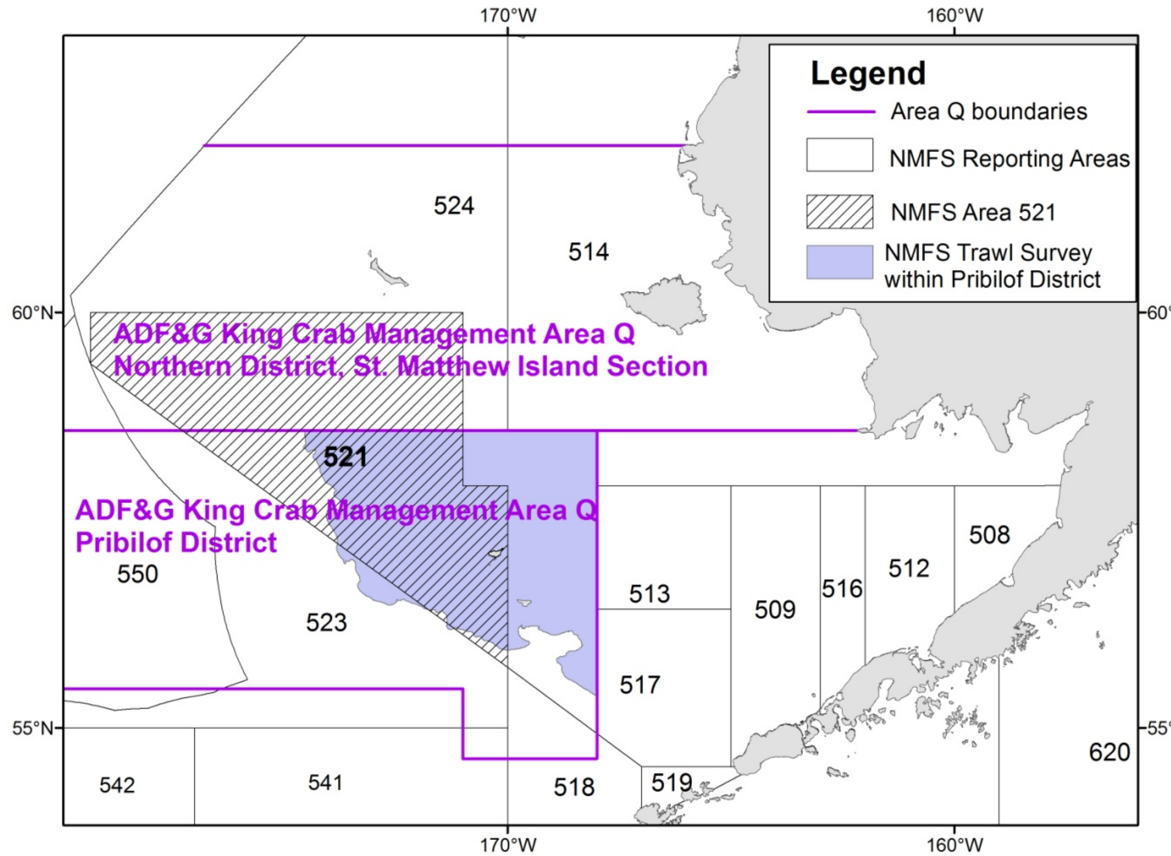

Figure 6: NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.

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. Subsequently the model developed and used since 2012, was a variant of the previous four-stage SMBKC CSA model and similar in complexity to that described by Collie et al. (2005). Like the earlier model, it considered only male crab 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.

In 2016 the accepted SMBKC assessment model made use of the modeling framework Gmacs (Webber et al. 2016). In that assessment, an effort to match the 2015 SMBKC stock assessment model to bridge a framework which provided greater flexibility and opportunity to evaluate model assumptions more fully.

Assessment Methodology

This assessment model again uses the modeling framework Gmacs and is detailed in Appendix A.

Model Selection and Evaluation

Five models were presented in the previous assessment. This year, four models are presented with the reference model being the same configuration as last year, three sensitivities are considered, one with a different treatment of NMFS bottom trawl survey (BTS) data using a geo-spatial model (VAST; Thorson and Barnett 2017), another which weights the survey data more heavily, and a third which weights the size composition data according to Francis' 2011 approach. In addition to these sensitivities, we also evaluated the impact of adding new data to the reference model. In summary, the following lists the models presented and the naming convention used:

1. **2016 Model**: the 2016 recommended model without any new data
2. **BTS**: adds in the 2017 bottom trawl survey (BTS) data
3. **BTS and pot**: as with previous but including the 2017 ADFG pot survey data (Model 16.0 or “reference case”)

4. **VAST**: applies a geo-spatial delta-GLMM model (Thorson and Barnett 2017) to the BTS data which provides a different BTS index. See appendix B for details and diagnostics. This is a preliminary examination as more work is needed to ensure options for the BTS CPUE data were specified appropriately.

5. **Fit survey**: an exploratory scenario that's the same as the reference model except the NMFS trawl survey is up-weighted by $\lambda^{\text{NMFS}} = 1.5$ and the ADF&G pot survey is up-weighted by $\lambda^{\text{ADFG}} = 2$.

6. **Francis weights**: is similar to the reference model except that it also uses the Francis iterative re-weighting method (Francis 2011), to re-weight the size-composition data relative to the abundance indices. The trawl survey and pot survey weights were unchanged. In this scenario the multinomial distribution was used instead as the theory underpinning the Francis weighting method is based on this distribution.

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

Results

a. Sensitivity to new data

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

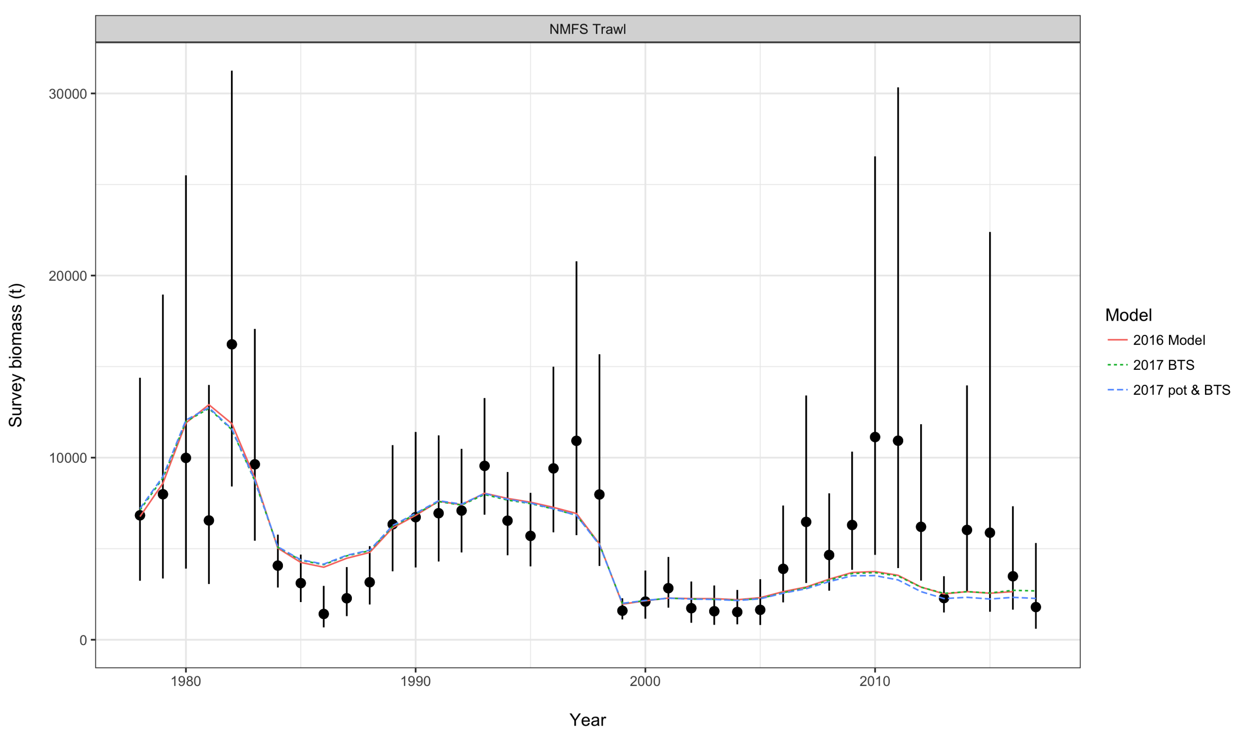

Figure 7: Fits to NMFS area-swept trawl estimates of total (>90mm) male survey biomass with the addition of new data. Error bars are plus and minus 2 standard deviations.

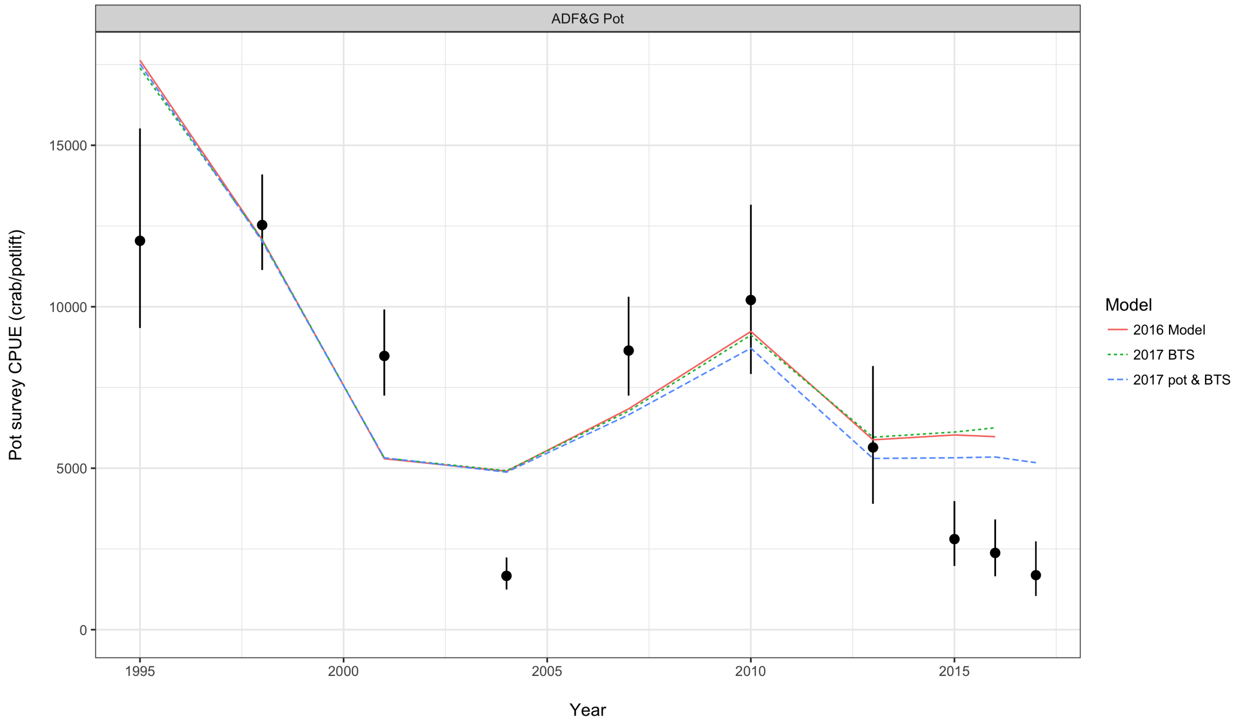

Figure 8: Comparisons of fits to CPUE from the ADF&G pot surveys with the addition of new data. Error bars are plus and minus 2 standard deviations.

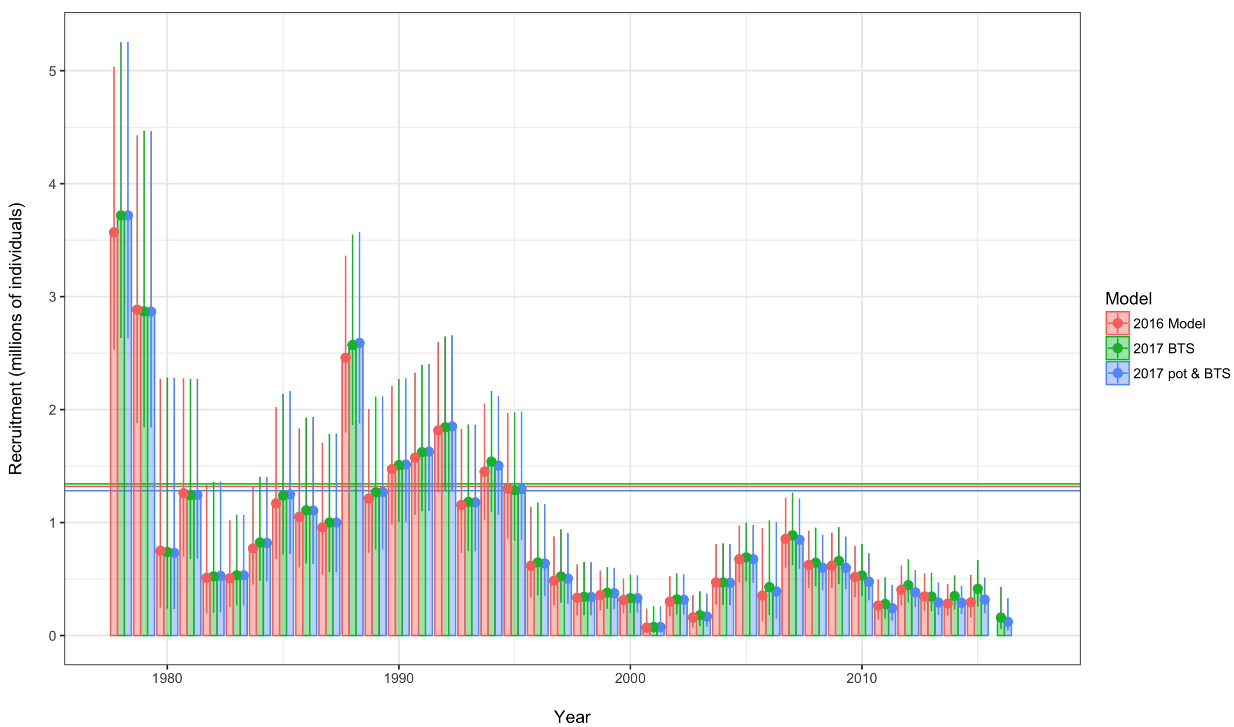

Figure 9: Sensitivity of new data in 2017 on estimated recruitment ; 1978-2017.

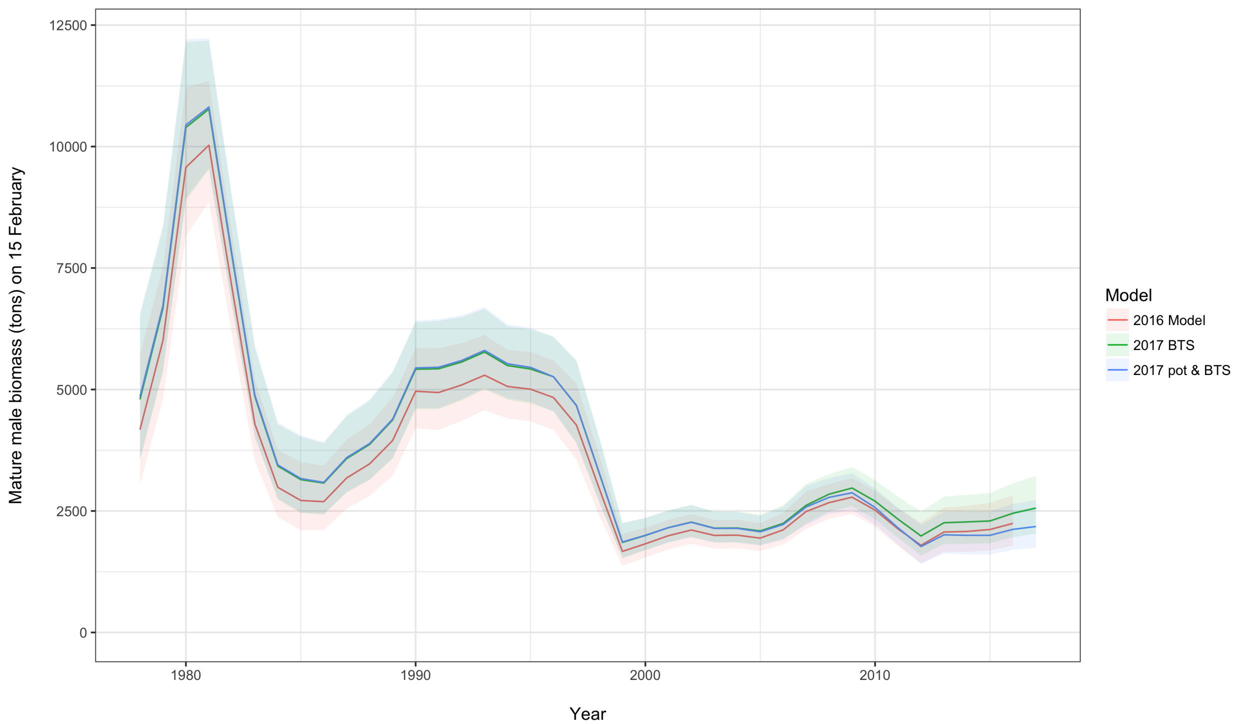

Figure 10: Sensitivity of new data in 2017 on estimated mature male biomass (MMB); 1978-2017.

b. Alternative NMFS bottom-trawl survey index

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

c. Effective sample sizes and weighting factors

Observed and estimated effective sample sizes are compared in Table 11. Effective sample sizes are also shown on size-composition plots (Figures 18, 19, and 20).

