St. Matthew Blue King Crab Stock Assessment in Fall 2008

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Executive Summary

A catch-survey analysis was updated with trawl survey data from 1978 to 2008, triennial pot survey data from 1995 to 2007, and commercial catch data from 1978 to 2007 to assess St. Matthew Island blue king crab abundance in 2008. A maximum likelihood approach was used to estimate abundance and recruitment. Five scenarios of the model were evaluated. Scenario (1) fixed natural mortality for both 1978-1998 and 2000-2008 (M=0.18) and trawl survey catchability (Q=1) with estimating M in 1999; scenario (2) fixed Q = 1 and estimated two M values (one for 1978-1998 and 2000-2008 and one for 1999); scenario (3) fixed M=0.18 for 1978-1998 and 2000-2008 and estimated Q and also estimated M for 1999; scenario (4) fixed a constant M = 0.18 for the whole time series and Q = 1; and scenario (5) fixed Q = 1 and estimated a constant M for the whole time series. Estimated legal abundance and mature male biomass in 2008 are:

	Scenario (1)	Scenario (2)
Legal males:	2,244,000 crab or 10.200 million lbs,	2,007,000 crab or 8.876 million lbs
Mature male biomass:	13.855 million lbs	12.190 million lbs.

Estimated B_{MSY} proxy:

	Model scenario (1)	Model scenario (2)

Based on average during 1978-2008:	7.610 million lbs,	7.014 million lbs,
Based on average during 1983-1998:	7.085 million lbs,	6.526 million lbs,
Based on average during 1983-2008:	6.690 million lbs.	6.018 million lbs.

Estimated F_{MSY} proxy:

	Model scenario (1)	Model scenario (2)
$\gamma = 1$:	0.180,	0.308,
$\gamma = 1.5$:	0.270,	0.462.

Estimated mature male biomass in 2008 was above any of the suggested B_{MSY} proxies. The stock appears to have increased greatly during the last few years.

If $\gamma = 1$ to 1.5, F_{MSY} proxy can range from 0.18 to 0.462, corresponding to harvest rates ranging from 16.5% to 37.0% of legal abundance at the time of fishing. After adjusting the time difference of surveys and the directed fishery, the overfishing limits for retained catch in 2008 range from 1.630 million lbs to 2.338 million lbs for model scenario (1) and from 2.227 million lbs to 3.109 million lbs for model scenario (2) depending on the γ value.

Response to CPT Comments (from May 2008)

"Bycatch data needs to be compiled with an analysis to generate a total catch OFL for next year's assessments. Bycatch estimates from the model should be tabulated to provide information for estimating a total catch OFL. Figures of standardized residuals should be provided, along with providing clarification on whether the residual patterns reflect a cohort effect or a growth effect. The assessments need to include figures showing data and fits to these data for both pot and trawl surveys including confidence intervals on data and model results. The assessment should also examine the sensitivity of the weighting choices employed in the model to examine relative influence on results [e.g. conducting the assessment using each of the two indices of abundance in turn (pot and trawl survey)]. The plan team recomends examining the sensitivity of constant M over the whole time period."

Lack of trawl bycatch estimates for this stock from NMFS and limited pot bycatch data make it difficult to use total catch as OFL this year. Standardized residuals were plotted in the May, 2008 report and are re-graphed in this report for a better presentation. The residuals are highly dependent on the choice of natural mortality. There are no apparent growth or cohort effects from the residuals. In addition to the abundance residual plots, the model fits are also compared by graphing model estimates and survey abundance estimates in this report. The CVs of the survey data may be used in the assessment next year. The relative influence on results from each of two survey indices can be examined next year. Prior to this year, the sensitivity of a constant *M* over the whole time period had been examined every year since 1999. The reasons that a constant *M* over the whole time period does not work well (bad fits of the survey data and leading to overexploiting the stock) have been addressed in a paper. The constant *M* scenario is added to this report to satisfy the request of the CPT.

Response to SSC Comments specific to this assessment (from June 2008)

"The Plan Team was uncomfortable with some features of the assessment data (particularly the failure to include available bycatch data) and model fit, and therefore chose not to place this stock in Tier 3. Instead the team for this year preferred to use the biomass estimates from the model fit but to use the standard Tier 4 procedures to set OFL. ***The SSC agrees with management of this stock under tier 4 this year and all the plan team recommendations with respect to years of data, gamma, and natural mortality rate.*** *However, we look forward to having the authors and the team resolve the questions about the assessment model fit so that it can be used in the near future for the OFL determination. The SAFE document has a preface stating that the authors will get together before the September plan team meeting to work through some of the issues. The SSC would like to get a progress report and the opportunity to review the model at the October meeting."*

So far, NMFS has not been able to provide trawl bycatch estimates for this stock. Pot bycatch observer data are available for a few years for mostly 1 to 3 catcher processor vessels only. There has been no observer coverage for catcher vessels (about 168 of total 174 fishing vessels). So pot bycatch estimates are also highly uncertain and are not used in the model directly. The model assumes a bycatch selectivity to assess the impact of pot bycatch on abundance estimates. Because of these bycatch estimation problems, we use retained catch for OFL in this report.

The authors have not been able to meet before the September plan team meeting to discuss the issues. However, the authors discussed the issues during the CPT meeting in May 2008.

Response to SSC Comments in General (from June 2008)

"General recommendations to all assessment authors for future assessments:

1. *To the extent possible, a consistent format should be used for the assessments; sections that are not relevant to a particular stock should be omitted."*

Agree.

2. *"Each assessment should provide a range of alternatives for the Plan Team and SSC to consider when setting OFLs, for example, alternative model configurations for Tier 1-3 stocks, alternative parameter values where these are highly uncertain and cannot be estimated, or alternative time periods used in Tier 4 and Tier 5 calculations."*

Agree.

3. *"Model-based stock assessments should clearly document all data sources, model equations, the number of parameters, a list of which parameters are estimated in the model, and a list of fixed parameters, and a justification for the selected parameter values."*

Agree.

4. *"The rationale for selecting a specific time period for establishing B_{MSY} proxies based on time series of recruitment (Tier 1-3) or biomass (Tier 4) or for establishing an OFL based on catch histories (Tier 5) should be clearly articulated. Unless compelling reasons exist to choose a different period, the default should be the full time series for which data are available. When alternative time periods are considered, the rationale and the resulting reference points should be presented for consideration by the Plan Team and SSC."*

Agree.

5. *"The crab OFL definitions are designed to provide a guide for defining the best available proxy for MSY when data are insufficient to directly estimate MSY. The guidelines allow gamma in the formula for computing F_{OFL} under Tier 4 to be set at a value higher or lower than 1. A gamma less than 1 might be justifiable if the available biomass measure includes a large portion of small crab that has not recruited to the fishery. A gamma greater than 1 might be justifiable if the directed fishery can be expected to harvest male*

crab with carapace widths well above the size at 50% maturity. The SSC agrees with the Plan Team recommendation that ***future stock assessments should provide analyses to support the choice of gamma****. These analyses could include an exploration of fishery selectivity and a comparison of minimum size limits and size at 50% maturity for male crab. The SSC does not recommend the use of an $F_{35\%}/M$ ratio derived from one stock as a default for gamma on an unrelated stock unless there is a strong rationale for concluding that the fishery is likely to be prosecuted in an identical manner and knowledge of stock status is sufficient to justify the harvest rate."*

Agree. The gamma value can be evaluated next year.

6. *"To the extent possible, bycatch information should be provided for all stocks included in the SAFE so that stock OFLs can be moved from "retained catch OFL" to "total catch OFL""*.

See the response above. Due to lack of bycatch data, retained catch is used as OFL in this report.

7. *"For stocks with an assessment model, the SSC requests that the authors include a table summarizing the fit to data (including number of parameters, likelihood for each data component, etc.)."*

These are included in this report.

8. *"The ecosystem considerations sections could be expanded to include information on prey and predator composition in a consistent format (e.g., pie charts similar to the groundfish assessments). A discussion of seabird predation on crab would be a useful addition. We note that seabirds feed on larval through juvenile crab, particularly in shallow or nearshore areas, such as the Pribilof Islands. Plankton-feeding birds eat larval crab and juveniles are consumed by seaducks and seabirds, particularly during winter months."*

Few prey and predator data are available for this stock.

9. *"Each assessment should include figures showing the available time series of catch and survey biomass, in addition to tables, to facilitate comparisons and the selection of appropriate time periods."*

Agree. These are in this report.

10. *"The presentation of recruitment time series should be standardized as to year (examples include year of recruitment to maturity for spawner/recruit data, or perhaps year of*

hatching; and year of recruitment to legal size for catch data) to clearly illustrate specific cohort strength."

Recruitment is referred to year of recruitment to the model in this report. The year of recruitment to the mode is one year less than the year of recruitment to maturity.

11. *"Assessment authors should provide alternative options for setting OFLs to the Plan Team and the SSC, particularly where there are large uncertainties about correct model structure or parameter estimates."*

Agree.

Introduction

Blue king crab, *Paralithodes platypus* (Brant 1850), are sporadically distributed throughout their range in the North Pacific Ocean from Hokkaido, Japan to southeastern Alaska. 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 cold water areas of the Gulf of Alaska at Olga Bay- Kodiak Island and at Port Wells- Prince William Sound, Russell Fjord, Glacier Bay, Lynn Canal, and Endicott Arm- Southeast Alaska (Figure 1) (Somerton 1985). Adult blue king crab are found at depths less than 180 meters and in average bottom water temperatures of 0.6° C (NPFMC 1998). The St. Matthew Island Section for blue king crab is within the Northern District of the Bering Sea king crab registration area (Area Q2) and includes the waters north of the latitude of Cape Newenham (58°39' N. lat.) and south of the latitude of Cape Romanzof (61°49' N. lat.) (Figure 2) (Bowers et al. 2008).

The Alaska Department of Fish and Game (ADF&G) Gene Conservation Laboratory division has detected regional populations between blue king crab collected from St. Matthew Island and the Pribilof Islands based on a limited number of variable genetic markers using allozyme electrophoresis methods (1997, NOAA grant Bering Sea Crab Research II, NA16FN2621). Tag return data from studies by the National Marine Fisheries Service (NMFS) on blue king crab in the Pribilof Islands (n = 317) and St. Matthew Island (n = 253) support the idea that legal-sized males do not migrate between the two areas (Otto and Cummiskey 1990). These two stocks are managed separately based on different life history characteristics and exploitation by the fishery.

Catch History

Fisheries

The St. Matthew Island fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990); 10 U.S. vessels harvested 1.202 million pounds in 1977. Harvests peaked in 1983 when 164 vessels landed 9.454 million pounds (Figure 3). The fishing seasons were generally short, lasting less than a month (Table 1). From 1986 to 1990 the fishery was fairly stable, harvesting a mean of 1.252 million pounds by <70 vessels (Figure 3; Table 2). The mean catch increased to 3.297 million pounds during 1991-1998. Participation increased from 68 vessels in 1991 to 174 vessels in 1992. After 1992, the St. Matthew and Pribilof Islands blue king crab fisheries were opened concurrently, dividing vessel effort between the two fisheries and initially stabilizing vessel participation at about 90 vessels. To reduce total fishing effort and improve manageability of the relatively small allowable harvests, maximum limits of 60 pots and 75 pots were set in 1993 for vessels <38.1 m and ≥38.1 m, respectively. Those limits reduced the number of pots registered by a third from 1992 to 1993 (Bowers et al. 2008). However, the number of potlifts in the fishery increased slightly because the season length doubled and pot turnover rates increased. During 1996-1998 participation increased to an average of 123 vessels per year and the average number of potlifts increased 54% from 1992 (Bowers et al. 2008).

This fishery was declared overfished and closed in 1999 when the stock size 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 1998). In November of 2000, Amendment 15 to the FMP for the Bering Sea/Aleutian Islands King and Tanner crabs was approved to implement a rebuilding plan for St. Matthew Island blue king crab stock. The rebuilding plan included an Alaska Board of Fisheries approved harvest strategy and area closures to control bycatch as well as gear modifications and an area closure for habitat protection. Since 1999, the abundance estimates calculated from the National Marine Fisheries Service (NMFS) annual eastern Bering Sea shelf survey data have not met the harvest strategy threshold defined in the rebuilding plan although 2006 and 2007 abundance estimates, 11.2 and 15.6 million pounds respectively, were above MSST and the stock is considered rebuilding (Bowers et al. 2008). Currently, there is no directed commercial fishery for blue king crab in the St. Matthew Island district.

Zheng and Kruse (2002) hypothesized a high level of natural mortality in the St. Matthew blue king crab stock from 1998 to 1999 as an explanation for the low catch per unit effort (CPUE) in the 1998 commercial fishery and in the 1999 ADF&G nearshore pot survey, as well as the low numbers across all male crab size groups caught in the eastern Bering Sea NMFS annual trawl survey from 1999 to 2005. Watson (2005) has found similar trends in the population estimates for St. Matthew blue king crab based on the 1995-2004 ADF&G pot survey conducted triennially in the St. Matthew Island district.

Commercial crab fisheries near St. Matthew Island have been scheduled in the fall and early winter to reduce the potential for bycatch from handling mortalities due to molting and mating crabs. Some bycatch has been observed of non-retained St. Matthew blue king crab in both the St. Matthew blue king crab fishery and the eastern Bering Sea snow crab fishery. The St. Matthew Island golden king crab fishery, the third commercial crab fishery in that area, is executed in areas with depths deeper than blue king crab distribution. Discard mortality rates have been established by the NPFMC (1999), and could be species or fishery specific. Bycatch mortality rates for all crab species were set at 80% in trawl fisheries, 40% in dredge fisheries and 20% in fixed gear fisheries. The directed crab fishery mortality rate was set at 8% for blue king crab, averaged across different crab fisheries (NPFMC 2006).

Harvest Strategy

Subject to the federal overfishing limits, the current TAC is determined based on the state harvest strategy (**5 AAC 34.917**), which was adopted by the BOF in March 2000 as part of a rebuilding plan developed for the stock (NPFMC 2000). The harvest strategy has four components for determining the TAC:

- A threshold of 2.9-million pounds of mature male biomass,
- An exploitation rate on mature male abundance that is a function of mature male biomass,
- A 40% cap on the harvest of legal males, and
- A minimum 2.778-million pound TAC for a fishery opening.

Mature male biomass (MMB) is defined for the harvest strategy as the biomass of males ≥105-mm carapace length (CL) in July. When MMB is below the 2.9-million-pound threshold of the State's harvest strategy, the stock is closed to commercial fishing. When the stock is above that threshold, an exploitation rate on mature male abundance (defined for management purposes as the abundance of all males ≥105-mm CL) is determined as a function of MMB. The exploitation rate on mature male abundance increases linearly from 10% when MMB = 2.9-million pounds to 20% when MMB = 11.6-million pounds. For MMB >11.6-million pounds, the exploitation rate remains at 20%. Application of the mature male exploitation rate to mature male abundance determines the targeted number of legal-sized males for commercial harvest. Minimum legal size is 5.5-in carapace width (CW), but 120-mm CL is used as a proxy for the size limit in stock-assessment computations. To protect from excessive harvest of the legal-sized component of the mature male stock, the targeted number of legal-sized males for commercial harvest is capped at 40% of the estimated legal-sized male abundance.

The BOF originally adopted a minimum guidline harvest level (GHL) as a management tool to help prevent harvest from exceeding low GHLs. With rationalization, this has been retained as a 2.5-million-pound minimum TAC for the "non-CDQ" portion of the overall TAC. The CDQ fishery is allocated 10% of the overall TAC; hence for the fishery to open, the TAC, including the allocation to the CDQ fishery, must be 2.778-million pounds or higher. It is important to note that, although the minimum GHL was adopted as management tool, it also plays an important role in promoting stock rebuilding. The minimum GHL was included as a management measure in the analyses of the effectiveness of the current harvest strategy when the BOF considered alternative strategies for managing and rebuilding the St. Matthew blue king crab stock. The analyses showed the minimum GHL to be an important determinant of the rebuilding schedule.

Besides the directed commercial fishery, some St. Matthew Island blue king crab have been caught in the eastern Bering Sea snow crab fishery and groundfish trawl fisheries.

Data

Fishery Catch Data

Vessel numbers, potlifts, catches in number and weight and CPUE for the directed pot fishery are summarized in Table 2. In this report, total annual retained catches were used in the catch-survey analysis.

Trawl Survey Data

NMFS has conducted annual summer trawl surveys of St. Matthew Island blue king crab since 1978. Indices of St. Matthew Island blue king crab abundance are affected by the portion of the stock occupying inshore rocky untrawlable grounds. Only 55 legal males (≥ 5.5 in CW or 120 mm CL) and eight large females (≥80 mm CL) were captured on the 2007 NMFS annual eastern Bering Sea shelf survey. On the NMFS 2008 survey, 69 legal males and nine large females were caught.

The catch-survey model was fit to NMFS trawl survey and commercial catch data from 1978 to 2008. Survey stations were stratified based on the approach developed by Zheng et al. (1997). Basically, the number of tows per station was used as a criterion to stratify the stations: (1) frequent two-tow stations were grouped together as one stratum, (2) frequent one-tow stations formed another stratum, and (3) any single station with four or more tows was regarded as a separate stratum. The stratification was constant over time and similar to that used by NMFS during recent years.

The area-swept approach was used to estimate average crab density (abundance per nmi^2) for each stratum. Crab abundance by length, sex, and shell condition was estimated for each stratum by taking the product of average crab density and total stratum area. Total abundance of the stock was estimated by summing the abundances from all strata. Stage-specific survey abundances for the catch-survey model are summarized in Table 3.

Pot Survey Data

ADF&G performed a triennial pot survey for Saint Matthew Island blue king crab in 1995, 1998, 2001, 2004 and 2007 (Watson 2008), which is able to sample from areas of important habitat for blue king crab, particularly females, that the NMFS trawl survey cannot sample from. The pot surveys were usually conducted during late July and August with a chartered commercial crab pot vessel. The 2007 survey station grid encompassed the 2,850 nmi^2 area between 59º30' - 60º30' N. latitude and 172º00' - 174º00' W. longitude and contained 141 primary stations and 24 secondary stations (Figure 4, Watson 2008). Watson (2008) described the detailed survey design, pot structures and biological sampling.

Ninety-six stations were fished in common in each of the five surveys (Figure 5, Watson 2008). Among all stations fished in each survey year, the peak catch of legal male blue king crab declined from a high of 256 crabs in 1995 to a low of 57 crabs in 2004 and increased to 119 crabs in 2007 (Figure 6). The peak catch of sublegal male crabs also declined, from a high of 167 crabs in 1995 to a low of 37 crabs in 2004 and increased to 86 crabs in 2007 (Figure 7). Peak catches of females mirrored that observed for male crabs, with a peak catch of 590 crabs in 1995 declining to a low of 50 crabs in 2004; in 2007, however, the peak catch rebounded to 490 crabs (Figure 8). The CPUE indices from these 96 stations (Table 4) were used in the catch survey analysis.

