Saint Matthew Island Blue King Crab Stock Assessment for Fall 2015

Jie Zheng and Doug Pengilly, ADF&G
September 2015

Executive Summary

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

2. Catches: Peak historical harvest was 9.454 million pounds (4,288 t) in 1983/84. 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 0.461 million pounds (209 t), less than half the 1.167 million pound (529.3 t) TAC. Following three more years of modest harvests supported by a fishery 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. Non-negligible male bycatch mortality resulting from other fisheries with potential to impact the stock in 2013/14 consists of only in an estimated 0.0006 million pounds (0.3 t) in the Bering Sea groundfish fisheries.

3. Stock biomass: Following a period of low numbers after the stock was declared overfished in 1999, trawl-survey indices of SMBKC stock abundance and biomass generally increased in subsequent years, with survey estimated mature male biomass reaching 20.98 million pounds (9,516 t; CV 0.55) in 2011, the second highest in the 37-year time series used in this assessment. Survey mature male biomass then declined to 12.46 million pounds (5,652 t; CV 0.33) in 2012 and to 4.459 million pounds (2,202 t; CV 0.22) in 2013 before going back up to 12.06 million pounds (5,472 t; CV 0.44) in 2014 and 11.32 million pounds (5,134 t; CV 0.76).

4. Recruitment: Because little information about the abundance of small crab is available for this stock, recruitment has been assessed in terms of the number of male crab within the 90-104 mm CL size class in each year. The 2013 trawl-survey area-swept estimate of 0.335 million male SMBKC in this size class marked a three-year exponential decline and was the lowest since 2005. That decline came to an end with the 2014 survey, however, with an estimate of 0.723 million. The survey recruitment is 0.992 million, but the majority of them came from one tow with a great deal of uncertainty.

5. Management performance: In recent assessments, estimated total male catch has been determined as the sum of fishery-reported retained catch, estimated male discard mortality in the directed fishery, and estimated male bycatch mortality in the groundfish fisheries, as these have been the only sources of non-negligible fishing mortality to consider.

Status and catch specifications (1,000 t) (scenario 10-4):

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Male Catch	OFL	ABC
2011/12	1.50[A]	5.03[A]	1.15	0.85	0.95	1.70	1.54
2012/13	1.80[B]	2.85[B]	0.74	0.73	0.82	1.02	0.92

2013/14	1.50[C]	3.01[C]	0	0	0.0003	0.56	0.45
2014/15	1.71[D]	1.90[D]	0.30	0.14	0.15	0.43	0.34
2015/16		1.80[D]				0.16	0.13

The stock was above MSST in 2014/15 and is hence not overfished. Overfishing did not occur.

Status and catch specifications (million lbs) (scenario 10-4):

Year	MSST	Biomass (MMB_{mating})	TAC	Retained Catch	Total Male Catch	OFL	ABC
2011/12	3.4[A]	11.09[A]	2.539	1.881	2.10	3.74	3.40
2012/13	4.0[B]	6.29[B]	1.630	1.616	1.81	2.24	2.02
2013/14	3.4[C]	6.64[C]	0	0	0.0006	1.24	0.99
2014/15	3.8[D]	4.18[D]	0.655	0.309	0.329	0.94	0.75
2015/16		3.97[D]				0.36	0.28

Notes:

A – Calculated from the assessment reviewed by the Crab Plan Team in September 2012
B – Calculated from the assessment reviewed by the Crab Plan Team in September 2013
C – Calculated from the assessment reviewed by the Crab Plan Team in September 2014
D – Calculated from the assessment reviewed by the Crab Plan Team in September 2015

6. Basis for the OFL: Estimated Feb 15 mature-male biomass (MMB_{mating}) 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_{mating} over a specific reference period, and current CPT/SSC guidance recommends using the full assessment time frame as the default reference period.

Basis for the OFL: All table values are in 1000 t (Scenario 10-4):

Year	Tier	B_{MSY}	B (MMB_{mating})	B/B_{MSY}	F_{OFL}	γ	Basis for B_{MSY}	Natural Mortality
2011/12	4a	3.11	7.17	2.31	0.18	1	1989-2010	0.18
2012/13	4a	3.56	5.63	1.56	0.18	1	1978-2012	0.18
2013/14	4b	3.06	3.01	0.98	0.18	1	1978-2013	0.18
2014/15	4b	3.28	2.71	0.82	0.14	1	1978-2014	0.18
2015/16	4b	3.42	1.80	0.53	0.08	1	1978-2015	0.18

Basis for the OFL: All table values are in million lbs (Scenario 10-4):

Year	Tier	B_{MSY}	B (MMB_{mating})	B/B_{MSY}	F_{OFL}	γ	Basis for B_{MSY}	Natural Mortality
2011/12	4a	6.85	15.80	2.31	0.18	1	1989-10	0.18
2012/13	4a	7.93	12.41	1.56	0.18	1	1978-12	0.18
2013/14	4b	6.76	6.64	0.98	0.18	1	1978-2013	0.18
2014/15	4b	7.24	5.98	0.82	0.14	1	1978-2014	0.18
2015/16	4b	7.54	3.97	0.53	0.08	1	1978-2015	0.18

A. Summary of Major Changes

Changes in Management of the Fishery

There are no new changes in management of the fishery.

Changes to the Input Data

All time series used in the assessment have been updated to include the most recent fishery and survey results. This assessment makes use of an updated full trawl-survey time series supplied by R. Foy in August 2015 (new time series), updated groundfish bycatch estimates based on 1999-2014 AKRO data also supplied by R. Foy, and the ADF&G pot survey data in 2015.

Spatial trawl survey and bottom temperatures from 1978 to 2015 are used in this assessment as well.

Changes in Assessment Methodology

This assessment employs the 3-stage length-based assessment model first presented in May 2011 by Bill Gaeuman and accepted by the CPT in May 2012. The model was developed to replace a similar 4-stage model used prior to 2011. During the assessment in May 2015 and this assessment, many combinations of molting probability and trawl survey selectivities were evaluated to address the residual bias problems in the previous model. We also considered bottom temperature data and spatial abundance density in station R-24 in the assessment in May 2015. In September 2015, twenty scenarios were investigated. The detailed changes to the model parameters are described in details in §E (Analytic Approach).

Changes in Assessment Results

Changes in assessment results depend on model scenarios. Many model scenarios in this assessment have satisfactorily addressed the problems of biased residual patterns.

B. Responses to SSC and CPT Comments

CPT and SSC Comments on Assessments in General

Spring 2015 CPT and SSC

Comments: *all final assessments consider stepwise changes to data and individual model runs, such that the effects of a single change to the model structure or data elements on estimates of stock status and catch recommendations can be evaluated.*

Response: Many model scenarios were created in this assessment to compare stepwise changes in the data and model structures.

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.

Spring 2015 CPT

Comments: (1) *Drop all current models from further consideration, and (2) develop new model scenarios incorporating the following elements: (i) data weighting, (ii) additional variance, (iii) revised survey time series, (iv) selectivity (various time-blocks), and (v) molting probability (various time-blocks). The above elements should be added singly to model scenarios building from the base (2014 assessment model) to more easily discern the effects of the individual changes. In addition, the author should try to achieve parsimony in the final models.*

Response: Twenty model scenarios were examined to address these 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: The authors share the comments made by the CPT and SSC and think that addressing these issues is important to improve the model.

Near-shore bottom temperatures from NMFS summer surveys are obtained to create an annual temperature index during 1978-2015. 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.

In May 2015, a scenario that the annual trawl survey catachability was 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. However, the fit did not improve with this approach. The scenario was not repeated in this report.

We also investigated the "data method" similar to Schirippa et al. (2009) to estimate trawl survey selectivities with temperature data. However, the systematic residual patterns for stage-composition data cannot be corrected by this approach. The main problem is that the temperature data do not show such systematic patterns. To save space for other scenarios, we do not present the results in this report.

Doug Pengilly has examined the crab spatial patterns from NMFS trawl surveys and ADF&G pot surveys and their associations with bottom temperatures in a great detail. He presented his findings to the CPT in May 2015. His work shows the impacts of bottom temperatures on crab availability are complex. Unfortunately we do not have annual spatial temperature data very close to the island to develop a relationship to use temperature data to estimate annual trawl survey selectivities. His study also shows that the change of area-swept estimates in Station R-24 over time may be part of the reasons for the temporally patterned residuals in the survey composition data. We used pot survey data to estimate the high density area in station R-24 and developed an adjustment factor to reduce the biased area-swept estimates in station R-24.

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.

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 biological reasons for the big differences in molting probabilities or trawl survey selectivities between two periods are still unclear. The model retrospective patterns of biomass could also not be satisfactorily addressed in this assessment; 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.

Spring 2015 SSC
Comments: None

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[1]. 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 its lithodid cousins the golden or brown 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 70m (NPFMC 1998). Mature females have a biennial ovarian cycle (cf. Jensen and Armstrong, 1989) and 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 77.0 mm 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. They noted, however, that although spermataphore presence indicates physiological sexual maturity, it may not be an indicator of functional sexual maturity. For purposes of management of the St. Matthew Island blue king crab fishery, the State of Alaska uses 105 mm CL to define the lower size bound of functionally mature males (Pengilly and Schmidt 1995). Otto and Cummiskey (1990) report an average growth increment of 14.1 mm CL for adult SMBKC males.

Management History

The SMBKC fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990). Ten U.S. vessels harvested 1.202 million pounds in 1977, and harvests peaked in 1983 when 164 vessels landed 9.454 million pounds (Fitch et al. 2012; Table 1). 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 11.0 million pounds as defined by the Fishery Management Plan for the Bering Sea/Aleutian Islands King and Tanner crabs (NPFMC 1999). Zheng and Kruse (2002) hypothesized a high level of SMBKC natural mortality from 1998 to 1999 as an explanation for the low catch per unit effort (CPUE) in the 1998/99 commercial fishery and the low numbers across all male crab size groups caught in the annual NMFS eastern Bering Sea trawl survey from 1999 to 2005 (Table 2). In Nov 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 Sept 21, 2009, and the fishery was reopened after a 10-year closure on Oct 15, 2009 with a TAC of 1.167 million pounds, closing again by regulation on Feb

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

1, 2010. Seven participating vessels landed a catch of 460,859 pounds with a reported effort of 10,697 pot lifts and an estimated CPUE of 9.9 retained crab per pot lift. The fishery remained open the next three years with modest harvests and similar CPUE, but large declines in the NMFS trawl-survey estimate of stock abundance raised concerns about the health of the stock, prompting ADF&G to close the fishery again for the 2013/14 season. Due to abundance above thresholds, the fishery was reopen for the 2014/15 season with a low TAC.

Though historical observer data are limited due to very limited samplings, bycatch of female and sublegal male crab from the directed blue king crab fishery off St. Matthew Island was relatively high in past years, with estimated total bycatch in terms of number of crab captured sometimes twice or more 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 3), with total male discard mortality in the 2012/13 directed fishery estimated at about 12% (0.193 million pounds) of the reported retained catch weight, assuming 20% handling mortality. On the other hand, these same data suggest a significant reduction in the bycatch of females, which may be attributable to the later timing of the contemporary fishery[2]. Some bycatch of discarded blue king crab has also been observed historically in the eastern Bering Sea snow crab fishery, but in recent years it has generally been negligible, and observers recorded no bycatch of blue king crab in sampled pot lifts during 2013/14. The St. Matthew Island golden king crab fishery, the third commercial crab fishery to have taken place in the area, typically occurred in areas with depths exceeding blue king crab distribution. NMFS observer data suggest that variable but mostly limited SMBKC bycatch has also occurred in the eastern Bering Sea groundfish fisheries (Table 4).

D. Data

Summary of New Information

Data used in this assessment have been updated to include the most recently available fishery and survey numbers. In addition, this assessment makes use an updated trawl-survey time series provided by R. Foy in August 2015 (new time series), as well as updated 1993-2014 groundfish bycatch estimates based on AKRO data also supplied by R. Foy. The new and old time series of trawl survey area-swept estimates were compared in May 2015 and only the new time series was used in this assessment.

Major Data Sources

Major data sources used in this assessment are annual directed-fishery retained-catch statistics from fish tickets (1978/79-1998/99, 2009/10-2014/15; Table 1); results from the annual NMFS eastern Bering Sea trawl survey (1978-2015; Table 2); results from the triennial ADF&G SMBKC pot survey (every third year during 1995-2013) and 2015 pot survey (Table 3); size-frequency information from ADF&G crab-observer pot-lift sampling (1990/91-1998/99, 2009/10-2014/15; Table 4); and NMFS groundfish-observer bycatch biomass estimates (1992/93-2014/15; Table 5). Figure 3 maps stations from which SMBKC trawl-survey and pot-

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

survey data were obtained. Further information concerning the NMFS trawl survey as it relates to commercial crab species is available in Daly et al. (2014); see Gish et al. (2012) for a description of ADF&G SMBKC pot-survey methods. It should be noted that the two surveys cover different geographic regions and that each has in some years encountered proportionally large numbers of male blue king crab in areas where the other is not represented (Figure 4). 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 5). Note that for this assessment the newly available NMFS groundfish observer data reported by ADF&G statistical area was not used.

Other Data Sources

The alternative model configuration developed for this assessment makes use of a growth transition matrix based on Otto and Cummiskey (1990). Other relevant data sources, including assumed population and fishery parameters, are presented in Appendix A, which provides a detailed description of the base-model configuration used for the 2012 and 2013 assessments.

Major Excluded Data Sources

Groundfish bycatch size-frequency data available for selected years, though used in the model-based assessment in place prior to 2011, play no direct role in this analysis. This is because these data tend to be severely limited: for example, 2012/13 data include a total of just 4 90-mm+ CL male blue king crab from reporting areas 521 and 524.

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 more 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 derives 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 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 for use a slightly revised and better documented version of the alternative model.

Assessment Methodology

The current SMBKC stock assessment model, first used in Fall 2012, is a variant of the previous four-stage SMBKC CSA model (2010 SAFE; Zheng et al. 1997) and similar in complexity to that described by Collie et al. (2005). Like the earlier model, it considers only male crab at least 90 mm in CL, but it combines stages 3 and 4 of the earlier model resulting in just three stages (male size classes) determined by carapace length measurements of (1) 90-104 mm, (2) 105-119 mm, and (3) 120 mm+. This consolidation was heavily 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. A detailed description of the base model and its implementation in the software AD Model Builder (Fournier et al. 2012) is presented in technical Appendix A to this report.

Model Selection and Evaluation

In May 2015, eight model scenarios were considered. In this assessment (September 2015), twenty scenarios are examined:

T. Model T from September 2014.

0. Effective sample sizes are determined differently from scenario T. With scenario T, 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)** for the surveys and **= min(N, 0.1*observed values)** for the pot fishery observer data, where N is 50 for the trawl surveys, N is 50 for the observer data, and N is 100 for the pot surveys. 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.

   The second change is to convert the weights to catch and discard biomass likelihoods into CVs.

   The third change is to reduce the mean weights for legals (stage 3) based on the trawl survey data and retained catch mean weights. In scenario T, annual mean retained catch weights were used for legal males. However, mean retained catch weights are always higher than the mean legal male weights. With scenario 0, the annual mean weight is the product of the ratio of mean legal male weight to retained catch weight and the annual mean retained catch weight.

   Scenario 0 is the same as scenario T except for above three changes. The first change is a major change and the last two changes are like housekeeping changes.

00. Scenario 0 plus reduction of penalty weights for groundfish fisheries bycatch fishing mortality. The weight changes from 1 to 0.01. Higher weights result in more constant fishing mortalities over time. Since the groundfish fisheries bycatch varied greatly over

time, a small weight should be used.

1. Scenario 00 plus changes in the effective sample sizes for pot fishery observer length composition data and use of pot fishery discarded biomass. In scenario T, the maximum effective sample size is the same over time for the pot fishery observer length composition data. However, before 2005, the observer coverage was very limited, and the observer data came from a small segment of the fleet and a very small amount of pots. The observer data after 2005 were from 100% coverage of the fleet and a large sampling of pots. The maximum effective sample size before 2005 (25) is set as 50% of that after 2005 for scenario 1 (50).

   In scenario T, the pot fishery discard biomass is not used to compute the likelihood. With scenario 1, the discarded biomass is used to compute the likelihood and a CV of 0.2 is set for the biomass after 2005 and 0.6 for biomass before 2005. The trawl survey CVs are generally higher than 0.2 and lower than 0.6.

2. Scenario 1 plus estimating an additional CV for the pot survey CPUE.
3. Scenario 2 plus estimating a molting probability for stage 1. The molting probability for stage 2 is based on the ratio (0.6923) of the molting probabilities between stage 1 and 2 from the tagging data (Otto and Cummiskey 1990). The transition matrix is estimated from the growth matrix after molting and molting probability. In scenario T, the transition matrix (including molting probability and growth matrix) was fixed.
4. Scenario 3 plus estimating trawl survey selectivities for two periods (before 2000 and 2000-present).
5. Scenario 3 plus estimating molting probabilities for two periods (before 2000 and 2000-present).
6. Scenario 4 plus estimating molting probabilities for two periods (before 2000 and 2000-present).
7. The same as scenario 4 except molting probabilities are 0.91 and 0.63 for respective stages 1 and 2 based on tagging data (Otto and Cummiskey 1990).
8. The same as scenario 5 except without estimating an additional CV for the pot survey CPUE and the molting probabilities during the period (1978-1999) are based on tagging data (0.91 and 0.63 for stages 1 and 2).
9. Scenario 7 plus estimating two pot survey selectivities for two periods (before 2000 and 2000-present).
10. The same as scenario 9 except without estimating an additional CV for the pot survey CPUE.
11. The same as scenario 10 except estimating annual trawl selectivity for stage 1 with a random walk approach (penalty weight = 50 for annual change):

    $S_{1,t} = S_{1,t-1}$ exp(ε_t), and $S_{2,t} = S_{2,t-1}$ exp(ε_t). The penalty is $L_{pen} = 50 \sum(\varepsilon_t * \varepsilon_t)$. The weight of 50 results in relatively smooth annual estimates of the selectivities.

10-4. The same as scenario 10 except reducing station R-24 trawl CPUE by multiplying a factor of 0.4*(401-25)/401, or 37.51%. The 401 is total square nautical miles of a station, the 25 is about the square nautical miles of land in station R-24, and the 0.4 means the high density area is 40% in station R-24.

10-3. The same as scenario 10-4 except reduction factor is 0.3*(401-25)/401, or 28.13%.

10-2. The same as scenario 10-4 except reduction factor is 0.2*(401-25)/401, or 18.75%.

10-0. The same as scenario 10-4 except assuming no trawl survey occurred in station R-24.

9-4. The same as scenario 9 except reducing station R-24 trawl CPUE by multiplying a factor of 0.4*(401-25)/401, or 37.51%.

9-0. The same as scenario 9-4 except assuming no trawl survey occurred in station R-24.

Results

Additional results are presented for model scenarios 3, 8, 10, 11, and 10-4, as these scenarios represent different approaches. We recommended scenario 10-4 be used for the overfishing determination in 2015, based on the fit of the data, plausibility of parameter estimates, and quality of area-swept abundance estimates.

a. Trawl survey station R-24.

NMFS summer trawl surveys normally did not catch many crab in station R-24 except during the 1990s and recent 10 years (Table 6). The extremely high survey catch in station R-24 during recent years merits a close examination whether there are any sampling problems. The high temporal variation and high catch rates during some periods make station R-24 be an outlier relative to the two strata (Table 6). Station R-24 makes up a high proportion of area-swept estimates of abundance in recent years.

There are four sets of pot survey data in trawl survey station R-24: 10 pot stations in 1998 and 2013, and 20 pot stations in 2013 and 2015. These pot surveys are with systematic sampling, equally covering the 401 square nautical miles. We ranked the catch by pot stations and summarized the data in Table 7. Clearly, high catch occurred only in a small area of R-24, and this area is close to the shore. The northeastern part of R-24 had low catch or no catch. The trawl survey area in R-24 is within the high density area (Figure 6). From the four pot surveys, top 40% of the pot survey stations caught about 85% to 95% of males >89 mm CL (Table 7).

We propose that the trawl CPUE in station R-24 should be applied to the high density area only. Based on the pot survey data, we define the high density area to be about 40% of R-24. With about 25 square nautical miles in R-24 being land, the reduction factor is 0.4*(401-25)/401, or 37.51%. Alternatively, we also examine the high density area as 30% and 20% and without using the trawl CPUE in R-24. Figure 7 illustrates the area-swept abundance estimates of males >89 mm CL with and without 37.51% reduction applied to station R-24.

b. Effective sample sizes.

Observed and estimated effective sample sizes are compared in Table 8.

c. Tables of estimates.

Model parameter estimates are summarized in Table 9 for six scenarios. Negative log likelihood values and management measures for 18 scenarios are compared in Table 10. Estimated abundances by stage and mature male biomasses are listed in Table 11 for four scenarios.

Generally speaking, scenarios with different molting probabilities or survey selectivities for two periods fit the data better. Scenarios with additional CV for the pot survey CPUE fit the trawl survey data better and result in higher abundance and biomass estimates in most recent years. Like the results in May 2015, large differences exist for estimated molting probabilities or survey selectivities during the two periods. Plausible biological reasons have not been found to explain the large different molting probabilities. Estimated trawl survey selectivities > 1.0 for both stages 1 and 2 during 2000-2015 are also troublesome, but might be possible due to changes in crab spatial distributions, based on the examination on pot survey data presented by Doug Pengilly to the CPT in May 2015. Differences of estimated trawl survey selectivities between two periods decrease with scenarios 10-4, 10-3, 10-2, and 10-0. The high estimated trawl survey selectivities imply that the catchability of trawl surveys during recent years is greater than the assumed value of 1.0.

d. Graphs of estimates.

Estimated trawl survey selectivities are compared in Figure 8 and molting probabilities are shown in Figure 9. The fits of total male (>89mm CL) trawl survey biomass are compared in Figure 10, and the fits of pot survey CPUE are contrasted in Figure 11 for 18 scenarios. Standardized residuals of total male trawl survey biomass are plotted in Figure 12, and bubble plots of stage compositions for trawl survey, pot survey, and commercial observer data are in Figure 13 for scenarios 3, 8, 10, 10-4 and 11. Fits to retained catch biomass and bycatch death biomass are shown for scenario 10 in Figure 14. The fits of catch and bycatch biomasses for other scenarios are not shown in the report because the differences of fits are very small among scenarios. Estimated recruitment and mature male biomass are compared in Figure 15 and 16, respectively.

Estimated trawl survey selectivities with scenario 11 (random walk approach) show the strong temporal trends (Figure 8); estimated selectivities start to increase in mid-1990s and accelerate after 1999. The values decrease somewhat during the last four years. With the trawl survey gear change in 1982 and relatively high estimated selectivities during 1978-1980 (Figure 8), it would be reasonable to estimate trawl survey selectivities separately during 1978-1981. We did run a scenario for this, but the fit does not statistically, significantly improve over scenario 10, so we do not report the scenario.

Estimated trawl survey selectivities and molting probabilities are generally confounded. For example, the estimated lower molting probabilities with scenario 8 after 1999 are associated with lower trawl survey selectivity estimates, and the assumed higher molting probabilities with scenario 10 result in higher estimated trawl survey selectivities (Figures 8 and 9; Table 9). To reduce the confounding, molting probabilities are fixed at the values estimated from tagging data during the same period for scenarios 9, 10, and 11.

e. Graphic evaluation of the fit to the data.

Model estimated relative survey biomasses depend on scenarios. Scenarios T, 0, 00, and 1 have relatively high biomass in the early period and during recent years (Figure 10).

Scenarios 2 and 3 with constant molting probabilities and trawl survey selectivities over time and with an additional CV for the pot survey CPUE result in much higher biomass estimates in recent years; the trend of the biomass estimates also differ from other scenarios (Figure 10). Estimated pot survey CPUEs are also dependent on scenarios, and the difference among scenarios are very similar to the relative survey biomasses (Figure 11).

There are strong temporal patterns for residuals of total trawl survey biomass and stage composition data for scenarios T, 0, 00, 1, 2, and 3 (showing only scenario 3), and no apparent residual patterns occur for other scenarios with two levels of trawl selectivities or molting probabilities over time (Figures 12 and 13). The stage compositions for observer data were not fit very well before 2000 for all scenarios, because the data are low quality and effective sample size is assumed small accordingly. The absolute values of standardized residuals of survey biomass are relatively smaller for scenarios 10-4, 10-3, 10-2, and 10-0 than those for scenario 10 (Figure 12). All scenarios fit well to retained catch biomass and bycatch biomass are generally (Figure 14 for scenario 10).

Estimated recruitments to the model vary greatly over time (Figure 15). Estimated recruitments during recent years are generally low except for scenarios 2 and 3. Estimated mature male biomasses on Feb. 15 also fluctuate strongly over time; the high biomass estimates in recent years for scenarios 2 and 3 show an opposite trend from the other scenarios (Figure 16).

f. Retrospective and historic analyses.

Retrospective results with scenarios 10 and 10-4 are very good except during 2010-2012 (Figures 17 and 18). Both scenarios 10 and 10-4, as well as all other scenarios, could not account for the high abundances mainly due to two or three extremely high abundance tows during these years. These results generally perform better than Model ST in the SAFE report of September 2014. Scenario 10-4 performs slightly better than scenario 10.

g. Uncertainty and sensitivity analyses.

Estimated standard deviations of parameters are summarized in Table 9 for six scenarios. Probabilities for mature male biomass and OFL in 2015 are illustrated in the section "**F. Calculation of the OFL**"

h. Comparison of alternative model scenarios.

Among the 20 scenarios, scenario T was used in 2014 and scenarios 0, 00, and 1 have some corrections and some modifications to scenario T. The results among scenarios T, 0, 00 and 1 do not have large differences, and strong temporal residual patterns occur for both survey biomass and stage composition data. Scenarios 2 and 3 are similar, and with an additional CV for the pot survey CPUE, these two scenarios result in not only strong temporal residual patterns but also an opposite trend of biomass relative to the pot survey CPUE during recent years. Scenarios 4-7 have either different molting probabilities or trawl survey selectivities for two periods, thus solving the problems of temporal residual patterns. However, with an additional CV for the pot survey CPUE, scenarios 4-7 also downweight the pot survey data and result in biomass estimates quite different from the pot survey CPUE during recent years. With the poor performance of the commercial fishery during 2014/15 season and the trawl survey issue in station R-24 in 2015, the low pot survey CPUE in 2015 seems to be more reasonable than the high abundance estimated by the trawl survey in 2015. Scenario 9 has the same problem with scenarios 4-7, but with different pot survey selectivities for two periods, it fits the pot survey data better than scenarios 4-7.

Considering all the problems for scenarios T-7 and 9 above, we would consider only the remaining scenarios for overfishing/overfished determination. With two different molting probabilities for two periods and without an additional CV for the pot survey CPUE, Scenario 8 has no temporal residual pattern issue and fits the data reasonable well. If we think that change in molting probability between two periods is real, then our choice will be scenario 8. However, it seems easy to explain the change in survey selectivities than molting probability over time and scenario 10 fits the data better than scenario 8 (Table 10). Therefore, scenario 10 is a better choice than scenario 8. Scenario 11 shows the annual change in trawl survey selectivities over time and fits the data well. Considering there are 35 more estimated parameters with scenario 11 than with scenario 10, statistically, scenario 10 fits the data better than scenario 11 (Table 10).

Scenarios 10-4, 10-3, 10-2 and 10-0 provide interesting options to adjust the trawl survey CPUE in station R-24. Estimated trawl survey biomass and mature male biomass over time are very close among these four scenarios and scenario 10 (Figures 19 and 20). With the reduction of trawl survey CPUE in station R-24, the estimated trawl survey biomasses are closer to the observed values with these four scenarios than scenario 10 (Figure 19).

We also used scenario 9 to show the impact with an additional CV for the pot survey CPUE. The reduction of trawl survey CPUE in station R-24 results in lower biomass estimates during recent years with scenarios 9-4 and 9-0 than with scenario 9 (Figures 21 and 22).

Among scenarios 10-4, 10-3, 10-2 and 10-0, completely throwing out the data in R-24 provides an interesting comparison but seems not a valid option. Therefore, we will eliminate scenario 10-0 for consideration for overfishing/overfished determination. Choice among scenarios 10-4, 10-3, and 10-2 depends on high density area definition in station R-24. Based on Table 7, it seems more reasonable to define 40% of pot survey stations as high density area than 20% or 30%. So, we select scenario 10-4 as an option to compare with scenario 10. Estimates of biomass and OFL are almost the same between these two scenarios, primarily due to the pot survey data in 2015 and change in trawl survey biomass CV estimates between them. Without the pot survey in 2015, the difference exists as shown in the retrospective analysis (Figures 17 and 18). The fit to data other than the trawl survey data is slightly better with scenario 10-4 than with scenario 10 (Table 10). Estimated trawl survey selectivities during 2000-2015 are lower for scenario 10-4 than scenario 10 (Figures 8 and 9; Table 9). Although both scenario 10 and 10-4 are a good choice for using for overfishing/overfished determination, we would prefer scenario 10-4 over scenario 10, based on the reasons above.