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

d. Parameter estimates

Model parameter estimates for each of the Gmacs scenarios are summarized in Tables 12, 13, 15, and 16. These parameter estimates are compared in Table 16. Negative log-likelihood values and management measures for each of the model configurations are compared in Tables 9 through 18.

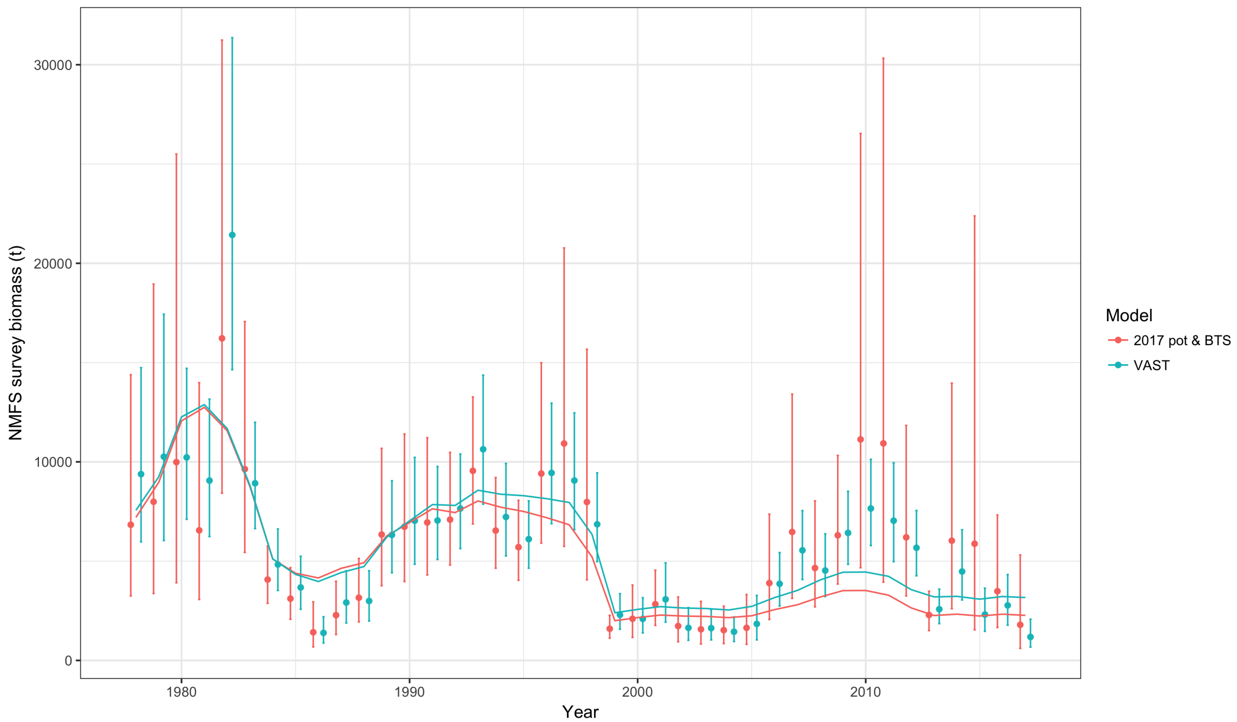

Figure 11: Comparisons of fits to area-swept estimates of total (>90mm) male survey biomass (t) for the standard design-based estimate and for estimates derived from the VAST spatio-temporal model of Thorson and Barnett (2017). Error bars are plus and minus 2 standard deviations.

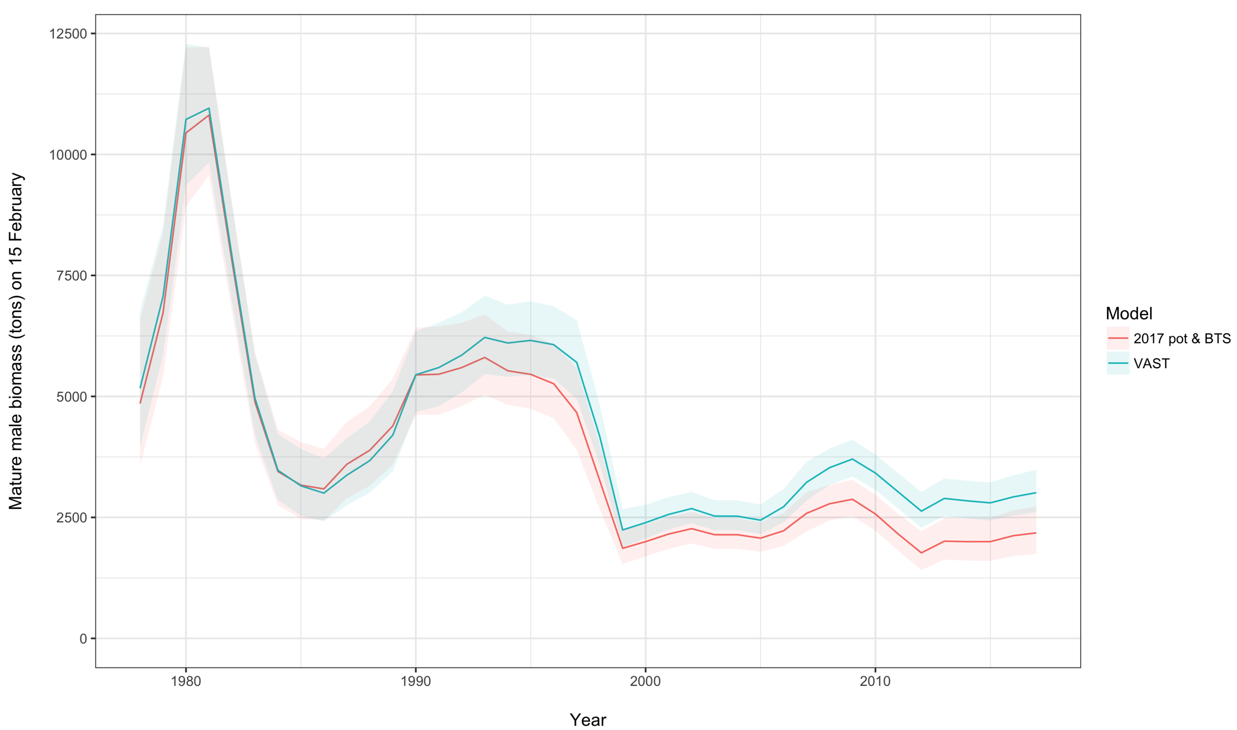

Figure 12: Sensitivity of new data in 2017 on estimated mature male biomass (MMB); 1978-2017 comparing the reference model with that fitted to the VAST BTS estimates.

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

c. Graphs of estimates.

Selectivity estimates show some variability between models (Figure 13). Estimated recruitment is variable over time for all models and in recent years is well below average (Figure 24). Estimated mature male biomass on 15 February also fluctuates considerably (Figure 25). Estimated natural mortality each year (M_t) is presented in Figure 29.

d. Evaluation of the fit to the data.

The model fits to total male (> 89 mm CL) trawl survey biomass tend to miss the recent peak around 2010 and is slightly above the 2017 value for the key sensitivities (Figures 14). All of the models fit the pot survey CPUE poorly (Figure 15. For both surveys the standardized residuals tend to have similar patterns with some improvement (generally) for the VAST model (Figures 16 and 17).

Fits to the size compositions for trawl survey, pot survey, and commercial observer data are reasonable (Figures 18, 19, and 20) for all scenarios. Representative residual plots of the composition data fits are generally poor (Figures 21 and 22). The model fits to different types of retained and discarded catch values performed as expected given the assumed levels of uncertainty on the input data (Figure 23).

The contrast between the reference model and the "Francis weighted" model show minor differences (Figures 14 and 15). Unsurprisingly, the **fit surveys** model configuration fits the the NMFS survey biomass and ADF&G pot survey CPUE data better but still has a similar residual pattern (note that that this scenario was only included for exploratory purposes and forcing these weights resulted in worse SDNR and MAR values for the two abundance indices).

e. Retrospective and historic analyses.

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

f. Uncertainty and sensitivity analyses.

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

g. Comparison of alternative model scenarios.

The estimates of mature male biomass (Figure 25), for the **fit surveys** sensitivity stands out as being quite different to the other models due to a low value for pot survey catchability being estimated (which tends to scale the population). This scenario results in a lower MMB from the mid-1980s through to the late-1990s, and is again lower in the most recent 5 years. This scenario upweights both the trawl survey and the pot survey abundance indices (it upweights the pot survey more than the trawl survey) and represents a model run that places greater trust in the abundance indices, particularly the pot survey, than other data sources.

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

F. Calculation of the OFL and ABC

The overfishing level (OFL) is the fishery-related mortality biomass associated with fishing mortality F_{OFL}. The SMBKC stock is currently managed as Tier 4 (2013 SAFE), and only a Tier 4 analysis is presented here. Thus given stock estimates or suitable proxy values of B_{MSY} and F_{MSY}, along with two additional parameters α and β, F_{OFL} is determined by the control rule

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

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 2017 for all scenarios are summarized in Table 9. ABC is 80% of the OFL.

Table 9: Comparisons of management measures for the four model scenarios. Biomass and OFL are in tons.

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

G. Rebuilding Analysis

This stock is not currently subject to a rebuilding plan.

H. Data Gaps and Research Priorities

The following topics have been listed as areas where more research on SMBKC is needed:

1. Growth increments and molting probabilities as a function of size.

2. Trawl survey catchability and selectivities.
3. Temporal changes in spatial distributions near the island.
4. Natural mortality.

I. Projections and Future Outlook

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

J. Acknowledgements

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.

K. References

Alaska Department of Fish and Game (ADF&G). 2013. Crab observer training and deployment manual. Alaska Department of Fish and Game Shellfish Observer Program, Dutch Harbor. Unpublished.

Collie, J.S., A.K. Delong, and G.H. Kruse. 2005. Three-stage catch-survey analysis applied to blue king crabs. Pages 683-714 [In] Fisheries assessment and management in data-limited situations. University of Alaska Fairbanks, Alaska Sea Grant Report 05-02, Fairbanks.

Daly, B., R. Foy, and C. Armistead. 2014. The 2013 eastern Bering Sea continental shelf bottom trawl survey: results for commercial crab species. NOAA Technical Memorandum, NMFS-AFSC.

Donaldson, W.E., and S.C. Byersdorfer. 2005. Biological field techniques for lithodid crabs. University of Alaska Fairbanks, Alaska Sea Grant Report 05-03, Fairbanks.

Fitch, H., M. Deiman, J. Shaishnikoff, and K. Herring. 2012. Annual management report for the commercial and subsistence shellfish fisheries of the Bering Sea, 2010/11. Pages 75-1776 [In] Fitch, H., M. Schwenzfeier, B. Baechler, T. Hartill, M. Salmon, M. Deiman, E.

Evans, E. Henry, L. Wald, J. Shaishnikoff, K. Herring, and J. Wilson. 2012. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the Westward Region's Shellfish Observer Program, 2010/11. Alaska Department of Fish and Game, Fishery Management Report No. 12-22, Anchorage.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optim. Methods Softw. 27:233-249.

Francis, R.I.C.C. 2011. Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68: 1124-1138.

Gaeuman, W.B. 2013. Summary of the 2012/13 mandatory crab observer program database for the Bering Sea/Aleutian Islands commercial crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 13-54, Anchorage.

Gish, R.K., V.A. Vanek, and D. Pengilly. 2012. Results of the 2010 triennial St. Matthew Island blue king crab pot survey and 2010/11 tagging study. Alaska Department of Fish and Game, Fishery Management Report No. 12-24, Anchorage.

Jensen, G.C. and D.A. Armstrong. 1989. Biennial reproductive cycle of blue king crab, Paralithodes platypus, at the Pribilof Islands, Alaska and comparison to a congener, P. camtschatica. Can. J. Fish. Aquat. Sci. 46: 932-940.

Moore, H., L.C. Byrne, and D. Connolly. 2000. Alaska Department of Fish and Game summary of the 1998 mandatory shellfish observer program database. Alaska Dept. Fish and Game, Commercial Fisheries Division, Reg. Inf. Rep. 4J00-21, Kodiak.

North Pacific Fishery Management Council (NPFMC). 1998. Fishery Management Plan for Bering Sea/Aleutian Islands king and Tanner crabs. North Pacific Fishery Management Council, Anchorage.

North Pacific Fishery Management Council (NPFMC). 1999. Environmental assessment/regulatory impact review/initial regulatory flexibility analysis for Amendment 11 to the Fishery Management Plan for Bering Sea/Aleutian Islands king and Tanner crabs. North Pacific Fishery Management Council, Anchorage.

North Pacific Fishery Management Council (NPFMC). 2000. Environmental assessment/regulatory impact review/initial regulatory flexibility analysis for proposed Amendment 15 to the Fishery Management Plan for king and Tanner crab fisheries in the Bering Sea/Aleutian Islands and regulatory amendment to the Fishery Management Plan for the groundfish fishery of the Bering Sea and Aleutian Islands area: A rebuilding plan for the St. Matthew blue king crab stock. North Pacific Fishery Management Council, Anchorage. Draft report.

North Pacific Fishery Management Council (NPFMC). 2007. Public Review Draft: Environmental assessment for proposed Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands king and Tanner crabs to revise overfishing definitions. 14 November 2007. North Pacific Fishery Management Council, Anchorage.

Otto, R.S. 1990. An overview of eastern Bering Sea king and Tanner crab fisheries. Pages 9-26 [In] Proceedings of the international symposium on king and Tanner crabs. University of Alaska Fairbanks, Alaska Sea Grant Program Report 90-4, Fairbanks.

Otto, R.S., and P.A. Cummiskey. 1990. Growth of adult male blue king crab (Paralithodes platypus). Pages 245-258 [In] Proceedings of the international symposium on king and Tanner crabs. University of Alaska Fairbanks, Alaska Sea Grant Report 90-4, Fairbanks.

Paul, J.M., A. J. Paul, R.S. Otto, and R.A. MacIntosh. 1991. Spermatophore presence in relation to carapace length for eastern Bering Sea blue king crab (Paralithodes platypus, Brandt, 1850) and red king crab (P. Camtschaticus, Tilesius, 1815). J. Shellfish Res. 10: 157-163.

Pengilly, D. and D. Schmidt. 1995. Harvest Strategy for Kodiak and Bristol Bay Red king Crab and St. Matthew Island and Pribilof Blue King Crab. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Special Publication Number 7, Juneau.

Somerton, D.A., and R.A. MacIntosh. 1983. The size at sexual maturity of blue king crab, Paralithodes platypus, in Alaska. Fishery Bulletin 81: 621-828.

Thorson, J.T., Ianelli, J.N., Larsen, E., Ries, L., Scheuerell, M.D., Szuwalski, C., and Zipkin, E. 2016. Joint dynamic species distribution models: a tool for community ordination and spatiotemporal monitoring. Glob. Ecol. Biogeogr. 25(9): 1144–1158. doi:10.1111/geb.12464. url: http://onlinelibrary.wiley.com/doi/10.1111/geb.12464/abstract.

Thorson, J.T., Scheuerell, M.D., Shelton, A.O., See, K.E., Skaug, H.J., and Kristensen, K. 2015. Spatial factor analysis: a new tool for estimating joint species distributions and correlations in species range. Methods Ecol. Evol. 6(6): 627–637. doi:10.1111/2041-210X.12359. url: http://onlinelibrary.wiley.com/doi/10.1111/2041-210X.12359/abstract

Thorson, J. T., and L. A. K. Barnett. 2017. Comparing estimates of abundance trends and distribution shifts using single- and multispecies models of fishes and biogenic habitat. ICES Journal of Marine Science 75:1311-1321.

Webber, D., J. Zheng, and J. Ianelli, 2016. Stock assessment of Saint Matthews Island Blue King Crab. North Pacific Fishery Managment Council. Anchorage AK.

Zheng, J. 2005. A review of natural mortality estimation for crab stocks: data-limited for every stock? Pages 595-612 [In] Fisheries Assessment and Management in Data-Limited Situations. University of Alaska Fairbanks, Alaska Sea Grant Program Report 05-02, Fairbanks.

Zheng, J., and G.H. Kruse. 2002. Assessment and management of crab stocks under uncertainty of massive die-offs and rapid changes in survey catchability. Pages 367-384 [In] A.J. Paul,E.G. Dawe, R. Elner, G.S. Jamieson, G.H. Kruse, R.S. Otto, B. Sainte-Marie, T.C. Shirley, and D. Woodby (eds.). Crabs in Cold Water Regions: Biology, Management, and Economics. University of Alaska Fairbanks, Alaska Sea Grant Report 02-01, Fairbanks.