Analytical Approach

Main Assumptions for the Model

A list of main assumptions for the model:

(1) Natural mortality is constant over time and stages except for 1999, which was estimated separately in the model. For scenarios with a fixed natural mortality value, it was estimated with a maximum age of 25 and the 1% rule (Zheng 2005).

(2) Survey selectivities are a function of stage and are constant over time.

(3) Growth is a function of stage and does not change over time.

(4) Molting probability is a function of stage and changes over time with a random walk process.

(5) A fishing season for the directed fishery is short.

(6) Handling mortality was assumed to be 0.2 and bycatch selectivities were assumed to be 0.4 and 0.6 for prerecruit-2s and prerecruit-1s, which are similar to bycatch selectivities estimated for Bristol Bay red king crab (Zheng and Siddeek 2008).

(7) Annual retained catch was measured without error.

(8) Trawl survey catchability was set to be 1.0 for legal males when fixed in the model.

(9) Male crab are mature at sizes ≥105 mm CL.

(10) Abundance had a log-normal error structure.

Model Structure

A four-stage catch survey analysis (CSA) is principally similar to a full length-based analysis (Zheng et al. 1995) with the major difference being coarser length groups for the CSA. Because of large size categories, the CSA is particularly useful for a small stock with low survey catches each year. Currently, a four-stage CSA is used to assess abundance and prescribe fishery quotas for the St. Matthew Island blue king crab fishery.

Only male crab abundance is modeled by CSA because the analysis requires commercial catch data and only males may be retained by the fishery. Male crab abundance was divided into four groups: prerecruit-2s ($P2$), prerecruit-1s ($P1$), recruits (R), and postrecruits (P). To be of legal size, St. Matthew Island male king crab must be ≥140 mm carapace width (regulatory measurement), corresponding to males ≥120 mm carapace length (CL). The average growth increment per molt is about 14 mm CL for adult male blue king crab (Otto and Cummiskey 1990). We categorized St. Matthew Island male blue king crab into $P2$ (90-104 mm CL), $P1$ (105-119 mm CL), R (newshell 120-133 mm CL), and P (oldshell ≥120 mm CL and newshell ≥134 mm CL).

For each stage of crab, the molting portions of crab "grow" into different stages based on a growth matrix, and the non-molting portions of crab remain the same stage. The model links the crab abundances in four stages in year t+1 to the abundances and catch in the previous year through natural mortality, molting probability, and the growth matrix:

$$\begin{aligned}
&P2_t^b = P2_t\{1-[h\,H2^q\,C_t/(R_t+P_t)]e^{(y_t-1)M_t}\},\\
&P1_t^b = P1_t\{1-[h\,H1^q\,C_t/(R_t+P_t)]e^{(y_t-1)M_t}\},\\
&P2_{t+1} = P2_t^b[(1-m2_t)+m2_t\,G_{P2,P2}]e^{-M_t}+N_{t+1},\\
&P1_{t+1} = \{P1_t^b[(1-m1_t)+m1_t\,G_{P1,P1}]+P2_t^b\,m2_t\,G_{P2,P1}\}e^{-M_t},\\
&R_{t+1} = (P2_t^b\,m2_t\,G_{P2,R}+P1_t^b\,m1_t\,G_{P1,R})e^{-M_t},\\
&P_{t+1} = (P_t+R_t+P2_t^b\,m2_t\,G_{P2,P}+P1_t^b\,m1_t\,G_{P1,P})e^{-M_t}-C_t\,e^{(y_t-1)M_t},
\end{aligned} \qquad (1)$$

where $P2_t^b$ and $P1_t^b$ are prerecruit-2 and prerecruit-1 abundances after handling mortality in year t, h is handling mortality rate, $H2^q$ and $H1^q$ are fishery selectivities for prerecruit-2s and prerecruit-1s, N_t is new crab entering the model in year t, $m2_t$ and $m1_t$ are molting probabilities for prerecruit-2s and prerecruit-1s in year t, $G_{i,j}$ is a growth matrix containing the proportions of molting crab growing from stage i to stage j, M_t is natural mortality in year t, C_t is commercial catch in year t, and y_t is the time lag from the survey to the mid-point of the fishery in year t. By definition, all recruits become postrecruits in the following year.

We modeled molting probability for prerecruit-1s, $m1_t$, as a random walk process:

$$m1_{t+1} = m1_t e^{\eta_t}, \qquad (2)$$

where η_t are independent, normally distributed random variables with a mean of zero.

Parameters Estimated Independently

Five scenarios of the model were developed for St. Matthew Island blue king crab, depending on parameters estimated independently and conditionally. In scenarios (1) and (4), both *M* for 1978-1998 and 2000-2008 and *Q* were fixed (estimated independently) and *M* for 1999 was independently estimated for scenario (1) and fixed for scenario (4); in model scenarios (2) and (5), *M* was estimated conditionally whereas *Q* was fixed and *M* was constant for the whole time series for scenario (5) and a different *M* value was independently estimated for 1999 for scenario (2); and in model scenario (3), *Q* was estimated conditionally and *M* was fixed for 1978-1998 and 2000-2008 and estimated for 1999:

	Scenario				
	(1)	(2)	(3)	(4)	(5)
M for 1978-1998, 2000-2008	0.18	Estimate	0.18	0.18	Estimate
M for 1999	Estimate	Estimate	Estimate	0.18	Same as above
Q	1.0	1.0	Estimate	1.0	1.0

The independently-estimated *Q* is 1. To reduce the number of parameters estimated, we used the ratio (1.44) of *m*1 to *m*2 from tagging data to estimate *m*2 from *m*1. The growth matrix was estimated from tagging data (Table 5; Otto and Cummiskey 1990). We assumed that the relative frequencies of length groups from the first-year trawl survey data approximate the true relative frequencies. Thus, we did not need to conditionally estimate length-specific abundance for the first year. Handling mortality rate was assumed to be 0.2, and to be 0.0 and 0.5 in a sensitivity study. Observer coverage was very limited for the directed fishery, and only 1-3 out of 90-131 vessels were covered from 1995 to 1998 (Moore et al. 2000). Due to limited observer data, fishery selectivities of pre-recruits 2 and 1 in the directed pot fishery were assumed to be 0.4 and 0.6 relative to legal crab, respectively, based on the results of Bristol Bay red king crab (Zheng and Siddeek 2008).

Natural Mortality

The estimate of natural mortality for all species of king crab in the eastern Bering Sea is 0.2 as defined by the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs (1998). Siddeek et al. (2002) reexamined tagging experiments conducted around St.

Matthew Island in 1995 and 1998 to estimate natural mortality (M). Based on a multinomial likelihood M estimator using returned the tag data, values of Z (annual instantaneous total mortality) for both male and female blue king crab ranged from 0.65 to 0.74 assuming that M and SR (initial tagging survival/recapture ratio) did not vary by sex. Using the combined sexes return tag data (80-157 mm CL) from the 1995 tagging experiment, the mean estimate of M = 0.19. One other natural mortality estimate has been reported for St. Matthew Island blue king crab based on tagging data. Values ranged from 0.19 to 2.04 with a mean estimate of 0.81 for adult male blue king crab (105-139 mm CL) (Otto and Cummiskey 1990).

The independently-estimated *M* is 0.18 in this report, based on a maximum age of 25 and the 1% rule (Zheng 2005).

Length-weight Relationships

Based on 136 samples collected in 1978 to 1981 from St. Matthew Island (Somerton and MacIntosh 1983b), the carapace length (mm)-weight (g) relationship for blue king crab males (range = 59-147 mm) is described by the equation:

$$W = 0.000329 * CL^{3.175}$$

Somerton and MacIntosh (1983b) compared the carapace size-weight relationship of blue king crab males collected in the Bering Sea and found no statistical difference between St. Matthew Island and the Pribilof Islands stocks. Recent samples collected from both the Pribilof Islands and St. Matthew Island area in 2006 and 2007 on the annual AFSC eastern Bering Sea shelf trawl survey provide an updated carapace length-weight relationship for male blue king crab (n = 172, range = 57-172 mm) described by the equation: $W = 0.0005257 * CL^{3.1040800}$. The carapace size-weight relationship for blue king crab ovigerous females is: $W = 0.114389 * CL^{1.919200}$ and non-ovigerous females is: $W = 0.035988 * CL^{2.155575}$.

Sizes at Maturity

Blue king crab males do not have a specific morphometric indication of maturity. Earlier studies exploring the relationship of the major chela height measurement to the carapace length (CL) of an individual crab as a measurement of male maturity did not produce statistically sound results, although one study reports males from St. Matthew were considered mature at 77 mm CL based on this relationship (Somerton and MacIntosh 1983a). St. Matthew blue king crab males were found to produce spermatophores at the 50-59 mm CL size range which indicates these crab are reaching sexual maturity at a smaller size than estimated using chela height morphology (Paul et al. 1991). ADF&G considers males mature at carapace length of $\geq$ 105 mm when estimating total mature biomass (TMB) to determine guideline harvest levels (GHL). Size at functional maturity used by the North Pacific Fishery Management Council (NPFMC 1998) in fishery management for blue king crab males in the St. Matthew district is 105 mm carapace length.

Blue king crab females in the St. Matthew Island area are considered mature at 80.6 mm CL based on 50% maturity estimates determined by the presence of eggs or empty egg cases (Somerton and MacIntosh 1983a). They are biennial spawners, with a 14-15 month period of embryonic development, and are less fecund but with larger sized eggs (1.2 mm) than red king crab females (Somerton and MacIntosh 1985, Jensen and Armstrong 1989). Molting is necessary for egg extrusion, thus the intermolt period is two years for blue king crab females. Somerton and MacIntosh (1985) suggested that blue king crab females live longer and have larger sized eggs than red king crab females as a reproductive strategy to compensate for their biennial spawning cycle. Reproductive studies on Pribilof Island blue king crab females supports a biennial reproduction cycle for large multiparous females but found smaller, primiparous (first year of maturity) females were often able to reproduce in two consecutive years (Jensen and Armstrong 1989).

Parameters Estimated Conditionally

Estimated parameters include natural mortality, molting probabilities, catchabilities, selectivities, *M* in 1999, crab entering the model for the first time each year except the first, and total abundance in the first year (Tables 6-9). Depending on the model scenario, *M* and *Q* may be estimated conditionally (Table 6).

Measurement errors of survey estimates of relative abundances were assumed to follow a lognormal distribution. Parameters of the model were estimated using a maximum likelihood approach:

$$
\begin{aligned}
Ln(L) = -\sum_t \{ & [\ln(P2_t Q\, S2+1) - \ln(p2_t+1)]^2 + [\ln(P1_t Q\, S1+1) - \ln(p1_t+1)]^2 \\
& + [\ln(R_t\, Q+1) - \ln(r_t+1)]^2 + [\ln(P_t\, Q+1) - \ln(p_t+1)]^2 \\
& + [\ln(P2_t s2/q+1) - \ln(ip2_t+1)]^2 + [\ln(P1_t s1/q+1) - \ln(ip1_t+1)]^2 \\
& + [\ln(R_t/q+1) - \ln(ir_t+1)]^2 + [\ln(P_t/q+1) - \ln(ip_t+1)]^2 + 10\eta_t^2 \}
\end{aligned} \quad , \quad (3)
$$

where $p2_t$, $p1_t$, r_t, and p_t are relative trawl survey (area-swept) abundances (thousands of crabs) of prerecruit-2s, prerecruit-1s, recruits, and postrecruits in year t; $ip2_t$, $ip1_t$, ir_t, and ip_t are catches per 1000 pot lifts of prerecruit-2s, prerecruit-1s, recruits, and postrecruits from pot surveys in year t; $S2$ and $S1$ are trawl survey selectivities for prerecruit-2s and prerecruit-1s; Q is a trawl survey catchability, $s2$ and $s1$ are pot survey selectivities for prerecruit-2s and prerecruit-1s; and q is a scaling parameter (per millions of pot lifts) to convert crab per pot lift to absolute crab abundance. P_t/q is the expected postrecruits per 1000 pot lifts in year t. Using AD Model Builder (Otter Research Ltd. 1994), we estimated parameters using the quasi-Newton method to minimize –Ln(L).

Model Results

Abundance and Parameter Estimates

Estimated abundance, recruitment to the model and mature male biomass are summarized in Tables 6-8 for five scenarios. Scenarios (1) and (4) with fixed Q and M resulted in relatively high abundance and biomass estimates during recent 10 years (Figure 9). Scenario (2) fitted both trawl and pot survey abundance best whereas scenario (4) was the worst (Figures 9 and 10; Table 6). All scenarios indicate an increasing abundance and biomass since 1999, and projected legal abundance and mature male biomass without fishing in 2008 were the highest values since 1999 (Figure 9; Tables 6-8). Residuals were about random for both trawl and pot survey data except that the residuals for post-recruit abundance from the trawl survey after the stock collapse in 1999 were mostly negative (Figures 11 and 12). This may suggest a higher mortality than we assumed in the model for the post-recruit crab. When M was estimated in the model, its value (0.308) was much higher than the fixed value of 0.18.

Legal harvest rate was defined as the ratio of retained catch to estimated legal abundance adjusted by natural mortality to the midpoint of each fishing season. Estimated harvest rates were very high during 1982-1985, above 45% (Figure 13). The fishery has been closed since 1999.

Likelihood profiles of estimated *M*, *Q* and mature male biomass on February 15, 2009 are illustrated in Figure 14. With a fixed $Q = 1$, estimated *M* was 0.308, much higher than we assumed in the model. The likelihood was very low for $M = 0.18$. When fixing $M = 0.18$, estimated Q was greater than 1, an unlikely value (Figure 14). Both model scenarios (1) and (2) were evaluated for setting overfishing limits in this report.

Handling mortality may also affect abundance estimates. Handling mortality reduces future recruitment to fisheries by reducing both prerecruit abundance and spawning biomass. Besides mortality, handling may also produce sublethal effects on crab, such as reduced growth (Kruse 1993). Based on limited observer data, bycatch of sublegal male and female crabs from the directed blue king crab fishery off St. Matthew Island was relatively high, and total bycatches were often twice as high or higher than total catch of legal crabs (Moore et al. 2000). But observer data were extremely limited for the St. Matthew Island blue king crab directed pot fishery. We assumed fishery selectivities to be 0.4 and 0.6 for prerecruit-2s and prerecruit-1s and handling mortality rate to be 0.2, based on the results of Bristol Bay red king crab (Zheng and Siddeek 2008). Although estimated recruitment to the model is affected by handling mortality, handling mortality rates ranging from 0 to 50% do not affect legal male abundance and mature male biomass estimates much (Figure 15).

Retrospective Analyses

Two kinds of retrospective analyses are presented in this report: (1) historical results and (2) the 2008 model results. The historical results are the trajectories of biomass and abundance from previous assessments that capture both new data and changes in methodology over time. Assuming the estimates in 2008 as the baseline values, we can also evaluate how well the model had done in the past. The 2008 model results are based on leaving one-year data out at a time to evaluate how well the current model performs with less data.

Historically, the model performed very well. The model scenario (2) assumed $Q=1$ and estimated *M* up to the 2008 model. The trajectories of biomass and abundance from the assessments made during 1999-2007 were very close to each other and close to those made in 2008 with scenario (2) estimating M and fixed Q (Figure 16). Historical estimates after 1999 were quite different from those made in 2008 with scenario (1) of fixed M and Q (Figure 17).

The 2008 model with scenario (1) of fixed M and Q also did not perform very well when leaving one-year of data out at a time for a retrospective analysis (Figure 18). Because of relatively low legal abundance from the trawl survey data during the early and mid 2000s, the estimated legal males and mature male biomass during the terminal years tended to be higher during this period than those estimated with the terminal year of 2008 (Figure 18).

Overfishing Limits for 2008

The St. Matthew Island blue king crab stock has been recommended for placement in Tier 4 (NPFMC 2007). For Tier 4 stocks, abundance estimates are available, but complete population parameters are not available for computer simulation studies and spawning biomass per recruit analyses needed for Tier 3 stocks. Average of estimated biomasses for a certain period was used to develop B_{MSY} proxy for Tier 4 stocks. We evaluated averages of mature male biomasses from three periods for a B_{MSY} proxy: 1978-2008, 1983-1998 and 1983-2008 (Figures 19 and 20).

Besides B_{MSY} proxy, a γ value also needs to be determined. We evaluated two γ values for setting overfishing limits for 2008: $\gamma = 1$ and $\gamma = 1.5$. Model scenario (1) (fixed M=0.18 and Q=1) and scenario (2) (fixed Q=1 and estimating M=0.308) were also evaluated (Figures 19 and 20).

Estimated B_{MSY} proxy:

	Model scenario (1)	Model scenario (2)
Based on average during 1978-2008:	7.610 million lbs,	7.014 million lbs,
Based on average during 1983-1998:	7.085 million lbs,	6.526 million lbs,
Based on average during 1983-2008:	6.690 million lbs.	6.018 million lbs.

Estimated F_{MSY} proxy:

	Model scenario (1)	Model scenario (2)
$\gamma = 1$:	0.180,	0.308,
$\gamma = 1.5$:	0.270,	0.462.

Estimated mature male biomass in 2008 was 13.855 and 12.190 million lbs, respectively for model scenarios (1) and (2) under an assumption that no directed fishing would occur in 2008.

The estimated mature male biomass in 2008 will exceed all six B_{MSY} proxies even after adjusting the catch should directed fishing be allowed in 2008. Year classes after the 1976/77 regime shift (Overland et al. 1999) were about to reach the mature population after 1982, so two of the three periods used to estimate B_{MSY} proxy started in 1983. The stock collapsed and was at a low level during the early and mid 2000s, so this period might reasonably be excluded from estimating the B_{MSY} proxy, resulting in use of the period of 1983-1998. The period of 1978-2008 includes all data. For a given model scenario, the averages from the three periods were not greatly different.

The F_{MSY} proxy can range from 0.18 to 0.462, corresponding to harvest rates ranging from 16.5% to 37.0% of legal abundance at the time of fishing. Estimated legal male biomass in 2008 at the time of fishing was 9.879 million lbs and 8.403 million lbs for model scenarios (1) and (2). Therefore, the overfishing limits for retained catch in 2008 range from 1.630 million lbs to 2.338 million lbs for model scenario (1) and from 2.227 million lbs to 3.109 million lbs for model scenario (2), depending on the γ value.

The high abundance estimate for 2008 was primarily caused by the relatively good trawl survey abundance of prerecruit-2s in 2006, very high trawl survey abundance of prerecuti-1s and prerecruit-2s in 2007 and high trawl survey abundance of postrecruits in 2008, and high pot survey abundance in 2007. The abundance estimated by the model for 2008 is subject to potential sampling errors of these surveys and is uncertain. Considering that the stock is still rebuilding from the “overfished” declaration in 1999, we should consider a low γ value for overfishing determination for 2008.