The remaining question is what reasons cause the trawl survey selectivities greater than 1 when selecting scenario 10 or scenario 10-4. Since we assume trawl survey catchability to be 1, the trawl survey selectivities are a combination of the catchability and selectivities. If the catchability is greater than 1, then selectivities can be less than 1. Trawl survey catchability was estimated to be greater than 1 in the past for this stock (Collie et al. 2005). During our past modeling experience with this stock, the catchability would be greater than 1 if estimated in the model like Collie et al. (2005). The spatial distribution of blue king crab around the island and the systematic design of survey stations may be the reason for catchability greater than 1. The area-swept estimate of abundance in station R-24 is an example for abundance overestimation. Much more field work may be needed to completely answer this question.

In summary, we recommend scenario 10-4 be used for overfishing/overfished determination in September 2015 in 2015.

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

$$a) \quad F_{OFL} = F_{MSY}, \; when \;\; B / B_{MSY} > 1;$$

$$b) \quad F_{OFL} = F_{MSY} \, (B / B_{MSY} - \alpha) / (1 - \alpha), \; when \;\; \beta < B / B_{MSY} \le 1;$$

$$c) \quad F_{OFL} < F_{MSY} \;\; with \; directed \;\; fishery \; F = 0, \; when \;\; B / B_{MSY} \le \beta,$$

where B is quantified as mature-male biomass at mating MMB_{mating}, with time of mating assigned a nominal date of Feb 15. Note that as B is itself a function of the fishing mortality F_{OFL}, in case b) numerical approximation of F_{OFL} is required. As implemented for this assessment, all calculations proceed according to the model equations given in Appendix A. In particular, the OFL catch is computed using equations [A3], [A4], and [A5], with F_{OFL} 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 -2015, to define a B_{MSY} proxy in terms of average estimated MMB_{mating} and to put $\gamma = 1.0$ with assumed stock natural mortality $M = 0.18$ yr^{-1} in setting the F_{MSY} proxy value γM. The parameters α and β are assigned their default values $\alpha = 0.10$ and $\beta = 0.25$. The F_{OFL}, OFL, and MMB in 2015 for 18 scenarios are summarized in Table 10. Figures 19 and 20 illustrate the OFL and MMB probabilities in 2015 for scenarios 10 and 10-4 using the mcmc appproach. ABC is 80% of the OFL.

OFL, ABC, retained catch and bycatches for 2015 are summarized for scenarios 10 and 10-4 below:

	OFL	ABC	Ret. catch	Pot male bycatch	Groundfish bycatch
Scen. 10 (1000t):	0.1560	0.1248	0.1495	0.0064	0.0001
(million lbs):	0.3440	0.2752	0.3296	0.0141	0.0003
Scen.10-4 (1000t):	0.1616	0.1292	0.1545	0.0069	0.0001
(million lbs):	0.3562	0.2849	0.3407	0.0152	0.0003

G. Rebuilding Analysis

This stock is not currently subject to a rebuilding plan.

H. Data Gaps and Research Priorities

1. Growth increments and molting probabilities as a function of size.
2. Trawl survey catchability and selectivities.
3. Temporal changes in spatial distributions near the island.
4. Natural mortality.

I. Projections and Future Outlook

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

J. Acknowledgements

We thank the Crab Plan Team and Joel Webb for reviewing the earlier draft of this manuscript. Some materials in the report are from the SAFE report prepared by Bill Gaeuman in 2014.

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.

Schirripa, M.J., C.P. Goodyear, and R.M. Methot. 2009. Testing different methods of incorporating climate data into the assessment of US West Coast sablefish. ICES Journal of Marine Science, 66: 1605–1613.

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.

Wilderbuer, T., D. G. Nichol, and J. Ianelli. 2013. Assessment of the yellowfin sole stock in the Bering Sea and Aleutian Islands. Pages 619-708 in 2013 North Pacific Groundfish Stock Assessment and Fishery Evaluation Reports for 2014. North Pacific Fishery Management Council, Anchorage.

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 1. The 1978/79 – 2014/15 directed St. Matthew Island blue king crab pot fishery. Source: Fitch et al. 2012; ADF&G Dutch Harbor staff, pers. comm.

			Harvest[b]					
season	dates	GHL/TAC[a]	crab	pounds	pot lifts	CPUE[c]	avg wt[d]	avg CL[e]
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	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	10/15-12/05	0.66	69,109	308,582	10,133	7	4.5	132.3

[a] Guideline Harvest Level/Total Allowable Catch in millions of pounds.
[b] Includes deadloss.
[c] Harvest number/pot lift.
[d] Harvest weight/harvest number, in pounds.
[e] Average CL of retained crab in millimeters, from dockside sampling of delivered crab.

Table 2a. 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 ≥ 90 mm CL is also given. Source: R.Foy, NMFS.

	abundance					biomass		
year	stage 1 (90-104mm CL)	stage 2 (105-119mm CL)	stage 3 (120mm+ CL)	Total	CV	Total (90mm+ CL)	CV	number of crab
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
1999	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

Table 2b. 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 ≥ 90 mm CL is also given. The CPUE in station R-24 is reduced by a factor 0.4*(401-25)/401, or 37.51%. Source: Doug Pengilly, ADF&G.

	abundance					biomass		
	stage 1	stage 2	stage 3			Total		number
year	(90-104mm CL)	(105-119mm CL)	(120mm+ CL)	Total	CV	(90mm+ CL)	CV	of crab
1978	1.975	1.753	1.348	5.075	0.430	13.360	0.410	157
1979	3.035	2.256	1.808	7.099	0.476	17.519	0.466	178
1980	2.833	2.430	2.474	7.738	0.588	21.311	0.523	185
1981	0.483	1.213	2.247	3.943	0.370	14.389	0.403	140
1982	1.669	2.431	5.865	9.965	0.402	35.696	0.345	271
1983	1.061	1.651	3.345	6.057	0.332	21.240	0.298	231
1984	0.435	0.475	1.452	2.362	0.176	8.920	0.181	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	0.307	0.613	0.696	1.616	0.308	4.857	0.297	71
1988	0.385	0.791	0.932	2.109	0.290	6.751	0.256	81
1989	2.169	1.154	1.766	5.089	0.315	13.878	0.273	208
1990	1.053	1.013	2.229	4.295	0.308	14.393	0.279	170
1991	1.128	1.568	2.155	4.851	0.263	14.714	0.252	197
1992	1.040	1.175	2.153	4.368	0.186	14.412	0.180	220
1993	1.439	1.729	3.128	6.297	0.179	20.005	0.160	324
1994	0.823	1.239	2.138	4.200	0.179	13.730	0.170	211
1995	0.969	1.114	1.648	3.731	0.181	11.844	0.168	178
1996	0.995	1.556	2.952	5.503	0.230	19.021	0.226	285
1997	0.873	1.566	3.185	5.624	0.228	19.366	0.217	296
1998	0.591	1.266	2.317	4.175	0.299	14.315	0.277	243
1999	0.206	0.222	0.558	0.986	0.194	3.492	0.183	52
2000	0.282	0.248	0.703	1.232	0.309	4.356	0.317	61
2001	0.399	0.482	0.899	1.779	0.246	5.975	0.248	91
2002	0.111	0.184	0.640	0.935	0.318	3.689	0.328	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	0.262	0.281	0.414	0.957	0.398	3.121	0.364	42
2006	0.862	0.642	1.240	2.744	0.345	8.506	0.337	126
2007	1.752	1.509	1.010	4.271	0.250	11.003	0.238	250
2008	1.316	0.693	1.403	3.411	0.294	9.710	0.288	167
2009	1.398	1.724	1.288	4.410	0.187	12.010	0.187	251
2010	2.082	2.174	2.155	6.411	0.337	17.585	0.287	388
2011	1.070	1.968	2.208	5.245	0.365	15.764	0.343	318
2012	0.517	1.473	1.517	3.507	0.214	10.890	0.203	193
2013	0.294	0.411	0.766	1.471	0.201	4.684	0.206	74
2014	0.500	0.997	1.420	2.917	0.339	9.809	0.304	181
2015	0.492	0.711	0.997	2.200	0.577	6.747	0.567	153

Table 2c. 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 ≥ 90 mm CL is also given. Assuming that no tows were made in station R-24. Source: Doug Pengilly, ADF&G.

	abundance					biomass		
	stage 1	stage 2	stage 3			Total		number
year	(90-104mm CL)	(105-119mm CL)	(120mm+ CL)	Total	CV	(90mm+ CL)	CV	of crab
1978	1.831	1.609	1.244	4.685	0.463	12.338	0.440	127
1979	3.020	2.240	1.808	7.068	0.477	17.462	0.467	176
1980	2.820	2.350	2.434	7.605	0.598	20.887	0.534	175
1981	0.483	1.213	2.237	3.933	0.370	14.356	0.404	139
1982	1.669	2.431	5.854	9.954	0.402	35.656	0.344	270
1983	1.061	1.651	3.345	6.057	0.332	21.240	0.298	231
1984	0.435	0.463	1.452	2.349	0.177	8.887	0.181	104
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	0.387	46
1987	0.296	0.602	0.685	1.583	0.314	4.757	0.302	68
1988	0.371	0.776	0.917	2.064	0.296	6.625	0.260	78
1989	2.169	1.154	1.754	5.077	0.316	13.820	0.274	207
1990	1.053	1.002	2.164	4.218	0.314	14.126	0.284	163
1991	1.116	1.509	2.108	4.734	0.269	14.352	0.258	187
1992	1.019	1.051	2.070	4.140	0.190	13.675	0.183	198
1993	1.389	1.670	3.040	6.099	0.182	19.377	0.162	304
1994	0.787	1.203	2.066	4.057	0.183	13.318	0.173	199
1995	0.936	1.069	1.592	3.598	0.186	11.405	0.172	166
1996	0.850	1.354	2.885	5.089	0.236	17.985	0.232	248
1997	0.698	1.168	2.822	4.688	0.190	16.535	0.192	216
1998	0.550	1.029	1.998	3.577	0.308	12.352	0.281	185
1999	0.195	0.222	0.558	0.975	0.196	3.478	0.184	51
2000	0.282	0.226	0.681	1.188	0.318	4.195	0.327	57
2001	0.387	0.470	0.875	1.732	0.251	5.815	0.253	87
2002	0.111	0.157	0.640	0.908	0.327	3.610	0.334	37
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	0.227	0.264	0.362	0.853	0.434	2.821	0.391	36
2006	0.829	0.642	1.240	2.711	0.349	8.459	0.338	123
2007	1.292	1.203	0.901	3.395	0.183	9.045	0.194	170
2008	1.294	0.628	1.370	3.293	0.303	9.380	0.297	156
2009	1.293	1.462	1.214	3.969	0.179	10.880	0.182	209
2010	0.968	1.526	1.973	4.467	0.221	13.411	0.218	217
2011	0.631	1.195	1.608	3.434	0.199	10.761	0.205	161
2012	0.404	1.175	1.343	2.922	0.171	9.222	0.166	136
2013	0.269	0.386	0.742	1.398	0.206	4.468	0.212	68
2014	0.367	0.618	1.186	2.171	0.300	7.718	0.275	114
2015	0.191	0.376	0.408	0.976	0.344	3.020	0.293	47

Table 3. Observed proportion of crab by size class during ADF&G crab observer pot-lift sampling. Source: ADF&G Crab Observer Database.

year	pot lifts (sampled/total)	number of crab (90 mm+ CL)	stage 1 (90-104 mm CL)	stage 2 (105-119 mm CL)	stage 3 (120 mm+ CL)
1990/91	10/26,264	150	0.113	0.393	0.493
1991/92	125/37,104	3,393	0.133	0.177	0.690
1992/93	71/56,630	1,606	0.191	0.268	0.542
1993/94	84/58,647	2,241	0.281	0.210	0.510
1994/95	203/60,860	4,735	0.294	0.271	0.434
1995/96	47/48,560	663	0.148	0.212	0.640
1996/97	96/91,085	489	0.160	0.223	0.618
1997/98	133/81,117	3,195	0.182	0.205	0.613
1998/99	135/91,826	1,322	0.193	0.216	0.591
1999-2008			**FISHERY CLOSED**		
2009/10	989/10,484	19,802	0.141	0.324	0.535
2010/11	2,419/29,356	45,466	0.131	0.315	0.553
2011/12	3,359/48,554	58,666	0.131	0.305	0.564
2012/13	2,841/37,065	57,298	0.141	0.318	0.541
2013/14			**FISHERY CLOSED**		
2014/15	895/10,133	9,906	0.094	0.228	0.679

Table 4. Size-class and total CPUE (90 mm+ CL) and estimated CV and total number of captured crab (90 mm+ CL) from the 96 common stations surveyed during the six triennial ADF&G SMBKC pot surveys. Source: D.Pengilly and R.Gish, ADF&G.

year	stage 1 (90-104mm CL)	stage 2 (105-119mm CL)	stage 3 (120mm+ CL)	Total CPUE	CV	number of crab
1995	1.919	3.198	6.922	12.042	0.13	4,624
1998	0.964	2.763	8.804	12.531	0.06	4,812
2001	1.266	1.737	5.487	8.477	0.08	3,255
2004	0.112	0.414	1.141	1.667	0.15	640
2007	1.086	2.721	4.836	8.643	0.09	3,319
2010	1.326	3.276	5.607	10.209	0.13	3,920
2013	0.878	1.398	3.367	5.643	0.19	2,167
2015	0.198	0.682	1.924	2.805	0.18	1,077

Table 5. Groundfish SMBKC male bycatch biomass (10^3 pounds) estimates. Source: J. Zheng, ADF&G, and author estimates based on data from R. Foy, NMFS. AKRO estimates used after 2008/09.

	bycatch		
year	trawl[a]	fixed gear	total mortality[b]
1991/92	7.8	0.1	6.3
1992/93	4.4	5.0	6.0
1993/94	3.4	0.0	2.7
1994/95	0.7	0.2	0.7
1995/96	1.4	0.3	1.3
1996/97	0.0	0.1	0.1
1997/98	0.0	0.4	0.2
1998/99	0.0	2.0	1.0
1999/00	0.0	3.0	1.5
2000/01	0.0	0.0	0.0
2001/02	0.0	1.9	1.0
2002/03	1.6	0.9	1.7
2003/04	2.2	2.5	3.0
2004/05	0.2	1.4	0.9
2005/06	0.0	1.3	0.7
2006/07	6.2	3.2	6.6
2007/08	0.1	153.7	76.9
2008/09	0.6	14.6	7.8
2009/10	1.4	16.6	9.4
2010/11	0.8	21.1	11.2
2011/12	0.4	1.3	1.0
2012/13	1.3	0.0	1.0
2013/14	0.4	0.6	0.6
2014/15	0.0	0.3	0.2

[a] Trawl, pelagic trawl, and non-pelagic trawl gear types.
[b] Assuming handling mortalities of 0.8 for trawl and 0.5 for fixed gear.

Table 6. Density (number of crab per sq-nm) of male blue king crab ≥ 90 mm CL in trawl station R-24 relative to the single-tow and multi-tow strata averages.

	R-24	SM single-tow stratum (without R-24)				SM multi-tow stratum			
Year	Density	N tows	Average density	Sample Std Dev	(R-24 - Avg)/(St. D.)	N tows	Average density	Sample Std Dev	(R-24 - Avg)/(St. D.)
1978	2,531.8	38	299.7	855.5	2.61	0	-	-	-
1979	202.6	36	489.6	1,402.0	-0.20	0	-	-	-
1980	883.4	37	512.6	1,864.9	0.20	0	-	-	-
1981	64.3	36	265.3	589.1	-0.34	0	-	-	-
1982	73.7	39	636.5	1,598.2	-0.35	0	-	-	-
1983	0.0	26	60.8	220.4	-0.28	27	751.3	1,411.0	-0.53
1984	85.3	26	49.8	111.3	0.32	27	253.6	251.4	-0.67
1985	-	26	11.1	33.5	-	27	243.3	286.7	-
1986	0.0	26	17.9	77.7	-0.23	27	116.2	294.6	-0.39
1987	219.4	28	8.4	32.6	6.47	23	206.2	327.1	0.04
1988	294.9	28	9.4	36.3	7.87	26	271.4	428.2	0.05
1989	79.8	28	13.2	69.6	0.96	27	682.9	1,148.9	-0.52
1990	507.7	28	24.2	128.1	3.78	24	546.8	878.9	-0.04
1991	778.7	28	77.1	148.1	4.74	25	535.9	855.0	0.28
1992	1,510.8	28	52.7	145.0	10.05	27	491.6	519.6	1.96
1993	1,312.8	28	20.7	73.4	17.61	27	812.8	789.8	0.63
1994	950.2	28	22.4	74.4	12.48	26	527.1	511.6	0.83
1995	886.8	28	88.4	202.0	3.95	27	361.0	368.4	1.43
1996	2,753.0	28	16.4	48.8	56.05	26	679.5	845.1	2.45
1997	6,218.4	28	37.6	124.2	49.75	27	591.0	612.6	9.19
1998	3,971.3	28	24.2	82.7	47.73	27	457.9	782.8	4.49
1999	69.2	28	10.3	32.7	1.80	26	119.1	126.1	-0.40
2000	296.3	28	5.7	29.9	9.71	27	155.8	268.2	0.52
2001	316.8	28	0.0	0.0	-	27	239.9	312.7	0.25
2002	182.0	28	7.1	20.9	8.36	27	114.7	211.2	0.32
2003	0.0	28	0.0	0.0	-	27	165.4	343.0	-0.48
2004	0.0	28	4.7	25.1	-0.19	27	130.2	260.7	-0.50
2005	691.8	28	29.7	145.3	4.56	26	72.0	144.7	4.28
2006	218.3	28	15.2	56.6	3.59	27	351.9	675.8	-0.20
2007	5,821.9	28	22.4	54.2	106.93	27	435.6	440.6	12.23
2008	788.3	28	9.5	23.7	32.87	27	441.4	716.2	0.48
2009	2,929.6	28	53.0	139.8	20.58	27	467.4	465.6	5.29
2010	12,920.7	28	57.5	118.6	108.47	27	529.4	687.4	18.03
2011	12,041.2	28	62.3	204.5	58.57	27	378.8	379.9	30.70
2012	3,894.9	28	57.3	125.5	30.57	27	315.7	303.8	11.78
2013	487.1	28	24.5	54.1	8.56	27	155.6	190.5	1.74
2014	4,958.0	28	0.0	0.0	-	27	300.8	468.6	9.94
2015	8,140.7	28	2.3	12.3	661.43	27	131.6	241.2	33.20

Table 7. Pot survey station rank within trawl survey station R-24, male catch (>89 mm CL) in each station, and cumulative percentage of catch in 1998, 2013 and 2015. Two pot surveys in 2013, one with 10 stations and another with 20 stations. The highlighted is top 40% of total pot stations.

Station	1998		2013		2013		2015	
rank	Catch	Cumu.%	Catch	Cumu.%	Catch	Cumu.%	Catch	Cumu.%
1	43	43.88%	76	45.51%	63	18.86%	105	35.12%
2	27	71.43%	43	71.26%	53	34.73%	66	57.19%
3	8	79.59%	33	91.02%	48	49.10%	25	65.55%
4	7	86.73%	7	95.21%	38	60.48%	17	71.24%
5	4	90.82%	6	98.80%	30	69.46%	12	75.25%
6	4	94.90%	1	99.40%	30	78.44%	10	78.60%
7	2	96.94%	1	100.00%	22	85.03%	10	81.94%
8	2	98.98%	0	100.00%	19	90.72%	8	84.62%
9	1	100.00%	0	100.00%	11	94.01%	7	86.96%
10	0	100.00%	0	100.00%	5	95.51%	7	89.30%
11					3	96.41%	6	91.30%
12					2	97.01%	5	92.98%
13					2	97.60%	4	94.31%
14					2	98.20%	3	95.32%
15					2	98.80%	3	96.32%
16					2	99.40%	3	97.32%
17					1	99.70%	3	98.33%
18					1	100.00%	2	99.00%
19					0	100.00%	2	99.67%
20					0	100.00%	1	100.00%
Total	98		167		334		299	
Mean	9.8		16.7		16.7		14.95	

Table 8. 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 T			Effective Sample Sizes Scen. 0-11		Scen. 0, 00	Scen. 1-11
Year	Trawl	Pot	Observer	Trawl	Pot	Observer	Trawl	Pot	Observer	Observer
1978	157			50			50			
1979	178			50			50			
1980	185			50			50			
1981	140			50			50			
1982	271			50			50			
1983	231			50			50			
1984	105			50			50			
1985	93			50			46.5			
1986	46			46			23			
1987	71			50			35.5			
1988	81			50			40.5			
1989	208			50			50			
1990	170		150	50		100	50		15	15
1991	197		3393	50		100	50		50	25
1992	220		1606	50		100	50		50	25
1993	324		2241	50		100	50		50	25
1994	211		4735	50		100	50		50	25
1995	178	4624	663	50	100	100	50	100	50	25
1996	285		489	50		100	50		48.9	25
1997	296		3195	50		100	50		50	25
1998	243	4812	1323	50	100	100	50	100	50	25
1999	52			50			26			
2000	61			50			30.5			
2001	91	3255		50	100		45.5	100		
2002	38			38			19			
2003	65			50			32.5			
2004	48	640		48	100		24	100		
2005	42			42			21			
2006	126			50			50			
2007	250	3319		50	100		50	100		
2008	167			50			50			
2009	251		19802	50		100	50		50	50
2010	388	3920	45466	50	100	100	50	100	50	50
2011	318		58667	50		100	50		50	50
2012	193		57282	50		100	50		50	50
2013	74	2167		50	100		37	100		
2014	181		9906	50		100	50		50	50
2015	153	1077		50	100		50	100		

Table 9(T & 3). Model parameter estimates and standard deviations for scenarios T and 3. Ranges are given for log recruit, log fishing mortality and log trawl-survey selectivity deviations.

	Scenario T		Scenario 3	
parameter	estimate	standard dev.	estimate	standard dev.
1998/99 natural mortality	0.875	0.118	1.405	0.230
pot-survey catchability	4.416	0.352	2.889	0.765
trawl-survey stage-1 selectivity (1978-2015)	0.696	0.047	0.682	0.049
trawl-survey stage-2 selectivity (1978-2015)	0.944	0.055	0.856	0.049
pot-survey stage-1 selectivity	0.301	0.043	0.293	0.042
pot-survey stage-2 selectivity	0.732	0.072	0.628	0.055
pot-fishery stage-1 selectivity (1978-1998)	0.341	0.033	0.473	0.076
pot-fishery stage-2 selectivity (1978-1998)	0.518	0.041	0.654	0.061
pot-fishery stage-1 selectivity (2009-2014)			0.271	0.058
pot-fishery stage-2 selectivity (2009-2014)			0.659	0.082
molting probability for stage 1 (1978-2015)			0.990	0.000
additional cv for pot survey			0.695	0.271
log initial stage-1 abundance	8.212	0.203	8.040	0.169
log initial stage-2 abundance	7.779	0.227	7.706	0.196
log initial stage-3 abundance	7.428	0.243	7.285	0.220
mean log recruit abundance	6.735	0.051	6.945	0.057
mean log recruit abundance deviations (37)	[-1.92, 1.56]	[0.15, 0.54]	[-1.58, 1.29]	[0.16, 0.39]
mean log pot-fishery fishing mortality	-1.388	0.057	-1.474	0.056
log pot-fishery fishing mortality dev. (26)	[-3.18, 1.31]	[0.08, 0.27]	[-3.01, 1.41]	[0.08, 0.25]
mean log GF trawl-gear fishing mortality	-10.454	0.220	-11.079	0.485
log GF trawl-gear fishing mortality dev. (24)	[-1.73, 1.69]	[0.70, 0.72]	[-4.43, 3.97]	[1.07, 3.81]
mean log GF fixed-gear fishing mortality	-9.584	0.215	-9.859	0.320
log GF fixed-gear fishing mortality dev. (24)	[-2.27, 2.60]	[0.69, 0.70]	[-5.62, 5.80]	[1.01, 3.36]

Table 9(8 & 11). Model parameter estimates and standard deviations for scenarios 8 and 11. Ranges are given for log recruit, log fishing mortality and log trawl-survey selectivity deviations.

	Scenario 8		Scenario 11	
parameter	estimate	standard dev.	estimate	standard dev.
1998/99 natural mortality	1.131	0.115	1.234	0.141
pot-survey catchability	3.779	0.290	3.697	0.292
trawl-survey stage-1 selectivity (1978-2015)	0.454	0.037		
trawl-survey stage-2 selectivity (1978-2015)	0.636	0.039		
initial trawl-survey stage-1 selectivity			1.112	0.174
Initial trawl-survey stage-2 selectivity			1.344	0.203
trawl-survey stage-1 & 2 selectivity deviations (37)			[-2.01, 1.40]	[0.15, 0.53]
pot-survey stage-1 selectivity (1995-2015)	0.154	0.025		
pot-survey stage-2 selectivity (1995-2015)	0.398	0.037		
pot-survey stage-1 selectivity (1995-1998)			0.253	0.070
pot-survey stage-2 selectivity (1995-1998)			0.382	0.064
pot-survey stage-1 selectivity (2001-2015)			0.413	0.066
pot-survey stage-2 selectivity (2001-2015)			0.919	0.087
pot-fishery stage-1 selectivity (1978-1998)	0.375	0.057	0.385	0.062
pot-fishery stage-2 selectivity (1978-1998)	0.540	0.051	0.549	0.054
pot-fishery stage-1 selectivity (2009-2014)	0.154	0.035	0.446	0.095
pot-fishery stage-2 selectivity (2009-2014)	0.363	0.049	0.839	0.105
molting probability for stage 1 (2000-2015)	0.416	0.030		
log initial stage-1 abundance	8.137	0.204	7.943	0.187
log initial stage-2 abundance	7.746	0.222	7.632	0.219
log initial stage-3 abundance	7.333	0.242	7.650	0.241
mean log recruit abundance	6.966	0.058	6.744	0.048
mean log recruit abundance deviations (37)	[-1.49, 1.30]	[0.17, 0.52]	[-1.79, 1.38]	[0.16, 0.42]
mean log pot-fishery fishing mortality	-1.274	0.059	-1.344	0.059
log pot-fishery fishing mortality dev. (26)	[-2.98, 1.44]	[0.08, 0.29]	[-3.16, 1.53]	[0.08, 0.25]
mean log GF trawl-gear fishing mortality	-11.296	0.477	-11.074	0.460
log GF trawl-gear fishing mortality dev. (24)	[-4.34, 3.64]	[1.06, 3.57]	[-4.68, 3.41]	[0.95, 3.33]
mean log GF fixed-gear fishing mortality	-10.107	0.318	-9.856	0.298
log GF fixed-gear fishing mortality dev. (24)	[-5.40, 5.11]	[1.00, 3.56]	[-4.79, 5.40]	[0.90, 3.55]

Table 9(10 & 10-4). Model parameter estimates and standard deviations for scenarios 10 and 10-4. Ranges are given for log recruit, log fishing mortality and log trawl-survey selectivity deviations.

	Scenario 10		Scenario 10-4	
parameter	estimate	standard dev.	estimate	standard dev.
1998/99 natural mortality	1.150	0.129	1.146	0.127
pot-survey catchability	3.740	0.291	3.745	0.274
trawl-survey stage-1 selectivity (1978-1999)	0.460	0.039	0.446	0.038
trawl-survey stage-2 selectivity (1978-1999)	0.604	0.042	0.575	0.040
trawl-survey stage-1 selectivity (2000-2015)	1.418	0.137	1.290	0.124
trawl-survey stage-2 selectivity (2000-2015)	1.551	0.130	1.427	0.119
pot-survey stage-1 selectivity (1995-1998)	0.240	0.066	0.235	0.065
pot-survey stage-2 selectivity (1995-1998)	0.368	0.060	0.375	0.061
pot-survey stage-1 selectivity (2001-2015)	0.420	0.069	0.436	0.073
pot-survey stage-2 selectivity (2001-2015)	0.968	0.092	0.939	0.089
pot-fishery stage-1 selectivity (1978-1998)	0.375	0.058	0.378	0.058
pot-fishery stage-2 selectivity (1978-1998)	0.538	0.051	0.534	0.050
pot-fishery stage-1 selectivity (2009-2014)	0.437	0.093	0.445	0.094
pot-fishery stage-2 selectivity (2009-2014)	0.817	0.100	0.836	0.101
log initial stage-1 abundance	8.062	0.172	8.039	0.172
log initial stage-2 abundance	7.650	0.191	7.627	0.190
log initial stage-3 abundance	6.904	0.232	6.833	0.235
mean log recruit abundance	6.711	0.047	6.719	0.044
mean log recruit abundance deviations (37)	[-1.88, 1.54]	[0.17, 0.50]	[-1.83, 1.51]	[0.16, 0.50]
mean log pot-fishery fishing mortality	-1.265	0.059	-1.247	0.058
log pot-fishery fishing mortality dev. (26)	[-2.99, 1.45]	[0.08, 0.30]	[-2.96, 1.48]	[0.08, 0.31]
mean log GF trawl-gear fishing mortality	-11.059	0.458	-11.063	0.458
log GF trawl-gear fishing mortality dev. (24)	[-4.69, 3.42]	[0.96, 3.51]	[-4.67, 3.93]	[0.95, 3.55]
mean log GF fixed-gear fishing mortality	-9.844	0.297	-9.848	0.296
log GF fixed-gear fishing mortality dev. (24)	[-5.78, 5.38]	[0.89, 3.56]	[-5.77, 5.36]	[0.90, 3.20]

Table 10a. Comparisons of negative log-likelihood values and management measures for eighteen model scenarios. Note that scenarios 10-0, 10-2, 10-3, and 10-4 are the same as scenario 10 except using different adjustments for station R-24. Biomass and OFL are in million lbs.

