# Draft

**"Do to the short amount of time available this year for model development and SAFE document review not all authors have fully reviewed this document nor were given ample time to weigh in on model choices for this stock. However, model parameters will be discussed in full by the Crab Plan Team in May 2008. All authors will have reviewed the SAFE by May and will be present for the discussion at that time. In addition, the authors will meet prior to September to weigh the discussions by the CPT to come to an agreement as to final SAFE structure and model alternatives provided to the CPT for final recommendations in September 2008."**

## St. Matthew Blue King Crab Stock Assessment in 2008

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## Executive Summary

A catch-survey analysis was updated with trawl survey data from 1978 to 2007, 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. Three scenarios of the model were evaluated. Scenario (1) fixed both natural mortality ($M$=0.18) and trawl survey catchability ($Q$=1), scenario (2) fixed $Q$ =

1 and estimated $M$, and scenario (3) fixed $M$=0.18 and estimated $Q$. Estimated legal abundance and mature male biomass in 2008 are:

| | Scenario (1) | Scenario (2) |
|---|---|---|
| Legal males: | 2,505,000 crab or 15.946 million lbs, | 2,164,000 crab or 14.007 million lbs |
| Mature male biomass: | 15.946 million lbs | 14.007 million lbs. |

Estimated $B_{MSY}$ proxy:

| | Model scenario (1) | Model scenario (2) |
|---|---|---|
| Based on average during 1978-2008: | 8.051 million lbs, | 7.473 million lbs, |
| Based on average during 1983-1998: | 7.404 million lbs, | 6.892 million lbs, |
| Based on average during 1983-2008: | 7.107 million lbs. | 6.467 million lbs. |

Estimated $F_{MSY}$ proxy:

| | Model scenario (1) | Model scenario (2) |
|---|---|---|
| $\gamma$= 1: | 0.180, | 0.296, |
| $\gamma$= 1.5: | 0.270, | 0.444. |
| $\gamma$= 1.844: | 0.332, | |

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

The $F_{MSY}$ proxy can range from 0.18 to 0.444, corresponding to harvest rates ranging from 16.5% to 35.9% of legal abundance at the time of fishing. After adjusting the time difference of surveys and directed fishery, the overfishing limits for retained catch in 2008 range from 2.548 million lbs to 4.363 million lbs for model scenario (1) and from 3.404 million lbs to 4.764 million lbs for model scenario (2) depending on the $\gamma$ value. Since scenario (2) performed much better retrospectively than scenario (1), it is the preferred scenario for the overfishing determination for 2008.

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

## Catch History

### Fisheries

The St. Matthew Island fishery developed subsequent to baseline ecological studies associated with oil exploration (Otto 1990); 10 U.S. vessels harvested 1.202 million pounds in 1977. Harvests peaked in 1983 when 164 vessels landed 9.454 million pounds. 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 (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) observed a high level of natural mortality in the St. Matthew blue king crab stock from 1998 to 1999 evidenced by the low catch per unit effort (CPUE) in the 1998 commercial fishery and in the 1999 ADF&G nearshore pot survey as well as the low numbers across all male crab size groups caught in the eastern Bering Sea NMFS annual trawl survey from 1999 to 2005. Watson (2005) has found similar trends in the population estimates for St. Matthew blue king crab based on the 1995-2004 ADF&G pot survey conducted triennially in the St. Matthew Island district.

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

and 20% in fixed gear fisheries. The directed crab fishery mortality rate was set at 8% for blue king crab, averaged across different crab fisheries (NPFMC 2006).

**Harvest Strategy**

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

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

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

The BOF originally adopted a minimum guidline harvest level (GHL) as a management tool to help prevent harvest from exceeding low GHLs. With rationalization, this has been retained as a 2.5-million-pound minimum TAC for the "non-CDQ" portion of the overall TAC. The CDQ fishery is allocated 10% of the overall TAC; hence for the fishery to open, the TAC, including the allocation to the CDQ fishery, must be 2.778-million pounds or higher. It is

important to note that, although the minimum GHL was adopted as management tool, it also plays an important role in promoting stock rebuilding. The minimum GHL was included as a management measure in the analyses of the effectiveness of the current harvest strategy when the BOF considered alternative strategies for managing and rebuilding the St. Matthew blue king crab stock. The analyses showed the minimum GHL to be an important determinant of the rebuilding schedule.

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

## Data

### Fishery Catch Data

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

### Trawl Survey Data

NMFS has conducted annual summer trawl survey of St. Matthew Island blue king crab since 1978. Indices of St. Matthew Island blue king crab abundance are affected by the portion of the stock occupying inshore rocky untrawlable grounds. Only 16 legal males ($\geq$ 5.5 in cw or 120 mm CL) and five large females ($\geq$ 80 mm CL) were captured on the 2007 National Marine Fisheries Service annual eastern Bering Sea shelf survey.

The catch-survey model was fit to NMFS trawl survey and commercial catch data from 1978 to 2007. Survey stations were stratified based on the approach developed by Zheng et al. (1997). Basically, the number of tows per station was used as a criterion to stratify the stations: (1) frequent two-tow stations were grouped together as one stratum, (2) frequent one-tow stations formed another stratum, and (3) any single station with four or more tows was regarded as a separate stratum. The stratification was constant over time and similar to that used by NMFS during recent years.

The area-swept approach was used to estimate average crab density (abundance per nmi$^2$) for each stratum. Crab abundance by length, sex, and shell condition was estimated for each stratum by taking the product of average crab density and total stratum area. Total abundance of

the stock was estimated by summing the abundances from all strata. Stage-specific survey abundances for the catch-survey model are summarized in Table 3.

**Pot Survey Data**

ADF&G performed a triennial pot survey for Saint Matthew Island blue king crab in 1995, 1998, 2001, 2004 and 2007 (Watson 2008), which is able to sample from areas of important habitat for blue king crab, particularly females, that the NMFS trawl survey cannot sample from. The pot surveys were usually conducted during late July and August with chartered a 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 3, 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 4, 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 5). 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 6). 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 7). 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 was 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.
(7) Annual retained catch was measured without error.
(8) Trawl survey catchability was set to be 1.0 for legal males when fixed in the model.
(9) Male crab are mature at sizes ≥105 mm CL.
(10) Abundance had a log-normal error structure.

**Model Structure**

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

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

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

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

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:

$$m1_{t+1} = m1_t e^{\eta_t}, \tag{2}$$

where $\eta_t$ are independent, normally distributed random variables with a mean of zero.

**Parameters Estimated Independently**

Three scenarios of the model were developed for St. Matthew Island blue king crab, depending on parameters estimated independently and conditionally. In scenario (1), both $M$ and $Q$ were fixed (estimated independently); in model scenario (2), $M$ was estimated conditionally whereas $Q$ was fixed; and in model scenario (3), $Q$ was estimated conditionally and $M$ was fixed.

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 sensitive 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 0.4

and 0.6 relative to legal crab, respectively.

### *Natural Mortality*

The conservative estimate of natural mortality for all species of king crab in the eastern Bering Sea is 0.2 as defined by the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs (1998). Siddeek et al. (2002) reexamined tagging experiments conducted around St. Matthew Island in 1995 and 1998 to estimate natural mortality (M). Based on a multinomial likelihood M estimator using returned the tag data, values of Z (annual instantaneous total mortality) for both male and female blue king crab ranged from 0.65 to 0.74 assuming that M and SR (initial tagging survival/recapture ratio) did not vary by sex. Using the combined sexes return tag data (80-157 mm CL) from the 1995 tagging experiment, the mean estimate of M = 0.19. One other natural mortality estimate has been reported for St. Matthew Island blue king crab based on tagging data. Values ranged from 0.19 to 2.04 with a mean estimate of 0.81 for adult male blue king crab (105-139 mm CL) (Otto and Cummiskey 1990).

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

### *Length-weight Relationships*

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

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

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

***Sizes at Maturity***

Blue king crab males do not have a specific morphometric indication of maturity. Earlier studies exploring the relationship of the major chela height measurement to the carapace length (CL) of an individual crab as a measurement of male maturity did not produce statistically sound results, although one study reports males from St. Matthew were considered mature at 77 mm CL based on this relationship (Somerton and MacIntosh 1983a). St. Matthew blue king crab males were found to produce spermatophores at the 50-59 mm CL size range which indicates these crab are reaching sexual maturity at a smaller size than estimated using chela height morphology (Paul et al. 1991). ADF&G considers males mature at carapace length of ≥ 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 than red king crab females with larger sized eggs (1.2 mm) (Somerton and MacIntosh 1985, Jensen and Armstrong 1989). Molting is necessary for egg extrusion, thus the intermolt period is two years for blue king crab females. Somerton and MacIntosh (1985) suggested that blue king crab females live longer and have larger sized eggs than red king crab females as a reproductive strategy to compensate for their biennial spawning cycle. Reproductive studies on Pribilof Island blue king crab females supports a biennial reproduction cycle for large multiparous females but found smaller, primiparous (first year of maturity) females were often able to reproduce in two consecutive years (Jensen and Armstrong 1989).

**Parameters Estimated Conditionally**

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

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

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

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

## Model Results

### Abundance and Parameter Estimates

Estimated abundance, recruitment to the model and mature male biomass are summarized in Tables 6-8 for three scenarios. The scenario with fixed $Q$ and $M$ resulted in the highest abundance and biomass estimates during recent 10 years (Figure 8). All scenarios indicate an increasing abundance and biomass since 1999, and projected legal abundance and mature male biomass without fishing in 2008 were among the highest estimated since 1978 (Figure 8; Tables 6-8). Residuals were about random for both trawl and pot survey data except that the residuals for post-recruit abundance from the trawl survey after the stock collapse in 1999 were mostly negative (Figure 9). This may suggest a higher mortality than we assumed in the model for the post-recruit crab. When $M$ was estimated in the model, its value (0.296) was much higher than the fixed value of 0.18.

Legal harvest rate was defined as the ratio of retained catch to estimated legal abundance adjusted by natural mortality to the midpoint of each fishing season. Estimated harvest rates were very high during 1982-1985, above 45% (Figure 10). The fishery has been closed since 1999.

Likelihood profiles of estimated *M* and *Q* are illustrated in Figure 11. With a fixed $Q = 1$, estimated *M* was 0.296, much higher than we assumed in the model. The likelihood was very low for $M = 0.18$. When fixing $M = 0.18$, estimated Q was greater than 1, an unlikely value (Figure 11). Both model scenarios (1) and (2) were evaluated for setting overfishing limits in this report.