Ecosystem Considerations

Ecosystem Effects on Stock

Prey Availability/Abundance Trends

Early juvenile and larval *Paralithodes* spp. are planktotrophic, actively feeding on diatoms, nauplii and copepods (Paul et al. 1979, Abrunhosa and Kittaka 1997). Blue king crab larvae are described as obligate plankton feeders (Otto 2006). Zheng and Kruse (2000) found a relationship between periods of weak year class strength in blue king crab stocks in the eastern Bering Sea and decadal climate shifts, which exhibit strong winter Aleutian lows with periods of unstable water columns due to vertical mixing. These winter Aleutian lows may prevent diatom growth, such as *Thalassiosira* spp., that are rich in nutrients and are important prey for early stages of larval blue king crab.

Recently settled blue king crab juveniles switch from a planktivorous diet to benthic prey such as echinoderms (including sea stars, sea urchins and sand dollars), mollusks (bivalves and snails), and polychaetes, as well as other crustaceans including crab. Invertebrates accounted for 23% of the total demersal animal biomass of 15.4 million tons estimated for the eastern Bering Sea shelf. The 2007 biomass of invertebrates was composed primarily of crustaceans minus commercially important crab and shrimp species (1.4 million t), echinoderms (1.3 million t), and crab (1.3 million t) (Acuna and Lauth 2008).

Predator Population Trends

Since it is difficult to distinguish between red and blue king crab prey without the whole carapace, there is no predator information specific to blue king crab in data published by the AFSC food habitats laboratory. Pacific cod, Pacific halibut and skate stomachs contained small amounts of unidentified king crab collected from the eastern Bering Sea annual summer shelf survey (Lang et al. 2005).

The 2007 abundance estimate for Pacific cod in the eastern Bering Sea shelf was 423,703 metric tons, with the highest catch rate of Pacific cod occurring in the northwestern part of the eastern Bering Sea shelf. Biomass estimates of Pacific cod have been declining, although there has been an increase in population size indicating an increase in a number of smaller sized fish and suggesting the emergence of a strong year class (Acuna and Lauth 2008).

The International Pacific Halibut Commission predicts low levels of recruitment and even lower estimates of productivity for Pacific halibut in the St. Matthew Island area, resulting in a 2008 harvest level below the optimal rate of 20% (IPHC 2008). Low commercial and survey catch rates support a general decline in abundance estimates of Pacific halibut in the eastern Bering Sea (Clarke 2008).

Paralithodid species are especially vulnerable as adults when in the soft shell state just after the molting process (Loher et al. 1998) and as recently settled juveniles. Numerous planktivorous fishes prey on *Paralithodid* larvae (Livingston et al. 1993, Wespestad et al. 1994).

Changes in Habitat Quality

Table 10 lists the potential ecosystem effects by changes in habitat quality. According to Somerton (1985), blue king crab (BKC) have a restricted distribution in Alaska waters made up of isolated populations which are thought to be relicts from a former, broader distribution (Figure 1). The general rise in water temperature that has occurred during the present inter-glacial period is thought to be the primary factor in shaping their distribution into these isolated refuges. Somerton (1985) attributed the isolated distribution of BKC to three mechanisms either singly or in combination: reproductive interference, competitive displacement and predatory exclusion. Due to these restricted and discrete isolated populations of BKC, they are particularly susceptible to any perturbations during critical life history stages and to their critical habitats. An increase in temperature, ocean acidification, and oil mishaps could affect their survival, reproductive success, distribution, habitat quality, recruitment success, year class strength, and predator or prey distribution.

Early life history studies of blue king crab around the Pribilof Islands during the spring of 1983 and 1984 by Armstrong et al. (1985) have demonstrated that larvae hatch in mid to late April. Although the average current patterns in the southeastern Bering Sea show a general northwest direction and slow speeds along the shelf breaks of the islands, for the local scale of the Pribilof and presumably St. Matthew Island there must be current patterns and eddies that will retain the larvae nearshore to enhance settlement to the preferred but limited refuge in the area. Armstrong et al. (1985) also pointed out that in certain years it would be probable that anomalous events could occur that would transport larvae well beyond the Pribilof Islands, resulting in settlement into unfavorable habitats and very low survival.

Juvenile blue king crab (<30 mm carapace length) are known to occur predominately along nearshore rocky and shell hash (a mixture of broken bivalve and gastropod shells) habitats near the Pribilof Islands, and these habitats are considered vital refuge from predation and for successful recruitment (Palacios et al. 1985). Shell hash is a key material for refuge and thus the survival of blue king crab is ultimately linked to certain mollusk species that are abundant within the species assemblage that characterize the BKC juvenile habitat along the Pribilof Islands (Armstrong et al. 1985). The preferred shelltype epibenthic substrate for juvenile BKC was composed primarily of four species of bivalves (*Serripies groenlandicus*, *Spisula polynyma*, *Chlamys sp*., *Modiolus modiolus*), and large neptunid gastropods. Shells of this type were usually intact or in large pieces and usually covered with dense epiphytic growth including feathery bryozoans, barnacles, anemones, and ascidians.

Male and female adult blue king crab along the Pribilof Islands had a high occurrence offshore on deeper, mud-sand substrates. In August of 1989, ovigerous females occurred in high abundance and dominated all catches (99% females, almost all ovigerous) along mostly rocky habitats in nearshore waters sampled during St Matthew Island pot surveys (Blau and Watson 1999). A high percentage of mature blue king crab also occurred in the vicinity of St. Matthew Island during a trawl survey (NMFS 1984) and have not been located anywhere else in the Bering Sea (Armstrong et al. 1985, Palacios et al. 1985, Moore et al. 1998). The high incidence of ovigerous females ranged in depth from 7 to 20 fathoms in mostly rocky habitats and CPUE (number of crab per pot) ranged from 10 at 7 fm and 146 at 8 fm, while all male CPUE were <2. The nearshore rocky habitats of St Matthew Island are very important habitat for ovigerous females during the summer and fall months. Nearshore dive surveys along St. Matthew Island by the Alaska Department of Fish & Game (ADF&G) have not revealed juvenile blue king crab nor has habitat associations been described (Blau 2000).

Recently several studies have investigated the effects of temperature on embryonic development, hatch timing, respiration, and larval survival of BKC (Stevens 2006a, Stevens 2006b, Stevens et al. 2008). This research will aid in an understanding of the impacts of climate change, especially seawater warming, has on the reproduction of BKC.

Due to their restricted distribution along the Pribilof and St Mathews Islands, blue king crab are considered highly vulnerable to oil mishaps (Armstrong et al. 1987). There have been numerous studies that have investigated the potential impacts of oil on blue king crab along the Pribilof Islands (Armstrong et al. 1983, Armstrong et al. 1987, Laevastu et al. 1985). The life history stage considered most vulnerable is the larval stages since they are in the water column and would follow the same currents as the oil. The restricted distribution of early juveniles on and in substrates such as shellhash and gravel/cobble that are limited to the Pribilof Islands (compared to hundreds of km in all directions) underscores the unique habitat required by this species. The high concentrations and dominance by ovigerous females that occur in nearshore waters during the summer and fall would be at great risk during an oil mishap for St. Matthew and the Pribilof Islands. If oil reaches these islands the impact on BKC could be great depending on a variety of biological and physical factors (Laevastu et al. 1985).

Calcium carbonate saturation horizons are relatively shallow in the North Pacific Ocean; thus this ocean is a sentinel for ocean acidification effects (M. Sigler, AFSC NOAA Fisheries, pers. comm.). These effects have been measured as decreased pH of the water, as well as measurable increases in dissolved inorganic carbon over a large section of the northeastern Pacific suspected to be a problem in surface water effecting calcifying planktonic organisms in the northeast Pacific Ocean (R. Feely, NOAA PMEL, pers. comm.). Some investigators believe that the effects of decreased calcification in microscopic algae and animals could impact food webs and, combined with other climatic changes in salinity, temperature and upwelled nutrients, could substantially alter the biodiversity and productivity of the ocean (Orr et al. 2005). A recent trial laboratory study has shown a 15% reduction in growth and 67% reduction in survival when pH was reduced 0.5 units (Litzow et al., trial data, AFSC NOAA Fisheries). Lower pH could adversely affect calcification, reproduction, development, larval growth, and larval survival. Current studies underway will investigate the effect pH has on survival, growth, and morphology of larval and juvenile blue and red king crab (K. Swiney, NMFS/AFSC/Kodiak Lab, pers. comm.).

Disease

Diseases that may infect *Paralithodid* species include a herpes-type viral disease of the bladder, a pansporoblastic microsporidian (*Thelohania* sp.), and a parasitic rhizocephalan (*Briarosaccus* sp.) which feeds on female egg clutches (Sparks and Morado 1997).

Fishery Effects on the Ecosystem

The St. Matthew blue king crab commercial fishery has been closed since 1999. Non-retained blue king crab such as females and sub-legal males may have been caught in previous directed fishing for St. Matthew blue king crab and eastern Bering Sea snow crab commercial fisheries (see bycatch in directed fishery section).

Seapens or seawhips, corals, anemones, and sponges are species groups in the eastern Bering Sea considered as Habitat Areas of Particular Concern (HAPC), which are defined as living substrates in shallow or deep waters, although not many corals (gorgonians, soft corals and stony corals) are encountered on the EBS shelf. Relative CPUE from EBS shelf survey data 1982-2007 is available for these species groups but the survey gear is not appropriate for effective sampling of these types of organisms and survey results provide imprecise abundance information. Since most of the eastern Bering Sea survey stations are repeated from survey to survey, apparent decreases in abundance for many of the slow growing HAPC organisms could result from repeated trawling of these areas by the survey (Lauth 2007).

Acknowledgments

We thank Doug Woodby of ADF&G for reviewing the earlier draft of this report. The study was funded, in part, by cooperative agreement from the National Oceanic and Atmospheric Administration (NOAA). The views expressed are those of the authors and do not necessarily reflect the views of NOAA or any of its sub-agencies.

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Table 1. Harvest level, economic performance and season length summary for the Saint Matthew Island Section commercial blue king crab fishery, 1983 -2006/07 (Bowers et al., 2008).

		Value		Season Length	
Season	GHL/TAC[a]	Ex-vessel[b]	Total[c]	Days	Dates
1983	8	$3.00	$25.80	17	08/20-09/06
1984	2.0-4.0	$1.75	$6.50	7	09/01-09/08
1985	0.9-1.9	$1.60	$3.80	5	09/01-09/06
1986	0.2-0.5	$3.20	$3.20	5	09/01-09/06
1987	0.6-1.3	$2.85	$3.10	4	09/01-09/05
1988	0.7-1.5	$3.10	$4.00	4	09/01-09/05
1989	1.7	$2.90	$3.50	3[d]	09/01-09/04
1990	1.9	$3.35	$5.70	6	09/01-09/07
1991	3.2	$2.80	$9.00	4	09/16-09/20
1992	3.1	$3.00	$7.40	3[d]	09/04-09/07
1993	4.4	$3.23	$9.70	6	09/15-09/21
1994	3.0	$4.00	$15.00	7	09/15-09/22
1995	2.4	$2.32	$7.10	5	09/15-09/20
1996	4.3	$2.20	$6.70	8	09/15-09/23
1997	5.0	$2.21	$9.80	7	09/15-09/22
1998	4.0[e]	$1.87	$5.34	11	09/15-09/26
1999-2006/07		FISHERY CLOSED			

[a]Guideline harvest level in millions of pounds. Total allowable catch for IFQ beginning in 2005.

[b]Average price per pound.

[c]Millions of dollars.

[d]Actual length - 60 hours.

[e]General fishery only.

Table 2. Saint Matthew Island Section commercial blue king crab fishery data, 1977 - 2006/07 (Bowers et al., 2008).

	Number of				Number of Pots		Percent	Average			
Season	Vessels	Landings	Crabs[a]	Harvest[a,b]	Registered	Pulled	Recruits	Weight[b]	CPUE[c]	Length[d]	Deadloss[b]
1977	10	24	281,665	1,202,066	NA	17,370	7	4.3	16	130.4	129,148
1978	22	70	436,126	1,984,251	NA	43,754	NA	4.5	10	132.2	116,037
1979	18	25	52,966	210,819	NA	9,877	81	4.0	5	128.8	128.8
1980	CONFIDENTIAL										
1981	31	119	1,045,619	4,627,761	NA	58,550	NA	4.4	18	NA	53,355
1982	96	269	1,935,886	8,844,789	NA	165,618	20	4.6	12	135.1	142,973
1983	164	235	1,931,990	9,454,323	38,000	133,944	27	4.8	14	137.2	828,994
1984	90	169	841,017	3,764,592	14,800	73,320	34	4.5	11	135.5	31,983
1985	79	103	441,479	2,200,781	13,000	47,748	9	5.0	9	139	2,613
1986	38	43	219,548	1,003,162	5,600	22,073	10	4.6	10	134.3	32,560
1987	61	62	227,447	1,039,779	9,370	28,230	5	4.6	8	134.1	600
1988	46	46	302,098	1,325,185	7,780	23,058	65	4.4	30	133.3	10,160
1989	69	69	247,641	1,166,258	11,983	30,803	9	4.7	8	134.6	3,754
1990	31	38	391,405	1,725,349	6,000	26,264	4	4.4	15	134.3	17,416
1991	68	69	726,519	3,372,066	13,100	37,104	12	4.6	20	134.1	216,459
1992	174	179	545,222	2,475,916	17,400	56,630	9	4.6	10	134.1	1,836
1993	92	136	630,353	3,003,089	5,895	58,647	6	4.8	11	135.4	3,168
1994	87	133	827,015	3,764,262	5,685	60,860	60	4.6	14	133.3	46,699
1995	90	111	666,905	3,166,093	5,970	48,560	45	4.8	14	135	90,191
1996	122	189	660,665	3,078,959	8,010	91,085	47	4.7	7	134.6	36,892
1997	117	166	939,822	4,649,660	7,650	81,117	31	4.9	12	139.5	209,490
1998	131	255	612,440	2,869,655	8,561	89,500	46	4.7	7	135.8	15,107
1999-2006/07	FISHERY CLOSED										

[a]Deadloss included.

[b]In pounds.

[c]Number of legal crabs per pot lift.

[d]Carapace length in millimeters.

NA = Not available.

Table 3. Summer trawl survey abundance (million of crab) for 4 length groups.

Year	Pre-R 2	Pre-R 1	R	Post-R	Matures	Legals
1978	2.336	2.175	1.187	0.587	3.948	1.773
1979	2.258	1.793	1.455	0.333	3.581	1.788
1980	1.717	2.588	1.699	1.197	5.484	2.897
1981	0.637	1.480	1.195	1.648	4.323	2.844
1982	1.713	2.615	3.617	3.263	9.495	6.880
1983	1.052	1.639	1.399	1.956	4.993	3.354
1984	0.416	0.500	0.788	0.762	2.050	1.550
1985	0.434	0.431	0.541	0.708	1.680	1.249
1986	0.190	0.425	0.164	0.185	0.774	0.349
1987	0.350	0.757	0.492	0.292	1.541	0.785
1988	0.362	0.703	0.417	0.411	1.530	0.827
1989	2.181	1.235	0.940	0.954	3.129	1.894
1990	0.942	0.957	0.954	1.164	3.075	2.119
1991	1.031	1.636	1.353	0.889	3.878	2.242
1992	1.178	1.582	1.338	1.247	4.167	2.585
1993	1.653	1.994	1.605	2.000	5.599	3.605
1994	0.908	1.350	1.246	1.120	3.716	2.366
1995	1.118	1.321	0.993	0.902	3.216	1.895
1996	1.290	1.970	1.950	1.331	5.251	3.281
1997	1.211	2.319	2.213	1.853	6.385	4.066
1998	0.714	1.843	1.397	1.766	5.006	3.163
1999	0.244	0.215	0.179	0.436	0.830	0.615
2000	0.304	0.310	0.323	0.488	1.121	0.811
2001	0.432	0.527	0.345	0.681	1.554	1.026
2002	0.133	0.266	0.186	0.576	1.028	0.762
2003	0.535	0.330	0.188	0.379	0.898	0.567
2004	0.281	0.210	0.286	0.348	0.844	0.634
2005	0.600	0.445	0.295	0.259	0.999	0.554
2006	1.019	0.760	0.766	0.635	2.162	1.402
2007	2.756	2.224	0.752	0.565	3.540	1.317
2008	1.430	0.873	0.580	1.006	2.459	1.585

Table 4. Crabs per pot lift for the pot surveys from the common 96 stations.

Year	Pre-R 2	Pre-R 1	R	Post-R
1995	1.919	3.198	3.214	3.708
1998	0.964	2.763	3.906	4.898
2001	1.266	1.737	2.378	3.109
2004	1.719	0.453	0.299	0.826
2007	0.500	2.721	2.773	2.063

Table 5. Growth matrix for St. Matthew Island blue king crab.

	Growth Matrix (*G*): From	
	Prerecruit-2s	Prerecruit-1s
Prerecruit-2s	0.11	0.00
Prerecruit-1s	0.83	0.11
Recruits	0.06	0.83
Postrecruits	0.00	0.06

Table 6. Parameter estimates and negative likelihood values for a catch-survey analysis of St. Matthew Island blue king crab with data from 1978 to 2008. Five scenarios of the model are (1) fixed M = 0.18 and Q=1 with 2 *Ms*, (2) fixed Q = 1 and estimating M with 2 *Ms*, (3) fixed M = 0.18 and estimating Q with 2 *Ms*, (4) fixed M = 0.18 for the whole time series and Q=1, (5) fixed Q = 1 and estimating M for the whole time series. An M value is estimated for 1999 with the "2 *Ms*" scenario. A value of "fix" indicates that it is fixed in the model.

Parameter	Model Scenario (1)	(2)	(3)	(4)	(5)
Natural mortality (M) for years other than 1999	fix	0.308	fix	fix	0.356
Natural mortality in 1999	1.864	1.724	1.865	fix	0.356
Trawl survey catchability (Q)	fix	fix	1.209	fix	fix
Trawl survey selectivity: prerecruit-2s ($S2$)	0.630	0.500	0.561	0.711	0.500
Trawl survey selectivity: prerecruit-1s ($S1$)	0.849	0.872	0.775	0.856	0.747
Pot survey selectivity: prerecruit-2s ($s2$)	0.214	0.165	0.218	0.231	0.153
Pot selectivity: prerecruit-1s ($s1$)	0.583	0.622	0.605	0.561	0.493
Pot scaling parameter (q)	0.323	0.318	0.300	0.268	0.274
Molting probability in 1978: prerecruit-1s	0.721	0.909	0.729	0.692	0.802
Negative likelihood components					
Trawl survey: prerecruit-2s	5.261	6.269	5.434	5.740	7.315
Trawl survey: prerecruit-1s	3.326	3.165	3.308	5.651	5.189
Trawl survey: recruits	5.733	4.099	4.415	9.077	5.653
Trawl survey: postrecruits	6.380	5.252	6.573	8.603	6.453
Pot survey: total	6.717	5.911	6.789	8.003	6.000
Molting probability variation penalty	0.556	0.209	0.724	1.266	1.218
Total	27.973	24.905	27.243	38.339	31.827

Table 7. Estimated recruits to the model (Model R), abundance (Pre-R2, Pre-R1, R, Post-R, legals and matures), mature male biomass on February 15 (Bio215), and molting probabilities for pre-recruit-1s (Molt1) for model scenario (1) fixing *M* and *Q*. Recruits and abundance are in million of crab and biomass is in million lbs.