Model Scenario

Neg.log.LL	T	0	00	1	2	3	4	5	6	7	8	9	10	11	10-0	10-2	10-3	10-4
Ret catch	0.595	0.497	0.449	0.638	0.462	0.462	0.415	0.416	0.418	0.420	0.436	0.425	0.445	0.458	0.458	0.460	0.459	0.458
Trawl bio	37.937	37.182	37.387	38.233	36.852	36.759	25.698	25.687	25.496	26.043	31.565	25.194	29.993	25.610	25.190	26.945	27.699	28.255
Pot CPUE	69.541	69.812	69.200	67.202	1.388	1.383	-0.322	-0.498	-0.579	-0.276	37.535	-0.755	30.644	33.196	29.943	31.353	31.382	31.290
Trawl length	1925.87	-132.49	-133.36	-128.50	-144.98	-144.84	-160.56	-161.25	-162.55	-160.72	-158.63	-161.75	-160.16	-163.02	-159.09	-161.15	-161.37	-161.42
Pot length	688.46	-47.82	-47.82	-45.58	-48.14	-48.23	-45.16	-45.63	-46.56	-44.97	-44.28	-48.99	-47.53	-48.31	-48.38	-48.12	-48.03	-47.95
Obser length	1307.40	-60.51	-60.78	-53.56	-53.93	-53.96	-53.64	-54.48	-54.38	-53.58	-54.24	-53.87	-53.73	-54.04	-54.54	-54.42	-54.36	-54.27
Obser Bio1				19.519	19.581	19.475	18.393	17.563	17.742	18.893	18.213	18.080	18.116	18.341	18.778	18.562	18.486	18.423
Obser Bio2				0.597	0.612	0.611	0.679	0.699	0.706	0.681	0.735	0.703	0.742	0.722	0.801	0.758	0.750	0.747
Trawl byc bio	17.495	17.503	0.171	0.171	0.167	0.167	0.171	0.171	0.172	0.171	0.174	0.173	0.178	0.176	0.177	0.177	0.177	0.178
Fix-g. byc bio	17.752	17.909	0.348	0.345	0.162	0.174	0.092	0.087	0.087	0.092	0.087	0.087	0.087	0.087	0.089	0.088	0.088	0.088
Tem. Dev.														8.524				
Rec Pen	13.747	13.667	13.776	13.009	10.671	10.614	12.885	8.825	9.677	12.897	11.595	13.686	17.933	15.513	18.474	17.421	17.401	17.470
Direct F pen	0.012	0.012	0.012	0.012	0.013	0.013	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.013	0.011	0.011	0.011	0.011
Trawl by F pen	13.545	13.557	0.961	0.966	0.946	0.948	0.972	0.973	0.974	0.970	0.987	0.984	1.053	1.043	1.045	1.048	1.049	1.050
Fix-g by F pen	16.136	16.302	0.869	0.868	0.891	0.893	0.873	0.811	0.822	0.874	0.780	0.863	0.863	0.862	0.854	0.856	0.857	0.858
Total	4108.48	-54.39	-118.78	-86.09	-175.30	-175.53	-199.49	-206.61	-207.96	-198.49	-155.02	-205.16	-161.36	-160.83	-166.18	-166.01	-165.40	-164.81
Total est para	126	126	126	128	129	130	132	131	133	131	129	133	132	167	132	132	132	132
Bmsy (mill.lbs)	8.146	8.081	8.069	8.185	8.457	8.402	7.743	8.138	7.997	8.0235	8.288	7.863	7.62	7.925	7.343	7.497	7.527	7.543
MMB2015	5.139	5.132	5.117	5.396	11.131	11.086	6.775	7.901	7.409	7.001	5.604	6.349	3.922	4.091	3.564	3.932	3.968	3.966
OFL2015	0.532	0.558	0.554	0.617	1.986	1.986	1.094	1.182	1.098	1.103	0.53	0.929	0.344	0.357	0.289	0.352	0.357	0.356
Fofl	0.106	0.107	0.107	0.112	0.18	0.18	0.155	0.174	0.165	0.155	0.115	0.141	0.083	0.083	0.077	0.085	0.085	0.085

Table 10b. Comparisons of differences of negative log-likelihood values and number of parameters between different model scenarios.

	Model Scenario												
Neg.log.LL	2-1	3-2	4-3	5-4	6-4	7-4	11-5	9-7	10-9	10-7	11-10	13-10	12-8
Ret catch	-0.176	0.000	-0.047	0.001	0.003	0.005	0.019	0.005	0.020	0.025	-0.010	0.013	-0.187
Trawl bio	-1.381	-0.092	-11.061	-0.011	-0.202	0.345	5.878	-0.849	4.799	3.950	1.572	-4.383	11.605
Pot CPUE	-65.814	-0.004	-1.705	-0.176	-0.257	0.046	38.033	-0.479	31.399	30.920	6.890	2.552	31.259
Trawl length	-16.480	0.148	-15.725	-0.688	-1.984	-0.160	2.622	-1.026	1.587	0.561	1.533	-2.863	-6.925
Pot length	-2.557	-0.097	3.076	-0.469	-1.408	0.190	1.350	-4.027	1.466	-2.561	3.252	-0.782	11.536
Obser length	-0.362	-0.038	0.320	-0.834	-0.732	0.062	0.242	-0.289	0.137	-0.152	-0.502	-0.305	3.522
Obser Bio1	0.062	-0.106	-1.083	-0.830	-0.650	0.500	0.650	-0.813	0.036	-0.777	0.096	0.225	-6.543
Obser Bio2	0.015	-0.001	0.068	0.020	0.028	0.002	0.036	0.021	0.040	0.061	-0.007	-0.020	-0.005
Trawl byc bio	-0.004	0.000	0.004	0.000	0.000	0.000	0.003	0.002	0.005	0.007	-0.004	-0.001	0.005
Fix-g. byc bio	-0.183	0.012	-0.082	-0.005	-0.005	-0.001	0.000	-0.004	0.000	-0.004	0.000	-0.001	0.015
Tem. Dev.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	8.524	6.787
Rec Pen	-2.338	-0.056	2.271	-4.060	-3.208	0.012	2.770	0.788	4.247	5.036	-6.338	-2.420	-1.496
Direct F pen	0.000	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.006
Trawl by F pen	-0.020	0.002	0.024	0.001	0.002	-0.002	0.014	0.014	0.070	0.083	-0.066	-0.011	0.031
Fix-g by F pen	0.023	0.001	-0.019	-0.063	-0.052	0.001	-0.031	-0.011	0.000	-0.011	-0.083	-0.001	-0.070
Total	-89.213	-0.231	-23.961	-7.115	-8.464	1.000	51.584	-6.668	43.804	37.136	6.333	0.529	49.539
Diff para.	1	1	2	-1	1	-1	-2	2	-1	1	-3	35	-1

Table 11(8&11). 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 8 and 11. All abundances are at time of survey.

	Scenario 8				Scenario 11			
Year	N1	N2	N3	MMB	N1	N2	N3	MMB
1978	3.214	2.056	1.033	6.743	2.815	2.063	2.100	10.925
1979	4.375	2.682	1.412	10.642	3.809	2.487	2.329	13.255
1980	4.143	3.732	2.385	17.446	3.682	3.309	3.062	19.040
1981	1.814	3.978	3.709	18.658	1.587	3.534	4.077	19.052
1982	1.887	2.535	4.023	13.377	1.820	2.241	4.133	13.180
1983	0.933	2.028	2.847	7.879	1.021	1.886	2.813	7.448
1984	0.804	1.246	1.609	5.508	0.861	1.248	1.521	5.172
1985	1.219	0.918	1.179	5.063	1.235	0.949	1.104	4.814
1986	1.568	1.070	1.022	5.440	1.705	1.087	0.973	5.284
1987	1.694	1.356	1.155	6.564	1.763	1.445	1.121	6.628
1988	1.565	1.539	1.391	7.519	1.538	1.612	1.403	7.724
1989	2.441	1.524	1.627	8.840	2.485	1.534	1.670	9.030
1990	1.572	2.072	1.849	9.986	1.551	2.102	1.889	10.203
1991	2.382	1.718	2.160	9.261	2.391	1.716	2.208	9.443
1992	2.581	2.070	1.953	9.853	2.597	2.074	1.992	10.012
1993	2.952	2.328	2.096	10.886	3.015	2.339	2.131	11.051
1994	2.174	2.643	2.255	11.114	2.215	2.686	2.290	11.342
1995	2.212	2.262	2.351	11.654	2.067	2.302	2.400	11.935
1996	2.457	2.169	2.422	11.601	2.470	2.093	2.481	11.662
1997	2.161	2.289	2.439	11.045	2.145	2.270	2.454	11.065
1998	1.609	2.126	2.243	5.699	1.215	2.108	2.247	5.295
1999	0.816	0.672	0.840	4.733	0.488	0.519	0.751	4.044
2000	0.952	0.761	1.016	5.608	0.417	0.498	0.870	4.450
2001	1.113	0.747	1.012	5.558	0.474	0.446	0.960	4.672
2002	0.824	0.785	1.005	5.618	0.217	0.463	1.011	4.901
2003	1.065	0.725	1.007	5.488	0.375	0.307	1.060	4.731
2004	0.858	0.757	0.996	5.521	0.282	0.349	1.029	4.709
2005	2.050	0.718	0.994	5.423	0.602	0.306	1.022	4.587
2006	2.615	1.037	0.984	6.113	0.832	0.492	0.997	4.912
2007	2.537	1.397	1.043	7.121	0.812	0.705	1.062	5.588
2008	3.361	1.589	1.162	8.058	1.096	0.762	1.203	6.314
2009	2.645	1.955	1.310	8.911	0.871	0.970	1.360	6.835
2010	2.297	1.966	1.415	8.286	0.913	0.895	1.489	6.087
2011	1.540	1.856	1.325	7.196	0.594	0.880	1.375	5.125
2012	1.092	1.562	1.097	5.923	0.342	0.667	1.138	4.018
2013	1.096	1.255	0.897	6.289	0.440	0.438	0.899	4.423
2014	0.925	1.095	1.018	6.017	0.316	0.438	0.956	4.279
2015	0.912	0.943	1.021	5.604	0.315	0.357	0.939	4.091

Table 11(10&10-4). 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 10 and 10-4. All abundances are at time of survey.

	Scenario 10				Scenario 10-4			
Year	N1	N2	N3	MMB	N1	N2	N3	MMB
1978	3.173	2.101	0.996	6.697	3.100	2.053	0.928	6.317
1979	4.313	2.669	1.400	10.574	4.221	2.600	1.318	10.143
1980	4.174	3.688	2.369	17.285	4.297	3.604	2.269	16.712
1981	1.767	3.981	3.675	18.537	1.801	4.028	3.552	18.177
1982	1.947	2.506	3.995	13.210	1.979	2.541	3.912	12.963
1983	0.948	2.054	2.811	7.787	0.937	2.083	2.756	7.619
1984	0.803	1.263	1.590	5.473	0.810	1.265	1.556	5.345
1985	1.189	0.923	1.170	5.039	1.179	0.926	1.141	4.925
1986	1.572	1.053	1.018	5.383	1.564	1.047	0.995	5.282
1987	1.682	1.353	1.143	6.510	1.651	1.345	1.121	6.408
1988	1.555	1.530	1.380	7.456	1.542	1.508	1.358	7.323
1989	2.475	1.515	1.613	8.764	2.502	1.498	1.584	8.611
1990	1.550	2.089	1.833	9.965	1.540	2.100	1.801	9.869
1991	2.395	1.710	2.154	9.223	2.348	1.707	2.132	9.130
1992	2.576	2.075	1.945	9.834	2.618	2.044	1.924	9.689
1993	2.972	2.326	2.091	10.865	2.989	2.340	2.061	10.773
1994	2.223	2.655	2.251	11.124	2.230	2.669	2.231	11.082
1995	2.088	2.296	2.353	11.736	2.086	2.304	2.343	11.719
1996	2.510	2.105	2.439	11.524	2.374	2.106	2.435	11.514
1997	2.249	2.299	2.424	11.007	2.203	2.216	2.422	10.814
1998	1.285	2.182	2.235	5.677	1.345	2.125	2.196	5.539
1999	0.395	0.591	0.831	4.512	0.381	0.599	0.812	4.459
2000	0.347	0.466	0.970	4.757	0.365	0.460	0.958	4.698
2001	0.374	0.390	1.029	4.803	0.379	0.399	1.016	4.777
2002	0.185	0.379	1.042	4.827	0.194	0.386	1.035	4.819
2003	0.345	0.256	1.047	4.563	0.364	0.264	1.045	4.575
2004	0.266	0.311	0.994	4.490	0.269	0.326	0.996	4.533
2005	0.571	0.282	0.976	4.355	0.614	0.289	0.984	4.404
2006	0.785	0.464	0.947	4.659	0.811	0.493	0.958	4.766
2007	0.816	0.665	1.007	5.292	0.783	0.692	1.030	5.440
2008	1.111	0.750	1.140	6.046	1.155	0.740	1.171	6.142
2009	0.873	0.975	1.302	6.628	0.918	0.999	1.323	6.762
2010	0.933	0.898	1.442	5.930	0.863	0.935	1.471	6.112
2011	0.592	0.893	1.337	5.021	0.598	0.862	1.378	5.100
2012	0.320	0.670	1.113	3.937	0.330	0.664	1.134	3.994
2013	0.411	0.426	0.880	4.322	0.395	0.430	0.894	4.384
2014	0.281	0.415	0.935	4.146	0.304	0.407	0.948	4.177
2015	0.278	0.326	0.910	3.922	0.278	0.338	0.917	3.966

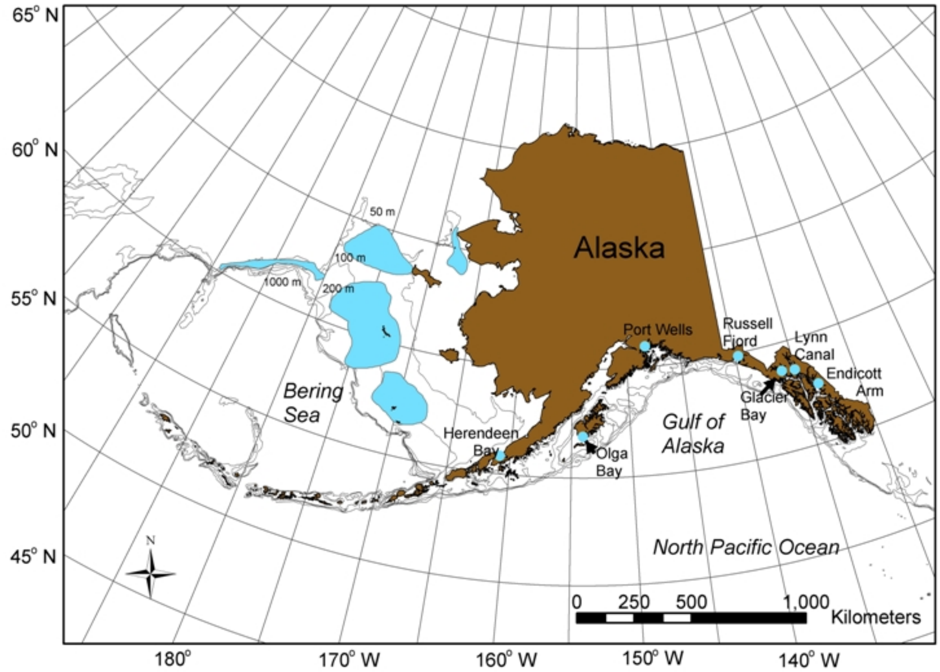


Figure 1. Distribution of blue king crab *Paralithodes platypus* in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters. Shown in blue.

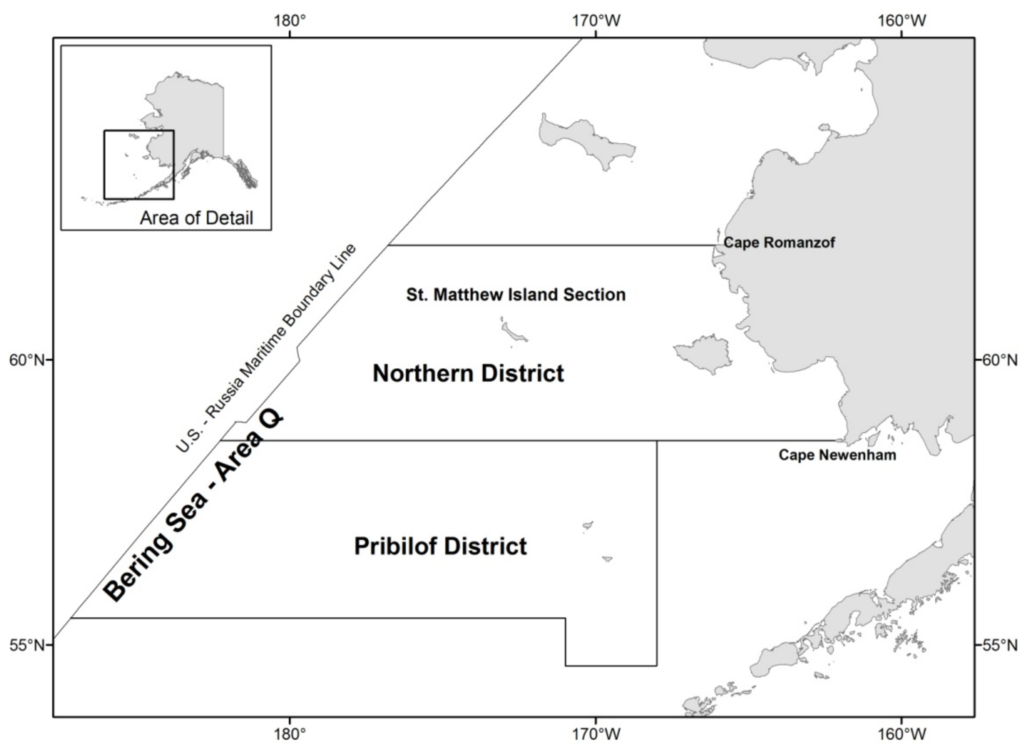


Figure 2. King crab Registration Area Q (Bering Sea).

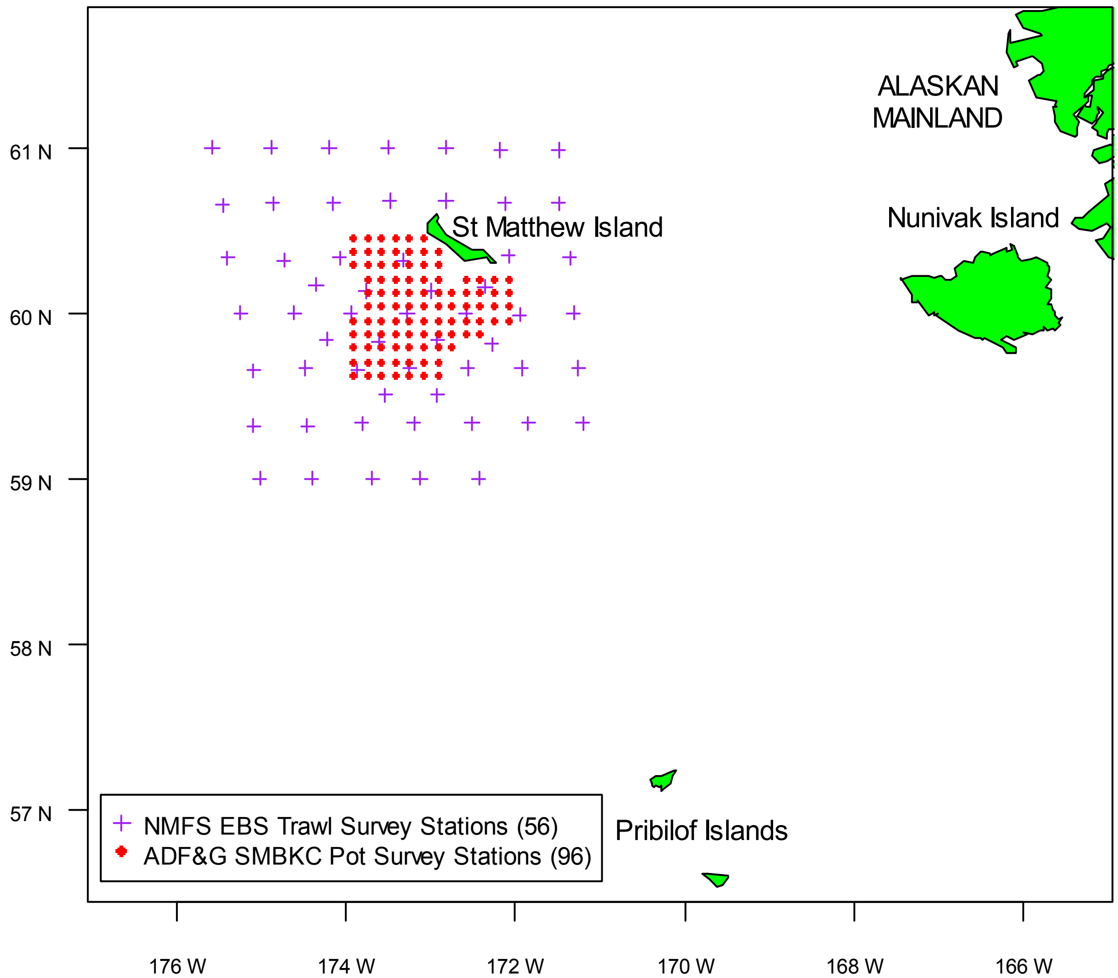


Figure 3. Trawl and pot-survey stations used in the SMBKC stock assessment.

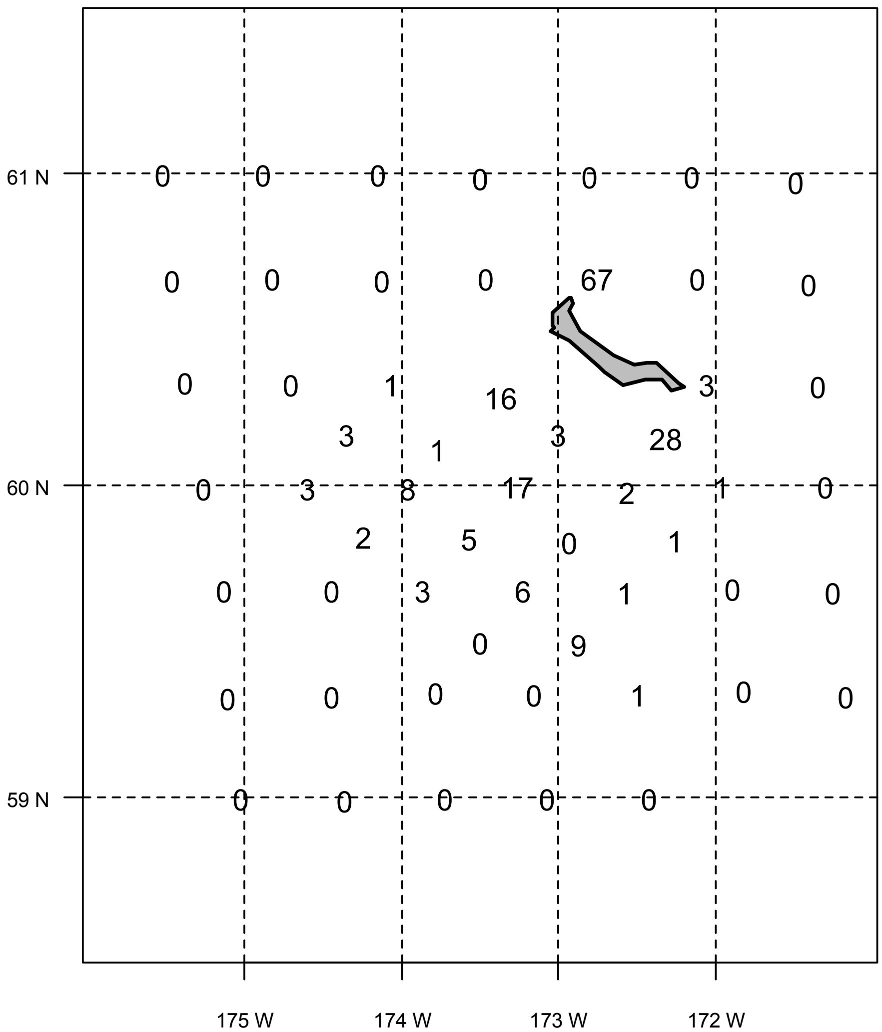


Figure 4. Catches of 181 male blue king crab measuring at least 90 mm CL from the 2014 NMFS trawl-survey at the 56 stations used to assess the SMBKC stock. Note that the area north of St. Matthew Island, which includes the large catch of 67 crab at station R-24, is not represented in the ADF&G pot-survey data used in the assessment.

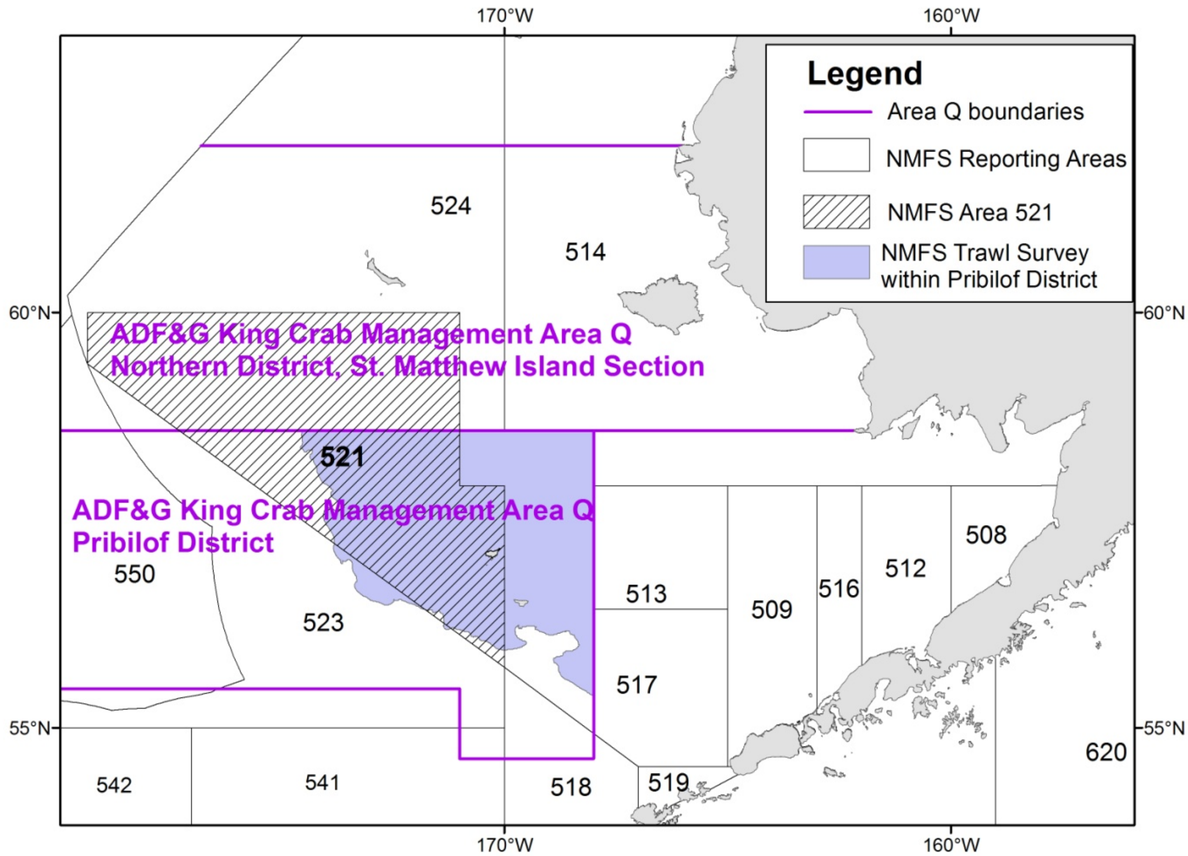


Figure 5. NFMS Bering Sea reporting areas. Estimates of SMBKC bycatch in the groundfish fisheries are based on NMFS observer data from reporting areas 524 and 521.

