Saint Matthew Island Blue King Crab Stock Assessment Update for Spring 2015

Jie Zheng, ADF&G, Juneau
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Preamble

1. Due to pending personnel change, I updated this SAFE report to address CPT and SSC review comments in September and October 2014, compared the current and new time series of NMFS survey area-swept abundance estimates, and propose a model scenario that does not have systematic residual patterns for the September 2015 assessment.

2. For time-saving reading and comparison, this update does not contain a full SAFE report. This update is mostly new information and results, except the Appendix, which is revised from the SAFE report in September 2014.

3. The base scenario for this update is the Model T adopted by the CPT and SSC for the stock assessment in September 2014. Model T is renamed as scenario 0 in this update.

A. Responses to SSC and CPT Comments

CPT and SSC Comments Specific to SMBKC Stock Assessment

Fall 2014 CPT
Comment: *The CPT requested further investigation of the time-varying selectivity, including further explanation/investigation of plausible explanations. Research needs include better molting probability information for the two smaller stages (of the three used in the model).*

Response: See following author response to Fall 2014 SSC comments.

Fall 2014 SSC
Comment: *The CPT had a number of recommendations for future model explorations and the SSC agrees with these recommendations. The SSC appreciates the author providing a likelihood profile on the natural mortality rate and recommends further model explorations on model fit to each data component as natural mortality rate changes. The SSC also requests the author explore the inclusion of potential environmental variables such as nearshore temperature data as an explanation for the temporally patterned residuals in the survey composition data. The mechanism might be environmentally-driven changes in biological factors such as growth or mortality or simply changes in the availability of different life stages to the survey. Any available data that might distinguish these phenomena should be examined.*

Response: This author shares the comments made by the CPT and SSC and thinks that addressing these issues is important to improve the model. Unfortunately, due to very short time to work on this update due to the recent pending personnel change, I have not been able to satisfactorily address all these issues.

Near-shore bottom temperatures from NMFS summer surveys are obtained to create an annual temperature index during 1978-2014. Spatial NMFS survey data are examined and are used to estimate distribution centers for different stages of crab. The patterns of crab distribution centers and temperature index over time are examined, and the association between the crab distribution centers and temperature index is investigated. It appears that crab distributions are somewhat affected by the temperatures, but the association is generally weak.

Doug Pengilly has examined the crab spatial patterns from NMFS trawl surveys and ADF&G pot surveys and their associations with bottom temperatures in much greater detail than this update. His work can continue to provide information for future model improvement.

Both trawl survey selectivity and molting probability may be implicated as reasons for the systematic residual patterns in the models presented in 2014. Based on the results of Model ST with trawl survey selectivities and the random walk approach on molting probability, a reasonable approach is to have different selectivities and molting probabilities for two different periods separated in about 2000, after the 1999 crash. A better fit is also achieved by dividing selectivity into two periods, 1978-1999 and 2000-2014 and similarly for molting probability with 1978-2000 and 2001-2014.

The systematic residual patterns for stage-composition data can be satisfactorily addressed with one to four additional parameters from Model T, far fewer parameters than Model ST. However, the model retrospective patterns of biomass could not be satisfactorily addressed in this update; the patterns are primarily caused by the two or three high abundance tows. It is difficult to deal with the high abundance tows in a three stage model. Future investigation may include development of a five or six stage model, like Norton Sound red king crab model, to see whether it can improve the model retrospective patterns.

B. New Data

Spatial trawl survey and bottom temperatures from 1978 to 2014 are used in this update.

C. Temporal Changes in Bottom Temperatures and Crab Distributions

There are eight NMFS survey stations (R23, R24, R25, Q23, Q25, P23, P24, and P25) around St. Matthew Island (Figure 1). If three (O23, O24 and O25), or another six more stations (N23, N24 and N25), are added, there are either 11 stations or 14 stations (Figure 1). Mean bottom temperatures for these 8, 11 and 14 stations have nearly uniform temporal trends (Figure 2). The mean temperatures from the 14 stations are used as the temperature index in this report.

Distribution centers for three stage crab and mature males (stage 2 plus stage 3) are illustrated in Figure 3. In general, crab in stage 3 (legal crab) occur in more southern area, and crab in stage 1 more northern area, but the differences are very small. Associations between latitudes and longitudes of distribution centers of three stages of crab and bottom temperatures are positive, with crab occurring more northeastern areas in warm temperatures (Figures 4-6); however, the relationships are generally weak.

D. Model Scenarios

Eight model scenarios are considered, six for the current time series of NMFS survey area-swept estimates and two for the new time series:

0. This is renamed from Model T, which was selected by the CPT and SSC in September/October, 2014.
1. Effective sample sizes are determined differently from scenario 0. With scenario 0, effective sample sizes are equal to min(N, observed values), where N is 50 for trawl surveys and 100 for pot surveys and pot fishery bycatch. The drawback with this approach is that some observed values are 1-to-1 to effective sample size and some observed values are more than 10 to 1. Also, effective sample sizes for the pot fishery bycatch should not be 100% more than those of the trawl surveys, since the observer coverages are not very good for this fishery, especially for the early data. An approach modified from The Bristol Bay red king crab approach is used here: **effective sample size = min(N, 0.5*observed values) *min(1.0,s/CV)** for the surveys and **= min(N, 0.1*observed values)** for the pot fishery observer data, where N is 50 and s is 0.3 for the trawl surveys; and N is 50 for the observer data and N is 100 and s = 0.13 for the pot surveys. The 0.3 and 0.13 are about the median CV of the surveys. A higher CV results in a lower effective sample size. Besides effective sample sizes, length composition likelihood is computed by the robust normal approximation. There are only three stages, and stage 3 has about 50% of stage compositions. I prefer the robust normal approximation over the multinomial, although the difference between them is small. Scenario 1 is the same as scenario 0 except for these two changes.
2. The same as scenario 1 except that a random walk approach is used to estimate annual molting probabilities for stage 1 and molting probabilities for stage 2 are determined by the ratio of molting probabilities between stages 1 and 2 from the tagging data. An annual transition matrix is created by combining the molting probabilities of stages 1 and 2 and the growth matrix from Zheng and Kruse (2002). An additional CV is estimated for the pot survey CPUE index to address the narrow confidence intervals of the index.
3. The same as scenario 2 except that the annual trawl survey catachability is estimated from the near-shore bottom temperatures using the approach of Wilderbuer et al. (2013): $Q = exp(-a+b*T)$, where a and b are parameters and T is temperature.
4. The same as scenario 2 except that (i) molting probabilities are 0.91 and 0.63 for respective stages 1 and 2 during 1978-2000 based on tagging data (Otto and Cummiskey 1990) during that period and are estimated in the model for stage 1 and using the estimated stage-1 value and the molting probability ratio between stage 1 and 2 to derive values for stage 2 during 2001-2014; and (ii) trawl survey selectivities are estimated separately during 1978-1999 and 2000-2014. The period separations are determined by the results of scenario 2 for molting probabilities and by the results of Model ST for trawl

survey selectivities.

5. The same as scenario 4 except that the annual trawl survey catachability is estimated from the near-shore bottom temperatures like scenario 3.

In addition to these six scenarios using the current time series of NMFS survey area-swept estimates, scenarios 0 and 4 are run with the new time series of NMFS survey area-swept estimates and named them as scenarios 0n and 4n.

E. Model Results

Observed and effective sample sizes are compared in Table 1. Estimated parameters are summarized in Table 2 for scenarios 0 and 4, negative log likelihoods and management measures are compared in Table 3 for all eight scenarios, and estimated population abundances and biomasses are listed in Table 4 for scenarios 0 and 4. Model estimated relative survey biomasses are very similar among scenarios 2, 3, 4, and 5 and are very close between scenarios 0 and 1 (Figure 7). Estimated pot survey CPUEs are also similar among scenarios 2, 3, 4, and 5 and differ from scenarios 0 and 1 (Figure 8). Estimated trawl survey catchabilities from bottom temperatures with scenarios 3 and 5 do not improve the fits from scenarios 2 and 4, respectively (Table 3). Scenario 4 with relatively few number of parameters fits the data best statistically among all scenarios considered.

There are strong temporal patterns for residuals of total trawl survey biomass and stage composition data for scenario 0 (Figures 9 and 11) and there are no apparent residual patterns for scenario 4 (Figures 10 and12). Although they are not shown in this update, the residual patterns for scenarios 2, 3, and 5 are similar to those of scenario 4 and do not have any apparent trends.

Estimated recruitments to the model vary greatly over time (Figure 13). Estimated mature male biomasses on Feb. 15 also fluctuate strongly over time (Figure 14). Estimated recruitments during recent years are generally low.

Estimated trawl survey selectivities and molting probabilities are generally confounded. The fixed higher molting probabilities with scenario 0 are associated with higher trawl survey selectivities estimates and the estimated lower molting probabilities with scenario 2 result in lower estimated trawl survey selectivities (Figures 15 and 16). To reduce the confounding, molting probabilities during 1978-2000 are fixed at the values estimated from tagging data during the same period for scenarios 4 and 5. Molting probabilities used for scenarios 0 and 1 are higher than scenarios 2-5 (Figure 16).

Estimated trawl survey catchabilities from near-shore bottom temperatures do not improve the model fit. Estimated catchabilities with scenario 3 are generally less than 1.0 while estimated catchabilities with scenario 5 are higher than 1.0 (Figure 17).

Retrospective results with scenario 4n are very good except during 2010-2012 (Figures 18 and 19). Since the results are about the same between scenarios 4 and 4n, I used scenario 4n for retrospective analysis. Scenario 4n, as well as all other scenarios, could not account for the high abundances mainly due to two or three high abundance tows during these years, although they generally perform slightly better than Model ST.

In summary, scenario 4 with a low number of parameters fits the data best statistically among all scenarios considered. (I also investigated a few more scenarios other than the eight scenarios in this update, but their results are not as good as scenario 4). I recommend scenario 4 to be used for overfishing/overfished determination in September 2015.

F. Comparison of Results from Current and New Time Series

Estimates of total male trawl survey biomasses, pot survey CPUEs, recruitments and mature male biomasses on Feb. 15 are almost identical between scenarios 0 and 0n and between scenarios 4 and 4n (Figures 20-23).

G. References

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Table 1. Observed and effective sample sizes for trawl survey, pot survey, and observer data of the directed pot fishery.

	Observed Sample Sizes			Effective Sample Sizes Scenario 0			Effective Sample Sizes Scenarios 1-5		
Year	Trawl	Pot	Observer	Trawl	Pot	Observer	Trawl	Pot	Observer
1978	163			50			38.3		
1979	187			50			37.2		
1980	188			50			29.7		
1981	140			50			37.2		
1982	269			50			43.7		
1983	231			50			50		
1984	104			50			50		
1985	93			50			46.5		
1986	46			46			17.9		
1987	71			50			35.5		
1988	81			50			40.5		
1989	211			50			50		
1990	170		150	50		100	50		15
1991	198		3393	50		100	50		50
1992	220		1606	50		100	50		50
1993	324		2241	50		100	50		50
1994	211		4735	50		100	50		50
1995	178	4624	663	50	100	100	50	100	50
1996	285		489	50		100	50		48.9
1997	296		3195	50		100	44.5		50
1998	243	4812	1323	50	100	100	42.3	100	50
1999	52			50			26		
2000	61			50			29.5		
2001	91	3255		50	100		45.5	100	
2002	38			38			17.8		
2003	65			50			29.1		
2004	48	640		48	100		23.7	86.7	
2005	42			42			17		
2006	126			50			44.9		
2007	250	3319		50	100		39.1	100	
2008	167			50			50		
2009	251		19802	50		100	50		50
2010	385	3920	45466	50	100	100	32.2	100	50
2011	315		58667	50		100	26.9		50
2012	193		57282	50		100	44.2		50
2013	74	2167		50	100		37	68.4	
2014	181			50			33.4		

Table 2. Model parameter estimates and standard deviations for scenarios 0 and 4. Ranges are given for log recruit, log fishing mortality and log trawl-survey selectivity deviations.

	Scenario 0		Scenario 4	
parameter	estimate	standard dev.	estimate	standard dev.
1998/99 natural mortality	0.938	0.121	1.473	0.236
pot-survey catchability	4.840	0.388	3.924	0.772
trawl-survey stage-1 selectivity (1978-2014)	0.618	0.042		
trawl-survey stage-2 selectivity (1978-2014)	0.857	0.051		
trawl-survey stage-1 selectivity (1978-1999)			0.441	0.040
trawl-survey stage-2 selectivity (1978-1999)			0.575	0.042
trawl-survey stage-1 selectivity (2000-2014)			0.453	0.083
trawl-survey stage-2 selectivity (2000-2014)			0.705	0.094
pot-survey stage-1 selectivity	0.268	0.041	0.152	0.031
pot-survey stage-2 selectivity	0.649	0.068	0.414	0.048
pot-fishery stage-1 selectivity	0.302	0.031	0.223	0.033
pot-fishery stage-2 selectivity	0.468	0.039	0.343	0.035
molting probability for stage 1 (2001-2014)			0.512	0.056
additional cv for pot survey			0.401	0.158
log initial stage-1 abundance	8.137	0.204	7.993	0.200
log initial stage-2 abundance	7.746	0.222	7.650	0.209
log initial stage-3 abundance	7.333	0.242	6.900	0.253
mean log recruit abundance	6.820	0.051	6.974	0.071
mean log recruit abundance deviations (36)	[-2.01, 1.40]	[0.15, 0.53]	[-1.34, 1.18]	[0.17, 0.55]
mean log pot-fishery fishing mortality	-1.259	0.058	-1.118	0.064
log pot-fishery fishing mortality dev. (25)	[-3.23, 1.31]	[0.08, 0.27]	[-3.12, 1.46]	[0.09, 0.32]
mean log GF trawl-gear fishing mortality	-10.339	0.223	-10.518	0.228
log GF trawl-gear fishing mortality dev. (23)	[-1.76, 1.63]	[0.70, 0.72]	[-1.75, 1.53]	[0.70, 0.72]
mean log GF fixed-gear fishing mortality	-9.549	0.219	-9.733	0.224
log GF fixed-gear fishing mortality dev. (23)	[-2.25, 2.57]	[0.69, 0.70]	[-2.14, 2.46]	[0.69, 0.70]

Table 3. Comparisons of negative log-likelihood values and management measures for eight model scenarios. Note that scenarios 0n and 4n are the same as scenarios 0 and 4 except that scenario 0n and 4n use the new time series data, and all other scenarios use the current time series data.

Model Scenario

Scenarios (sc)/Neg.log.LL	0	0n	1	2	3	4	4n	5	Sc3-Sc2	Sc4-Sc2	Sc5-Sc2
Ret catch	0.398	0.397	0.363	0.025	0.019	0.024	0.024	0.029	-0.005	-0.001	0.005
Trawl bio	33.211	33.204	33.343	22.903	22.997	24.756	24.425	23.769	0.094	1.853	0.866
Pot CPUE	62.369	62.457	61.478	-1.183	-1.143	-1.494	-1.498	-1.453	0.040	-0.311	-0.270
Trawl length	1872.10	1871.55	-130.94	-151.46	-152.11	-153.66	-153.71	-153.50	-0.649	-2.196	-2.035
Pot length	611.979	611.983	-40.280	-41.018	-41.267	-40.960	-40.948	-40.752	-0.249	0.059	0.266
Obser length	1228.06	1228.08	-54.825	-57.724	-57.642	-57.538	-57.562	-57.504	0.081	0.186	0.220
Trawl byc bio	15.695	15.694	15.678	15.654	15.663	15.823	15.842	15.716	0.010	0.170	0.063
Fix-g. byc bio	17.552	17.549	17.625	16.240	16.356	16.578	16.574	16.496	0.116	0.338	0.256
Rec Pen	11.988	12.043	12.067	8.526	8.367	8.499	8.544	8.856	-0.159	-0.027	0.330
Direct F pen	0.012	0.011	0.011	0.012	0.011	0.011	0.011	0.011	0.000	-0.001	0.000
Trawl by F pen	12.238	12.238	12.220	12.217	12.226	12.369	12.387	12.273	0.008	0.152	0.055
Fix-g by F pen	15.917	15.916	15.984	14.453	14.565	14.784	14.781	14.703	0.113	0.332	0.251
Molting pen	0.000	0.000	0.000	2.894	2.746	0.000	0.000	0.000	-0.149	-2.894	-2.894
Total	3881.52	3881.12	-57.277	-158.46	-159.22	-160.81	-161.13	-161.35	-0.751	-2.342	-2.890
Tot est param	122	122	122	160	162	126	126	128	2	-34	-32
Bmsy(mi.lbs)	7.793	7.727	7.859	8.262	9.410	7.729	7.672	7.135	1.148	-0.533	-1.127
MMB2015	7.063	7.090	7.177	8.038	9.251	7.446	7.465	7.049	1.213	-0.592	-0.989
OFL2015	1.046	1.065	1.080	1.063	1.276	1.012	1.024	0.963	0.213	-0.051	-0.100
Fofl	0.161	0.164	0.163	0.175	0.177	0.173	0.175	0.176	0.002	-0.002	0.001

Table 4. Population abundances (N) by crab stage in thousands of crab, mature male biomasses at survey (MMB) in thousands of pounds on Feb. 15 for scenarios 0 and 4. All abundances are at time of survey.