Handling mortality may also affect abundance estimates. Handling mortality reduces future recruitment to fisheries by reducing both prerecruit abundance and spawning biomass. Besides mortality, handling may also produce sublethal effects on crab, such as reduced growth (Kruse 1993). Based on limited observer data, bycatch of sublegal male and female crabs from the directed blue king crab fishery off St. Matthew Island was relatively high, and total bycatches were often twice as high or higher than total catch of legal crabs (Moore et al. 2000). But observer data were extremely limited for the St. Matthew Island blue king crab directed pot fishery. We assumed fishery selectivities to be 0.4 and 0.6 for prerecruit-2s and prerecruit-1s and handling mortality rate to be 0.2. Although estimated recruitment to the model is affected by handling mortality, handling mortality rates ranging from 0 to 50% do not affect legal male abundance and mature male biomass estimates much (Figure 12).

**Retrospective Analyses**

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

Historically, the model performed very well. The model assumed $Q$=1 and estimated *M* up to the 2008 model. The trajectories of biomass and abundance from the assessments made during 1999-2007 were very close to each other and close to those made in 2008 with a scenario estimating

*M* and fixed *Q* (Figure 13). Historical estimates after 1999 were quite different from those made in 2008 with a scenario of fixed *M* and *Q* (Figure 14).

The 2008 model with a scenario of fixed *M* and *Q* also did not perform very well when leaving one-year data out at a time for a retrospective analysis (Figure 15). The errors in Figure 15 include the error for the terminal year estimates as well as one-year-ahead projections. During the spring assessment, the trawl data were not available for the terminal year, so the abundance and biomass in the terminal year were projected from the model fitted to the survey data in the previous years. Because of relatively low legal abundance from the trawl survey data during the early and mid 2000s, the estimated legal males and mature male biomass during the terminal years tended to be higher during this period than those estimated with the terminal year of 2008 (Figure 15).

## Overfishing Limits for 2008

The St. Matthew Island blue king crab stock is currently placed in Tier 4 (NPFMC 2007). For Tier 4 stocks, abundance estimates are available, but complete population parameters are not available for computer simulation studies and spawning biomass per recruit analyses needed for Tier 3 stocks. Average of estimated biomasses for a certain period was used to develop $B_{MSY}$ proxy for Tier 4 stocks. We evaluated averages of mature male biomasses from three periods for $B_{MSY}$ proxy: 1978-2008, 1983-1998 and 1983-2008 (Figures 16 and 17).

Besides $B_{MSY}$ proxy, a $\gamma$ value also needs to be determined. NPFMC (2007) set the default $\gamma$ for Tier 4 king crab stocks to be the ratio of $F_{35\%}$ to *M* based on the results for Bristol Bay Red king crab. This ratio is 1.844 (0.332/0.18) from the 2008 assessment results of Bristol Bay red king crab. We evaluated three $\gamma$ values for setting overfishing limits for 2008: $\gamma = 1$, $\gamma = 1.5$ and $\gamma = 1.844$. Model scenario (1) (fixed *M*=0.18 and *Q*=1) and scenario (2) (fixed *Q*=1 and estimating *M*=0.296) were also evaluated (Figures 16 and 17).

Estimated $B_{MSY}$ proxy:

| | Model scenario (1) | Model scenario (2) |
|---|---|---|
| Based on average during 1978-2008: | 8.051 million lbs, | 7.473 million lbs, |
| Based on average during 1983-1998: | 7.404 million lbs, | 6.892 million lbs, |
| Based on average during 1983-2008: | 7.107 million lbs. | 6.467 million lbs. |

Estimated $F_{MSY}$ proxy:

Model scenario (1) Model scenario (2)

| | | |
|---|---|---|
| $\gamma = 1$: | 0.180, | 0.296, |
| $\gamma = 1.5$: | 0.270, | 0.444, |
| $\gamma = 1.844$: | 0.332, | 0.546. |

Estimated mature male biomass in 2008 was 15.956 and 14.007 million lbs, respectively for model scenarios (1) and (2) under an assumption that no directed fishing would occur in 2008. The estimated mature male biomass in 2008 will exceed all six $B_{MSY}$ proxies even after adjusting the catch should a 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 may be excluded from estimating the $B_{MSY}$ proxy, resulting in use of the period of 1983-1998. The period of 1978-2008 includes all data. For a given model scenario, the averages from the three periods were not greatly different.

Since the estimated $M$ (0.296) was much higher than the assumed $M$ (0.18) for Bristol Bay red king crab, the $\gamma$ value from Bristol Bay red king crab may not be applied to the estimated $M$. Therefore, we threw out the highest $F_{MSY}$ proxy (0.546). The $F_{MSY}$ proxy can range from 0.18 to 0.444, corresponding to harvest rates ranging from 16.5% to 35.9% of legal abundance at the time of fishing. Estimated legal male biomass in 2008 at the time of fishing was 15.443 million lbs and 13.288 million lbs for model scenarios (1) and (2). Therefore, the overfishing limits for retained catch in 2008 range from 2.548 million lbs to 4.363 million lbs for model scenario (1) and from 3.404 million lbs to 4.764 million lbs for model scenario (2), depending on the $\gamma$ value. Since scenario (2) performed much better retrospectively than scenario (1), it is the preferred scenario for the overfishing determination for 2008.

The high abundance estimate for 2008 was primarily caused by the relative good trawl survey abundance of prerecruit-2s in 2006, very high trawl survey abundance of prerecuti-1s and prerecruit-2s in 2007, 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 $\gamma$ value for overfishing determination for 2008.

## Ecosystem Considerations

### Ecosystem Effects on Stock

***Prey Availability/Abundance Trends***

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

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

***Predator Population Trends***

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

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

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

catch rates support a general decline in abundance estimates of Pacific halibut in the eastern Bering Sea (Clarke 2008).

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

***Changes in Habitat Quality***

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

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

Juvenile blue king crab (<30 mm carapace length) are known to occur predominately along nearshore rocky and shell hash (a mixture of broken bivalve and gastropod shells) habitats near the Pribilof Islands, and these habitats are considered vital refuge from predation and for

successful recruitment (Palacios et al. 1985). Shell hash is a key material for refuge and thus the survival of blue king crab is ultimately linked to certain mollusk species that are abundant within the species assemblage that characterize the BKC juvenile habitat along the Pribilof Islands (Armstrong et al. 1985). The preferred shelltype epibenthic substrate for juvenile BKC was composed primarily of four species of bivalves (*Serripies groenlandicus*, *Spisula polynyma*, *Chlamys sp*., *Modiolus modiolus*), and large neptunid gastropods. Shells of this type were usually intact or in large pieces and usually covered with dense epiphytic growth including feathery bryozoans, barnacles, anemones, and ascidians.

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

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

Due to their restricted distribution along the Pribilof and St Mathews Islands, blue king crab are considered highly vulnerable to oil mishaps (Armstrong et al. 1987). There have been numerous studies that have investigated the potential impacts of oil on blue king crab along the Pribilof Islands (Armstrong et al. 1983, Armstrong et al. 1987, Laevastu et al. 1985). The life history stage considered most vulnerable is the larval stages since they are in the water column and would follow the same currents as the oil. The restricted distribution of early juveniles on

and in substrates makes 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 (Sigler, unpublished, AFSC NOAA Fisheries). These effects have been measured as decreased pH of the water, as well as measurable increases in dissolved inorganic carbon over a large section of the northeastern Pacific suspected to be a problem in surface water effecting calcifying planktonic organisms in the northeast Pacific Ocean (Feely, unpublished data, NOAA PMEL). 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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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 crab) for 4 length groups.

| Year | Pre-R 2 | Pre-R 1 | R | Post-R |
|---|---|---|---|---|
| 1978 | 2.336 | 2.175 | 1.187 | 0.587 |
| 1979 | 2.258 | 1.793 | 1.455 | 0.333 |
| 1980 | 1.717 | 2.588 | 1.699 | 1.197 |
| 1981 | 0.637 | 1.480 | 1.195 | 1.648 |
| 1982 | 1.713 | 2.615 | 3.617 | 3.263 |
| 1983 | 1.052 | 1.639 | 1.399 | 1.956 |
| 1984 | 0.416 | 0.500 | 0.788 | 0.762 |
| 1985 | 0.434 | 0.431 | 0.541 | 0.708 |
| 1986 | 0.190 | 0.425 | 0.164 | 0.185 |
| 1987 | 0.350 | 0.757 | 0.492 | 0.292 |
| 1988 | 0.362 | 0.703 | 0.417 | 0.411 |
| 1989 | 2.181 | 1.235 | 0.940 | 0.954 |
| 1990 | 0.942 | 0.957 | 0.954 | 1.164 |
| 1991 | 1.031 | 1.636 | 1.353 | 0.889 |
| 1992 | 1.178 | 1.582 | 1.338 | 1.247 |
| 1993 | 1.653 | 1.994 | 1.605 | 2.000 |
| 1994 | 0.908 | 1.350 | 1.246 | 1.120 |
| 1995 | 1.118 | 1.321 | 0.993 | 0.902 |
| 1996 | 1.290 | 1.970 | 1.950 | 1.331 |
| 1997 | 1.211 | 2.319 | 2.213 | 1.853 |
| 1998 | 0.714 | 1.843 | 1.397 | 1.766 |
| 1999 | 0.244 | 0.215 | 0.179 | 0.436 |
| 2000 | 0.304 | 0.310 | 0.323 | 0.488 |
| 2001 | 0.432 | 0.527 | 0.345 | 0.681 |
| 2002 | 0.133 | 0.266 | 0.186 | 0.576 |
| 2003 | 0.535 | 0.330 | 0.188 | 0.379 |
| 2004 | 0.281 | 0.210 | 0.286 | 0.348 |
| 2005 | 0.600 | 0.445 | 0.295 | 0.259 |
| 2006 | 1.019 | 0.760 | 0.766 | 0.635 |
| 2007 | 2.756 | 2.224 | 0.752 | 0.565 |

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

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

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

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

Table 6. Parameter estimates for a catch-survey analysis of St. Matthew Island blue king crab with data from 1978 to 2007. Three scenarios of the model are (1) fixed *M* and *Q*, (2) fixed *Q* and estimating *M*, and (3) fixed *M* and estimating *Q*. A value "fix" indicates that it is fixed in the model.

| | Model Scenario | | |
|---|---|---|---|
| Parameter | (1) | (2) | (3) |
| Natural mortality (*M*) for years other than 1999 | fix | 0.296 | fix |
| Natural mortality in 1999 | 1.900 | 1.715 | 1.888 |
| Trawl survey catchability (*Q*) | fix | fix | 1.234 |
| Trawl survey selectivity: prerecruit-2s (*S*2) | 0.594 | 0.500 | 0.540 |
| Trawl survey selectivity: prerecruit-1s (*S*1) | 0.784 | 0.771 | 0.764 |
| Pot survey selectivity: prerecruit-2s (*s*2) | 0.197 | 0.313 | 0.206 |
| Pot selectivity: prerecruit-1s (*s*1) | 0.540 | 0.499 | 0.580 |
| Pot scaling parameter (*q*) | 0.332 | 0.313 | 0.300 |
| Molting probability in 1978: prerecruit-1s | 0.690 | 0.775 | 0.731 |

