St. Matthew Blue King Crab Stock Assessment in Spring 2009

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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 (*M*=0.18) for both 1978-1998 and 2000-2008 and fixed trawl survey catchability (*Q*=1) with estimating *M* in 1999; scenario (2) fixed *Q* = 1 and estimated two *M* values (one for 1978-1998, 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. Scenario (2) resulted in the lowest negative likelihood value, and scenario (4) had the highest negative likelihood (Table 6). The Chi-Square test was used to compare scenarios with different number of degrees of freedom. Overall, scenario (2) fit the data best, followed by scenario (3), (1), (5) and (4). All scenarios indicate an increasing abundance and biomass since 1999, and estimated legal abundance and mature male biomass in 2008 were the highest values since 1999.

Estimated legal abundance and mature male biomass in 2008 are:

	Scenario (1)	Scenario (2)
Legal males:	1,952,000 crab or 8.753 million lbs,	1,839,000 crab or 7.917 million lbs

	Model scenario (1)	Model scenario (2)
	(SD:237,080 crab)	(SD: 285,980 crab)
Mature male biomass ($\gamma = 0$):	10.782 million lbs	9.735 million lbs.

Estimated B_{MSY} proxy:

	Model scenario (1)	Model scenario (2)
Based on average during 1978-2008:	7.194 million lbs	7.339 million lbs
Based on average during 1983-1998:	7.059 million lbs	7.337 million lbs
Based on average during 1983-2008:	6.273 million lbs	6.260 million lbs
Based on average during 1989-2008:	7.073 million lbs	7.337 million lbs

Estimated F_{MSY} proxy:

	Model scenario (1)	Model scenario (2)
$\gamma = 1$:	0.180	0.372
$\gamma = 1.5$:	0.270	0.558
$F_{35\%}$:	0.330	0.810
$F_{40\%}$:	0.270	0.620

Estimated mature male biomass from either scenario in 2008 was above any of the suggested B_{MSY} proxies. Overfishing limits for 2009 depend on three factors: years used to average mature biomass as the B_{MSY} proxy, the choice of γ value or $F_{\%}$, and the updated stock assessment in August 2009 after the NMFS summer survey. In 2008, $\gamma = 1$ and years of 1989-2008 were used for overfishing limits. We will await May 13-14 assessemnt meeting to recommend gamma and appropriate years for B_{MSY} estimation for 2009.

Summary of Major Changes in 2009

1. Areas-swept for the NMFS surveys have been re-estimated and trawl survey abundances have been re-estimated, which are generally lower than previous assessments.
2. Survey CVs were used to compute likelihood values.
3. The Chi-Square test was used to compare five different scenarios.
4. $F_{35\%}$ and $F_{40\%}$ were estimated.

Response to CPT Comments (from September 2008)

"The model should continue to be refined for review at the May 2009 CPT meeting to allow this stock to be considered for Tier 3. Further analyses are needed to explore scenarios of constant M over the whole time period, including runs tests and justifications of lambda with log-likelihood analyses. Bycatch data in all fisheriesmust be compiled to generatge a total catch OFL for the May 2009 assessment. The CVs of the survey data should be used in the assessment next year. The assessment needs 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)]."

First, five scenarios, including a constant *M*, were compared and tested. Second, CVs were used to compute likelihoods so no lambda is needed. Third, NMFS is in a process to estimate trawl bycatch estimates for this stock, so no trawl bycatch was included in the model for this report. Once NMFS completes the trawl bycatch estimation, the model can include it easily. Fourth, both trawl and pot survey data and fits are plot. Finally, there are no enough data to fit the current model with pot survey data alone.

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

"For the upcoming assessment cycle, and in concurrence with the CPT, the SSC would like the author to explore alternative models in which M is held constant and the anomaly in 1999 is handled differently. The 1999 data point may be the result of the combination of low temperatures and an early survey in that year. Some other stocks appear to show the same 1999 anomaly.."

Five alternative scenarios (models) have been evaluated in this report. These scenarios include a constant *M* as well as treating the *M* in 1999 differently. The sharp drop in 1999 is not a sampling error caused by low temperatures or an early survey. If it were a sampling error, the survey abundance should have gone up during the following surveys during 2000-2008. The crabs disappearing in 1999 were not seen again during the following surveys. Low temperatures have not consistently been related to high *M* for crab stocks.

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 population differences 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). Ten U.S. vessels harvested 1.202 million pounds in 1977, and 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 were 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 as either 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, and 8% for king crabs (NPFMC 2006). A higher bycatch mortality rate for the directed pot fishery has been used for harvest strategy, and we assumed the directed crab fishery mortality rate to be 20% for blue king crab in this report.

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 guideline 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 (including loss) 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. The survey stations used to assess the St. Matthew Island blue king crab stock are located within the St. Matthew Island Section of the ADF&G Northern District. From 1978 to 1982 40 stations centered in 20 X 20 nm (37.04 X 37.04 km) cells were sampled in a total area of 16,040 nm^2. From 1983 to 2008, 2 strata were identified with low and high density of stations.

The low-density strata consisted of 28 stations within a 11,228 nm^2 area and the high density strata consisted of 29 stations in a 7,619 nm^2 area. Total area calculations for each stock management unit uses an area of 401 nm^2 for each 20 X 20 nm cell due to a spherical projection of the grid surface in an area as large as the EBS.

The fishing gear used from 1978 to 1980 was a 400-mesh Eastern otter trawl with an effective path width of 12.19 m, and in 1981 was an 83-112 trawl towed by the R/V *Chapman* with an effective path width of 18 m. From 1982 to 2008 a standardized 83-112 Eastern otter trawl with an 83 ft (25.3 m) headrope and a 112 ft (34.1 m) footrope (Acuna and Lauth 2008) was used and net width was measured from net mensuration equipment during each tow. Each tow was approximately 0.5 h in duration and 1.5 nm (2.8 km) in length at a speed of 3 knots (1.54 m/sec) (Stauffer 2004). Fishing power was assumed to be equal between vessels if more than one vessel was used.

Crab density (number/nm^2) was estimated at each station for pre-recruit 1 (105-119 mm CL), pre-recruit 2 (90-104 mm CL), recruit (newshell 120-133 mm CL), and post recruit (oldshell ≥120 mm CL and newshell ≥134 mm CL) males. The area swept by the trawl was calculated as the product of the distance traveled while the net had bottom contact by the effective width. Distance traveled by the trawl was determined from ship positions recorded at the beginning and end of each tow using LORAN or GPS equipment. Total crab population abundance within the St. Matthew Island Section management unit was estimated by averaging crab densities among all stations, multiplying by the total area of the strata, and then adding strata within the management unit. Variance was estimated by summing the individual strata variance weighted by squared area of each strata in each year. Stage-specific survey abundances for the catch-survey model are summarized in Table 3 and Figure 4.

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 5, 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 6, 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 7). 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 8). 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 9). 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 the 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 (*P*2), prerecruit-1s (*P*1), 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 *P*2 (90-104 mm CL), *P*1 (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 in the same stage or become postrecruits. 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. This allows us to model the changes in molting probability under a constraint condition.

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 $m1$ to $m2$ from tagging data to estimate $m2$ from $m1$. 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 the Bristol Bay red king crab stock assessment (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 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 returned 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:

$$W = 0.000329 * CL^{3.175}, \qquad (3)$$

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 Island were considered mature at 77 mm CL based on this relationship (Somerton and MacIntosh 1983a). St. Matthew Island 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 ≥ 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:

$$
\begin{aligned}
Ln(L) = -\sum_t \{ & [\ln(P2_t QS2+1) - \ln(p2_t+1)]^2 / (2\ln(CV^2_{p2,t}+1)) \\
& + [\ln(P1_t QS1+1) - \ln(p1_t+1)]^2 / (2\ln(CV^2_{p1,t}+1)) \\
& + [\ln(R_t Q+1) - \ln(r_t+1)]^2 / (2\ln(CV^2_{r,t}+1)) \\
& + [\ln(P_t Q+1) - \ln(p_t+1)]^2 / (2\ln(CV^2_{p,t}+1)) \\
& + [\ln(P2_t s2/q+1) - \ln(ip2_t+1)]^2 / (2\ln(CV^2_{ip2,t}+1)) \\
& + [\ln(P1_t s1/q+1) - \ln(ip1_t+1)]^2 / (2\ln(CV^2_{ip1,t}+1)) \\
& + [\ln(R_t/q+1) - \ln(ir_t+1)]^2 / (2\ln(CV^2_{ir,t}+1)) \\
& + [\ln(P_t/q+1) - \ln(ip_t+1)]^2 / (2\ln(CV^2_{ip,t}+1)) + 10\eta_t^2 \},
\end{aligned}
\tag{4}
$$

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; CV is coefficient of variation for the survey abundance; $S2$ 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 parameters and likelihood values for different scenarios are compared in Table 6 and estimated abundance, recruitment to the model and mature male biomass are summarized in Tables 7-10 for five scenarios. Scenarios (1) and (4) with fixed *Q* and *M* resulted in relatively high abundance and biomass estimates during the recent 10 years (Figure 10). Scenario (2) resulted in the lowest negative log likelihood value, and scenario (4) had the highest negative log likelihood (Table 6). The Chi-Square test was used to compare scenarios with different numbers of degrees of freedom. Scenario (2) outperformed scenarios (1), (4) and (5) with p-values of all less than 0.001. Scenario (3) performed better than scenario (1) (p-value of 0.030), scenario (4) (p-value < 0.001), and scenario (5) (p-value = 0.002). Scenario (1) performed better than scenario (4) (p-value < 0.001), and scenario (5) outperformed scenario (4) (p-value < 0.001). Overall, scenario (2) fit the data best, followed by scenario (3), (1), (5) and (4). All scenarios indicate an increasing abundance and biomass since 1999, and estimated legal abundance and mature male biomass in 2008 were the highest values since 1999 (Figure 10; Tables 7-10). 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 12 and 13). This may suggest a higher mortality than we assumed in the model for the post-recruit crab. When *M* was estimated in the model (scenarios 2 and 5), its values were 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 14). The fishery has been closed since 1999.

Natural mortality is strongly correlated with estimated trawl survey catchability: high assumed natural mortality leading to lower estimated catchability (Figure 15). A relatively high natural mortality fits the data better than a low natural mortality. With a fixed catchability = 1, estimated natural mortality was 0.373, much higher than the value (0.18) we assumed for this stock. The likelihood value was very low for an assumed natural mortality of 0.18 (Figure 15). When fixing natural mortality = 0.18, estimated trawl survey catchability was greater than 1, an unlikely value (Figure 15).

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 for 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 (Zheng et al. 2008).

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's data out at a time to evaluate how well the current model performs with less data.

The 2008 model results are compared in Figures 16-20. Scenarios with estimating natural mortality in 1999 performed very well with only a small bias of abundance estimates. 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 for scenario (1) (Figure 16). This bias is less for scenarios (2) and (3) than for scenario (1). 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) (Figure 17). Since scenario (2) has been used to manage the fishery during the last ten years, the performance of scenario (2) is similar to the historical performance. Scenario (3) performed close to or slightly worse than scenario (2). Because trawl survey catchability was estimated to be greater than 1 for scenario (3), estimated legal male abundance was generally less than survey area-swept estimates (Figure 18). Scenario (4) with fixed M and Q for the whole period performed poorly. The estimated legal abundance and mature male biomass during the terminal years were systematically higher during 1999-2007 than those estimated with the terminal year of 2008 for scenario (4) (Figure 19). This systematic bias also occurred for scenario (5) but was smaller than for scenario (4) (Figure 20). Retrospective abundance estimates were not stable in the late 1970s and early 1980s for scenario (5) due to unstable estimates of natural mortality (Figure 20).

Historically, the model performed very well. The model scenario (2) assumed Q=1 and estimated M up to the 2008 model. Since the model has not been changed during the last nine years, the performance of the 2008 model (scenario 2) is also the same as Figure 17.

Overfishing Limits for 2008 and 2009

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 is used to develop B_{MSY} proxy for Tier 4 stocks. We evaluated averages of mature male biomasses from four periods for a B_{MSY} proxy: 1978-2008, 1983-1998, 1983-2008, and 1989-2008 (Figures 21 and 22).

Besides B_{MSY} proxy, a γ value also needs to be determined. We evaluated two γ values for setting overfishing limits for 2008: γ = 1 and γ =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 21 and 22). The CPT selected γ = 1 for determining overfishing limits for 2008. The fishery was closed for 2008 because the OFL catch was below the target catch threshold.

Estimated B_{MSY} proxy:

	Model scenario (1)	Model scenario (2)
Based on average during 1978-2008:	7.194 million lbs	7.339 million lbs
Based on average during 1983-1998:	7.059 million lbs	7.337 million lbs
Based on average during 1983-2008:	6.273 million lbs	6.260 million lbs
Based on average during 1989-2008:	7.073 million lbs	7.337 million lbs

Estimated F_{MSY} proxy:

	Model scenario (1)	Model scenario (2)
γ = 1:	0.180	0.372
γ = 1.5:	0.270	0.558

$F_{35\%}$:	0.330	0.810
$F_{40\%}$:	0.270	0.620.

Estimated mature male biomass in 2008 was 10.782 and 9.735 million lbs, respectively for model scenarios (1) and (2) under the target level of $\gamma = 0$. The estimated mature male biomass in 2008 would 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 CPT suggested a period of 1989-2008. The period of 1978-2008 includes all data. For a given model scenario, the averages from the three periods were not greatly different.

Overfishing limits for 2009 depend on three factors: years used to average mature biomass as the B_{MSY} proxy, the choice of γ value or $F_{\%}$, and the updated stock assessment in August 2009 after the NMFS summer survey. In 2008, $\gamma = 1$ and years of 1989-2008 were used for overfishing limits.

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 2009.

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 with an 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 as prey items 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 12 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, occurring in isolated populations that 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) hypothesized that the isolated distribution of BKC could be due to three mechanisms that might come into play, either singly or in combination, following an increase in temperature: 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 near 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 to 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 have their 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 understanding the impacts of climate change, especially seawater warming, on BKC production.

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 stages considered most vulnerable are 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 affecting 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).

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References

Abrunhosa, F.A. and J.K. Kittaka. 1997. Functional morphology of mouthparts and foregut of the last zoea, glaucothoe and first juvenile of the king crabs *Paralithodes camtschaticus, P. brevipes and P. platypus.* Fisheries Sci. 63(6):923-930.

Acuna, E. and R. R. Lauth. 2008. Results of the 2007 eastern Bering Sea continental shelf bottom trawl survey of groundfish and invertebrate resources. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-181, 195 pp.

Armstrong, D.A., L.S. Incze, J.L. Armstrong, D.L. Wencker, and B.R. Dumbauld. 1983. Distribution and Abundance of Decapod Crustacean Larvae in the Southeast Bering Sea with Emphasis on Commercial Species. Final Report of Principal Investigators for the Year Ending 1983, RU 609. USDOC, NOAA, OCSEAP, Office of Marine Pollution Assessment, 406 pp.

Armstrong, D. A., R. Palacios, G. Williams, G. C. Jensen, and W. Pearson. 1985. Early life history of juvenile blue king crab, *Paralithodes platypus*, around the Pribilof Islands. Pages 211-230 *in* Proceedings of the International King Crab Symposium. Alaska Sea Grant College Program Report 85-12. University of Alaska Fairbanks.

Armstrong, D.A., J.L. Armstrong, G. Jensen, R. Palaios, and G. Williams. 1987. Distribution, abundance, and biology of blue king and Korean hair crabs around the Pribilof Islands.

Final report on 1983-1984 data. Contract No. 83-ABC-00066 from OCSEAP/OMPA. School of Fisheries WH-10 University of Washington Seattle, WA 98195.

Blau, S. F. 2000. Nearshore blue king crab survey St. Matthew Island, 1999. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 4K00-42 Kodiak, Alaska.

Blau, S.F. and L.J. Watson. 1999. St. Matthew Island blue king crab survey, 1998. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 4K99-66, Kodiak, Alaska.

Bowers, F.R., M. Schwenzfeier, S. Coleman, B. Failor-Rounds, K. Milani, K. Herring, M. Salmon, and M. Albert. 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and the westward region's shellfish observer program, 2006/07. Alaska Department of Fish and Game, Fishery Management Report No. 08-02, Anchorage. 230 pp.