	Scenario 0				Scenario 4			
Year	N1	N2	N3	MMB	N1	N2	N3	MMB
1978	3419.0	2311.1	1530.5	9581.7	2960.3	2100.7	992.4	6908.9
1979	4282.8	2715.2	2036.3	13259.2	3927.5	2577.7	1413.6	10731.1
1980	4133.8	3404.7	3013.2	19853.3	3872.0	3416.7	2339.9	17158.3
1981	1639.8	3551.3	4192.9	20359.6	1793.0	3693.4	3524.7	18057.2
1982	1669.1	2102.6	4359.7	14427.6	1785.4	2443.3	3756.7	12730.0
1983	998.1	1622.3	3017.4	8088.6	853.8	1964.5	2603.2	7038.0
1984	805.2	1069.5	1641.6	5482.0	711.0	1203.9	1400.8	4819.7
1985	1350.9	795.8	1167.8	4971.2	1012.4	859.5	994.4	4343.6
1986	1370.2	1027.8	986.7	5415.4	1401.6	931.4	846.3	4631.4
1987	1600.2	1126.1	1140.4	6238.2	1425.1	1209.2	947.0	5640.6
1988	1565.2	1293.0	1311.6	6940.6	1360.2	1325.3	1152.9	6396.8
1989	3626.7	1326.1	1490.7	8197.1	2752.6	1326.5	1333.1	7542.6
1990	1516.5	2534.5	1687.6	10753.0	1745.6	2202.1	1514.8	9343.3
1991	1957.2	1701.8	2317.4	10297.8	1954.4	1881.5	1942.7	9147.3
1992	2045.3	1673.3	2139.5	10159.7	2067.0	1883.7	1854.5	9482.0
1993	2734.3	1722.1	2139.6	10178.0	2647.6	1963.0	1945.4	9897.6
1994	2131.1	2128.3	2083.4	9714.7	2270.7	2348.9	1977.7	9788.8
1995	1857.4	1899.2	2057.3	10055.5	2388.6	2241.2	2004.6	10605.1
1996	1542.0	1679.0	2071.8	9540.7	1960.4	2286.8	2125.3	11135.9
1997	1103.5	1427.6	1981.3	7642.3	1662.8	2039.7	2252.8	10206.7
1998	852.6	1081.6	1536.9	3502.0	1372.3	1755.2	1998.3	3892.6
1999	396.5	388.3	549.9	3126.4	443.4	404.8	487.2	2909.2
2000	401.2	361.5	653.8	3487.8	579.1	428.2	596.4	3407.4
2001	403.5	355.4	727.3	3771.9	744.5	522.5	698.7	4039.2
2002	190.1	354.6	785.5	4006.5	619.1	562.8	721.1	4222.6
2003	426.2	229.6	833.6	3915.2	971.1	541.4	750.4	4292.3
2004	320.4	325.8	811.2	4045.1	783.2	653.9	769.1	4627.2
2005	534.4	296.2	840.7	4097.4	1284.2	651.7	814.5	4806.8
2006	926.9	411.4	850.6	4400.8	2058.4	828.2	851.9	5362.6
2007	866.4	679.2	916.3	5279.1	2005.4	1203.4	929.4	6535.3
2008	1412.5	732.8	1104.7	6171.3	3273.3	1398.6	1092.3	7648.8
2009	1236.8	1070.4	1289.6	7119.7	2345.7	1960.5	1280.4	9119.5
2010	1319.9	1073.7	1515.0	6905.7	2259.1	1942.8	1488.6	8791.1
2011	1100.6	1112.9	1520.2	6471.4	1595.4	1887.7	1476.7	8076.7
2012	752.9	992.0	1410.8	6004.0	1184.1	1613.5	1322.4	7086.9
2013	1044.3	754.7	1316.0	7081.7	1477.4	1317.3	1176.5	7805.5
2014	815.3	862.7	1477.3	7063.0	1330.7	1277.3	1329.4	7446.0

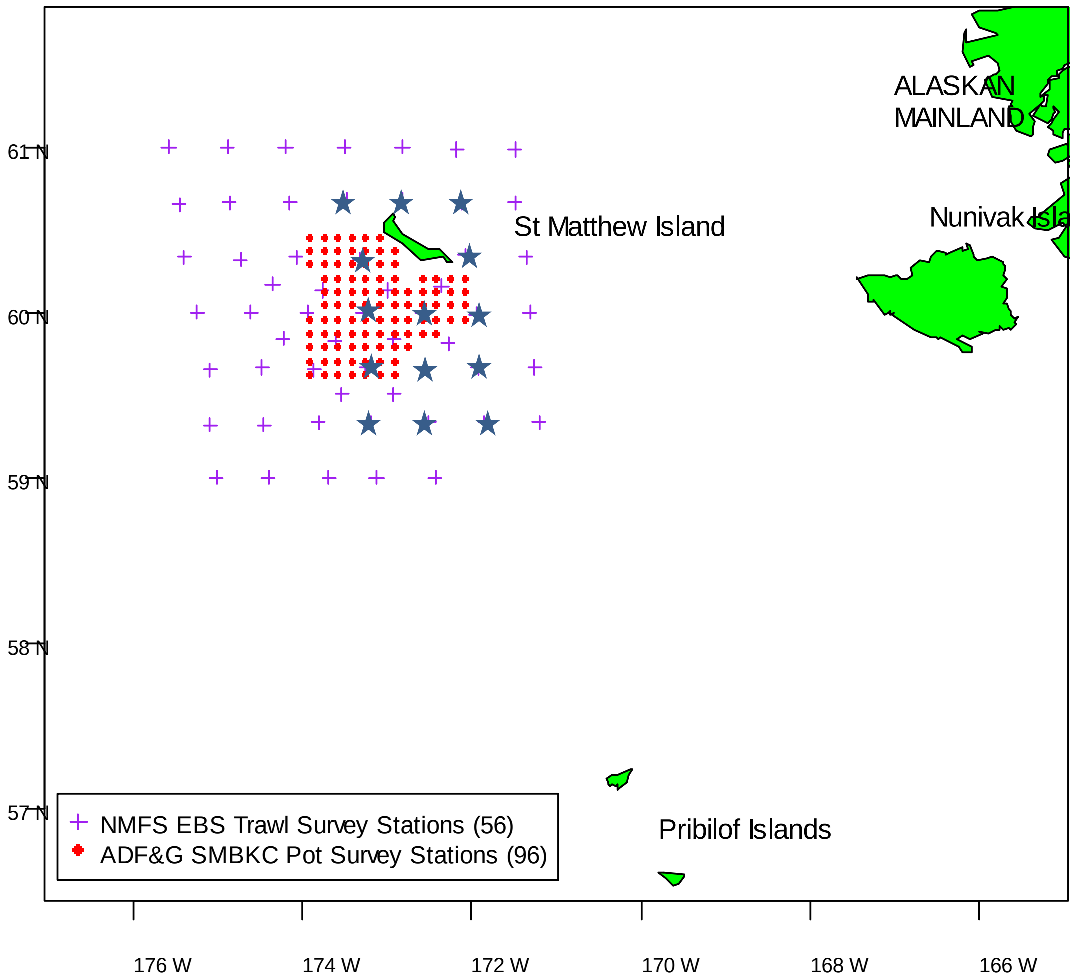


Figure 1. Trawl and pot-survey stations used in the St. Mathew Island blue king crab stock assessment. The stations with ★ are used for bottom temperature indices.

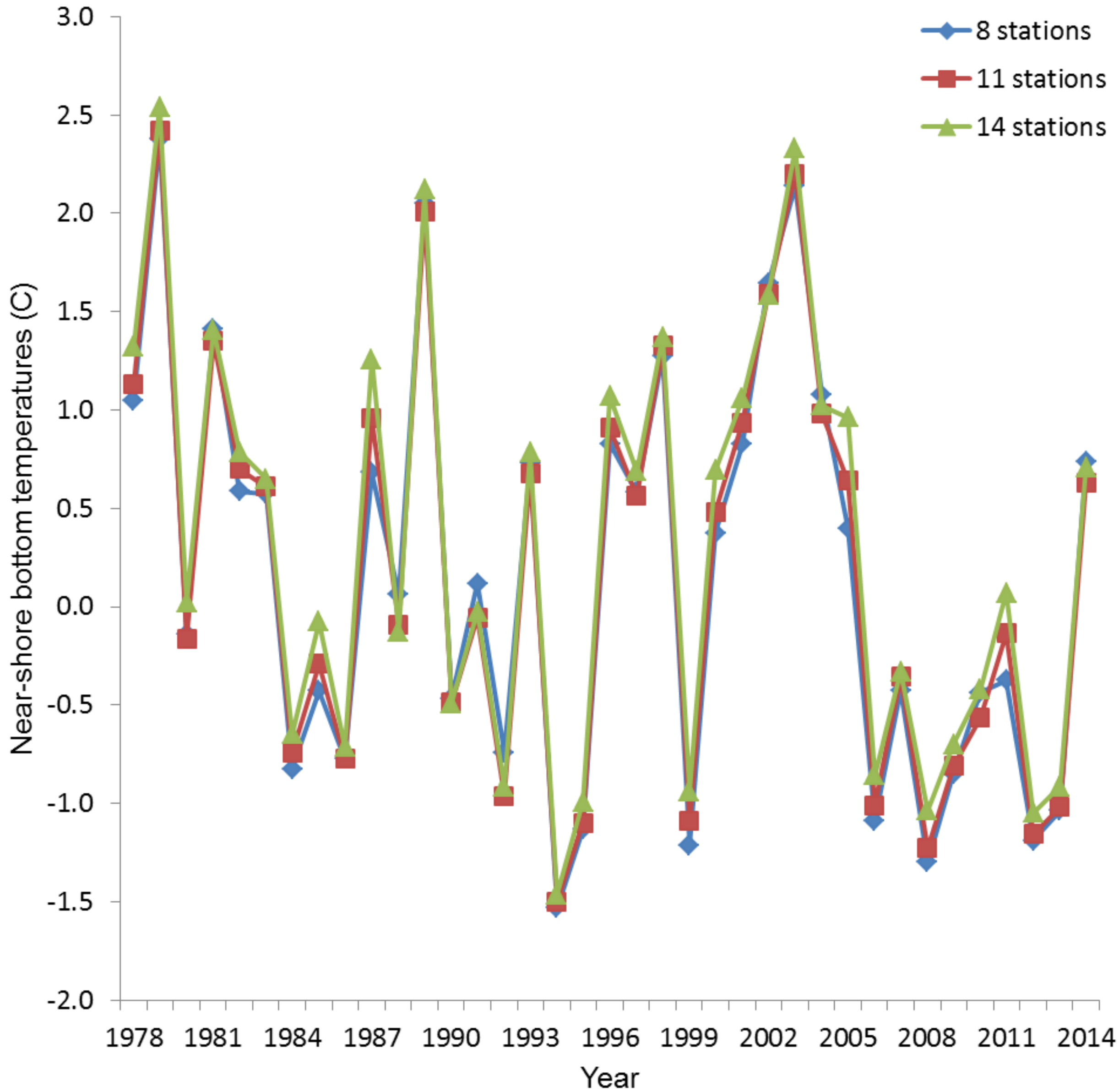


Figure 2. Mean near-shore bottom temperatures within 8, 11, and 14 NMFS survey stations around St. Matthew Island.

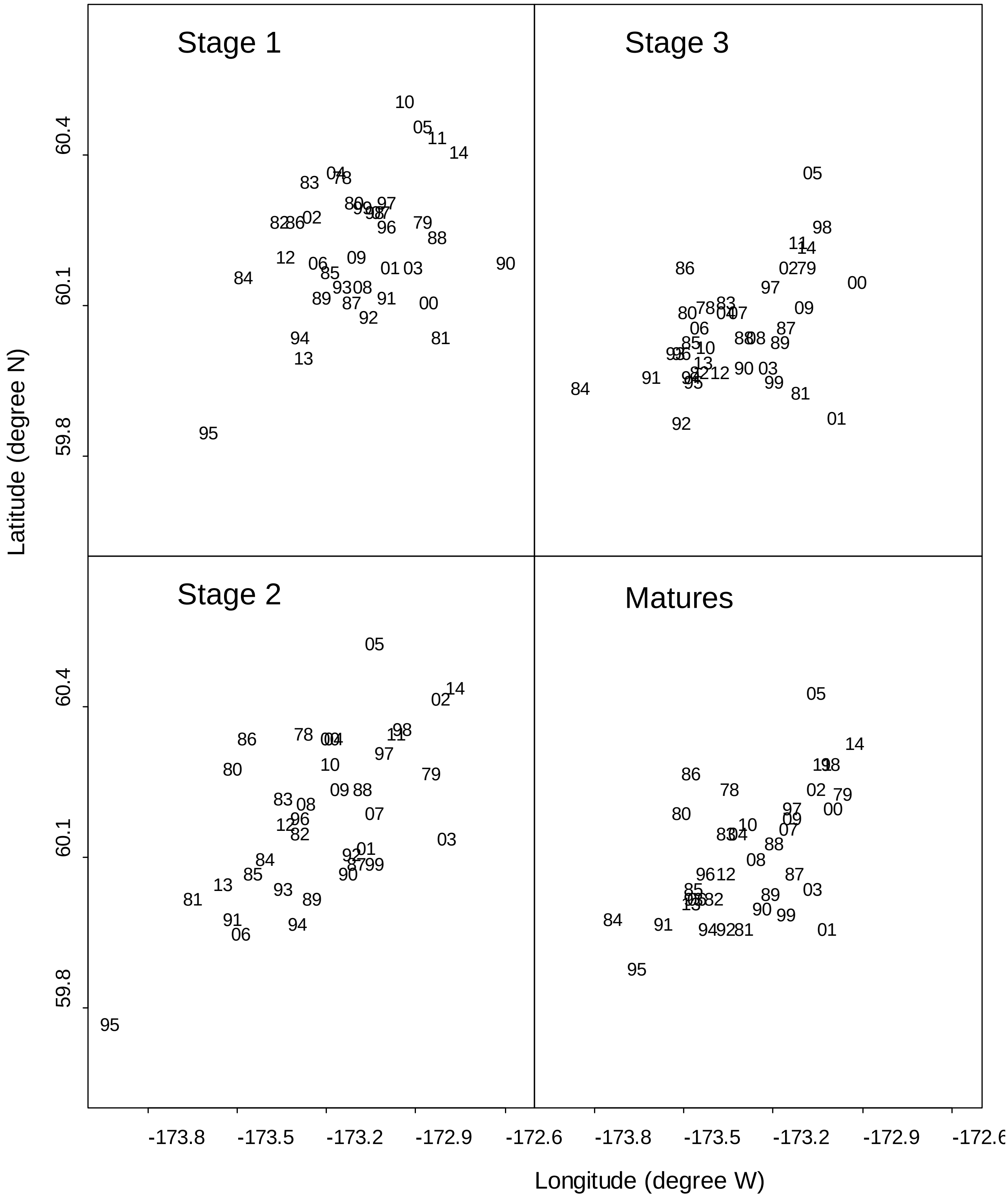
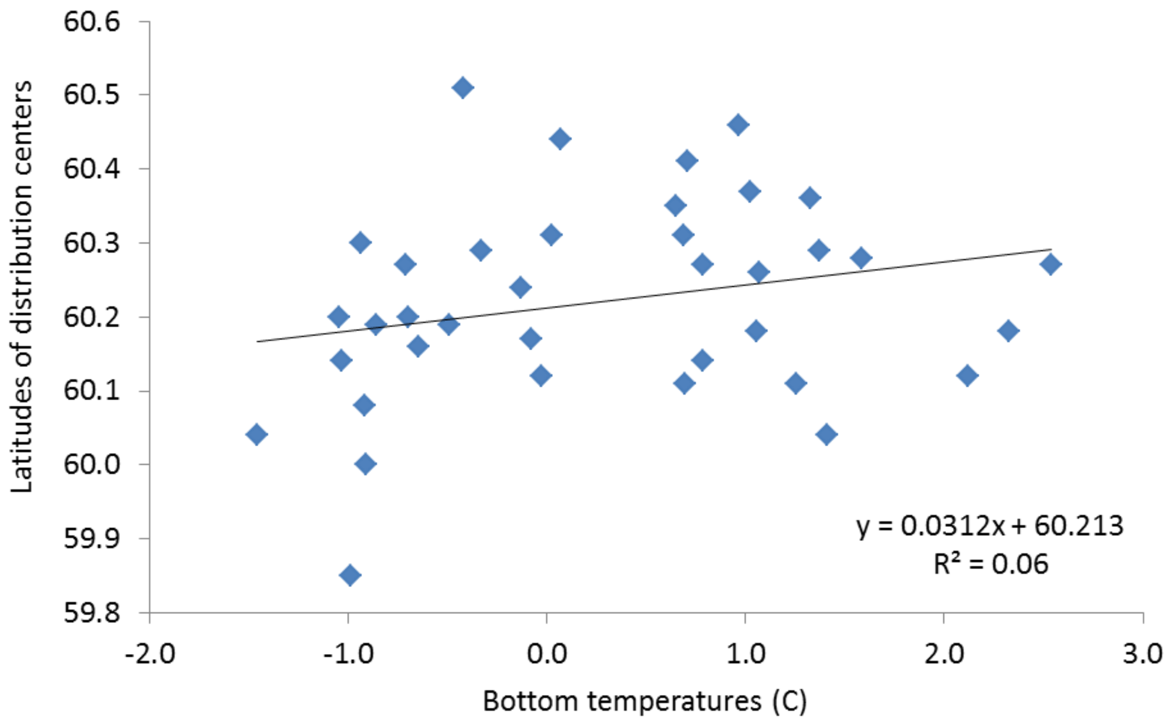


Figure 3. Distribution centers by stage defined by carapace length (CL) (1. 90-104 mm CL, 2. 105-119 mm CL, 3. ≥120 mm CL) for male St. Matthew blue king crab from NMFS summer trawl surveys. Mature males are a combination of stages 2 and 3.