Table 7. Estimated recruits to the model (Model R), abundance (Pre-R2, Pre-R1, R, Post-R, legals and matures), mature male biomass on 2/15 (Bio215), and molting probabilities for pre-recruit-1s (Molt1) for the model scenario fixing *M* and *Q*. Recruits and abundance are in million of crab and biomass is in million lbs.

| Year | Model R | Pre-R2 | Pre-R1 | R | Post-R | Legals | Matures | Bio215 | Molt1 |
|---|---|---|---|---|---|---|---|---|---|
| 1978 | na | 1.986 | 1.849 | 1.009 | 0.499 | 1.508 | 3.357 | 7.559 | 0.690 |
| 1979 | 3.224 | 3.408 | 1.924 | 0.956 | 0.953 | 1.909 | 3.833 | 11.100 | 0.687 |
| 1980 | 2.865 | 3.196 | 2.963 | 1.083 | 1.616 | 2.699 | 5.662 | 16.757 | 0.679 |
| 1981 | 0.966 | 1.304 | 3.150 | 1.551 | 2.327 | 3.878 | 7.028 | 17.606 | 0.684 |
| 1982 | 1.496 | 1.625 | 1.878 | 1.516 | 2.463 | 3.979 | 5.857 | 11.803 | 0.675 |
| 1983 | 0.654 | 0.828 | 1.657 | 0.912 | 1.747 | 2.658 | 4.316 | 5.972 | 0.664 |
| 1984 | 0.392 | 0.489 | 1.048 | 0.744 | 0.622 | 1.366 | 2.414 | 3.966 | 0.656 |
| 1985 | 0.865 | 0.927 | 0.649 | 0.469 | 0.458 | 0.928 | 1.576 | 2.925 | 0.664 |
| 1986 | 0.526 | 0.635 | 0.804 | 0.326 | 0.380 | 0.706 | 1.510 | 3.491 | 0.692 |
| 1987 | 1.176 | 1.233 | 0.680 | 0.405 | 0.429 | 0.833 | 1.514 | 3.660 | 0.716 |
| 1988 | 0.954 | 1.066 | 1.038 | 0.389 | 0.519 | 0.908 | 1.946 | 4.442 | 0.732 |
| 1989 | 2.629 | 2.724 | 1.014 | 0.561 | 0.536 | 1.097 | 2.111 | 5.280 | 0.734 |
| 1990 | 1.607 | 1.853 | 2.146 | 0.638 | 0.741 | 1.380 | 3.526 | 8.140 | 0.722 |
| 1991 | 1.709 | 1.876 | 1.882 | 1.133 | 0.892 | 2.026 | 3.908 | 8.551 | 0.712 |
| 1992 | 1.803 | 1.972 | 1.823 | 0.986 | 1.130 | 2.116 | 3.940 | 9.740 | 0.701 |
| 1993 | 2.045 | 2.223 | 1.900 | 0.960 | 1.363 | 2.323 | 4.223 | 10.466 | 0.690 |
| 1994 | 1.747 | 1.952 | 2.103 | 0.993 | 1.461 | 2.454 | 4.557 | 10.579 | 0.691 |
| 1995 | 2.745 | 2.923 | 1.972 | 1.067 | 1.407 | 2.474 | 4.446 | 11.010 | 0.697 |
| 1996 | 2.277 | 2.540 | 2.597 | 1.070 | 1.558 | 2.628 | 5.225 | 12.984 | 0.692 |
| 1997 | 1.665 | 1.895 | 2.541 | 1.339 | 1.713 | 3.052 | 5.593 | 13.284 | 0.677 |
| 1998 | 1.319 | 1.519 | 2.074 | 1.246 | 1.822 | 3.068 | 5.142 | 3.973 | 0.660 |
| 1999 | 0.561 | 0.595 | 0.308 | 0.183 | 0.344 | 0.527 | 0.835 | 2.779 | 0.650 |
| 2000 | 0.375 | 0.457 | 0.496 | 0.167 | 0.450 | 0.617 | 1.113 | 3.604 | 0.621 |
| 2001 | 0.572 | 0.649 | 0.469 | 0.234 | 0.531 | 0.765 | 1.234 | 4.123 | 0.571 |
| 2002 | 0.052 | 0.197 | 0.564 | 0.213 | 0.652 | 0.865 | 1.429 | 4.808 | 0.567 |
| 2003 | 0.484 | 0.529 | 0.345 | 0.230 | 0.738 | 0.968 | 1.313 | 4.798 | 0.592 |
| 2004 | 0.370 | 0.475 | 0.450 | 0.164 | 0.819 | 0.983 | 1.433 | 5.181 | 0.637 |
| 2005 | 1.388 | 1.460 | 0.466 | 0.220 | 0.836 | 1.056 | 1.522 | 5.465 | 0.678 |
| 2006 | 2.099 | 2.255 | 1.146 | 0.291 | 0.898 | 1.189 | 2.335 | 7.384 | 0.692 |
| 2007 | 1.769 | 1.976 | 1.931 | 0.663 | 1.033 | 1.696 | 3.626 | 12.222 | 0.690 |
| 2008 | 1.222 | 1.408 | 1.988 | 1.022 | 1.483 | 2.505 | 4.493 | 15.946 | na |

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

| Year | Model R | Pre-R2 | Pre-R1 | R | Post-R | Legals | Matures | Bio215 | Molt1 |
|---|---|---|---|---|---|---|---|---|---|
| 1978 | na | 2.301 | 2.142 | 1.169 | 0.578 | 1.746 | 3.888 | 8.328 | 0.775 |
| 1979 | 4.423 | 4.609 | 1.883 | 1.103 | 1.041 | 2.144 | 4.027 | 10.959 | 0.802 |
| 1980 | 4.066 | 4.443 | 3.242 | 1.136 | 1.623 | 2.759 | 6.001 | 16.184 | 0.817 |
| 1981 | 1.720 | 2.083 | 3.401 | 1.832 | 2.146 | 3.978 | 7.378 | 16.846 | 0.845 |
| 1982 | 2.133 | 2.300 | 1.878 | 1.825 | 2.295 | 4.120 | 5.998 | 11.202 | 0.874 |
| 1983 | 0.909 | 1.092 | 1.677 | 1.070 | 1.666 | 2.736 | 4.414 | 5.717 | 0.882 |
| 1984 | 0.540 | 0.626 | 0.896 | 0.901 | 0.608 | 1.509 | 2.404 | 3.824 | 0.872 |
| 1985 | 1.074 | 1.124 | 0.515 | 0.485 | 0.512 | 0.997 | 1.512 | 2.693 | 0.868 |
| 1986 | 0.849 | 0.938 | 0.756 | 0.312 | 0.385 | 0.697 | 1.454 | 3.102 | 0.891 |
| 1987 | 1.490 | 1.565 | 0.681 | 0.445 | 0.378 | 0.823 | 1.505 | 3.290 | 0.920 |
| 1988 | 1.383 | 1.509 | 1.039 | 0.446 | 0.458 | 0.904 | 1.943 | 4.023 | 0.936 |
| 1989 | 3.287 | 3.408 | 1.037 | 0.648 | 0.480 | 1.129 | 2.166 | 4.945 | 0.935 |
| 1990 | 2.347 | 2.622 | 2.203 | 0.737 | 0.690 | 1.428 | 3.631 | 7.710 | 0.915 |
| 1991 | 2.384 | 2.595 | 1.888 | 1.329 | 0.847 | 2.175 | 4.064 | 8.289 | 0.899 |
| 1992 | 2.509 | 2.717 | 1.841 | 1.129 | 1.122 | 2.252 | 4.093 | 9.407 | 0.880 |
| 1993 | 2.594 | 2.813 | 1.943 | 1.098 | 1.323 | 2.421 | 4.364 | 9.966 | 0.860 |
| 1994 | 2.508 | 2.735 | 2.040 | 1.130 | 1.380 | 2.511 | 4.551 | 9.704 | 0.841 |
| 1995 | 3.659 | 3.878 | 2.025 | 1.146 | 1.294 | 2.440 | 4.464 | 10.003 | 0.839 |
| 1996 | 2.975 | 3.287 | 2.727 | 1.192 | 1.366 | 2.558 | 5.285 | 11.780 | 0.819 |
| 1997 | 2.013 | 2.278 | 2.534 | 1.490 | 1.482 | 2.972 | 5.506 | 11.728 | 0.785 |
| 1998 | 1.571 | 1.754 | 1.931 | 1.292 | 1.561 | 2.852 | 4.783 | 4.095 | 0.746 |
| 1999 | 0.686 | 0.721 | 0.377 | 0.233 | 0.379 | 0.612 | 0.989 | 2.988 | 0.722 |
| 2000 | 0.524 | 0.583 | 0.546 | 0.200 | 0.468 | 0.668 | 1.213 | 3.590 | 0.689 |
| 2001 | 0.739 | 0.789 | 0.516 | 0.258 | 0.514 | 0.772 | 1.288 | 3.893 | 0.633 |
| 2002 | 0.135 | 0.245 | 0.613 | 0.234 | 0.589 | 0.823 | 1.436 | 4.326 | 0.626 |
| 2003 | 0.580 | 0.616 | 0.339 | 0.247 | 0.629 | 0.876 | 1.215 | 4.006 | 0.650 |
| 2004 | 0.522 | 0.597 | 0.463 | 0.162 | 0.662 | 0.823 | 1.286 | 4.138 | 0.692 |
| 2005 | 1.632 | 1.681 | 0.501 | 0.225 | 0.627 | 0.852 | 1.353 | 4.246 | 0.735 |
| 2006 | 2.571 | 2.709 | 1.167 | 0.303 | 0.650 | 0.953 | 2.120 | 5.847 | 0.759 |
| 2007 | 2.168 | 2.390 | 1.955 | 0.668 | 0.749 | 1.416 | 3.371 | 10.828 | 0.775 |
| 2008 | 1.495 | 1.690 | 1.928 | 1.042 | 1.122 | 2.164 | 4.092 | 14.007 | na |

Table 9. Estimated recruits to the model (Model R), abundance (Pre-R2, Pre-R1, R, Post-R, legals and matures), mature male biomass on 2/15 (Bio215), and molting probabilities for pre-recruit-1s (Molt1) for the model scenario fixing *M* and estimating *Q*. Recruits and abundance are in million of crab and biomass is in million lbs.