Clarke, W., G. and S. R. Hare. 2008. Assessment of the Pacific halibut stock at the end of 2007. p. 27. International Pacific Halibut Commission, Seattle, WA.

International Pacific Halibut Commission. 2008. Summary of 2008 International Pacific Halibut Commission annual meeting, p.7. International Pacific Halibut Commission, Seattle, WA.

Jensen, G. C. and D. A. Armstrong. 1989. Biennial reproduction 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.

Kruse, G.H. 1993. Biological perspectives on crab management in Alaska. Pages 355-384 *in*: G.H. Kruse, D.M. Eggers, R.J. Marasco, C. Pautzke & T.J. Quinn II (eds.), Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations. University of Alaska Fairbanks, Alaska Sea Grant Rep. 93-02.

Lang, G. M., P. A. Livingston, and K.A. Dodd. 2005. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1997 to 2001. U. S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-158. 230 pp.

Lauth, R. R. 2007. HAPC biota- Bering Sea. *In* J. Bolt (editor) Appendix C. Ecosystems Considerations for 2008. North Pacific Fishery Management Council, Anchorage, Alaska.

Laevastu, T., R. Marasco, N. Bax, F. Fredkin, F. Fukuhara, A. Gallagher, T. Honkalehto, J. Ingraham, P. Livingston, R. Miyahara, and N. Pola. 1985. Evaluation of the effects of oil development on the commercial fisheries in the eastern Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 36(1):1-48.

Livingston, P.A., Ward, A., Lang, G.M. and Yang, M-S. 1993. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1987 to 1989. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-AFSC-11,192 pp.

Loher, T., Hill, P.S., Harrington, G. and Cassano, E. 1998. "Management of Bristol Bay red king crab: a critical intersections approach to fisheries management." Rev. Fish. Sci.6(3):169-251.

Moore, H., L.C. Byrne, and D.E. Connolly. 1998. Alaska Department of Fish and Game summary of the 1997 mandatory shellfish observer program database. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report No. 4K98-50 Kodiak, Alaska.

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. 146 pp.

National Marine Fisheries Service. 1984. Cruise results, cruise no. 83-01 charter vessel *Valiant*. National Marine Fisheries Service, Northwest and Alaska Fisheries Science Center, Seattle.

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, Alaska.

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, Alaska.

North Pacific Fishery Management Coucil (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, AK. Draft report.

North Pacific Fishery Management Council (NPFMC). 2006. Bering Sea Habitat Conservation: Evaluating the need for possible protection measures for St. Matthew blue king crab and eastern Bering Sea snow crab. North Pacific Fishery Management Council, Anchorage, Alaska. 42 pp.

North Pacific Fishery Management Coucil (NPFMC). 2007. 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. A review draft.

Orr, J. C., V. J. Fabry, O. Aumont, L. Bopp, S.C. Doney, R. Feely, A.Gnanadesikan, N. Gruber, A. Ishida, F. Joos, R. M. Key, K. Lindsay, E. Maier-Reimer, R. Matear, P. Monfray, A. Mouchet, R. G. Najjar, Gian-Kasper Plattner, K. B. Rodgers, C. L. Sabine, Jorge L. Sarmiento, R. Schlitzer, R. D. Slater, I. J. Totterdell, Marie-France Weirig, Y. Yamanaka and A. Yool. 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature 437: 681-686.

Otter Research Ltd. 1994. An introduction to AD Model Builder: for use in nonlinear modeling and statistics. Otter Research Ltd., Nanaimo, British Columbia.

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.

Otto, R.S. 2006. A review of worldwide fisheries for lithodid crabs (Decapoda: Anomura: Lithodidae) and their fluctuations. Biology of Anomura II (A.Asakura, editor), Crustacean Research, Special Number 6:167-185, 2006.

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

Paul, A.J., Paul, J.M., Shoemaker, P.A. and Feder, H.M. 1979. Prey concentrations and feeding response in laboratory-reared stage-one zoeae of king crab, snow crab, and pink shrimp. Trans. Am. Fish. Soc. 108: 440-443.

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(1):157-163.

Palacios, R., D. A. Armstrong, J. L. Armstrong, and G. Williams. 1985. Community analysis applied to characterization of blue king crab habitat around the Pribilof Islands. Pages 193-209 *in* Proceedings of the international king crab symposium. Alaska Sea Grant Program Report 85-12, University of Alaska Fairbanks.

Siddeek, M. S. M., L. J. Watson, S. F. Blau, and H. Moore. 2002. Estimating natural mortality of king crabs from tag recapture data. Pages 51-75 *in* Crabs in cold water regions: Biology, management, and economics. Alaska Sea Grant College Program Report 02-01, University of Alaska Fairbanks.

Somerton, D.A. 1985. The disjunct distribution of blue king crab, *Paralithodes platypus*, in Alaska: some hypotheses. Pages 13-21 *in* Proceedings of the international king crab symposium. Alaska Sea Grant Program Report 85-12, University of Alaska Fairbanks.

Somerton, D. A. and R. A. MacIntosh. 1983a. The size at sexual maturity of blue king crab, *Paralithodes platypus*, in Alaska. Fish Bull. U.S. 81:621-628.

Somerton, D. A. and R. A. MacIntosh. 1983b. Weight-size relationships for three populations in Alaska of the blue king crab, *Paralithodes platypus* (Brandt, 1850) (Decapoda, Lithodidae). Crustaceana 45(2):169-175.

Somerton, D. A. and R. A. MacIntosh. 1985. Reproductive biology of the female blue king crab *Paralithodes platypus* near the Pribilof Islands, Alaska. J. Crust. Biol. 5:365-376.

Sparks, A. K. and J. F. Morado. 1997. Some diseases of northeastern Pacific commercial crabs. J. Shellfish Res. 16(1):321.

Stauffer, G. 2004. NOAA protocols for groundfish bottom trawl surveys of the nation's fishery resources. U.S. Dep. Commerce, NOAA Tech. Memo. NMFSF/SPO-65.

Stevens, B.G. 2006a. Embryonic development and morphometry in the blue king crab, *Paralithodes platypus*, studied by image and cluster analysis. J. Shellfish Res. 25(2):569-576.

Stevens, B.G. 2006b. Timing and duration of larval hatching for blue king crab *Paralithodes platypus*, held in the laboratory. J. Crust. Biol. 26(4):495-502.

Stevens, B.G., J.A. Haaga, and R.A. MacIntosh. 1996. Report to industry on the 1995 eastern Bering Sea crab survey. National Oceanic and Atmospheric Administration, National

Marine Fisheries Service, Alaska Fisheries Science Center Processed Report 96-01, Kodiak, Alaska.

Stevens, B.G., S. Persselin, and J. Matweyou. 2008. Survival of blue king crab larvae, *Paralithodes platypus*, in cultivation: Effects of diet, temperature, and density. Aquaculture Res. 39:390-397.

Watson, L.J. 2005. The 2004 triennial St. Matthew Island blue king crab survey and comparisons to the 1995, 1998, and 2001 survey. Alaska Department of Fish and Game Fishery Management report 05-22.

Watson, L. J. 2008. The 2007 triennial St. Matthew Island blue king crab survey and comparisons to historic surveys. Alaska Department of Fish and Game, Fishery Management Report No. 08-XX, Anchorage. In press.

Wespestad, V.G., Livingston, P.A. and Reeves, J.E. 1994. Juvenile sockeye salmon (*Oncorhynchus nerka*) predation on Bering Sea red king crab (*Paralithodes camtschaticus*) larvae as a cause of recruitment variation. ICEC C.M. 1994/R:10, Copenhagen, 10 pp.

Zheng, J. 2005. A review of natural mortality estimation for crab stocks: data-limited for every stock? Pages 595-612 *in* G.H. Kruse, V.F. Gallucci, D.E. Hay, R.I. Perry, R.M. Peterman, T.C. Shirley, P.D. Spencer, B. Wilson, and D. Woodby (eds.). Fisheries Assessment and Management in Data-limite Situation. Alaska Sea Grant College Program, AK-SG-05-02, Fairbanks.

Zheng, J. and G. H. Kruse. 2000. Recruitment patterns of Alaskan crabs in relation to decadal shifts in climate and physical oceanography. ICES J. Mar. Sci. 57(2): 438-451.

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 Sea Grant, AK-SG-02-01, Fairbanks.

Zheng, J., M.C. Murphy, and G.H. Kruse. 1995. A length-based population model and stock-recruitment relationships for red king crab, *Paralithodes camtschaticus*, in Bristol Bay, Alaska. Can. J. Fish. Aquat. Sci. 52:1229-1246.

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.

Zheng, J. and M.S.M. Siddeek. 2008. Bristol Bay red king crab stock assessment in fall 2008. A draft report for the crab SAFE reports.

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. In this and subsequent tables, P2 is an abbreviation for the prerecruit 2 length group; P1 = prerecruit 1, R – recruits, and P = postrecruits.

Year	P2	P1	R	P	Matures	Legals
1978	2.221	2.147	1.138	0.563	3.849	1.701
1979	2.791	2.107	1.719	0.394	4.221	2.113
1980	1.755	1.905	1.275	1.065	4.245	2.340
1981	0.468	1.218	0.959	1.365	3.542	2.324
1982	1.712	2.496	3.123	2.863	8.482	5.986
1983	1.078	1.663	1.390	1.967	5.020	3.357
1984	0.410	0.500	0.769	0.709	1.978	1.478
1985	0.381	0.377	0.489	0.634	1.500	1.123
1986	0.206	0.456	0.179	0.198	0.833	0.377
1987	0.325	0.631	0.477	0.238	1.346	0.715
1988	0.410	0.815	0.504	0.452	1.772	0.957
1989	2.145	1.154	0.884	0.903	2.940	1.786
1990	1.053	1.032	1.075	1.262	3.369	2.337
1991	1.084	1.665	1.305	0.930	3.900	2.235
1992	1.073	1.382	1.183	1.107	3.672	2.290
1993	1.522	1.828	1.460	1.818	5.105	3.277
1994	0.883	1.299	1.183	1.074	3.556	2.257
1995	1.025	1.189	0.909	0.831	2.929	1.741
1996	1.238	1.891	1.467	1.599	4.957	3.066
1997	1.165	2.229	2.056	1.733	6.018	3.789
1998	0.660	1.660	1.249	1.600	4.509	2.849
1999	0.223	0.222	0.164	0.393	0.779	0.557
2000	0.282	0.285	0.291	0.449	1.025	0.740
2001	0.419	0.502	0.325	0.614	1.441	0.939
2002	0.111	0.230	0.161	0.479	0.870	0.640
2003	0.449	0.280	0.156	0.308	0.745	0.464
2004	0.247	0.183	0.252	0.310	0.746	0.562
2005	0.320	0.310	0.258	0.243	0.811	0.501
2006	0.917	0.642	0.682	0.558	1.882	1.240
2007	2.517	2.020	0.681	0.512	3.212	1.193
2008	1.351	0.801	0.529	0.928	2.258	1.457

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

Year	P2	P1	R	P
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 log 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.

	Model Scenario				
Parameter	(1)	(2)	(3)	(4)	(5)
Natural mortality for years other than 1999	fix	0.372	fix	fix	0.406
Natural mortality in 1999	1.867	1.772	1.784	fix	0.406
Trawl survey catchability (*Q*)	fix	fix	1.270	fix	fix
Trawl survey selectivity: prerecruit-2s (*S*2)	0.582	0.325	0.492	0.654	0.326
Trawl survey selectivity: prerecruit-1s (*S*1)	0.869	0.615	0.728	0.794	0.600
Pot survey selectivity: prerecruit-2s (*s*2)	0.147	0.100	0.128	0.135	0.100
Pot selectivity: prerecruit-1s (*s*1)	0.475	0.372	0.412	0.394	0.335
Pot scaling parameter (*q*)	0.230	0.247	0.184	0.164	0.197
Molting probability in 1978: prerecruit-1s	0.780	0.813	0.768	0.744	0.843
Negative log likelihood components					
Trawl survey: prerecruit-2s	17.395	19.573	17.658	19.976	23.288
Trawl survey: prerecruit-1s	10.148	10.988	10.814	19.671	18.122
Trawl survey: recruits	22.950	12.831	17.659	36.205	18.236
Trawl survey: postrecruits	27.874	18.996	26.906	33.394	22.588
Pot survey: total	4.775	4.049	4.773	5.396	4.129
Molting probability variation penalty	3.133	2.951	3.766	5.180	4.533
Total	86.275	69.388	81.576	119.822	90.896

Table 7. Estimated recruits to the model (Model R), abundance (P2, P1, R, P, 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. $F = 0.0$ for 2008.

Year	Model R	P2	P1	R	P	Legals	Matures	Bio215	Molt1
1978	NA	1.876	1.813	0.961	0.476	1.437	3.250	7.226	0.788
1979	2.559	2.727	1.712	1.052	0.901	1.952	3.665	10.722	0.824
1980	2.367	2.617	2.268	1.112	1.656	2.768	5.036	15.586	0.841
1981	1.340	1.580	2.289	1.451	2.380	3.831	6.120	15.759	0.921
1982	1.401	1.544	1.411	1.499	2.421	3.920	5.330	10.635	0.996
1983	0.621	0.758	1.161	1.000	1.704	2.704	3.866	5.176	0.980
1984	0.469	0.535	0.615	0.767	0.662	1.430	2.044	3.372	0.917
1985	0.763	0.810	0.445	0.393	0.506	0.899	1.344	2.452	0.846
1986	0.751	0.823	0.627	0.285	0.354	0.639	1.267	2.879	0.891
1987	1.137	1.211	0.662	0.414	0.373	0.787	1.449	3.409	0.950
1988	1.237	1.346	0.905	0.482	0.487	0.969	1.874	4.354	0.963
1989	2.067	2.188	1.017	0.651	0.593	1.244	2.262	5.836	0.922
1990	1.798	1.996	1.645	0.745	0.874	1.619	3.264	8.077	0.849
1991	1.769	1.949	1.688	1.043	1.085	2.129	3.817	8.692	0.809
1992	1.833	2.008	1.700	1.009	1.217	2.226	3.926	9.952	0.798
1993	1.766	1.947	1.770	1.015	1.459	2.474	4.244	10.814	0.776
1994	1.476	1.652	1.772	1.023	1.590	2.613	4.385	10.588	0.754
1995	2.302	2.451	1.590	0.977	1.534	2.512	4.102	10.500	0.804
1996	2.131	2.352	2.036	0.982	1.585	2.567	4.603	11.669	0.805
1997	1.504	1.716	2.071	1.222	1.654	2.876	4.947	11.675	0.754
1998	1.178	1.332	1.712	1.131	1.667	2.798	4.510	3.493	0.692
1999	0.412	0.434	0.271	0.163	0.311	0.475	0.746	2.492	0.673
2000	0.340	0.389	0.383	0.148	0.406	0.553	0.937	3.107	0.598
2001	0.426	0.501	0.383	0.176	0.474	0.650	1.033	3.504	0.499
2002	0.055	0.205	0.428	0.151	0.552	0.703	1.131	3.878	0.495
2003	0.441	0.503	0.302	0.154	0.598	0.752	1.054	3.833	0.558
2004	0.400	0.519	0.408	0.137	0.637	0.774	1.182	4.179	0.613
2005	0.709	0.801	0.473	0.196	0.659	0.855	1.328	4.599	0.695
2006	1.605	1.678	0.706	0.268	0.731	0.999	1.705	5.635	0.744
2007	1.444	1.598	1.362	0.449	0.861	1.309	2.672	8.153	0.768
2008	2.177	2.324	1.468	0.806	1.146	1.952	3.420	10.782	0.788

Table 8. Estimated recruits to the model (Model R), abundance (P2, P1, R, P, 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. F = 0.0 for 2008.