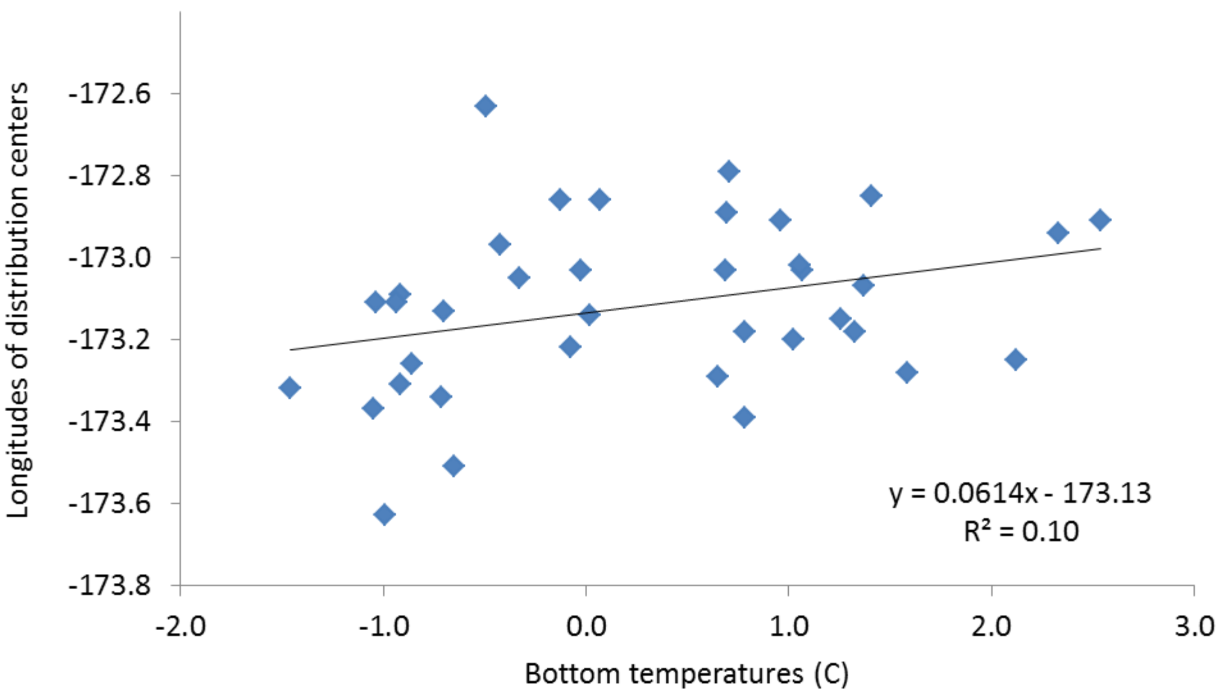


Figure 4. Relationships between annual latitudes and longitudes of stage 1 (90-104 mm carapace length) distribution centers and bottom temperatures for St. Matthew Island blue king crab.

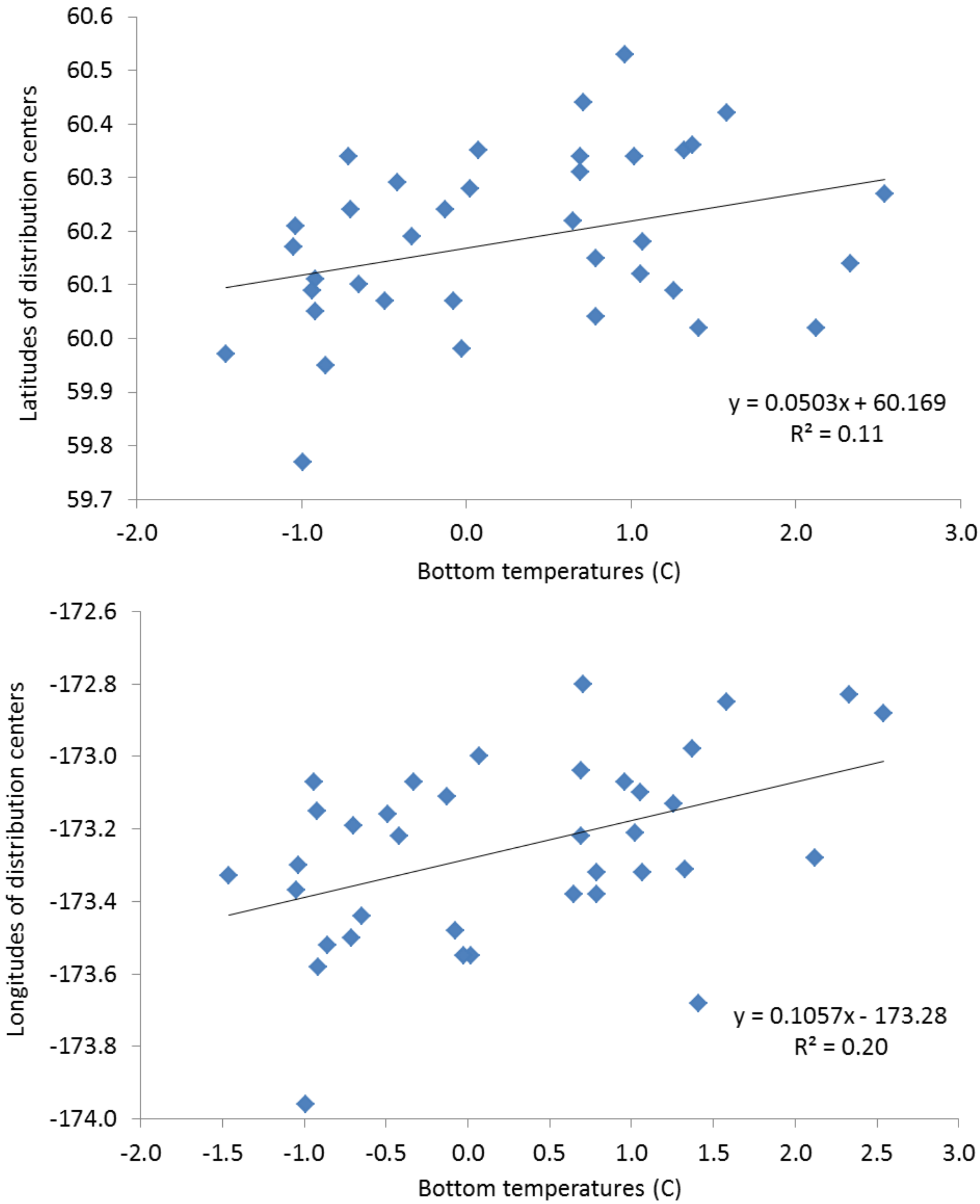
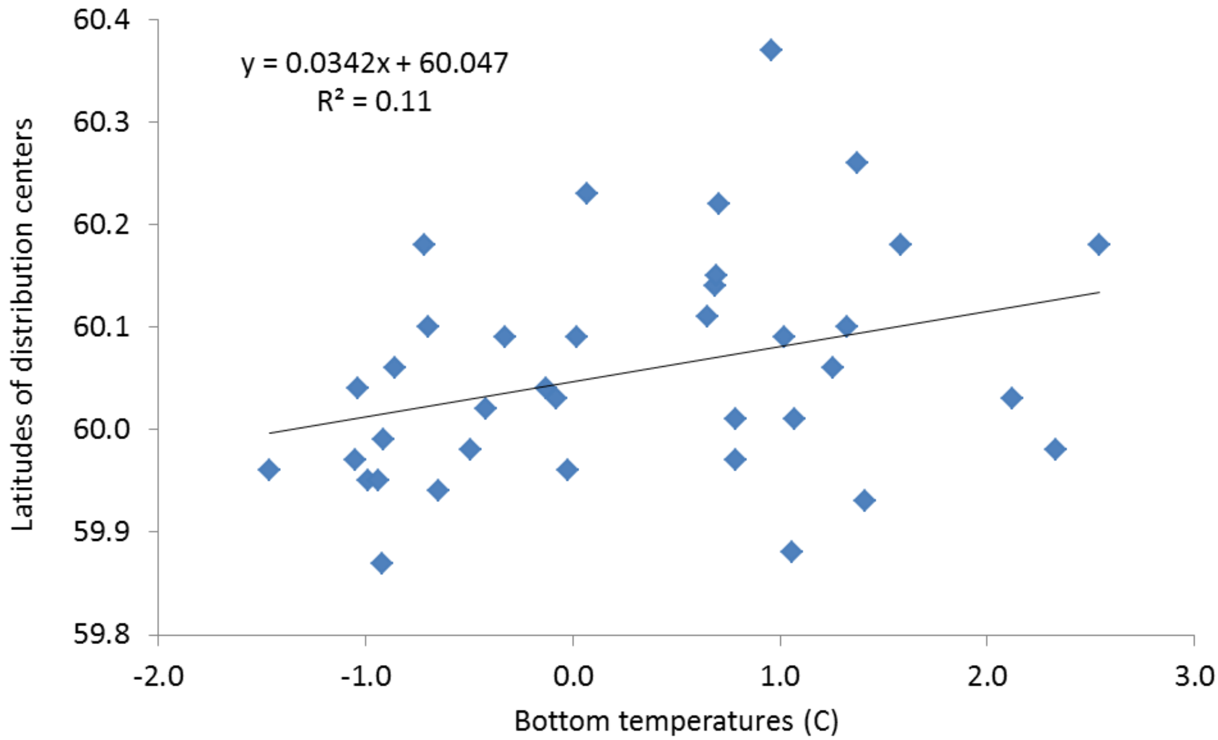


Figure 5. Relationships between annual latitudes and longitudes of stage 2 (105-119 mm carapace length) distribution centers and bottom temperatures for St. Matthew Island blue king crab.



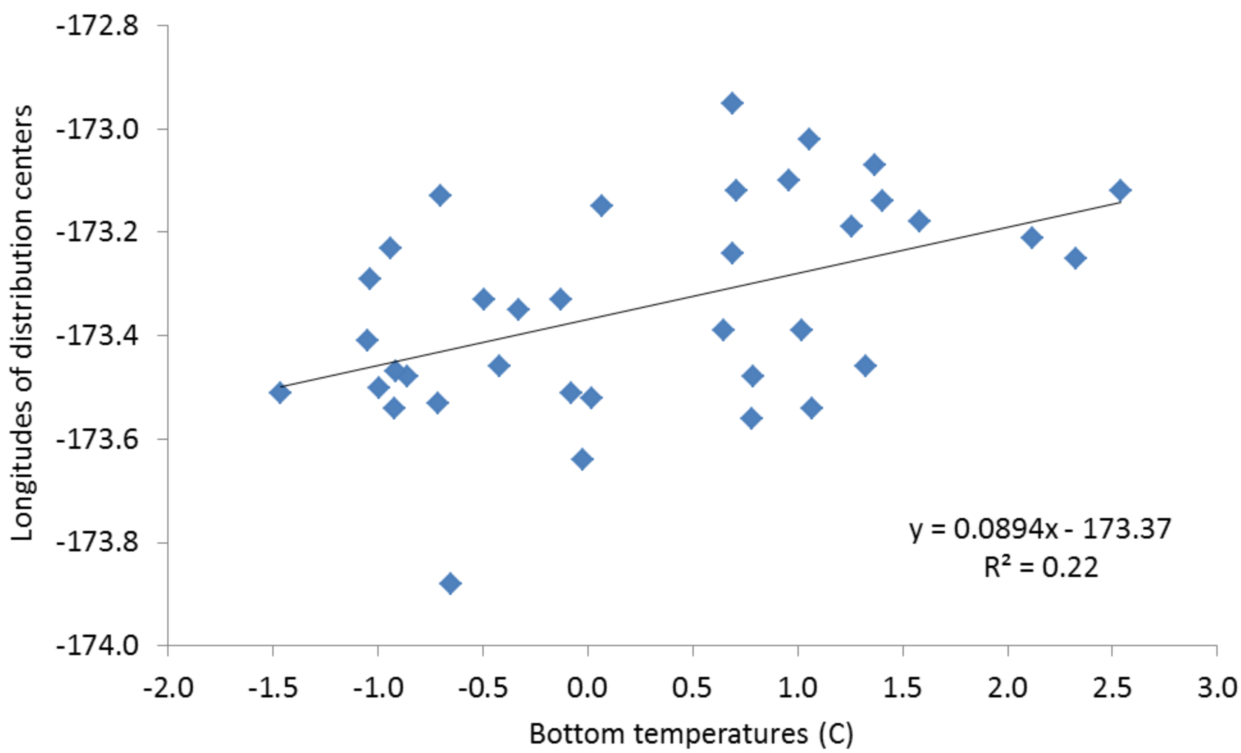


Figure 6. Relationships between annual latitudes and longitudes of stage 3 (≥120 mm carapace length) distribution centers and bottom temperatures for St. Matthew Island blue king crab.

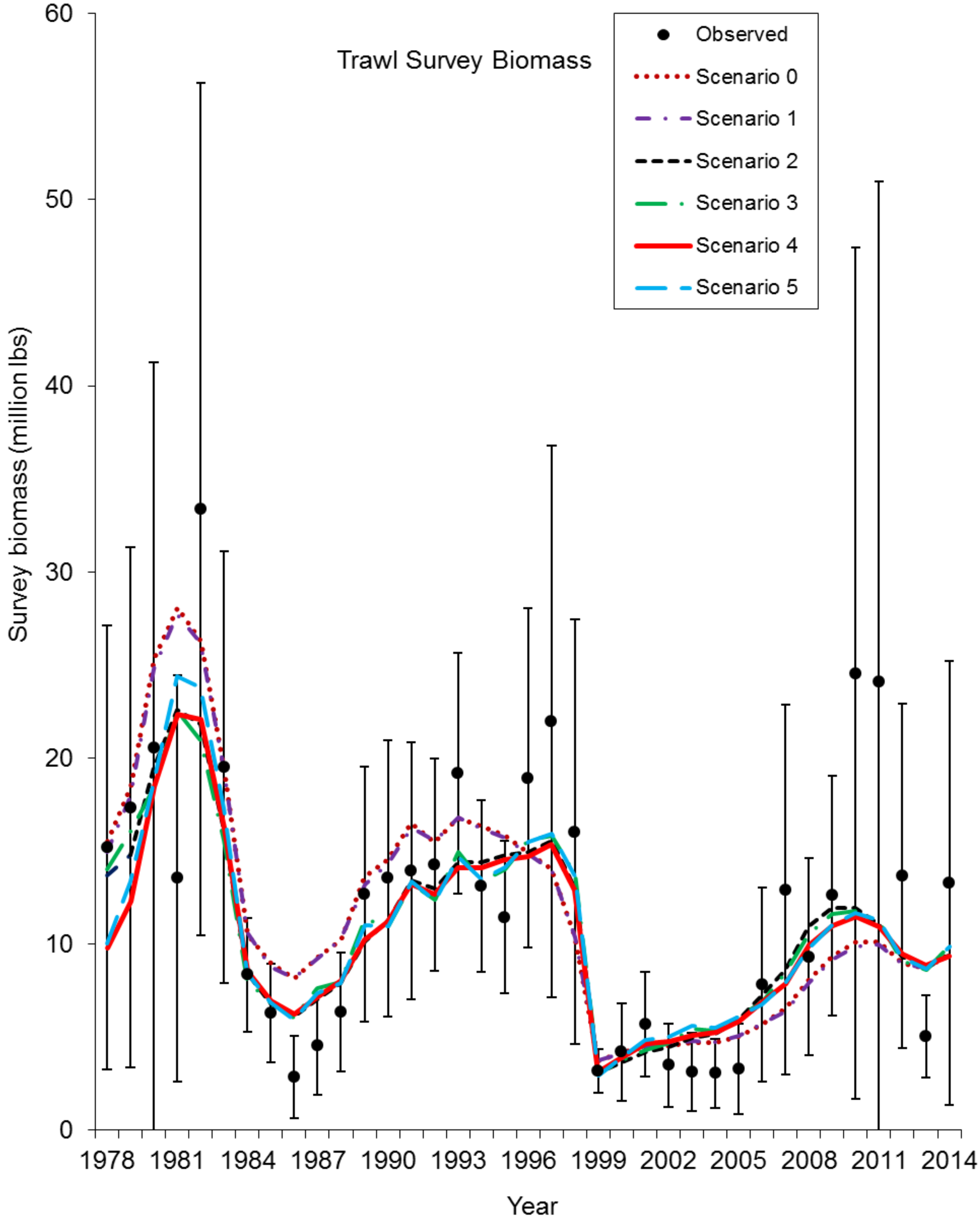


Figure 7. Comparisons of area-swept estimates of total male survey biomasses and model predictions for 2014 model estimates under scenarios 0-5. The error bars are plus and minus 2 standard deviations.