Zheng, J., M.C. Murphy, and G.H. Kruse. 1997. Application of catch-survey analysis to blue king crab stocks near Pribilof and St. Matthew Islands. Alaska Fish. Res. Bull. 4:62-74.

Table 10: Mean weight (kg) by stage in used in all of the models (provided as a vector of weights at length each year to Gmacs).

Year	Stage-1	Stage-2	Stage-3
1978	0.7	1.2	1.9
1979	0.7	1.2	1.7
1980	0.7	1.2	1.9
1981	0.7	1.2	1.9
1982	0.7	1.2	1.9
1983	0.7	1.2	2.1
1984	0.7	1.2	1.9
1985	0.7	1.2	2.1
1986	0.7	1.2	1.9
1987	0.7	1.2	1.9
1988	0.7	1.2	1.9
1989	0.7	1.2	2.0
1990	0.7	1.2	1.9
1991	0.7	1.2	2.0
1992	0.7	1.2	1.9
1993	0.7	1.2	2.0
1994	0.7	1.2	1.9
1995	0.7	1.2	2.0
1996	0.7	1.2	2.0
1997	0.7	1.2	2.1
1998	0.7	1.2	2.0
1999	0.7	1.2	1.9
2000	0.7	1.2	1.9
2001	0.7	1.2	1.9
2002	0.7	1.2	1.9
2003	0.7	1.2	1.9
2004	0.7	1.2	1.9
2005	0.7	1.2	1.9
2006	0.7	1.2	1.9
2007	0.7	1.2	1.9
2008	0.7	1.2	1.9
2009	0.7	1.2	1.9
2010	0.7	1.2	1.8
2011	0.7	1.2	1.8
2012	0.7	1.2	1.8
2013	0.7	1.2	1.9
2014	0.7	1.2	1.9
2015	0.7	1.2	1.9
2016	0.7	1.2	1.9
2017	0.7	1.2	1.9

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

	Number measured			Input sample sizes		
Year	Observer pot	NMFS trawl	ADF&G pot	Observer pot	NMFS trawl	ADF&G pot
1978		157			50	
1979		178			50	
1980		185			50	
1981		140			50	
1982		271			50	
1983		231			50	
1984		105			50	
1985		93			46.5	
1986		46			23	
1987		71			35.5	
1988		81			40.5	
1989		208			50	
1990	150	170		15	50	
1991	3393	197		25	50	
1992	1606	220		25	50	
1993	2241	324		25	50	
1994	4735	211		25	50	
1995	663	178	4624	25	50	100
1996	489	285		25	50	
1997	3195	296		25	50	
1998	1323	243	4812	25	50	100
1999		52			26	
2000		61			30.5	
2001		91	3255		45.5	100
2002		38			19	
2003		65			32.5	
2004		48	640		24	100
2005		42			21	
2006		126			50	
2007		250	3319		50	100
2008		167			50	
2009	19802	251		50	50	
2010	45466	388	3920	50	50	100
2011	58667	318		50	50	
2012	57282	193		50	50	
2013		74	2167		37	100
2014	9906	181		50	50	
2015	3248	153	1077	50	50	100
2016		108	777		50	100
2017		42	643		50	100

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

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.652	0.127
$\log(\bar{R})$	14.064	0.060
$\log(n^0_1)$	14.922	0.171
$\log(n^0_2)$	14.551	0.201
$\log(n^0_3)$	14.360	0.206
q_{pot}	3.644	0.280
$\log(\bar{F}^{\mathrm{df}})$	-1.923	0.053
$\log(\bar{F}^{\mathrm{tb}})$	-9.019	0.082
$\log(\bar{F}^{\mathrm{fb}})$	-8.217	0.082
log Stage-1 directed pot selectivity 1978-2008	-0.654	0.174
log Stage-2 directed pot selectivity 1978-2008	-0.315	0.126
log Stage-1 directed pot selectivity 2009-2017	-0.463	0.154
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.243	0.066
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.852	0.127
log Stage-2 ADF&G pot selectivity	-0.026	0.078
F_{OFL}	0.079	0.010
OFL	123.610	28.638

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

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.710	0.108
$\log(\bar{R})$	14.205	0.050
$\log(n^0_1)$	14.952	0.168
$\log(n^0_2)$	14.592	0.193
$\log(n^0_3)$	14.424	0.192
q_{pot}	2.926	0.166
$\log(\bar{F}^{\mathrm{df}})$	-2.037	0.042
$\log(\bar{F}^{\mathrm{tb}})$	-9.220	0.070
$\log(\bar{F}^{\mathrm{fb}})$	-8.419	0.070
log Stage-1 directed pot selectivity 1978-2008	-0.701	0.171
log Stage-2 directed pot selectivity 1978-2008	-0.331	0.124
log Stage-1 directed pot selectivity 2009-2017	-0.319	0.145
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.241	0.062
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.798	0.123
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.103	0.009
OFL	220.400	32.463

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

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	2.160	0.107
$\log(\bar{R})$	14.583	0.065
$\log(n^0_1)$	15.456	0.417
$\log(n^0_2)$	15.288	0.438
$\log(n^0_3)$	15.120	0.418
q_{pot}	1.010	0.052
$\log(\bar{F}^{\text{df}})$	-2.901	0.045
$\log(\bar{F}^{\text{tb}})$	-10.043	0.071
$\log(\bar{F}^{\text{fb}})$	-9.243	0.071
log Stage-1 directed pot selectivity 1978-2008	-0.343	0.141
log Stage-2 directed pot selectivity 1978-2008	-0.082	0.119
log Stage-1 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.000	0.000
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.000	0.000
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.083	0.006
OFL	367.950	44.694

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

Parameter	Estimate	SD
Natural mortality deviation in 1998/99 (δ^M_{1998})	1.634	0.136
$\log(\bar{R})$	14.033	0.064
$\log(n^0_1)$	14.885	0.285
$\log(n^0_2)$	14.561	0.318
$\log(n^0_3)$	14.361	0.317
q_{pot}	3.526	0.248
$\log(\bar{F}^{\text{df}})$	-1.884	0.060
$\log(\bar{F}^{\text{tb}})$	-9.044	0.081
$\log(\bar{F}^{\text{fb}})$	-8.243	0.081
log Stage-1 directed pot selectivity 1978-2008	-0.514	0.157
log Stage-2 directed pot selectivity 1978-2008	-0.319	0.128
log Stage-1 directed pot selectivity 2009-2017	-0.420	0.141
log Stage-2 directed pot selectivity 2009-2017	-0.000	0.000
log Stage-1 NMFS trawl selectivity	-0.181	0.083
log Stage-2 NMFS trawl selectivity	-0.000	0.000
log Stage-1 ADF&G pot selectivity	-0.799	0.092
log Stage-2 ADF&G pot selectivity	-0.000	0.000
F_{OFL}	0.076	0.010
OFL	117.650	26.963

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

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

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

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

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

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

Table 19: Population abundances ($\boldsymbol{n}$) by crab stage in numbers of crab at the time of the survey and mature male biomass (MMB) in tons on 15 February for the **2016 model**.

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

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

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

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

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

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

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

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

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

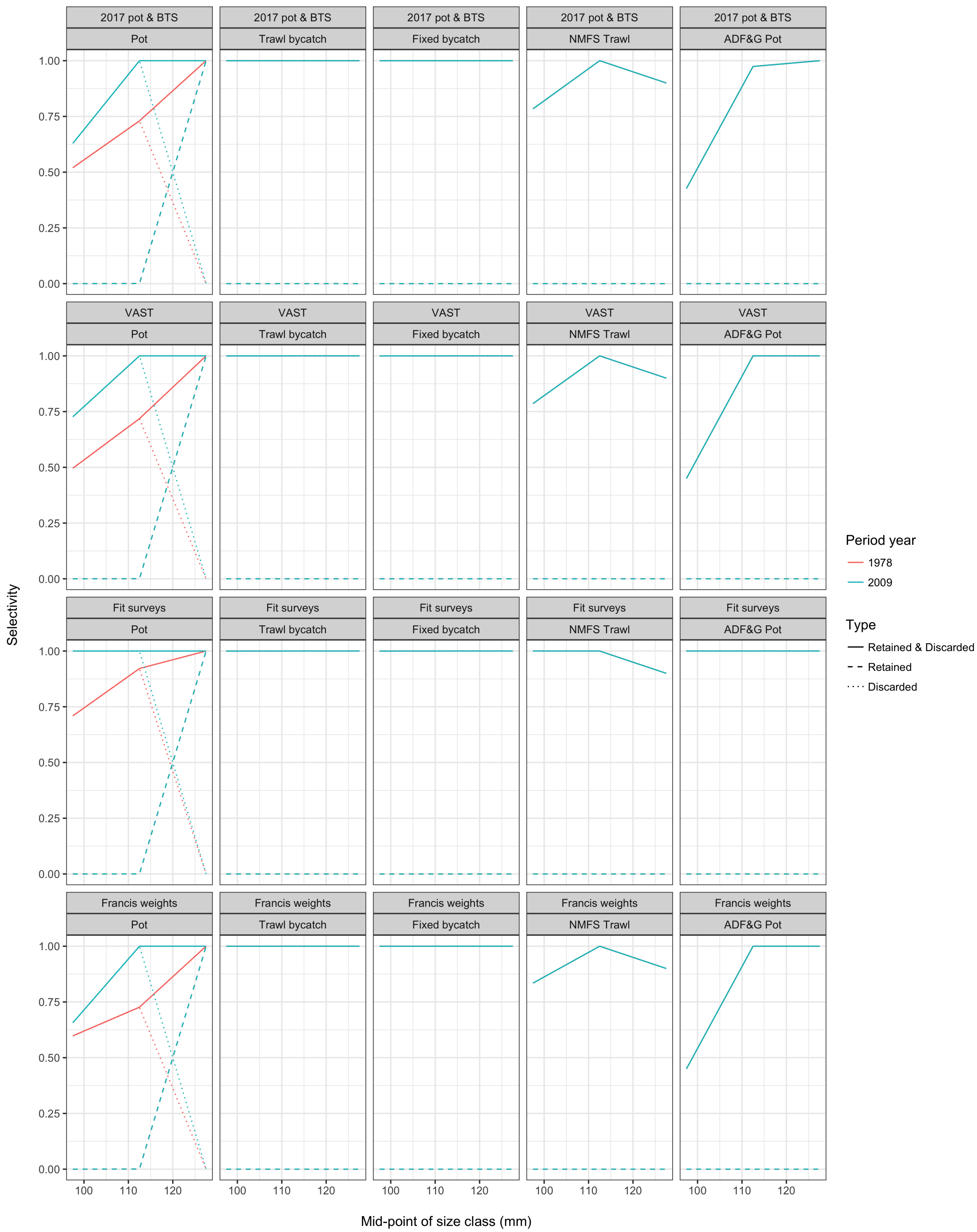

Figure 13: Comparisons of the estimated stage-1 and stage-2 selectivities for the different model scenarios (the stage-3 selectivities are all fixed at 1). Estimated selectivities are shown for the directed pot fishery, the trawl bycatch fishery, the fixed bycatch fishery, the NMFS trawl survey, and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

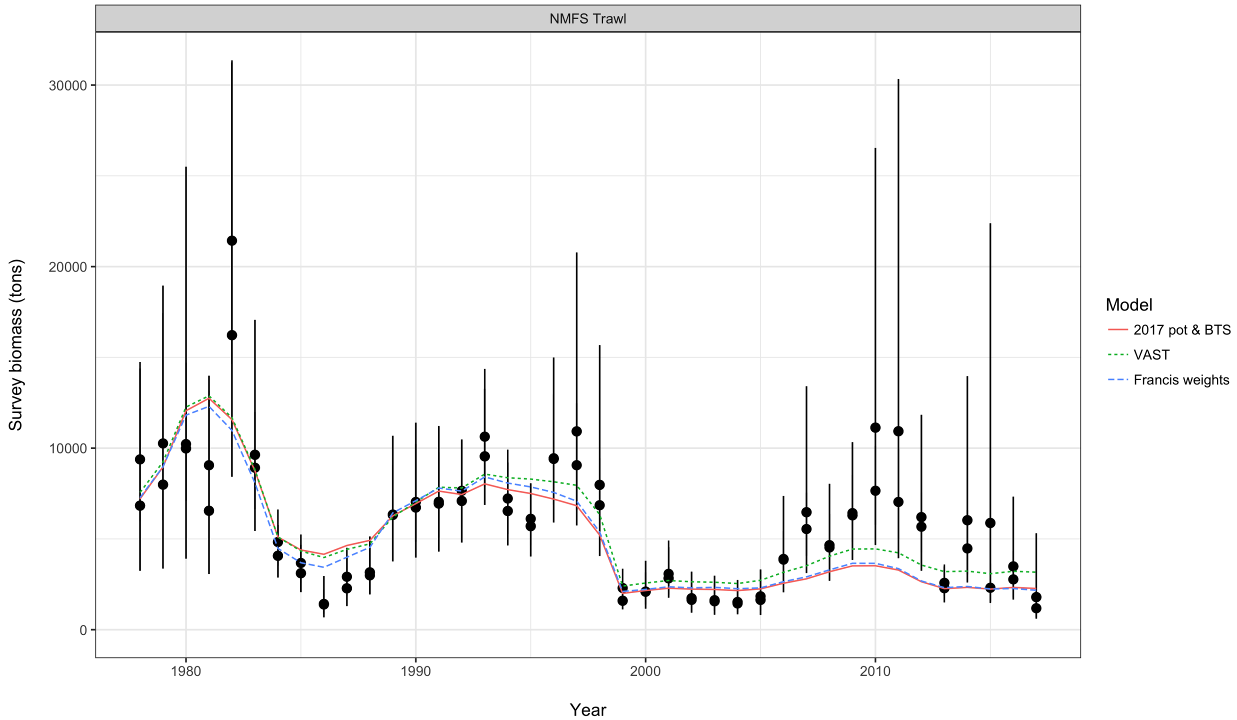

Figure 14: Comparisons of area-swept estimates of total (>89mm CL) male survey biomass (tons) and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

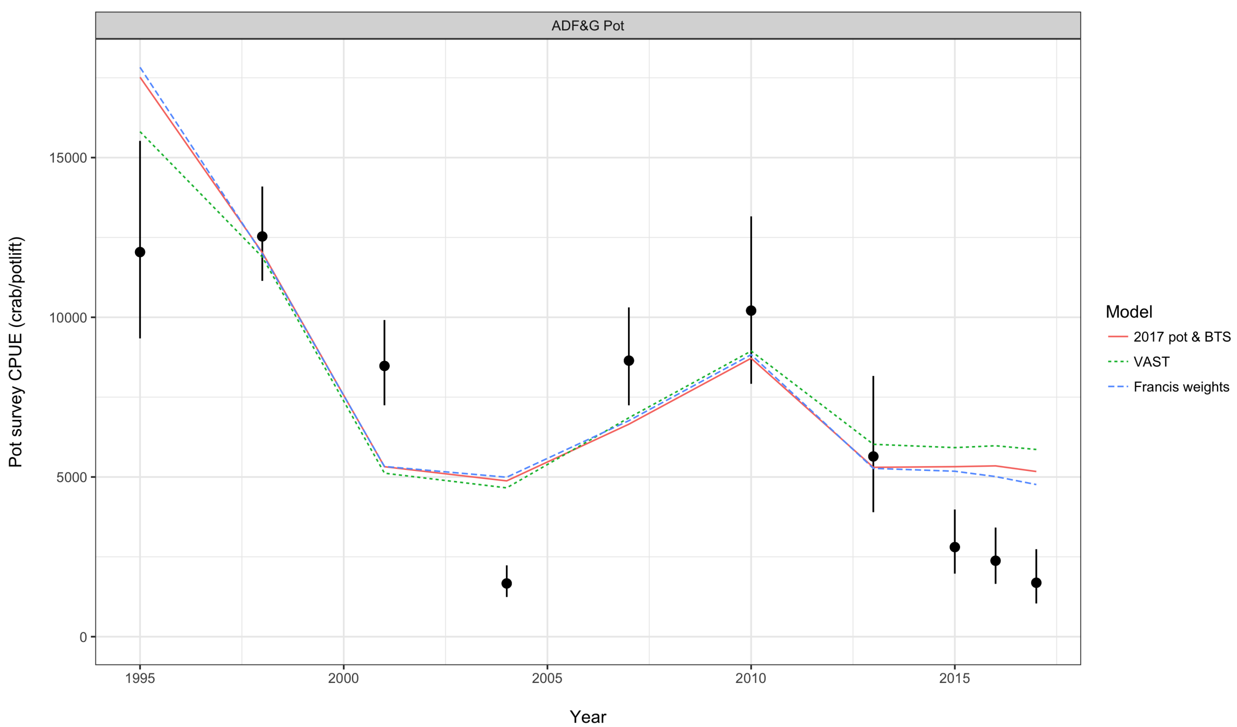

Figure 15: Comparisons of total (>89mm CL) male pot survey CPUEs and model predictions for the model scenarios. The error bars are plus and minus 2 standard deviations.