Year	Model R	Pre-R2	Pre-R1	R	Post-R	Legals	Matures	Bio215	Molt1
1978	NA	1.919	1.786	0.975	0.482	1.456	3.243	7.244	0.721
1979	2.963	3.135	1.822	0.960	0.910	1.870	3.692	10.706	0.734
1980	2.698	2.986	2.695	1.082	1.584	2.666	5.361	16.051	0.739
1981	1.064	1.338	2.838	1.528	2.298	3.827	6.664	16.769	0.761
1982	1.481	1.601	1.654	1.522	2.420	3.942	5.596	11.194	0.784
1983	0.659	0.801	1.470	0.931	1.717	2.648	4.119	5.562	0.787
1984	0.401	0.471	0.868	0.780	0.617	1.397	2.265	3.724	0.770
1985	0.839	0.881	0.527	0.458	0.484	0.941	1.468	2.751	0.757
1986	0.564	0.642	0.725	0.305	0.390	0.695	1.420	3.303	0.772
1987	1.119	1.177	0.619	0.407	0.420	0.827	1.446	3.503	0.794
1988	0.958	1.064	0.947	0.389	0.514	0.902	1.849	4.235	0.808
1989	2.477	2.572	0.936	0.564	0.532	1.096	2.032	5.113	0.808
1990	1.593	1.825	1.970	0.639	0.741	1.379	3.350	7.783	0.790
1991	1.676	1.840	1.715	1.138	0.893	2.030	3.745	8.230	0.777
1992	1.764	1.928	1.669	0.980	1.134	2.114	3.783	9.421	0.763
1993	1.971	2.145	1.748	0.955	1.361	2.315	4.064	10.130	0.750
1994	1.716	1.910	1.931	0.989	1.455	2.443	4.375	10.191	0.739
1995	2.599	2.770	1.826	1.048	1.397	2.445	4.271	10.606	0.744
1996	2.215	2.465	2.385	1.051	1.533	2.584	4.969	12.378	0.735
1997	1.553	1.775	2.350	1.305	1.674	2.978	5.328	12.606	0.717
1998	1.235	1.394	1.891	1.216	1.759	2.975	4.866	3.832	0.692
1999	0.526	0.550	0.291	0.181	0.341	0.522	0.813	2.721	0.680
2000	0.367	0.425	0.470	0.164	0.446	0.610	1.080	3.521	0.648
2001	0.539	0.598	0.442	0.231	0.525	0.756	1.198	4.030	0.595
2002	0.069	0.186	0.530	0.208	0.644	0.852	1.382	4.688	0.589
2003	0.449	0.486	0.320	0.224	0.728	0.952	1.272	4.681	0.612
2004	0.354	0.440	0.420	0.158	0.805	0.963	1.383	5.035	0.655
2005	1.281	1.339	0.435	0.211	0.818	1.029	1.464	5.291	0.692
2006	1.636	1.759	1.068	0.276	0.875	1.151	2.218	7.069	0.708
2007	1.388	1.550	1.549	0.612	0.999	1.611	3.161	9.682	0.712
2008	2.128	2.271	1.549	0.843	1.401	2.244	3.792	13.855	NA

Table 8. Estimated recruits to the model (Model R), abundance (Pre-R2, Pre-R1, R, Post-R, legals and matures), mature male biomass on February 15 (Bio215), and molting probabilities for pre-recruit-1s (Molt1) for model scenario (2) fixing *Q* and estimating *M*. Recruits and abundance are in million of crab and biomass is in million lbs.

Year	Model R	Pre-R2	Pre-R1	R	Post-R	Legals	Matures	Bio215	Molt1
1978	NA	2.233	2.079	1.134	0.561	1.695	3.773	7.964	0.909
1979	4.298	4.476	1.625	1.223	0.999	2.222	3.847	10.541	0.935
1980	4.013	4.374	2.925	1.121	1.660	2.781	5.707	15.551	0.943
1981	2.013	2.366	3.010	1.874	2.140	4.014	7.024	16.074	0.967
1982	2.199	2.387	1.722	1.836	2.294	4.129	5.851	10.843	0.991
1983	0.943	1.131	1.558	1.099	1.653	2.752	4.310	5.496	0.994
1984	0.553	0.641	0.783	0.931	0.613	1.544	2.327	3.700	0.980
1985	1.051	1.101	0.448	0.472	0.530	1.002	1.450	2.575	0.968
1986	0.889	0.976	0.695	0.300	0.383	0.683	1.378	2.913	0.982
1987	1.476	1.553	0.646	0.446	0.363	0.809	1.454	3.135	1.000
1988	1.407	1.530	0.981	0.450	0.442	0.893	1.874	3.832	1.000
1989	3.182	3.303	0.991	0.646	0.466	1.112	2.103	4.749	1.000
1990	2.367	2.630	2.065	0.735	0.670	1.406	3.471	7.297	0.998
1991	2.370	2.579	1.742	1.339	0.821	2.160	3.901	7.870	1.000
1992	2.507	2.711	1.676	1.140	1.097	2.237	3.913	8.945	0.998
1993	2.499	2.715	1.763	1.115	1.298	2.412	4.175	9.488	0.993
1994	2.464	2.680	1.775	1.160	1.359	2.519	4.294	9.130	0.987
1995	3.510	3.722	1.755	1.152	1.283	2.435	4.190	9.385	1.000
1996	2.997	3.293	2.369	1.204	1.347	2.551	4.920	10.965	0.994
1997	2.033	2.295	2.172	1.544	1.462	3.006	5.178	11.035	0.972
1998	1.566	1.748	1.581	1.349	1.569	2.918	4.500	3.897	0.947
1999	0.654	0.688	0.302	0.239	0.388	0.627	0.929	2.871	0.942
2000	0.549	0.605	0.456	0.204	0.473	0.677	1.132	3.420	0.926
2001	0.654	0.703	0.428	0.284	0.516	0.800	1.227	3.772	0.882
2002	0.220	0.276	0.496	0.261	0.604	0.865	1.361	4.206	0.849
2003	0.528	0.550	0.258	0.269	0.654	0.923	1.181	3.983	0.868
2004	0.563	0.607	0.378	0.161	0.688	0.849	1.227	4.048	0.884
2005	1.538	1.587	0.430	0.231	0.638	0.869	1.299	4.136	0.912
2006	2.069	2.197	1.027	0.309	0.656	0.965	1.992	5.570	0.915
2007	1.781	1.958	1.480	0.670	0.750	1.421	2.900	7.851	0.907
2008	2.702	2.860	1.404	0.905	1.103	2.007	3.411	12.190	NA

Table 9. Estimated recruits to the model (Model R), abundance (Pre-R2, Pre-R1, R, Post-R, legals and matures), mature male biomass on February 15 (Bio215), and molting probabilities for pre-recruit-1s (Molt1) for model scenario (3) fixing *M* and estimating *Q*. Recruits and abundance are in million of crab and biomass is in million lbs.

Year	Model R	Pre-R2	Pre-R1	R	Post-R	Legals	Matures	Bio215	Molt1
1978	0.000	1.699	1.582	0.863	0.427	1.290	2.871	6.220	0.729
1979	2.938	3.091	1.598	0.856	0.764	1.620	3.218	9.253	0.752
1980	2.784	3.067	2.578	0.985	1.368	2.353	4.931	14.524	0.766
1981	1.083	1.364	2.809	1.520	2.037	3.557	6.366	15.523	0.797
1982	1.469	1.592	1.589	1.573	2.198	3.771	5.360	10.294	0.828
1983	0.612	0.754	1.396	0.942	1.575	2.517	3.913	4.858	0.836
1984	0.378	0.443	0.770	0.781	0.507	1.288	2.059	3.087	0.816
1985	0.790	0.829	0.458	0.428	0.391	0.818	1.277	2.117	0.801
1986	0.553	0.626	0.655	0.279	0.286	0.565	1.219	2.613	0.813
1987	1.023	1.079	0.567	0.385	0.309	0.694	1.262	2.843	0.833
1988	0.891	0.988	0.849	0.369	0.402	0.771	1.620	3.480	0.843
1989	2.272	2.361	0.837	0.524	0.420	0.944	1.781	4.285	0.839
1990	1.497	1.710	1.780	0.590	0.611	1.201	2.980	6.655	0.819
1991	1.560	1.714	1.549	1.060	0.738	1.798	3.347	6.969	0.803
1992	1.665	1.818	1.508	0.910	0.935	1.845	3.354	7.986	0.787
1993	1.829	1.992	1.601	0.887	1.132	2.019	3.620	8.590	0.771
1994	1.606	1.785	1.757	0.926	1.203	2.129	3.886	8.518	0.758
1995	2.432	2.592	1.663	0.973	1.129	2.102	3.765	8.842	0.759
1996	2.030	2.263	2.193	0.974	1.242	2.216	4.409	10.434	0.747
1997	1.387	1.590	2.131	1.212	1.360	2.572	4.703	10.473	0.723
1998	1.118	1.261	1.685	1.106	1.412	2.518	4.203	3.109	0.692
1999	0.469	0.491	0.261	0.161	0.269	0.429	0.690	2.266	0.672
2000	0.322	0.377	0.418	0.146	0.367	0.513	0.931	2.997	0.637
2001	0.479	0.537	0.392	0.202	0.442	0.643	1.035	3.456	0.581
2002	0.056	0.169	0.470	0.180	0.549	0.729	1.200	4.042	0.575
2003	0.398	0.435	0.289	0.195	0.623	0.817	1.107	4.046	0.600
2004	0.312	0.395	0.374	0.139	0.691	0.831	1.204	4.364	0.644
2005	1.136	1.193	0.388	0.185	0.706	0.891	1.279	4.602	0.687
2006	1.448	1.565	0.946	0.244	0.758	1.002	1.948	6.184	0.706
2007	1.273	1.417	1.379	0.542	0.870	1.412	2.790	8.519	0.714
2008	1.978	2.108	1.402	0.753	1.229	1.982	3.384	12.304	NA

Table 10. Ecosystem effects on the St. Matthew Island blue king crab stock. Changes in habitat quality.

Ecosystem effects on St. Matthew Island blue king crab stocks			
Indicator	Observation	Interpretation	Evaluation
Changes in Habitat Quality			
EFH-HAPC	Rocky/shellhash nearshore habitats are critical habitat/vital refuge for juveniles in the Pribilof Islands. Ovigerous females dominate nearshore rocky habitats during the warmer months.	Effects on population dynamics of mollusk species that compose the shellhash and associated epiphytes, such as oil mishaps, coastal development, and dredging.	Concern
Temperature regime	Experimental studies.- temperature effects on hatch timing, embryonic development, larval growth and survival.	Lower temperatures delay development, hatch timing, and growth. Higher temperatures may increase all of the above and decrease survival.	Concern
Ocean Acidification	Calcium carbonate saturation horizons are relatively shallow in the North Pacific Ocean; thus this ocean is a sentinel for ocean acidification effects.	Lab studies have shown a ~15% reduction in growth and ~67% reduction in survival when pH was reduced 0.5 units. Lower pH could adversely affect calcification, reproduction, development, larval growth, and larval survival.	Concern
Oil exploration	Restricted distribution makes them vulnerable to oil mishaps.	Oil mishap would impact planktonic larvae the most. Juveniles in shallow water nearshore habitats would be impacted. As well as ovigerous females that occur in shallower warmer water during the summer and fall.	Concern
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability. Concern.
Production	Fairly stable nutrient flow from upwelled BS Basin	Inter-annual variability and recruitment in year class strength	Possible concern

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

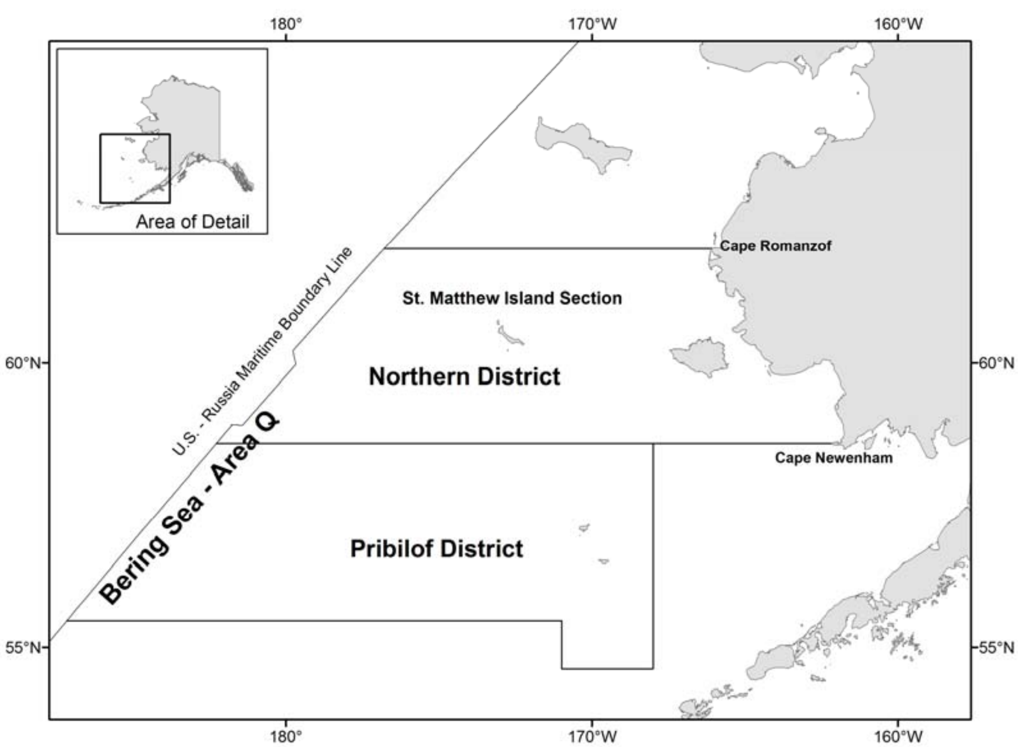


Figure 2. King crab Registration Area Q (Bering Sea).

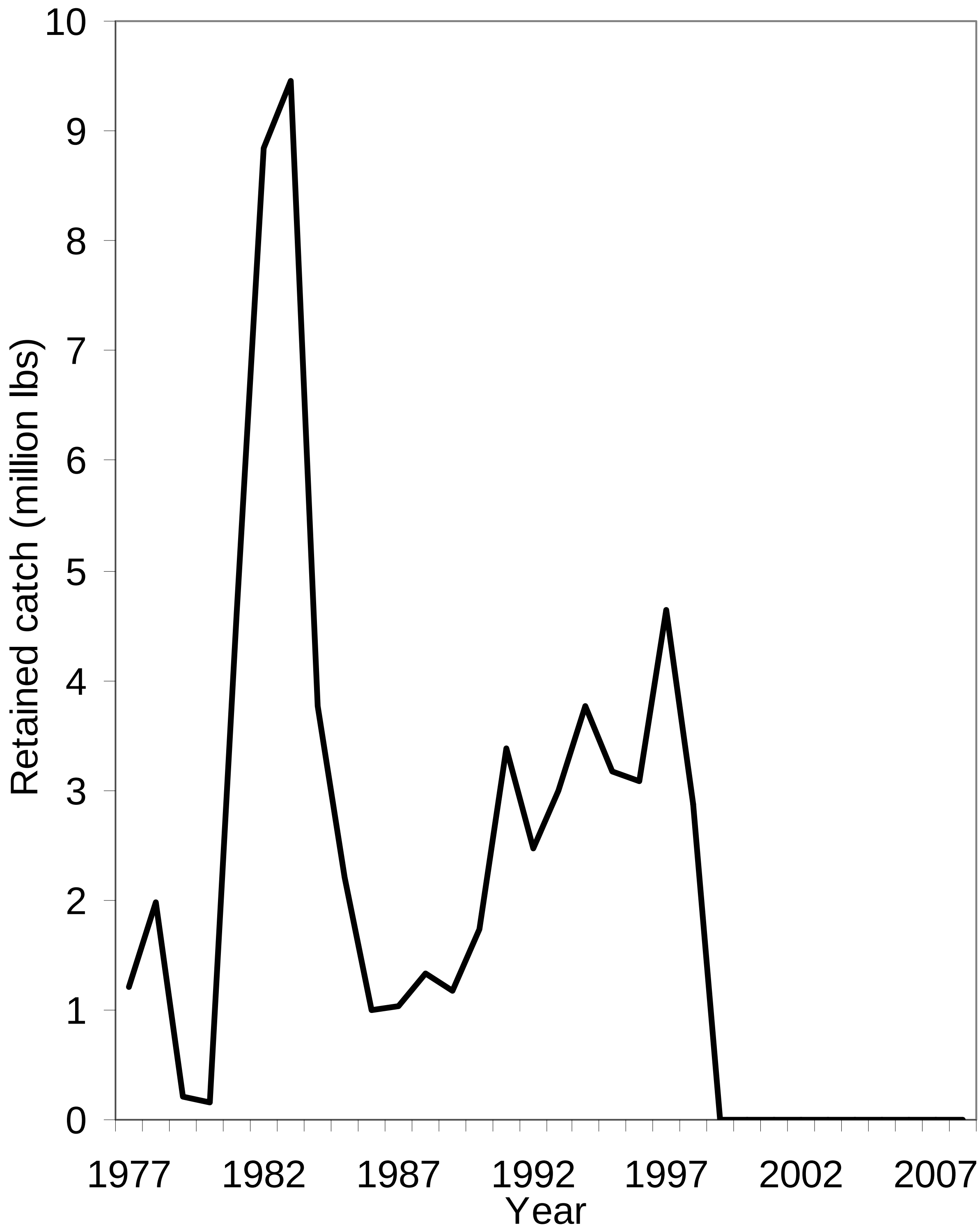


Figure 3. Retained catch over time for St. Matthew Island blue king crab.