Year	Model R	P2	P1	R	P	Legals	Matures	Bio215	Molt1
1978	NA	2.559	2.474	1.311	0.649	1.961	4.435	9.166	0.813
1979	5.803	5.995	1.907	1.232	1.124	2.356	4.263	11.112	0.874
1980	4.597	5.051	3.714	1.199	1.654	2.853	6.566	16.491	0.912
1981	2.741	3.123	3.367	2.143	2.081	4.224	7.590	16.556	0.984
1982	2.457	2.691	2.044	1.981	2.309	4.289	6.333	11.411	1.000
1983	1.083	1.281	1.648	1.232	1.668	2.900	4.547	5.858	0.969
1984	0.837	0.930	0.852	0.911	0.667	1.578	2.430	3.779	0.911
1985	1.312	1.380	0.622	0.460	0.517	0.978	1.599	2.667	0.864
1986	1.390	1.492	0.861	0.349	0.343	0.692	1.553	3.068	0.928
1987	2.103	2.214	0.938	0.505	0.350	0.854	1.792	3.632	1.000
1988	2.319	2.484	1.315	0.613	0.456	1.069	2.384	4.784	1.000
1989	3.757	3.942	1.494	0.834	0.571	1.405	2.899	6.377	0.963
1990	3.403	3.698	2.375	0.971	0.847	1.818	4.193	8.893	0.891
1991	3.166	3.443	2.420	1.337	1.054	2.391	4.812	9.579	0.847
1992	3.405	3.661	2.333	1.280	1.195	2.475	4.807	10.492	0.824
1993	3.160	3.434	2.486	1.227	1.386	2.613	5.100	11.009	0.800
1994	2.808	3.064	2.418	1.253	1.417	2.670	5.087	10.337	0.785
1995	4.409	4.637	2.207	1.180	1.306	2.486	4.694	9.926	0.856
1996	3.932	4.278	2.963	1.242	1.298	2.540	5.503	11.442	0.859
1997	2.494	2.813	2.878	1.595	1.366	2.960	5.839	11.554	0.792
1998	1.904	2.113	2.147	1.380	1.439	2.819	4.966	3.993	0.710
1999	0.747	0.786	0.430	0.235	0.352	0.587	1.017	2.825	0.692
2000	0.689	0.749	0.563	0.203	0.417	0.619	1.183	3.238	0.624
2001	0.782	0.884	0.558	0.229	0.441	0.670	1.228	3.397	0.529
2002	0.206	0.400	0.590	0.197	0.474	0.670	1.260	3.497	0.534
2003	0.883	0.970	0.390	0.193	0.475	0.667	1.057	3.126	0.601
2004	0.775	0.926	0.606	0.169	0.469	0.638	1.244	3.435	0.670
2005	1.366	1.455	0.681	0.269	0.456	0.726	1.407	3.791	0.745
2006	2.840	2.950	0.990	0.350	0.521	0.871	1.860	4.829	0.775
2007	2.549	2.772	1.898	0.560	0.631	1.192	3.090	7.496	0.776
2008	3.949	4.159	1.989	0.957	0.882	1.839	3.827	9.735	0.793

Table 9. Estimated recruits to the model (Model R), abundance (P2, P1, R, P, 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. *F* = 0.0 for 2008.

Year	Model R	P2	P1	R	P	Legals	Matures	Bio215	Molt1
1978	NA	1.634	1.580	0.837	0.415	1.252	2.831	6.077	0.768
1979	2.710	2.856	1.509	0.891	0.735	1.626	3.136	9.047	0.814
1980	2.422	2.684	2.322	0.992	1.375	2.367	4.689	14.043	0.849
1981	1.369	1.615	2.331	1.500	2.048	3.547	5.879	14.537	0.931
1982	1.380	1.526	1.421	1.540	2.187	3.727	5.147	9.795	1.000
1983	0.580	0.715	1.144	1.007	1.543	2.550	3.694	4.491	1.000
1984	0.449	0.512	0.567	0.766	0.534	1.299	1.867	2.745	0.923
1985	0.730	0.775	0.418	0.363	0.395	0.759	1.177	1.824	0.854
1986	0.720	0.788	0.592	0.268	0.235	0.504	1.096	2.232	0.893
1987	1.043	1.113	0.627	0.389	0.258	0.647	1.274	2.753	0.942
1988	1.132	1.232	0.834	0.448	0.368	0.816	1.650	3.575	0.940
1989	1.920	2.030	0.942	0.583	0.461	1.044	1.986	4.874	0.890
1990	1.639	1.823	1.544	0.667	0.701	1.368	2.912	6.843	0.814
1991	1.576	1.740	1.584	0.935	0.869	1.804	3.388	7.169	0.770
1992	1.682	1.837	1.572	0.895	0.939	1.834	3.406	8.079	0.751
1993	1.637	1.802	1.670	0.883	1.122	2.005	3.675	8.674	0.730
1994	1.382	1.544	1.695	0.906	1.191	2.097	3.792	8.271	0.707
1995	2.228	2.366	1.544	0.873	1.096	1.968	3.513	8.112	0.756
1996	1.958	2.170	2.009	0.897	1.125	2.022	4.032	9.285	0.748
1997	1.254	1.448	2.013	1.113	1.192	2.304	4.317	9.159	0.673
1998	0.992	1.151	1.595	0.968	1.179	2.148	3.742	2.756	0.597
1999	0.365	0.409	0.262	0.141	0.229	0.370	0.632	2.028	0.578
2000	0.282	0.370	0.343	0.122	0.317	0.439	0.782	2.539	0.519
2001	0.372	0.475	0.347	0.137	0.376	0.513	0.860	2.861	0.436
2002	0.004	0.178	0.384	0.120	0.436	0.556	0.940	3.161	0.437
2003	0.407	0.472	0.274	0.122	0.473	0.595	0.869	3.106	0.498
2004	0.318	0.460	0.363	0.112	0.504	0.615	0.978	3.400	0.560
2005	0.601	0.708	0.410	0.160	0.524	0.684	1.094	3.740	0.656
2006	1.406	1.499	0.608	0.220	0.585	0.805	1.412	4.615	0.695
2007	1.336	1.474	1.233	0.368	0.693	1.061	2.294	6.870	0.716
2008	2.029	2.164	1.396	0.686	0.931	1.616	3.012	9.277	0.743

Table 10. Estimated recruits to the model (Model R), abundance (P2, P1, R, P, legals and matures), mature male biomass on February 15 (Bio215), and molting probabilities for pre-recruit-1s (Molt1) for model scenario (4) fixing *M* for the whole time period and *Q*. Recruits and abundance are in million of crab and biomass is in million lbs. *F* = 0.0 for 2008.

Year	Model R	P2	P1	R	P	Legals	Matures	Bio215	Molt1
1978	NA	1.951	1.816	0.991	0.490	1.481	3.297	7.395	0.692
1979	2.996	3.172	1.891	0.942	0.929	1.871	3.762	10.879	0.709
1980	2.778	3.069	2.775	1.086	1.585	2.671	5.446	16.235	0.717
1981	0.973	1.254	2.964	1.532	2.302	3.834	6.798	17.053	0.741
1982	1.490	1.603	1.674	1.541	2.428	3.969	5.643	11.338	0.764
1983	0.644	0.786	1.500	0.920	1.739	2.659	4.160	5.670	0.767
1984	0.383	0.451	0.886	0.776	0.625	1.401	2.287	3.779	0.750
1985	0.854	0.894	0.531	0.454	0.487	0.941	1.472	2.760	0.736
1986	0.528	0.608	0.743	0.300	0.389	0.689	1.432	3.320	0.747
1987	1.147	1.202	0.613	0.402	0.415	0.817	1.430	3.455	0.765
1988	0.903	1.012	0.975	0.374	0.504	0.879	1.854	4.202	0.771
1989	2.601	2.692	0.932	0.552	0.512	1.064	1.996	4.976	0.761
1990	1.510	1.753	2.082	0.613	0.712	1.324	3.406	7.789	0.733
1991	1.605	1.763	1.776	1.112	0.845	1.957	3.734	8.060	0.707
1992	1.679	1.836	1.719	0.924	1.069	1.992	3.712	9.046	0.678
1993	1.887	2.080	1.777	0.874	1.254	2.128	3.905	9.440	0.645
1994	1.321	1.613	1.929	0.865	1.290	2.155	4.083	9.027	0.617
1995	1.782	2.053	1.667	0.862	1.144	2.006	3.673	8.534	0.594
1996	0.955	1.352	1.827	0.749	1.148	1.897	3.724	8.505	0.553
1997	0.499	0.818	1.477	0.728	1.063	1.791	3.269	6.166	0.508
1998	0.471	0.699	1.040	0.521	0.721	1.243	2.283	4.465	0.464
1999	0.125	0.352	0.798	0.340	0.533	0.873	1.670	5.145	0.463
2000	0.279	0.398	0.555	0.268	0.747	1.015	1.570	5.395	0.483
2001	0.461	0.587	0.457	0.200	0.861	1.061	1.518	5.500	0.482
2002	0.001	0.187	0.501	0.173	0.897	1.071	1.572	5.674	0.503
2003	0.441	0.497	0.326	0.182	0.907	1.089	1.414	5.377	0.543
2004	0.252	0.377	0.411	0.142	0.918	1.060	1.471	5.483	0.599
2005	1.277	1.350	0.386	0.187	0.898	1.085	1.471	5.480	0.652
2006	1.483	1.666	1.017	0.238	0.919	1.157	2.174	7.047	0.673
2007	1.152	1.340	1.463	0.555	1.001	1.556	3.019	9.333	0.677
2008	1.867	2.011	1.394	0.753	1.349	2.102	3.496	9.990	NA

Table 11. 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

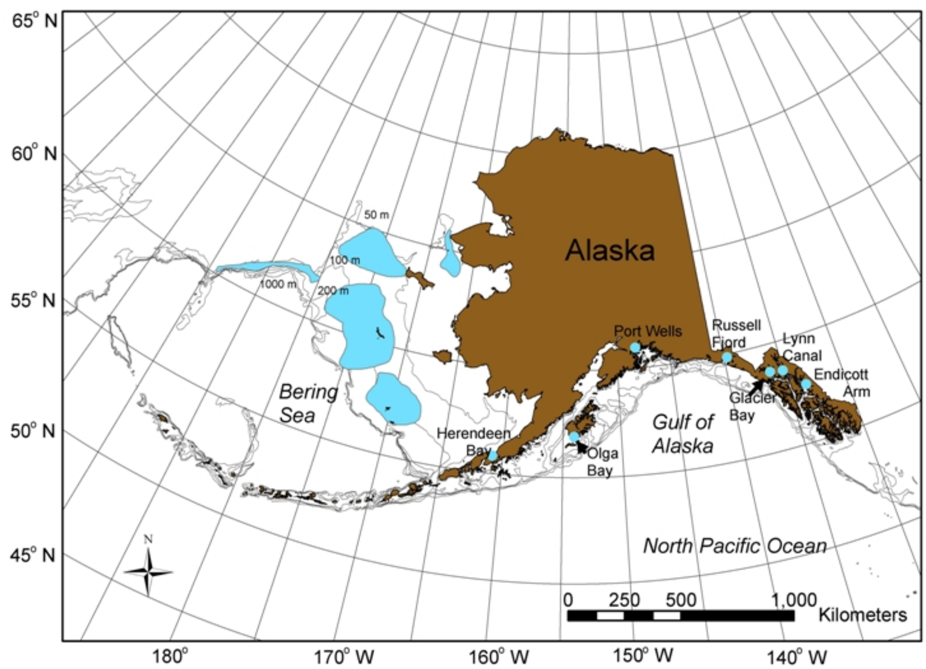


Figure 1. Distribution map of blue king crab *Paralithodes platypus* in the Gulf of Alaska, Bering Sea, and Aleutian Islands waters.

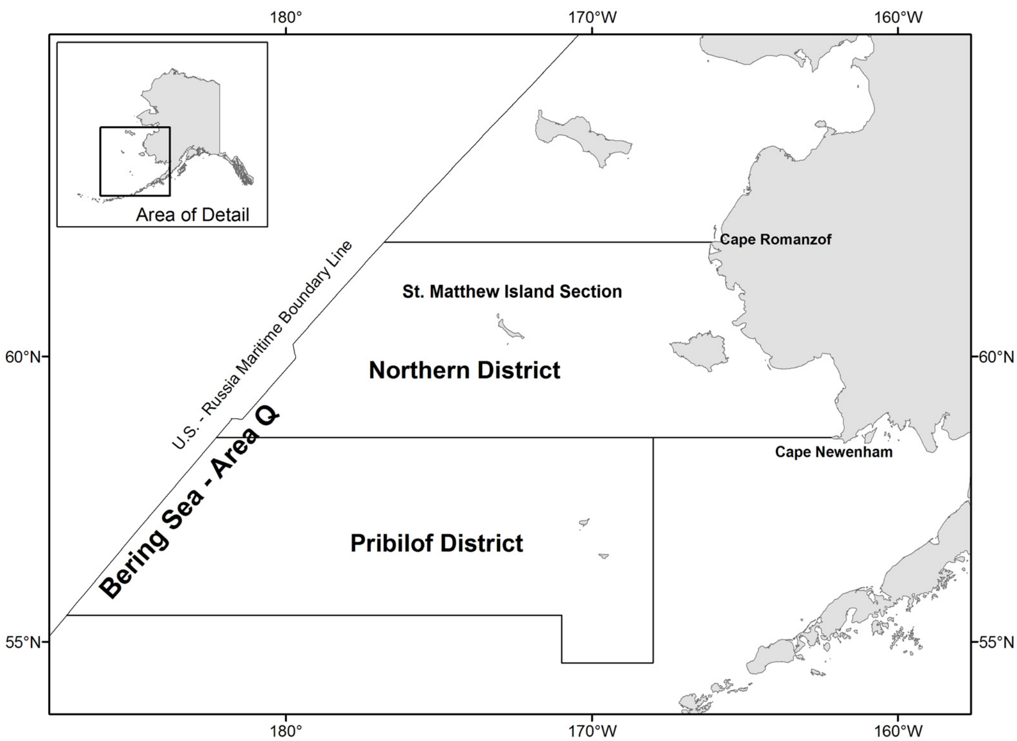


Figure 2. King crab Registration Area Q (Bering Sea).

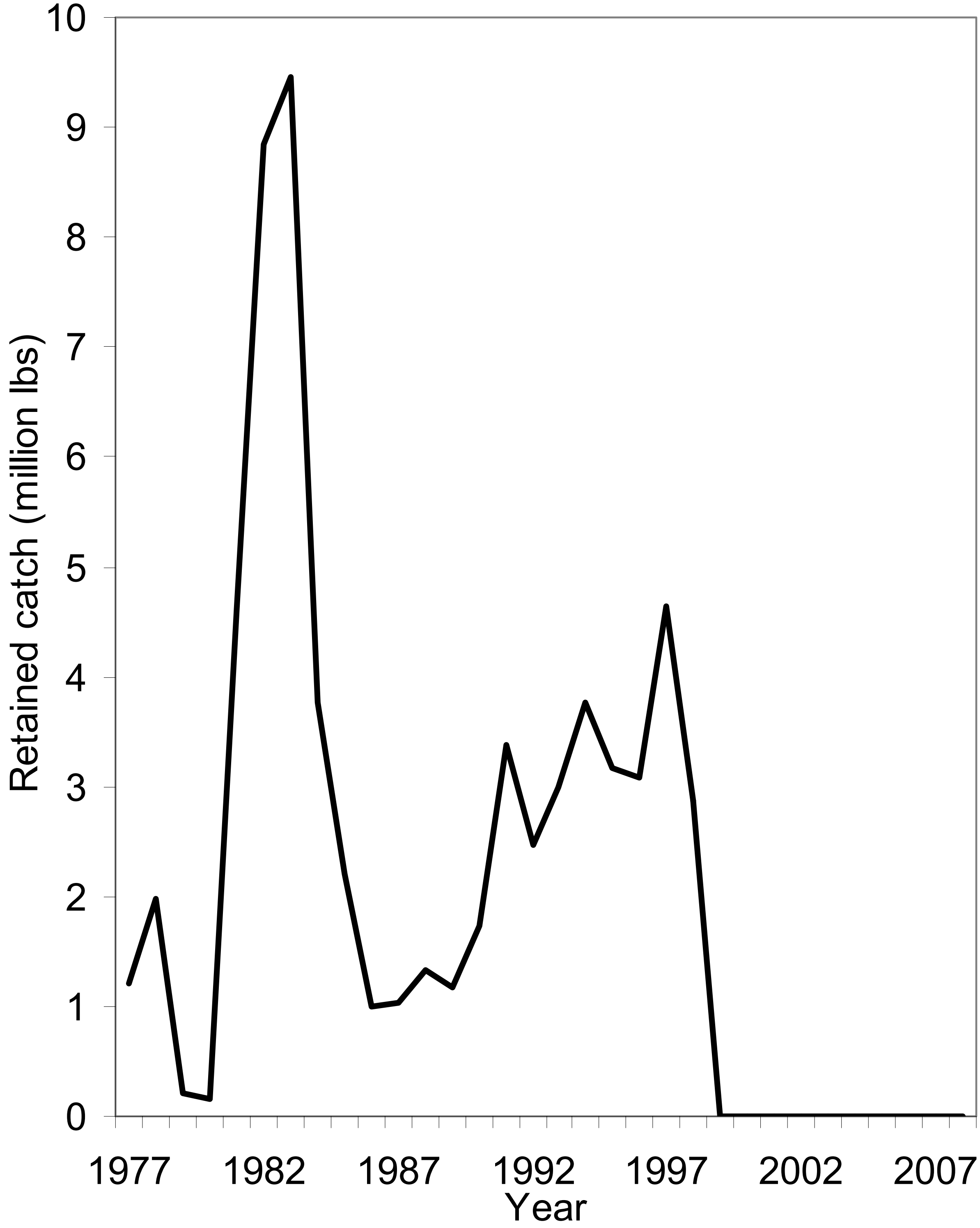


Figure 3. Retained catch over time for St. Matthew Island blue king crab.