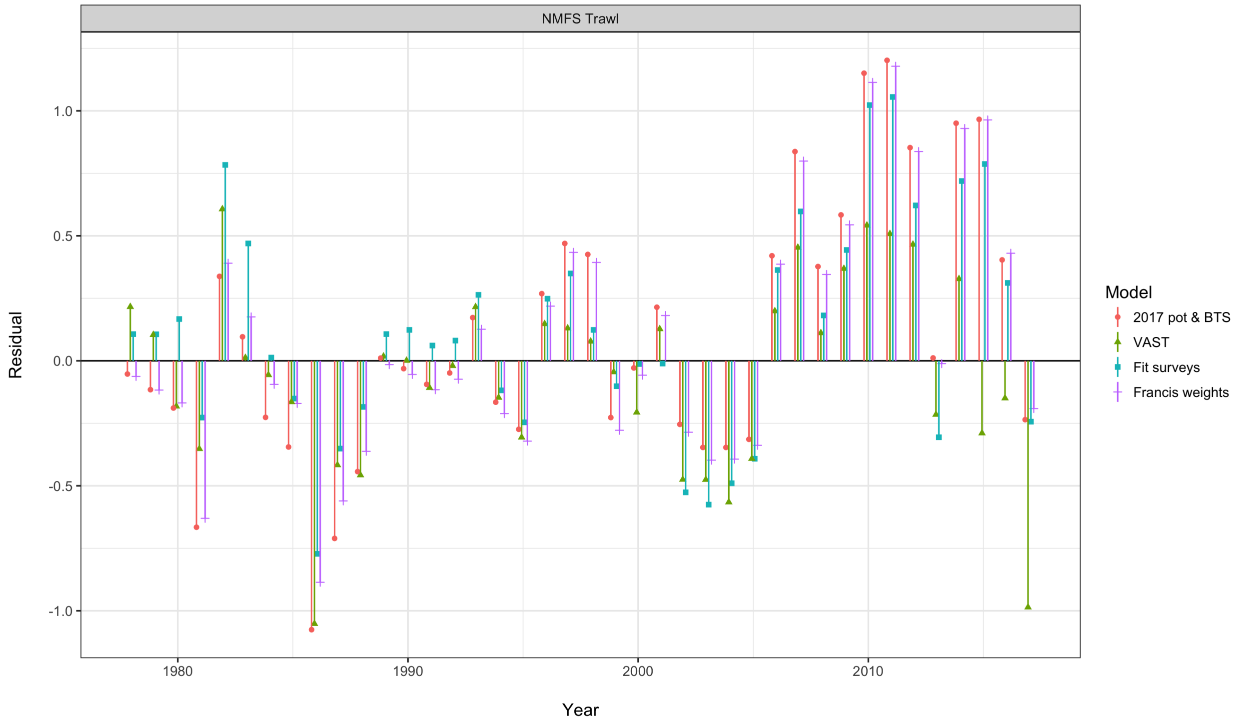

Figure 16: Standardized residuals for area-swept estimates of total male survey biomass for the model scenarios.

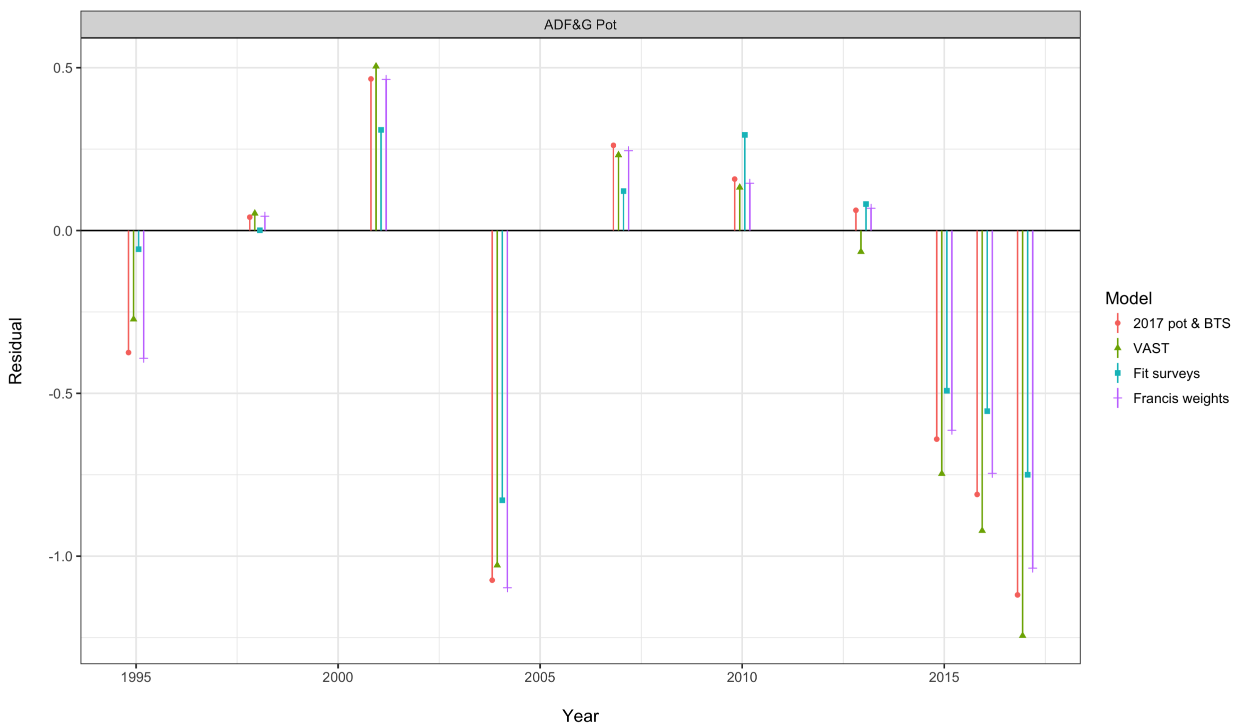

Figure 17: Standardized residuals for total male pot survey CPUEs for each of the Gmacs model scenarios.

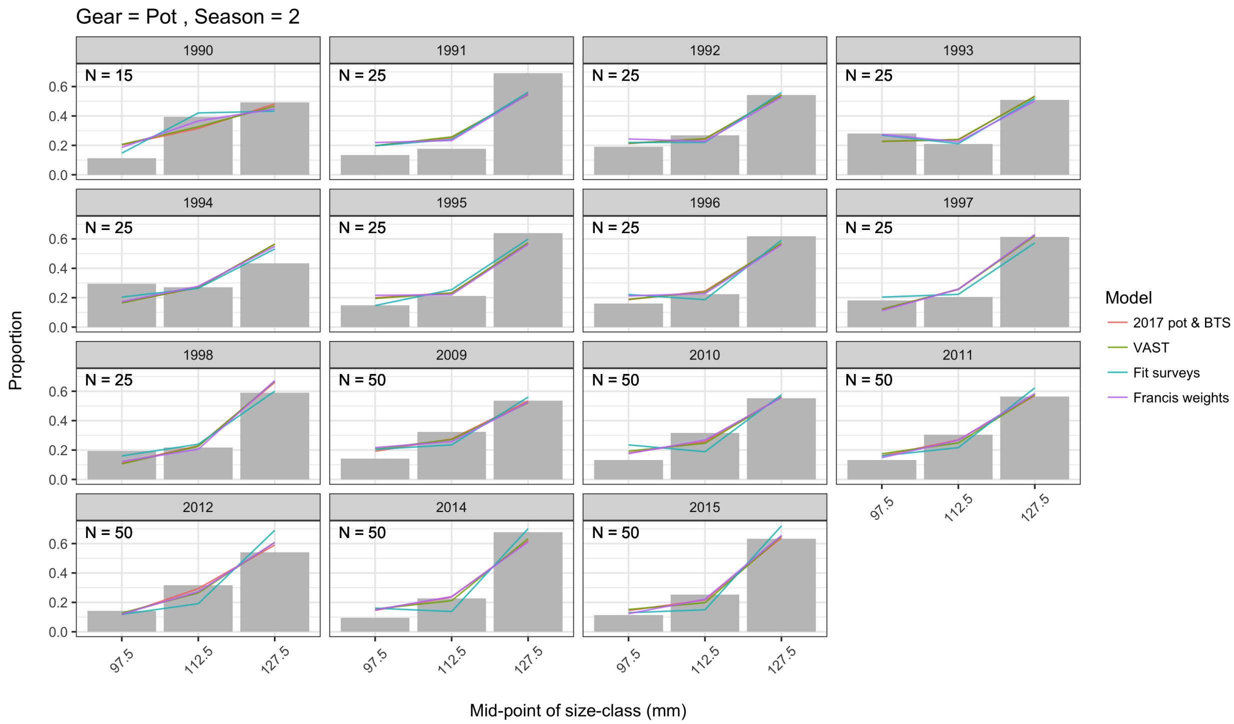

Figure 18: Observed and model estimated size-frequencies of SMBKC by year retained in the directed pot fishery for the model scenarios.

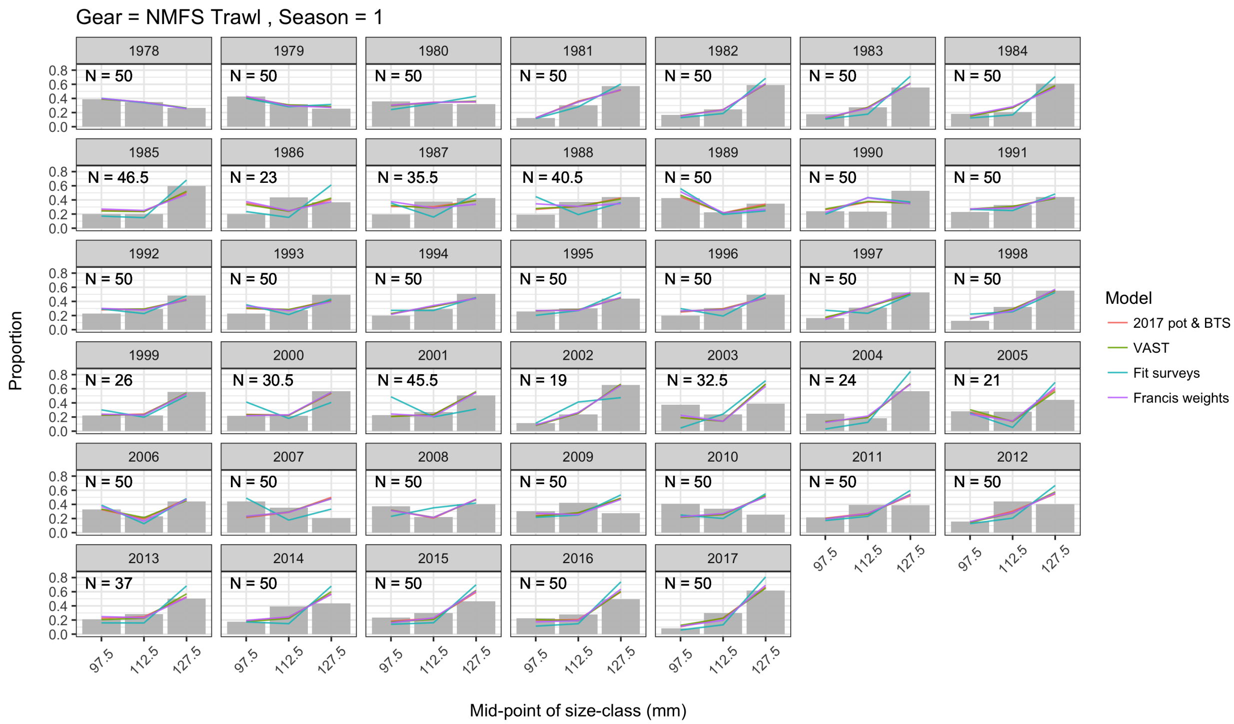

Figure 19: Observed and model estimated size-frequencies of discarded male SMBKC by year in the NMFS trawl survey for the model scenarios.

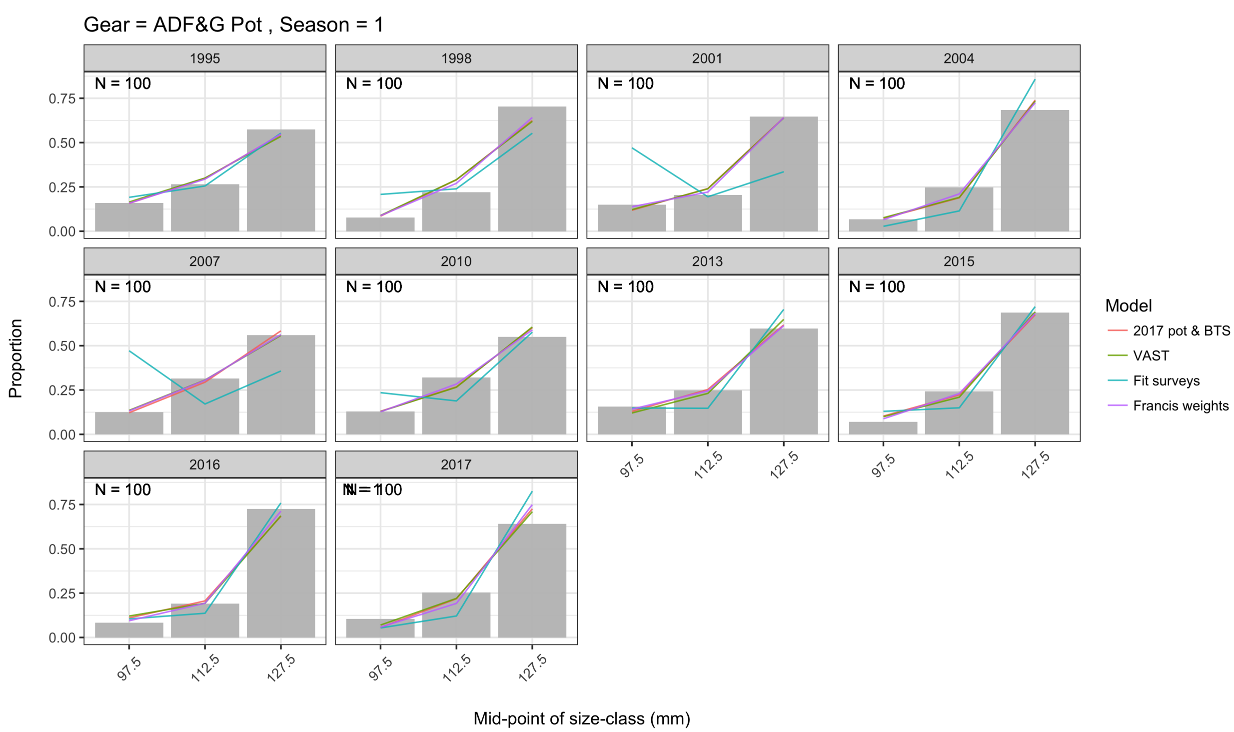

Figure 20: Observed and model estimated size-frequencies of discarded SMBKC by year in the ADF&G pot survey for the model scenarios.

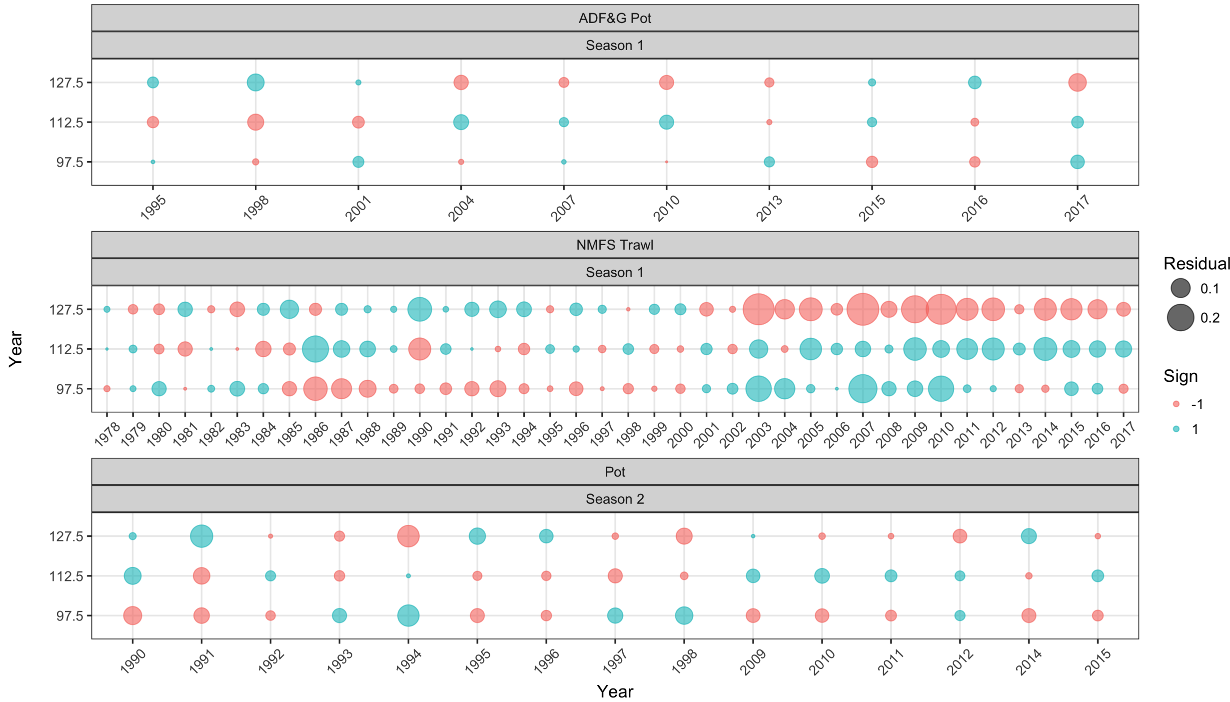

Figure 21: Bubble plots of residuals by stage and year for the directed pot fishery size composition data for SMBKC in the reference model.