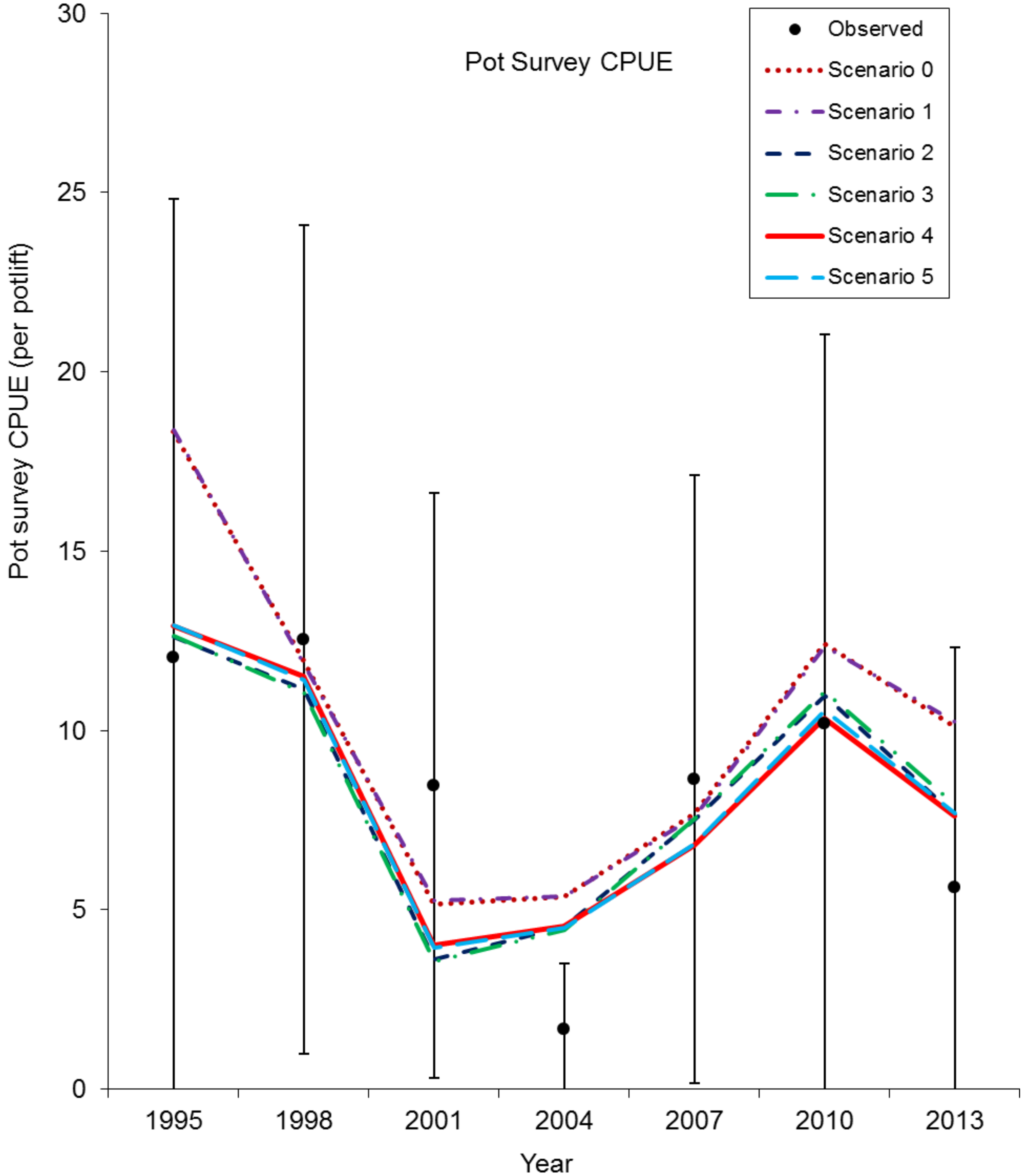


Figure 8. Comparisons of total male pot survey CPUEs and model predictions for 2014 model estimates under scenarios 0-5. The error bars are plus and minus 2 standard deviations of scenario 4.

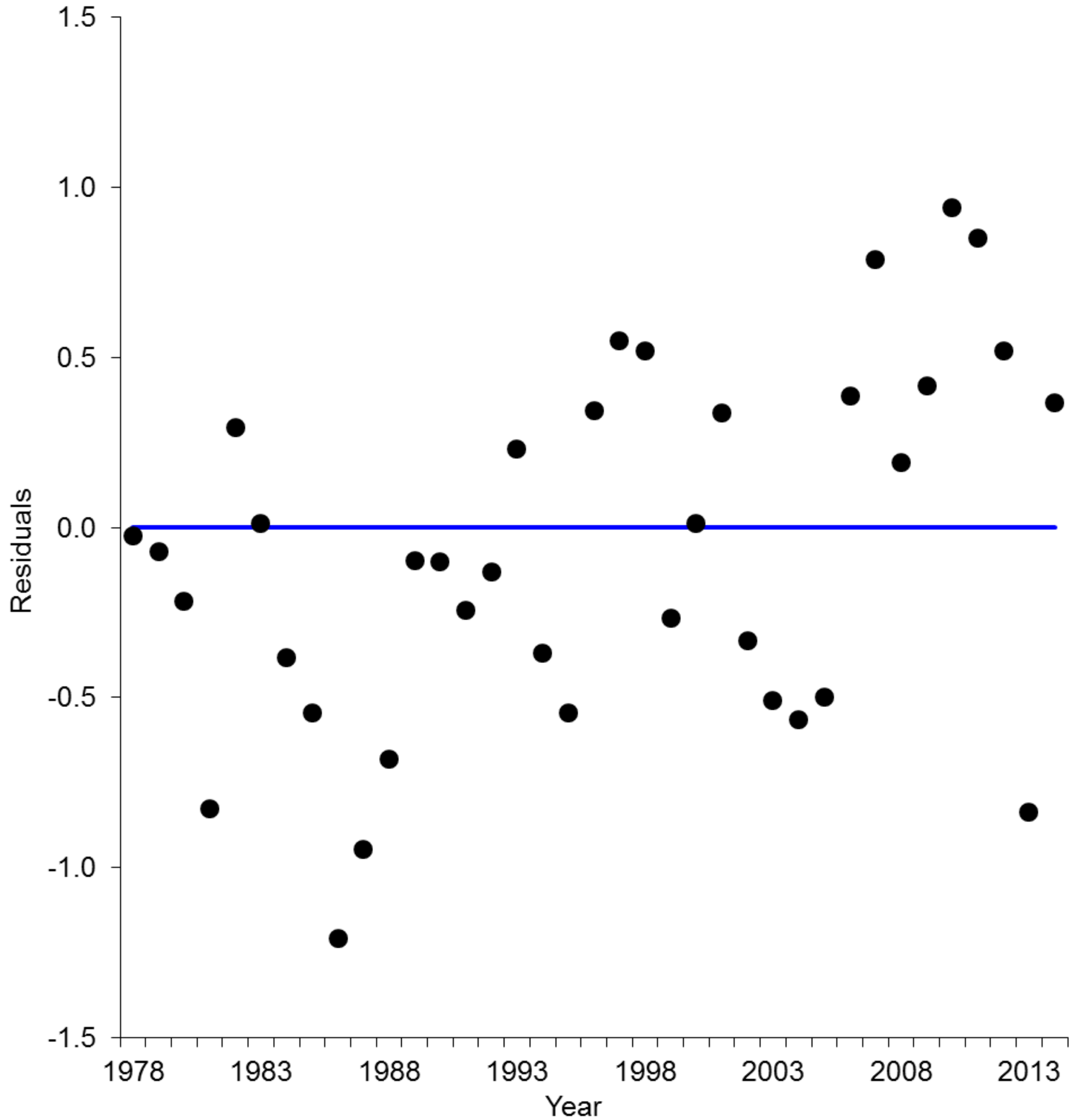


Figure 9. Standardized residuals for total trawl survey biomass for scenario 0.

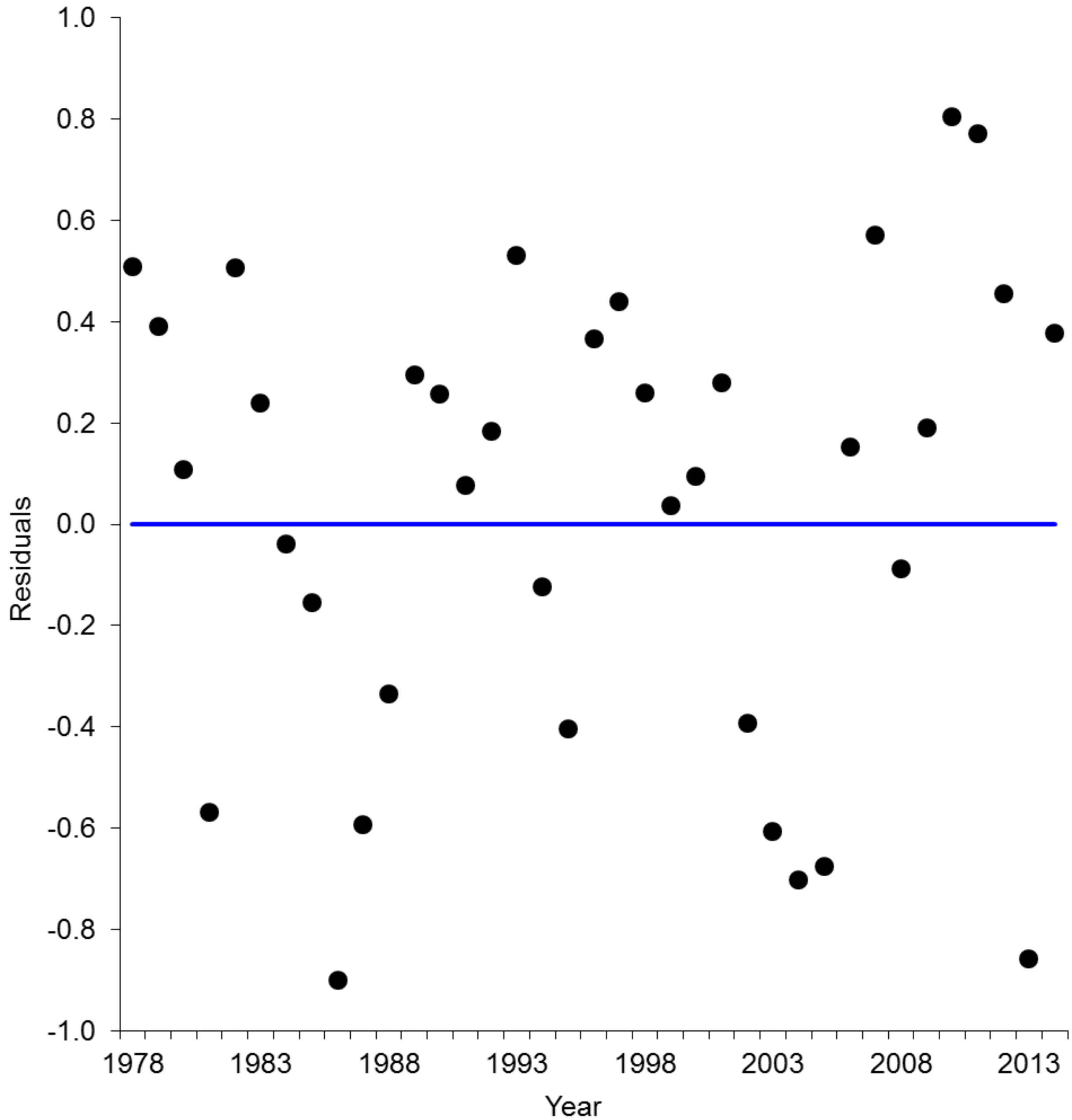


Figure 10. Standardized residuals for total trawl survey biomass for scenario 4.

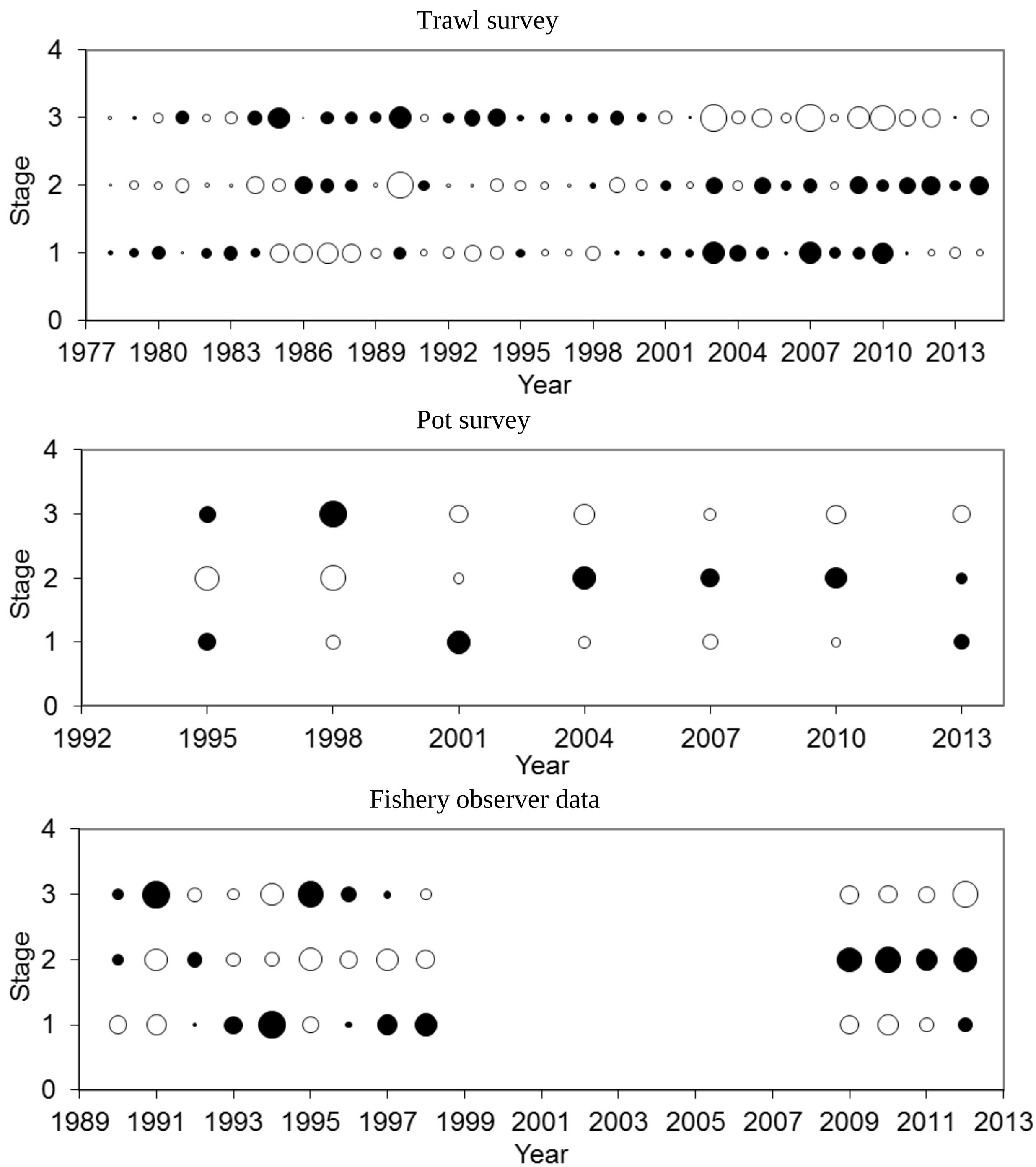


Figure 11. Bubble plots of residuals of stage compositions for scenario 0 for St. Mathew Island blue king crab. Empty circles indicate negative residuals, filled circles indicate positive residuals, and differences in bubble size indicate relative differences in the magnitude of residuals.