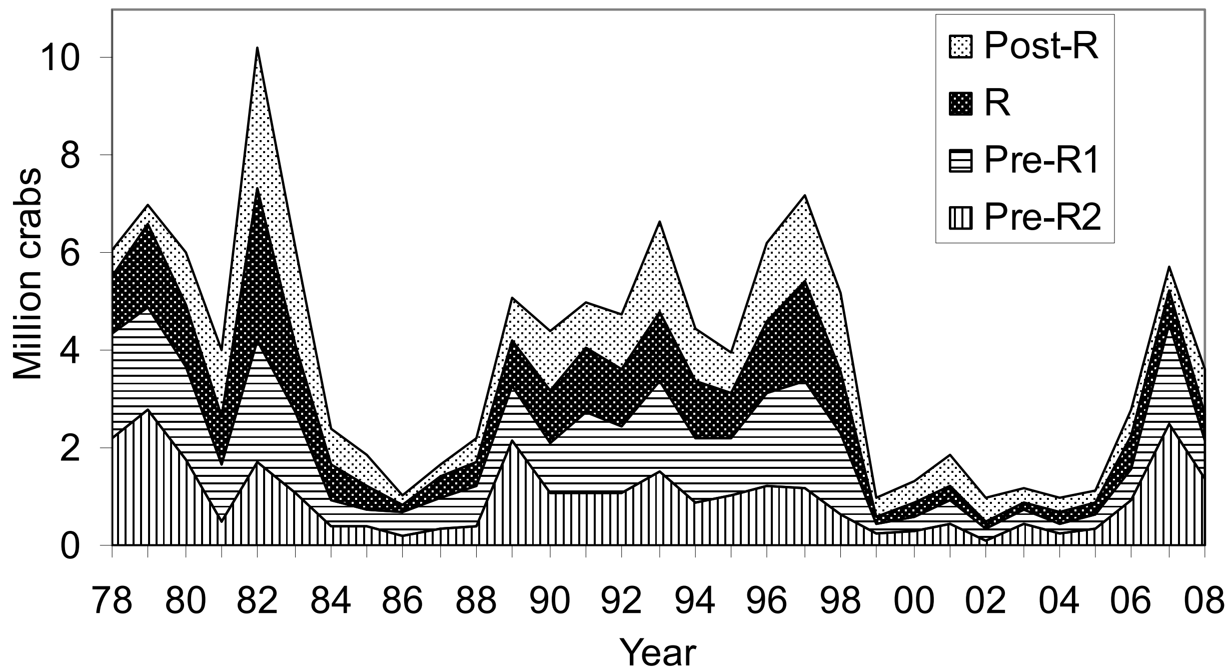


Figure 4. Area-swept abundance from trawl surveys from 1978 to 2008 for St. Matthew Island blue king crab.

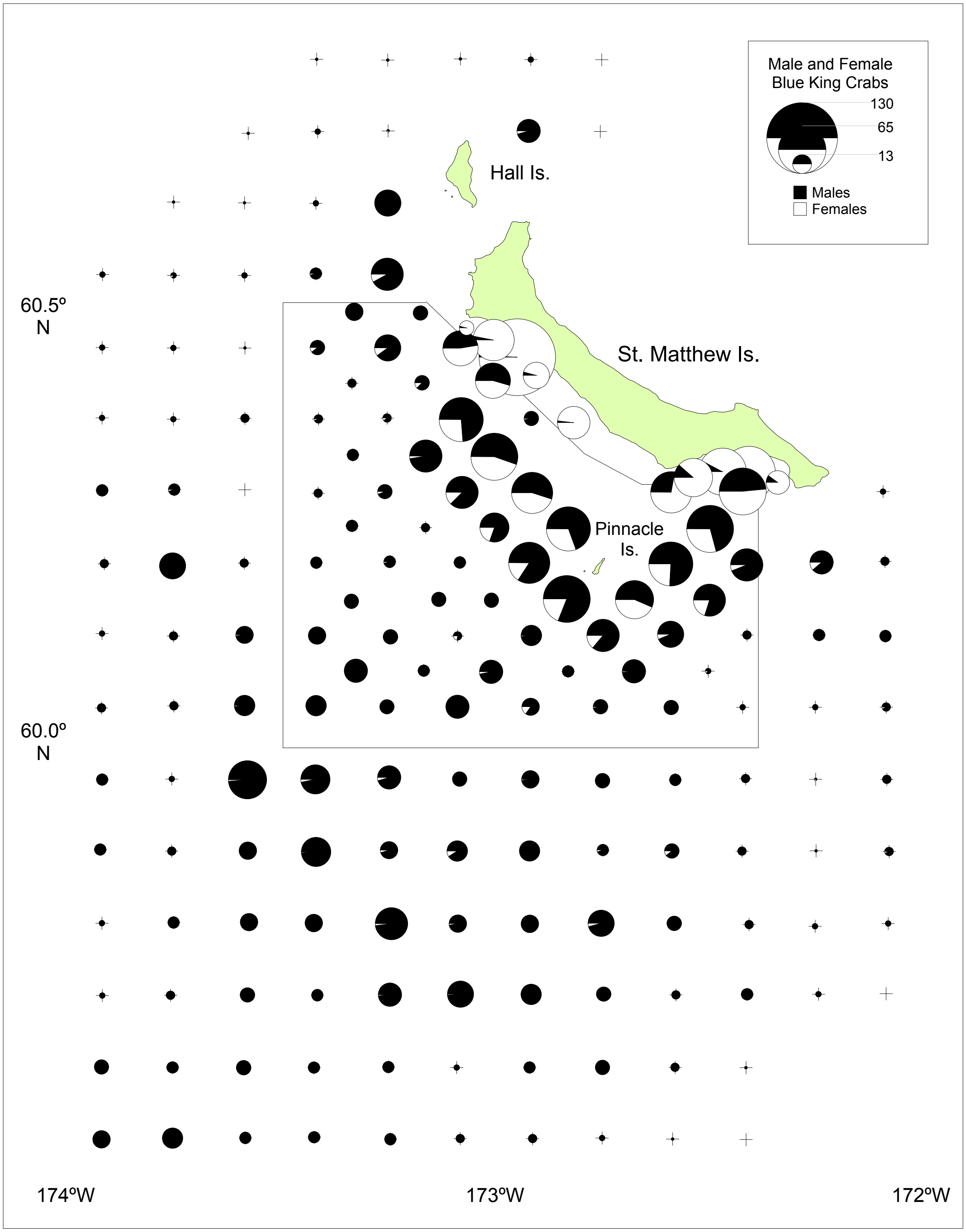


Figure 5. Male and female blue king crab catch per unit effort (CPUE) by station in the 2007 St. Matthew Island survey. (Source: Watson 2008).

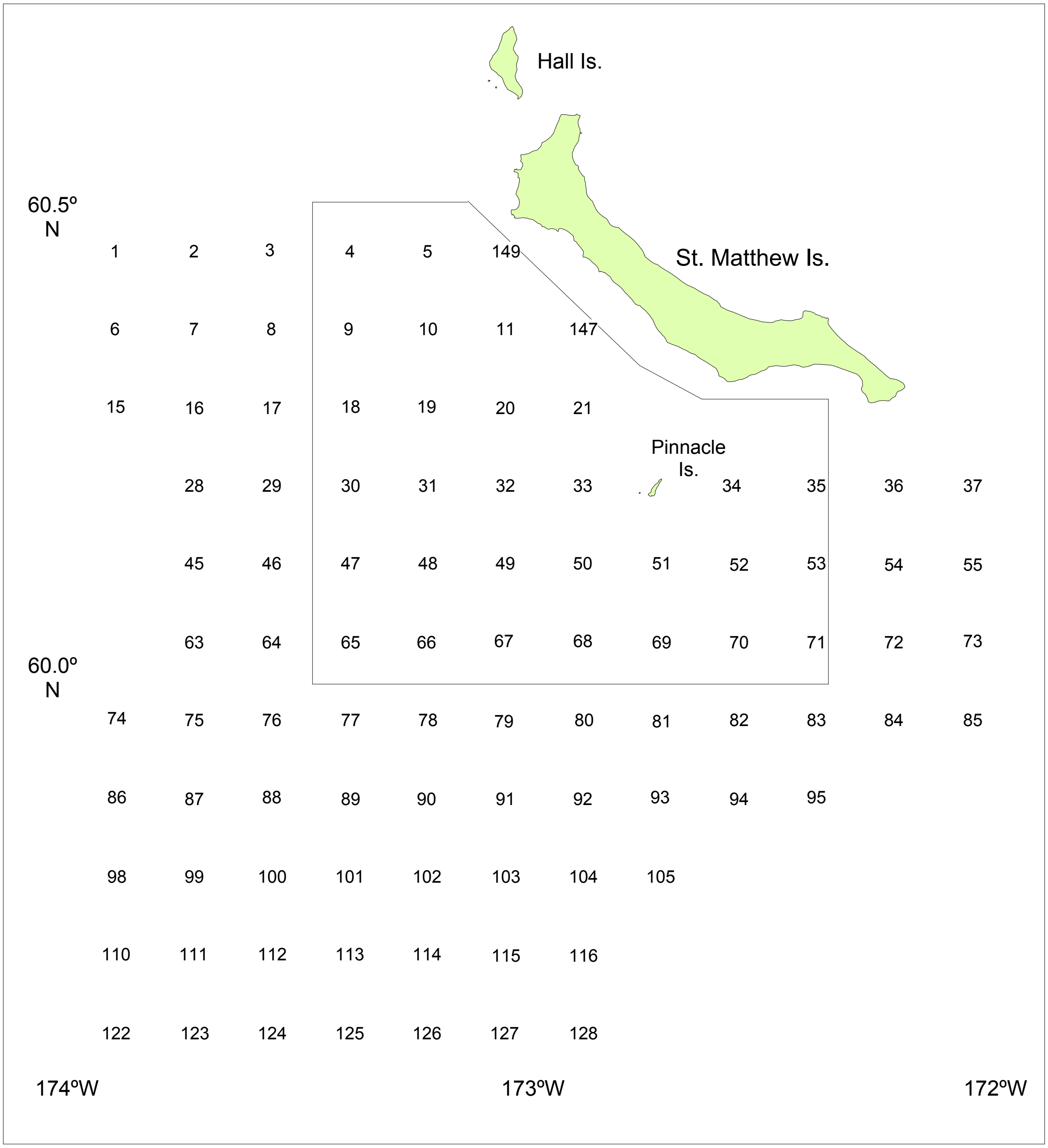


Figure 6. Location of the 96 stations fished in common during the five triennial St. Matthew Island blue king crab surveys, 1995 - 2007. (Source: Watson 2008).

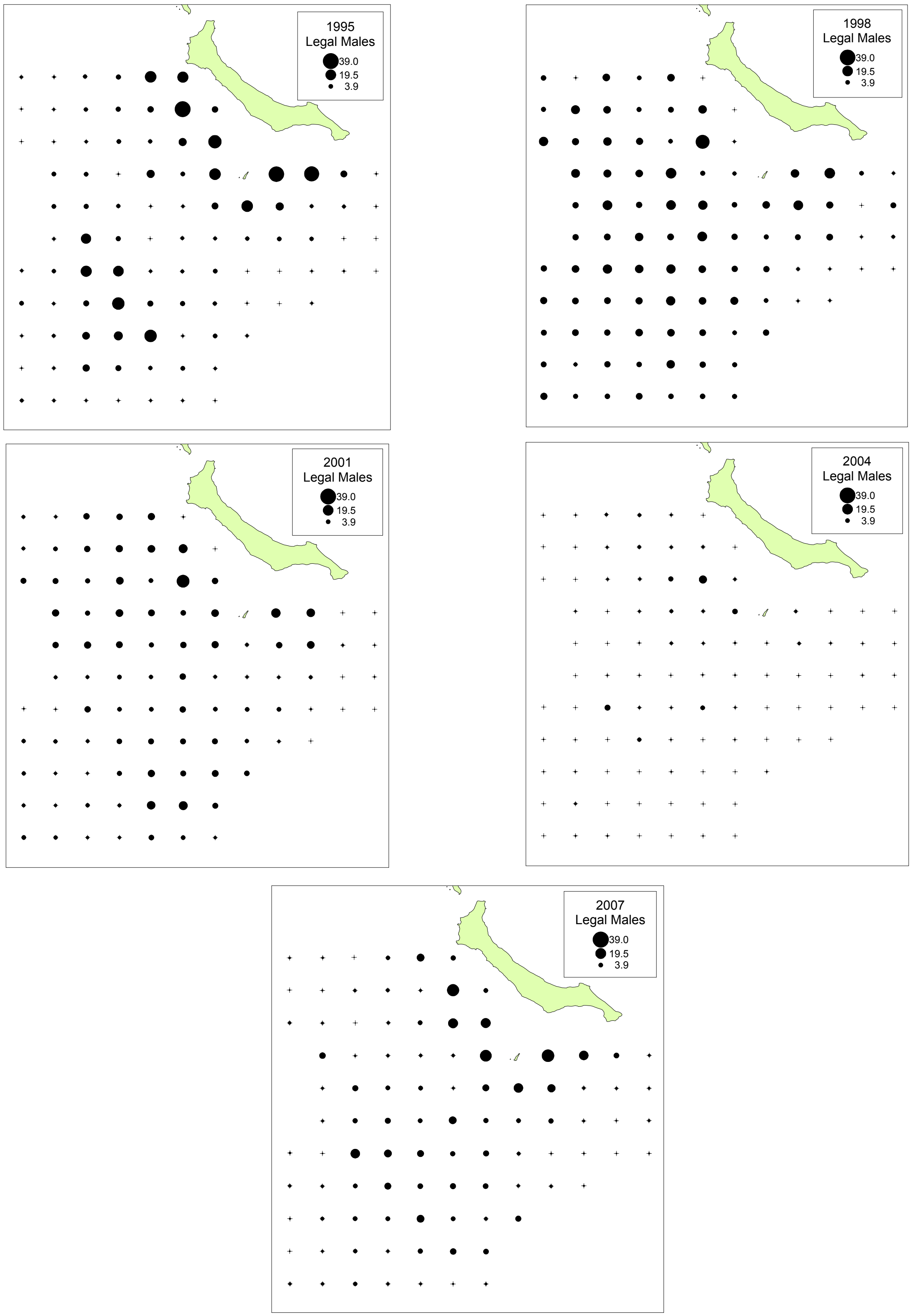


Figure 7. Legal male blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).