| Year | Model R | Pre-R2 | Pre-R1 | R | Post-R | Legals | Matures | Bio215 | Molt1 |
|---|---|---|---|---|---|---|---|---|---|
| 1978 | na | 1.676 | 1.560 | 0.851 | 0.421 | 1.272 | 2.832 | 6.113 | 0.731 |
| 1979 | 2.940 | 3.090 | 1.575 | 0.845 | 0.749 | 1.594 | 3.169 | 9.101 | 0.754 |
| 1980 | 2.786 | 3.069 | 2.569 | 0.975 | 1.346 | 2.320 | 4.890 | 14.370 | 0.768 |
| 1981 | 1.097 | 1.379 | 2.804 | 1.519 | 2.009 | 3.528 | 6.333 | 15.388 | 0.799 |
| 1982 | 1.467 | 1.591 | 1.593 | 1.575 | 2.174 | 3.750 | 5.342 | 10.208 | 0.831 |
| 1983 | 0.611 | 0.752 | 1.393 | 0.946 | 1.558 | 2.504 | 3.897 | 4.795 | 0.838 |
| 1984 | 0.379 | 0.445 | 0.766 | 0.781 | 0.496 | 1.277 | 2.044 | 3.035 | 0.817 |
| 1985 | 0.787 | 0.826 | 0.458 | 0.426 | 0.381 | 0.807 | 1.265 | 2.071 | 0.800 |
| 1986 | 0.556 | 0.628 | 0.652 | 0.278 | 0.276 | 0.554 | 1.207 | 2.565 | 0.813 |
| 1987 | 1.016 | 1.072 | 0.568 | 0.383 | 0.301 | 0.684 | 1.252 | 2.802 | 0.832 |
| 1988 | 0.890 | 0.986 | 0.845 | 0.369 | 0.393 | 0.762 | 1.607 | 3.432 | 0.841 |
| 1989 | 2.259 | 2.347 | 0.835 | 0.520 | 0.412 | 0.933 | 1.768 | 4.236 | 0.836 |
| 1990 | 1.492 | 1.704 | 1.771 | 0.587 | 0.601 | 1.188 | 2.959 | 6.583 | 0.816 |
| 1991 | 1.554 | 1.707 | 1.545 | 1.052 | 0.727 | 1.778 | 3.324 | 6.884 | 0.800 |
| 1992 | 1.660 | 1.813 | 1.506 | 0.905 | 0.918 | 1.823 | 3.328 | 7.887 | 0.784 |
| 1993 | 1.823 | 1.987 | 1.599 | 0.882 | 1.113 | 1.995 | 3.594 | 8.486 | 0.768 |
| 1994 | 1.619 | 1.797 | 1.756 | 0.921 | 1.183 | 2.104 | 3.860 | 8.410 | 0.755 |
| 1995 | 2.472 | 2.633 | 1.674 | 0.969 | 1.108 | 2.077 | 3.751 | 8.756 | 0.756 |
| 1996 | 2.021 | 2.257 | 2.227 | 0.978 | 1.221 | 2.199 | 4.425 | 10.422 | 0.744 |
| 1997 | 1.411 | 1.614 | 2.142 | 1.223 | 1.347 | 2.570 | 4.711 | 10.474 | 0.720 |
| 1998 | 1.160 | 1.305 | 1.709 | 1.107 | 1.410 | 2.517 | 4.226 | 3.068 | 0.689 |
| 1999 | 0.470 | 0.492 | 0.262 | 0.159 | 0.262 | 0.421 | 0.682 | 2.232 | 0.669 |
| 2000 | 0.324 | 0.381 | 0.418 | 0.145 | 0.360 | 0.505 | 0.923 | 2.963 | 0.633 |
| 2001 | 0.486 | 0.545 | 0.394 | 0.201 | 0.435 | 0.636 | 1.030 | 3.429 | 0.578 |
| 2002 | 0.053 | 0.170 | 0.475 | 0.181 | 0.543 | 0.723 | 1.199 | 4.026 | 0.573 |
| 2003 | 0.402 | 0.439 | 0.292 | 0.196 | 0.618 | 0.814 | 1.106 | 4.034 | 0.599 |
| 2004 | 0.323 | 0.407 | 0.378 | 0.140 | 0.688 | 0.829 | 1.206 | 4.362 | 0.646 |
| 2005 | 1.157 | 1.215 | 0.397 | 0.188 | 0.705 | 0.893 | 1.290 | 4.624 | 0.692 |
| 2006 | 1.834 | 1.945 | 0.970 | 0.252 | 0.759 | 1.011 | 1.981 | 6.263 | 0.715 |
| 2007 | 1.558 | 1.737 | 1.643 | 0.578 | 0.879 | 1.457 | 3.101 | 10.452 | 0.731 |
| 2008 | 1.055 | 1.214 | 1.684 | 0.919 | 1.278 | 2.197 | 3.881 | 13.806 | na |

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

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

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

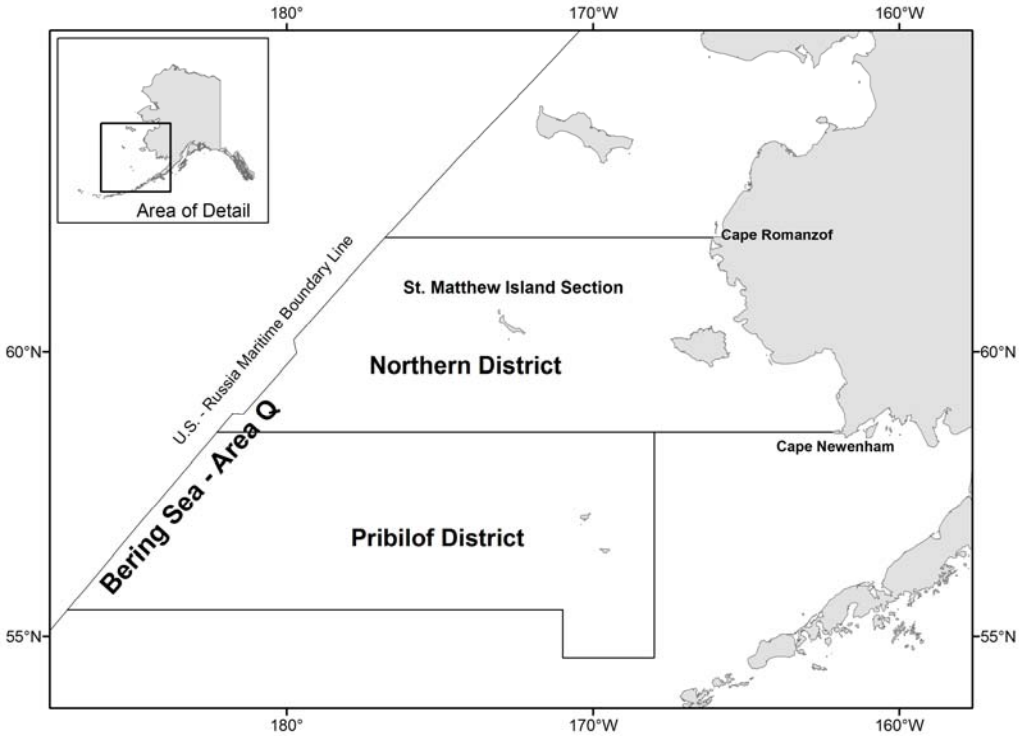



Figure 2. King crab Registration Area Q (Bering Sea).

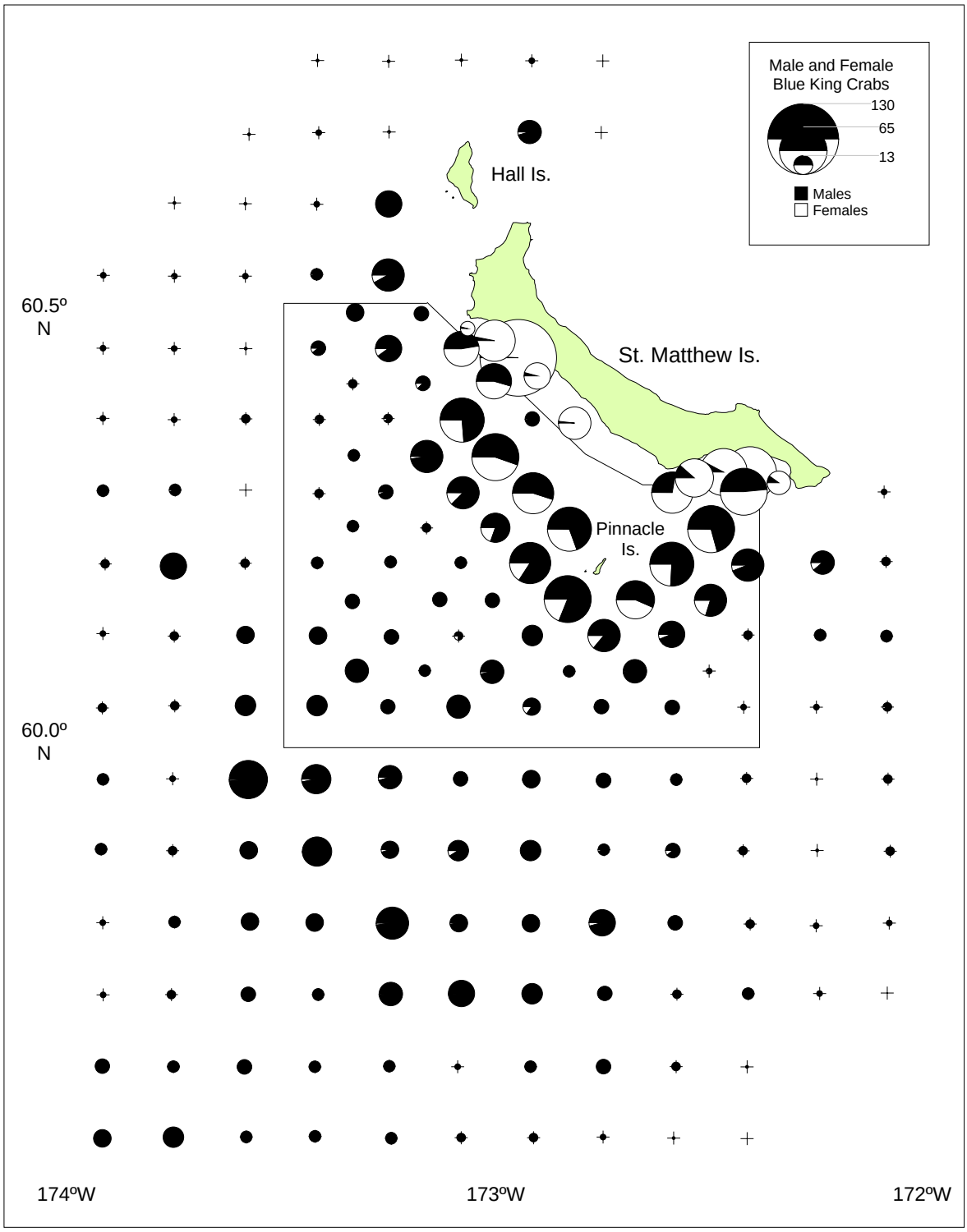



Figure 3. Male and female blue king crab catch per unit effort (CPUE) by station in the 2007 St. Matthew Island survey. (Source: Watson 2008).