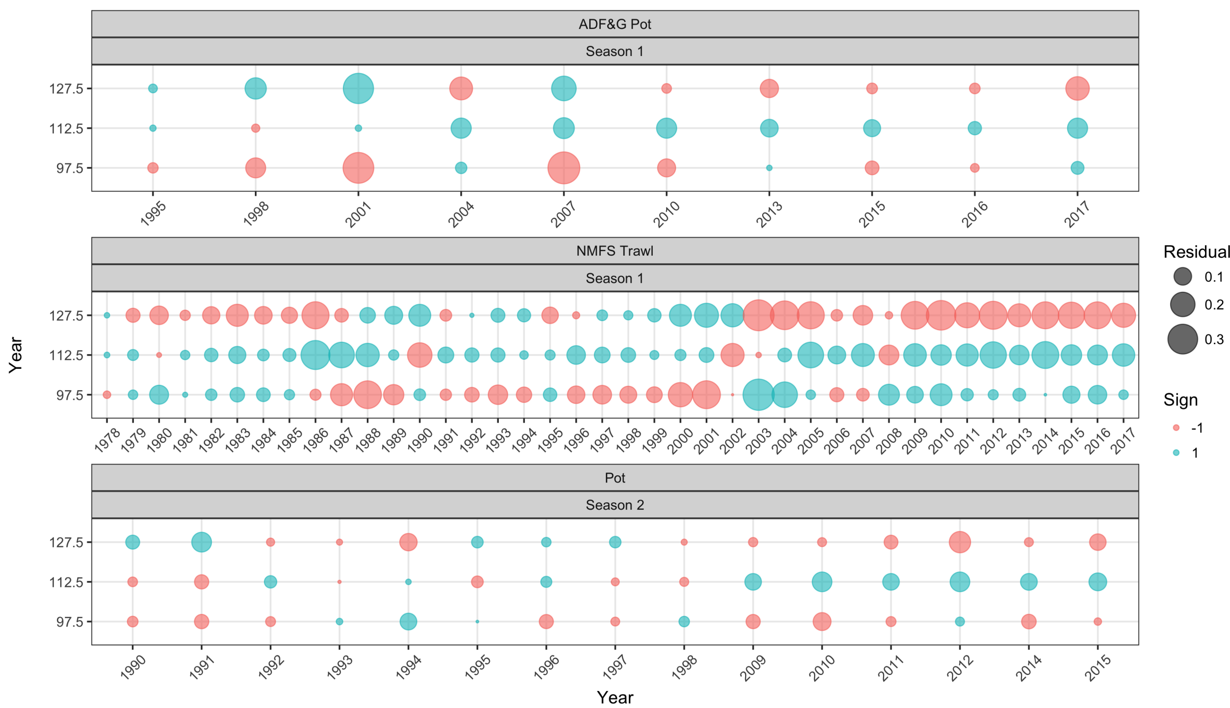

Figure 22: Bubble plots of residuals by stage and year for the ADF&G pot survey size composition data for SMBKC in the **fit surveys** model.

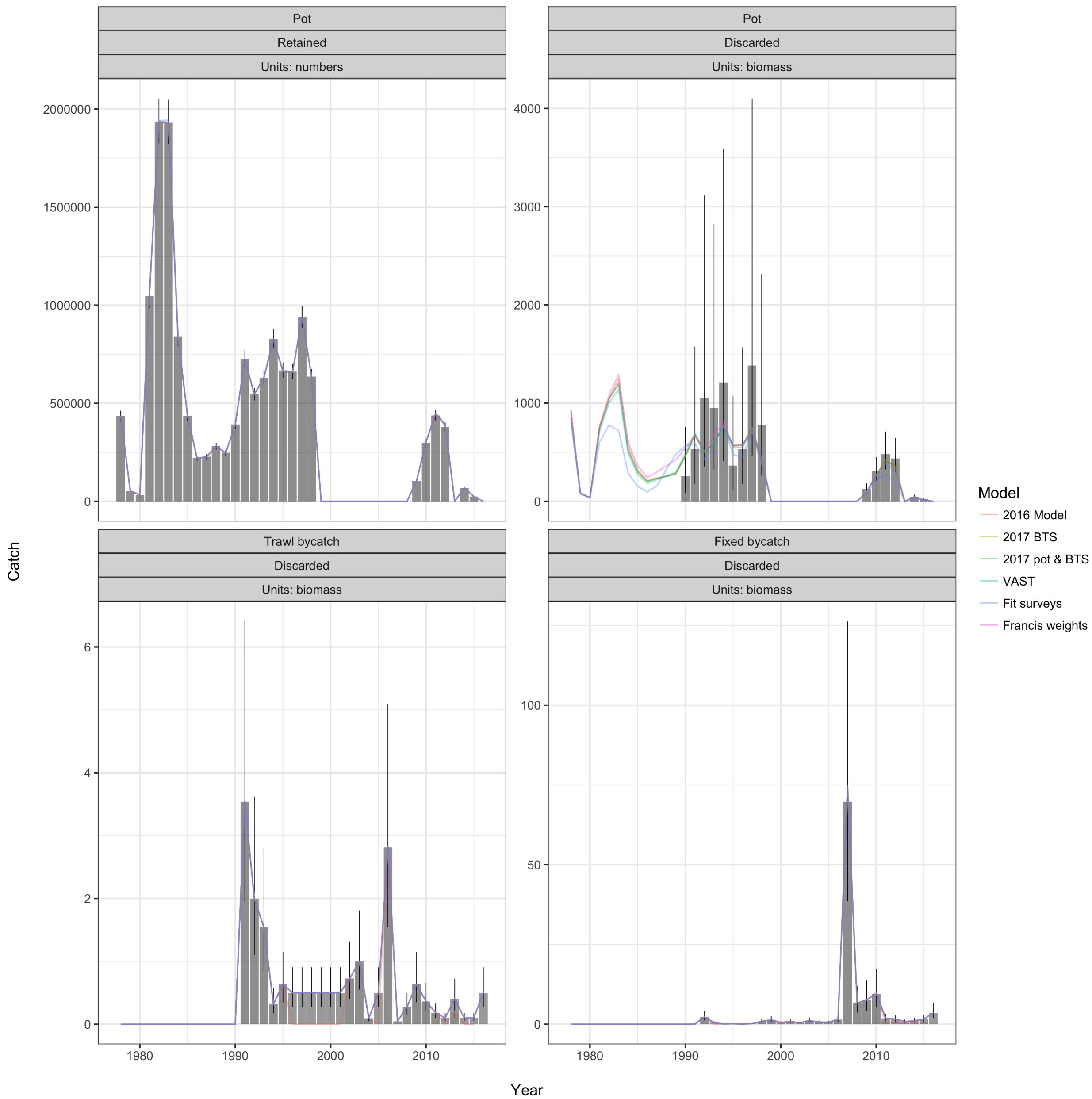

Figure 23: Comparison of observed and model predicted retained catch and bycatches in each of the Gmacs models. Note that difference in units between each of the panels, some panels are expressed in numbers of crab, some as biomass (tons).

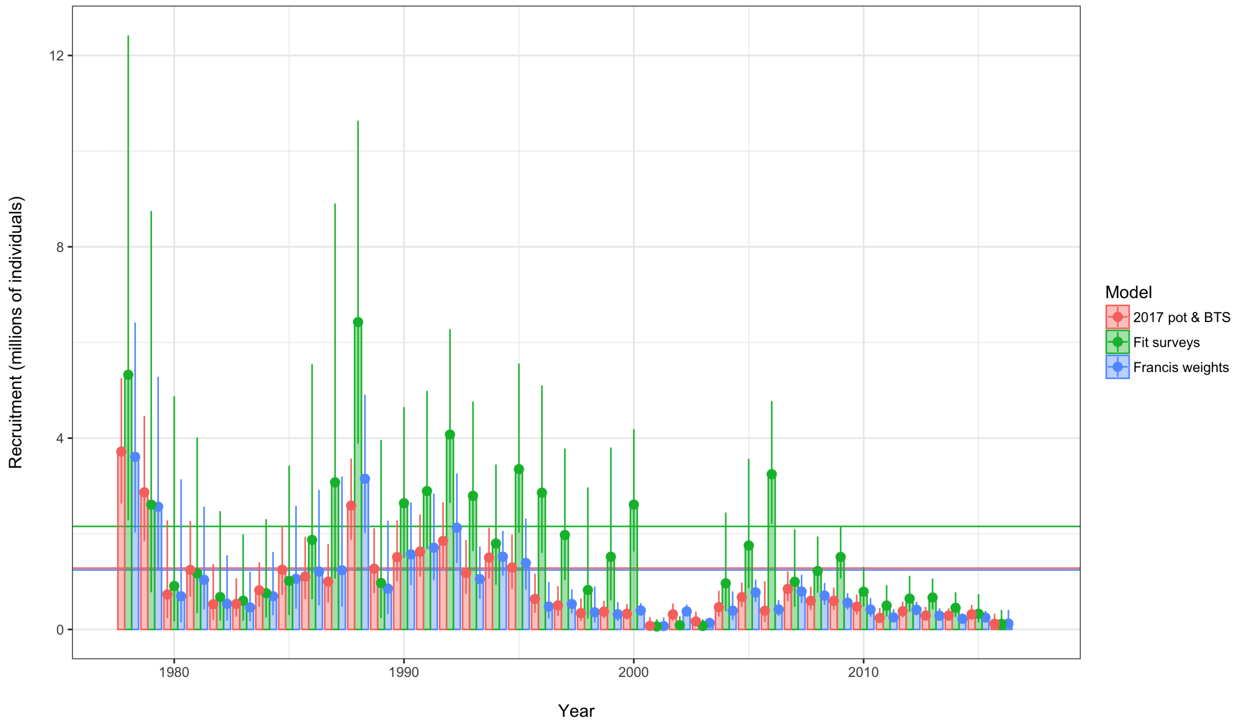

Figure 24: Estimated recruitment 1979-2017 comparing model alternatives. The solid horizontal lines in the background represent the estimate of the average recruitment parameter ($\bar{R}$) in each model scenario.

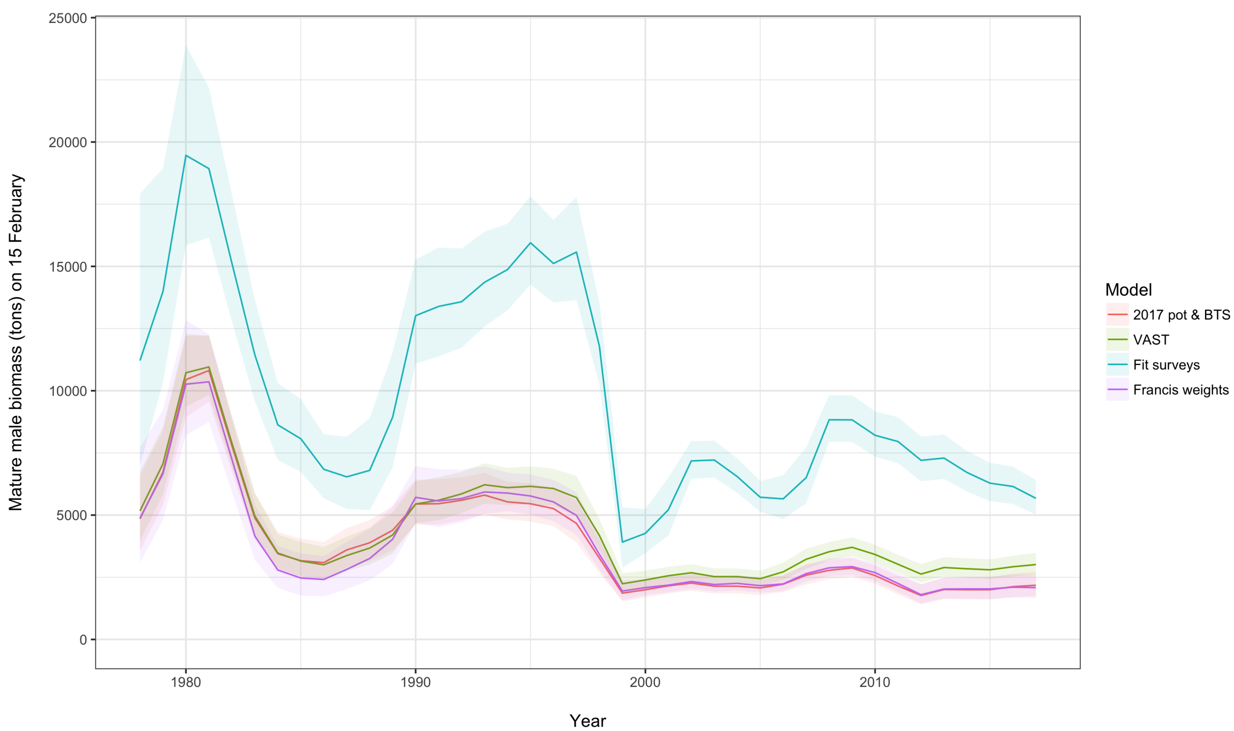

Figure 25: Comparisons of estimated mature male biomass (MMB) time series on 15 February during 1978-2017 for each of the model scenarios.

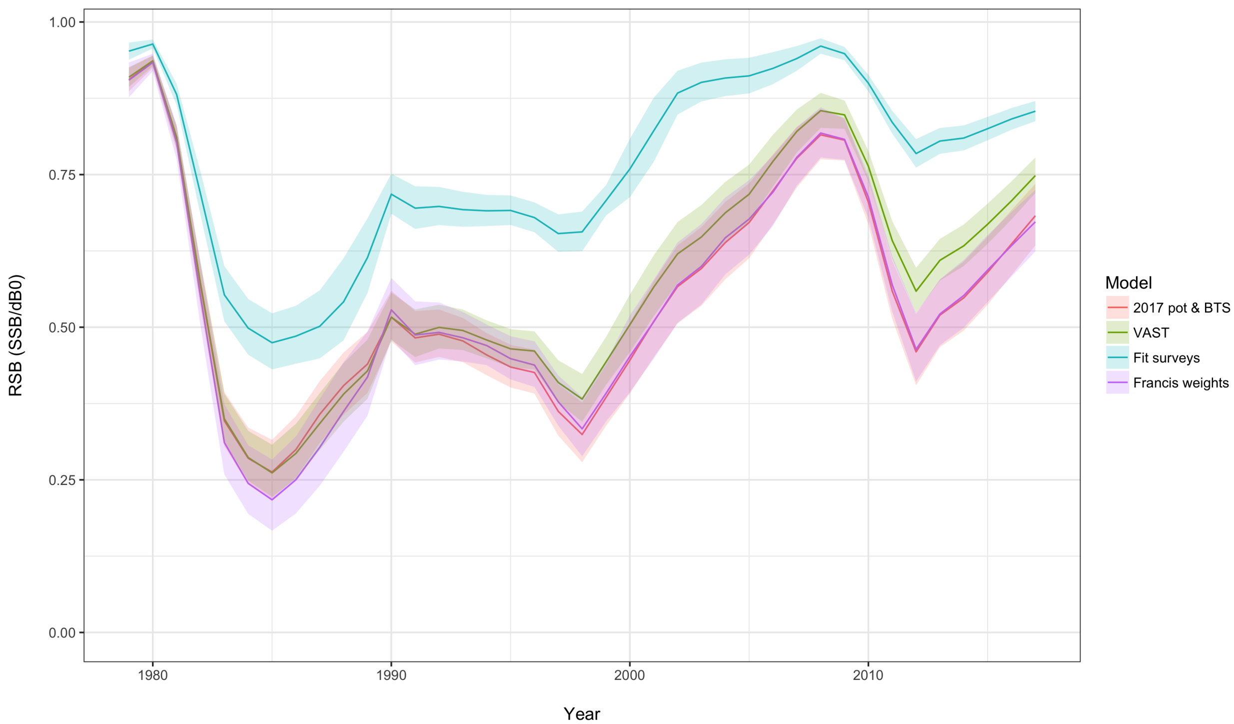

Figure 26: Comparisons of mature male biomass relative to the dynamic B_0 value, (15 February, 1978-2017) for each of the model scenarios.