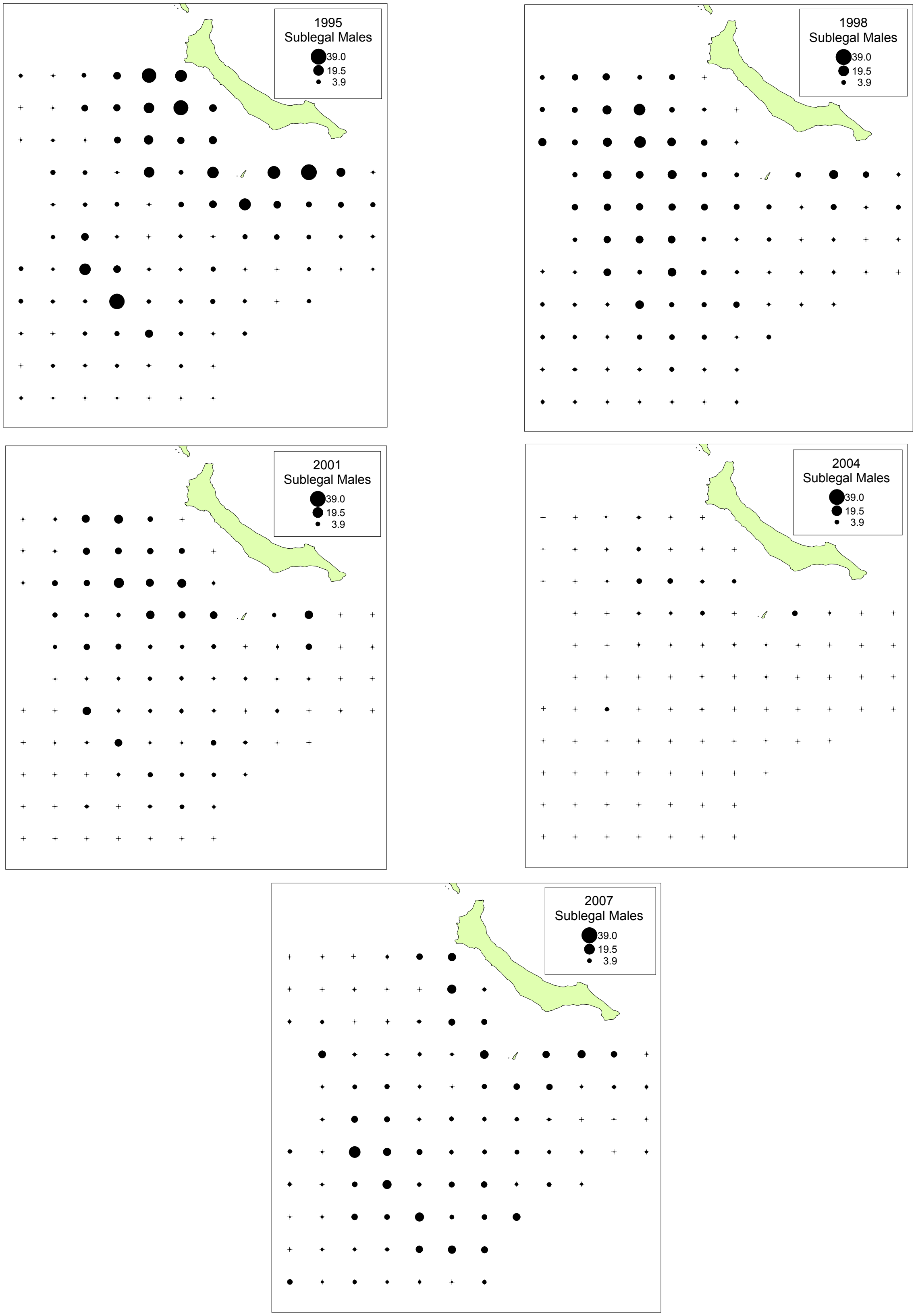


Figure 8. Sublegal male blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).

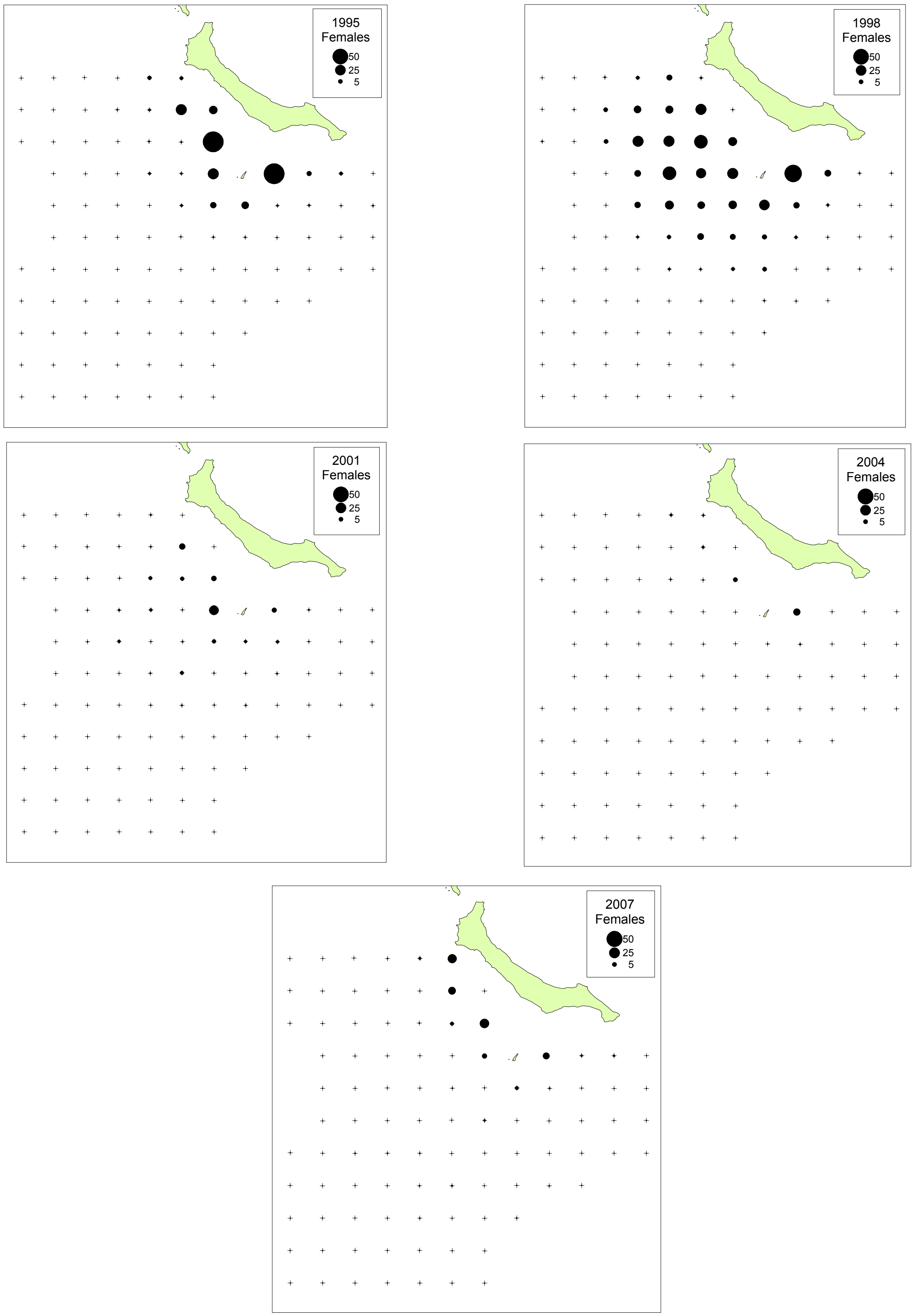


Figure 9. Female blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).

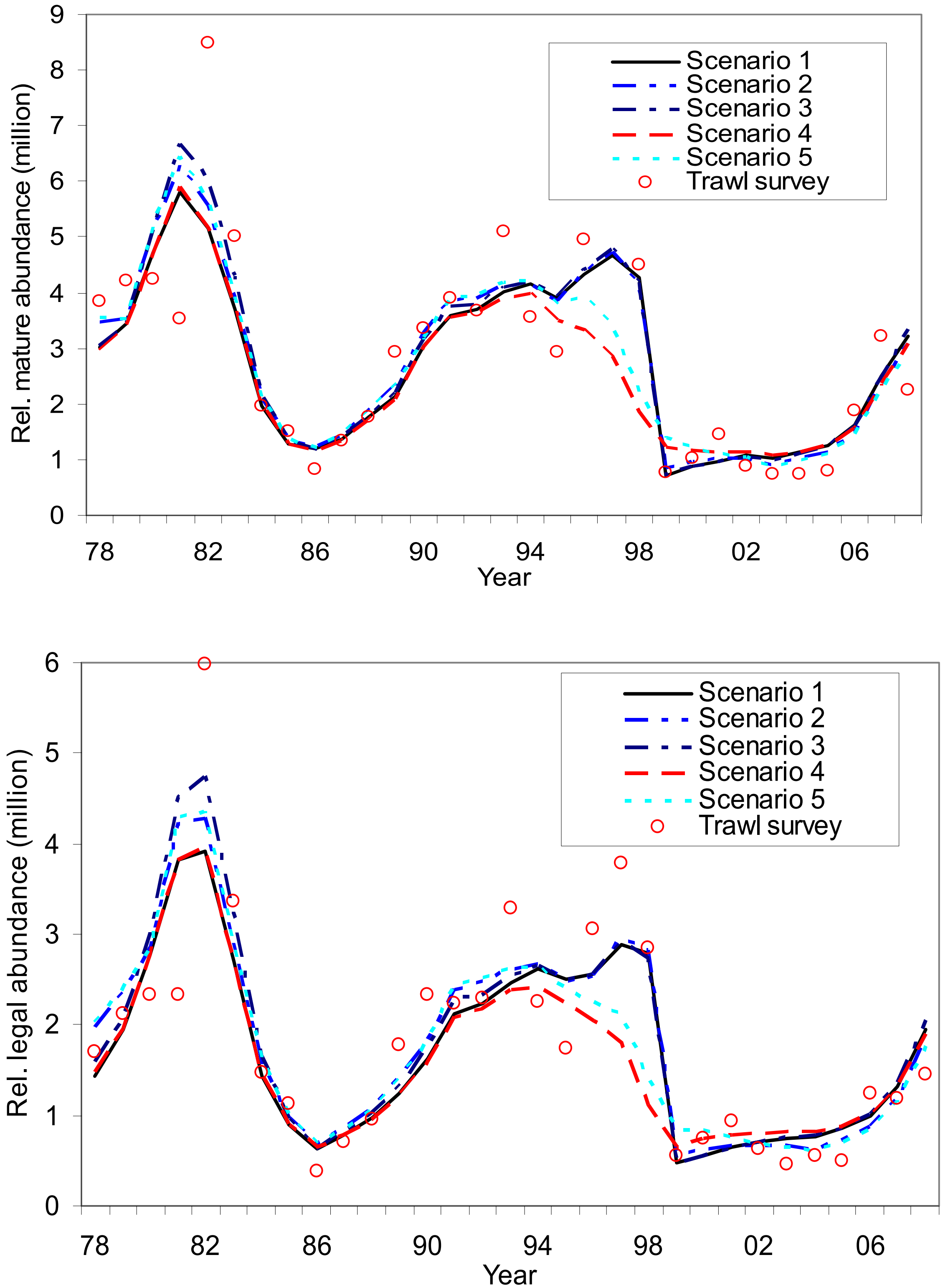
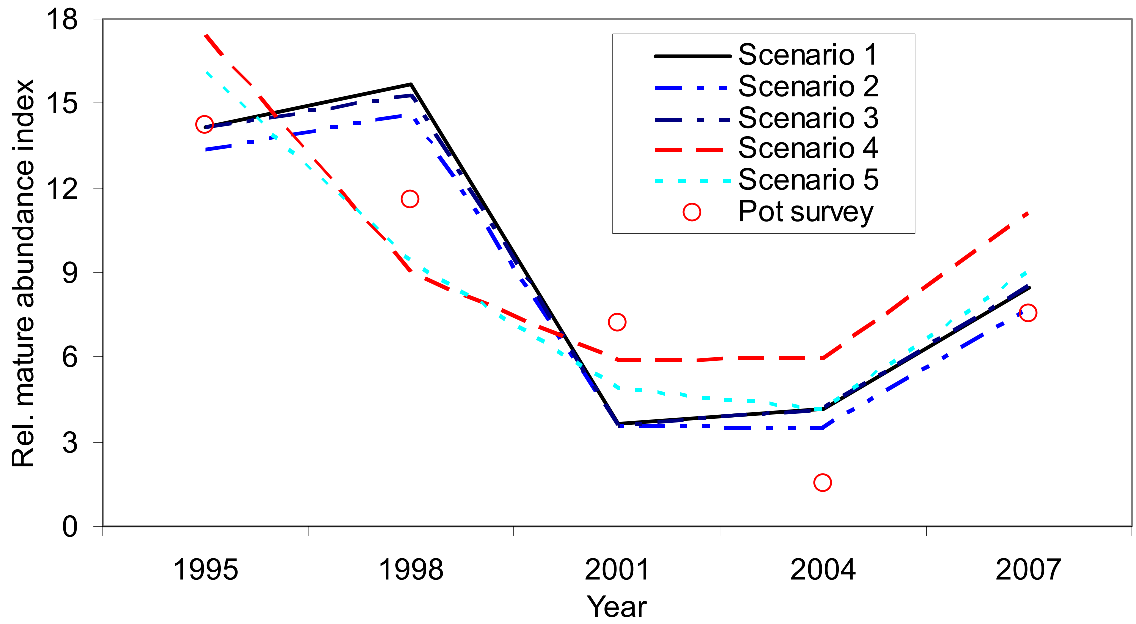


Figure 10. Comparison of relative mature male (upper plot) and legal abundance (lower plot) estimates of St. Matthew Island male blue king crab with five scenarios of the catch-survey analysis and trawl survey abundance.



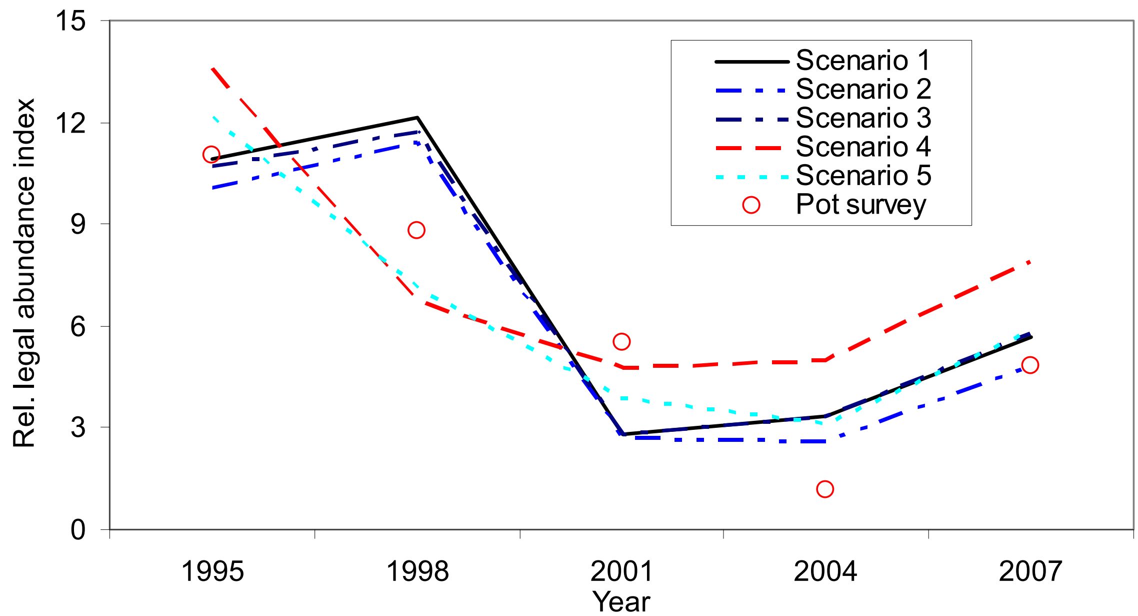


Figure 11. Comparison of relative mature male (upper plot) and legal abundance (lower plot) estimates of St. Matthew Island male blue king crab with five scenarios of the catch-survey analysis and pot survey abundance.