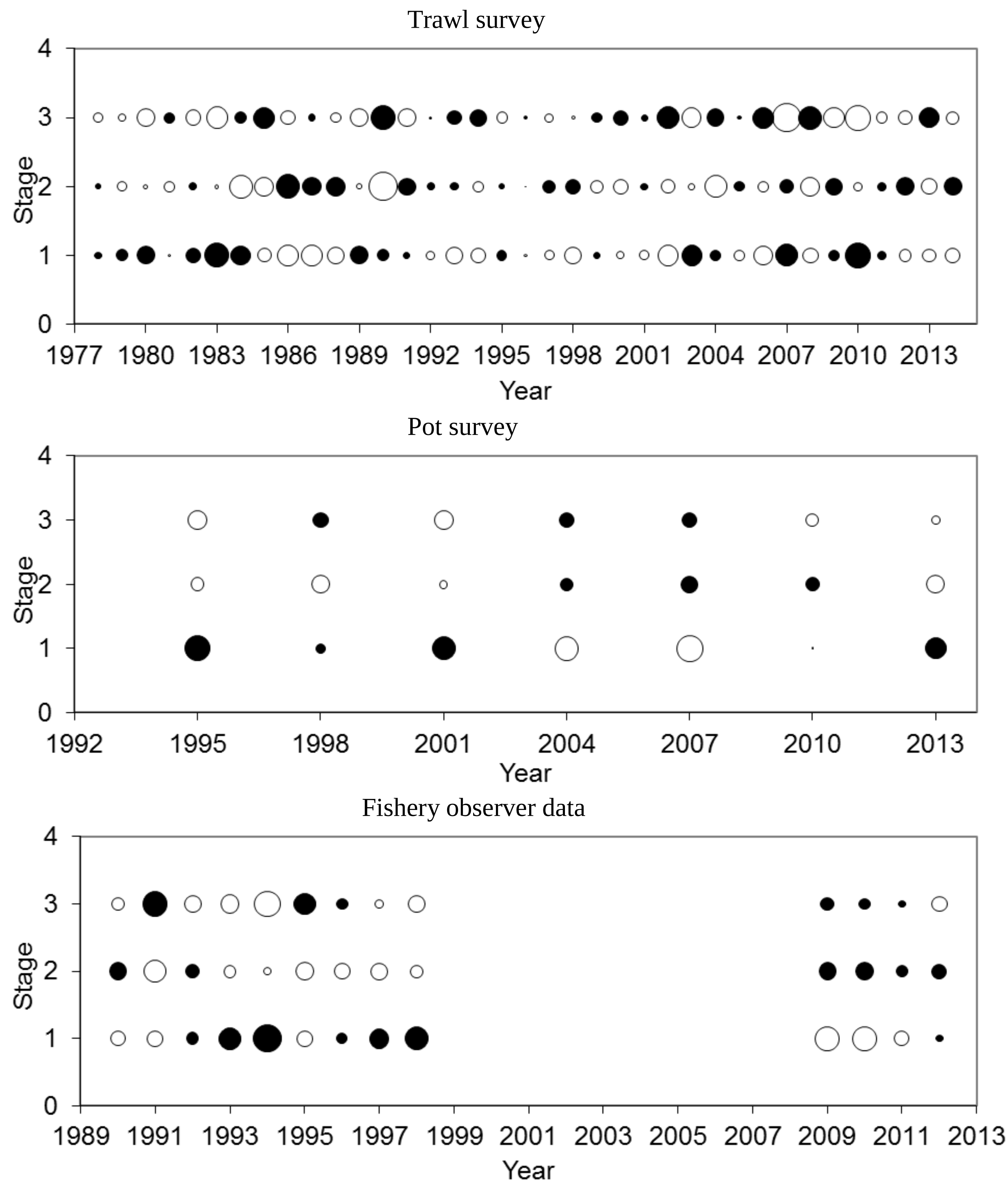


Figure 12. Bubble plots of residuals of length compositions for scenario 4 for St. Mathew Island blue king crab. Empty circles indicate negative residuals, filled circles indicate positive residuals, and differences in bubble size indicate relative differences in the magnitude of residuals.

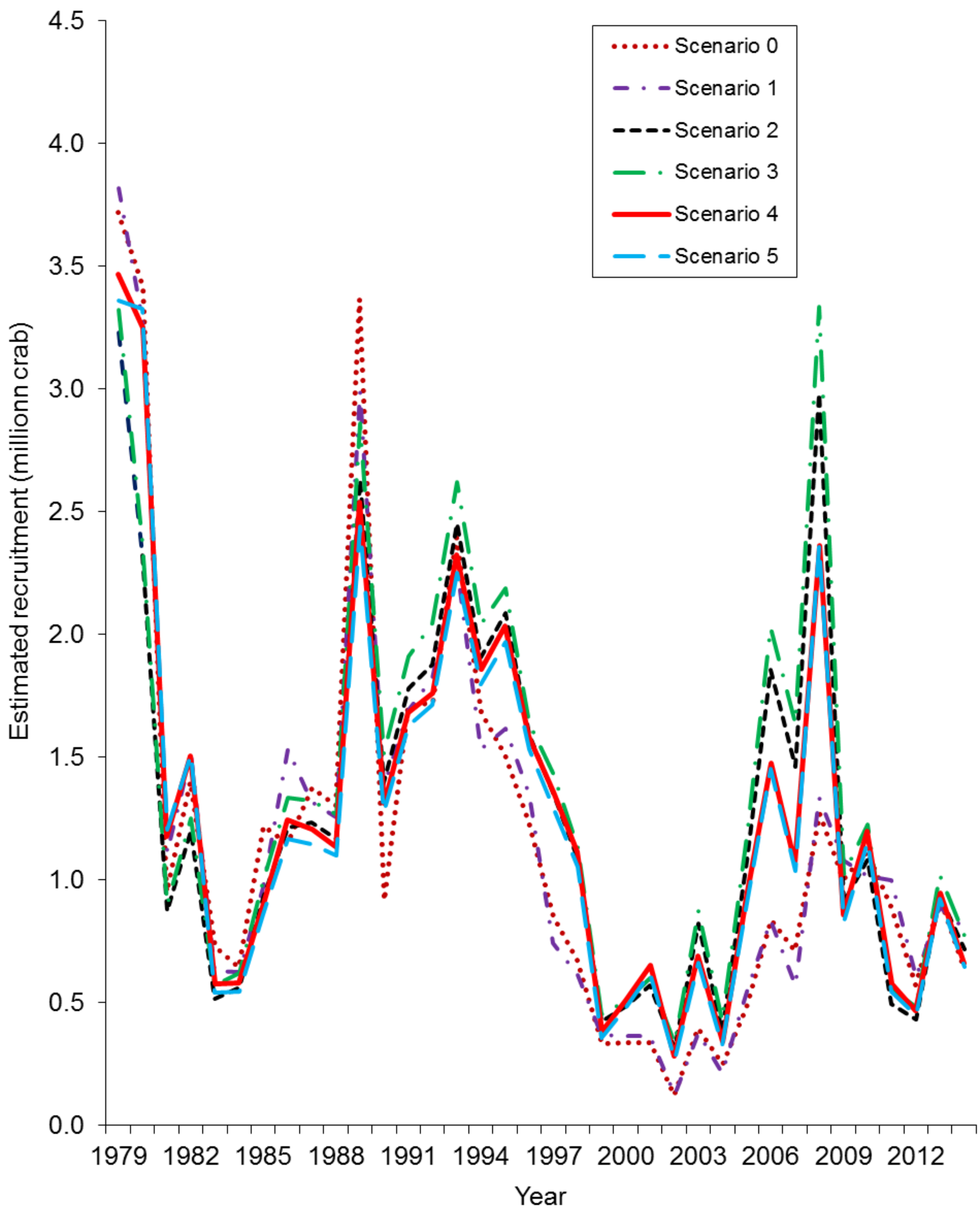


Figure 13. Estimated recruitment time series during 1979-2014 with scenarios 0-5.

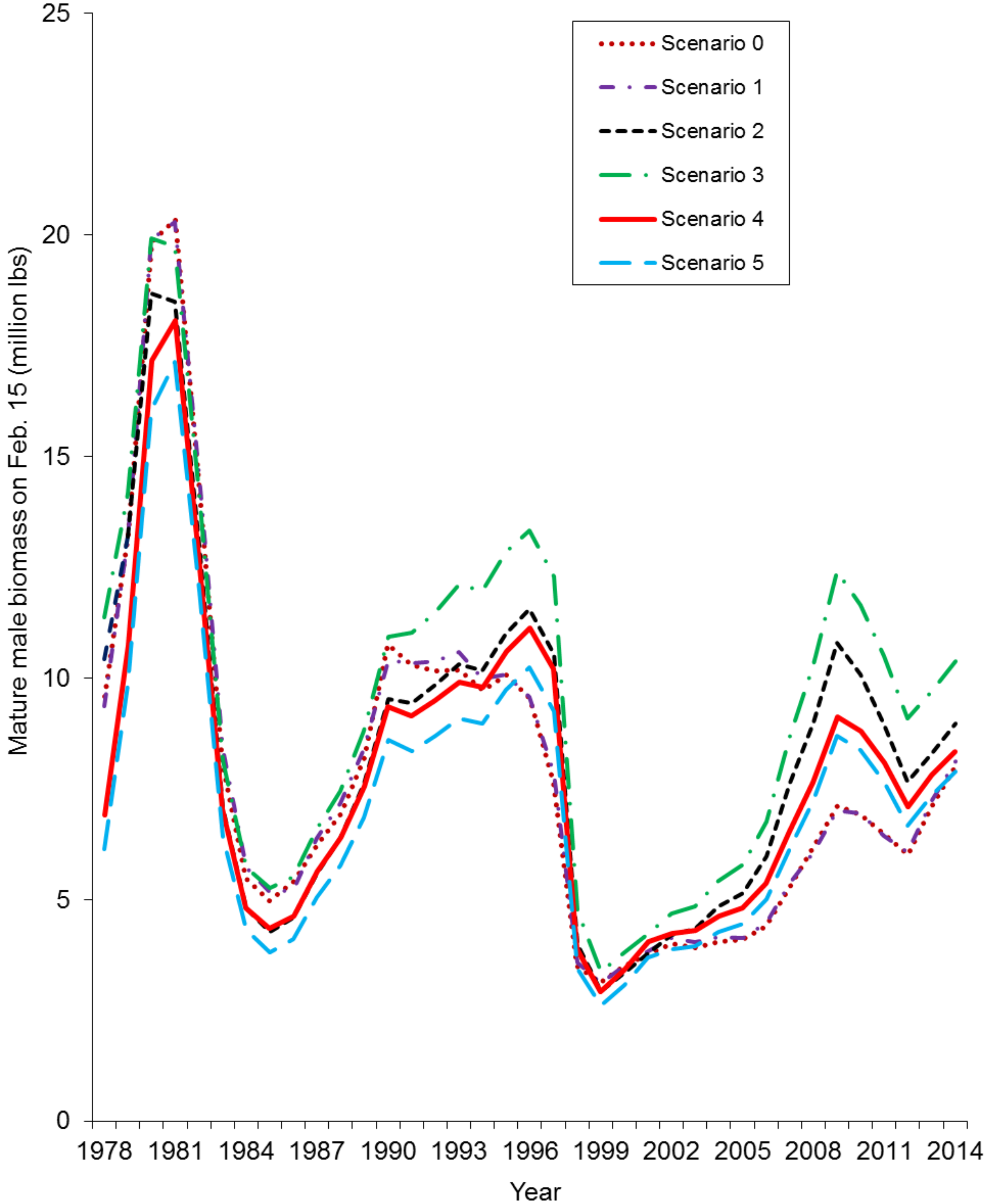


Figure 14. Estimated mature male biomass time series on Feb. 15 during 1978-2014 with scenarios 0-5.

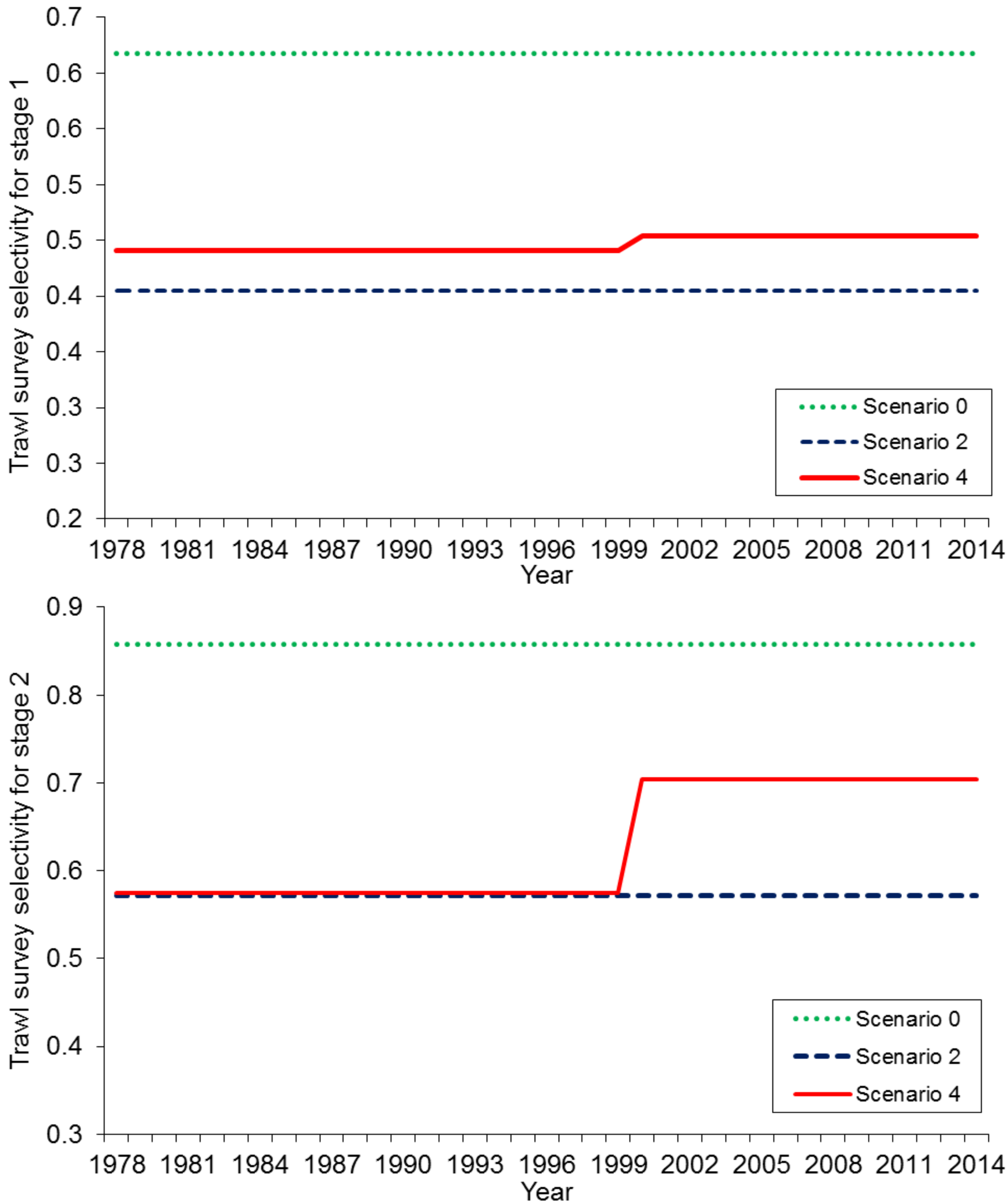


Figure 15. Estimated stage-1 (upper panel) and stage-2 (lower panel) trawl-survey selectivities for scenarios 0, 2 and 4.

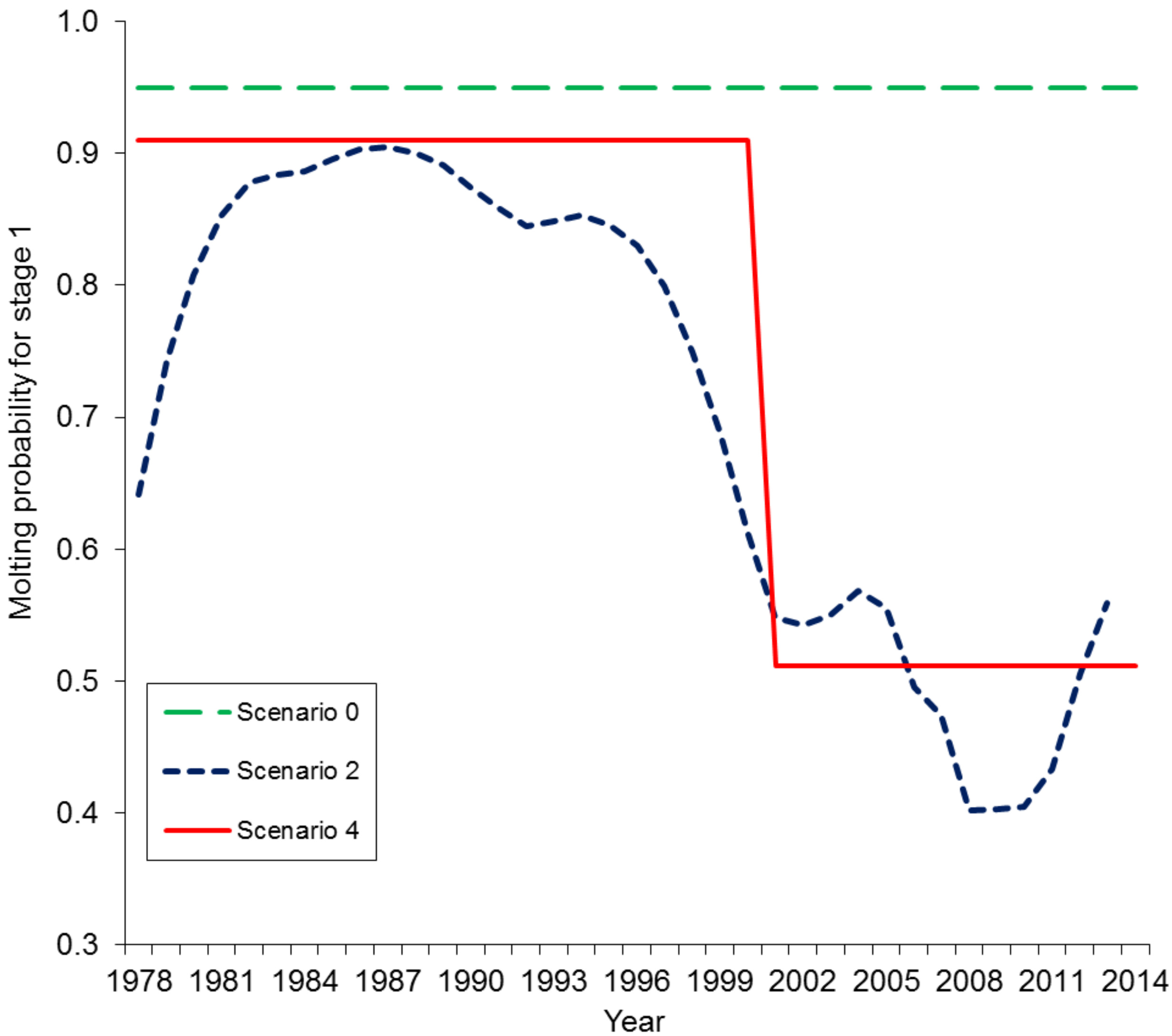


Figure 16. Estimated molting probabilities for stage-1 crab for scenarios 0, 2 and 4.