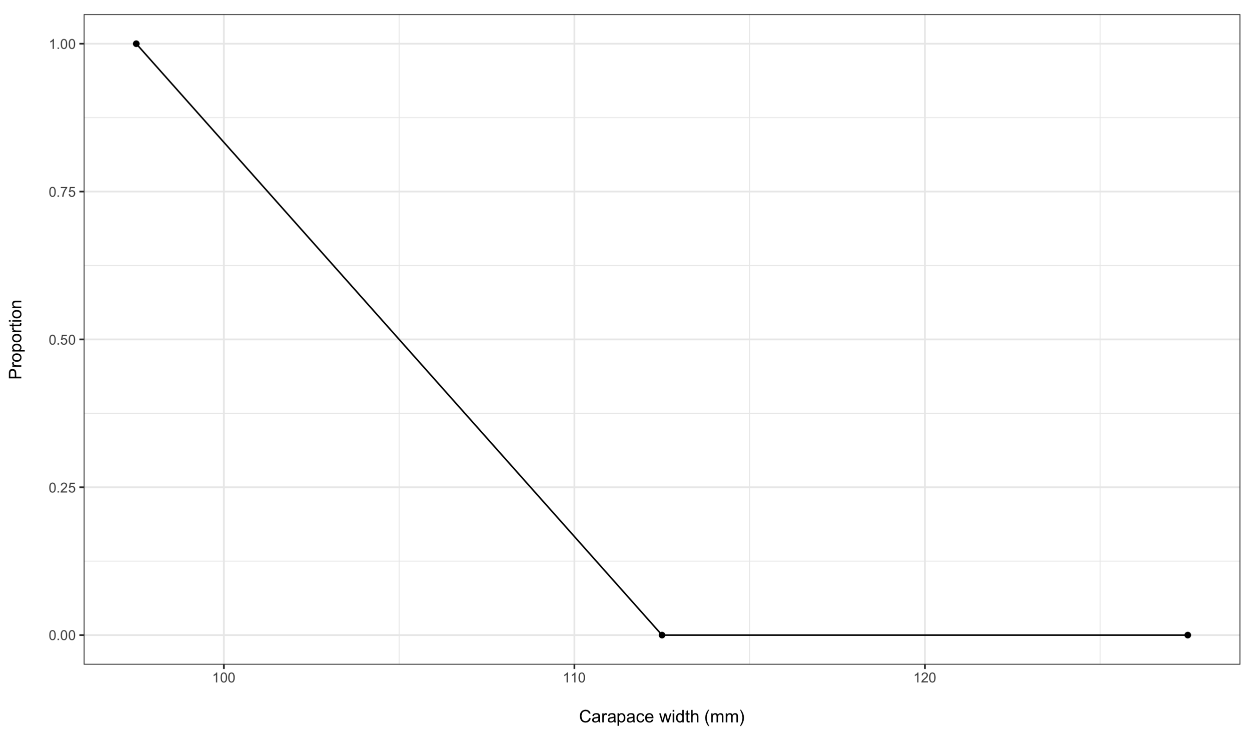

Figure 27: Distribution of carapace width (mm) at recruitment.

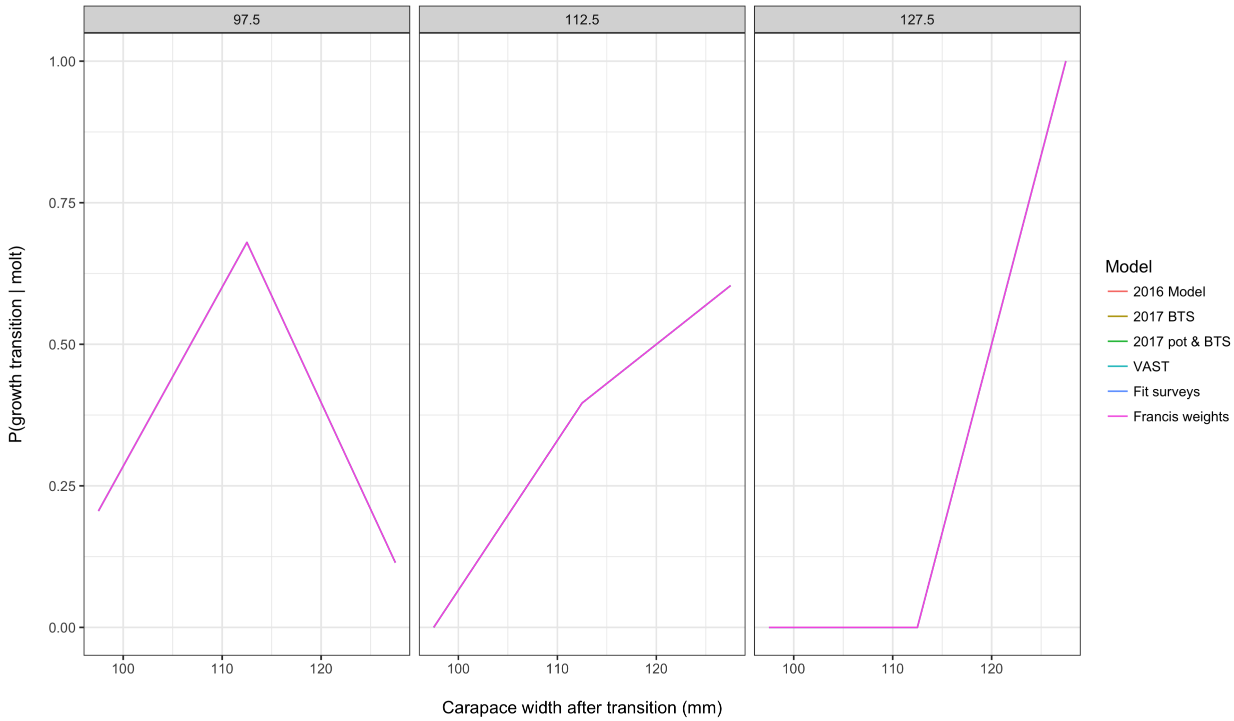

Figure 28: Probability of size transition by stage (i.e. the combination of the growth matrix and molting probabilities). Each of the panels represent the stage before a transition. The x-axes represent the stage after a transition. The size transition matrix was provided as an input directly to Gmacs (as it was during the 2015 SMBKC assessment).

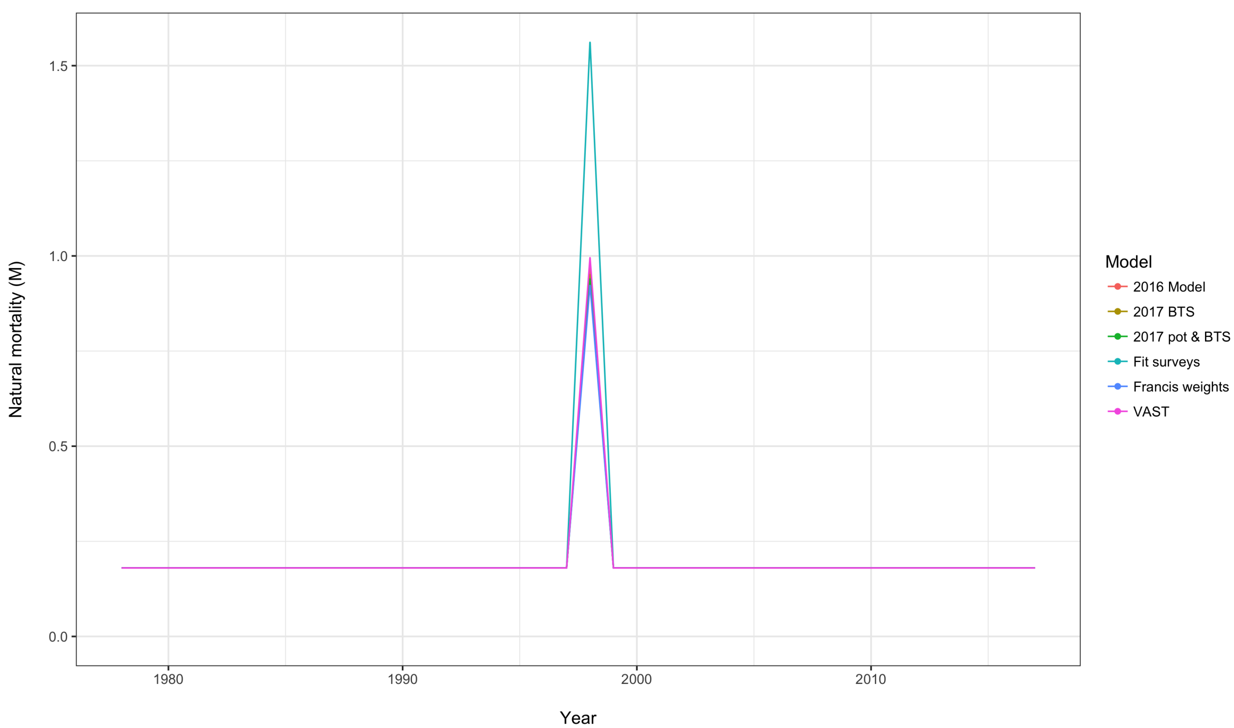

Figure 29: Time-varying natural mortality (M_t). Estimated pulse period occurs in 1998/99 (i.e. M_{1998}).

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 `r M[[2]]$nseason` 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 4)
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 24. The beginning of the year (1 July) to the date that MMB is measured (15 February) is 63% of the year. Therefore 63% of the natural mortality must be applied before the MMB is calculated. Because the timing of the fishery is different each year τ_2 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

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

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

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

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 $\delta^{\text{df}}_{t,y}$, $\delta^{\text{tb}}_{t,y}$, and $\delta^{\text{fb}}_{t,y}$ 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

$$\boldsymbol{S}_{t,y} = \begin{bmatrix} 1 - e^{-Z_{1,t,y}} & 0 & 0 \\ 0 & 1 - e^{-Z_{2,t,y}} & 0 \\ 0 & 0 & 1 - e^{-Z_{3,t,y}} \end{bmatrix}. \tag{11}$$

The basic population dynamics underlying Gmacs can thus be described as

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

3. Model Data

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

4. Model Parameters

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

$$\boldsymbol{G} = \begin{bmatrix} 0.2 & 0.7 & 0.1 \\ 0 & 0.4 & 0.6 \\ 0 & 0 & 1 \end{bmatrix} \tag{13}$$

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

Estimated parameters are listed in Table 27 and include an estimated natural mortality deviation parameter in 1998/99 (δ^{M}_{1998}) assuming an anomalous mortality event in that year, as hypothesized by Zheng and Kruse (2002), with natural mortality otherwise fixed at 0.18 yr^{-1}.

5. Model Objective Function and Weighting Scheme

The objective function consists of the sum of several "negative log-likelihood" terms characterizing the hypothesized error structure of the principal data inputs (Table 18). A lognormal distribution is assumed to characterize the catch data and is modelled as

$$\sigma^{\text{catch}}_{t,y} = \sqrt{\log\left(1 + \left(CV^{\text{catch}}_{t,y}\right)^2\right)} \tag{14}$$

$$\delta^{\text{catch}}_{t,y} = \mathcal{N}\left(0, \left(\sigma^{\text{catch}}_{t,y}\right)^2\right) \tag{15}$$

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

$$\sigma^{\mathrm{I}}_{t,y} = \frac{1}{\lambda}\sqrt{\log\left(1+\left(CV^{\mathrm{I}}_{t,y}\right)^2\right)} \tag{16}$$

$$\delta^{\mathrm{I}}_{t,y} = \log\left(I^{\mathrm{obs}}/I^{\mathrm{pred}}\right)/\sigma^{\mathrm{I}}_{t,y} + 0.5\sigma^{\mathrm{I}}_{t,y} \tag{17}$$

and the likelihood is

$$\sum \log\left(\delta^{\mathrm{I}}_{t,y}\right) + \sum 0.5\left(\sigma^{\mathrm{I}}_{t,y}\right)^2 \tag{18}$$

Gmacs calculates standard deviation of the normalised residual (SDNR) values and median of the absolute residual (MAR) values for all abundance indices and size compositions to help the user come up with resonable likelihood weights. For an abundance data set to be well fitted, the SDNR should not be much greater than 1 (a value much less than 1, which means that the data set is fitted better than was expected, is not a cause for concern). What is meant by "much greater than 1" depends on m (the number of years in the data set). Francis (2011) suggests upper limits of 1.54, 1.37, and 1.26 for $m = 5$, 10, and 20, respectively. Although an SDNR not much greater than 1 is a necessary condition for a good fit, it is not sufficient. It is important to plot the observed and expected abundances to ensure that the fit is good.

Gmacs also calculates Francis weights for each of the size composition data sets supplied (Francis 2011). If the user wishes to use the Francis iterative re-weighting method, first the weights applied to the abundance indices should be adjusted by trial and error until the SDNR (and/or MAR) are adequte. Then the Francis weights supplied by Gmacs should be used as the new likelihood weights for each of the size composition data sets the next time the model is run. The user can then iteratively adjust the abudance index and size composition weights until adequate SDNR (and/or MAR) values are achieved, given the Francis weights.

6. Estimation

The model was implemented using the software AD Model Builder (Fournier et al. 2012), with parameter estimation by minimization of the model objective function using automatic differentiation. Parameter estimates and standard deviations provided in this document are AD Model Builder reported values assuming maximum likelihood theory asymptotics.

Table 24: Proportion of the natural mortality (τ_t) that is applied during each season (t) in the model.

Year	Season 1	Season 2	Season 3	Season 4	Season 5
1978	0.00	0.07	0.00	0.56	0.37
1979	0.00	0.06	0.00	0.57	0.37
1980	0.00	0.07	0.00	0.56	0.37
1981	0.00	0.05	0.00	0.58	0.37
1982	0.00	0.07	0.00	0.56	0.37
1983	0.00	0.12	0.00	0.51	0.37
1984	0.00	0.10	0.00	0.53	0.37
1985	0.00	0.14	0.00	0.49	0.37
1986	0.00	0.14	0.00	0.49	0.37
1987	0.00	0.14	0.00	0.49	0.37
1988	0.00	0.14	0.00	0.49	0.37
1989	0.00	0.14	0.00	0.49	0.37
1990	0.00	0.14	0.00	0.49	0.37
1991	0.00	0.18	0.00	0.45	0.37
1992	0.00	0.14	0.00	0.49	0.37
1993	0.00	0.18	0.00	0.45	0.37
1994	0.00	0.18	0.00	0.45	0.37
1995	0.00	0.18	0.00	0.45	0.37
1996	0.00	0.18	0.00	0.45	0.37
1997	0.00	0.18	0.00	0.45	0.37
1998	0.00	0.18	0.00	0.45	0.37
1999	0.00	0.18	0.00	0.45	0.37
2000	0.00	0.18	0.00	0.45	0.37
2001	0.00	0.18	0.00	0.45	0.37
2002	0.00	0.18	0.00	0.45	0.37
2003	0.00	0.18	0.00	0.45	0.37
2004	0.00	0.18	0.00	0.45	0.37
2005	0.00	0.18	0.00	0.45	0.37
2006	0.00	0.18	0.00	0.45	0.37
2007	0.00	0.18	0.00	0.45	0.37
2008	0.00	0.18	0.00	0.45	0.37
2009	0.00	0.44	0.00	0.19	0.37
2010	0.00	0.44	0.00	0.19	0.37
2011	0.00	0.44	0.00	0.19	0.37
2012	0.00	0.44	0.00	0.19	0.37
2013	0.00	0.44	0.00	0.19	0.37
2014	0.00	0.44	0.00	0.19	0.37
2015	0.00	0.44	0.00	0.19	0.37
2016	0.00	0.44	0.00	0.19	0.37
2017	0.00	0.44	0.00	0.19	0.37

Table 25: Data inputs used in model estimation.

Data	Years	Source
Directed pot-fishery retained-catch number (not biomass)	1978/79 - 1998/99 2009/10 - 2015/16	Fish tickets (fishery closed 1999/00 - 2008/09 and 2016/17)
Groundfish trawl bycatch biomass	1992/93 - 2016/17	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93 - 2016/17	NMFS groundfish observer program
NMFS trawl-survey biomass index (area-swept estimate) and CV	1978-2017	NMFS EBS trawl survey
ADF&G pot-survey abundance index (CPUE) and CV	1995-2017	ADF&G SMBKC pot survey
NMFS trawl-survey stage proportions and total number of measured crab	1978-2017	NMFS EBS trawl survey
ADF&G pot-survey stage proportions and total number of measured crab	1995-2017	ADF&G SMBKC pot survey
Directed pot-fishery stage proportions and total number of measured crab	1990/91 - 1998/99 2009/10 - 2015/16	ADF&G crab observer program (fishery closed 1999/00 - 2008/09 and 2016/17)

Table 26: Fixed model parameters for all scenarios.

Parameter	Symbol	Value	Source/rationale
Trawl-survey catchability	q	1.0	Default
Natural mortality	M	0.18 yr^{-1}	NPFMC (2007)
Size transition matrix	$\boldsymbol{G}$	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 27: The lower bound (LB), upper bound (UB), initial value, prior, and estimation phase for each estimated model parameter.