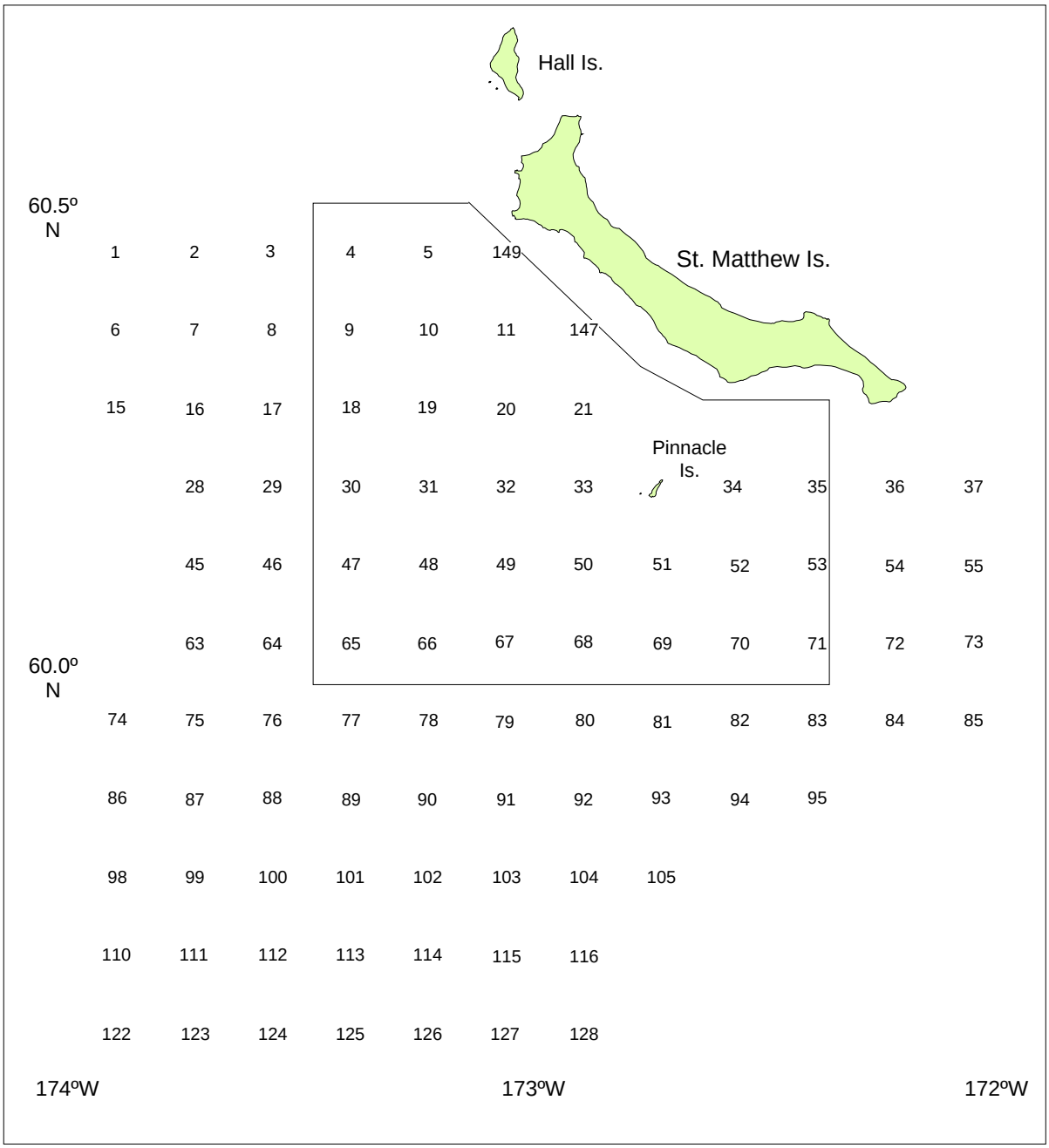



Figure 4. Location of the 96 stations fished in common during the five triennial St. Matthew Island blue king crab surveys, 1995 - 2007. (Source: Watson 2008).

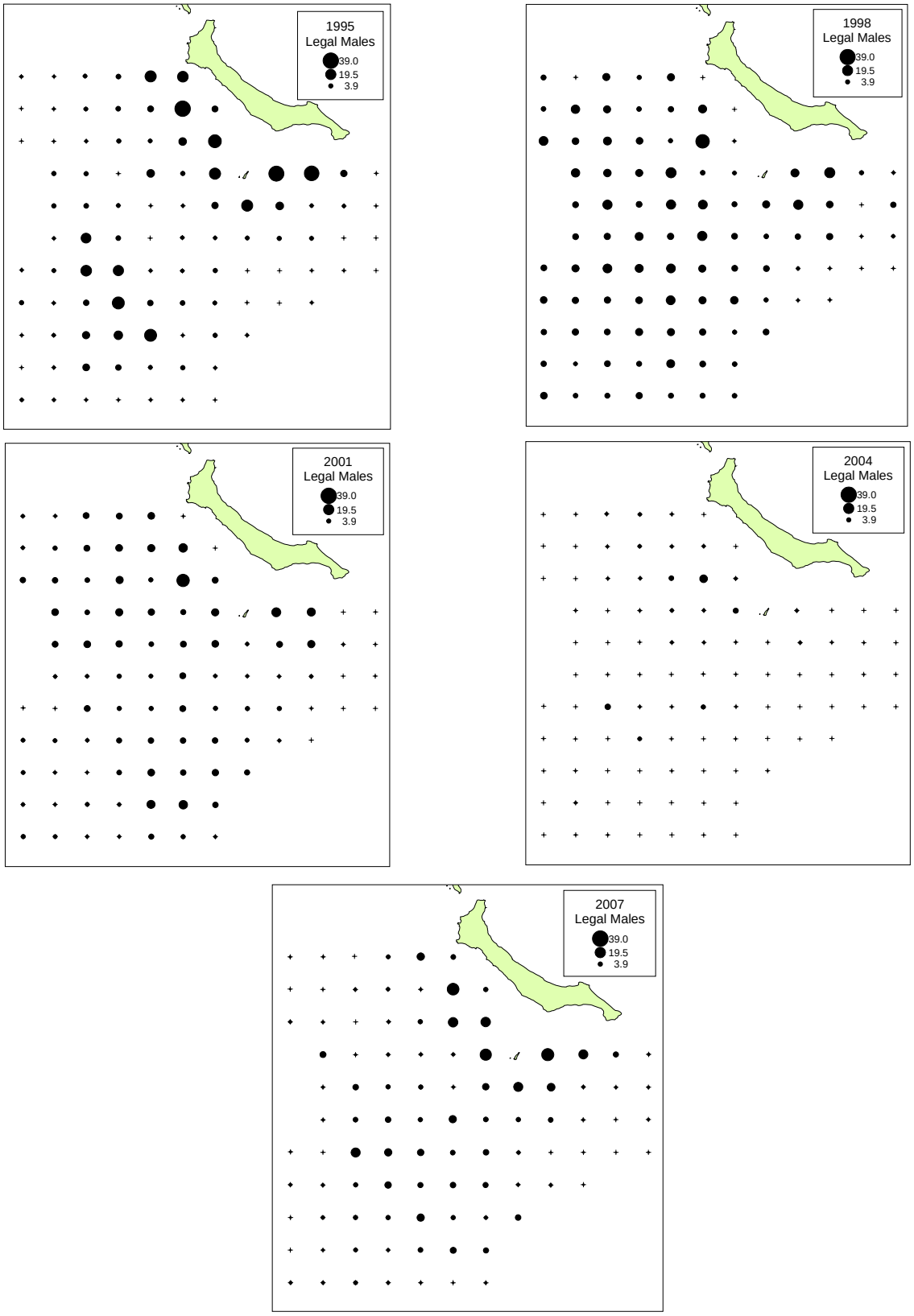



Figure 5. Legal male blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).

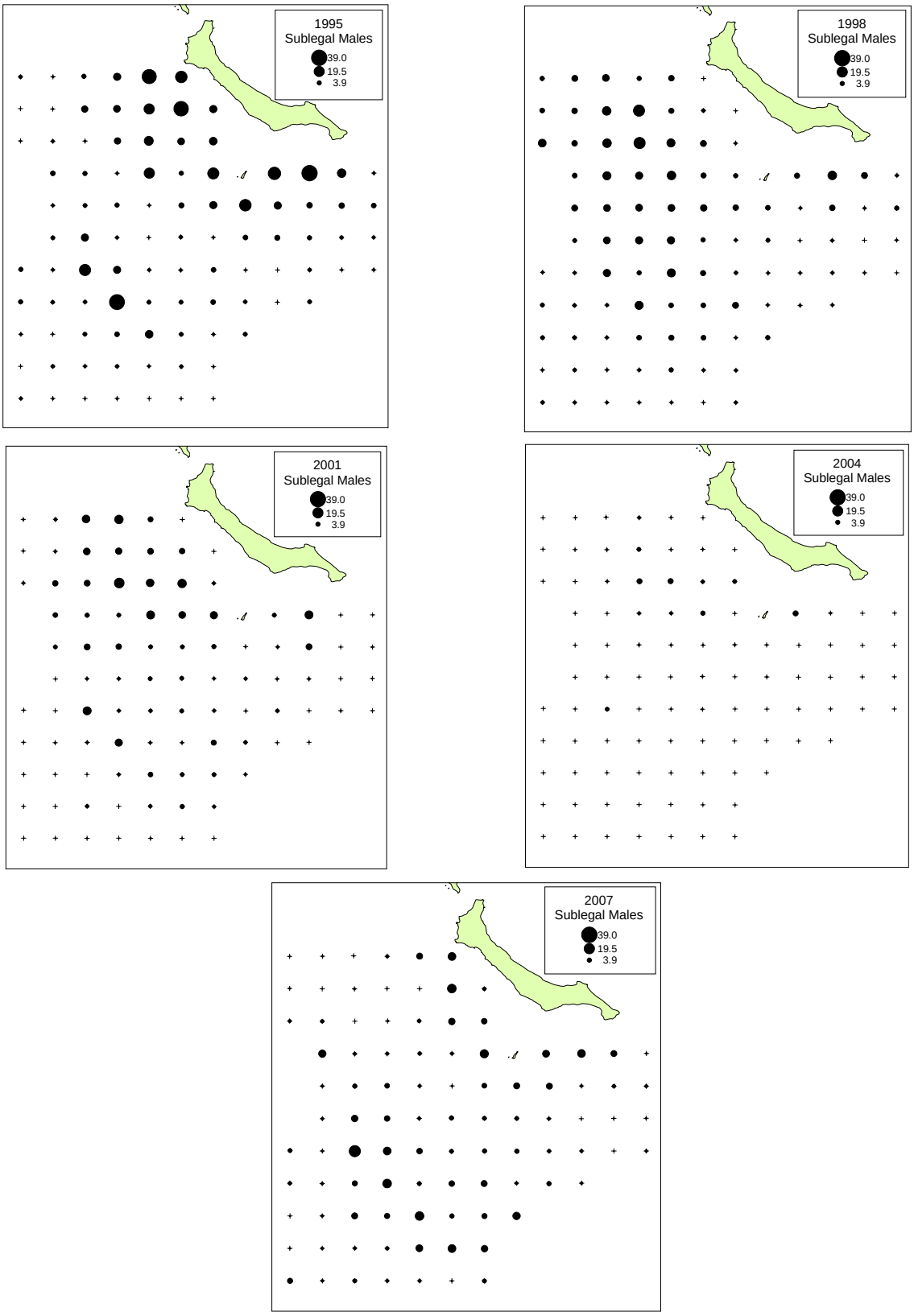



Figure 6. Sublegal male blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).