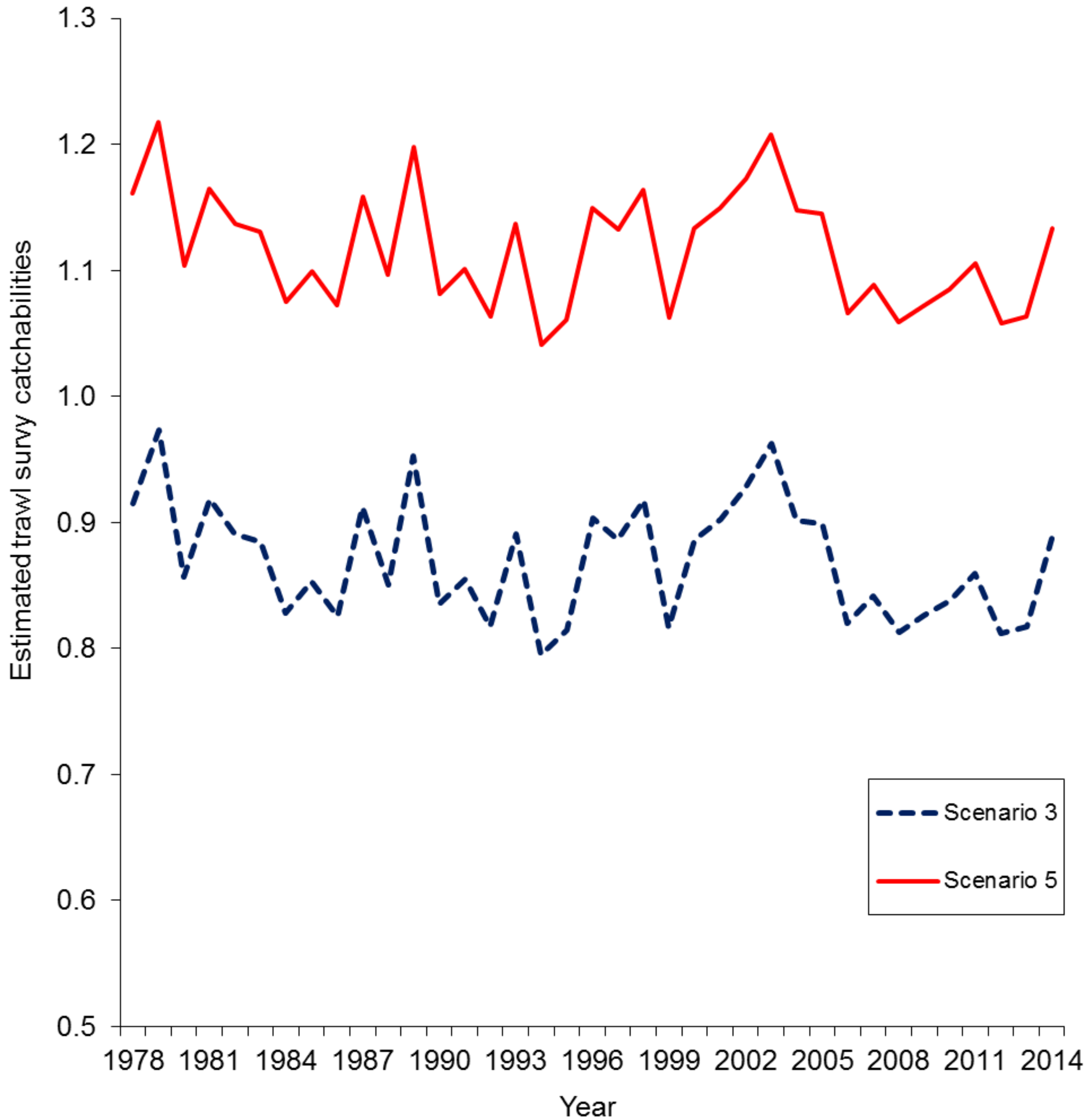
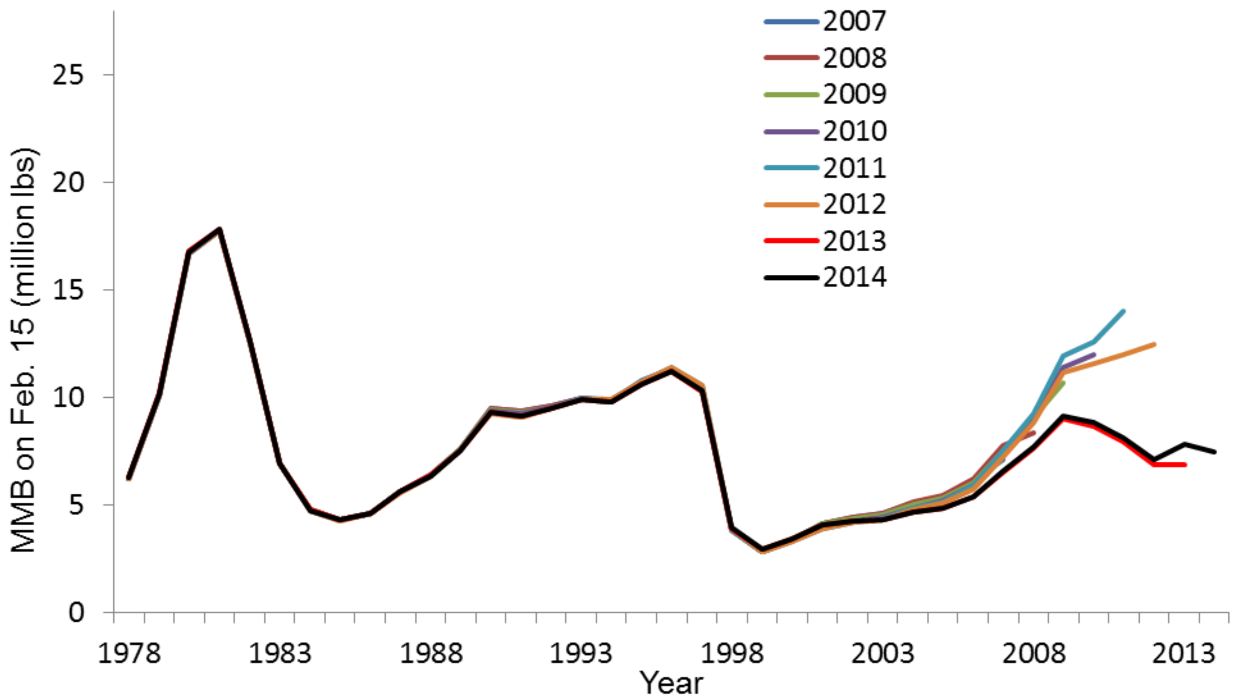


Figure 17. Estimated trawl survey catchabilities for scenarios 3 and 5.



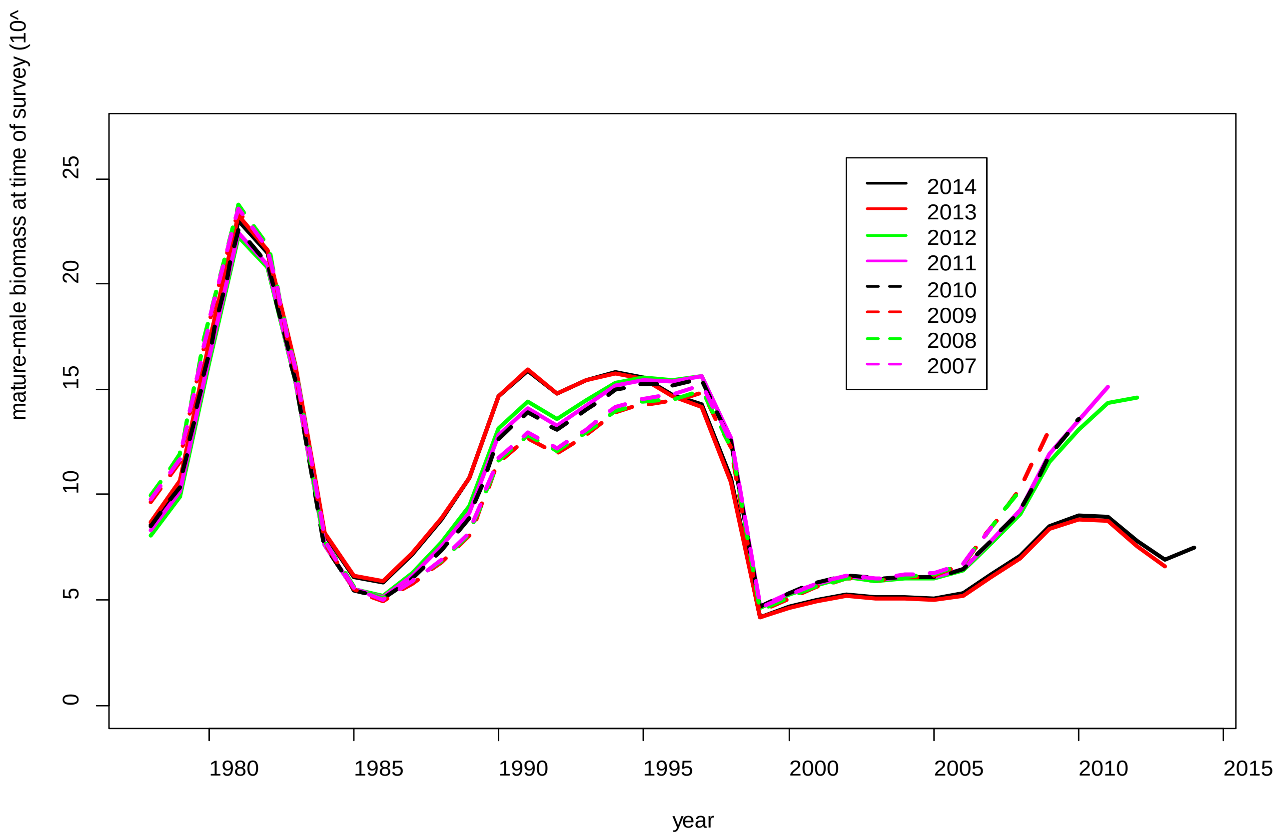
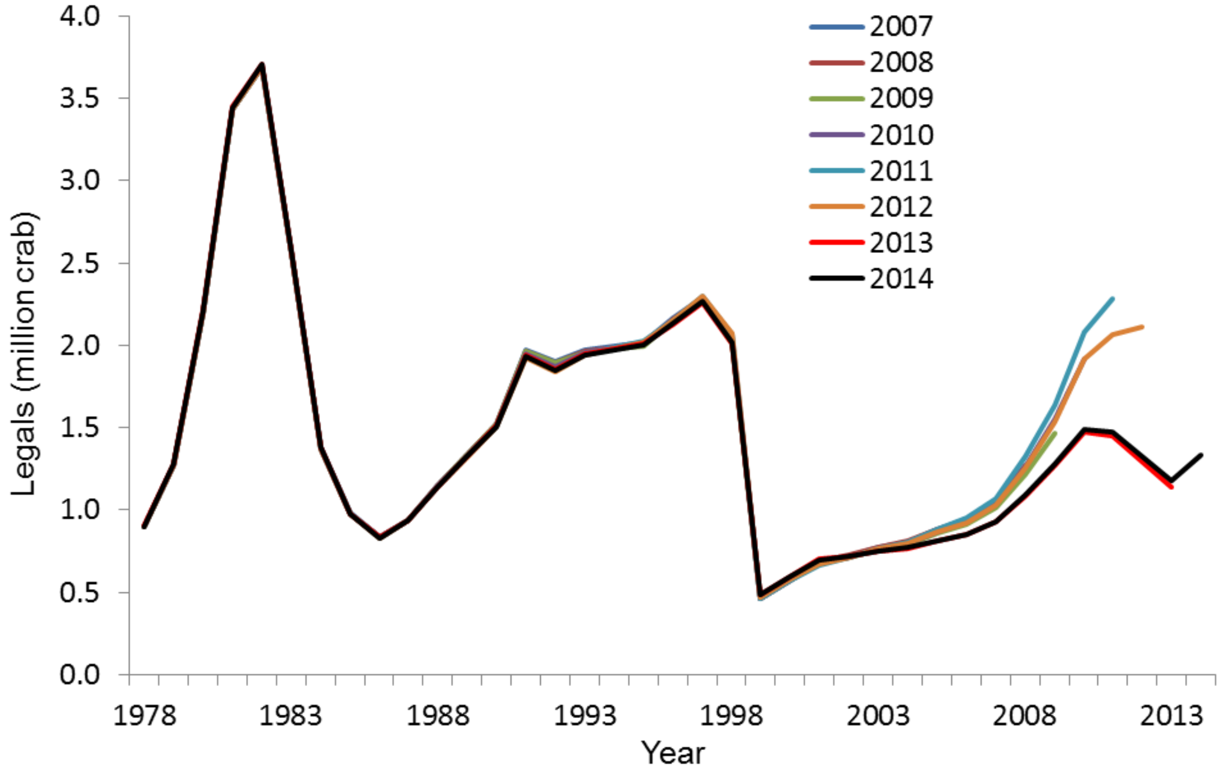


Figure 18. Retrospective plot of model-estimated mature male biomass for 2014 model scenario 4n (top panel) on Feb. 15 and Model ST (bottom panel) at time of survey with terminal years 2007-2014. Estimates are based on all available data up to and including terminal-year trawl and pot surveys.



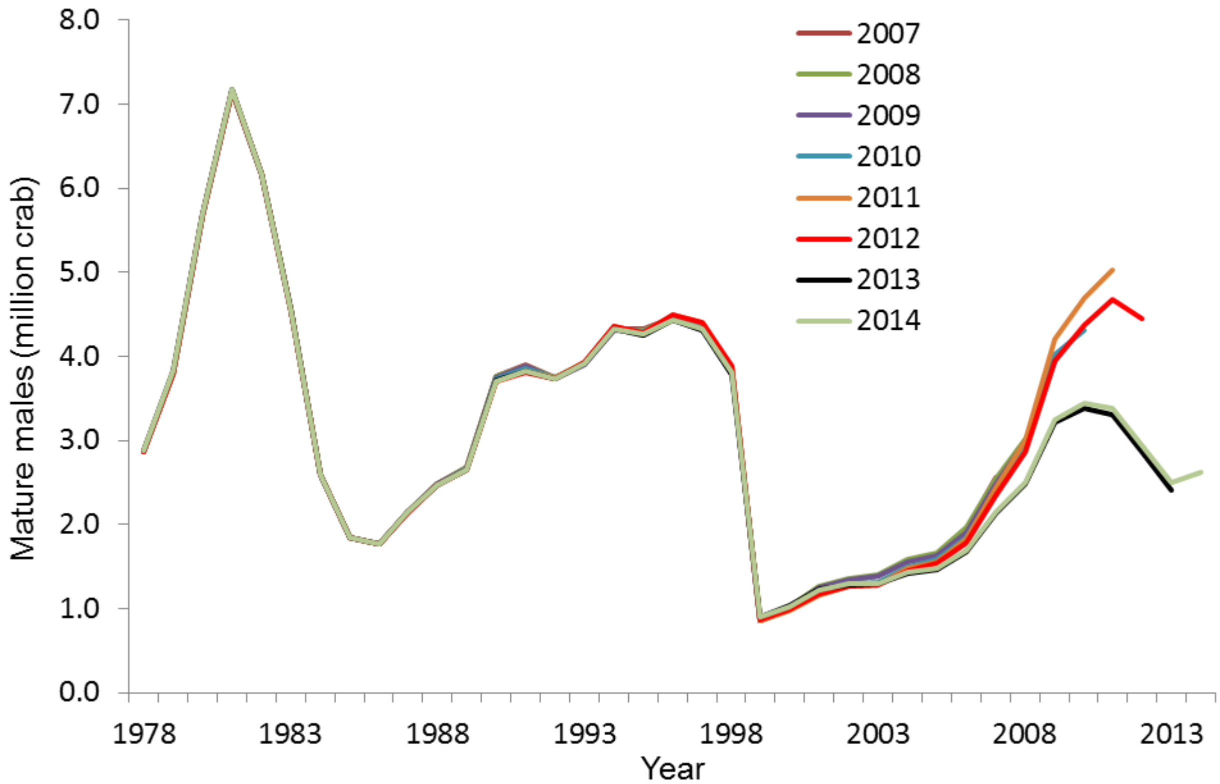


Figure 19. Retrospective plot of model-estimated legal and mature male abundance at time of survey for 2014 model scenario 4n with terminal years 2007-2014. Estimates are based on all available data up to and including terminal-year trawl and pot surveys.