Parameter	LB	Initial value	UB	Prior	Phase
Average recruitment $\log(\bar{R})$	-7	10.0	20	Uniform(-7,20)	1
Stage-1 initial numbers $\log(n_1^0)$	5	14.5	20	Uniform(5,20)	1
Stage-2 initial numbers $\log(n_2^0)$	5	14.0	20	Uniform(5,20)	1
Stage-3 initial numbers $\log(n_3^0)$	5	13.5	20	Uniform(5,20)	1
ADF&G pot survey catchability q	0	4.0	5	Uniform(0,5)	1
Stage-1 directed fishery selectivity 1978-2008	0	0.4	1	Uniform(0,1)	3
Stage-2 directed fishery selectivity 1978-2008	0	0.7	1	Uniform(0,1)	3
Stage-1 directed fishery selectivity 2009-2017	0	0.4	1	Uniform(0,1)	3
Stage-2 directed fishery selectivity 2009-2017	0	0.7	1	Uniform(0,1)	3
Stage-1 NMFS trawl survey selectivity	0	0.4	1	Uniform(0,1)	4
Stage-2 NMFS trawl survey selectivity	0	0.7	1	Uniform(0,1)	4
Stage-1 ADF&G pot survey selectivity	0	0.4	1	Uniform(0,1)	4
Stage-2 ADF&G pot survey selectivity	0	0.7	1	Uniform(0,1)	4
Natural mortality deviation during 1998 δ_{1998}^M	-3	0.0	3	Normal(0, σ_M^2)	4
Recruitment deviations δ_y^R	-7	0.0	7	Normal(0, σ_R^2)	3
Average directed fishery fishing mortality $\bar{F}^{\text{df}}$	-	0.2	-	-	1
Average trawl bycatch fishing mortality $\bar{F}^{\text{tb}}$	-	0.001	-	-	1
Average fixed gear bycatch fishing mortality $\bar{F}^{\text{fb}}$	-	0.001	-	-	1

Appendix B: SMBKC Stock Assessment Input Files

The data file used for the reference model (16.0) control file:

```
#====================================================================================================
# Gmacs Main  Data  File  Version 1.1:  SM17 example
# GEAR_INDEX   DESCRIPTION
#    1        : Pot fishery retained catch.
#    1        : Pot fishery with discarded catch.
#    2        : Trawl bycatch
#    3        : Fixed bycatch
#    4        : Trawl survey
#    5        : Pot survey

# Fisheries:  1 Pot Fishery,  2 Pot Discard,  3 Trawl by-catch, 3 Fixed by-catch
# Surveys:    4 NMFS Trawl Survey, 5 Pot Survey
#====================================================================================================

1978  # Start year
2017  # End year
2018  # Projection year
5     # Number of seasons
5     # Number of distinct data groups (among fishing fleets and surveys)
1     # Number of sexes
1     # Number of shell condition types
1     # Number of maturity types
3     # Number of size-classes in the model
5     # Season recruitment occurs
5     # Season molting and growth occurs
4     # Season to calculate SSB
1     # Season for N output
# size_breaks (a vector giving the break points between size intervals with dimension nclass+1)
90  105  120  135
# weight-at-length input method (1 = allometry i.e. w_l = a*l^b, 2 = vector by sex, 3 = matrix by sex)
3
# weight-at-length allometry w_l = a*l^b
4.03E-07
# b (male, female)
3.141334
# Male weight-at-length
0.000748427     0.001165731     0.001930510
0.000748427     0.001165731     0.001688886
0.000748427     0.001165731     0.001922246
0.000748427     0.001165731     0.001877957
0.000748427     0.001165731     0.001938634
0.000748427     0.001165731     0.002076413
0.000748427     0.001165731     0.001899330
0.000748427     0.001165731     0.002116687
0.000748427     0.001165731     0.001938784
0.000748427     0.001165731     0.001939764
0.000748427     0.001165731     0.001871067
0.000748427     0.001165731     0.001998295
0.000748427     0.001165731     0.001870418
0.000748427     0.001165731     0.001969415
```

```
0.000748427     0.001165731     0.001926859
0.000748427     0.001165731     0.002021492
0.000748427     0.001165731     0.001931318
0.000748427     0.001165731     0.002014407
0.000748427     0.001165731     0.001977471
0.000748427     0.001165731     0.002099246
0.000748427     0.001165731     0.001982478
0.000748427     0.001165731     0.001930932
0.000748427     0.001165731     0.001930932
0.000748427     0.001165731     0.001930932
0.000748427     0.001165731     0.001930932
0.000748427     0.001165731     0.001930932
0.000748427     0.001165731     0.001930932
0.000748427     0.001165731     0.001930932
0.000748427     0.001165731     0.001930932
0.000748427     0.001165731     0.001930932
0.000748427     0.001165731     0.001930932
0.000748427     0.001165731     0.001891628
0.000748427     0.001165731     0.001795721
0.000748427     0.001165731     0.001823113
0.000748427     0.001165731     0.001807433
0.000748427     0.001165731     0.001930932
0.000748427     0.001165731     0.001894627
0.000748427     0.001165731     0.001850611
0.000748427     0.001165731     0.001930932
0.000748427     0.001165731     0.001930932
# Male mature weight-at-length (weight * proportion  mature)
0 0.001165732 0.001945911
# Proportion mature by sex
0 1 1
# Natural mortality per season input type (1 = vector by season, 2 = matrix by season/year)
2
# Proportion of the total natural mortality to be applied each season (each row must add to 1)
#0  0.0025  0  0.6245  0.373
   0.0000   0.0700   0.0000   0.5600   0.3700
   0.0000   0.0600   0.0000   0.5700   0.3700
   0.0000   0.0700   0.0000   0.5600   0.3700
   0.0000   0.0500   0.0000   0.5800   0.3700
   0.0000   0.0700   0.0000   0.5600   0.3700
   0.0000   0.1200   0.0000   0.5100   0.3700
   0.0000   0.1000   0.0000   0.5300   0.3700
   0.0000   0.1400   0.0000   0.4900   0.3700
   0.0000   0.1400   0.0000   0.4900   0.3700
   0.0000   0.1400   0.0000   0.4900   0.3700
   0.0000   0.1400   0.0000   0.4900   0.3700
   0.0000   0.1400   0.0000   0.4900   0.3700
   0.0000   0.1400   0.0000   0.4900   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1400   0.0000   0.4900   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
   0.0000   0.1800   0.0000   0.4500   0.3700
```

```
   0.0000   0.4400   0.0000   0.1900   0.3700
   0.0000   0.4400   0.0000   0.1900   0.3700
   0.0000   0.4400   0.0000   0.1900   0.3700
   0.0000   0.4400   0.0000   0.1900   0.3700
   0.0000   0.4400   0.0000   0.1900   0.3700
   0.0000   0.4400   0.0000   0.1900   0.3700
   0.0000   0.4400   0.0000   0.1900   0.3700
   0.0000   0.4400   0.0000   0.1900   0.3700
   0.0000   0.4400   0.0000   0.1900   0.3700
# Fishing fleet names (delimited with : no spaces in names)
Pot_Fishery:Trawl_Bycatch:Fixed_bycatch
# Survey names (delimited with : no spaces in names)
NMFS_Trawl:ADFG_Pot
# Number  of  catch data  frames
4
# Number  of  rows  in  each  data  frame
28  16  26  26
##  CATCH DATA
##  Type of catch: 1 = retained, 2 = discard
##  Units of catch: 1 = biomass, 2 = numbers
##  for SMBKC Units are in number of crab for landed & 1000 kg for discards.
##  Male Retained
# year  seas    fleet   sex     obs     cv      type    units   mult    effort  discard_mortality
1978    2       1       1       436126  0.03    1       2       1       0       0
1979    2       1       1       52966   0.03    1       2       1       0       0
1980    2       1       1       33162   0.03    1       2       1       0       0
1981    2       1       1       1045619 0.03    1       2       1       0       0
1982    2       1       1       1935886 0.03    1       2       1       0       0
1983    2       1       1       1931990 0.03    1       2       1       0       0
1984    2       1       1       841017  0.03    1       2       1       0       0
1985    2       1       1       436021  0.03    1       2       1       0       0
1986    2       1       1       219548  0.03    1       2       1       0       0
1987    2       1       1       227447  0.03    1       2       1       0       0
1988    2       1       1       280401  0.03    1       2       1       0       0
1989    2       1       1       247641  0.03    1       2       1       0       0
1990    2       1       1       391405  0.03    1       2       1       0       0
1991    2       1       1       726519  0.03    1       2       1       0       0
1992    2       1       1       545222  0.03    1       2       1       0       0
1993    2       1       1       630353  0.03    1       2       1       0       0
1994    2       1       1       827015  0.03    1       2       1       0       0
1995    2       1       1       666905  0.03    1       2       1       0       0
1996    2       1       1       660665  0.03    1       2       1       0       0
1997    2       1       1       939822  0.03    1       2       1       0       0
1998    2       1       1       635370  0.03    1       2       1       0       0
2009    2       1       1       103376  0.03    1       2       1       0       0
2010    2       1       1       298669  0.03    1       2       1       0       0
2011    2       1       1       437862  0.03    1       2       1       0       0
2012    2       1       1       379386  0.03    1       2       1       0       0
2014    2       1       1       69109   0.03    1       2       1       0       0
2015    2       1       1       24407   0.03    1       2       1       0       0
2016    2       1       1       24.407   0.03    1       2       1       0       0
# Male  discards  Pot fishery
1990    2       1       1    254.9787861     0.6     2       1       1       0       0.2
1991    2       1       1    531.4483252     0.6     2       1       1       0       0.2
1992    2       1       1    1050.387026     0.6     2       1       1       0       0.2
1993    2       1       1    951.4626128     0.6     2       1       1       0       0.2
1994    2       1       1    1210.764588     0.6     2       1       1       0       0.2
1995    2       1       1    363.112032      0.6     2       1       1       0       0.2
1996    2       1       1    528.5244687     0.6     2       1       1       0       0.2
1997    2       1       1    1382.825328     0.6     2       1       1       0       0.2
1998    2       1       1    781.1032977     0.6     2       1       1       0       0.2
2009    2       1       1    123.3712279     0.2     2       1       1       0       0.2
2010    2       1       1    304.6562225     0.2     2       1       1       0       0.2
2011    2       1       1    481.3572126     0.2     2       1       1       0       0.2
2012    2       1       1    437.3360731     0.2     2       1       1       0       0.2
```

```
2014   2   1   1   45.4839749    0.2   2   1   1   0   0.2
2015   2   1   1   21.19378597   0.2   2   1   1   0   0.2
2016   2   1   1   0.021193786   0.2   2   1   1   0   0.2
# Trawl fishery discards
1991   2   2   1   3.538   0.31   2   1   1   0   0.8
1992   2   2   1   1.996   0.31   2   1   1   0   0.8
1993   2   2   1   1.542   0.31   2   1   1   0   0.8
1994   2   2   1   0.318   0.31   2   1   1   0   0.8
1995   2   2   1   0.635   0.31   2   1   1   0   0.8
1996   2   2   1   0.500   0.31   2   1   1   0   0.8
1997   2   2   1   0.500   0.31   2   1   1   0   0.8
1998   2   2   1   0.500   0.31   2   1   1   0   0.8
1999   2   2   1   0.500   0.31   2   1   1   0   0.8
2000   2   2   1   0.500   0.31   2   1   1   0   0.8
2001   2   2   1   0.500   0.31   2   1   1   0   0.8
2002   2   2   1   0.726   0.31   2   1   1   0   0.8
2003   2   2   1   0.998   0.31   2   1   1   0   0.8
2004   2   2   1   0.091   0.31   2   1   1   0   0.8
2005   2   2   1   0.500   0.31   2   1   1   0   0.8
2006   2   2   1   2.812   0.31   2   1   1   0   0.8
2007   2   2   1   0.045   0.31   2   1   1   0   0.8
2008   2   2   1   0.272   0.31   2   1   1   0   0.8
2009   2   2   1   0.635   0.31   2   1   1   0   0.8
2010   2   2   1   0.363   0.31   2   1   1   0   0.8
2011   2   2   1   0.181   0.31   2   1   1   0   0.8
2012   2   2   1   0.100   0.31   2   1   1   0   0.8
2013   2   2   1   0.400   0.31   2   1   1   0   0.8
2014   2   2   1   0.100   0.31   2   1   1   0   0.8
2015   2   2   1   0.100   0.31   2   1   1   0   0.8
2016   2   2   1   0.500   0.31   2   1   1   0   0.8
# Fixed fishery discards
1991   2   3   1   0.045   0.31   2   1   1   0   0.5
1992   2   3   1   2.268   0.31   2   1   1   0   0.5
1993   2   3   1   0.500   0.31   2   1   1   0   0.5
1994   2   3   1   0.091   0.31   2   1   1   0   0.5
1995   2   3   1   0.136   0.31   2   1   1   0   0.5
1996   2   3   1   0.045   0.31   2   1   1   0   0.5
1997   2   3   1   0.181   0.31   2   1   1   0   0.5
1998   2   3   1   0.907   0.31   2   1   1   0   0.5
1999   2   3   1   1.361   0.31   2   1   1   0   0.5
2000   2   3   1   0.500   0.31   2   1   1   0   0.5
2001   2   3   1   0.862   0.31   2   1   1   0   0.5
2002   2   3   1   0.408   0.31   2   1   1   0   0.5
2003   2   3   1   1.134   0.31   2   1   1   0   0.5
2004   2   3   1   0.635   0.31   2   1   1   0   0.5
2005   2   3   1   0.590   0.31   2   1   1   0   0.5
2006   2   3   1   1.451   0.31   2   1   1   0   0.5
2007   2   3   1   69.717  0.31   2   1   1   0   0.5
2008   2   3   1   6.622   0.31   2   1   1   0   0.5
2009   2   3   1   7.530   0.31   2   1   1   0   0.5
2010   2   3   1   9.571   0.31   2   1   1   0   0.5
2011   2   3   1   1.800   0.31   2   1   1   0   0.5
2012   2   3   1   1.600   0.31   2   1   1   0   0.5
2013   2   3   1   0.8     0.31   2   1   1   0   0.5
2014   2   3   1   1.1     0.31   2   1   1   0   0.5
2015   2   3   1   1.600   0.31   2   1   1   0   0.5
2016   2   3   1   3.600   0.31   2   1   1   0   0.5
##  RELATIVE  ABUNDANCE DATA
##  Units of abundance: 1 = biomass, 2 = numbers
##  for SMBKC Units are in  crabs for Abundance.
##  Number  of  relative  abundance indicies
2
##  Number  of  rows  in  each  index
40  9
# Survey data (abundance indices, units are mt for trawl survey and crab/potlift for pot survey)
```

```
# Year, Seas, Fleet,  Sex,  Abundance,  CV     units
1978  1 4 1 6832.819  0.394 1
1979  1 4 1 7989.881  0.463 1
1980  1 4 1 9986.830  0.507 1
1981  1 4 1 6551.132  0.402 1
1982  1 4 1 16221.933 0.344 1
1983  1 4 1 9634.250  0.298 1
1984  1 4 1 4071.218  0.179 1
1985  1 4 1 3110.541  0.210 1
1986  1 4 1 1416.849  0.388 1
1987  1 4 1 2278.917  0.291 1
1988  1 4 1 3158.169  0.252 1
1989  1 4 1 6338.622  0.271 1
1990  1 4 1 6730.130  0.274 1
1991  1 4 1 6948.184  0.248 1
1992  1 4 1 7093.272  0.201 1
1993  1 4 1 9548.459  0.169 1
1994  1 4 1 6539.133  0.176 1
1995  1 4 1 5703.591  0.178 1
1996  1 4 1 9410.403  0.241 1
1997  1 4 1 10924.107 0.337 1
1998  1 4 1 7976.839  0.355 1
1999  1 4 1 1594.546  0.182 1
2000  1 4 1 2096.795  0.310 1
2001  1 4 1 2831.440  0.245 1
2002  1 4 1 1732.599  0.320 1
2003  1 4 1 1566.675  0.336 1
2004  1 4 1 1523.869  0.305 1
2005  1 4 1 1642.017  0.371 1
2006  1 4 1 3893.875  0.334 1
2007  1 4 1 6470.773  0.385 1
2008  1 4 1 4654.473  0.284 1
2009  1 4 1 6301.470  0.256 1
2010  1 4 1 11130.898 0.466 1
2011  1 4 1 10931.232 0.558 1
2012  1 4 1 6200.219  0.339 1
2013  1 4 1 2287.557  0.217 1
2014  1 4 1 6029.220  0.449 1
2015  1 4 1 5877.433  0.770 1
2016  1 4 1 3485.909  0.393 1
2017  1 4 1 1793.760  0.599 1
1995  1 5 1 12042.000 0.130 2
1998  1 5 1 12531.000 0.060 2
2001  1 5 1 8477.000  0.080 2
2004  1 5 1 1667.000  0.150 2
2007  1 5 1 8643.000  0.090 2
2010  1 5 1 10209.000 0.130 2
2013  1 5 1 5643.000  0.190 2
2015  1 5 1 2805.000  0.180 2
2016  1 5 1 2378.000  0.186 2
##  Number  of  length  frequency matrices
3
##  Number  of  rows  in  each  matrix
15  40  9
##  Number  of  bins  in  each  matrix  (columns  of  size  data)
3  3  3
##  SIZE  COMPOSITION DATA  FOR ALL FLEETS
##  SIZE  COMP  LEGEND
##  Sex:  1 = male, 2 = female, 0 = both  sexes combined
##  Type  of  composition:  1 = retained, 2 = discard,  0 = total composition
##  Maturity  state:  1 = immature, 2 = mature, 0 = both  states  combined
##  Shell condition:  1 = new shell,  2 = old shell,  0 = both  shell types combined
##length  proportions of  pot discarded males
##Year, Seas, Fleet,  Sex,  Type, Shell,  Maturity, Nsamp,  DataVec
  1990  2 1 1 0 0 0 15  0.1133  0.3933  0.4933
```

```
  1991  2 1 1 0 0 0 25  0.1329  0.1768  0.6902
  1992  2 1 1 0 0 0 25  0.1905  0.2677  0.5417
  1993  2 1 1 0 0 0 25  0.2807  0.2097  0.5096
  1994  2 1 1 0 0 0 25  0.2942  0.2714  0.4344
  1995  2 1 1 0 0 0 25  0.1478  0.2127  0.6395
  1996  2 1 1 0 0 0 25  0.1595  0.2229  0.6176
  1997  2 1 1 0 0 0 25  0.1818  0.2053  0.6128
  1998  2 1 1 0 0 0 25  0.1927  0.2162  0.5911
  2009  2 1 1 0 0 0 50  0.1413  0.3235  0.5352
  2010  2 1 1 0 0 0 50  0.1314  0.3152  0.5534
  2011  2 1 1 0 0 0 50  0.1314  0.3051  0.5636
  2012  2 1 1 0 0 0 50  0.1417  0.3178  0.5406
  2014  2 1 1 0 0 0 50  0.0939  0.2275  0.6786
  2015  2 1 1 0 0 0 50  0.1148  0.2518  0.6333
##length  proportions of  trawl survey  males
##Year, Seas, Fleet,  Sex,  Type, Shell,  Maturity, Nsamp,  DataVec
  1978  1 4 1 0 0 0 50   0.3865  0.3478  0.2657
  1979  1 4 1 0 0 0 50   0.4281  0.3190  0.2529
  1980  1 4 1 0 0 0 50   0.3588  0.3220  0.3192
  1981  1 4 1 0 0 0 50   0.1219  0.3065  0.5716
  1982  1 4 1 0 0 0 50   0.1671  0.2435  0.5893
  1983  1 4 1 0 0 0 50   0.1752  0.2726  0.5522
  1984  1 4 1 0 0 0 50   0.1823  0.2085  0.6092
  1985  1 4 1 0 0 0 46.5 0.2023  0.2010  0.5967
  1986  1 4 1 0 0 0 23   0.1984  0.4364  0.3652
  1987  1 4 1 0 0 0 35.5 0.1944  0.3779  0.4277
  1988  1 4 1 0 0 0 40.5 0.1879  0.3737  0.4384
  1989  1 4 1 0 0 0 50   0.4246  0.2259  0.3496
  1990  1 4 1 0 0 0 50   0.2380  0.2332  0.5288
  1991  1 4 1 0 0 0 50   0.2274  0.3300  0.4426
  1992  1 4 1 0 0 0 50   0.2263  0.2911  0.4826
  1993  1 4 1 0 0 0 50   0.2296  0.2759  0.4945
  1994  1 4 1 0 0 0 50   0.1989  0.2926  0.5085
  1995  1 4 1 0 0 0 50   0.2593  0.3005  0.4403
  1996  1 4 1 0 0 0 50   0.1998  0.3054  0.4948
  1997  1 4 1 0 0 0 50   0.1622  0.3102  0.5275
  1998  1 4 1 0 0 0 50   0.1276  0.3212  0.5511
  1999  1 4 1 0 0 0 26   0.2224  0.2214  0.5562
  2000  1 4 1 0 0 0 30.5 0.2154  0.2180  0.5665
  2001  1 4 1 0 0 0 45.5 0.2253  0.2699  0.5048
  2002  1 4 1 0 0 0 19   0.1127  0.2346  0.6527
  2003  1 4 1 0 0 0 32.5 0.3762  0.2345  0.3893
  2004  1 4 1 0 0 0 24   0.2488  0.1848  0.5663
  2005  1 4 1 0 0 0 21   0.2825  0.2744  0.4431
  2006  1 4 1 0 0 0 50   0.3276  0.2293  0.4431
  2007  1 4 1 0 0 0 50   0.4394  0.3525  0.2081
  2008  1 4 1 0 0 0 50   0.3745  0.2219  0.4036
  2009  1 4 1 0 0 0 50   0.3057  0.4202  0.2741
  2010  1 4 1 0 0 0 50   0.4081  0.3371  0.2548
  2011  1 4 1 0 0 0 50   0.2179  0.3940  0.3881
  2012  1 4 1 0 0 0 50   0.1573  0.4393  0.4034
  2013  1 4 1 0 0 0 37   0.2100  0.2834  0.5065
  2014  1 4 1 0 0 0 50   0.1738  0.3912  0.4350
  2015  1 4 1 0 0 0 50   0.2340  0.2994  0.4666
  2016  1 4 1 0 0 0 50   0.2255  0.2780  0.4965
  2017  1 4 1 0 0 0 50   0.0849  0.2994  0.6157
  ##length  proportions of  pot survey
  ##Year, Seas, Fleet,  Sex,  Type, Shell,  Maturity, Nsamp,  DataVec
  1995  1 5 1 0 0 0 100 0.1594  0.2656  0.5751
  1998  1 5 1 0 0 0 100  0.0769  0.2205  0.7026
  2001  1 5 1 0 0 0 100  0.1493  0.2049  0.6457
  2004  1 5 1 0 0 0 100  0.0672  0.2484  0.6845
  2007  1 5 1 0 0 0 100  0.1257  0.3148  0.5595
  2010  1 5 1 0 0 0 100  0.1299  0.3209  0.5492
  2013  1 5 1 0 0 0 100  0.1556  0.2477  0.5967
```

```
  2015  1 5 1 0 0 0 100  0.0706  0.2431  0.6859
  2016  1 5 1 0 0 0 100  0.0832  0.1917  0.7251
##  Growth data (increment)
# nobs_growth
3
# MidPoint Sex Increment CV
 97.5  1  14.1  0.2197
112.5  1  14.1  0.2197
127.5  1  14.1  0.2197
#  97.5   1 13.8 0.2197
#  112.5  1 14.1 0.2197
#  127.5  1 14.4 0.2197
# Use custom transition matrix (0=no, 1=growth matrix, 2=transition matrix, i.e. growth and molting)
0
# The custom growth matrix (if not using just fill with zeros)
# Alternative TM (loosely) based on Otto and Cummiskey (1990)
0.2  0.7  0.1
0.0  0.4  0.6
0.0  0.0  1.0
#   Use custom  natural mortality   (0=no,  1=yes,  by  sex and year)
0
0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.12 0.1
## eof
9999
```