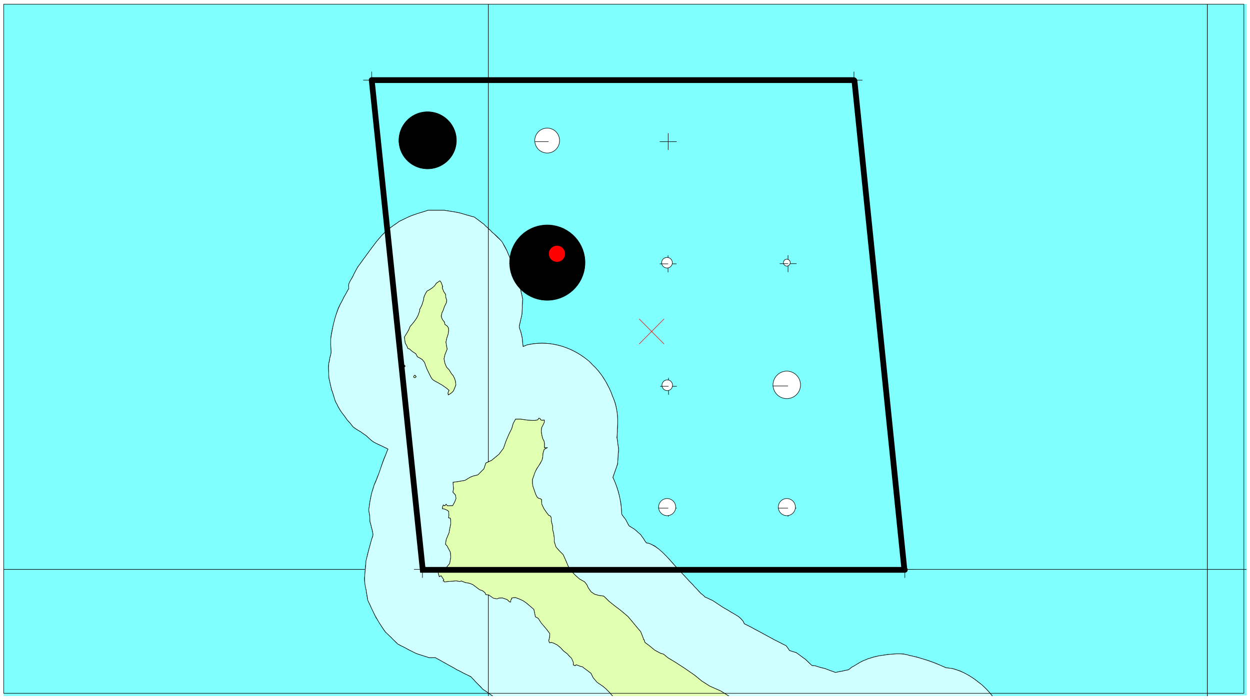


Figure 6a. ADF&G 1998 pot survey catch of male blue king crab ≥ 90 mm CL for the 10 standard (Stratum 1) stations fished during 17–19 August 1998 within NMFS trawl survey station R-24. Size (area) of circle is proportional to catch (largest = 43 crab). Black circles denote catch at a station was greater than the average catch for the 10 stations (10 crab); white circles denote catch at a station was less than the average catch for the 10 stations. Red circle is the centroid ('center of gravity") of distribution computed from the 10 stations. Red X is midpoint of the NMFS trawl survey tow performed in R-24 on 20 July 1998.

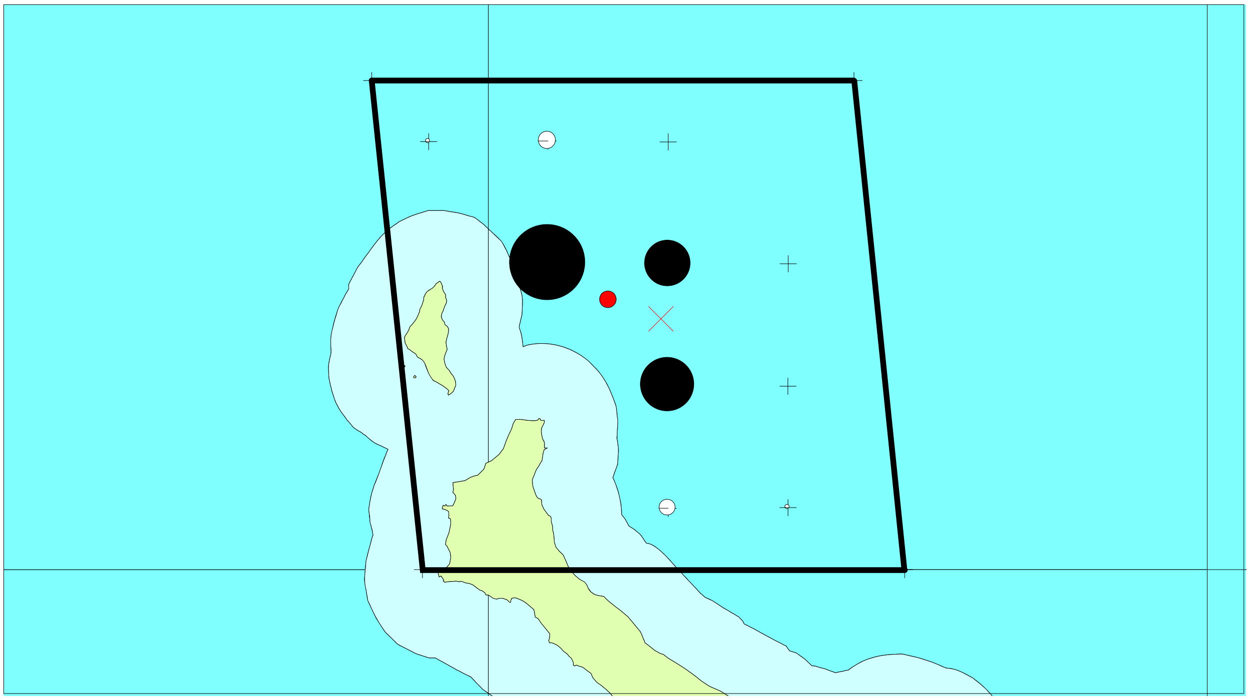


Figure 6b. ADF&G 2013 pot survey catch of male blue king crab ≥ 90 mm CL for the 10 standard (Stratum 1) stations fished during 21–25 September 2013 within NMFS trawl survey station R-24. Size (area) of circle is proportional to catch (largest = 76 crab). Black circles denote catch at a station was greater than the average catch for the 10 stations (17 crab); white circles denote catch at a station was less than the average catch for the 10 stations. Red circle is the centroid ('center of gravity") of distribution computed from the 10 stations. Red X is midpoint of the NMFS trawl survey tow performed in R-24 on 12 July 2013.

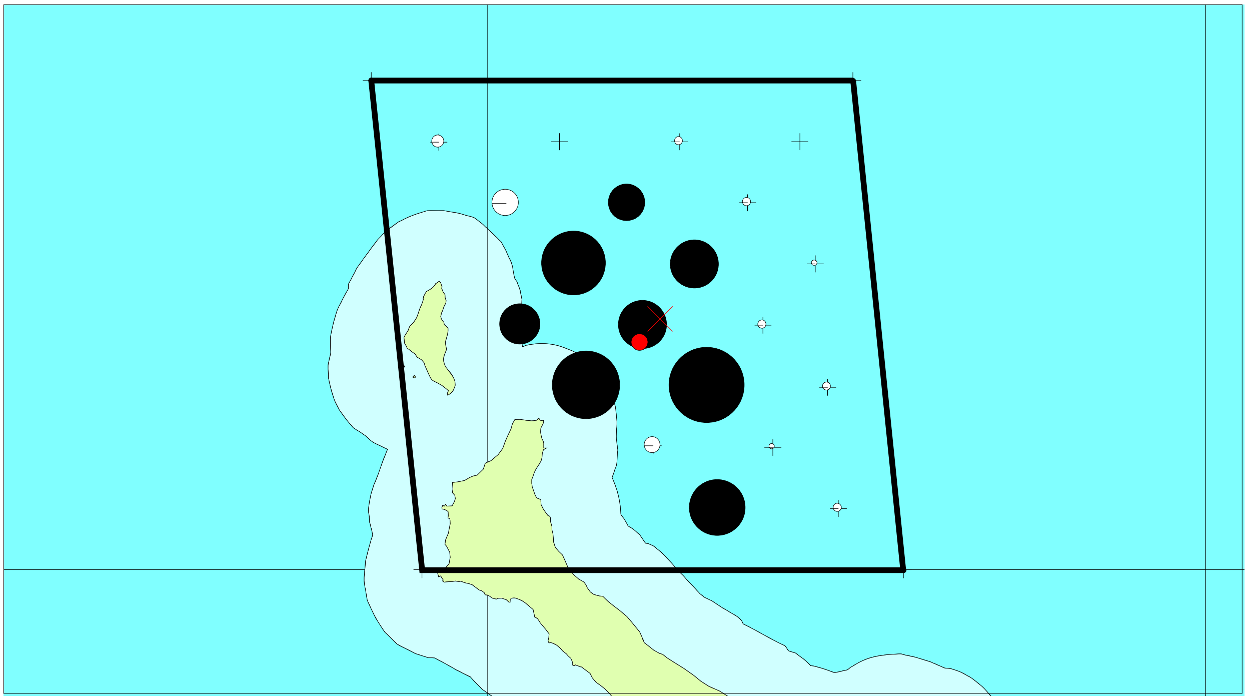


Figure 6c. ADF&G 2013 pot survey catch of male blue king crab ≥ 90 mm CL for the 20 special (Stratum 2) stations fished during 20–25 September 2013 within NMFS trawl survey station R-24. Size (area) of circle is proportional to catch (largest = 63 crab). Black circles denote catch at a station was greater than the average catch for the 20 stations (17 crab); white circles denote catch at a station was less than the average catch for the 20 stations. Red circle is the centroid ('center of gravity") of distribution computed from the 20 stations. Red X is midpoint of the NMFS trawl survey tow performed in R-24 on 12 July 2013.

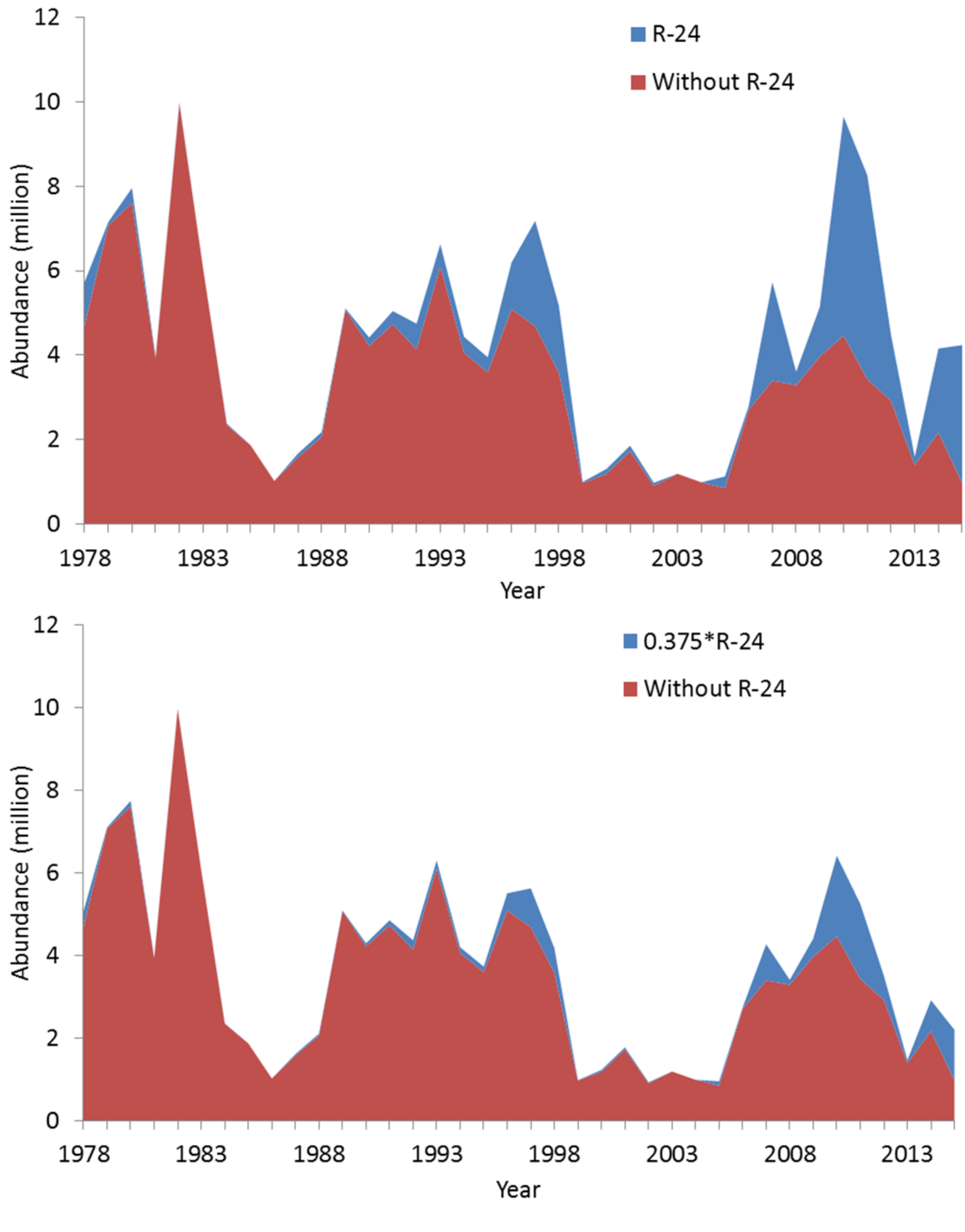


Figure 7. Comparisons of area-swept estimates of male (>89 mm CL) abundance without trawl survey station R-24, with reduction factor of 0.4*(401-25)/401, or 37.5%, applied to station R-24, and without reduction factor applied to station R-24 for St. Matthew Island blue king crab.

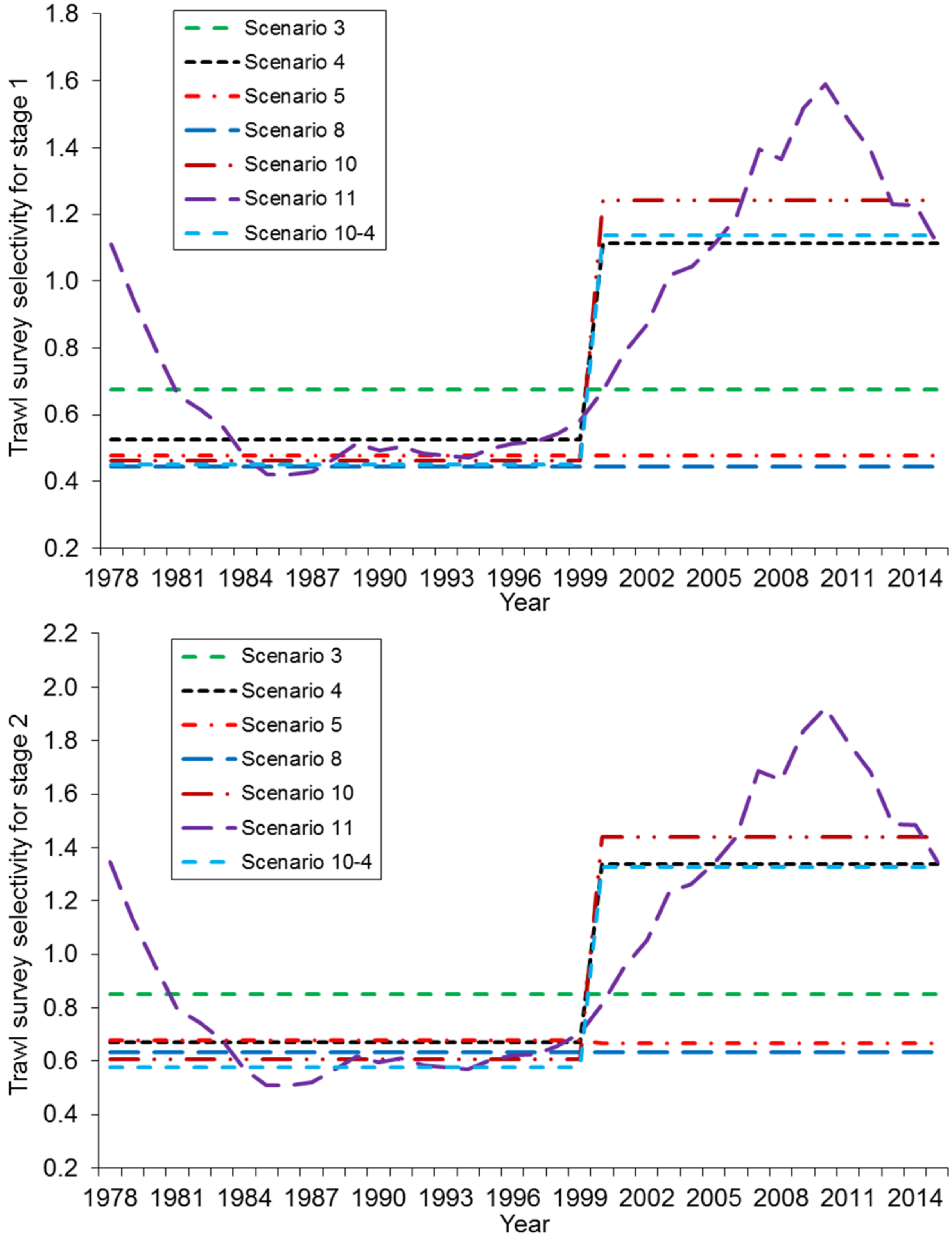


Figure 8. Estimated stage-1 (upper panel) and stage-2 (lower panel) trawl-survey selectivities for different scenarios.

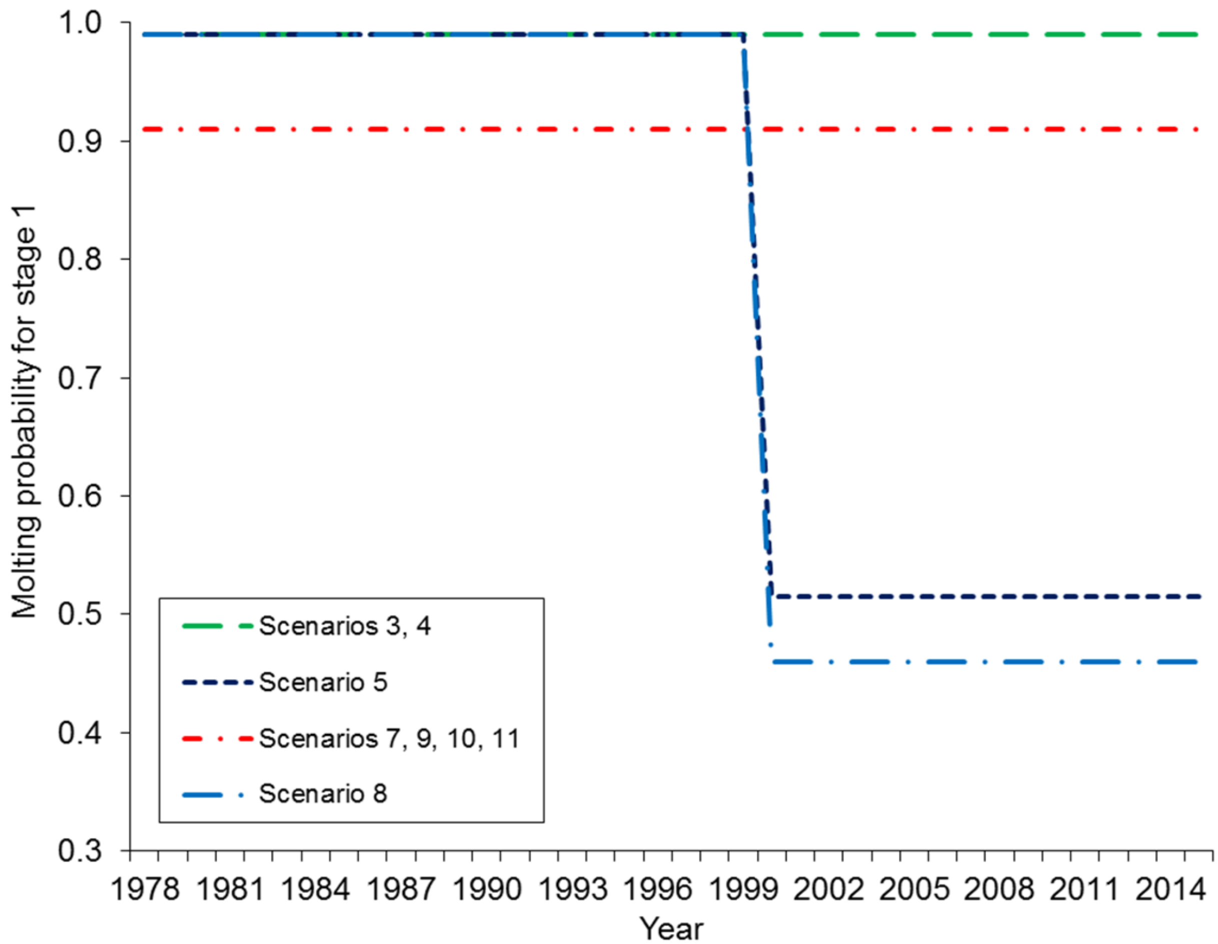


Figure 9. Estimated molting probabilities for stage-1 crab for different scenarios.

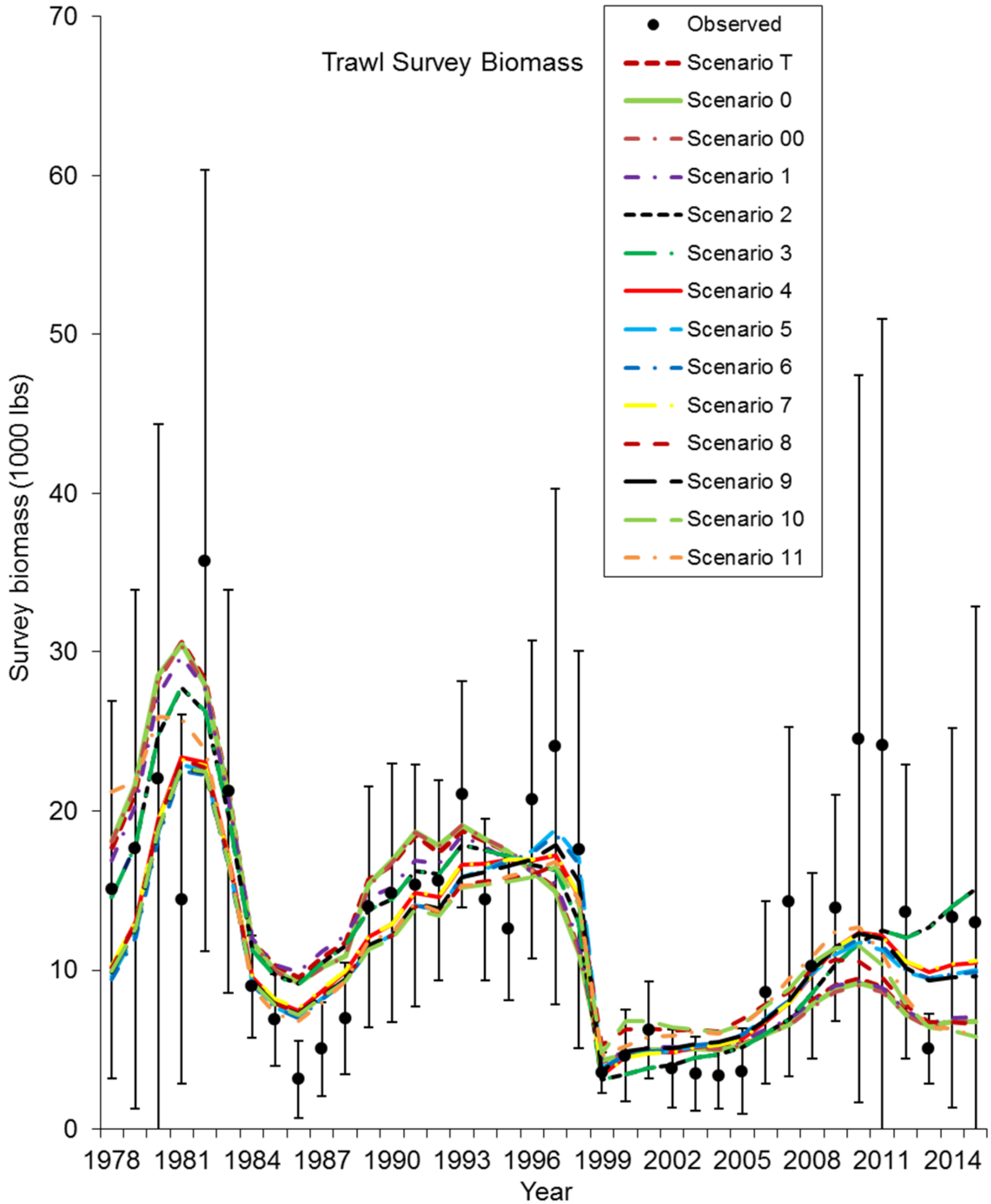


Figure 10. Comparisons of area-swept estimates of total male survey biomasses and model predictions for 2015 model estimates under 18 scenarios. The error bars are plus and minus 2 standard deviations.

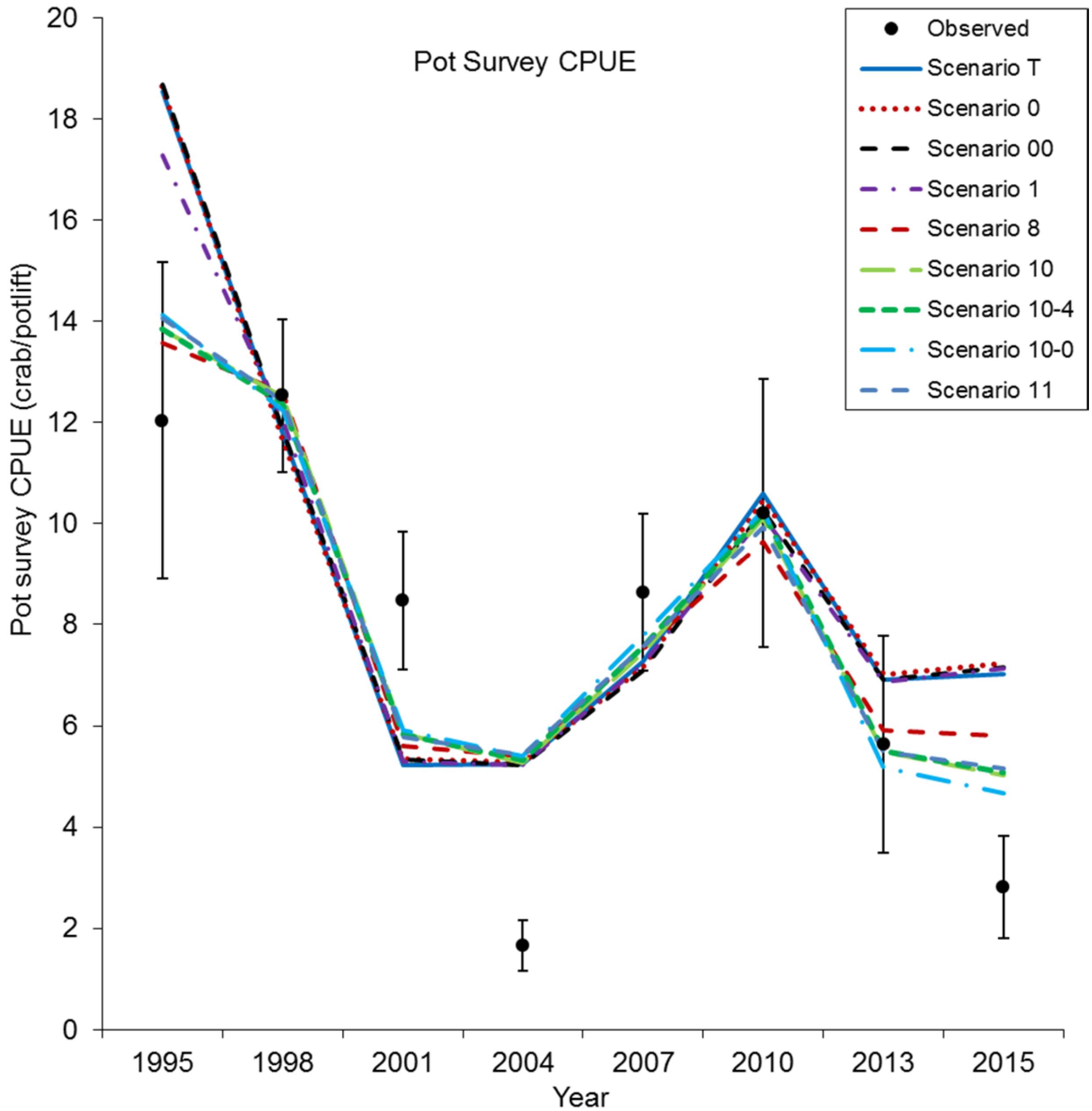


Figure 11a. Comparisons of total male pot survey CPUEs and model predictions for 2015 model estimates under 9 scenarios without additional CV for the pot survey CPUE. The error bars are plus and minus 2 standard deviations of scenario 10.