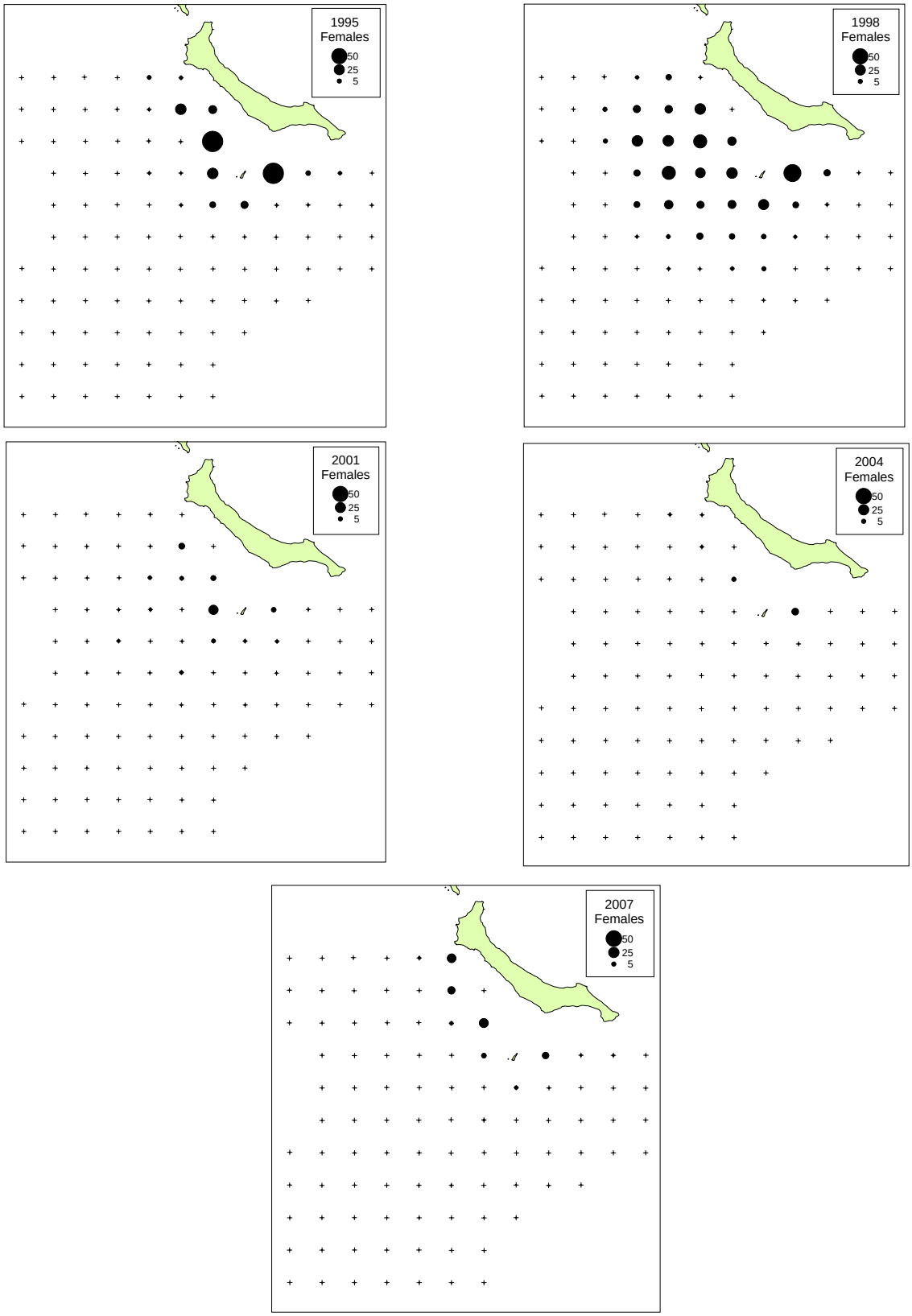
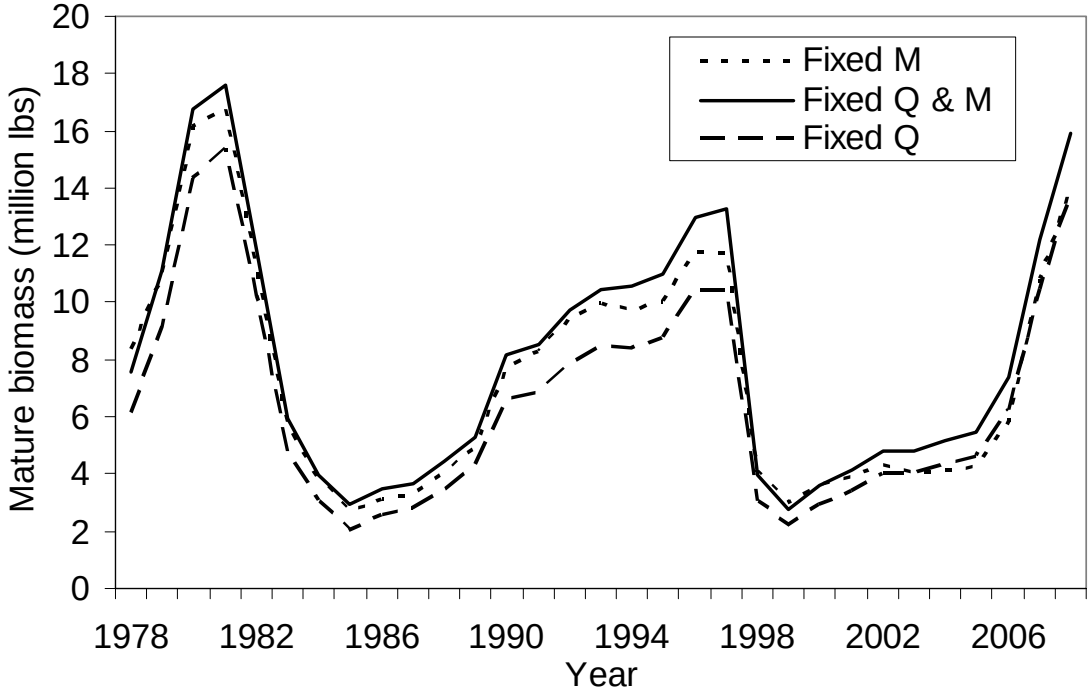



Figure 7. Female blue king crab catch per unit effort (CPUE) at the 96 in-common stations fished during the five triennial surveys, 1995 – 2007. (Source: Watson 2008).



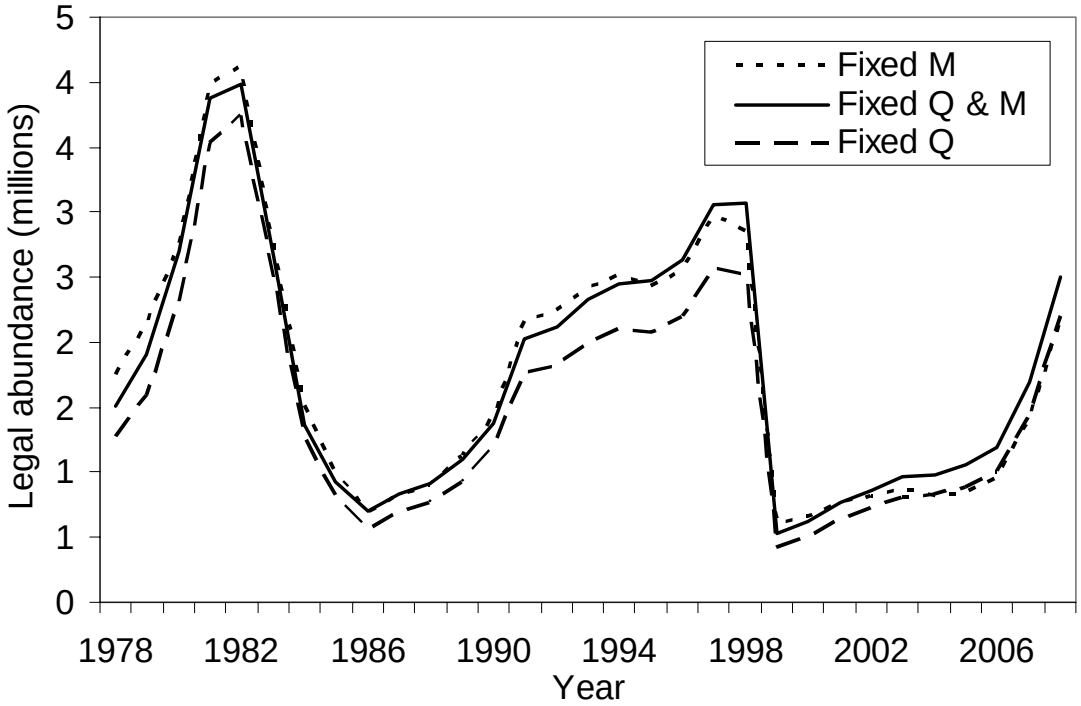




Figure 8. Comparison of mature male biomass (upper plot) and legal abundance (lower plot) estimates of St. Matthew Island male blue king crab with three scenarios of the catch-survey analysis.