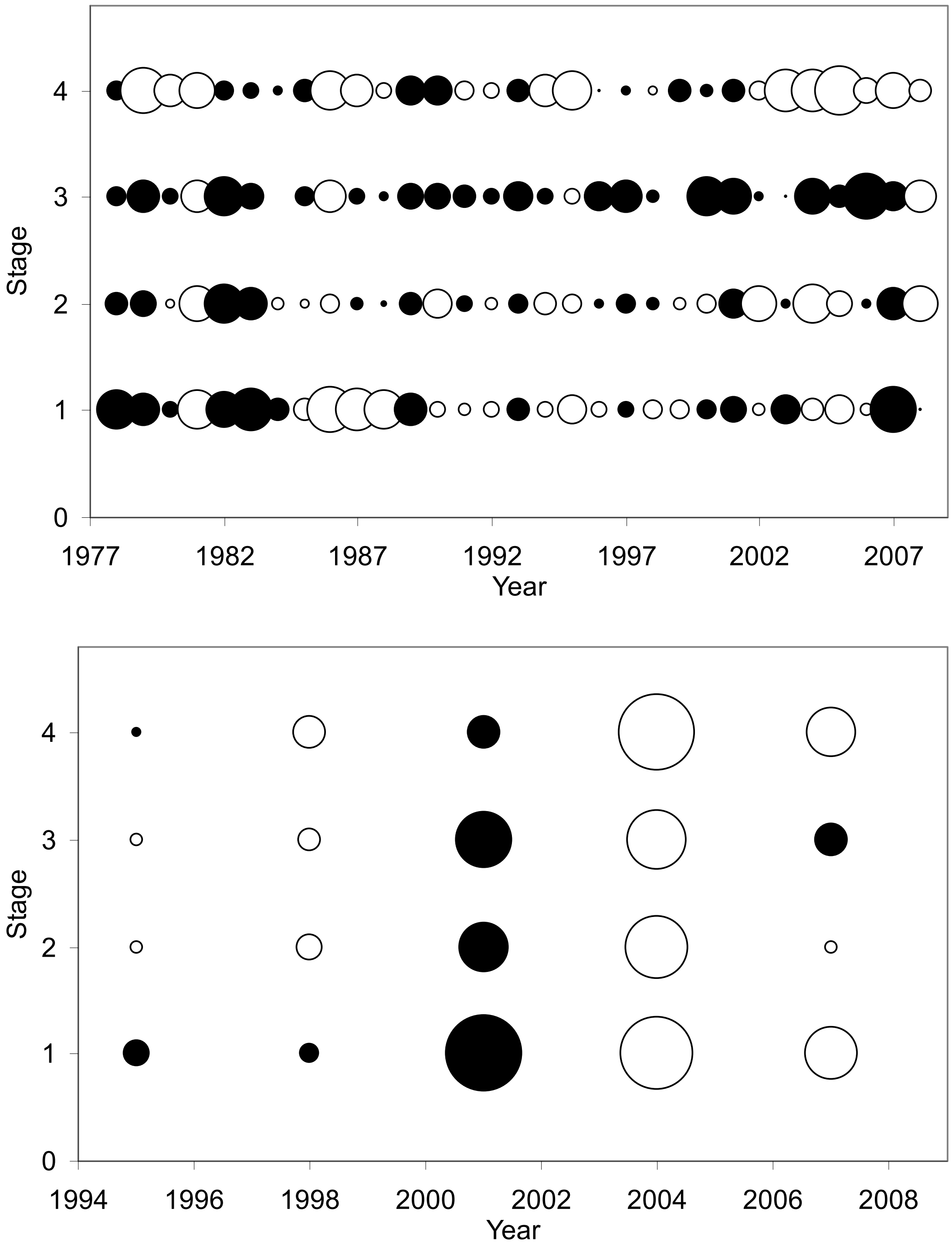


Figure 12. Residuals of the catch-survey analysis with scenario (1) of fixed both *M*=0.18 and *Q*=1. Upper plot is for trawl survey and lower plot is for pot survey. Stages 1-4 are prerecruit-2s, prerecruit-1s, recruits and postrecruits. Solid circles are positive residuals, and open circles are negative residuals.

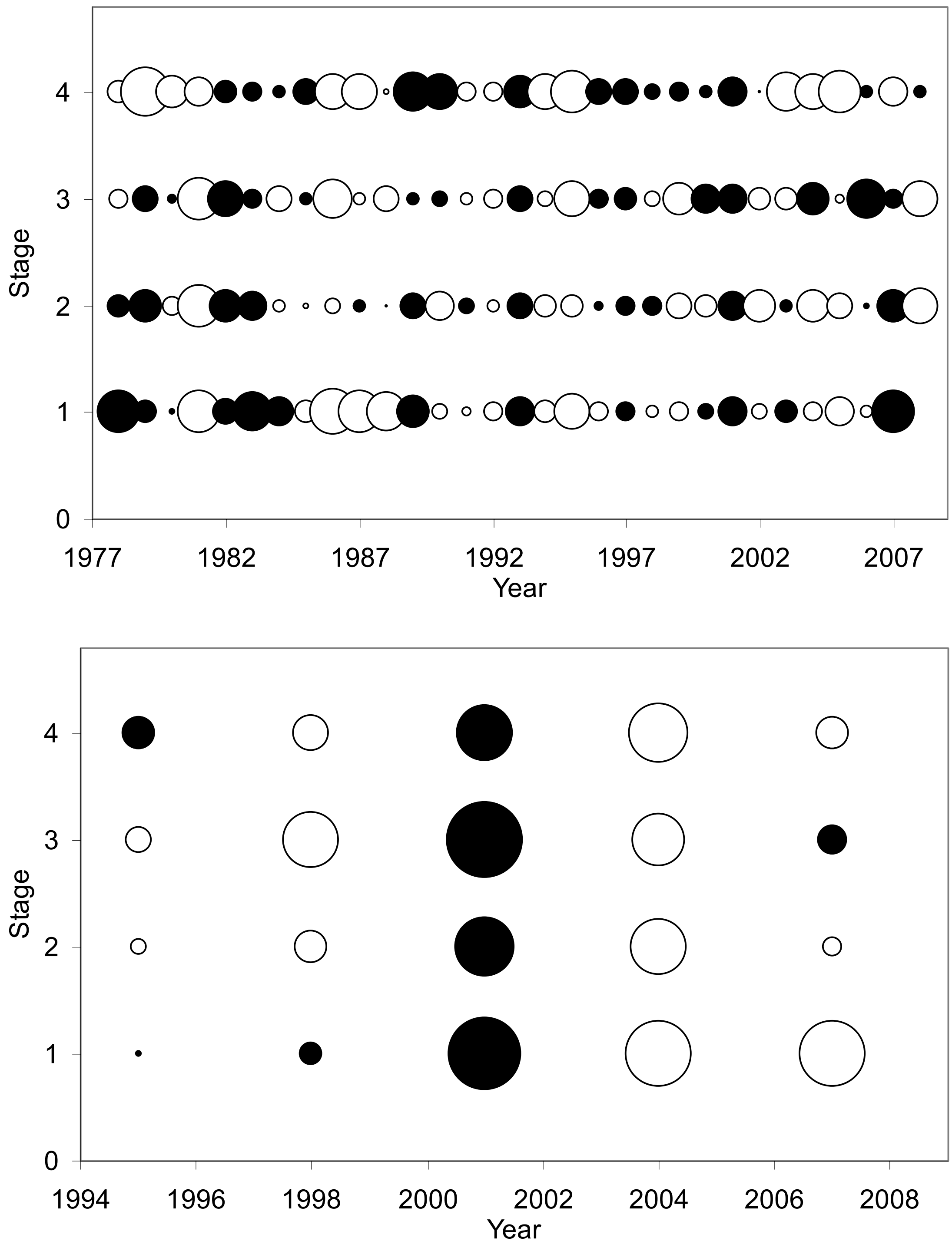
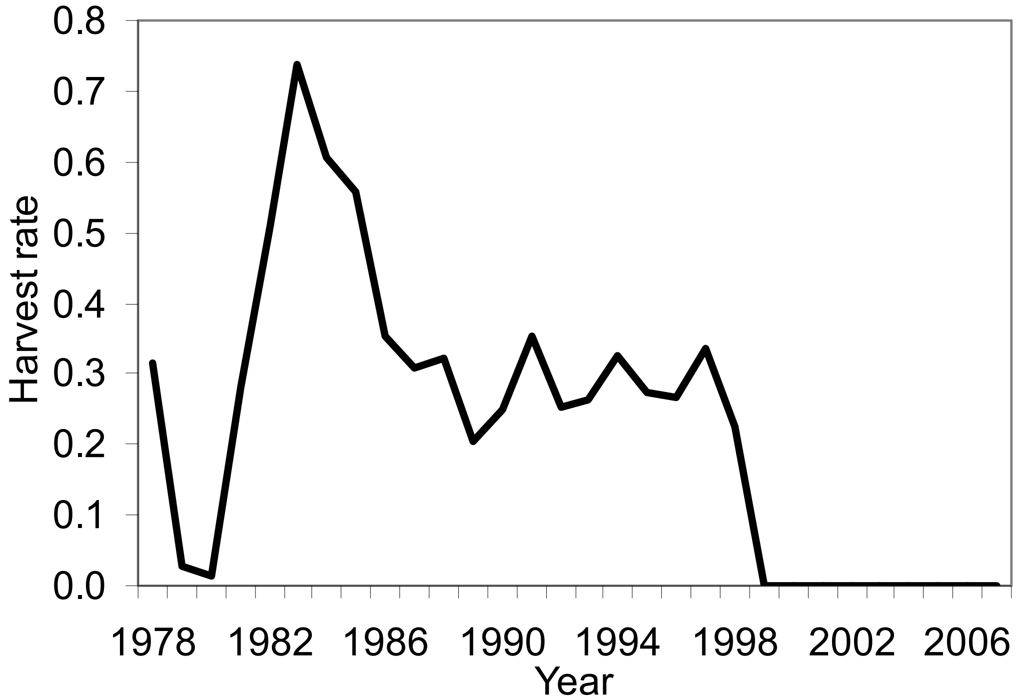


Figure 13. Residuals of the catch-survey analysis with scenario (2) of fixed Q=1 and estimating M. Upper plot is for trawl survey and lower plot is for pot survey. Stages 1-4 are prerecruit-2s, prerecruit-1s, recruits and postrecruits. Solid circles are positive residuals, and open circles are negative residuals.



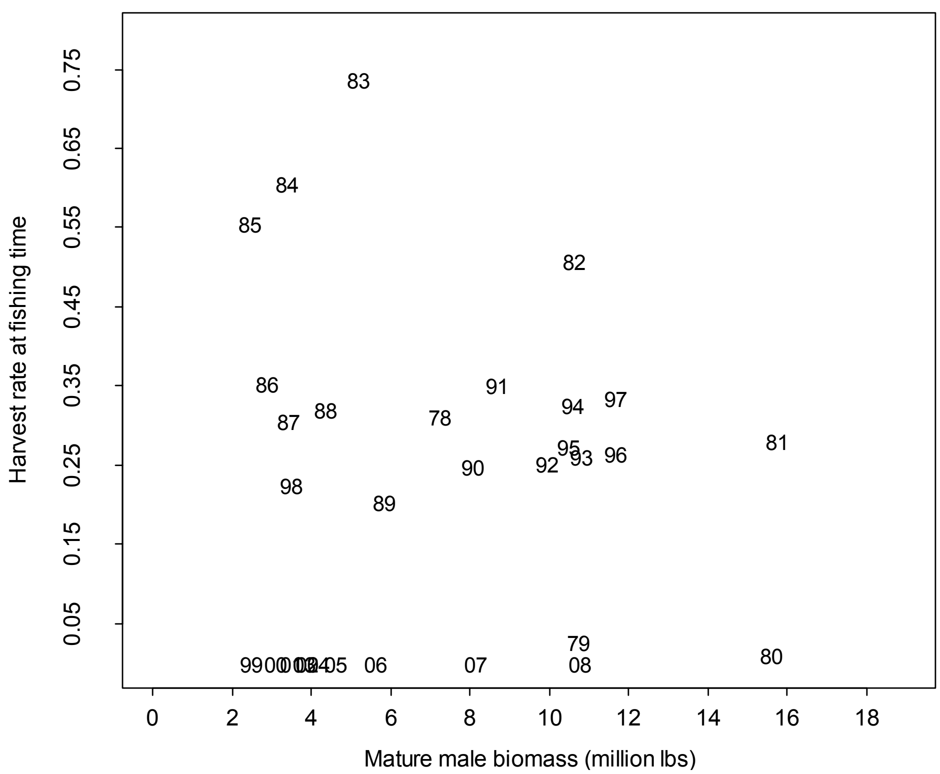


Figure 14. Estimated harvest rates (upper plot) and relationship between harvest rate and mature male biomass (lower plot) of St. Matthew Island blue king crab with scenario (1) of fixed *M*=0.18 and *Q*=1.0.

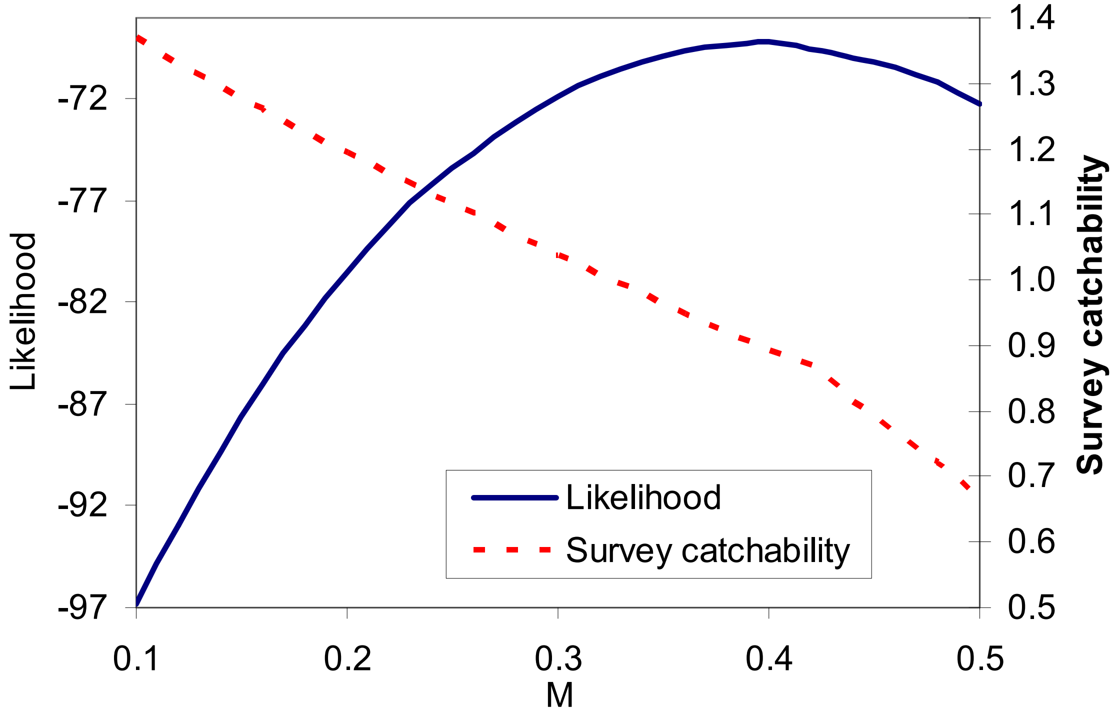
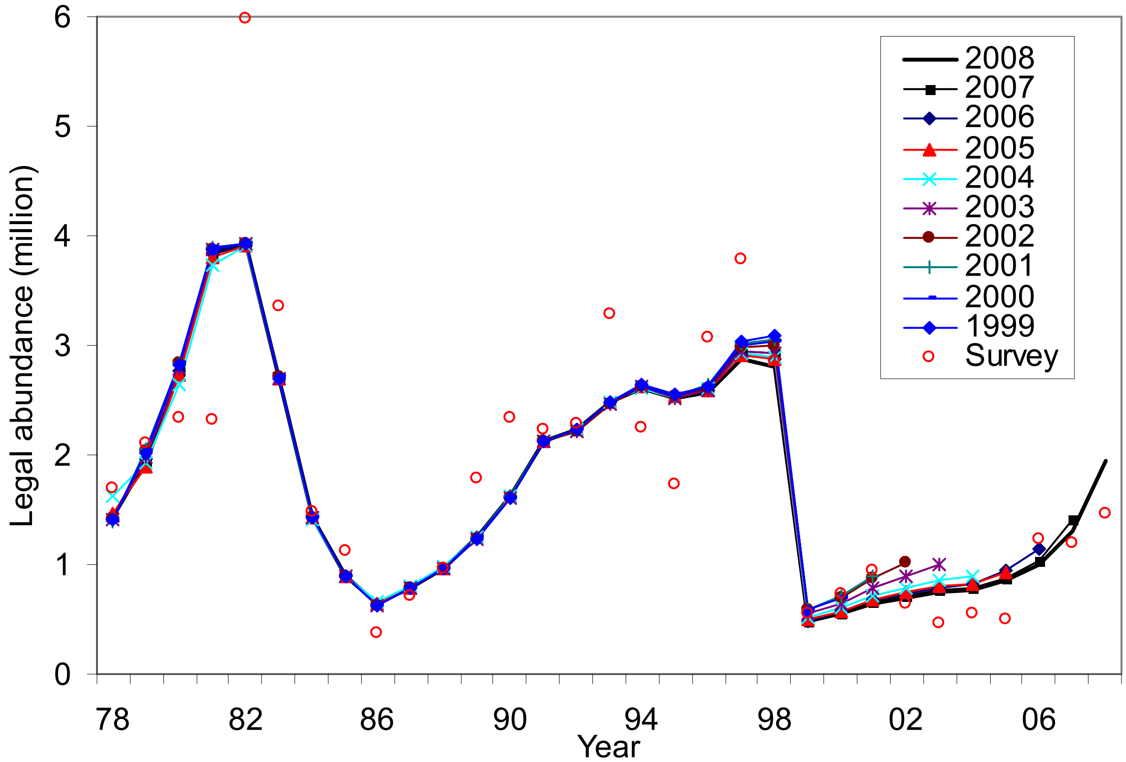


Figure 15. Relationships among natural mortaliy, trawl survey catchability and likelihood with a scenario of estimating natural mortality in 1999 and trawl survey catchability.Likelihood (similar to scenario 3).