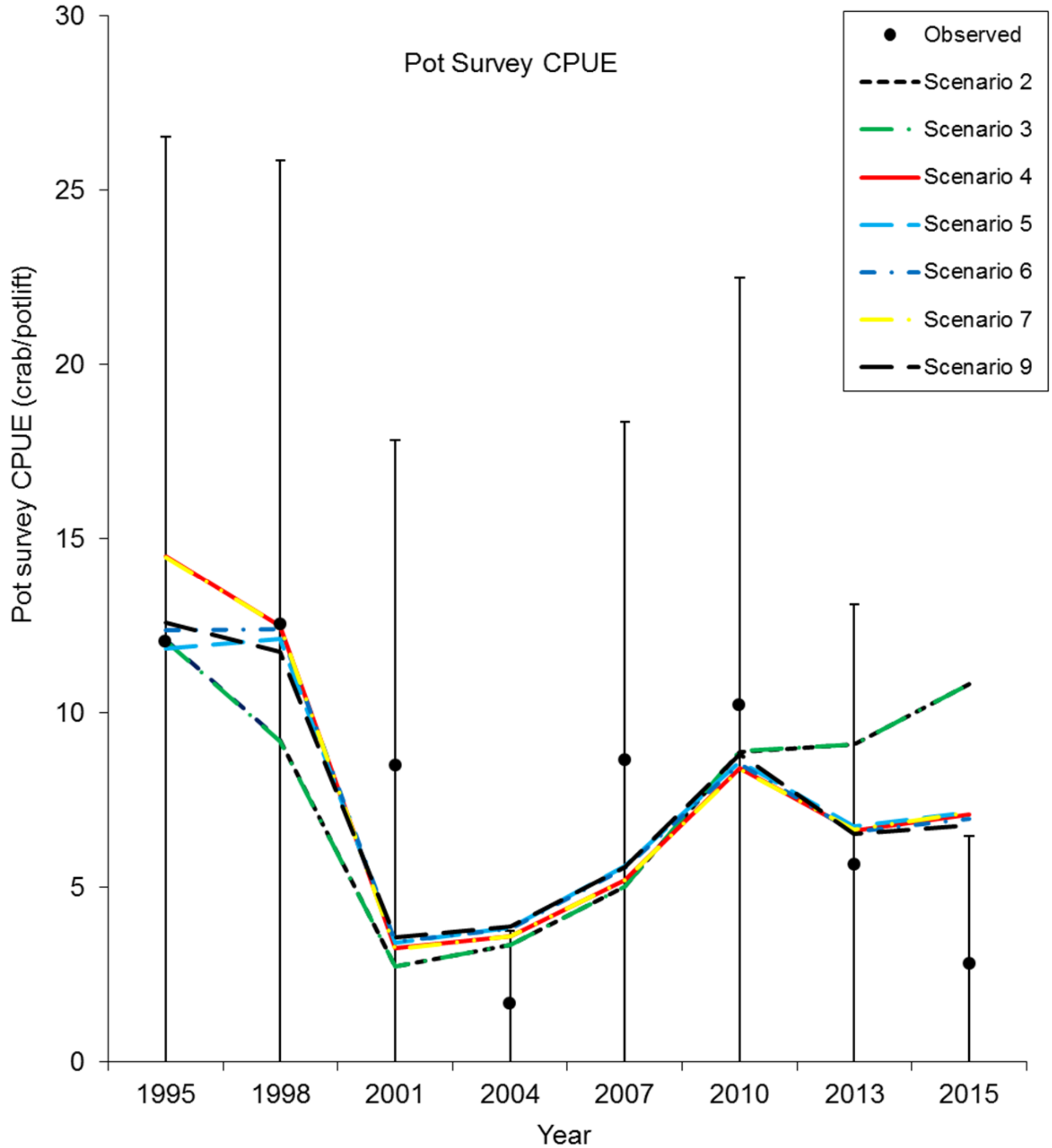


Figure 11b. Comparisons of total male pot survey CPUEs and model predictions for 2015 model estimates under 7 scenarios with additional CV for the pot survey CPUE. The error bars are plus and minus 2 standard deviations of scenario 9.

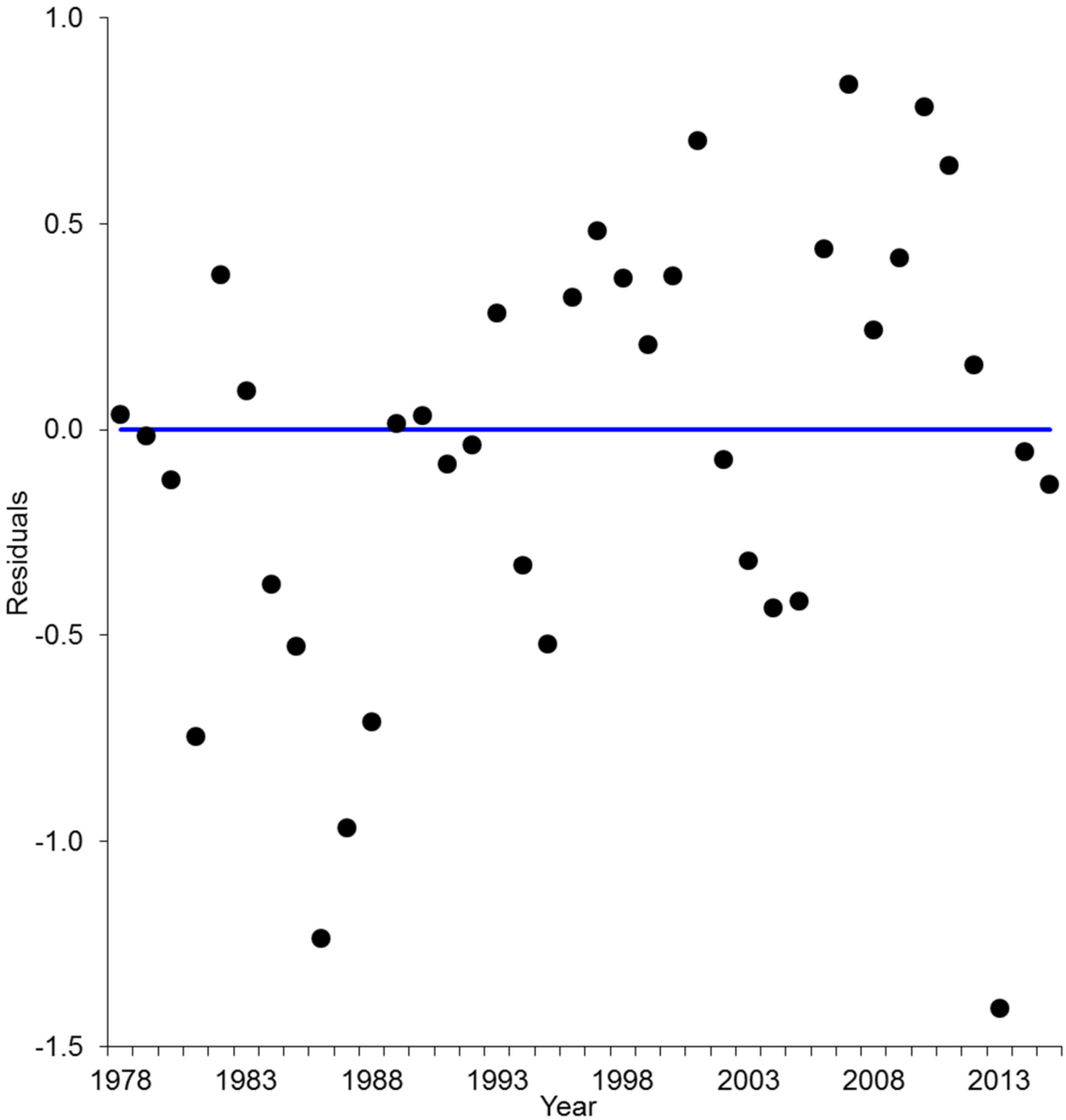


Figure 12(3). Standardized residuals for total trawl survey biomass for scenario 3.

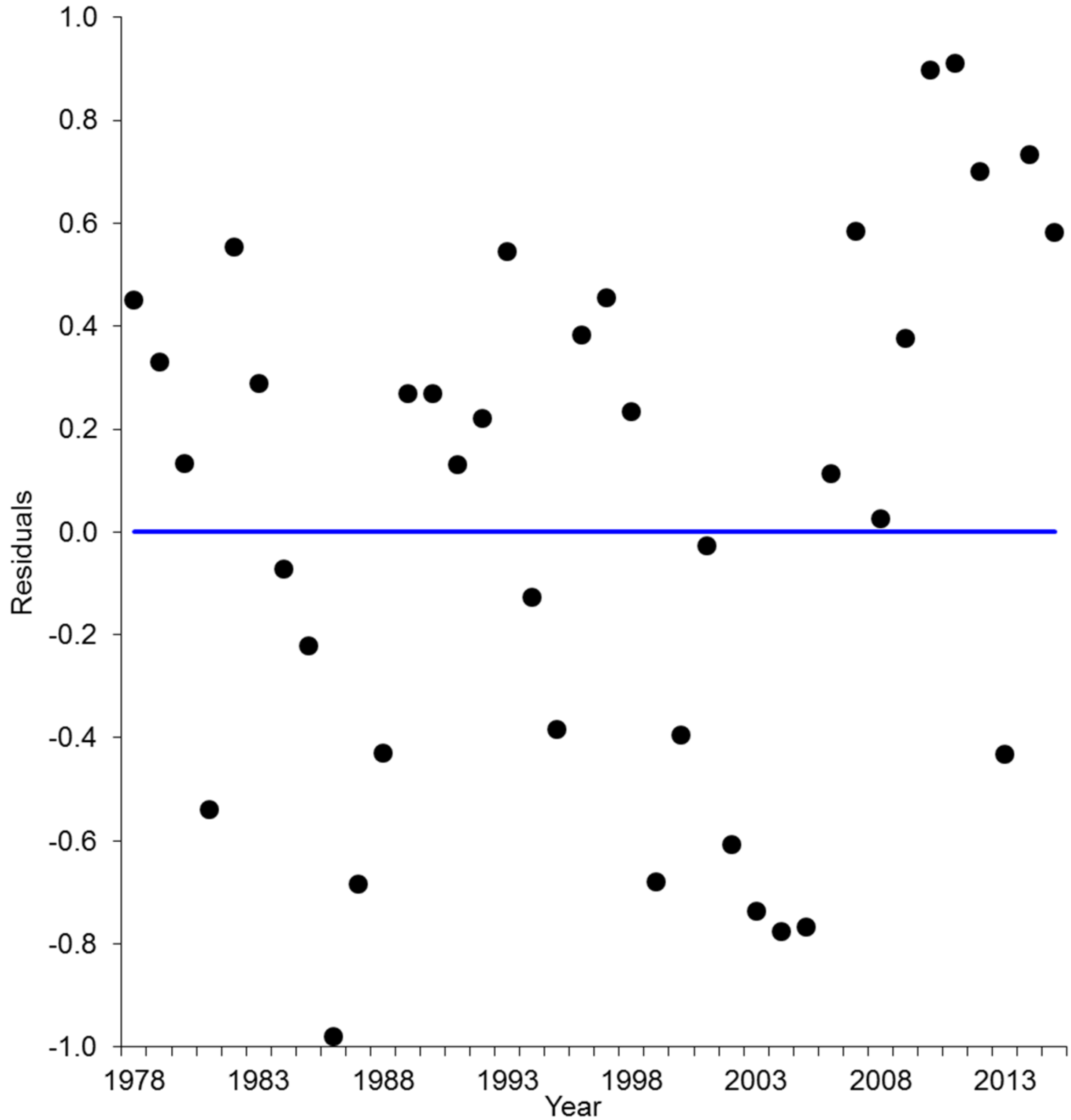


Figure 12(8). Standardized residuals for total trawl survey biomass for scenario 8.

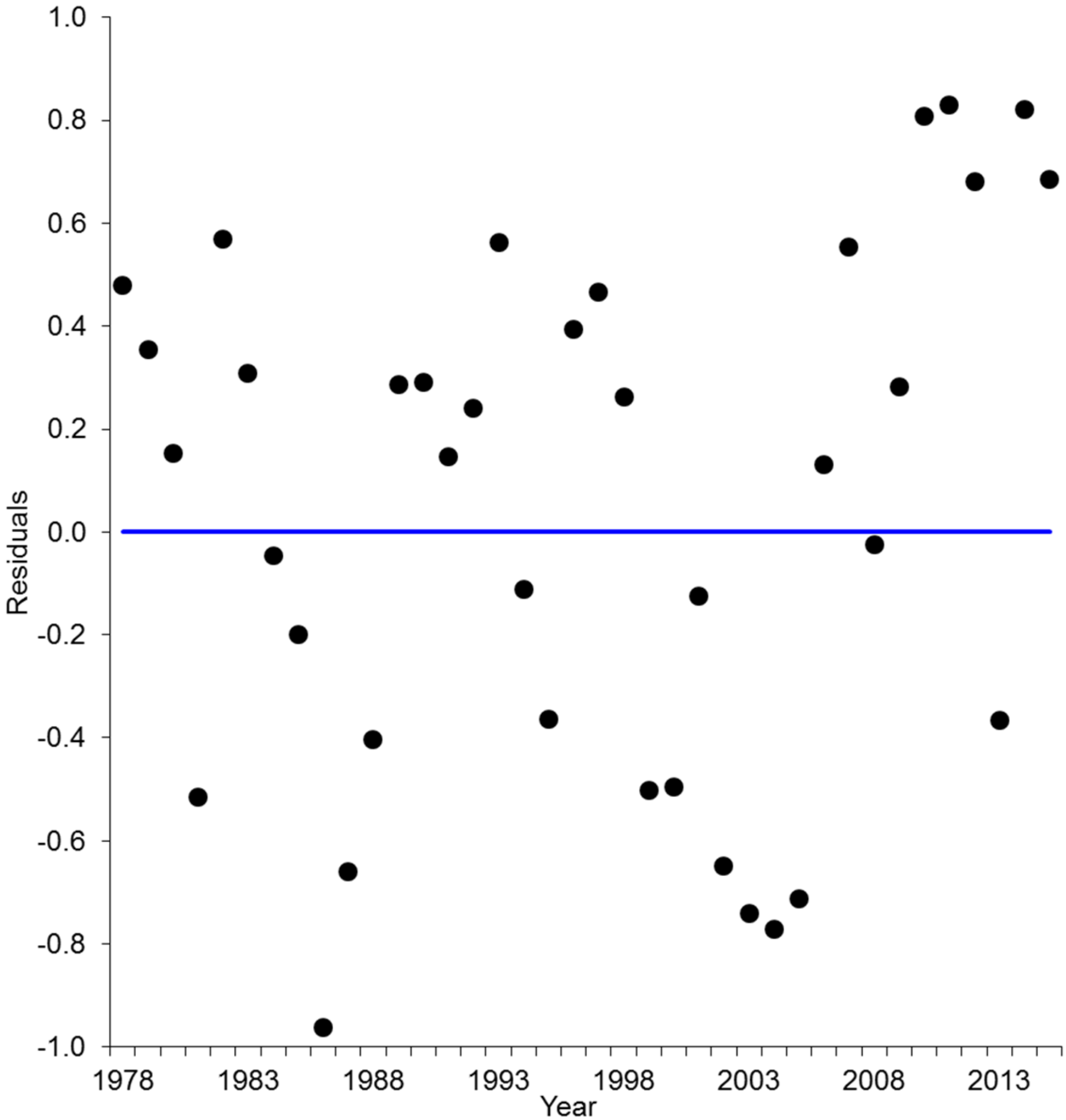


Figure 12(10). Standardized residuals for total trawl survey biomass for scenario 10.

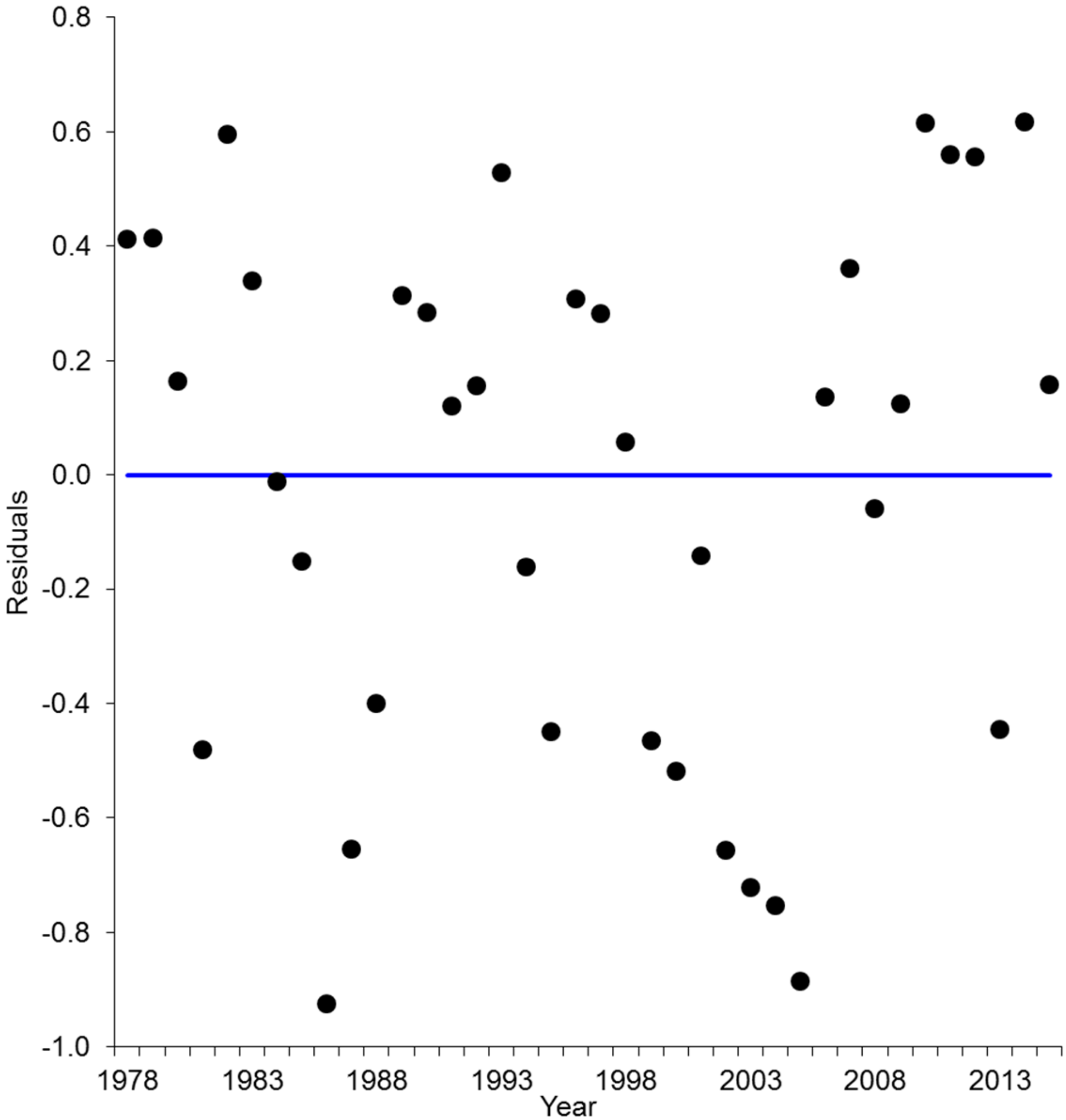


Figure 12(10-4). Standardized residuals for total trawl survey biomass for scenario 10-4.

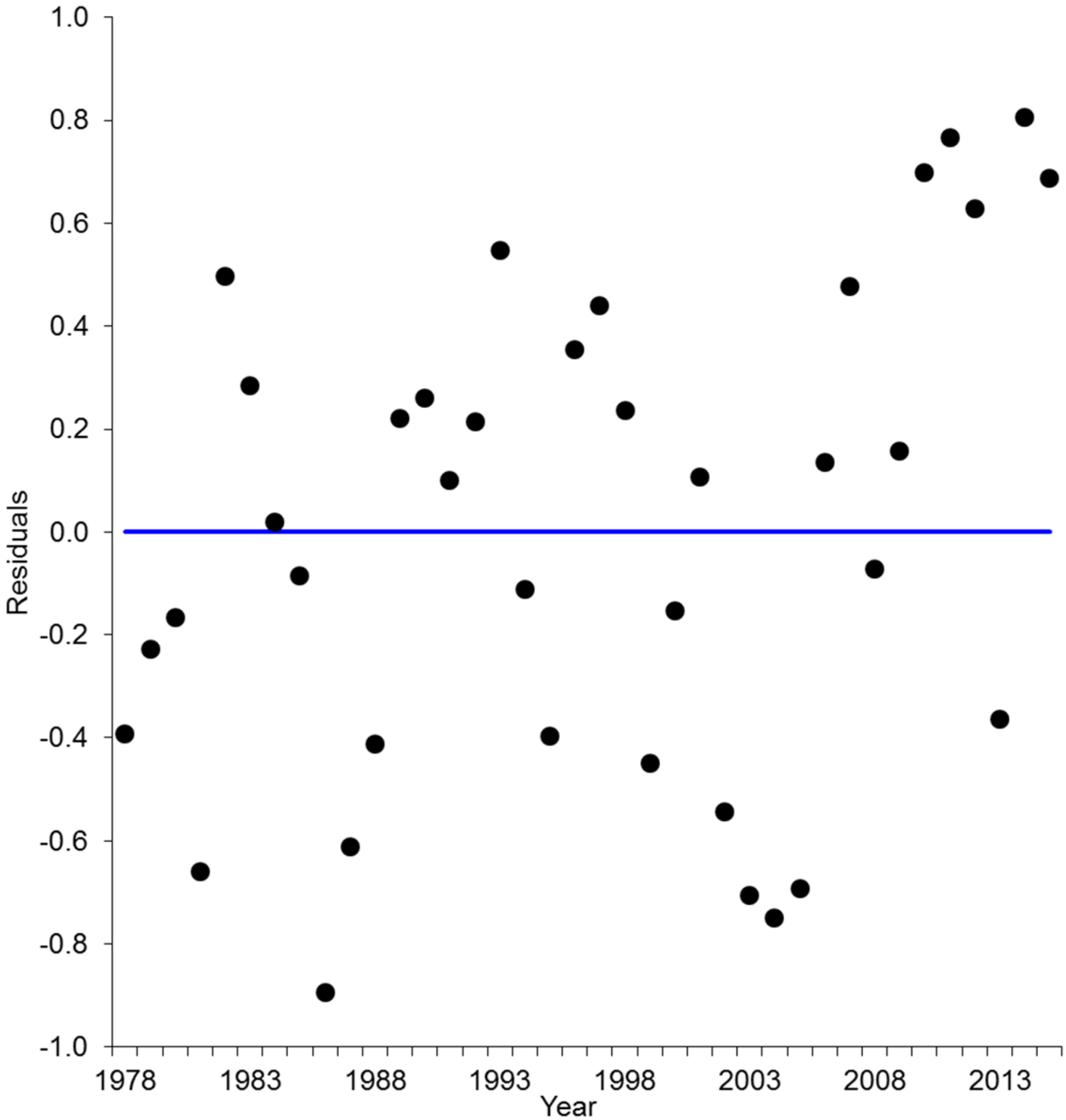


Figure 12(11). Standardized residuals for total trawl survey biomass for scenario 11.

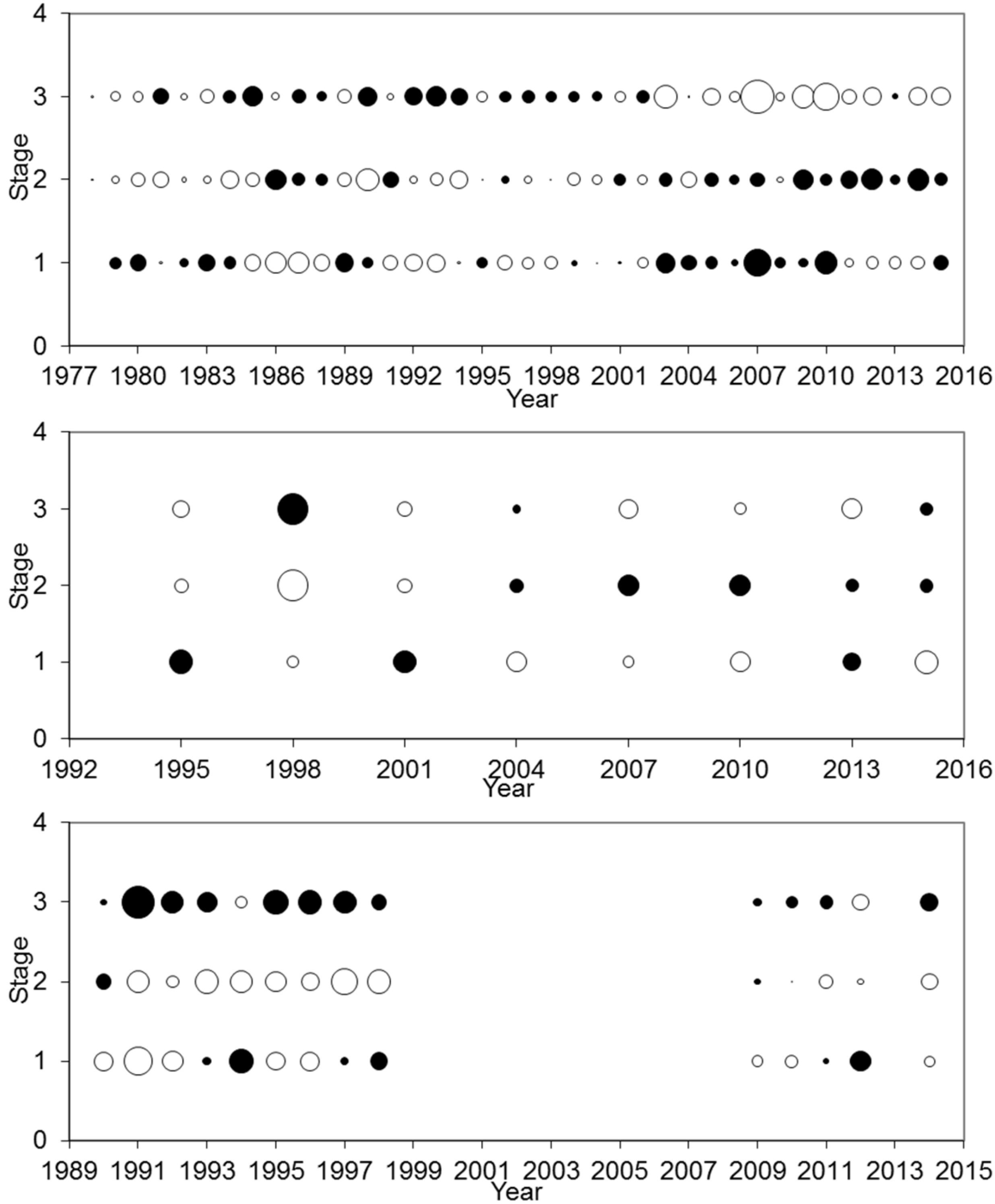


Figure 13(3). Bubble plots of residuals of stage compositions for scenario 3 for St. Mathew Island blue king crab. Empty circles indicate negative residuals, filled circles indicate positive residuals, and differences in bubble size indicate relative differences in the magnitude of residuals. Upper, middle, and lower plots are trawl survey, pot survey, and observer data.

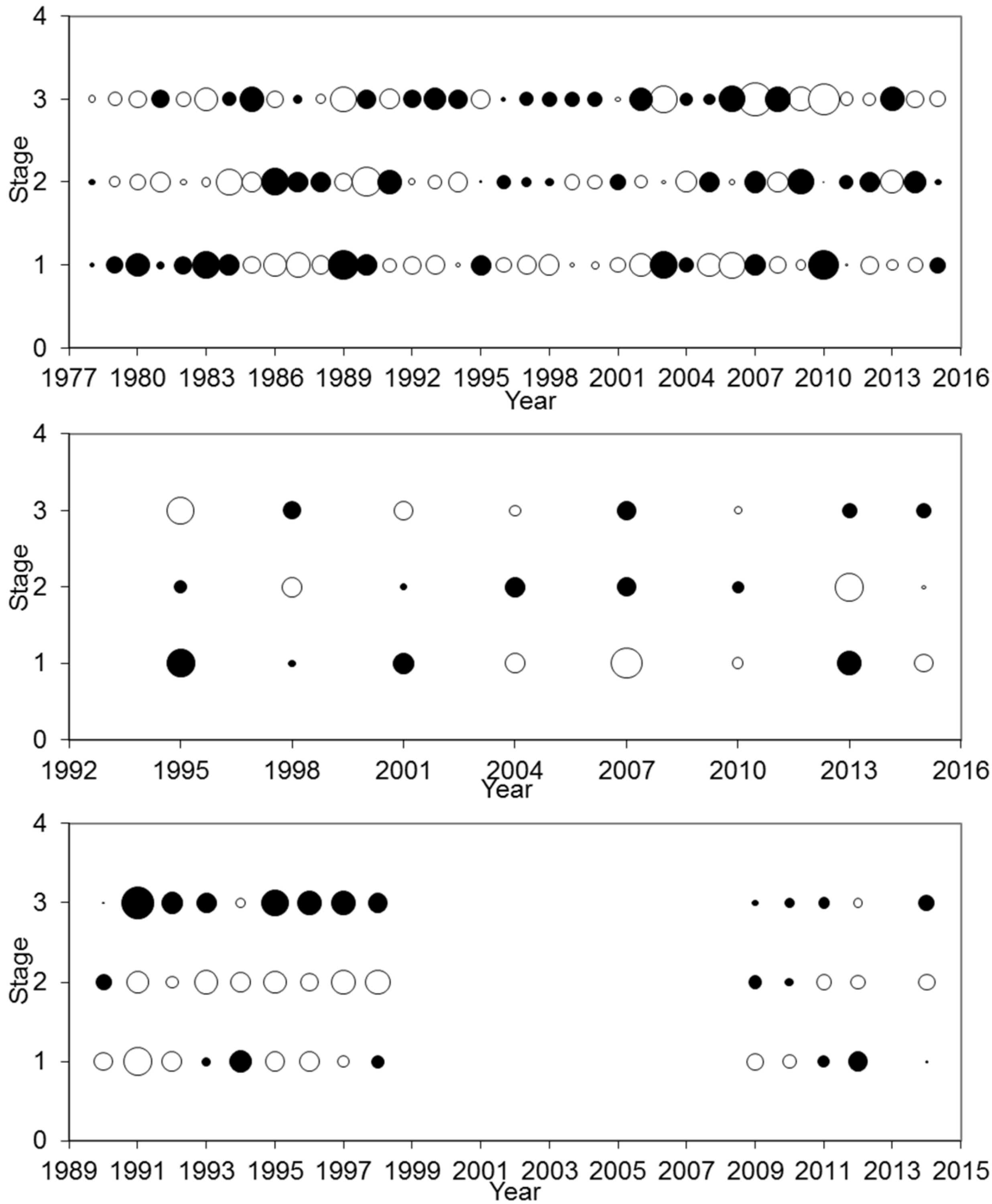


Figure 13(8). Bubble plots of residuals of stage compositions for scenario 8 for St. Mathew Island blue king crab. Empty circles indicate negative residuals, filled circles indicate positive residuals, and differences in bubble size indicate relative differences in the magnitude of residuals. Upper, middle, and lower plots are trawl survey, pot survey, and observer data.