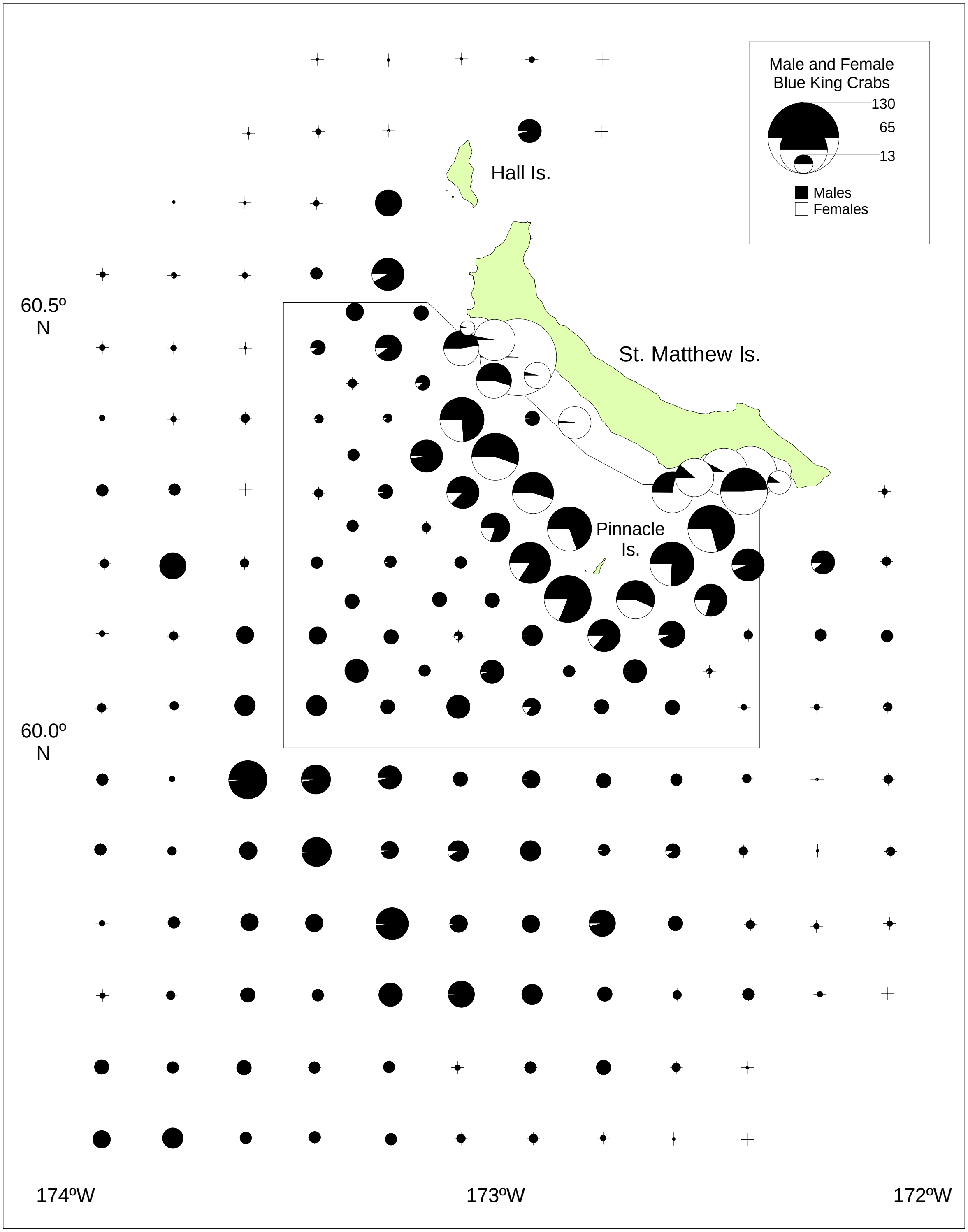


Figure 4. Male and female blue king crab catch per unit effort (CPUE) by station in the 2007 St. Matthew Island survey. (Source: Watson 2008).

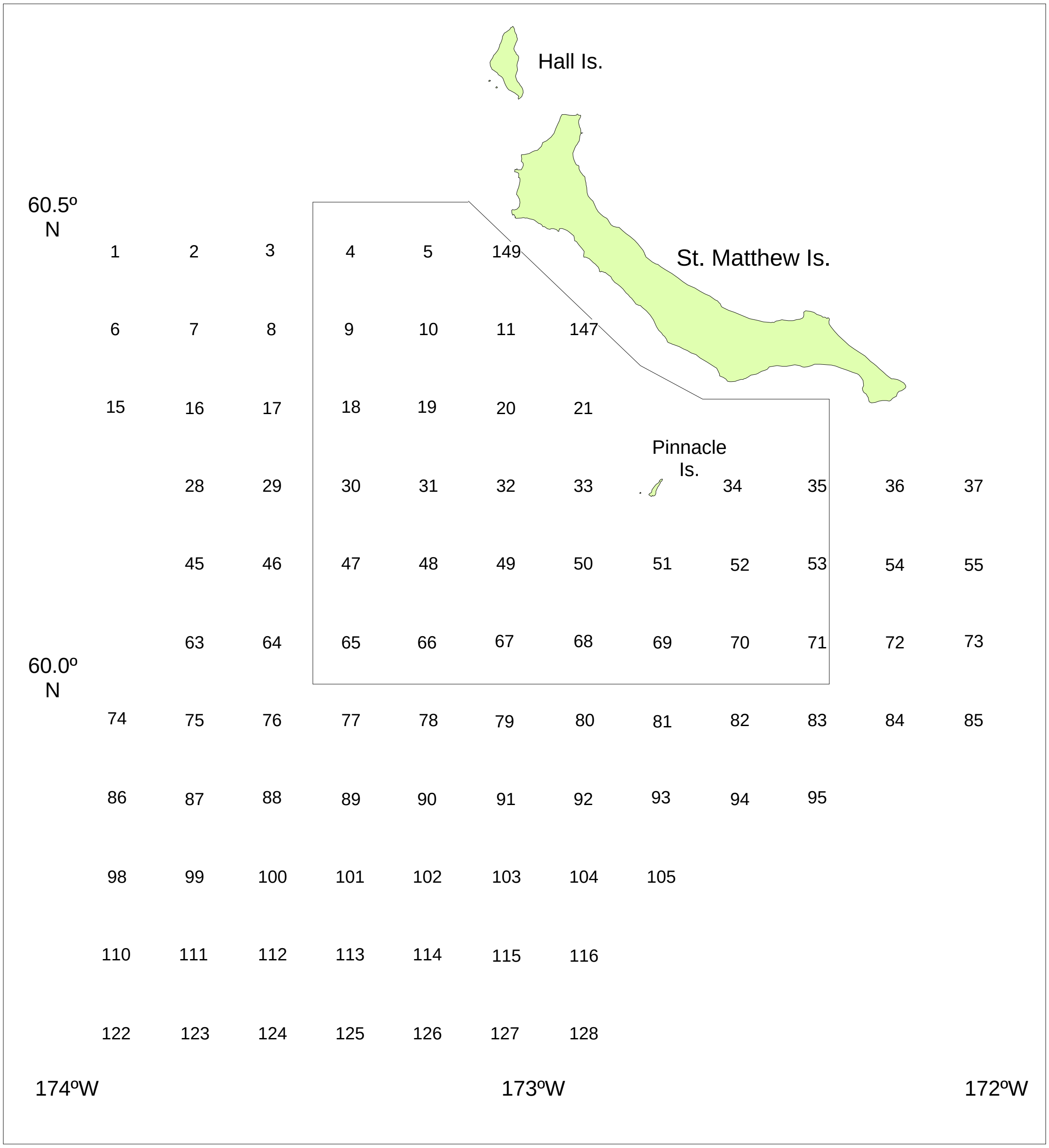


Figure 5. Location of the 96 stations fished in common during the five triennial St. Matthew Island blue king crab surveys, 1995 - 2007. (Source: Watson 2008).

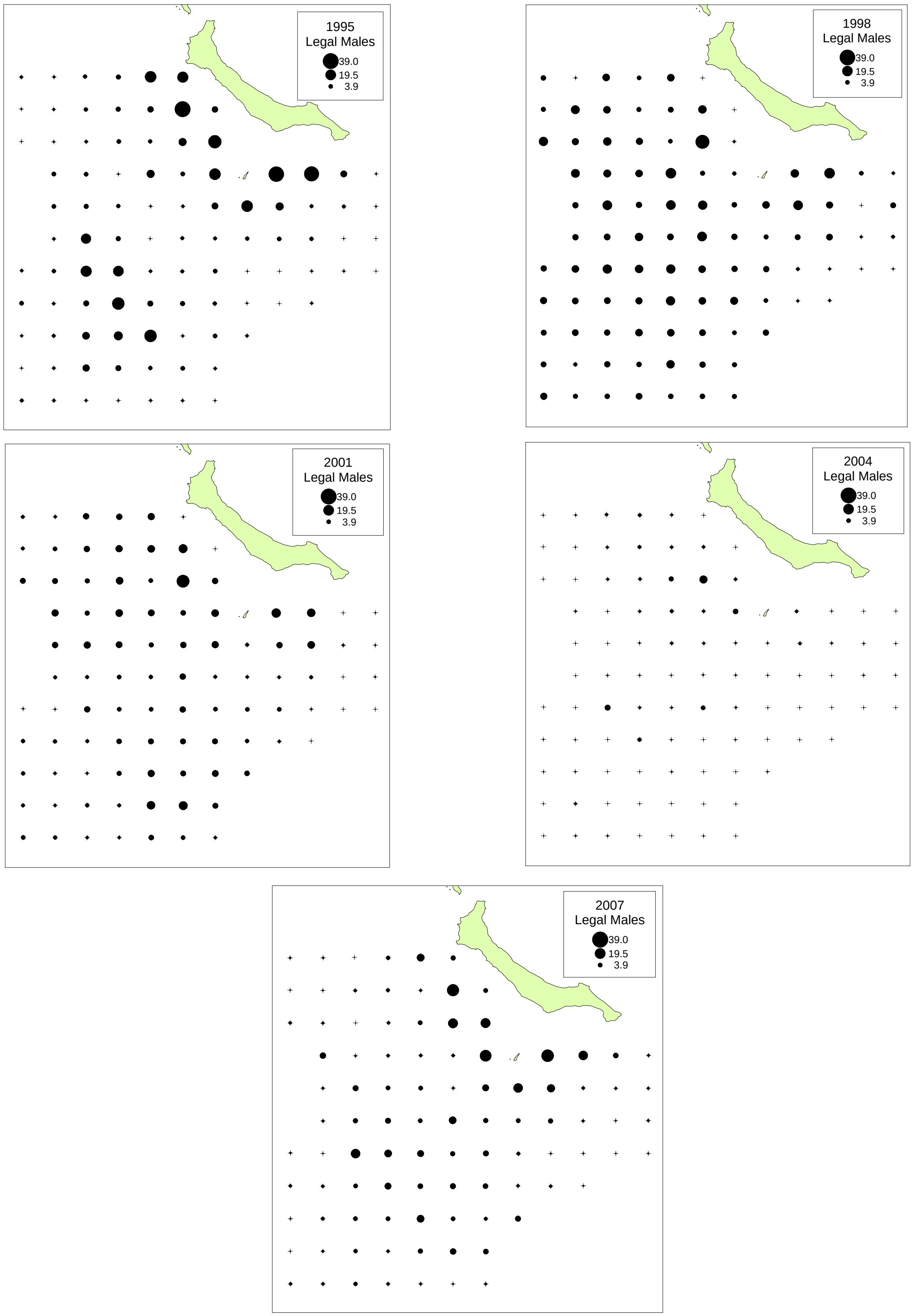


Figure 6. Legal male blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).

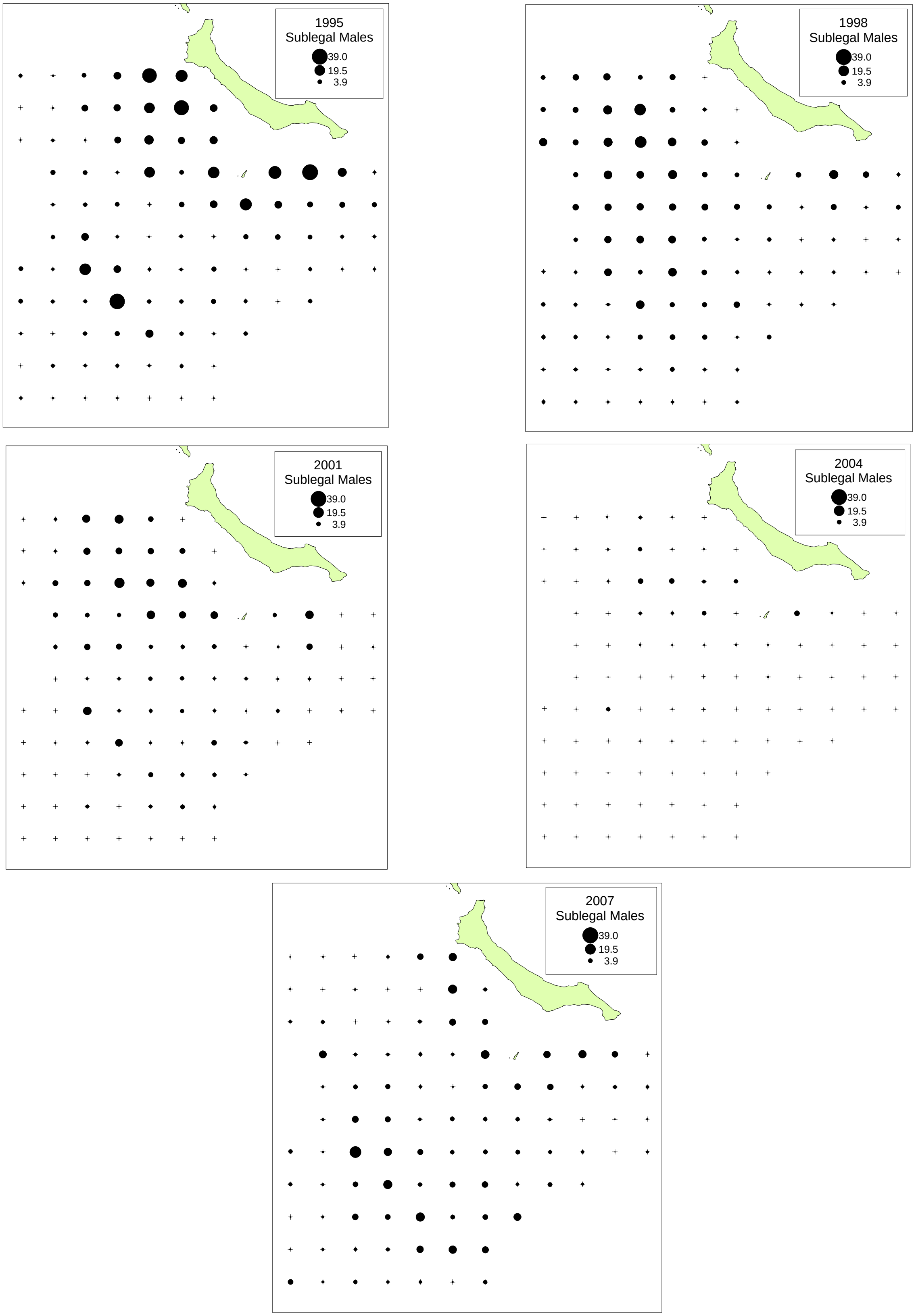


Figure 7. Sublegal male blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).

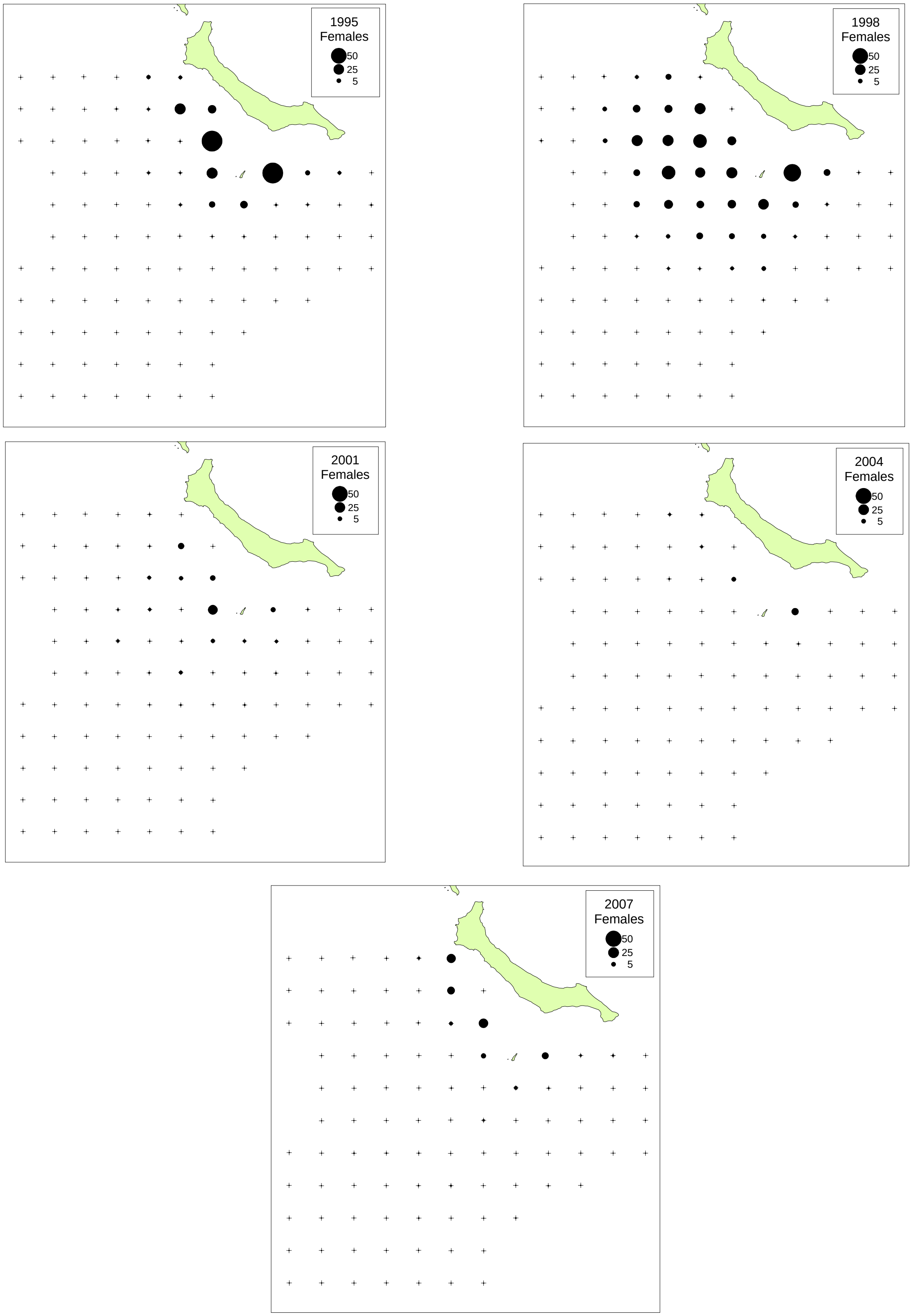
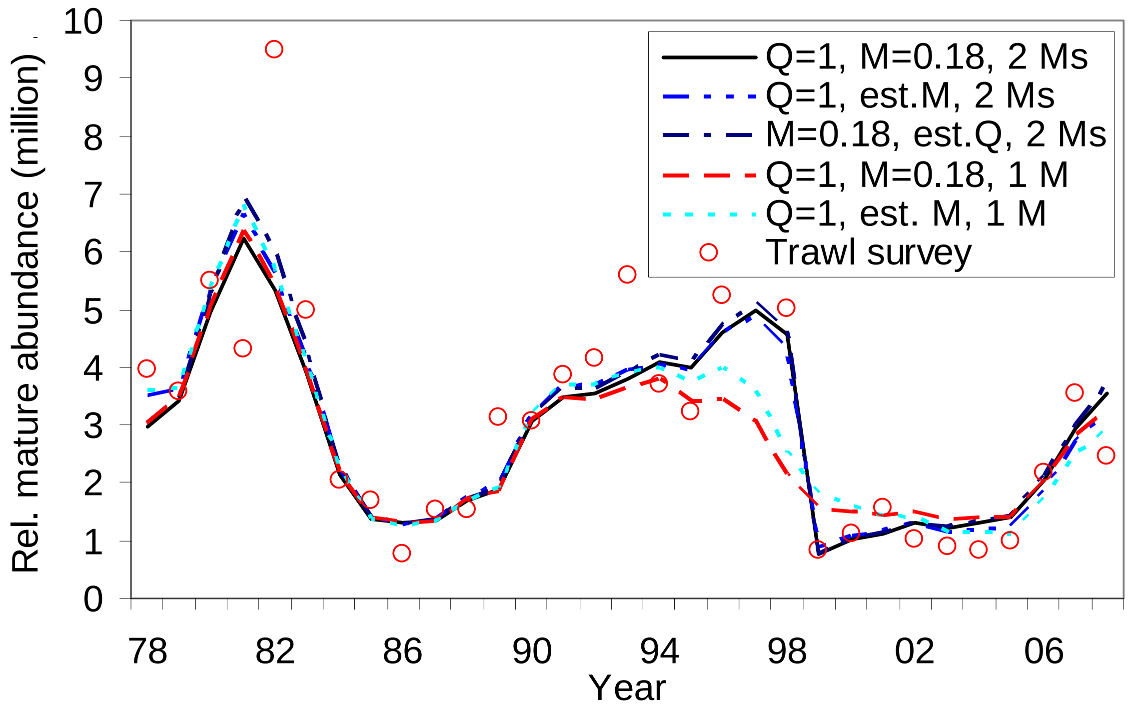


Figure 8 Female blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).