The reference model (16.0) control file:

```
## ———————————————————————————————————————————————————————————————————————————— ##
## LEADING PARAMETER CONTROLS                                                   ##
# Controls for leading parameter vector theta
# LEGEND FOR PRIOR:
#                 0 -> uniform #                 1 -> normal #                 2 -> lognormal
#                 3 -> beta
#                 4 -> gamma
# ntheta
  12
## ———————————————————————————————————————————————————————————————————————————— ##
# ival        lb        ub        phz   prior     p1      p2        # parameter        #
  0.18      0.01         1        -4       2   0.18    0.02         # M
  14.3      -7.0        30        -2       0    -7       30         # log(R0)
  10.0      -7.0        20        -1       1   -10.0     20         # log(Rini)
  14.13979   7.0        16         1       0     7.0     16.        # log(Rbar)
  80.0      30.0       310        -2       1    72.5    7.25        # Recruitment size distribution expected value
  0.25       0.1         7        -4       0     0.1     9.0        # Recruitment size scale (variance component)
  0.2      -10.0      0.75        -4       0  -10.0    0.75         # log(sigma_R)
  0.75      0.20      1.00        -2       3     3.0    2.00        # steepness
  0.01      0.00      1.00        -3       3    1.01    1.01        # recruitment autocorrelation
 14.9      10.00     15.00         3       0    5.00   20.00        # logN0 vector of initial numbers at length
 14.5      10.00     15.00         3       0    5.00   20.00        # logN0 vector of initial numbers at length
 14.3      10.00     15.00         3       0    5.00   20.00        # logN0 vector of initial numbers at length
## GROWTH PARAM CONTROLS                                                        ##
## Two lines for each parameter if split sex, one line if not                   ##
## number of molt periods
1
## Year(s) molt period changes (blank if no changes)

## ———————————————————————————————————————————————————————————————————————————— ##
# ival        lb        ub         phz  prior     p1      p2        # parameter        #
  14.1      10.0      30.0         -3       0    0.0   999.0        # alpha males or combined
   0.0001    0.0       0.01        -3       0    0.0   999.0        # beta males or combined
   0.45      0.01      1.0         -3       0    0.0   999.0        # gscale males or combined
 121.5      65.0     145.0         -4       0    0.0   999.0        # molt_mu males or combined
```

```
   0.060     0.0       1.0        -3       0    0.0   999.0        # molt_cv males or combined

## ---------------------------------------------------------------------------------- ##
## SELECTIVITY CONTROLS                                                                ##
##     Each gear must have a selectivity and a retention selectivity. If a uniform    ##
##     prior is selected for a parameter then the lb and ub are used (p1 and p2 are   ##
##     ignored)                                                                        ##
## LEGEND                                                                              ##
##     sel type: 0 = parametric, 1 = coefficients, 2 = logistic, 3 = logistic95,      ##
##               4 = double normal (NIY)                                               ##
##     gear index: use +ve for selectivity, -ve for retention                         ##
##     sex dep: 0 for sex-independent, 1 for sex-dependent                            ##
## ---------------------------------------------------------------------------------- ##
## ivector for number of year periods or nodes                                        ##
## POT       TBycatch FBycatch  NMFS_S   ADFG_pot
## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
   2         1        1         1        1         # Selectivity periods
   0         0        0         0        0         # sex specific selectivity
   0         3        3         0        0         # male selectivity type
## Gear-1    Gear-2   Gear-3    Gear-4   Gear-5
   1         1        1         1        1         # Retention periods
   0         0        0         0        0         # sex specific retention
   3         2        2         2        2         # male retention type
   1         0        0         0        0         # male retention flag (0 -> no, 1 -> yes)
## gear  par   sel                                                  phz    start  end    ##
## index index par sex  ival          lb    ub  prior     p1     p2  mirror period period   ##
# Gear-1
   1     1     1   0    0.4    0.001 1.0    0       0      1     3     1978   2008
   1     2     2   0    0.7    0.001 1.0    0       0      1     3     1978   2008
   1     3     3   0    1.0    0.001 2.0    0       0      1    -2     1978   2008
   1     1     1   0    0.4    0.001 1.0    0       0      1     3     2009   2017
   1     2     2   0    0.4    0.001 1.0    0       0      1     3     2009   2017
   1     3     3   0    1.0    0.001 2.0    0       0      1    -2     2009   2017
# Gear-2
   2     7     1   0    40      10.0  200    0      10    200   -3     1978   2017
   2     8     2   0    60      10.0  200    0      10    200   -3     1978   2017
# Gear-3
   3     9     1   0    40      10.0  200    0      10    200   -3     1978   2017
   3    10     2   0    60      10.0  200    0      10    200   -3     1978   2017
# Gear-4
   4     8     1   0    0.7     0.001 1.0    0       0      1     4     1978   2017
   4     9     2   0    0.7     0.001 1.0    0       0      1     4     1978   2017
   4    10     3   0    0.9     0.001 1.0    0       0      1    -2     1978   2017
# Gear-5
   5    11     1   0    0.4     0.001 1.0    0       0      1     4     1978   2017
   5    12     2   0    0.7     0.001 1.0    0       0      1     4     1978   2017
   5    13     3   0    1.0     0.001 2.0    0       0      1    -2     1978   2017
## Retained
# Gear-1
  -1    14     1   0   120   100    200    0      1    900   -1     1978   2017
  -1    15     2   0   123   110    200    0      1    900   -1     1978   2017
# Gear-2
  -2    16     1   0   595     1    700    0      1    900   -3     1978   2017
  -2    17     2   0    10     1    700    0      1    900   -3     1978   2017
# Gear-3
  -3    18     1   0   590     1    700    0      1    900   -3     1978   2017
  -3    19     2   0    10     1    700    0      1    900   -3     1978   2017
# Gear-4
  -4    20     1   0   580     1    700    0      1    900   -3     1978   2017
  -4    21     2   0    20     1    700    0      1    900   -3     1978   2017
# Gear-5
  -5    22     1   0   580     1    700    0      1    900   -3     1978   2017
  -5    23     2   0    20     1    700    0      1    900   -3     1978   2017

## ---------------------------------------------------------------------------------- ##
```

```
## PRIORS FOR CATCHABILITY
##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
##     and p2 are ignored). ival must be > 0                                            ##
## LEGEND                                                                               ##
##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma               ##
## ------------------------------------------------------------------------------------ ##
##  LAMBDA: Arbitrary relative weights for each series, 0 = do not fit.
## SURVEYS/INDICES ONLY
## ival    lb       ub    phz   prior   p1       p2    Analytic?   LAMBDA
   1.0     0        2     -1    0       0        9.0   0           1       # NMFS trawl
0.00411135867487 0 5       1    0       0        9.0   0           1       # ADF&G pot
## ------------------------------------------------------------------------------------ ##

## ------------------------------------------------------------------------------------ ##
## ADDITIONAL CV FOR SURVEYS/INDICES                                                    ##
##     If a uniform prior is selected for a parameter then the lb and ub are used (p1   ##
##     and p2 are ignored). ival must be > 0                                            ##
## LEGEND                                                                               ##
##     prior: 0 = uniform, 1 = normal, 2 = lognormal, 3 = beta, 4 = gamma               ##
## ------------------------------------------------------------------------------------ ##
## ival        lb        ub        phz   prior     p1      p2
   0.0000001      0.00000001   10.0      -4    4         1.0     100   # NMFS
   0.0000001      0.00000001   10.0      -4    4         1.0     100   # ADF&G
## ------------------------------------------------------------------------------------ ##

## ------------------------------------------------------------------------------------ ##
## PENALTIES FOR AVERAGE FISHING MORTALITY RATE FOR EACH GEAR
## ------------------------------------------------------------------------------------ ##
## Mean_F  STD_PHZ1  STD_PHZ2     PHZ
   0.2       0.05     50.0       1   # Pot
   0.001     0.05     50.0       1   # Trawl
   0.001     0.05     50.0       1   # Fixed
   0.00      2.00     20.00     -1   # NMFS
   0.00      2.00     20.00     -1   # ADF&G
## ------------------------------------------------------------------------------------ ##

## ----------------------------------------------------------------------------------- ##
## OPTIONS FOR SIZE COMPOSTION DATA (COLUMN FOR EACH MATRIX)
## ------------------------------------------------------------------------------------ ##
## LIKELIHOOD OPTIONS
##   -1) Multinomial with estimated/fixed sample size
##   -2) Robust approximation to multinomial
##   -3) logistic normal (NIY)
##   -4) multivariate-t (NIY)
##   -5) Dirichlet
## AUTOTAIL COMPRESSION
##   pmin is the cumulative proportion used in tail compression.
## ------------------------------------------------------------------------------------ ##
#  1   1   1  # Type of likelihood
  2   2   2  # Type of likelihood
#  5   5   5   # Type of likelihood
  0   0   0   # Auto tail compression (pmin)
  1   1   1   # Initial value for effective sample size multiplier
 -4  -4  -4   # Phz for estimating effective sample size (if appl.)
  1   2   3   # Composition aggregator
  1   1   1   # LAMBDA
## ------------------------------------------------------------------------------------ ##

## ------------------------------------------------------------------------------------ ##
## TIME VARYING NATURAL MORTALIIY RATES                                                 ##
## ------------------------------------------------------------------------------------ ##
## TYPE:
##      0 = constant natural mortality
##      1 = Random walk (deviates constrained by variance in M)
##      2 = Cubic Spline (deviates constrained by nodes & node-placement)
```

```
##      3 = Blocked changes (deviates constrained by variance at specific knots)
##      4 = Time blocks
## ---------------------------------------------------------------------------------- ##
## Sex-specific? (0=no, 1=yes)
0
## Type
3
## Phase of estimation
4
## STDEV in m_dev for Random walk
10.0
## Number of nodes for cubic spline or number of step-changes for option 3
2
0 # Females (ignored if single sex...)
## Year position of the knots (vector must be equal to the number of nodes)
1998 1999
# 1976 1980 1985 1994 # Females (ignored if single sex...)
## ---------------------------------------------------------------------------------- ##

## ---------------------------------------------------------------------------------- ##
## OTHER CONTROLS
## ---------------------------------------------------------------------------------- ##
  3       # Estimated rec_dev phase
  3       # Estimated rec_ini phase
  0       # VERBOSE FLAG (0 = off, 1 = on, 2 = objective func)
  2       # Initial conditions (0 = Unfished, 1 = Steady-state fished, 2 = Free parameters)
  1978    # First year for average recruitment for Bspr calculation
  2016    # Last year for average recruitment for Bspr calculation
  0.35    # Target SPR ratio for Bmsy proxy
  1       # Gear index for SPR calculations (i.e. directed fishery)
  1       # Lambda (proportion of mature male biomass for SPR reference points)
  1       # Use empirical molt increment data (0 = FALSE, 1 = TRUE)
  0       # Stock-Recruit-Relationship (0 = None, 1 = Beverton-Holt)
## EOF
9999
```