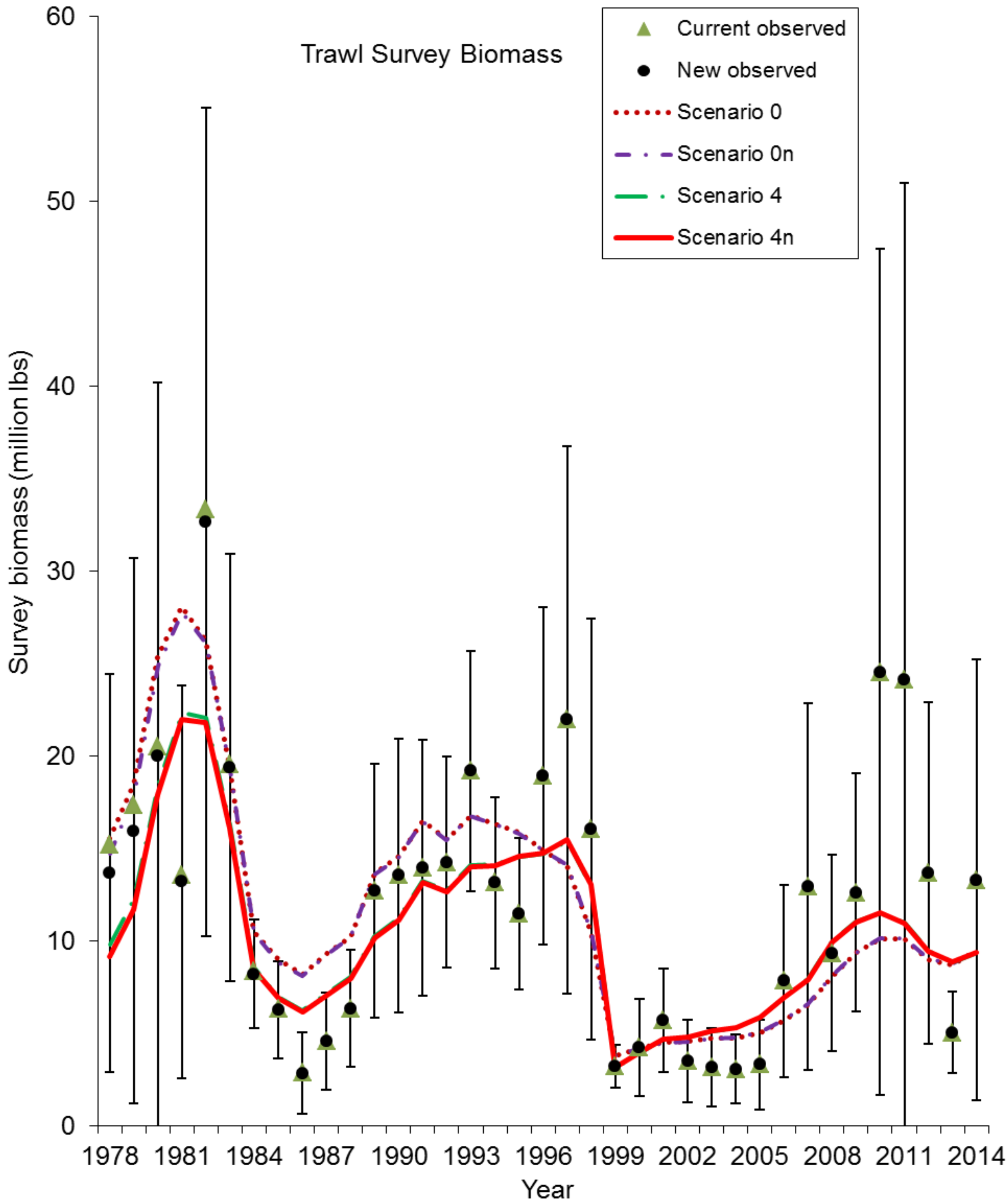


Figure 20. Comparisons of area-swept estimates of total male survey biomasses and model predictions for 2014 model estimates under scenarios 0, 0n, 4 and 4n. The error bars are plus and minus 2 standard deviations of new time series area-swept estimates.

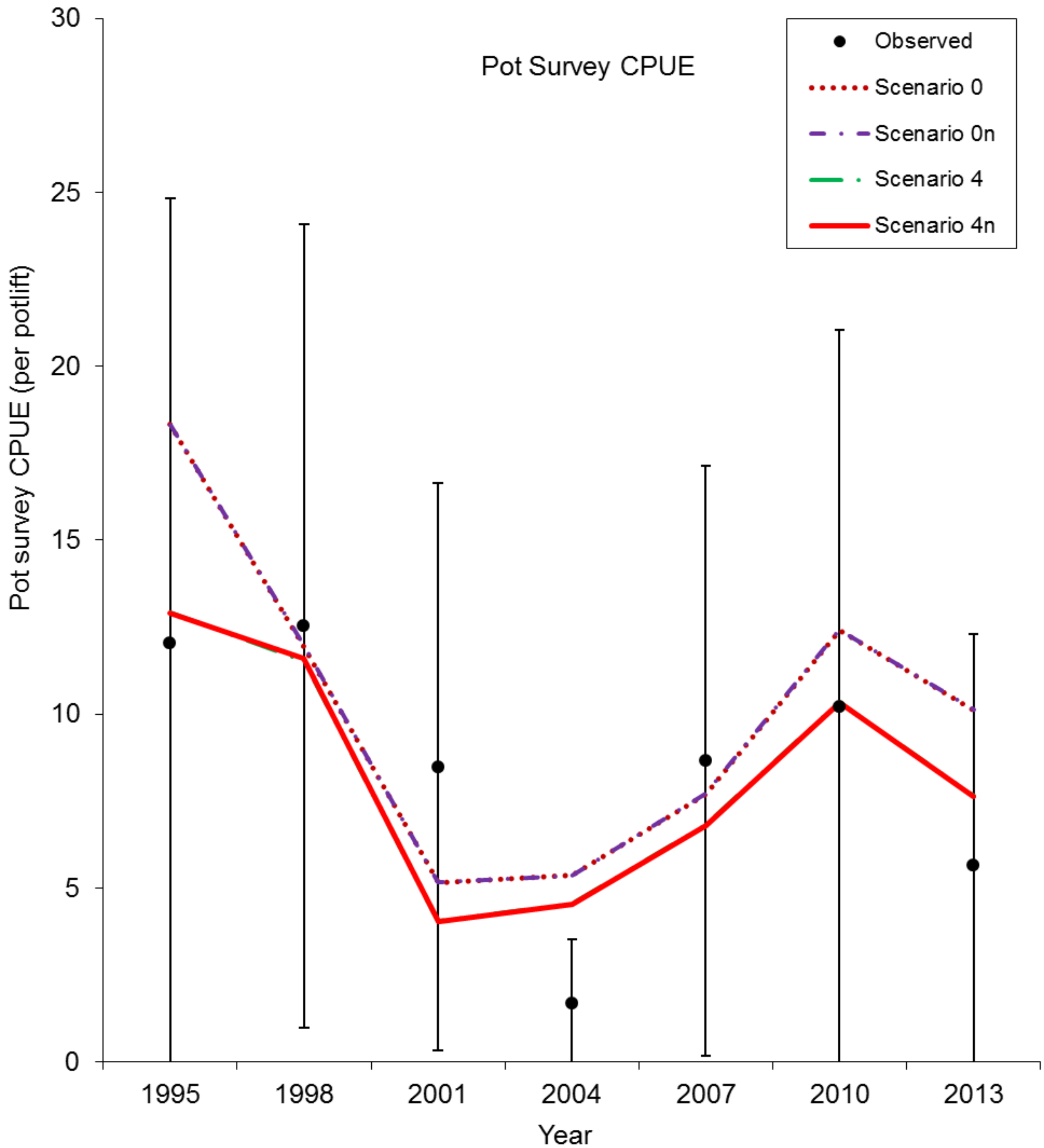


Figure 21. Comparisons of total male pot survey CPUEs and 2014 model predictions for model estimates under scenarios 0, 0n, 4 and 4n. The error bars are plus and minus 2 standard deviations of scenario 4n.

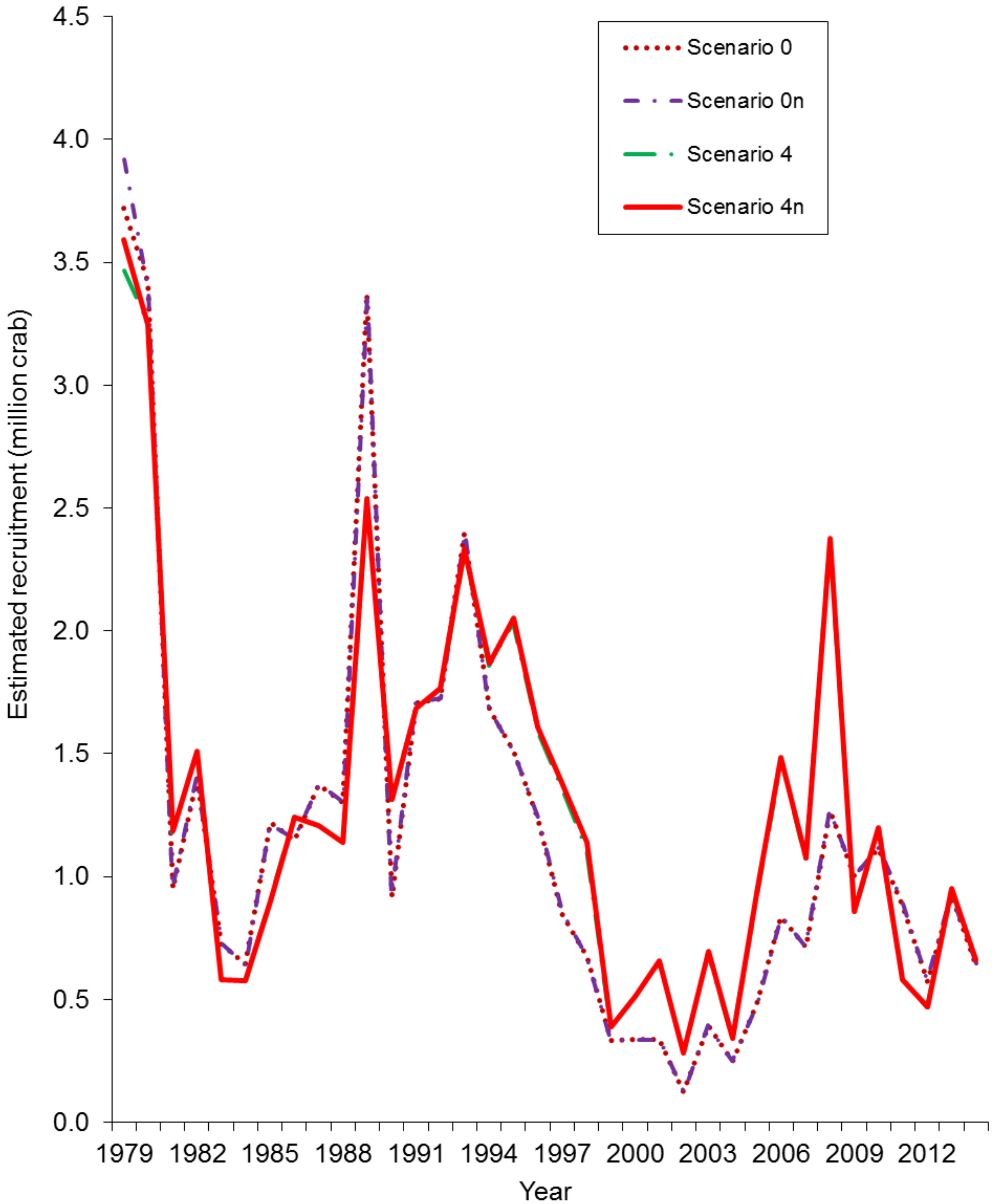


Figure 22. Estimated recruitment time series during 1979-2014 with scenarios 0, 0n, 4 and 4n.

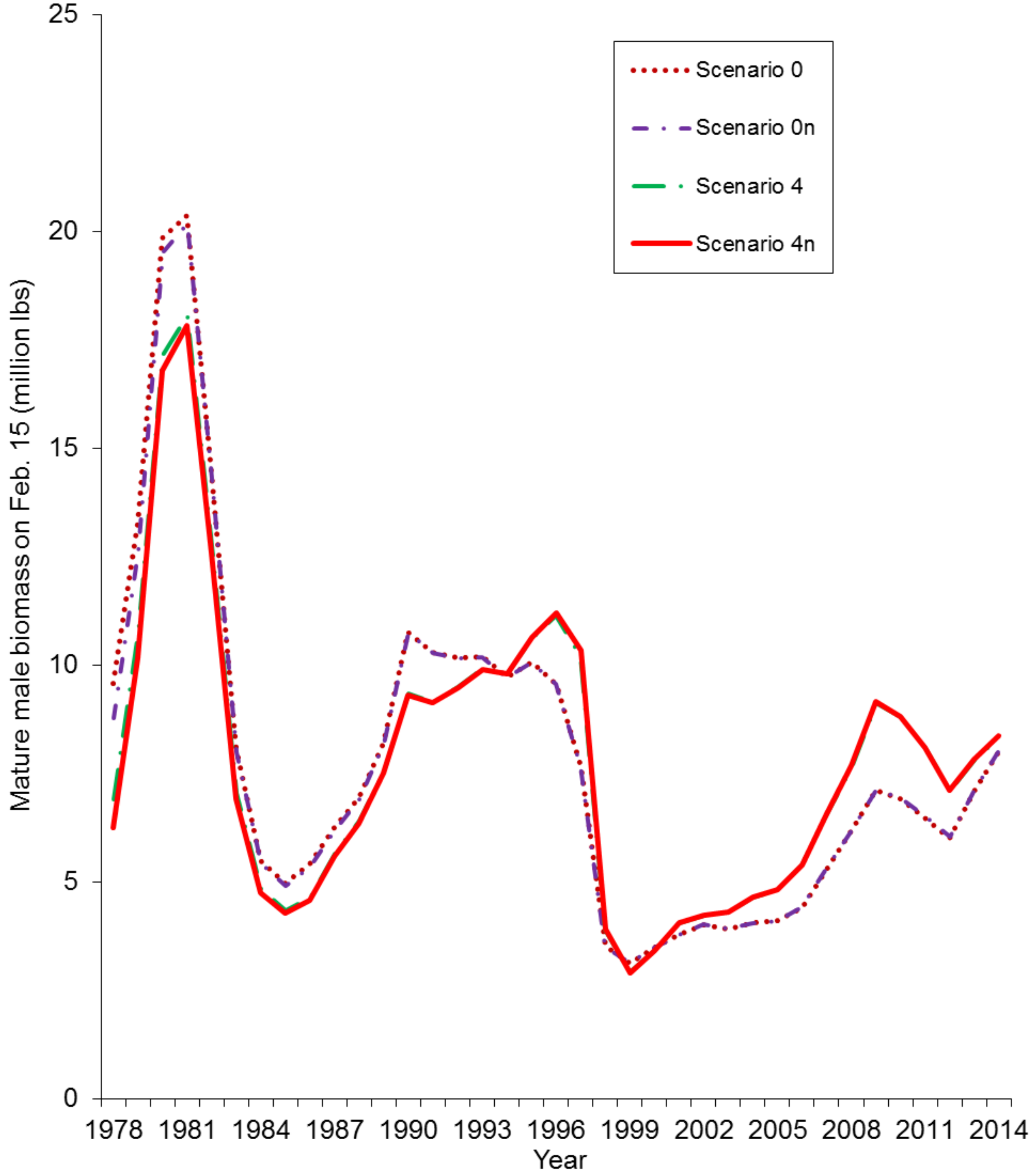


Figure 23. Estimated mature male biomass time series on Feb. 15 during 1978-2014 with scenarios 0, 0n, 4 and 4n.

Appendix A: SMBKC Model Description

1. Introduction

The model accounts only for male crab at least 90 mm in carapace length (CL). These are partitioned into three stages (male 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 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 base-model configuration.