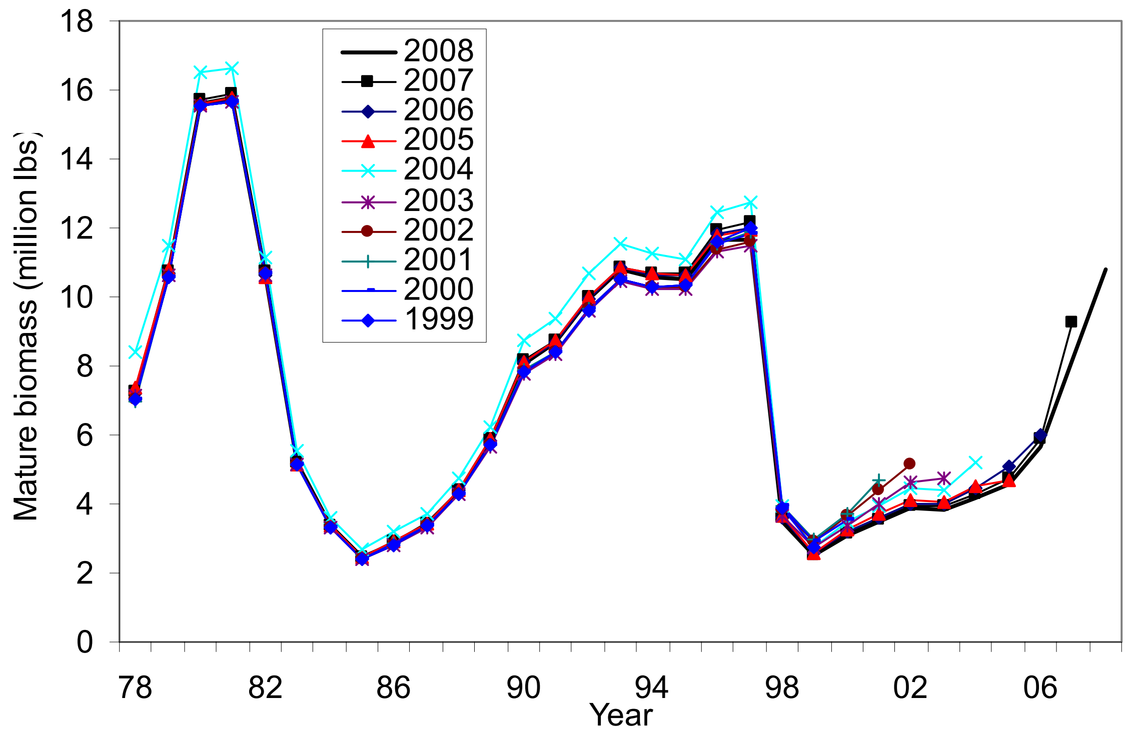
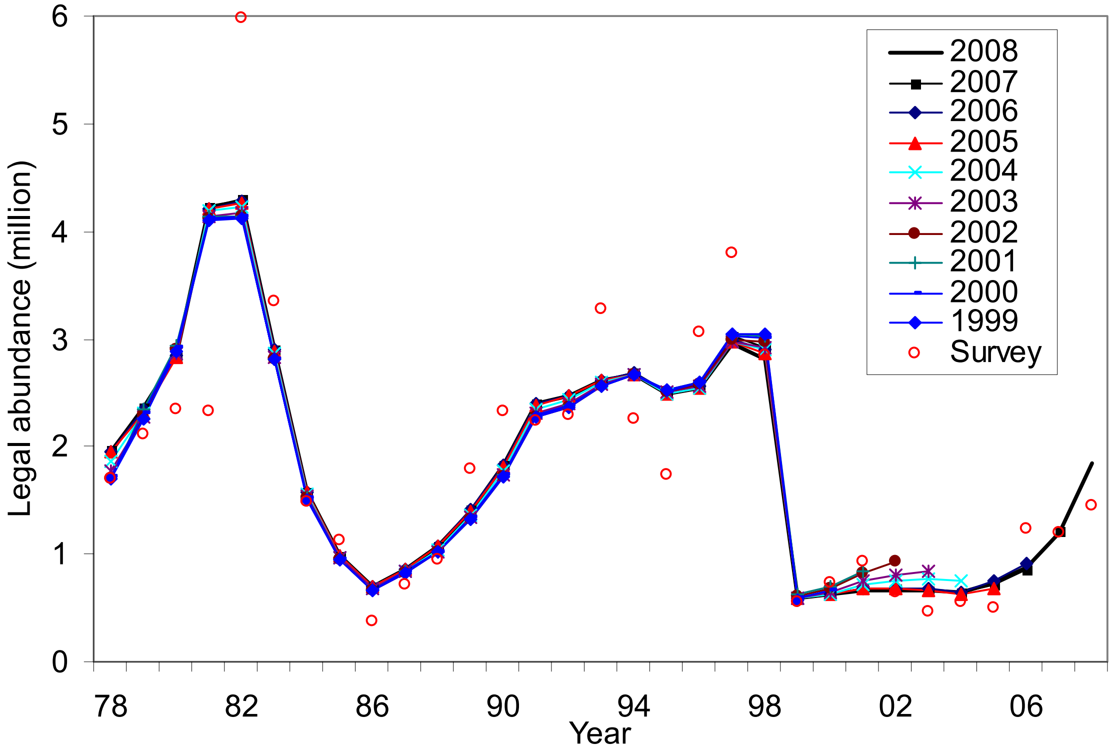


Figure 16. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2008 made with terminal years 1999-2008. These are results of the 2008 model with a fixed *M*=0.18 and *Q*=1.0 (scenario 1). Legend shows the year in which the assessment was conducted.



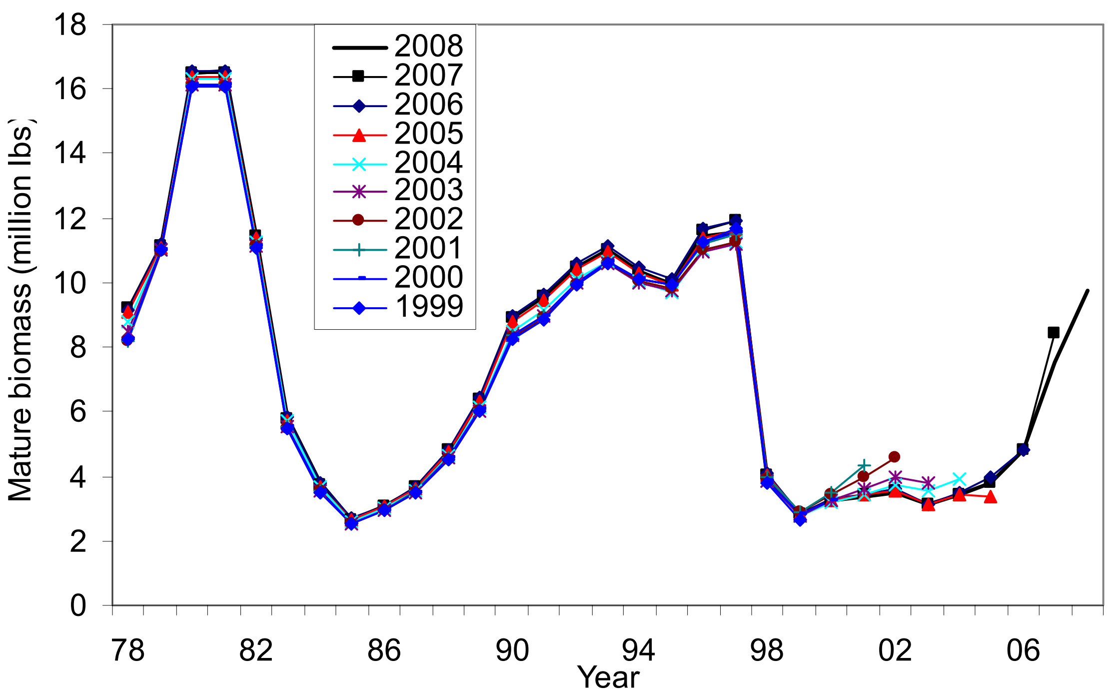


Figure 17. Comparison of estimates of legal male abundance and mature male biomass (lower plot) of St. Matthew Island blue king crab with terminal years 1999-2008. The 2008 model was with a fixed Q=1.0 and estimating 2 *Ms* (scenario 2). Legend shows the year in which the assessment was conducted.

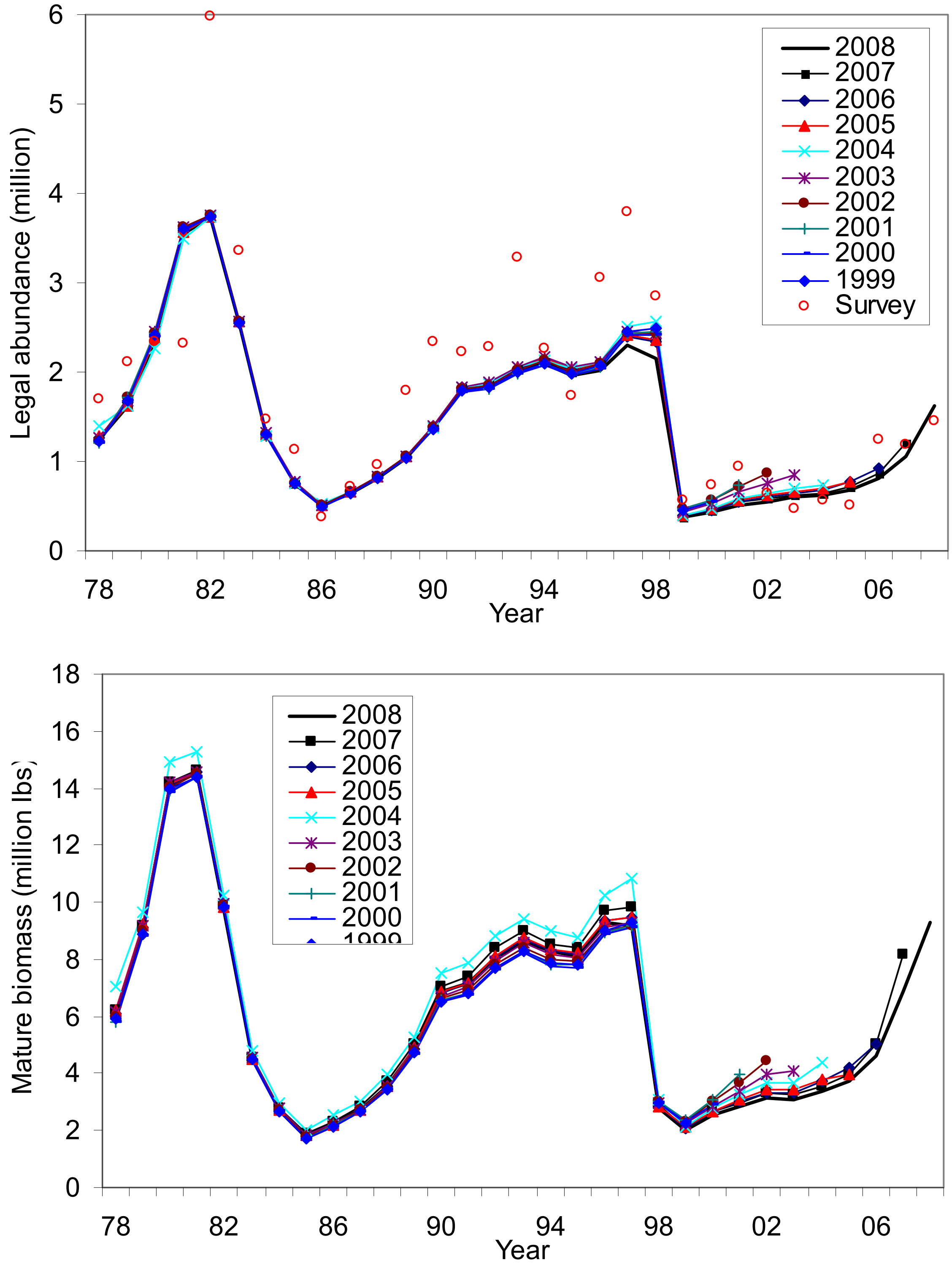
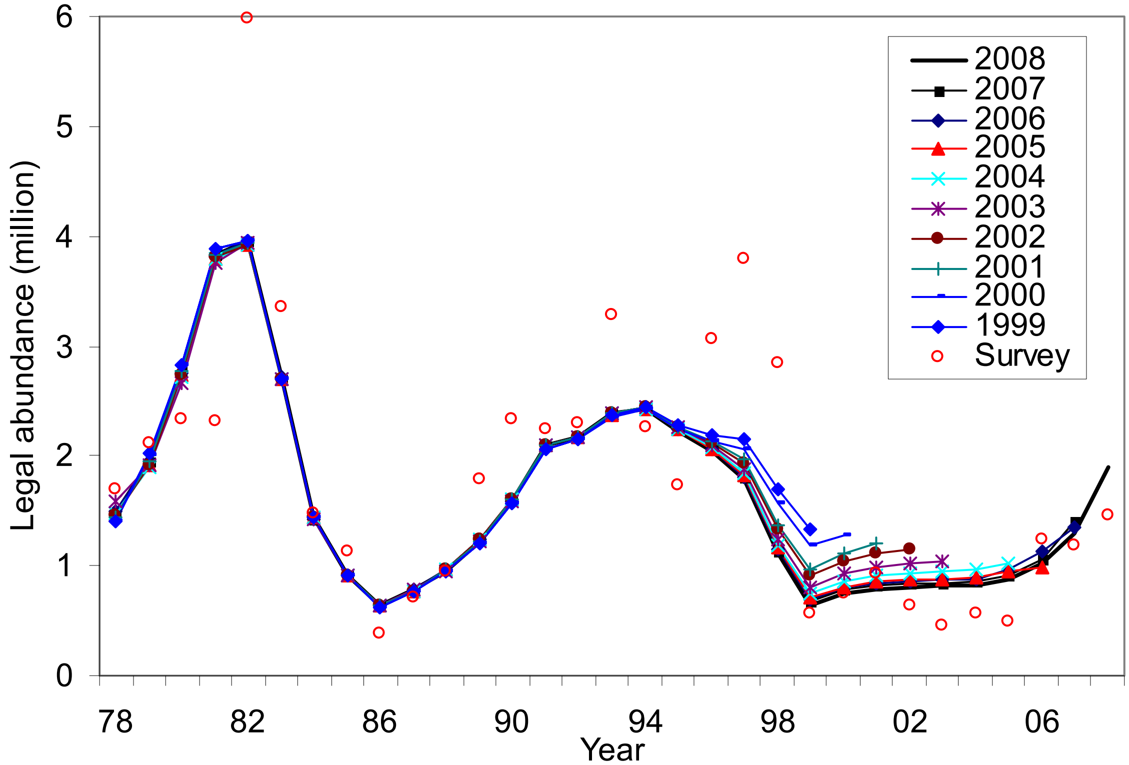


Figure 18. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2008 made with terminal years 1999-2008. These are results of the 2008 model with a fixed *M*=0.18 and estimating *Q* (scenario 3). Legend shows the year in which the assessment was conducted.