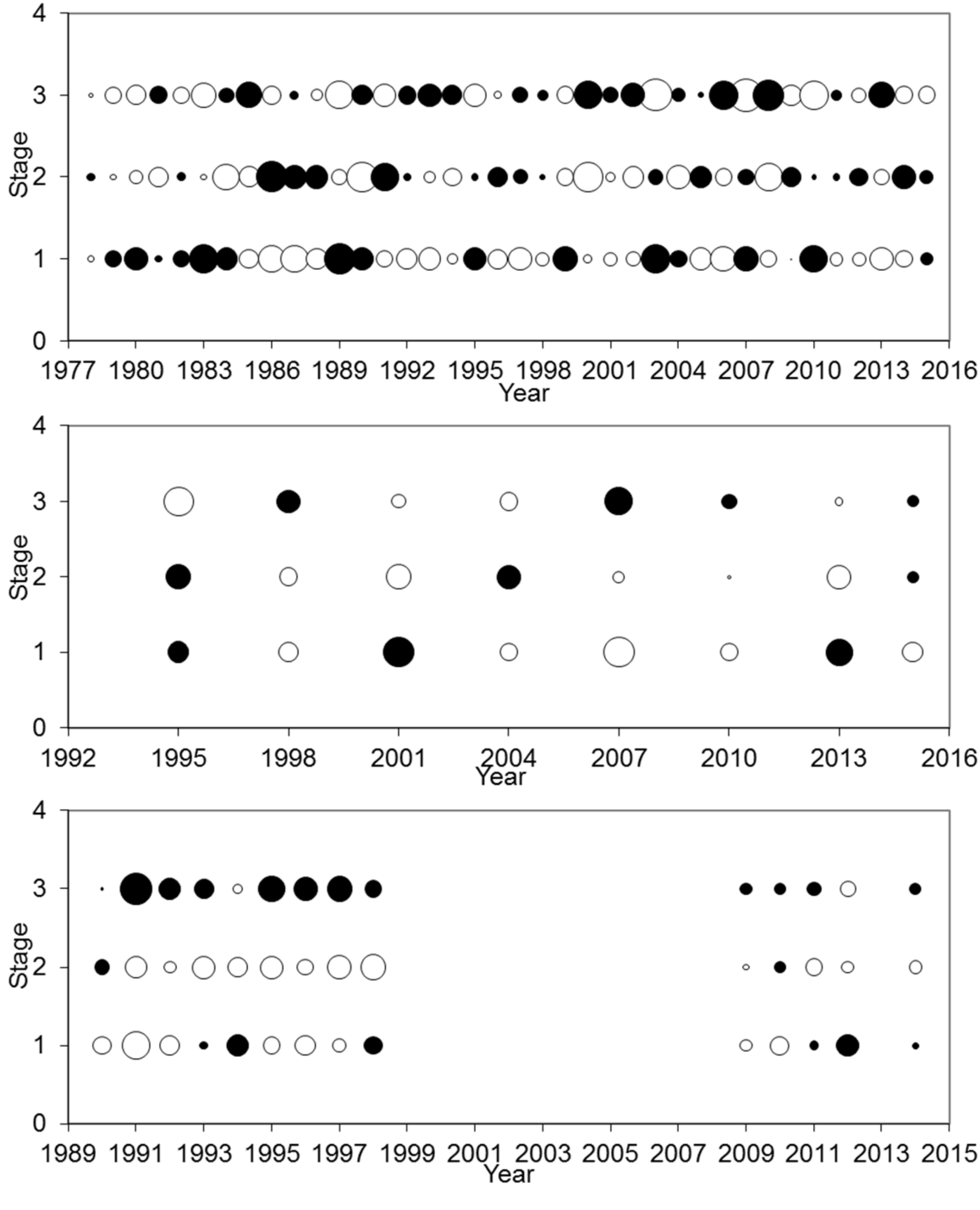


Figure 13(10). Bubble plots of residuals of stage compositions for scenario 10 for St. Mathew Island blue king crab. Empty circles indicate negative residuals, filled circles indicate positive residuals, and differences in bubble size indicate relative differences in the magnitude of residuals. Upper, middle, and lower plots are trawl survey, pot survey, and observer data.

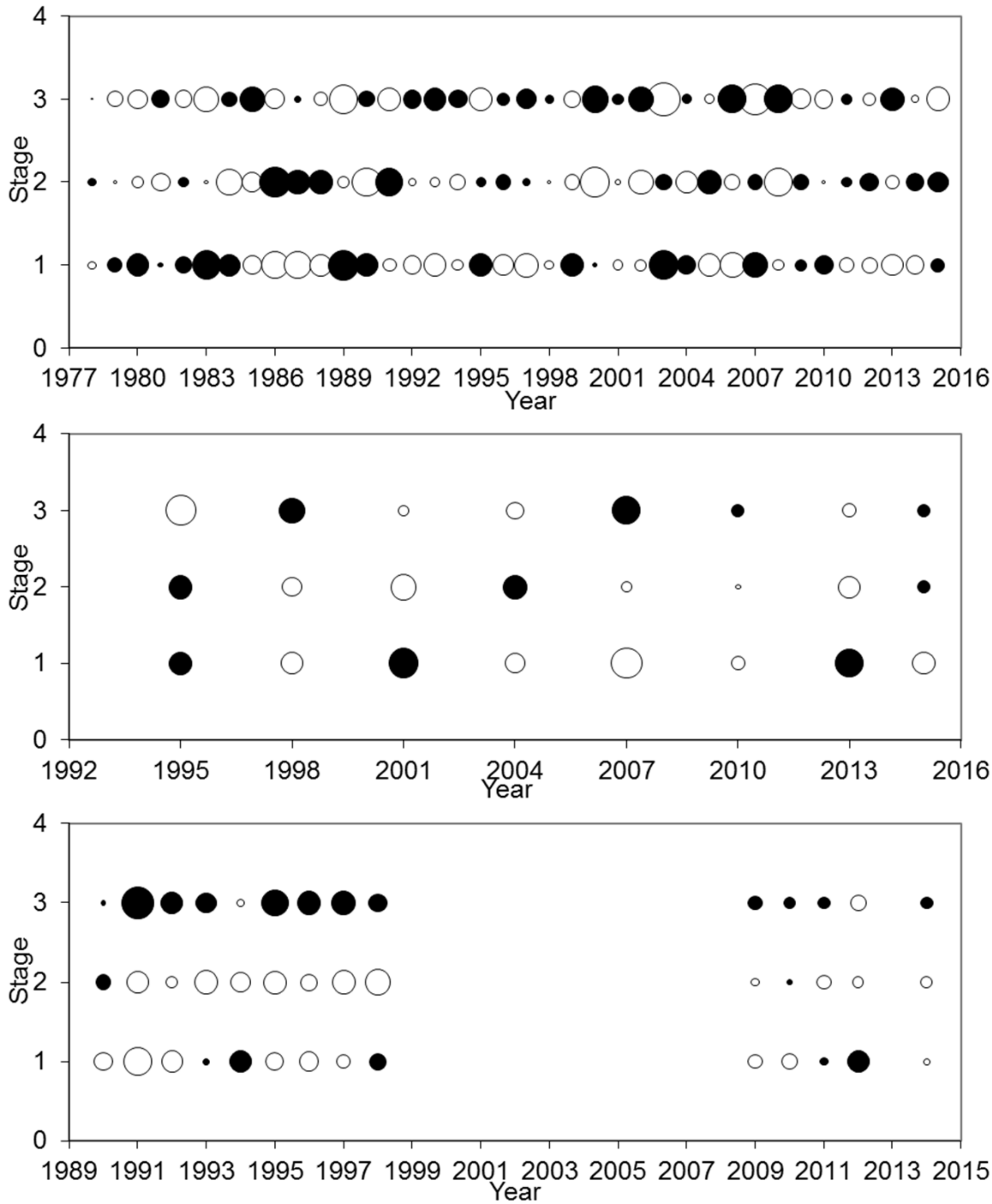


Figure 13(10-4). Bubble plots of residuals of stage compositions for scenario 10-4 for St. Mathew Island blue king crab. Empty circles indicate negative residuals, filled circles indicate positive residuals, and differences in bubble size indicate relative differences in the magnitude of residuals. Upper, middle, and lower plots are trawl survey, pot survey, and observer data.

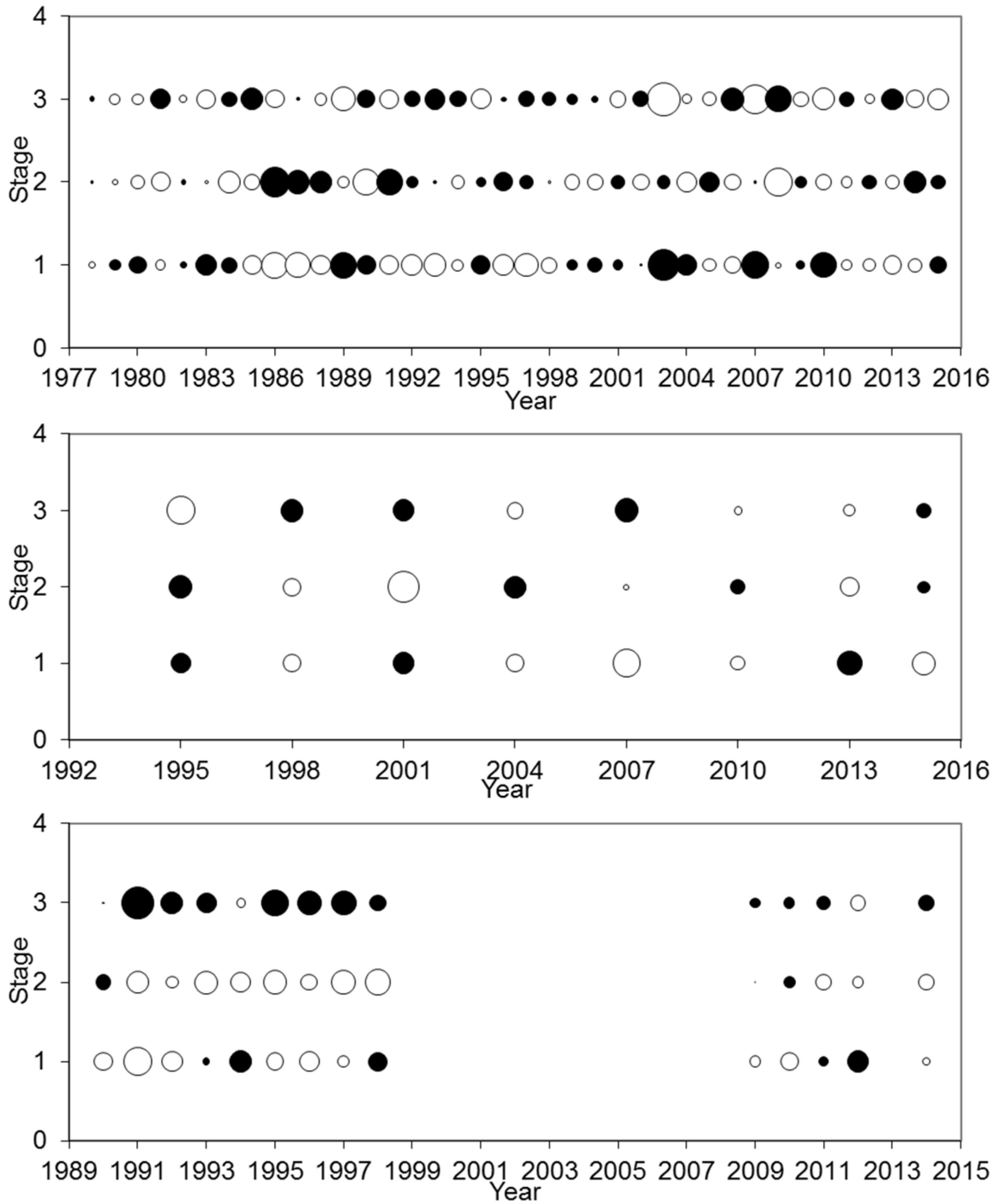


Figure 13(11). Bubble plots of residuals of stage compositions for scenario 11 for St. Mathew Island blue king crab. Empty circles indicate negative residuals, filled circles indicate positive residuals, and differences in bubble size indicate relative differences in the magnitude of residuals. Upper, middle, and lower plots are trawl survey, pot survey, and observer data.

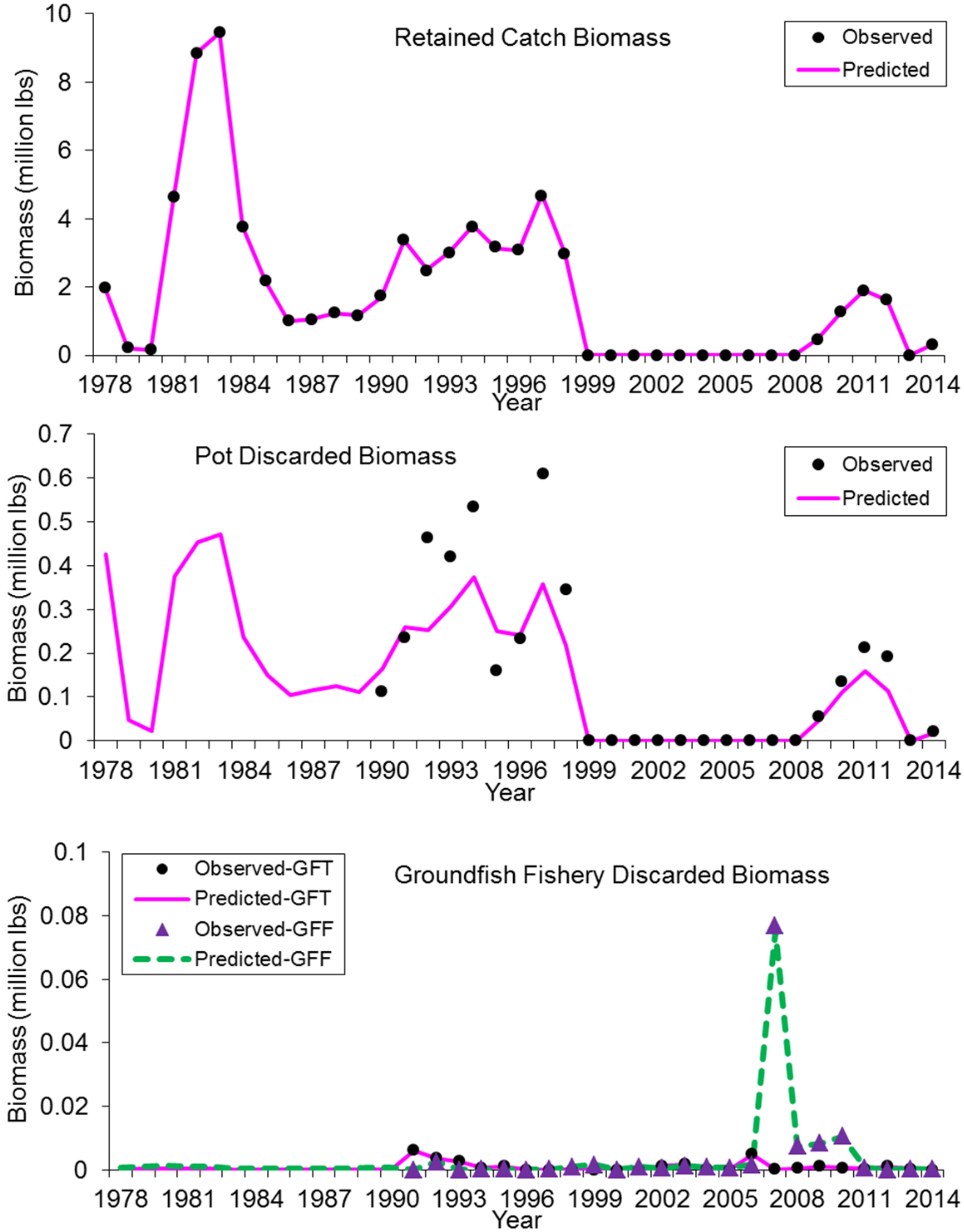


Figure 14. Comparison of observed and model predicted retained catch and bycatches with scenario 10.

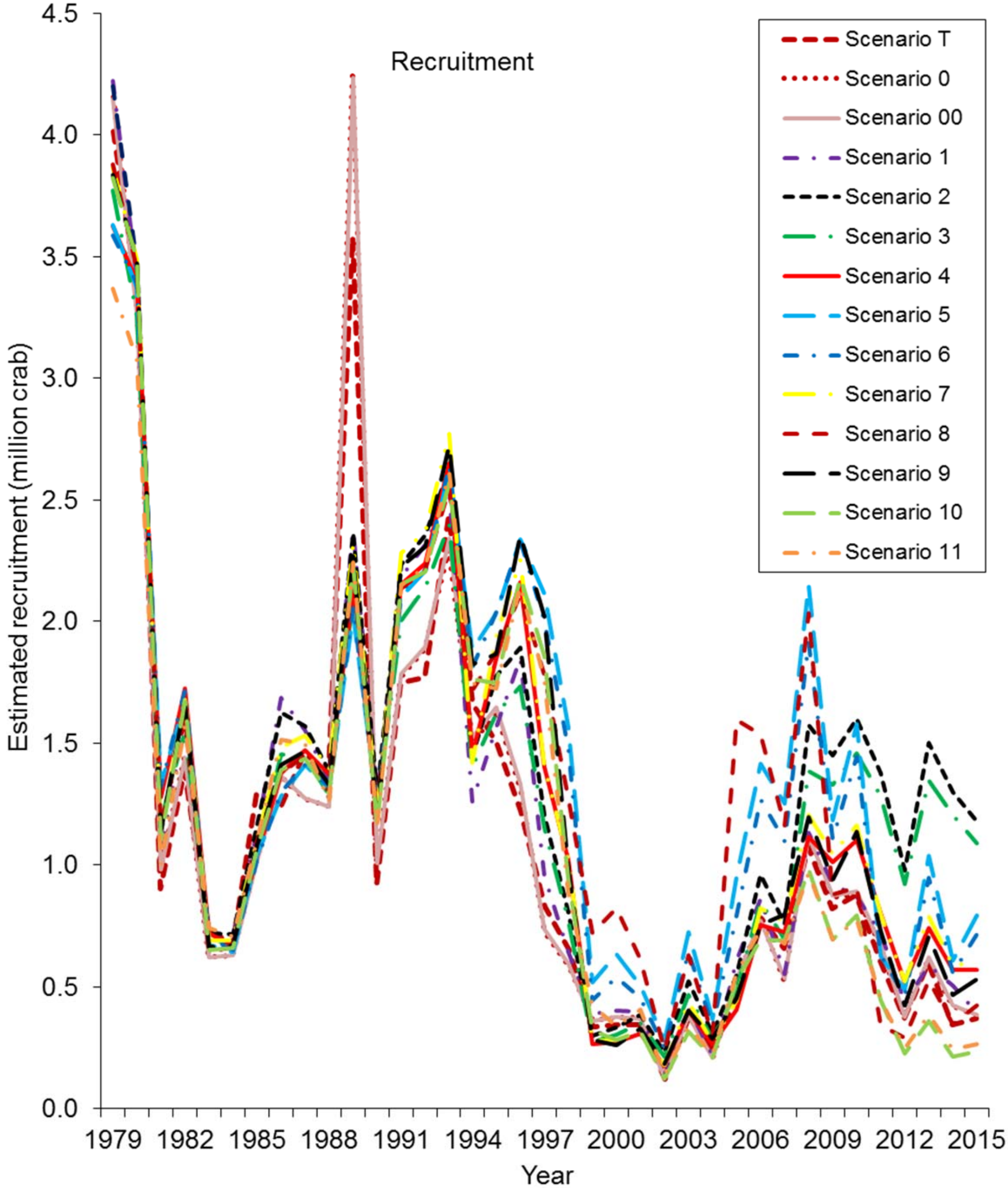


Figure 15. Estimated recruitment time series during 1979-2015 with 18 scenarios.

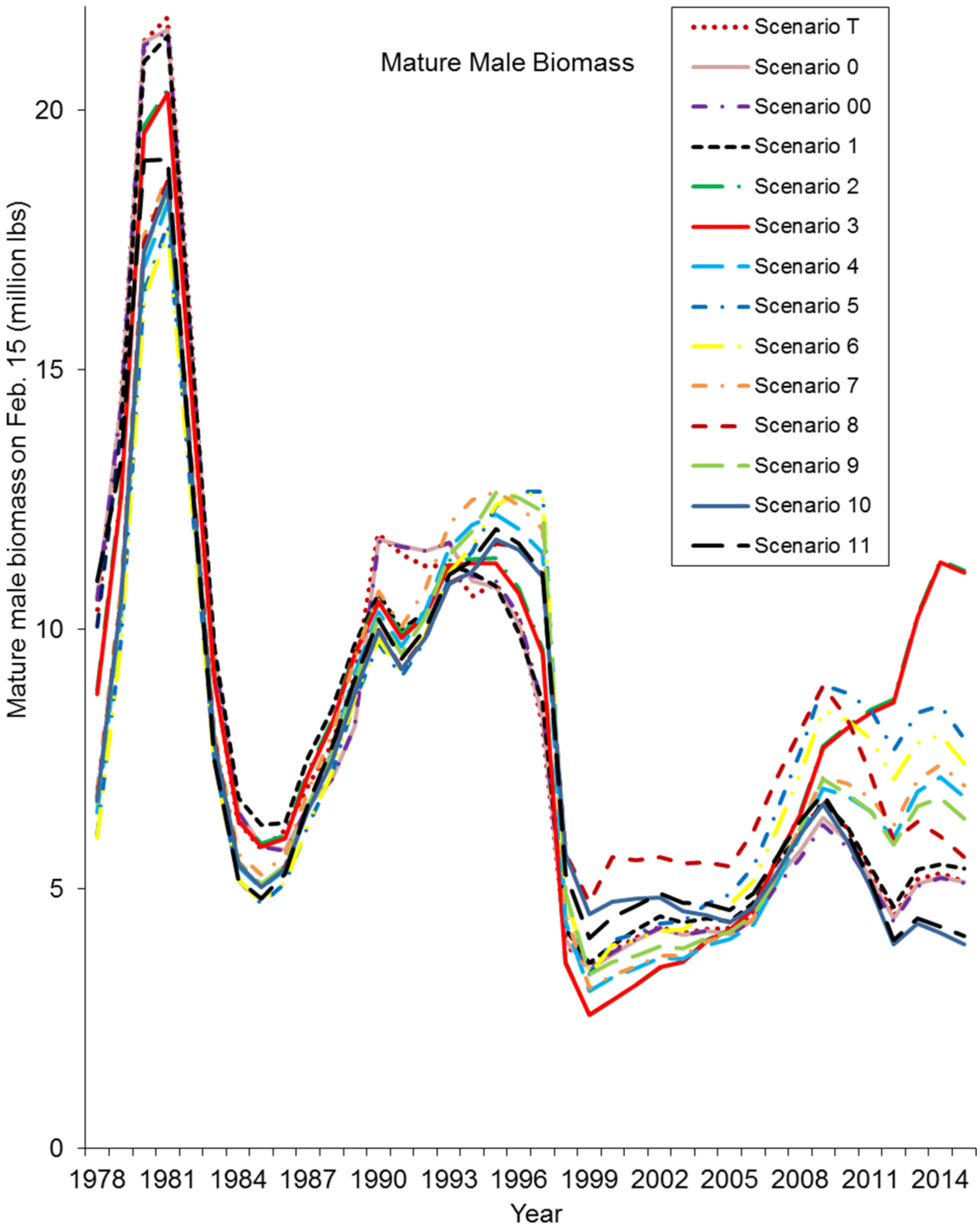


Figure 16. Estimated mature male biomass time series on Feb. 15 during 1978-2015 with 18 scenarios.

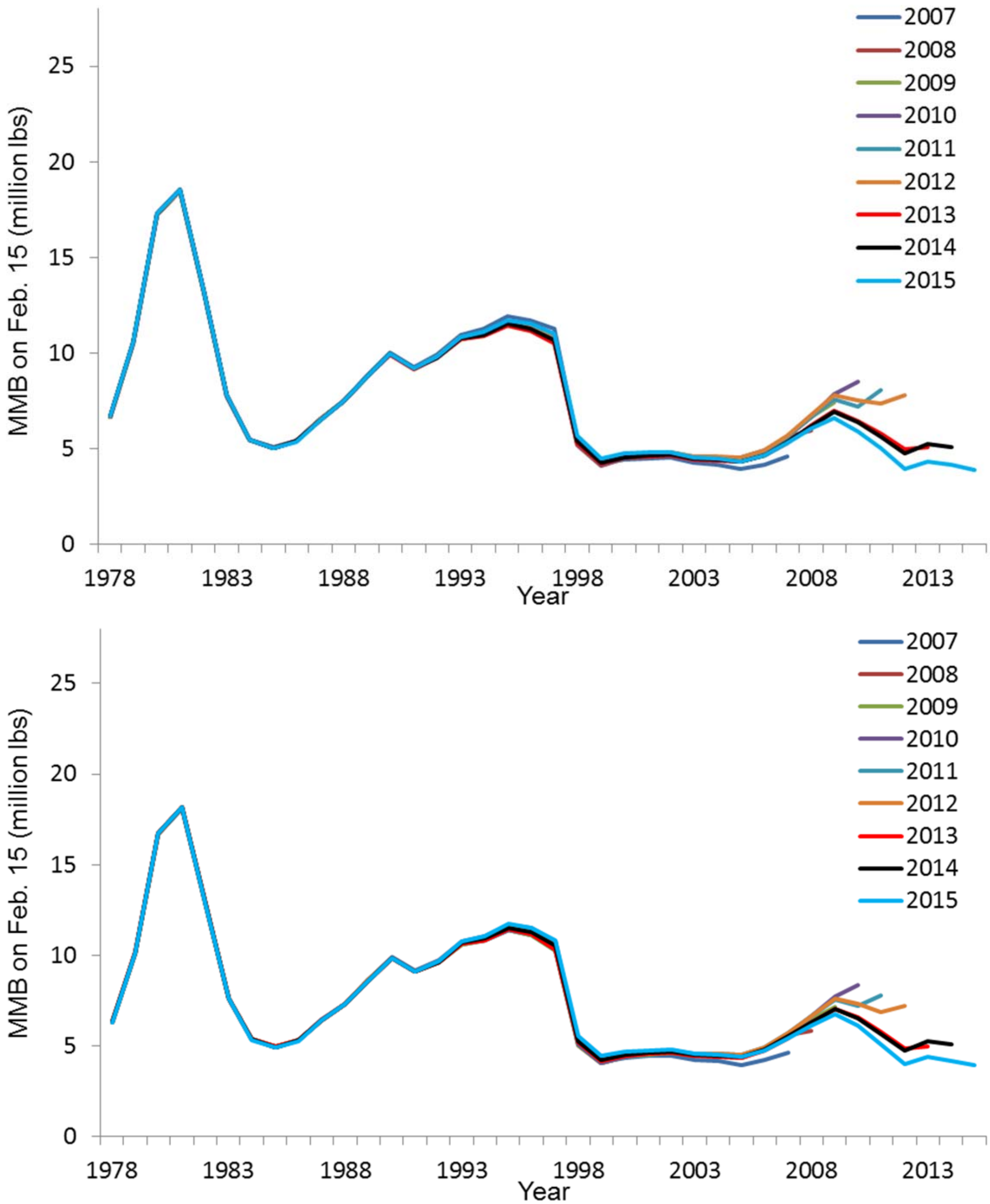


Figure 17. Retrospective plot of model-estimated mature male biomass for 2015 model scenario 10 (top panel) on Feb. 15 and scenario 10-4 (bottom panel) at time of survey with terminal years 2007-2015. Estimates are based on all available data up to and including terminal-year trawl and pot surveys.