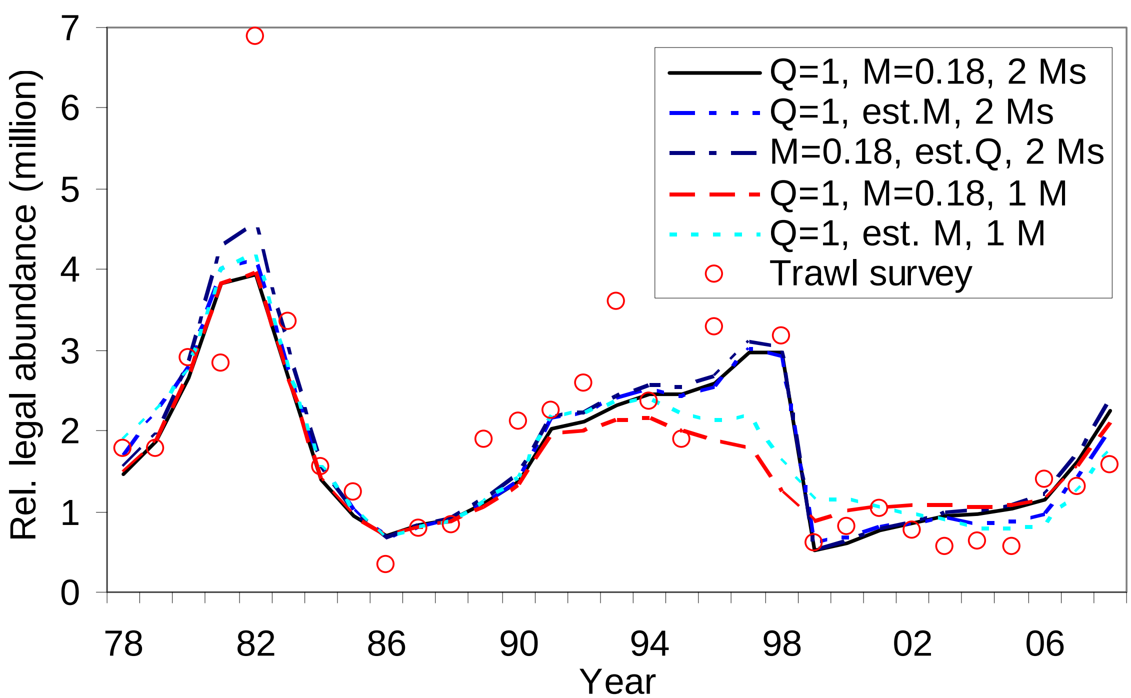


Figure 9. Comparison of relative mature male (upper plot) and legal abundance (lower plot) estimates of St. Matthew Island male blue king crab with five scenarios of the catch-survey analysis and trawl survey abundance.

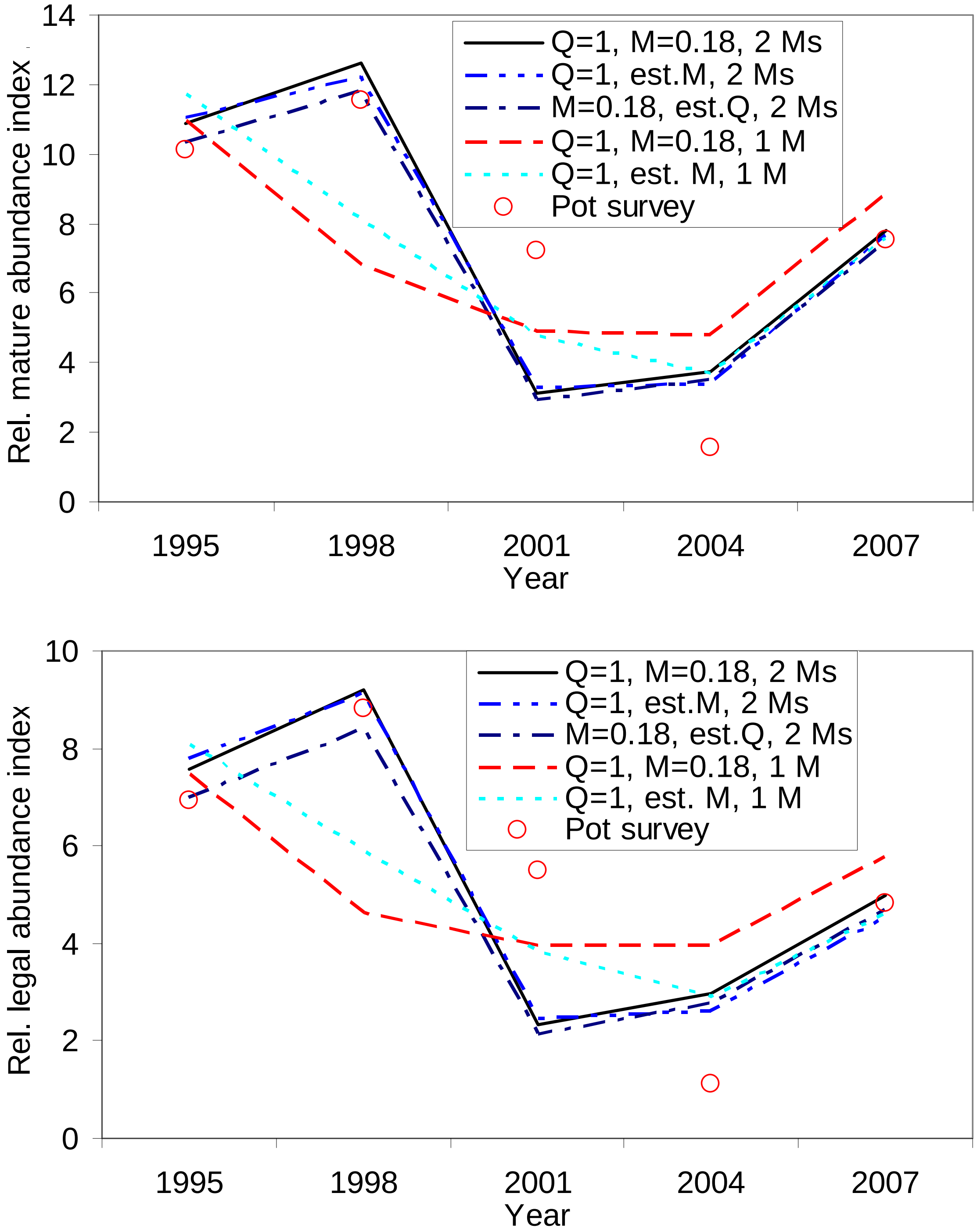


Figure 10. Comparison of relative mature male (upper plot) and legal abundance (lower plot) estimates of St. Matthew Island male blue king crab with five scenarios of the catch-survey analysis and pot survey abundance.

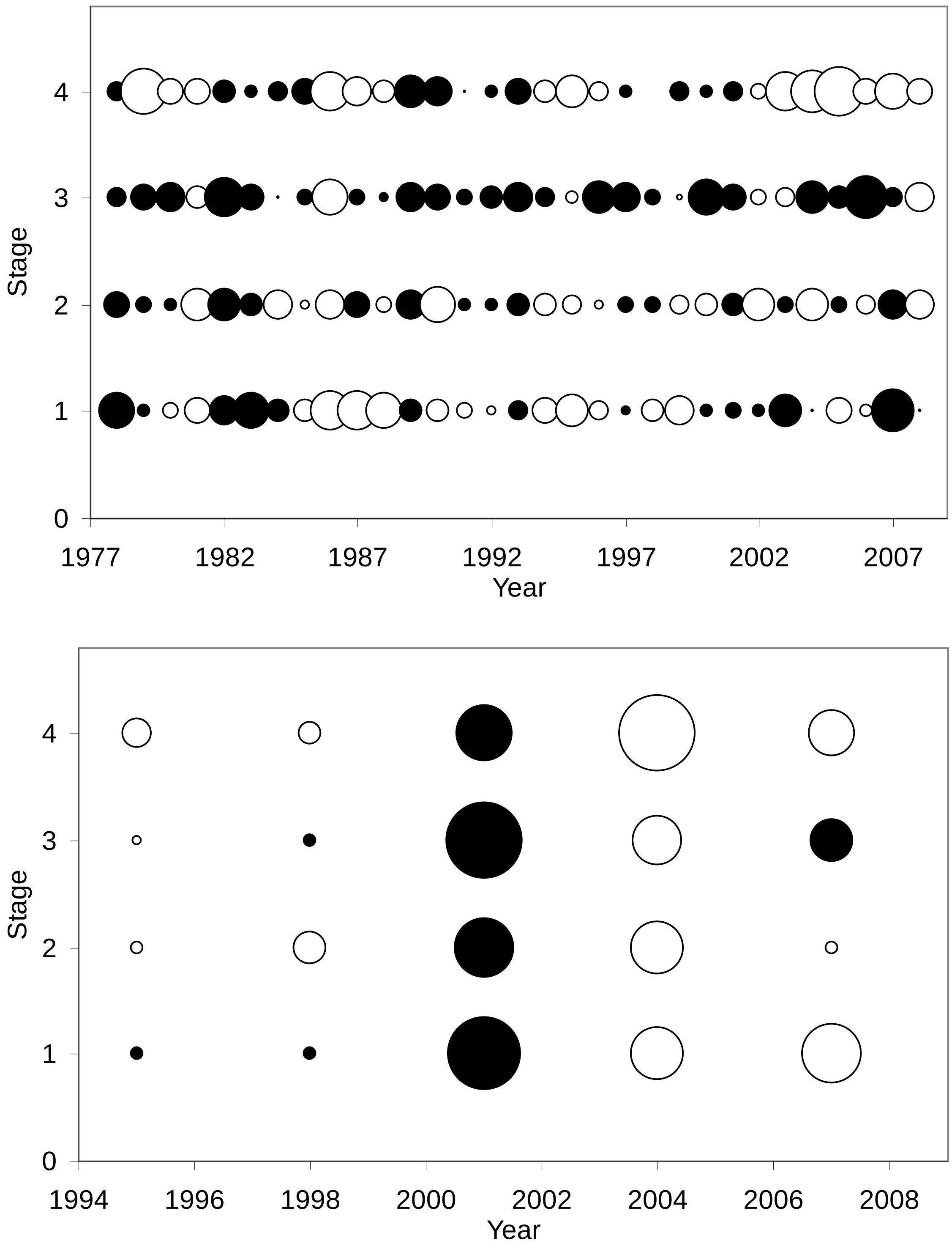
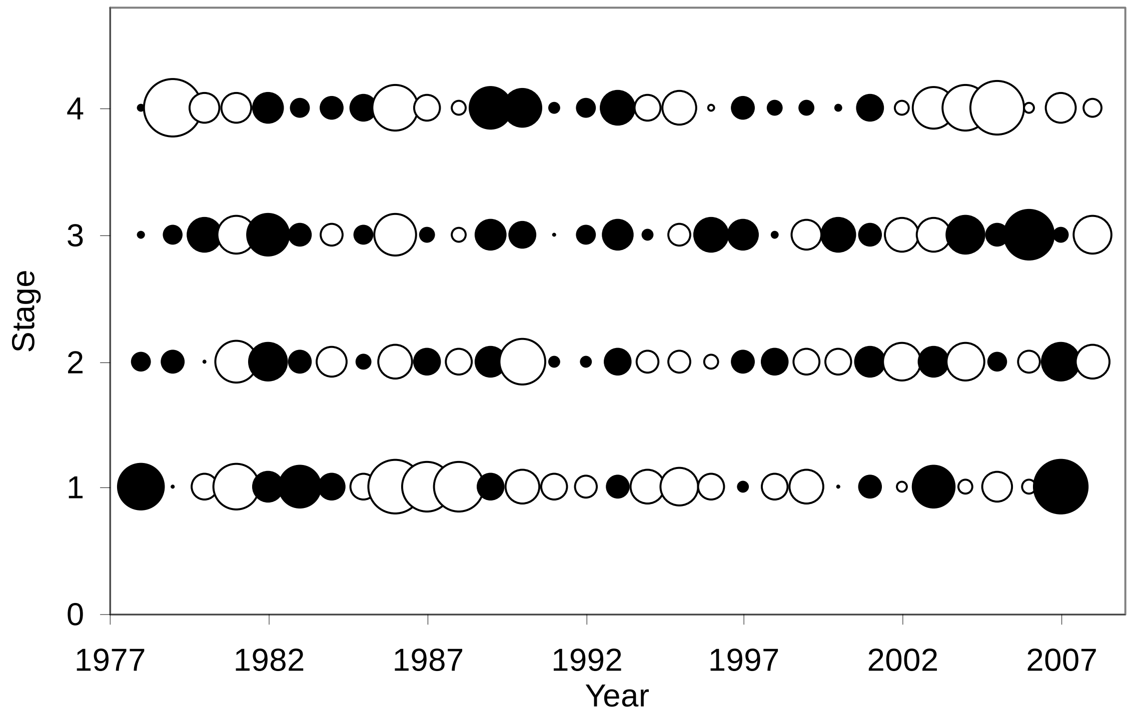


Figure 11. Residuals of the catch-survey analysis with scenario (1) of fixed both M=0.18 and Q=1. Upper plot is for trawl survey and lower plot is for pot survey. Stages 1-4 are prerecruit-2s, prerecruit-1s, recruits and postrecruits. Solid circles are positive residuals, and open circles are negative residuals.



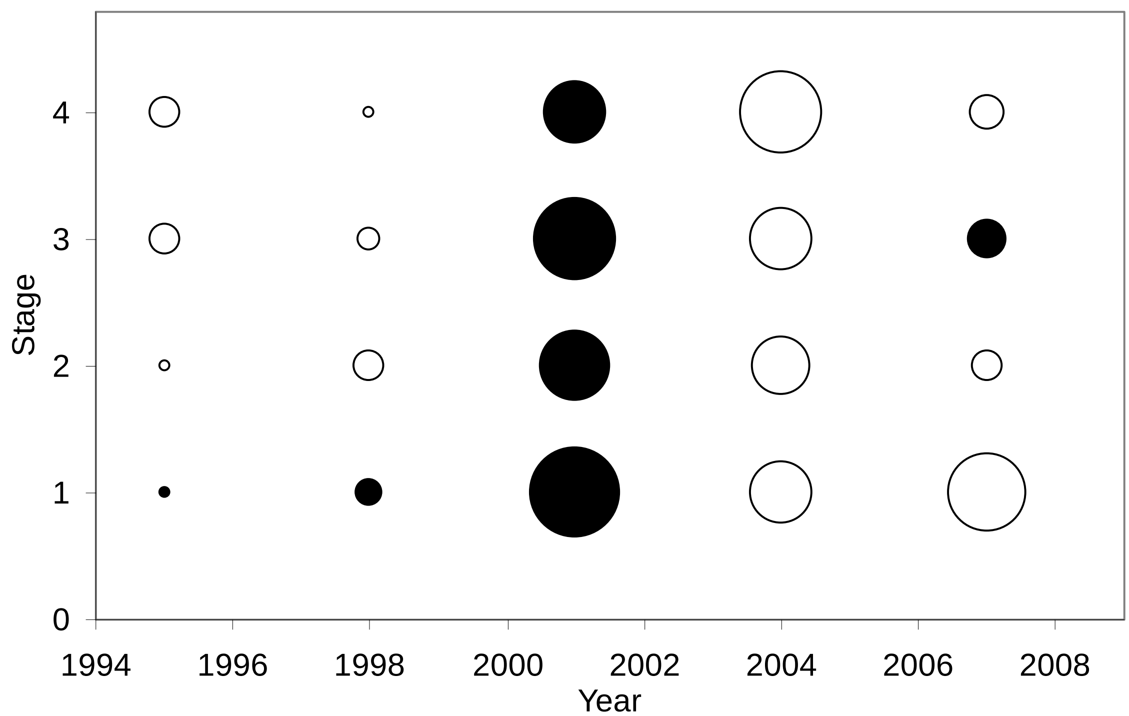
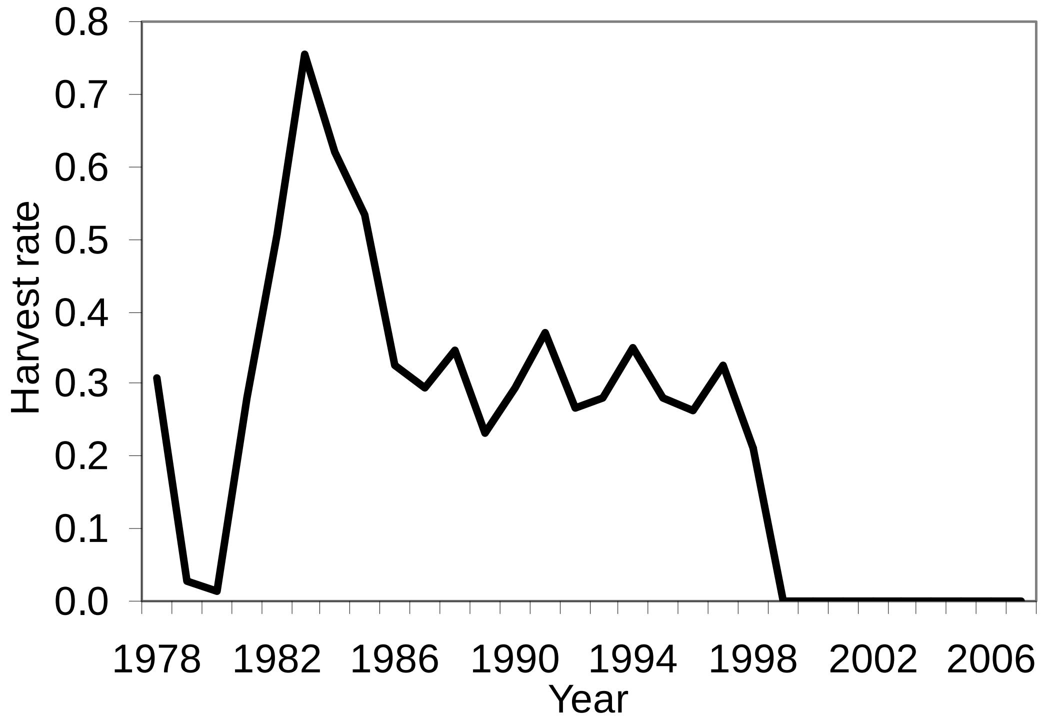


Figure 12. Residuals of the catch-survey analysis with scenario (2) of fixed Q=1 and estimating M. Upper plot is for trawl survey and lower plot is for pot survey. Stages 1-4 are prerecruit-2s, prerecruit-1s, recruits and postrecruits. Solid circles are positive residuals, and open circles are negative residuals.