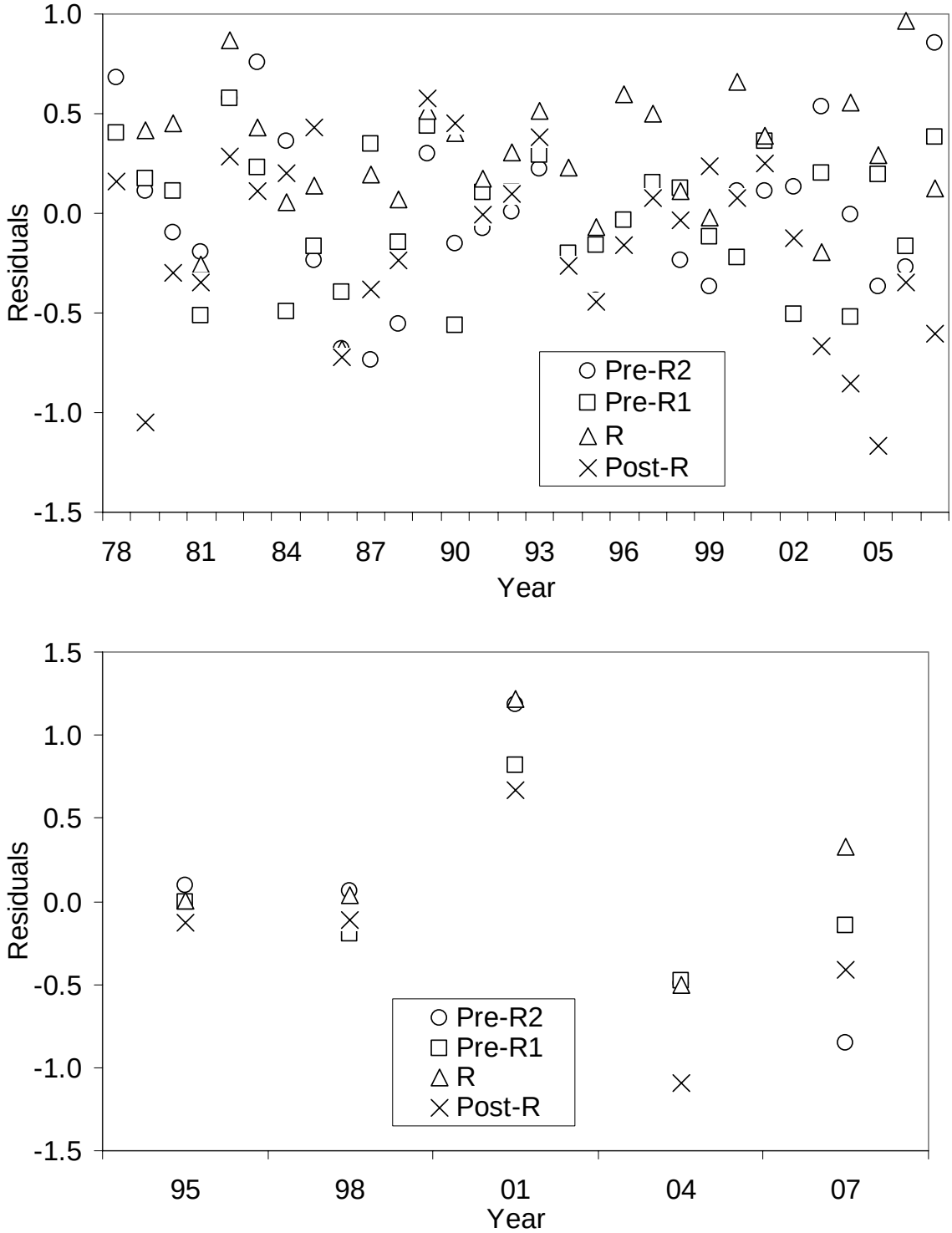



Figure 9. Residuals of the catch-survey analysis with a scenario of fixed both *M*=0.18 and *Q*=1.

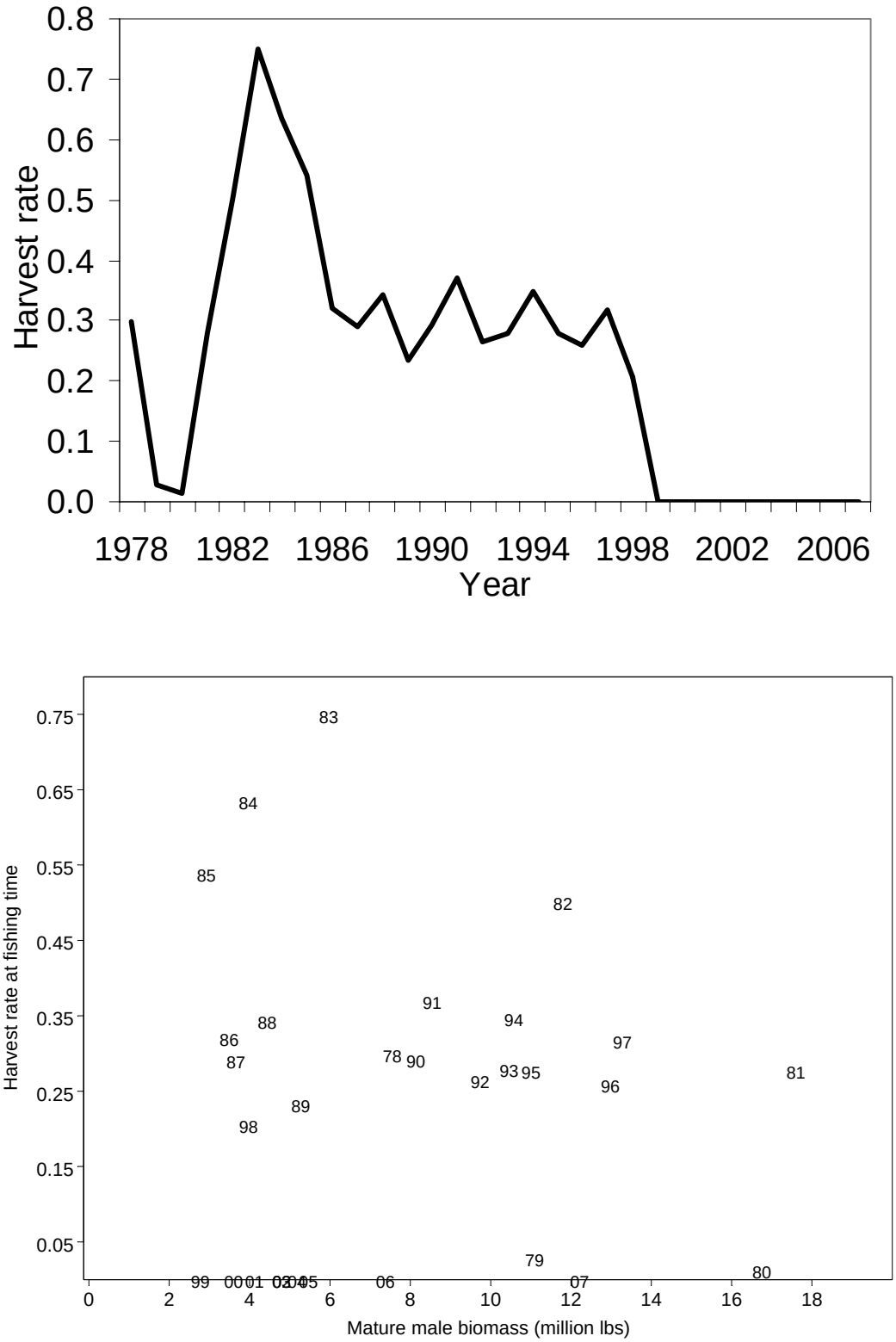



Figure 10. Estimated harvest rates (upper plot) and relationship between harvest rate and mature male biomass (lower plot) of St. Matthew Island blue king crab with a scenario of fixed *M*=0.18 and *Q*=1.0.

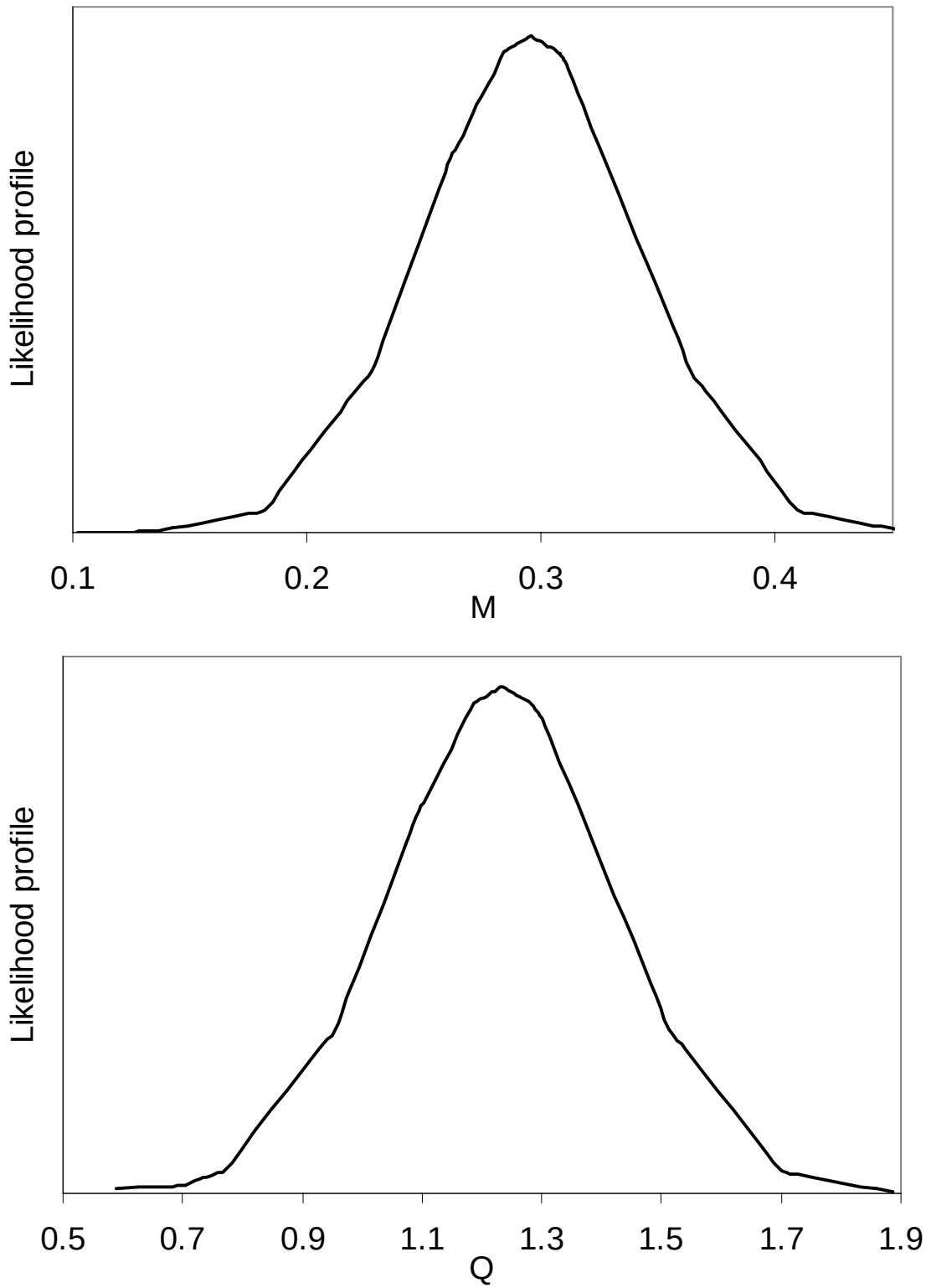



Figure 11. Likelihood profiles of estimated natural mortality (*M*) with a fixed trawl survey catchability (*Q*=1) and estimated trawl survey catchability with a fixed *M* (=0.18).