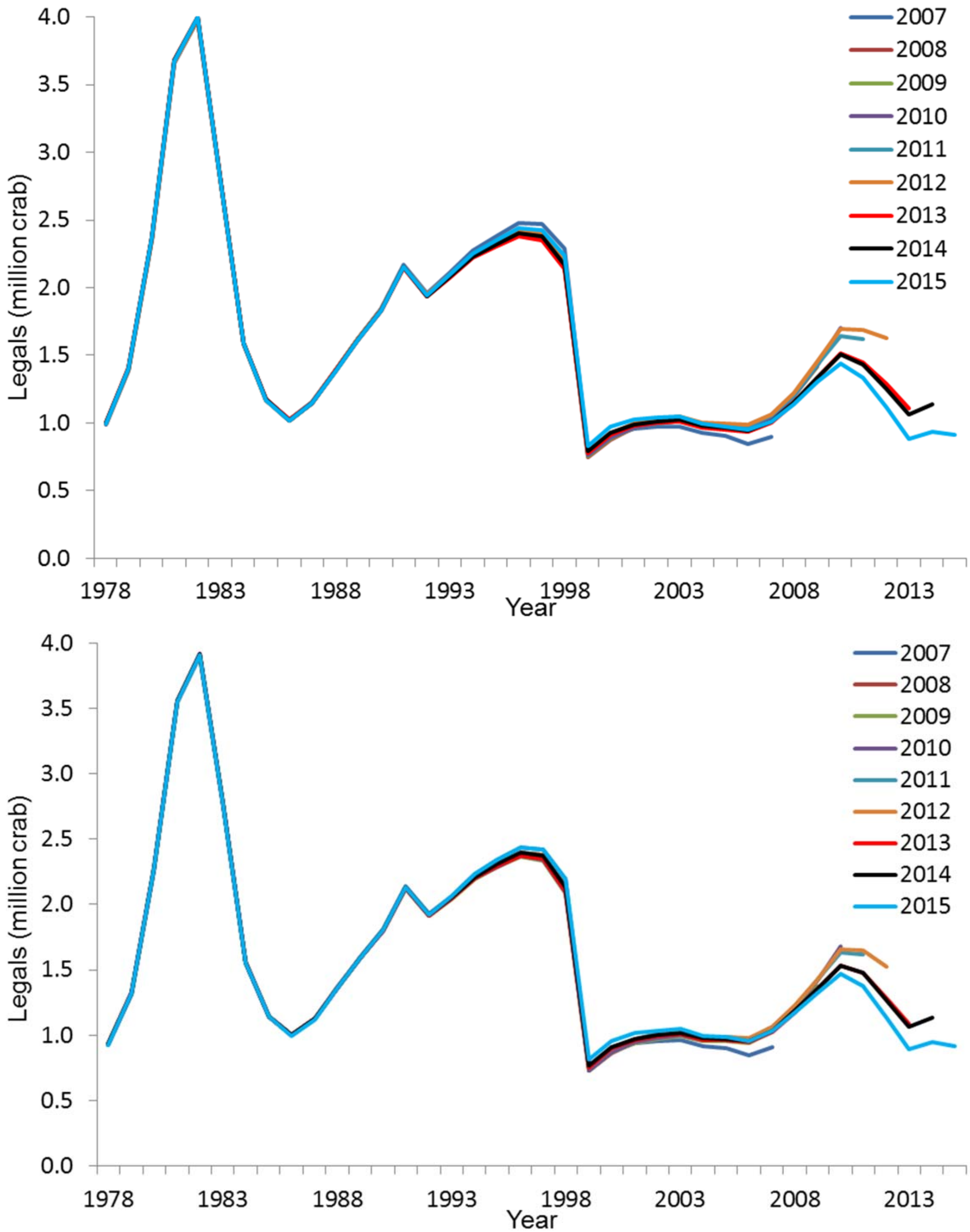


Figure 18. Retrospective plot of model-estimated legal male abundance at time of survey for 2015 model scenario 10 (top panel) and scenario 10-4 (bottom panel) with terminal years 2007-2015. Estimates are based on all available data up to and including terminal-year trawl and pot surveys.

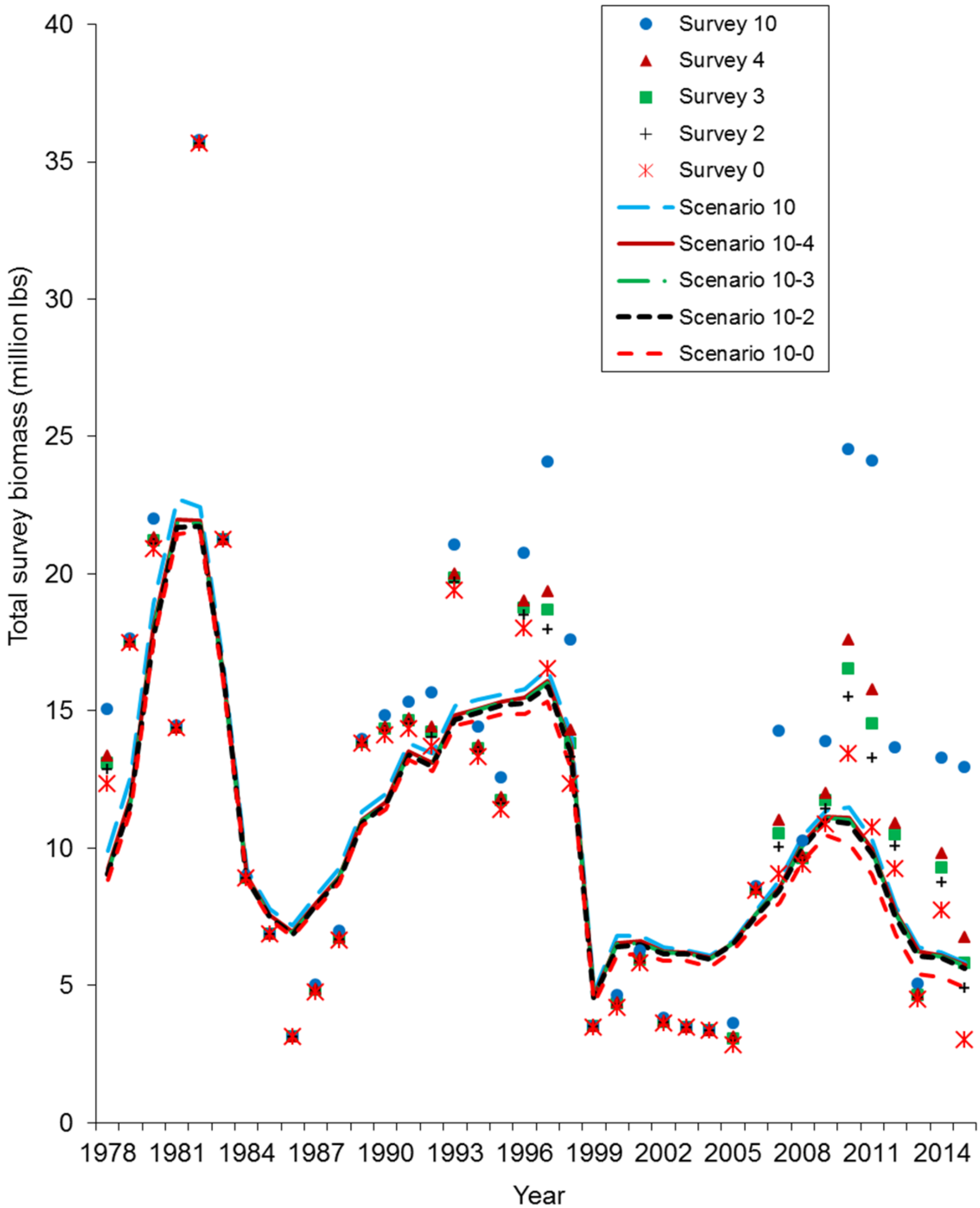


Figure 19. Comparisons of area-swept estimates of total male survey biomasses and model predictions for 2015 model estimates under scenarios 10, 10-4, 10-3, 10-2, and 10-0. "Survey 10, 4, 3, 2 and 0 denote area-swept estimates with 100%, 37.51%, 28.13%, 18.75%, and 0% of trawl survey station R-24 catch.

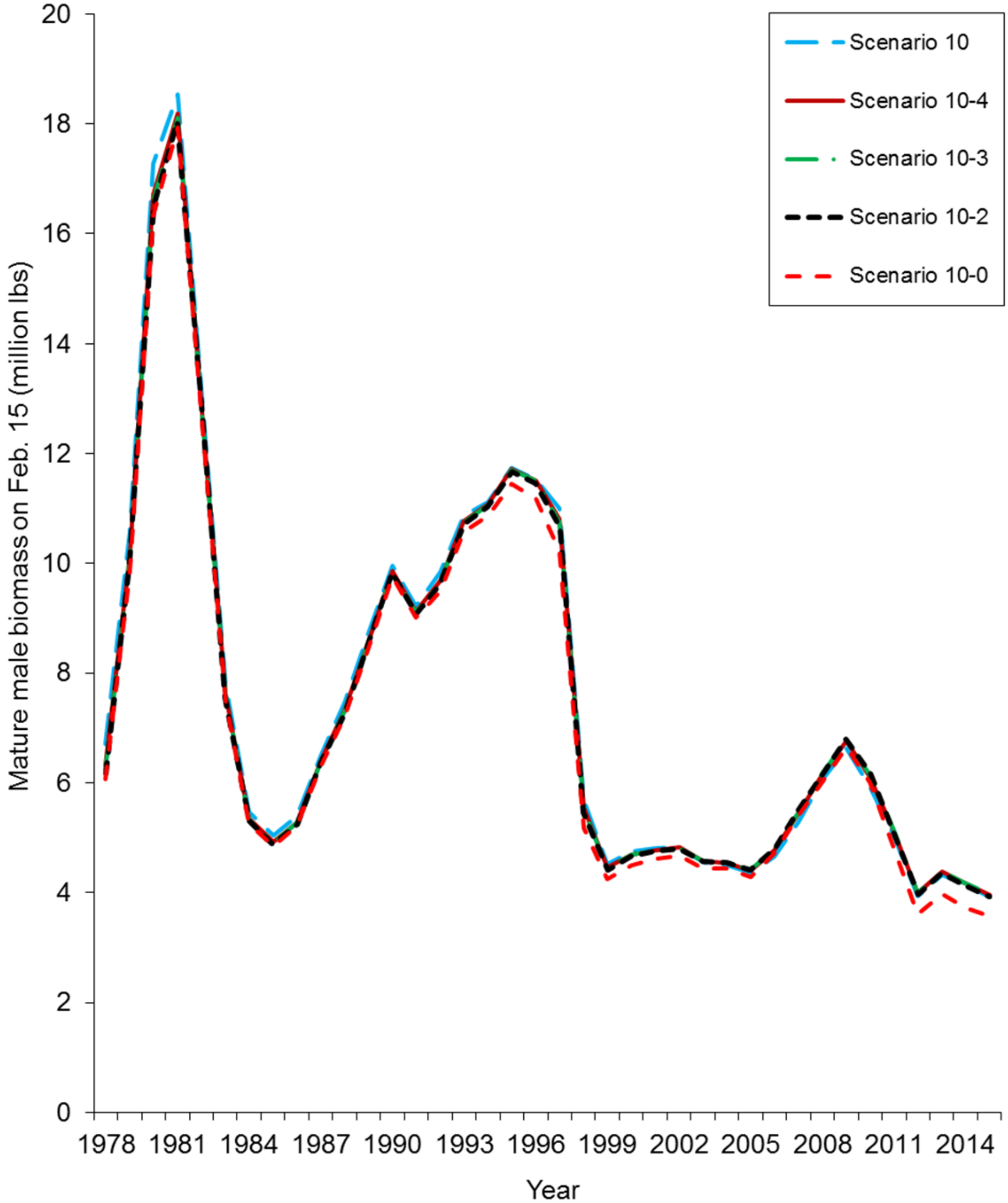


Figure 20. Estimated mature male biomass time series on Feb. 15 during 1978-2015 with scenarios 10, 10-4, 10-3, 10-2, and 10-0.

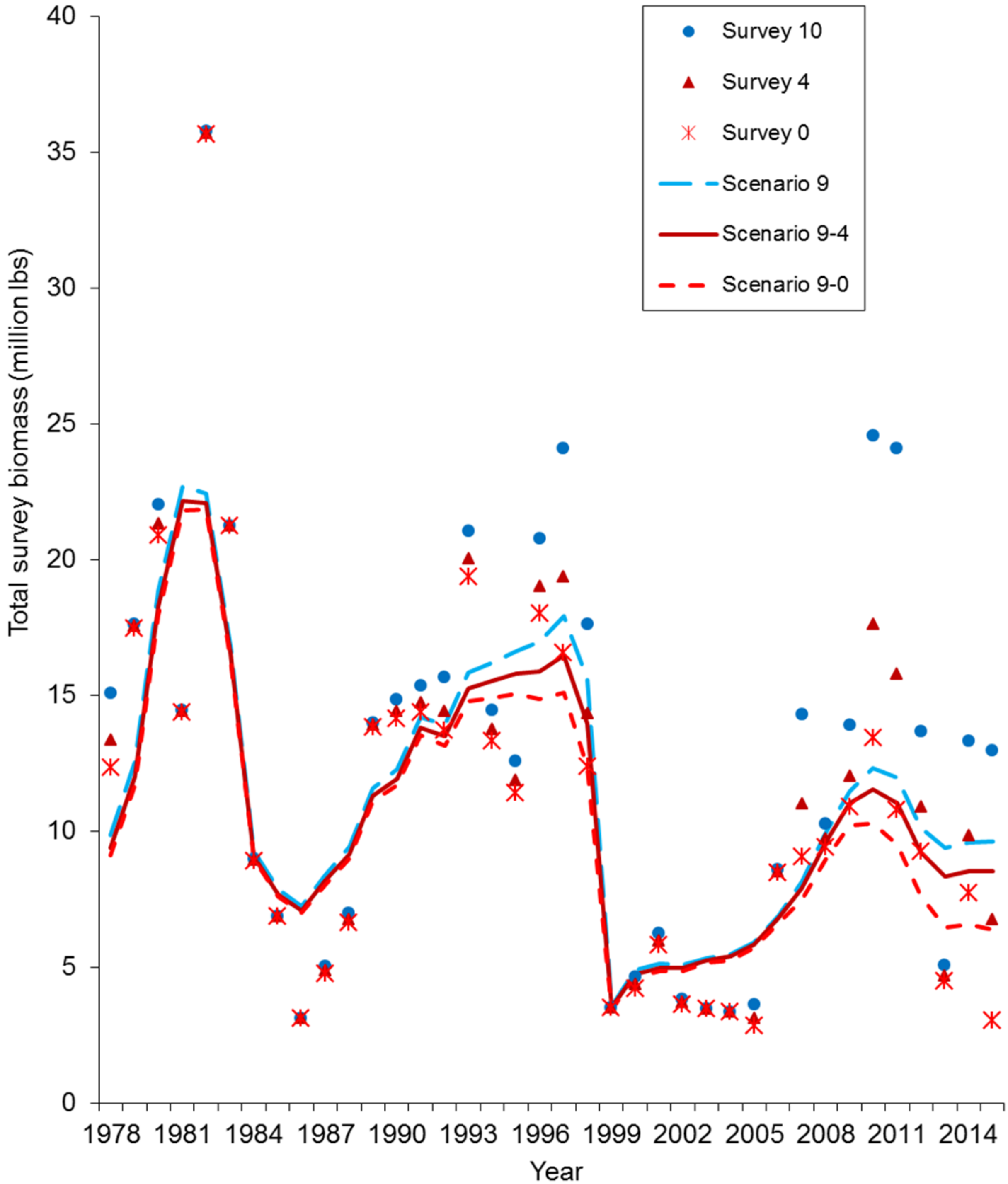


Figure 21. Comparisons of area-swept estimates of total male survey biomasses and model predictions for 2015 model estimates under scenarios 9, 9-4 and 9-0. "Survey 10, 4 and 0 denote area-swept estimates with 100%, 37.51% and 0% of trawl survey station R-24 catch.

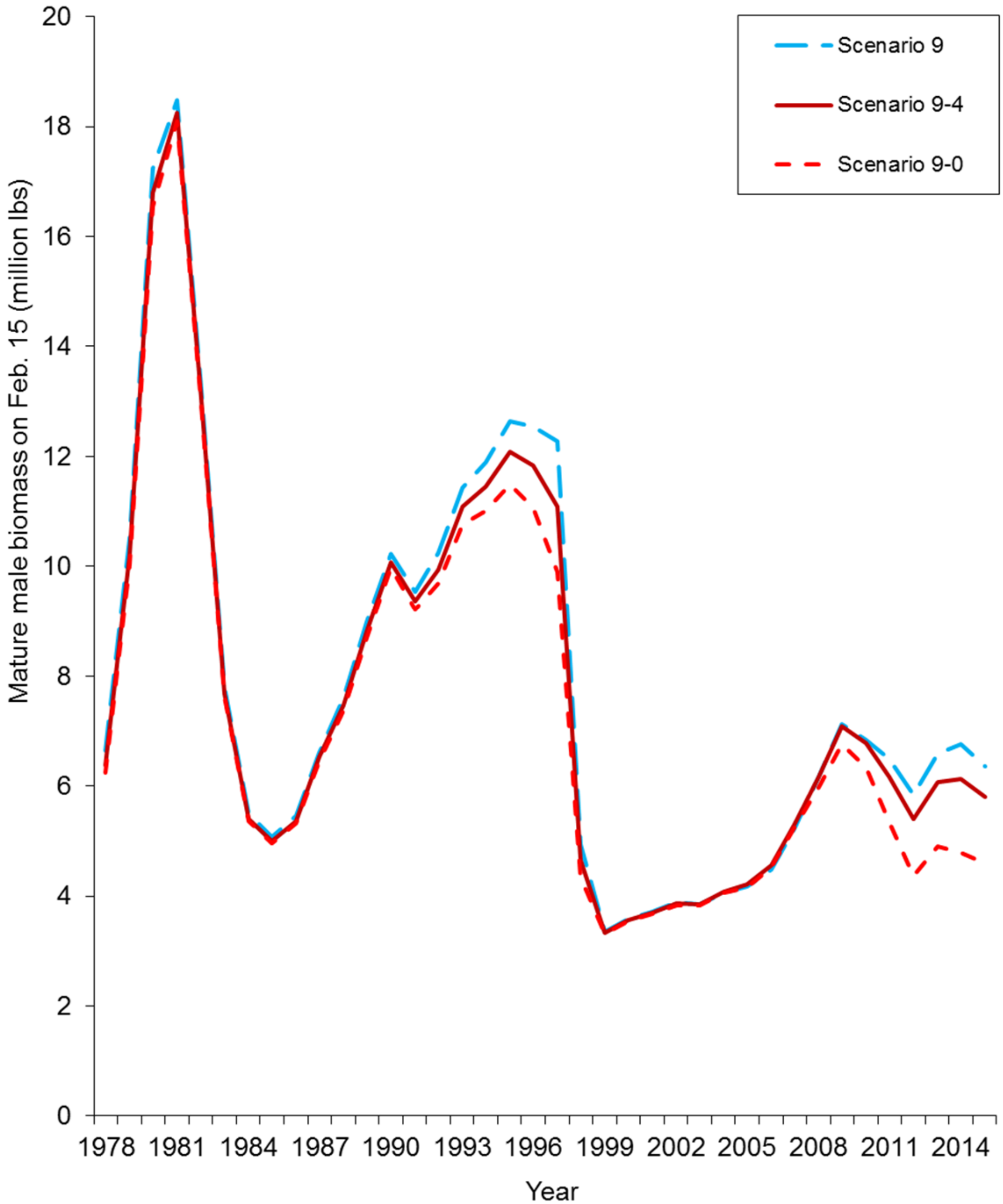
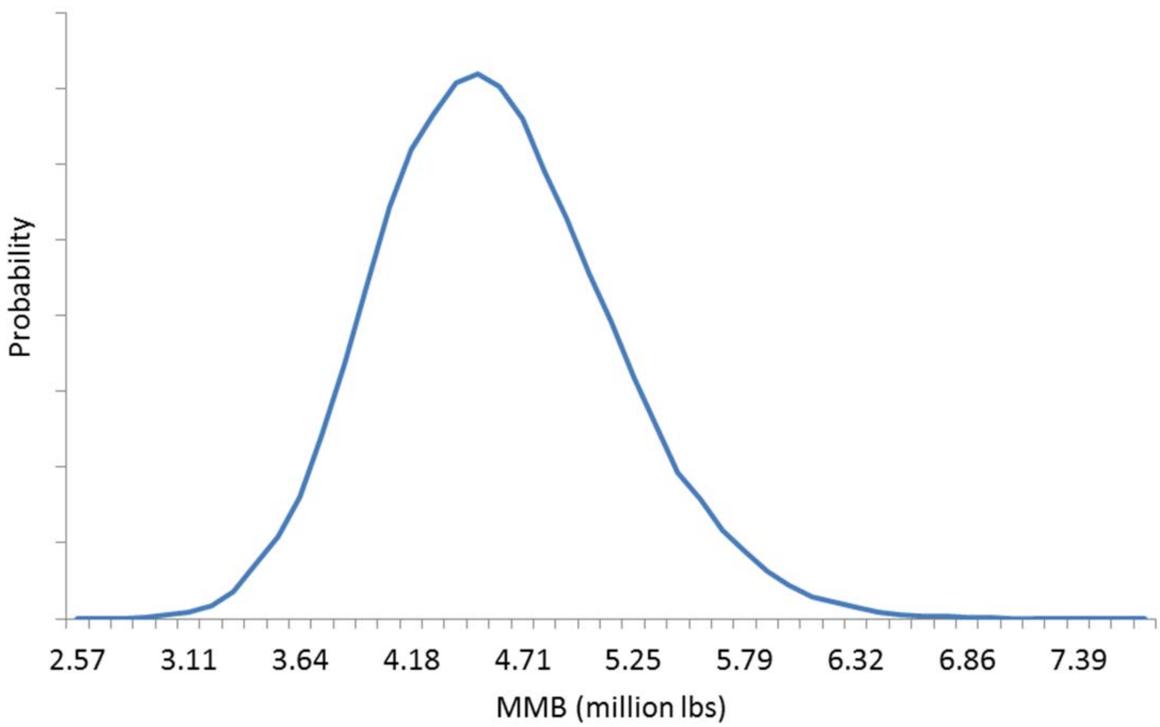


Figure 22. Estimated mature male biomass time series on Feb. 15 during 1978-2015 with scenarios 9, 9-4 and 9-0.



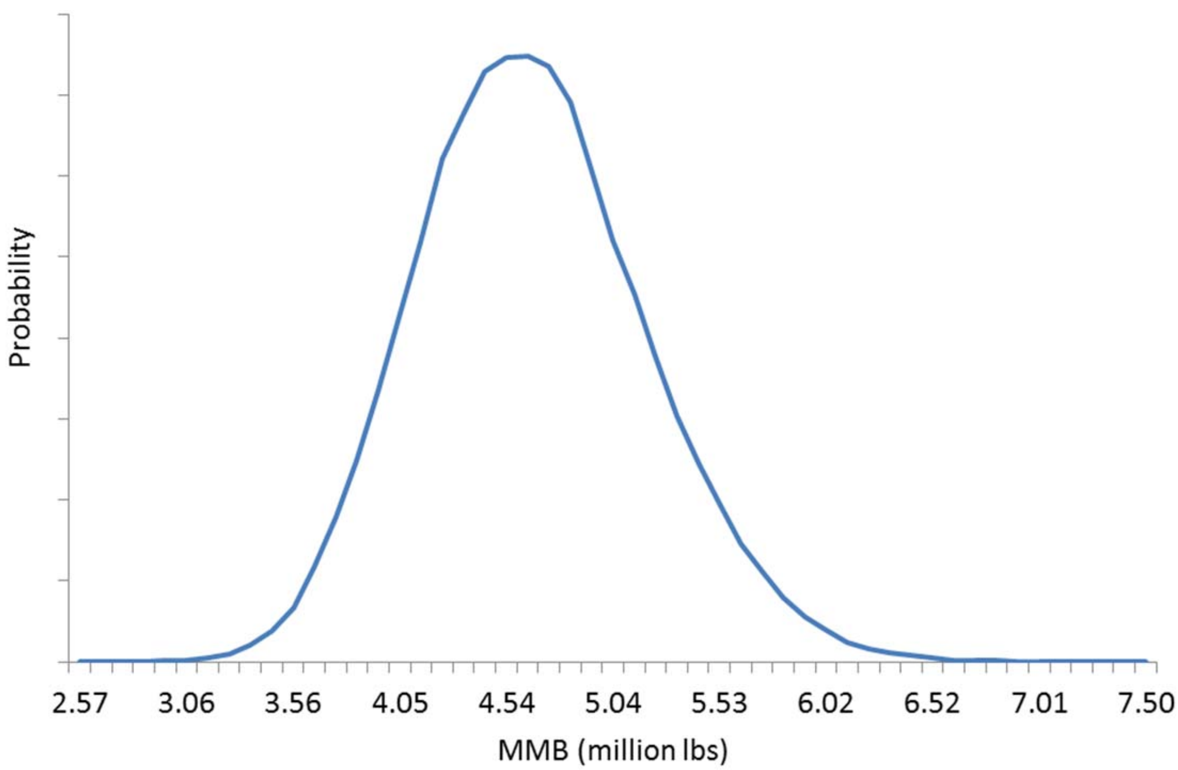


Figure 23. Probability distributions of estimated mature male biomass on Feb. 15, 2015 with Tier 4 control rule under scenarios 10 (top panel) and 10-4 (bottom panel) with the mcmc approach.

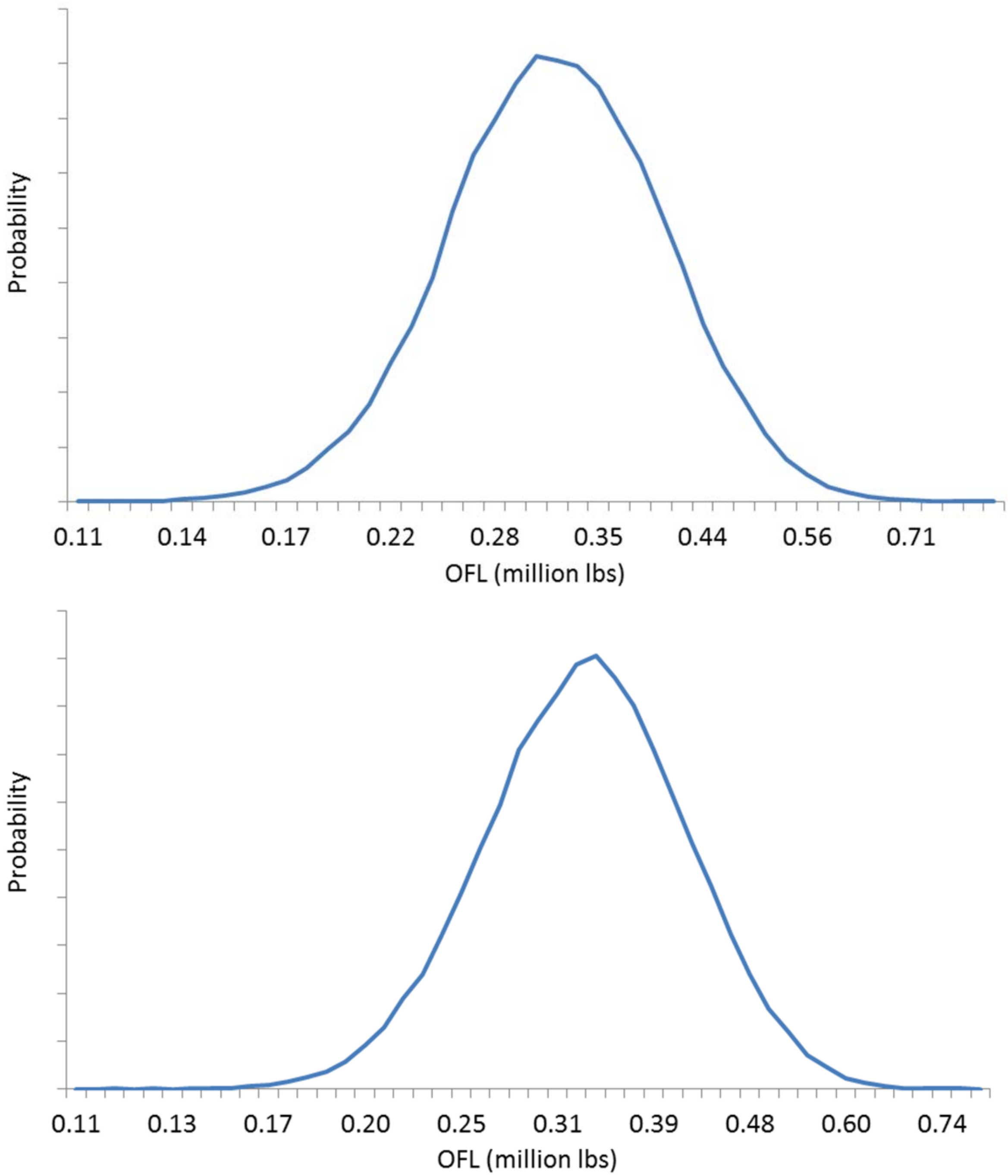


Figure 24. Probability distributions of the 2015 estimated OFL with scenarios 10 (top panel) and 10-4 (bottom panel) with the mcmc approach.