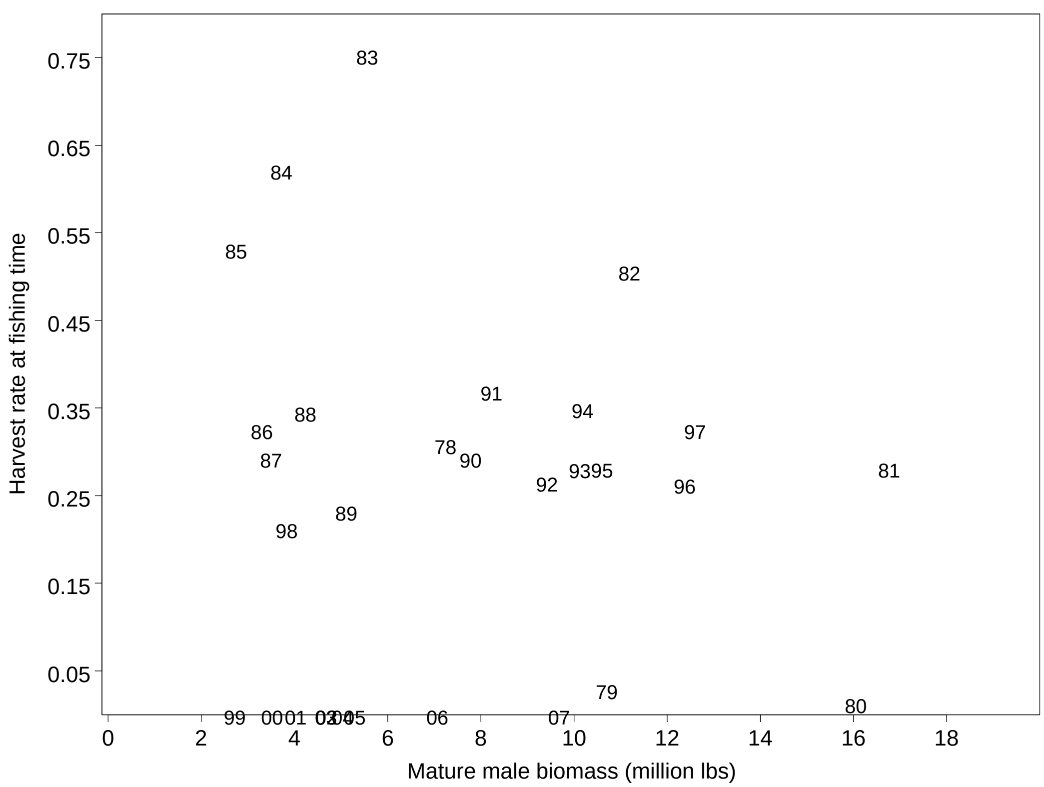


Figure 13. Estimated harvest rates (upper plot) and relationship between harvest rate and mature male biomass (lower plot) of St. Matthew Island blue king crab with scenario (1) of fixed M=0.18 and Q=1.0.

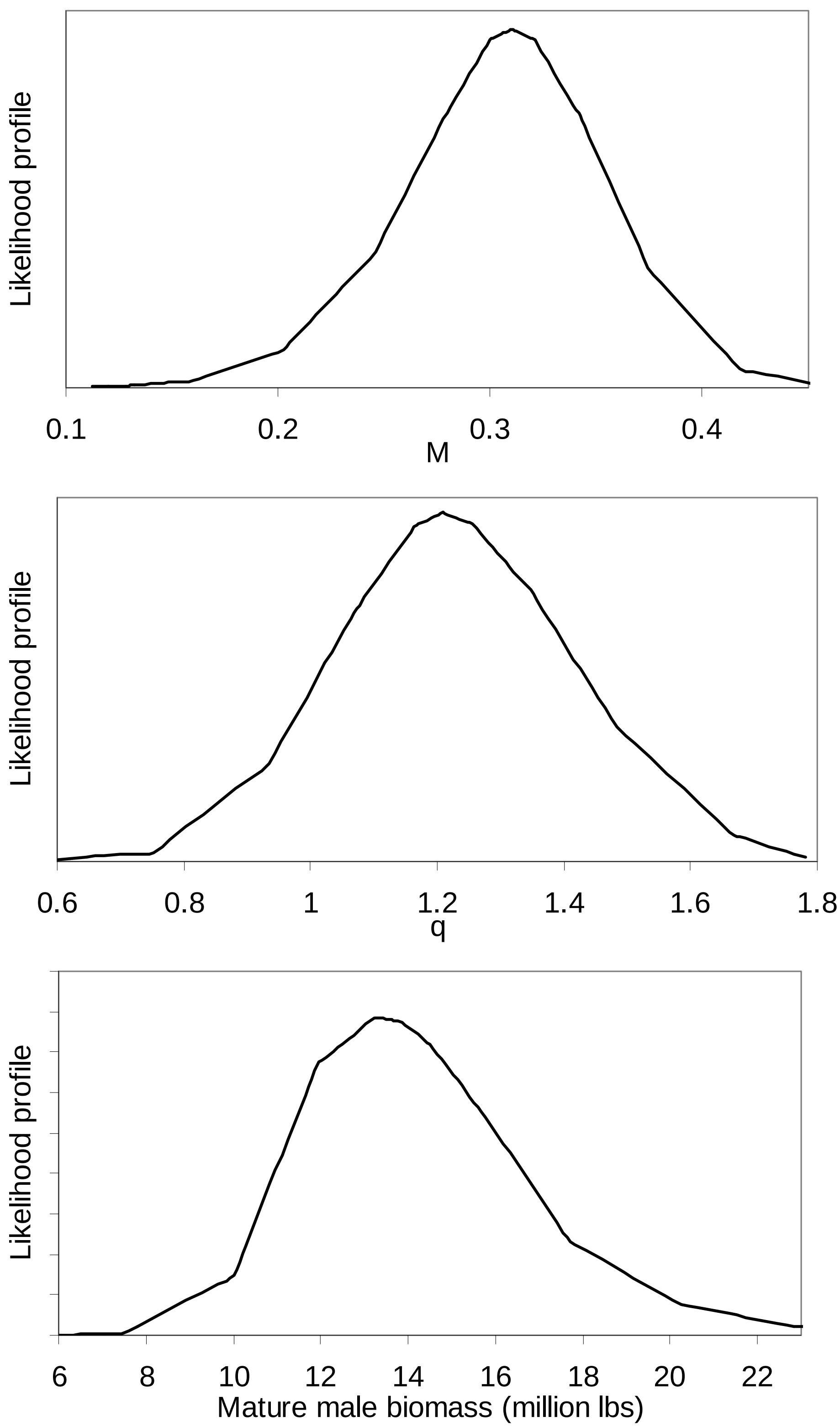
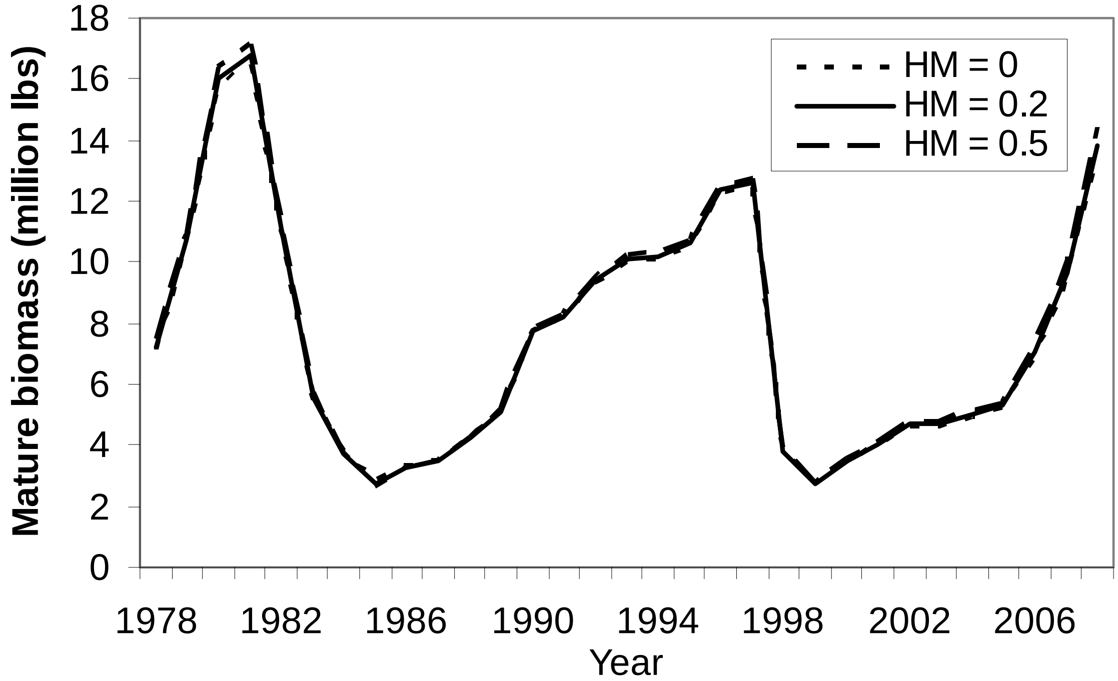


Figure 14. Likelihood profiles of estimated natural mortality (*M*) with a fixed trawl survey catchability (*Q*=1) (scenario 2), estimated trawl survey catchability with a fixed *M* (=0.18) (scenario 3), and estimated mature male biomass on Feb. 15, 2009 with fixed *M* =0.18 and *Q* = 1 and harvest rate = 0 in 2008 (scenario 1).



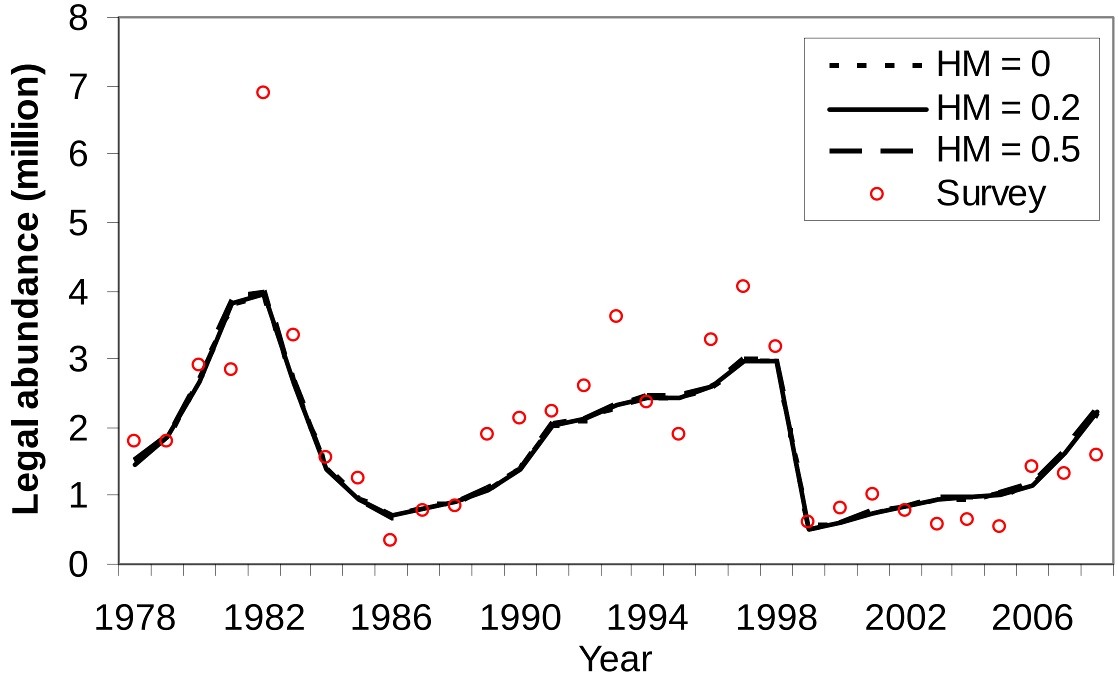
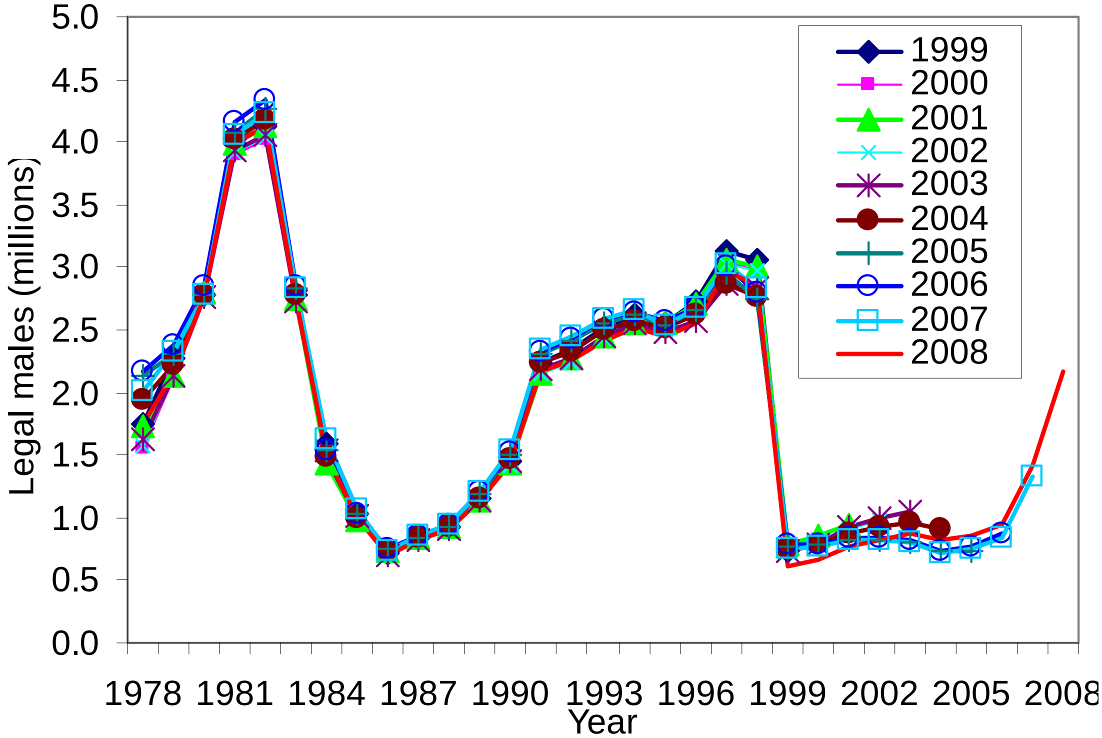


Figure 15. Comparison of estimated mature male biomass (upper plot) and legal male abundance (lower plot) with three levels of handling mortality under scenario (1) of fixed $M = 0.18$ and $Q = 1.0$.