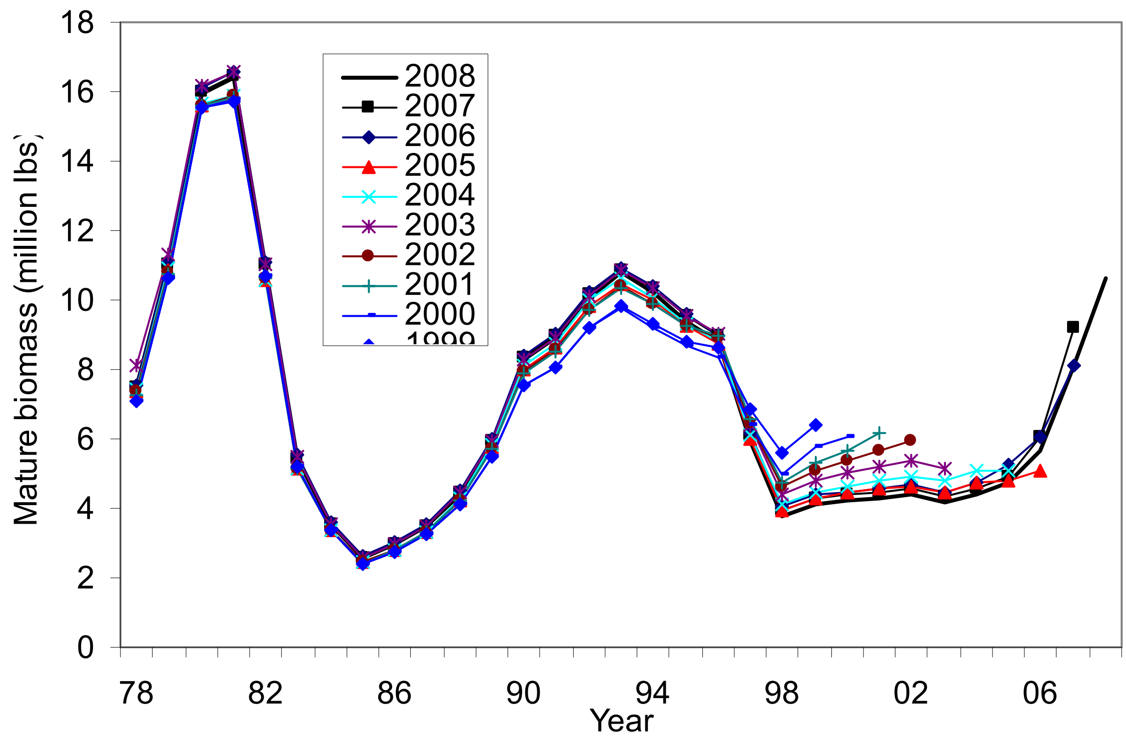
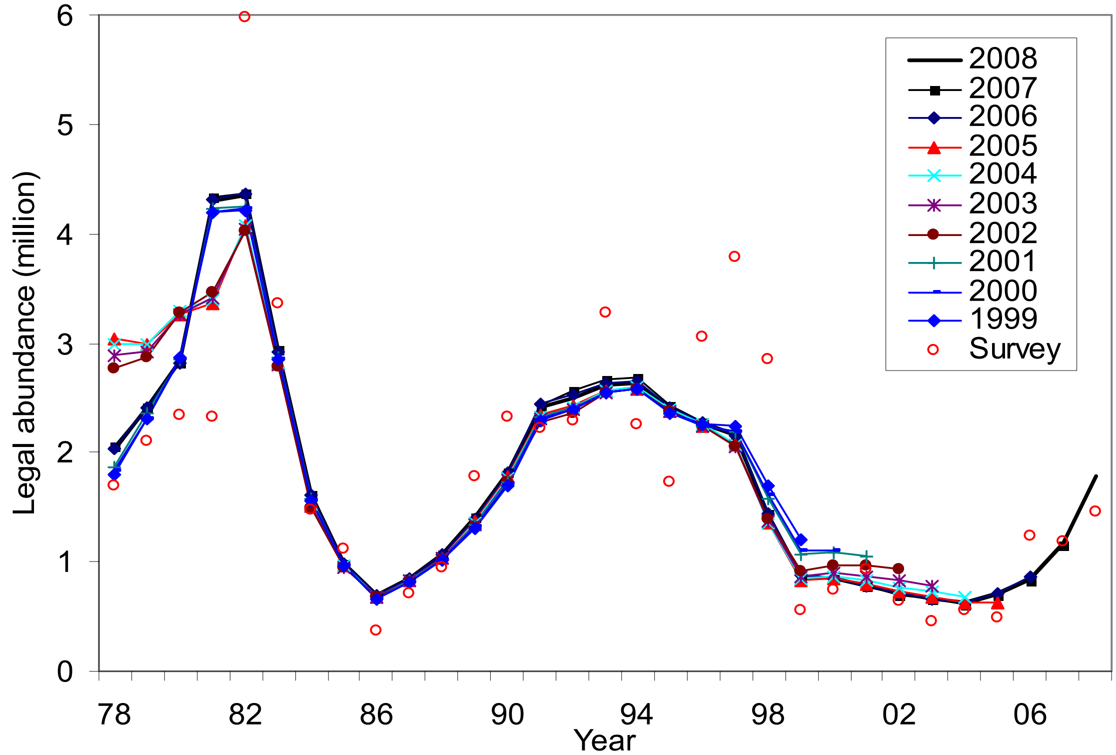


Figure 19. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2008 made with terminal years 1999-2008. These are results of the 2008 model with a fixed M=0.18 and Q=1.0 (scenario 4). Legend shows the year in which the assessment was conducted.



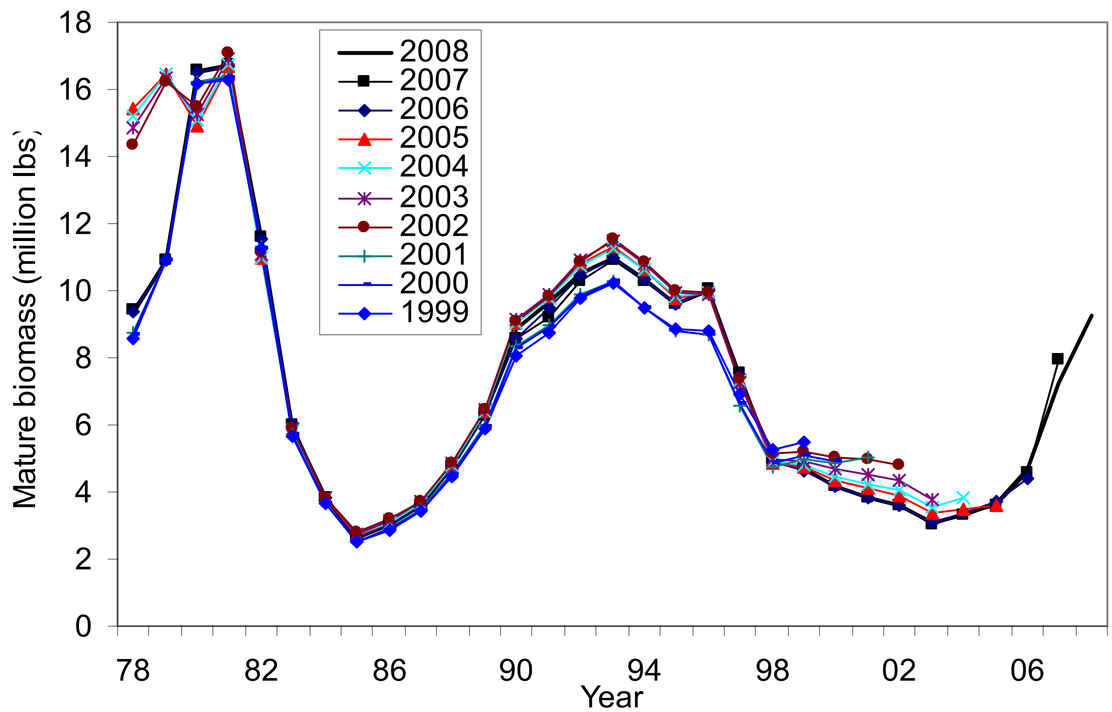


Figure 20. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2008 made with terminal years 1999-2008. These are results of the 2008 model with a fixed Q=1 and estimating a single M (scenario 5). Legend shows the year in which the assessment was conducted.

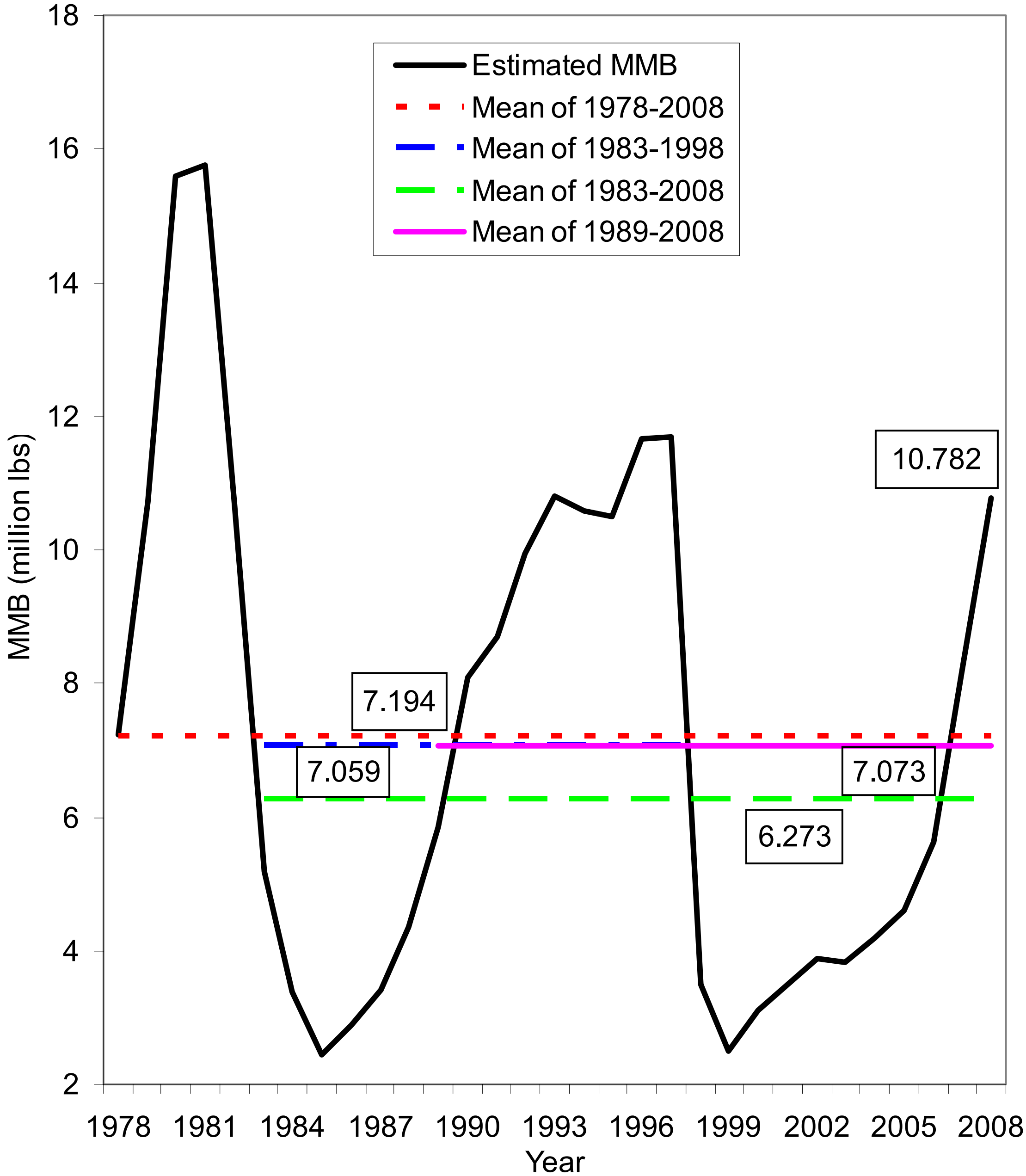


Figure 21. Comparison of estimated mean mature male biomasses during different periods of St. Matthew Island blue king crab. The model was with a fixed M=0.18 and Q=1.0 (scenario 1). γ = 0 was used for the 2008 fishery to project mature male biomass in 2008.

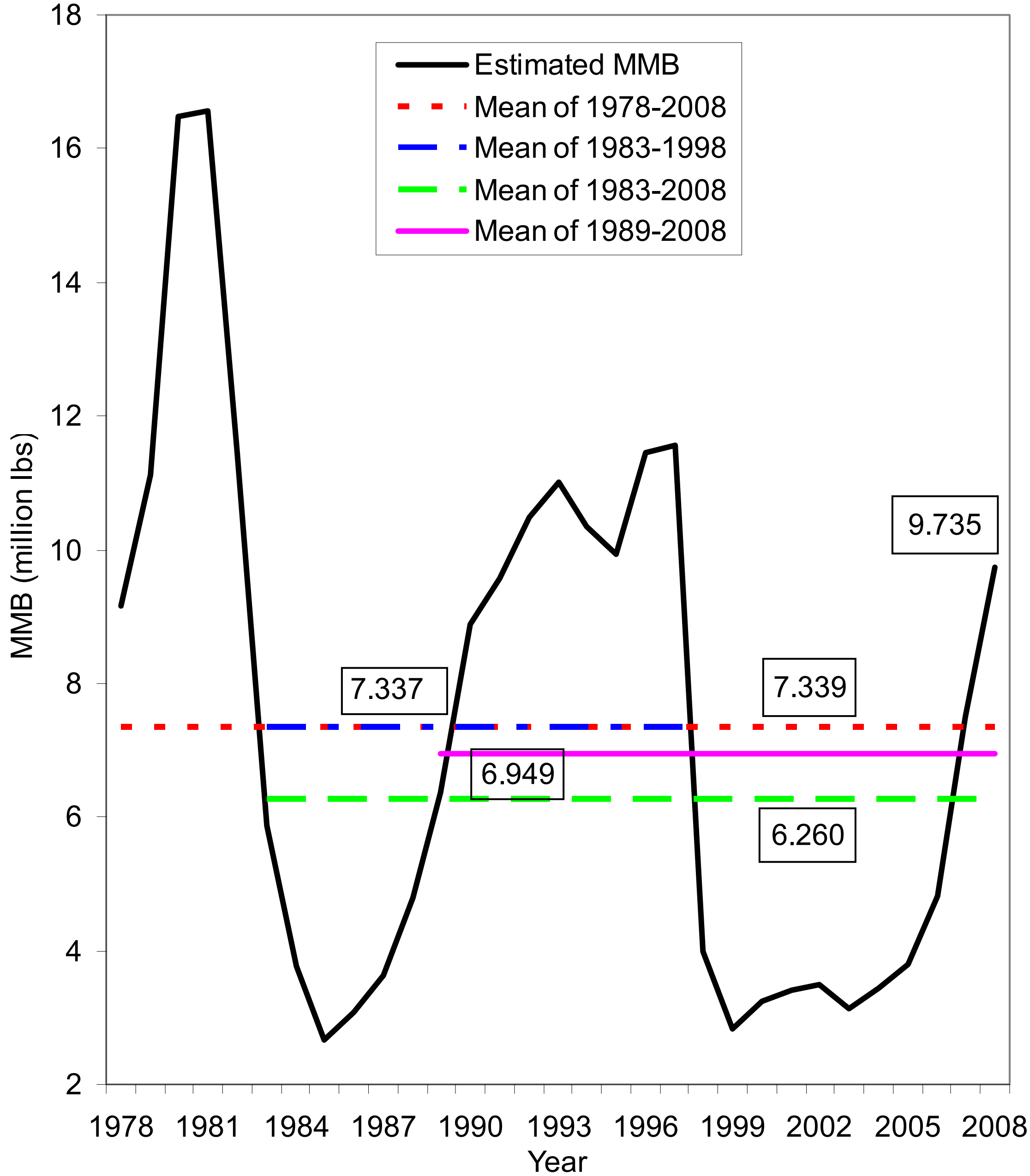


Figure 22. Comparison of estimated mean mature male biomasses during different periods of St. Matthew Island blue king crab. The model was with a fixed *Q*=1.0 and estimating *M* (scenario 2). $\gamma = 0$ was used for the 2008 fishery to project mature male biomass in 2008.