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 $\boldsymbol{N}_t = [\, N_{1,t},\ N_{2,t},\ N_{3,t}\,]^T$ 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 $\boldsymbol{N}^{new}{}_{t+1} = [\, N^{new}{}_{1,t+1},\ 0\ ,0\,]^T$ 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

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

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

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

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

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 2009/10-2014/15	Fish tickets (fishery closed 1999/00-2008/09)
NMFS trawl-survey biomass index (area-swept estimate) and CV	1978-2015	NMFS EBS trawl survey
ADFG pot-survey abundance index (CPUE) and CV	Triennial 1995-2015	ADF&G SMBKC pot survey
NMFS trawl-survey stage proportions and total number of measured crab	1978-2015	NMFS EBS trawl survey
ADFG pot-survey stage proportions and total number of measured crab	Triennial 1995-2015	ADF&G SMBKC pot survey
Directed pot-fishery stage proportions and total number of measured crab	1990/91-1998/99 2009/10-2014/15	ADF&G crab observer program (fishery closed 1999/00-2008/09)
Groundfish trawl bycatch biomass	1992/93-2014/15	NMFS groundfish observer program
Groundfish fixed-gear bycatch biomass	1992/93-2014/15	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

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

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

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

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

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

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

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

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

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

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

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 8 and 10 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 3-11, 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 3-11. Molting probability for stage 1 for scenarios 8, 9, 10, 11 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 8	Scenario 10
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	4
Stage 1 and 2 Directed-fishery selectivities	4	4
Molting probabilities	1	0
Additional CV for pot survey	0	0
Mean log recruit abundance	1	1
Log recruit abundance deviations	37[a]	37[a]
Mean log directed-fishery mortality	1	1
Log directed-fishery mortality deviations	26[a]	26[a]
Mean log groundfish trawl fishery mortality	1	1
Log groundfish trawl fishery mortality deviations	24[a]	24[a]
Mean log groundfish fixed-gear fishery mortality	1	1
Log groundfish fixed-gear fishery mortality deviations	24[a]	24[a]
Total	129	132

[a] Subject to zero-sum constraint.

Table 3. Fixed parameters for all scenarios except for T.

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 lbs.	Length-weight equation (B. Foy, NMFS) applied to stage size-interval midpoints.
Stage-3 mean weight	depends on year	Fishery-reported average retained weight from fish tickets, or its average, and mean weights of legal males.
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 biomass	Lognormal	$-0.5\sum[\ln(c_t/C_t)^2/\ln(1+cv_c^2\ )]$
Dis. Pot bycatch biomass	Lognormal	$-0.5\sum[\ln(d_t/D_t)^2/\ln(1+cv_{d,t}^2)]$
Trawl-survey biomass index	Lognormal	$-0.5\sum[\frac{\ln(b_t^{ts}\ )-\ln(B_t^{ts})}{sqrt(\ln\left(1+\widehat{cv_t^{ts}}^2\right))}]^2$
Pot-survey abundance index	Lognormal	$-0.5\sum[\frac{\ln\left(a_t^{ps}\right)-\ln\left(A_t^{ps}\right)}{\mathrm{sqrt}(\ln\left(1+\widehat{cv_t^{ps}}^2\right))}]^2$

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	$-0.5 \sum [\ln(b_t^{gt} / B_t^{gt})^2 / \ln(1 + {cv_g}^2)]$
Groundfish fixed-gear mortality biomass	Lognormal	$-0.5 \sum [\ln(b_t^{gf} / B_t^{gf})^2 / \ln(1 + {cv_g}^2)]$
$\ln(N_{1,t}^{new})$ 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 0-11, 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 scenario T. For all other scenarios, the log-likelihood is

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

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. A CV of 0.03 is applied to the lognormal fishery catch-biomass component corresponds. 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 CV of 1.31 on the lognormal groundfish bycatch mortality biomass components is 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 T 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 biomass cv	0.03
Dis. Pot bycatch biomass (1978-1998)	0.6
Dis. Pot bycatch biomass (2009-2014)	0.2
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 cv	1.31
Groundfish fixed-gear mortality biomass cv	1.31
Log model recruit-abundance deviations	1.25
Log directed fishing mortality deviations	0.001
Log groundfish trawl fishing mortality deviations	0.01
Log groundfish fixed-gear fishing mortality deviations	0.01
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.

Appendix B. Temporal Changes in Bottom Temperatures and Crab Distributions

There are eight NMFS survey stations (R-23, R-24, R-25, Q-23, Q-25, P-23, P-24, and P-25) around St. Matthew Island (Figure B1). If three (O-23, O-24 and O-25), or another six more stations (N-23, N-24 and N-25), 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 B2). 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 B3. 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 B4-6); however, the relationships are generally weak.

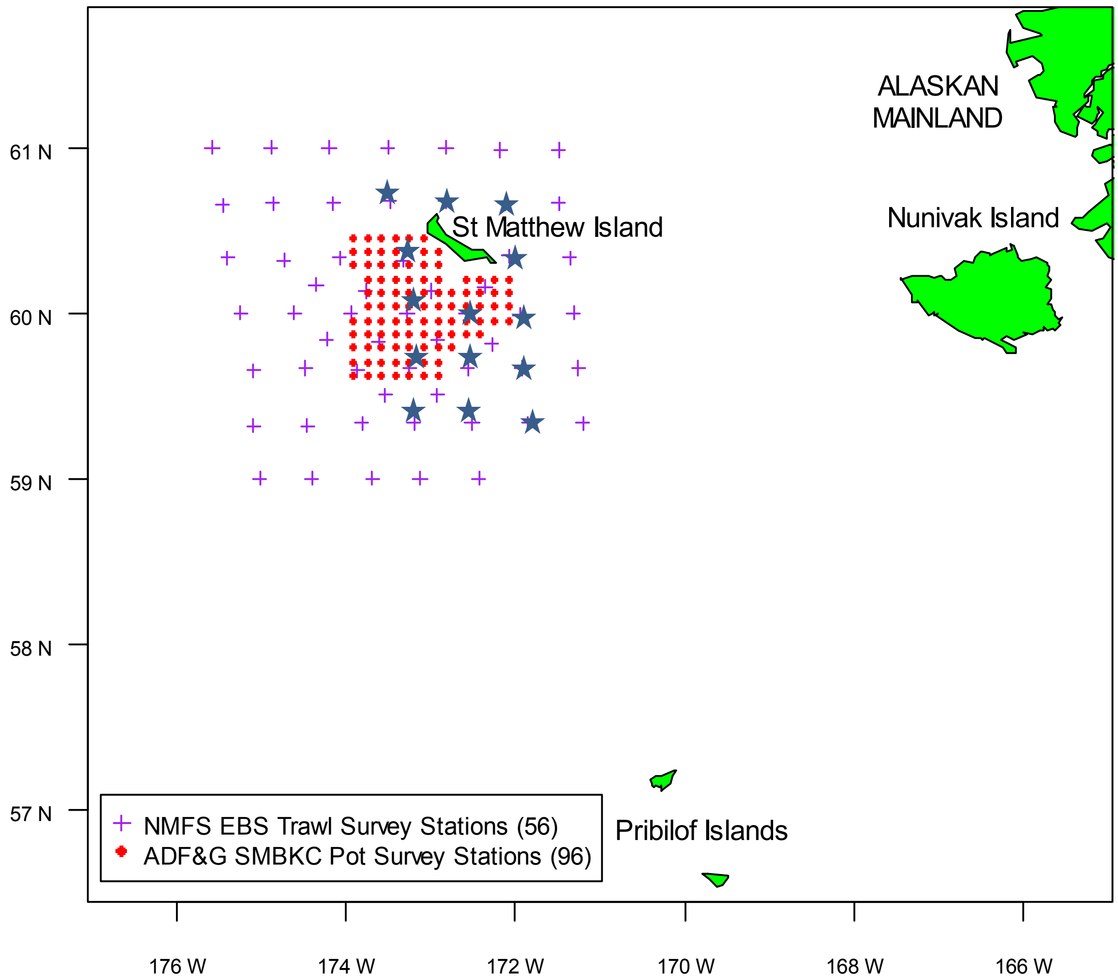


Figure B1. Trawl and pot-survey stations used in the St. Mathew Island blue king crab stock assessment. The stations with ★ are used for bottom temperature indices.

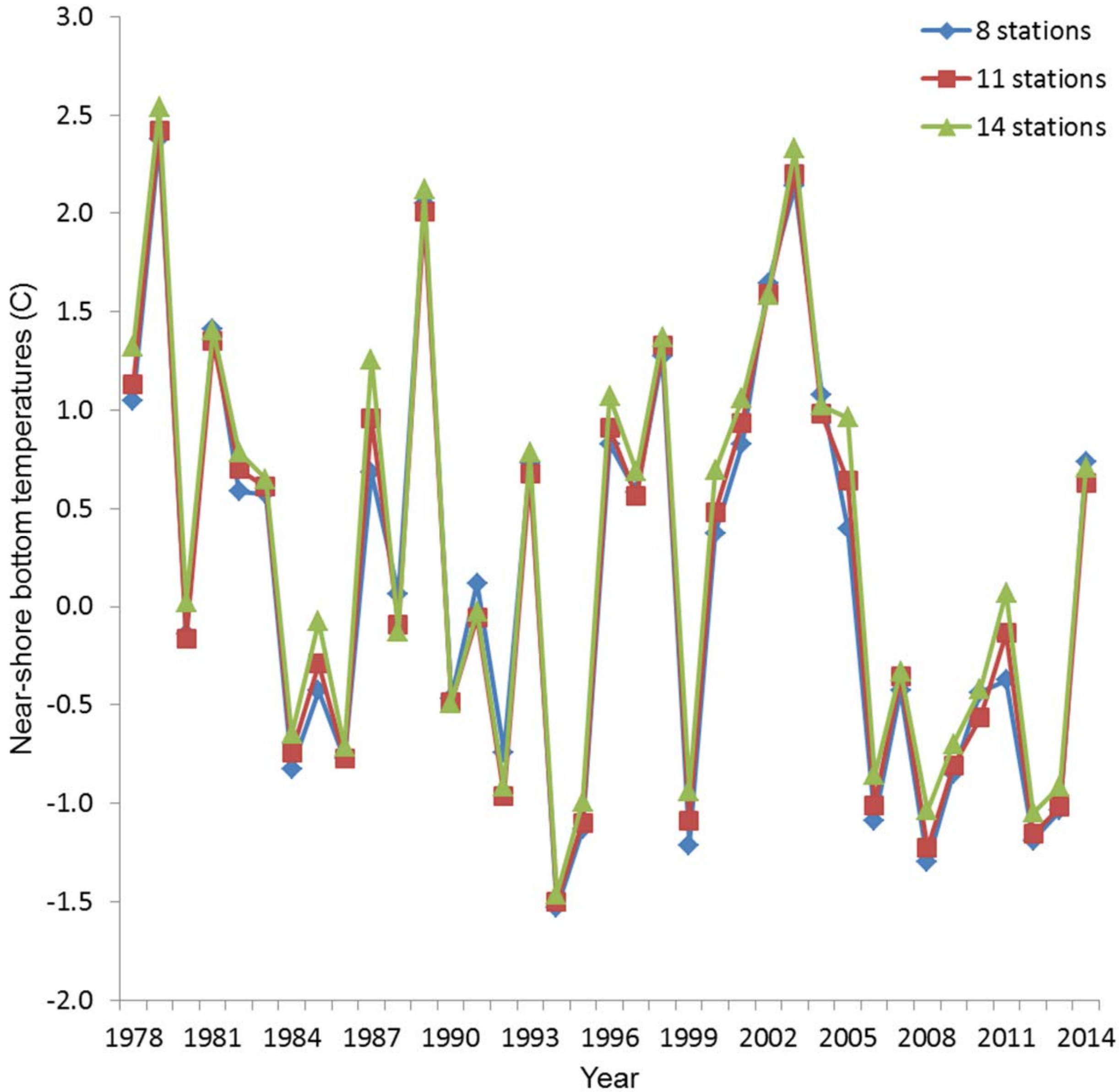


Figure B2. Mean near-shore bottom temperatures within 8, 11, and 14 NMFS survey stations around St. Matthew Island.

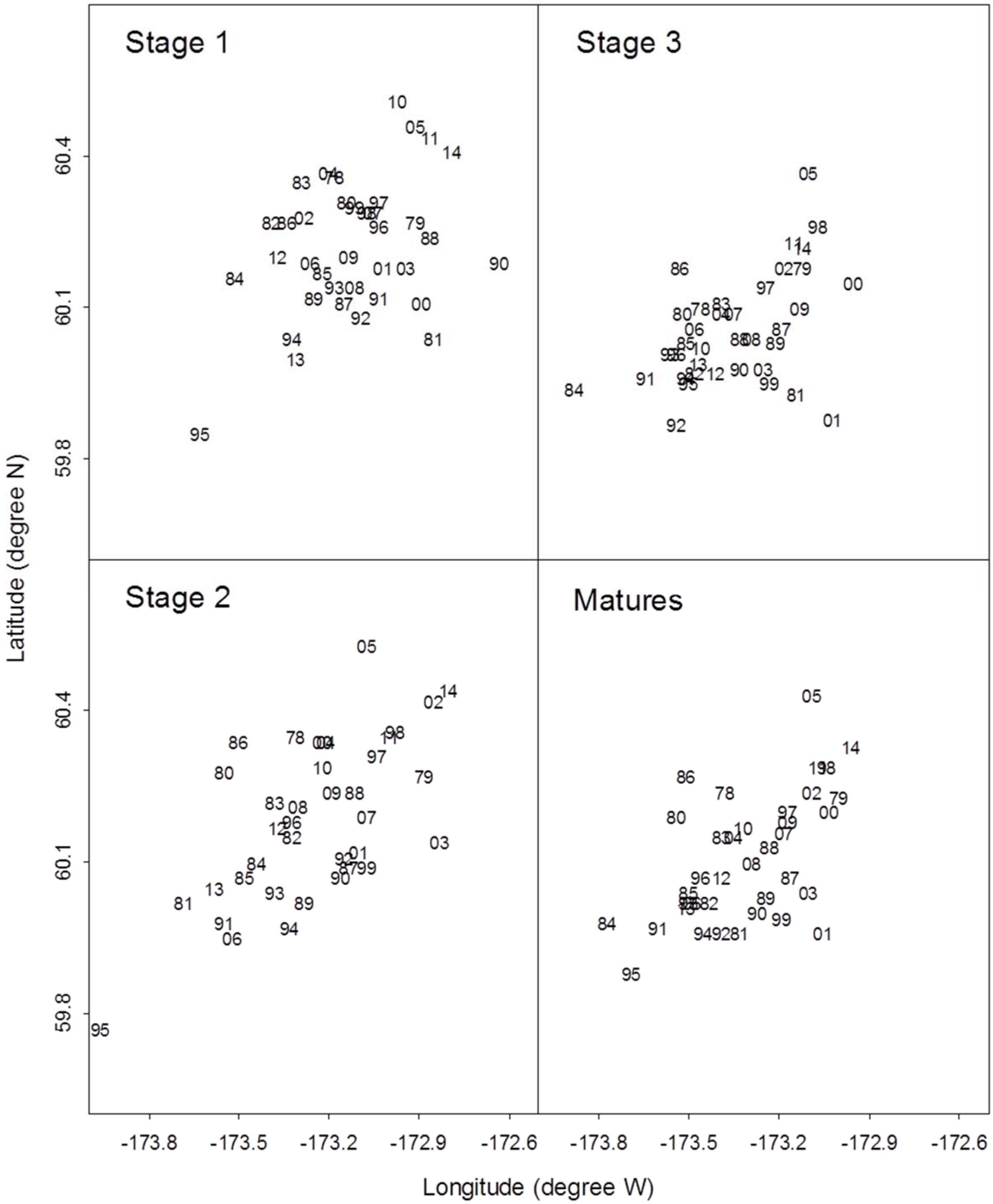
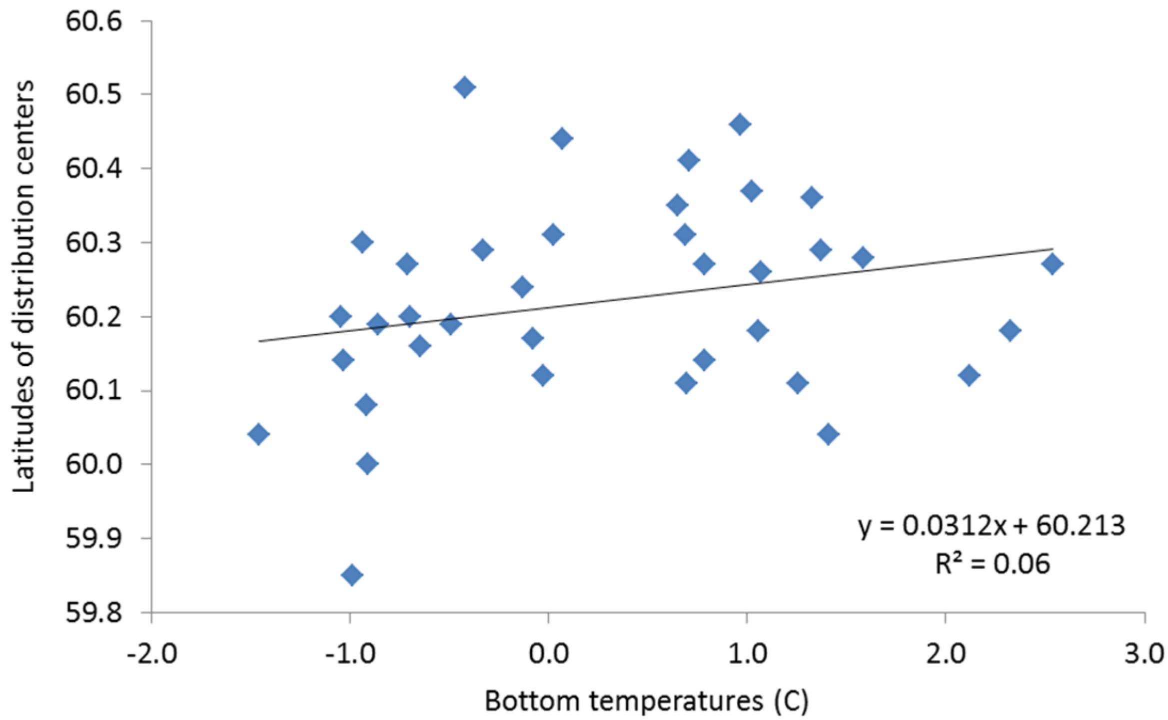


Figure B3. Distribution centers by stage defined by carapace length (CL) (1. 90-104 mm CL, 2. 105-119 mm CL, 3. ≥120 mm CL) for male St. Matthew blue king crab from NMFS summer trawl surveys. Mature males are a combination of stages 2 and 3.



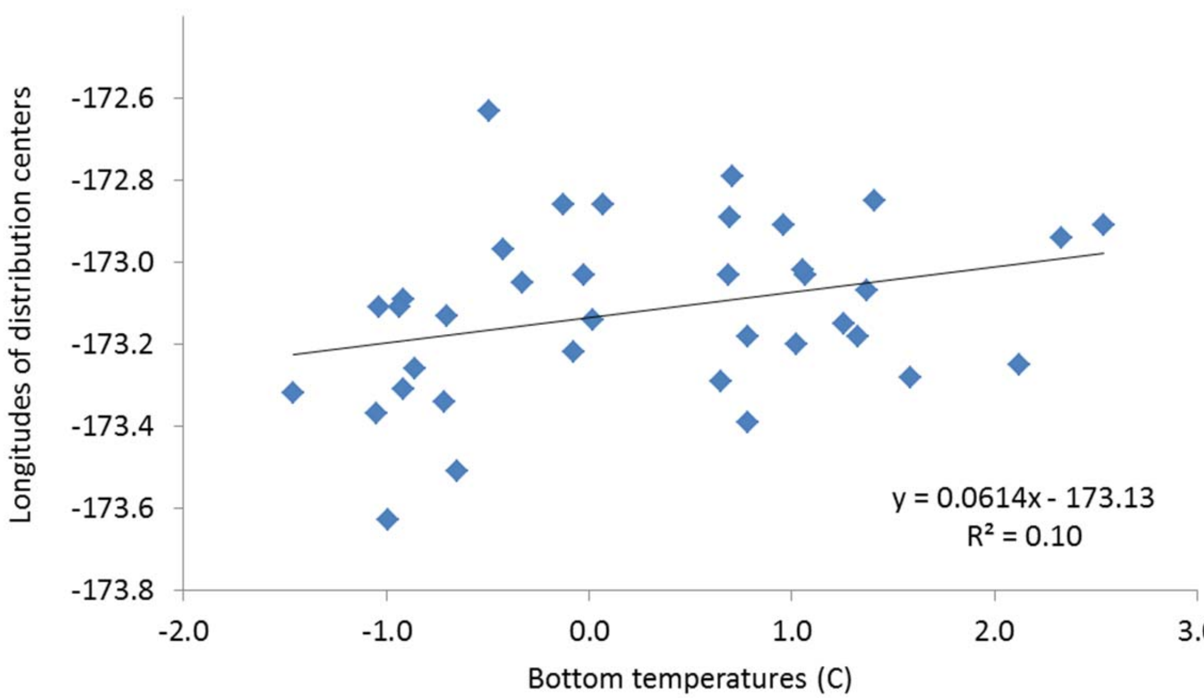


Figure B4. Relationships between annual latitudes and longitudes of stage 1 (90-104 mm carapace length) distribution centers and bottom temperatures for St. Matthew Island blue king crab.

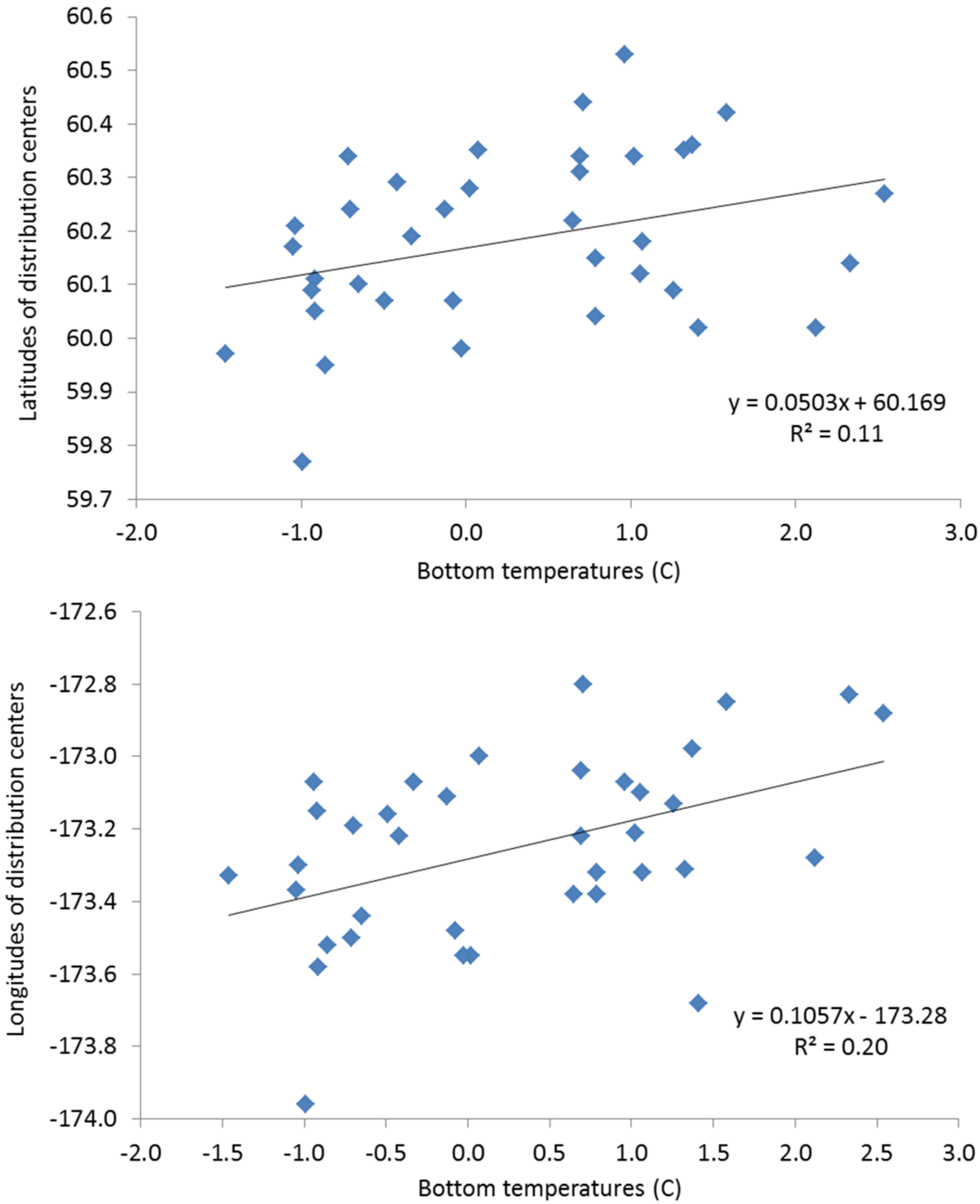


Figure B5. Relationships between annual latitudes and longitudes of stage 2 (105-119 mm carapace length) distribution centers and bottom temperatures for St. Matthew Island blue king crab.

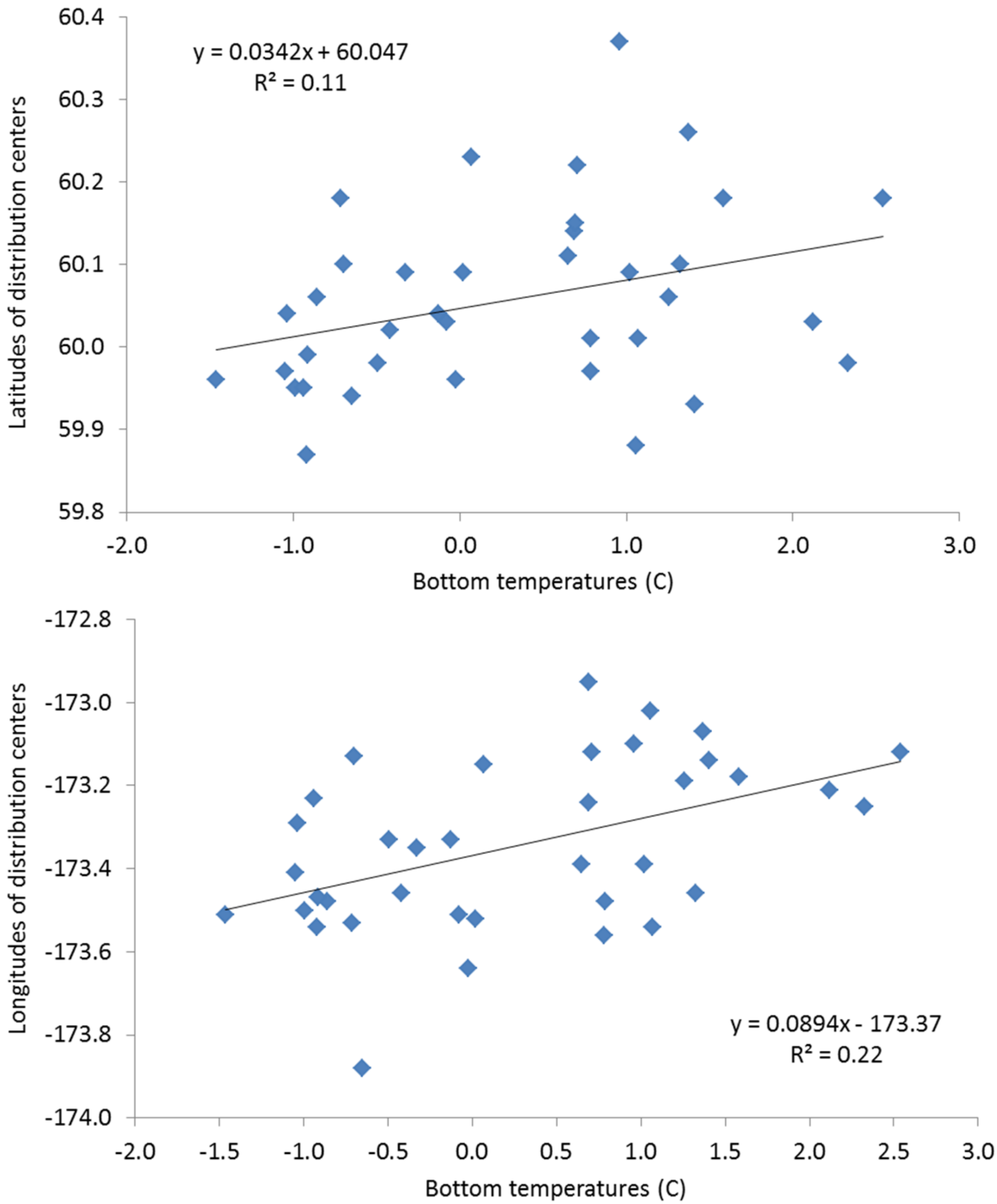


Figure B6. Relationships between annual latitudes and longitudes of stage 3 (≥120 mm carapace length) distribution centers and bottom temperatures for St. Matthew Island blue king crab.