2. Model Population Dynamics

Within the model framework, the beginning of the crab year is assumed contemporaneous with the NMFS trawl survey, nominally assigned a date of July 1. With boldface letters indicating vector quantities, let $\boldsymbol{N}_t = [\ N_{1,t},\ N_{2,t},\ N_{3,t}\ ]^{\mathrm{T}}$ designate the vector of stage abundances at the start of year t. Then the basic population dynamics underlying model construction are described by the linear equation

$$\boldsymbol{N}_{t+1} = \boldsymbol{G}e^{-M_t}\boldsymbol{N}_t + \boldsymbol{N}^{new}{}_{t+1}, \qquad \text{[A1]}$$

where the scalar factor e^{-M_t} accounts for the effect of year-t natural mortality M_t and the hypothesized transition matrix $\boldsymbol{G}$ has the simple structure

$$\boldsymbol{G} = \begin{bmatrix} 1-\pi_{12} & \pi_{12} & 0 \\ 0 & 1-\pi_{23} & \pi_{23} \\ 0 & 0 & 1 \end{bmatrix}, \qquad \text{[A2]}$$

with π_{jk} equal to the proportion of stage-j crab that molt and grow into stage k from any one year to the next. The vector $\boldsymbol{N}^{new}{}_{t+1} = [\ N^{new}{}_{1,t+1},\ 0\ ,0\ ]^{\mathrm{T}}$ registers the number $N^{new}{}_{1,\ t+1}$ of new crab, or "recruits," entering the model at the start of year $t + 1$, all of which are assumed to go into stage 1. Aside from natural mortality and molting and growth, only the directed fishery and some limited bycatch mortality in the groundfish fisheries are assumed to affect the stock. Nontrivial bycatch mortality with another fishery, as occurred in 2012/13, is assumed to be accounted for in the model in the estimate of groundfish bycatch mortality.) The directed fishery is modeled as a mid-season pulse occurring at time τ_t with full-selection fishing mortality F_t^{df} relative to stage-3 crab. Year-t directed-fishery removals from the stock are computed as

$$\boldsymbol{R}_t^{df} = \boldsymbol{H}^{df}\boldsymbol{S}^{df}(1 - e^{-F_t^{df}})e^{-\tau_t M}\boldsymbol{N}_t, \qquad \text{[A3]}$$

where the diagonal matrices $\boldsymbol{S}^{df} = \begin{bmatrix} s_1^{df} & 0 & 0 \\ 0 & s_2^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix}$ and $\boldsymbol{H}^{df} = \begin{bmatrix} h^{df} & 0 & 0 \\ 0 & h^{df} & 0 \\ 0 & 0 & 1 \end{bmatrix}$ account for stage selectivities s_1^{df} and s_2^{df} and discard handling mortality h^{df} in the directed fishery, both assumed constant over time. Yearly stage removals resulting from bycatch mortality in the groundfish trawl and fixed-gear fisheries are calculated as Feb 15 (0.63 yr) pulse effects in terms of the respective fishing mortalities F_t^{gt} and F_t^{gf} by

$$\boldsymbol{R}_t^{gt} = \frac{F_t^{gt}}{F_t^{gt}+F_t^{gf}} e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})(1-e^{-(F^{gt}+F^{gf})})h^{gt} \qquad \text{[A4]}$$

$$\boldsymbol{R}_t^{gf} = \frac{F_t^{gf}}{F_t^{gt}+F_t^{gf}} e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df})(1-e^{-(F^{gt}+F^{gf})})h^{gf}. \qquad \text{[A5]}$$

These last two computations assume that the groundfish fisheries affect all stages proportionally, i.e. that all stage selectivities equal one, and that handling mortalities h^{gt} and h^{gf} are constant across both stages and years. The author believes that the available composition data from these fisheries are of such dubious quality as to preclude meaningful use in estimation. Moreover, evidently with the exception of 2007/08, which in the author's view is suspiciously anomalous, the impact of these fisheries on the stock has typically been small. These considerations suggest that more elaborate efforts to model that impact are unwarranted. Model population dynamics are thus completely determined by the equation

$$\boldsymbol{N}_{t+1} = \boldsymbol{G}e^{-0.37M_t}(e^{-(0.63-\tau_t)M_t}(e^{-\tau_t M_t}\boldsymbol{N}_t - \boldsymbol{R}_t^{df}) - (\boldsymbol{R}_t^{gt} + \boldsymbol{R}_t^{gf})) + \boldsymbol{N}^{new}{}_{t+1}, \qquad \text{[A6]}$$

for $t \geq 1$ and initial stage abundances $\boldsymbol{N}_1$.

Necessary biomass computations, such as required for management purposes or for integration of groundfish bycatch biomass data into the model, are based on application of the SMBKC length-to-weight relationship from NMFS to the stage-1 and stage-2 CL interval midpoints and use fishery reported average retained weights for stage-3 ("legal") crab. In years with no fishery, including the current assessment year, the time average value over years with a fishery is used. The author believes this approach to be an appropriate simplification given the data limitations associated with the stock.

3. Model Data

Data inputs used in model estimation are listed in Table 1. All quantities relate to male SMBKC ≥ 90mm CL.

Table 1. Data inputs used in model estimation.

Data Quantity	Years	Source
Directed pot-fishery retained-catch number	1978/79-1998/99 2009/10-2012/13	Fish tickets (fishery closed 1999/00-2008/09)
NMFS trawl-survey biomass index (area-swept estimate) and CV	1978-2014	NMFS EBS trawl survey
ADFG pot-survey abundance index (CPUE) and CV	Triennial 1995-2013	ADF&G SMBKC pot survey
NMFS trawl-survey stage proportions and total number of measured crab	1978-2014	NMFS EBS trawl survey
ADFG pot-survey stage proportions and total number of measured crab	Triennial 1995-2013	ADF&G SMBKC pot survey
Directed pot-fishery stage proportions and total number of measured crab	1990/91-1998/99 2009/10-2012/13	ADF&G crab observer program (fishery closed 1999/00-2008/09)
Groundfish trawl bycatch biomass	1992/93-2013/14	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93-2013/14	NMFS groundfish observer program

Model-predicted retained-catch number C_t is calculated assuming catch consists precisely of those stage-three crab captured in the directed fishery so that

$$C_t = e^{-\tau_t M_t} N_{3,t}(1 - e^{-F^{df}}), \quad \text{[A7]}$$

which is just the third component of [3]. In fact, in the actual pot fishery a small number of captured stage-3 males are discarded, whereas some captured stage-2 males are legally retained, but data from onboard observers and dockside samplers suggest that [7] here provides a serviceable approximation (ADF&G Crab Observer Database). Model analogs of trawl-survey biomass and pot-survey abundance indices are given by

$$B_t^{ts} = Q^{ts}(s_1^{ts} N_{1,t} w_1 + s_2^{ts} N_{2,t} w_2 + N_{3,t} w_{3,t}) \quad \text{[A8]}$$

$$A_t^{ps} = Q^{ps}(s_1^{ps} N_{1,t} + s_2^{ps} N_{2,t} + N_{3,t}), \quad \text{[A9]}$$

these being year-t trawl-survey area-swept biomass and year-t pot-survey CPUE, respectively, both with respect to 90 mm+ CL males. In these expressions, Q^{ts} and Q^{ps} denote model proportionality constants, assumed independent of year and with $Q^{ts} = 1.0$ under all scenarios considered for this assessment, and s_j^{ts} and s_j^{ps} denote corresponding stage-j survey selectivities, also assumed independent of year. Model trawl-survey, pot-survey, and directed-fishery stage proportions $\boldsymbol{P}_t^{ts}$, $\boldsymbol{P}_t^{ps}$, and $\boldsymbol{P}_t^{df}$ are then determined by

$$\boldsymbol{P}_t^{ts} = \frac{Q^{ts}}{A_t^{ts}} \begin{bmatrix} s_1^{ts} & 0 & 0 \\ 0 & s_2^{ts} & 0 \\ 0 & 0 & 1 \end{bmatrix} \boldsymbol{N}_t \quad \text{[A10]}$$

$$\boldsymbol{P}_t^{ps} = \frac{Q^{ps}}{A_t^{ps}} \begin{bmatrix} s_1^{ps} & 0 & 0 \\ 0 & s_2^{ps} & 0 \\ 0 & 0 & 1 \end{bmatrix} \boldsymbol{N}_t \quad \text{[A11]}$$

$$\boldsymbol{P}_t^{df} = \frac{1}{\langle (\boldsymbol{H}^{df})^{-1} \boldsymbol{R}_t^{df},\ \mathbf{1} \rangle} (\boldsymbol{H}^{df})^{-1} \boldsymbol{R}_t^{df}. \quad \text{[A12]}$$

Letting $\boldsymbol{w}_t = [w_1, w_2, w_{3,t}]^T$ be an estimate of stage mean weights in year t as described above, model predicted groundfish bycatch mortality biomasses in the trawl and fixed-gear fisheries are given by

$$B_t^{gt} = \boldsymbol{w}_t{}^T \boldsymbol{R}_t^{gt} \text{ and } B_t^{gf} = \boldsymbol{w}_t{}^T \boldsymbol{R}_t^{gf}. \quad \text{[A13]}$$

Recall that stage-1 and stage-2 mean weights do not depend on year, being based on the NMFS length-to-weight relationship, whereas stage-3 mean weight is set equal to year-t fishery reported average retained weight or its time average for years with no fishery.

4. Model Parameters

Estimated parameters with scenarios 0 and 4 are listed in Table 2 and include an estimated parameter for natural mortality in 1998/99 on the assumption of an anomalous mortality event in that year, as hypothesized by Zheng and Kruse (2002), with natural mortality otherwise fixed at 0.18 yr^{-1}. In any year with no directed fishery, and hence zero retained catch, F_t^{df} is set to zero rather than model estimated. Similarly, for years in which no groundfish bycatch data are available, F_t^{gf} and F_t^{gt} are imputed to be the geometric means of the estimates from years for which there are data. Table 3 lists additional externally determined parameters used in model computations.

For scenarios 0 and 1, stage-transition matrix $\begin{bmatrix} 0.2 & 0.7 & 0.1 \\ 0 & 0.4 & 0.6 \\ 0 & 0 & 1 \end{bmatrix}$, which includes molting probabilities. For scenarios 2-5, the growth matrix with molting crab is $\begin{bmatrix} 0.11 & 0.83 & 0.06 \\ 0 & 0.11 & 0.89 \\ 0 & 0 & 1 \end{bmatrix}$. The combination of the growth matrix and molting probabilities results in the stage-transition matrix for scenarios 2-5. Molting probability for stage 1 for scenarios 4 and 5 during 1978-2000 is assumed to be 0.91 estimated from the tagging data and ratio of molting probabilities of stages 2 to stage 1 is fixed as 0.69231 from the tagging data as well.

Both surveys are assigned a nominal date of July 1, the start of the crab year. The directed fishery is treated as a season midpoint pulse. Groundfish bycatch is likewise modeled as a pulse effect, occurring at the nominal time of mating, Feb 15, which is also the reference date for calculation of federal management biomass quantities.

Table 2. Model estimated parameters for scenarios 0 and 4.

	Scenario 0	Scenario 4
Parameter	Number	Number
Log initial stage abundances	3	3
1998/99 natural mortality	1	1
Pot-survey "catchability"	1	1
Stage 1 and 2 Trawl-survey selectivities	2	4
Stage 1 and 2 Pot-survey selectivities	2	2
Stage 1 and 2 Directed-fishery selectivities	2	2
Molting probabilities	0	1
Additional CV for pot survey	0	1
Mean log recruit abundance	1	1
Log recruit abundance deviations	36[a]	36[a]
Mean log directed-fishery mortality	1	1
Log directed-fishery mortality deviations	25[a]	25[a]
Mean log groundfish trawl fishery mortality	1	1
Log groundfish trawl fishery mortality deviations	23[a]	23[a]
Mean log groundfish fixed-gear fishery mortality	1	1
Log groundfish fixed-gear fishery mortality deviations	23[a]	23[a]
Total	122	126

[a] Subject to zero-sum constraint.

Table 3. Base-model fixed parameters for scenario 0.

Parameter	Value	Source/Rationale
Trawl-survey "catchability", i.e. abundance-index proportionality constant	1.0	Default
Natural mortality (except 1998/99)	0.18 yr^{-1}	NPFMC (2007)
Stage 1 and 2 transition probabilities	1.0, 1.0	Default
Stage-1 and 2 mean weights	1.65, 2.57 lb	NMFS length-weight equation applied to stage size-interval midpoints.
Stage-3 mean weight	depends on year	Fishery-reported average retained weight from fish tickets, or its average.
Directed-fishery handling mortality	0.20	2010 Crab SAFE
Groundfish trawl handling mortality	0.80	2010 Crab SAFE
Groundfish fixed-gear handling mortality	0.50	2010 Crab SAFE

5. Model Objective Function and Weighting Scheme

The objective function consists of a sum of eight "negative loglikelihood" terms characterizing the hypothesized error structure of the principal data inputs with respect to their true, i.e., model-predicted, values and four "penalty" terms associated with year-to-year variation in model recruit abundance and fishing mortality in the directed fishery and groundfish trawl and fixed-gear fisheries. See Table 4, where upper and lower case letters designate model-predicted and data-computed quantities, respectively, and boldface letters again indicate vector quantities. Sample sizes n_t (observed number of male SMBKC ≥ 90 mm CL) and estimated coefficients of variation $\widehat{cv}_t$ were used to develop appropriate variances for stage-proportion and abundance-index components. The weights λ_j appearing in the objective function component expressions in Table 4 play the role of "tuning" parameters in the modeling procedure.

Table 4. Loglikelihood and penalty components of base-model objective function. The λ_k are weights, described in text; the $neff_t$ are effective sample sizes, also described in text. All summations are with respect to years over each data series.

Component		Form
Legal retained-catch number	Lognormal	$-\lambda_1 0.5\sum[\log(c_t+0.001)-\log(C_t+0.001)]^2$
Trawl-survey biomass index	Lognormal	$-\lambda_2 0.5\sum[\frac{\ln(b_t^{ts})-\ln(B_t^{ts})}{\ln(1+\widehat{cv_t^{ts}}^2)}]^2$
Pot-survey abundance index	Lognormal	$-\lambda_3 0.5\sum[\frac{\ln(a_t^{ps})-\ln(A_t^{ps})}{\ln(1+\widehat{cv_t^{ps}}^2)}]^2$
Trawl-survey stage proportions (scen.0)	Multinomial	$\lambda_4\sum neff_t^{ts}(\boldsymbol{p}_t^{ts})^T\ln(\boldsymbol{P}_t^{ts}+0.01)$
Pot-survey stage proportions (scen.0)	Multinomial	$\lambda_5\sum neff_t^{ps}(\boldsymbol{p}_t^{ps})^T\ln(\boldsymbol{P}_t^{ps}+0.01)$

Directed-fishery stage proport. (scen.0)	Multinomial	$\lambda_6 \sum neff_t^{df} (\boldsymbol{p}_t^{df})^T \ln(\boldsymbol{P}_t^{df} + 0.01)$
Groundfish trawl mortality biomass	Lognormal	$-\lambda_7 \sum [\ln(b_t^{gt}) - \ln(B_t^{gt})]^2$
Groundfish fixed-gear mortality biomass	Lognormal	$-\lambda_8 \sum [\ln(b_t^{gf}) - \ln(B_t^{gf})]^2$
$\ln(N_{1,t}^{new})$ deviations	Quadratic/Normal	$\lambda_9 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{df})$ deviations	Quadratic/Normal	$\lambda_{10} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{gft})$ deviations	Quadratic/Normal	$\lambda_{11} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$
$\ln(F_t^{gff})$ deviations	Quadratic/Normal	$\lambda_{12} 0.5 \sum \Delta_t^2$, with $\sum \Delta_t = 0$

For scenarios 1-5, stage compositions ($p_{l,t,k}$) likelihood functions are :

$$Rf = \prod_{l=1}^{L} \prod_{t=1}^{T} \prod_{k=1}^{3} \frac{\left\{ \exp\left[-\frac{(p_{l,t,k} - \hat{p}_{l,t,k})^2}{2\sigma^2} \right] + 0.01 \right\}}{\sqrt{2\pi\sigma^2}},$$

$$\sigma^2 = \left[p_{l,t,k}(1 - p_{l,t,k}) + 0.1/L \right] / neff_{t,k},$$

where

L is the number of stages,

T is the number of years,

k stands for trawl survey, pot survey, and observer fishery data, and

$neff_{t,k}$ is the effective sample size, which was estimated for trawl and pot surveys and observer stage composition data from the directed pot fishery. See Model Scenarios Section for effective sample size determinations.

The log-likelihood for the pot survey abundance index in Table 4 is for scenarios 0 and 1. For scenarios 2-5, the log-likelihood is

$$-\lambda_3 \sum [\ln(\ln(CV_t^2 + 1))^{0.5} + \ln(a_t^{ps} / A_t^{ps})^2 / (2\ln(CV_t^2 + 1))].$$

Determination of the weighting scheme involved a great deal of trial and error with respect to graphical and other diagnostic tools; however, the author's basic strategy was to begin with a baseline weighting scheme that was either unity or otherwise defensible in terms of plausible variances and then proceed in the spirit of Francis (2011). The CPT noted in May 2012 that survey weights should generally not exceed unity, and the author has complied with that advice for this assessment.

Table 5 shows the weighting scheme used for the model scenarios. The weight of 1,000 applied to the lognormal fishery catch-number component (λ_1) corresponds to a coefficient of variation of approximately 3% for the fishery estimate of catch number. The weights λ_2 and λ_3 on the lognormal trawl-survey and pot-survey abundance components are set at 1.0, allowing the yearly conventional survey-based CV estimates to govern the terms contributed by these two series. The default 1.0 weights on the lognormal groundfish bycatch mortality biomass components (λ_7 and λ_8) correspond to implied CVs of about 130%, which this author judges probably appropriate given the nature of the data. The weight of 1.25 applied to the quadratic/normal recruit-deviation penalty (λ_9) is approximately the inverse of the sample variance of trawl-survey time-series estimates of 90-104 mm male crab ("recruit") abundance. With λ_4, λ_5, and λ_6 equal to 1.0, the factors denoted by $neff_t$ appearing in the multinomial loglikelihood expressions or robust normal approximation of the objective function represent effective sample sizes describing observed survey and fishery stage-proportion error structure with respect to model predicted values. Each set is determined by a single set-specific parameter N_{max} such that the effective sample size in any given year $neff_t$ is equal to the observed number of crab n_t if $n_t < N_{max}$ and otherwise equal to N_{max} for scenario 0. For scenario 0 configuration, N_{max} was assigned a value of 50 for trawl-survey composition data and 100 for both pot-survey and fishery observer composition data. Graphical displays of the standardized residuals, including normal Q-Q plots, provided some guidance in making this choice, although model fit to the composition data tends to be rather poor under all scenarios.

Table 5. Model objective-function weighting scheme.

Objective-Function Component	Weight λ_j
Legal retained-catch number	1000
Trawl-survey abundance index	1.0
Pot-survey abundance index	1.0
Trawl-survey stage proportions	1.0
Pot-survey stage proportions	1.0
Directed-fishery stage proportions	1.0
Groundfish trawl mortality biomass	1.0
Groundfish fixed-gear mortality biomass	1.0
Log model recruit-abundance deviations	1.25
Log directed fishing mortality deviations	0.001
Log groundfish trawl fishing mortality deviations	1.0
Log groundfish fixed-gear fishing mortality deviations	1.0
Deviations from random walk approach for molting prob.	2.0

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.