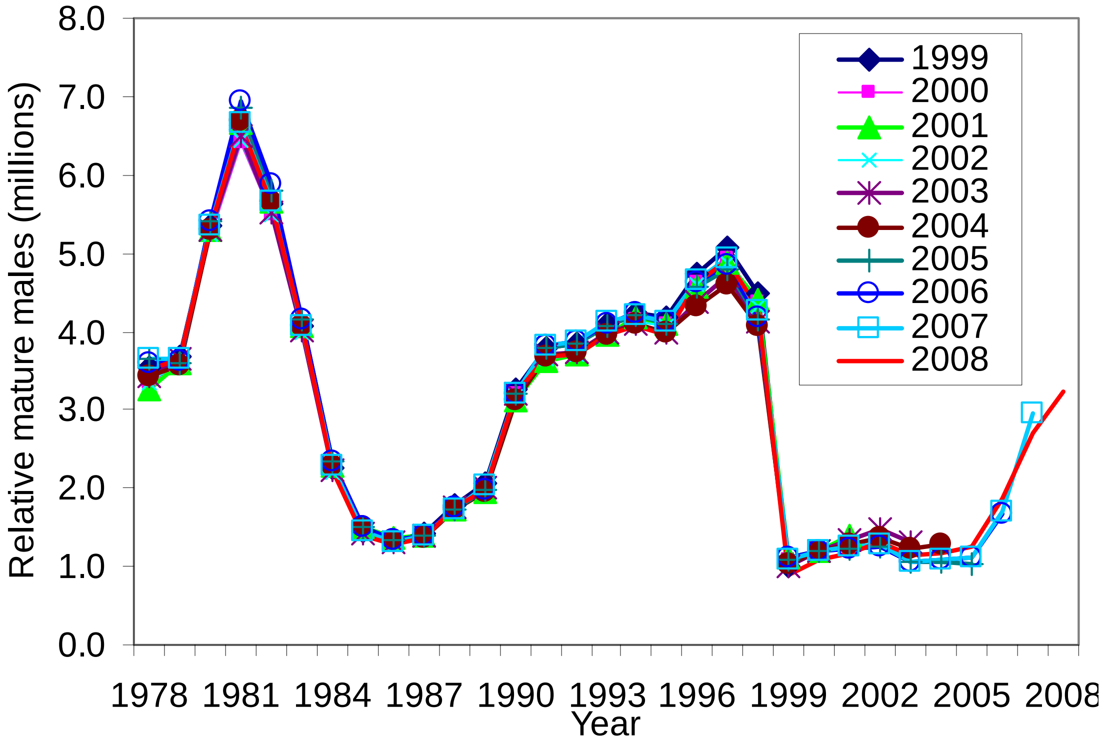
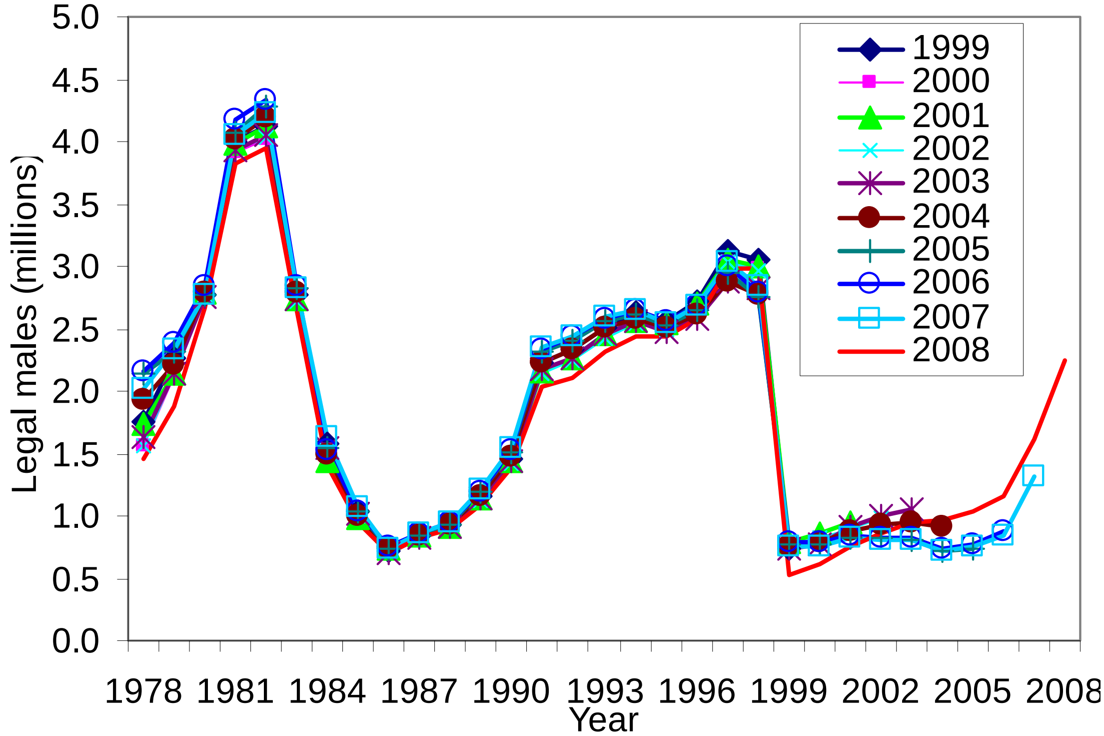


Figure 16. Comparison of estimates of legal male abundance and relative mature male abundance of St. Matthew Island blue king crab with terminal years 1999-2008. The 2008 model was with a fixed *Q*=1.0 and estimating *M* (scenario 2). These are results of historical assessments. Legend shows the year in which the assessment was conducted.



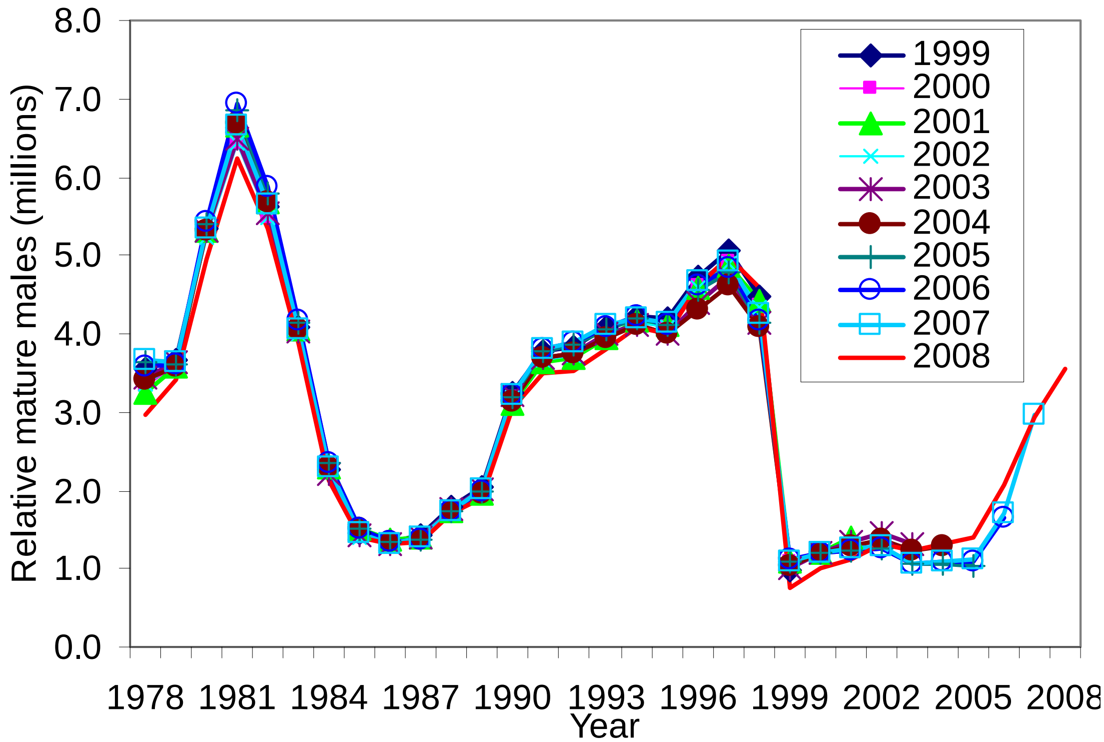


Figure 17. Comparison of estimates of legal male abundance and relative mature male abundance of St. Matthew Island blue king crab with terminal years 1999-2008. The 2008 model was with a fixed M=0.18 and Q=1.0 (scenario 1). These are results of historical assessments. Legend shows the year in which the assessment was conducted.

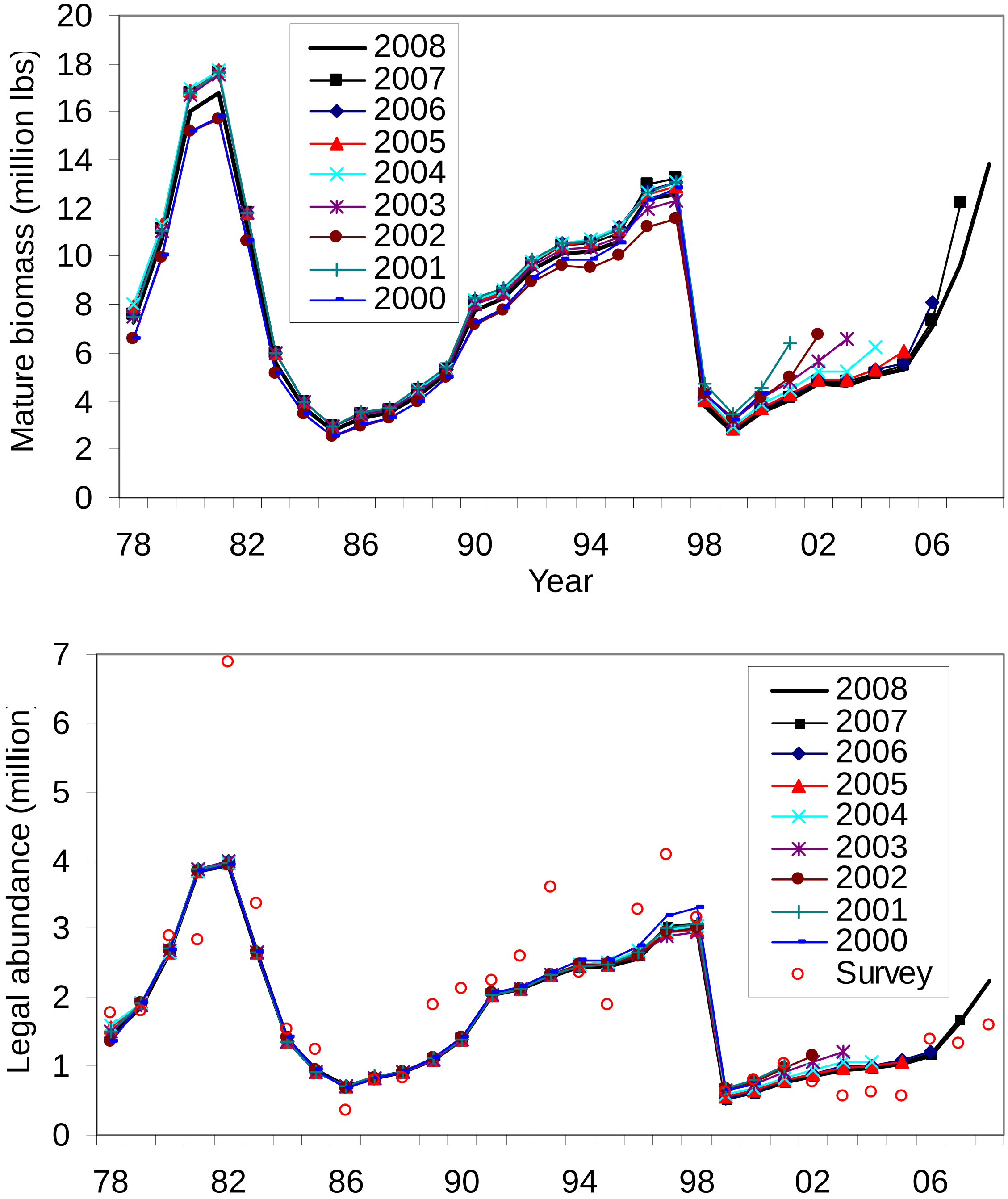


Figure 18. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2008 made with terminal years 2001-2008. These are results of the 2008 model with a fixed M=0.18 and Q=1.0 (scenario 1). Legend shows the year in which the assessment was conducted.

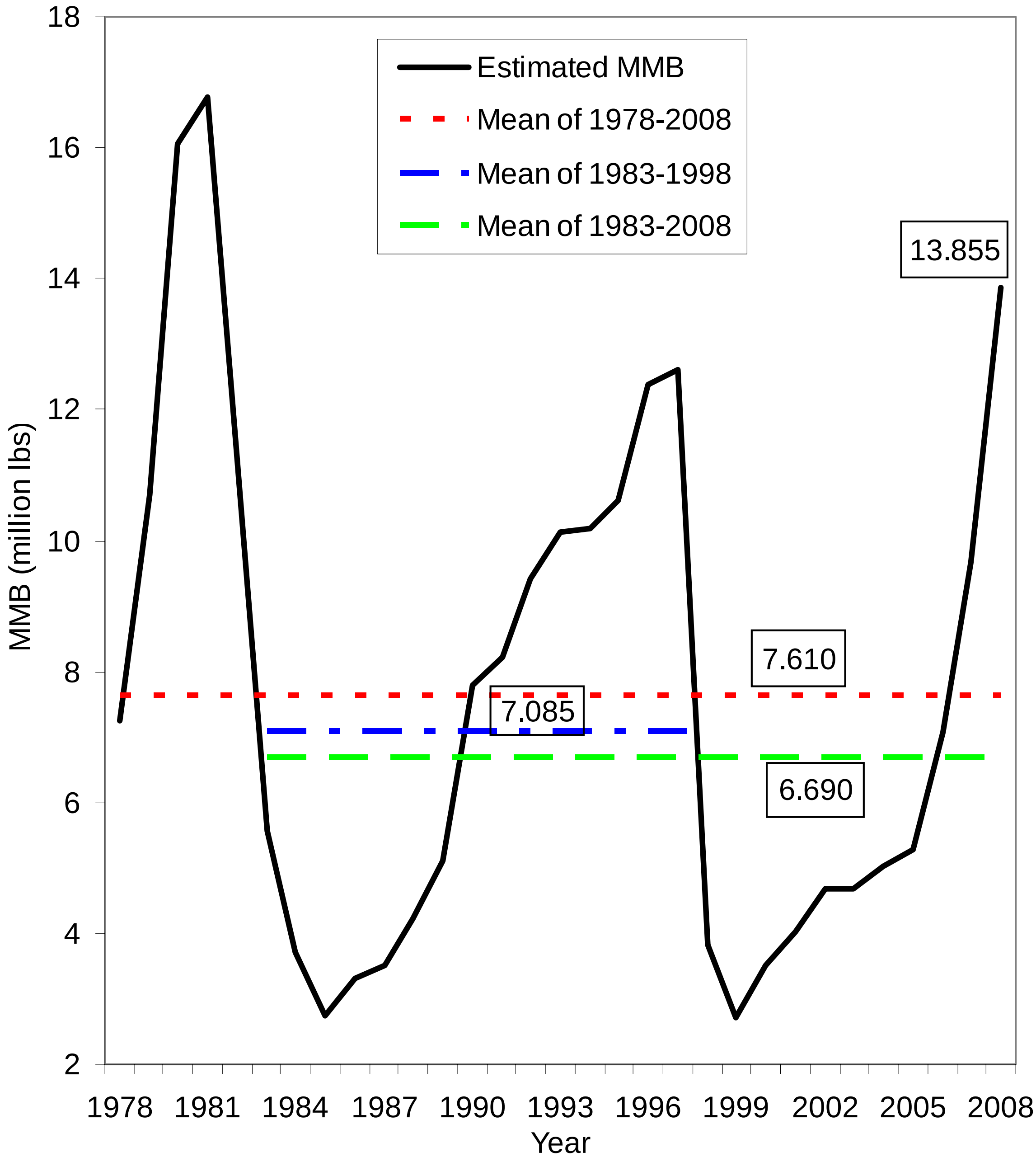


Figure 19. Comparison of estimated mean mature male biomasses during different periods of St. Matthew Island blue king crab. The model was with a fixed M=0.18 and Q=1.0 (scenario 1). Zero catch was assumed for the 2008 fishery to project mature male biomass in 2008.

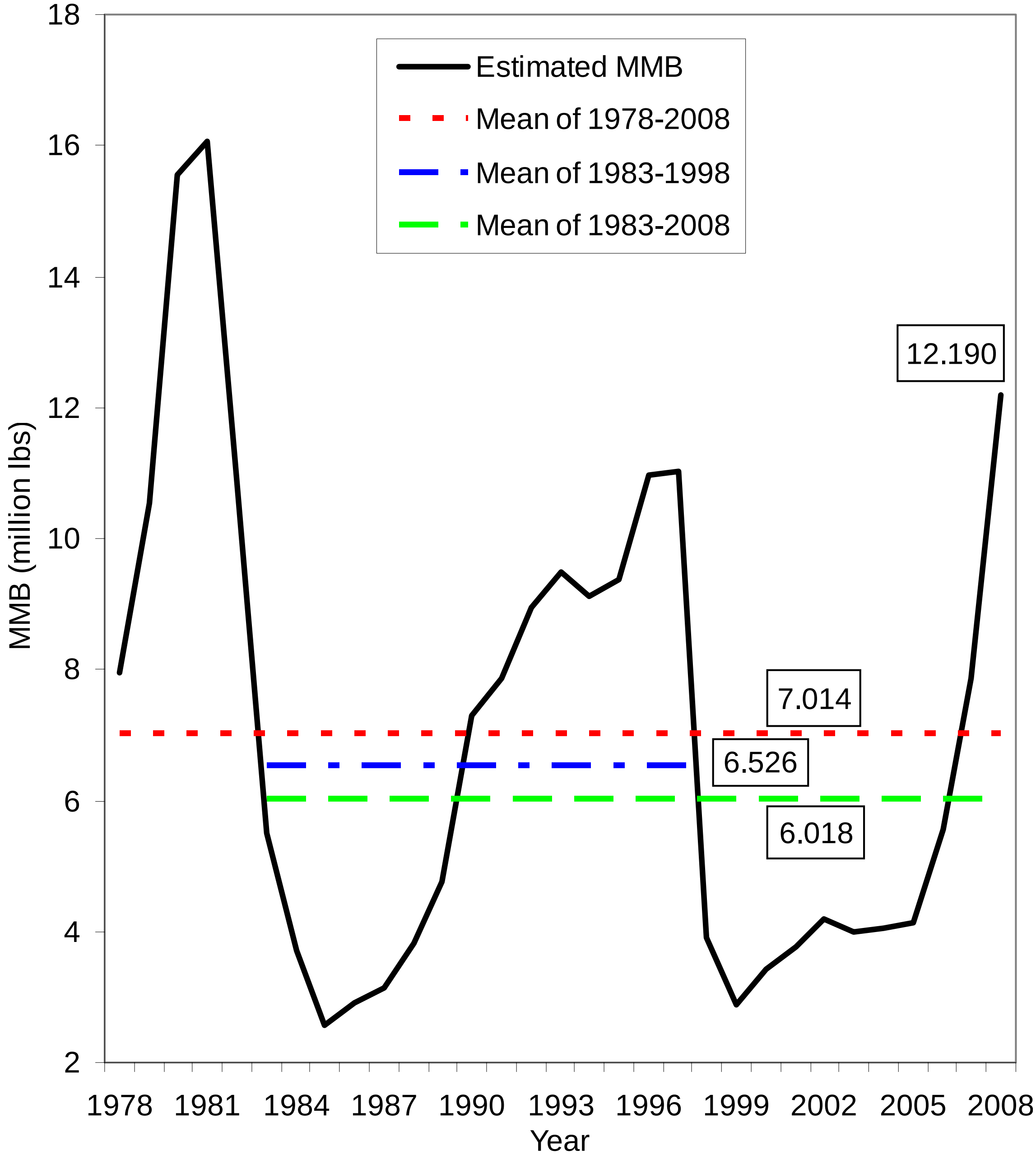


Figure 20. Comparison of estimated mean mature male biomasses during different periods of St. Matthew Island blue king crab. The model was with a fixed *Q*=1.0 and estimating *M* (scenario 2). Zero catch was assumed for the 2008 fishery to project mature male biomass in 2008.