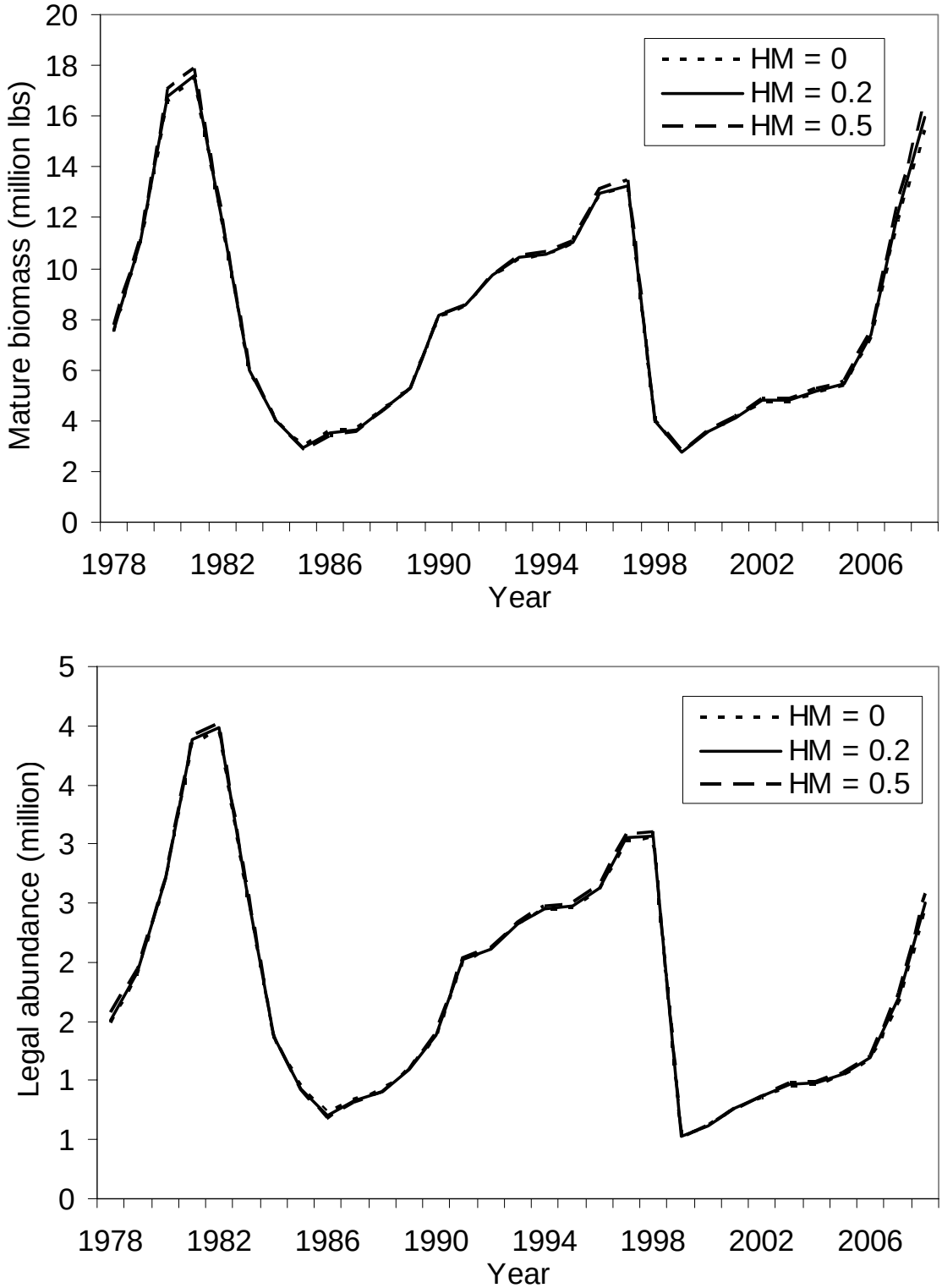
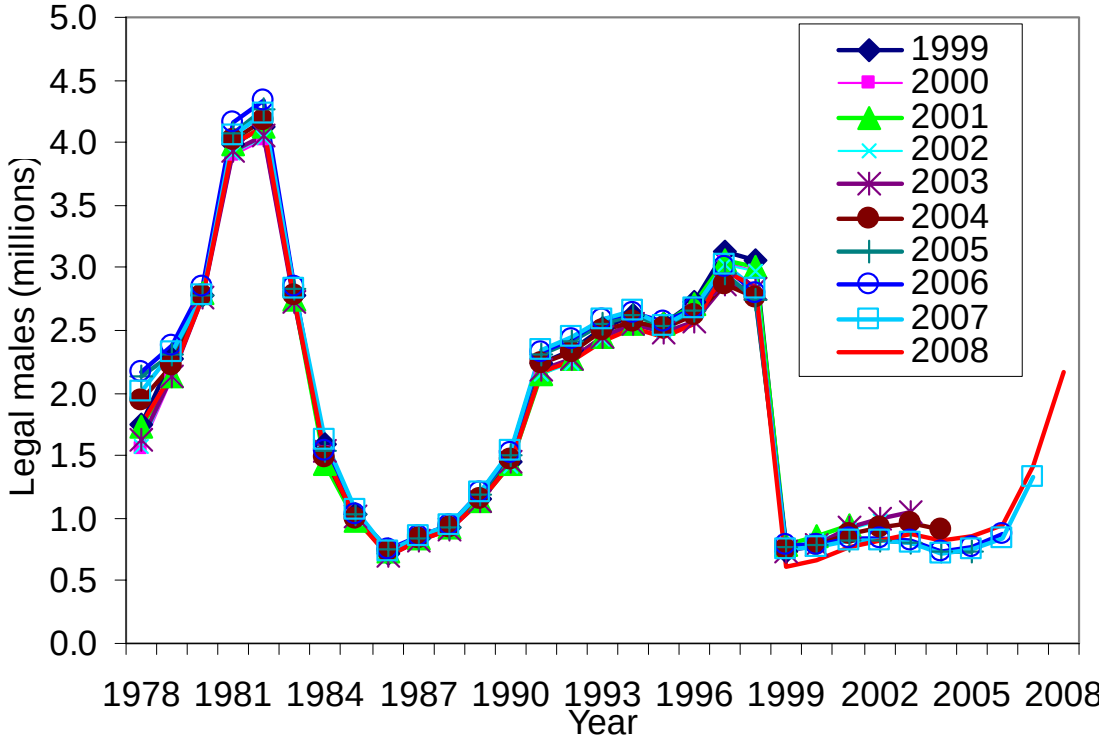



Figure 12. Comparison of estimated mature male biomass (upper plot) and legal male abundance (lower plot) with three levels of handling mortality under a scenario of fixed $M = 0.18$ and $Q = 1.0$.



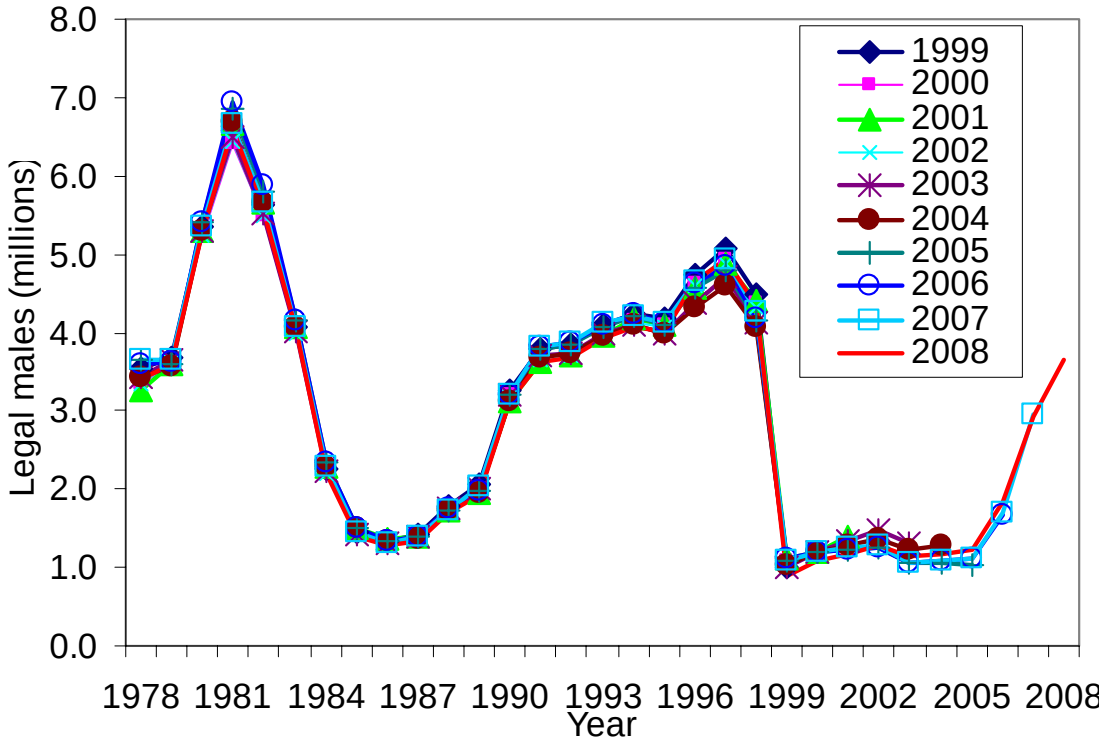




Figure 13. Comparison of estimates of legal male abundance and relative mature male abundance of St. Matthew Island blue king crab with terminal years 1999-2008. The 2008 model was with a fixed *Q*=1.0 and estimating *M*. These are results of historical assessments. Legend shows the year in which the assessment was conducted.

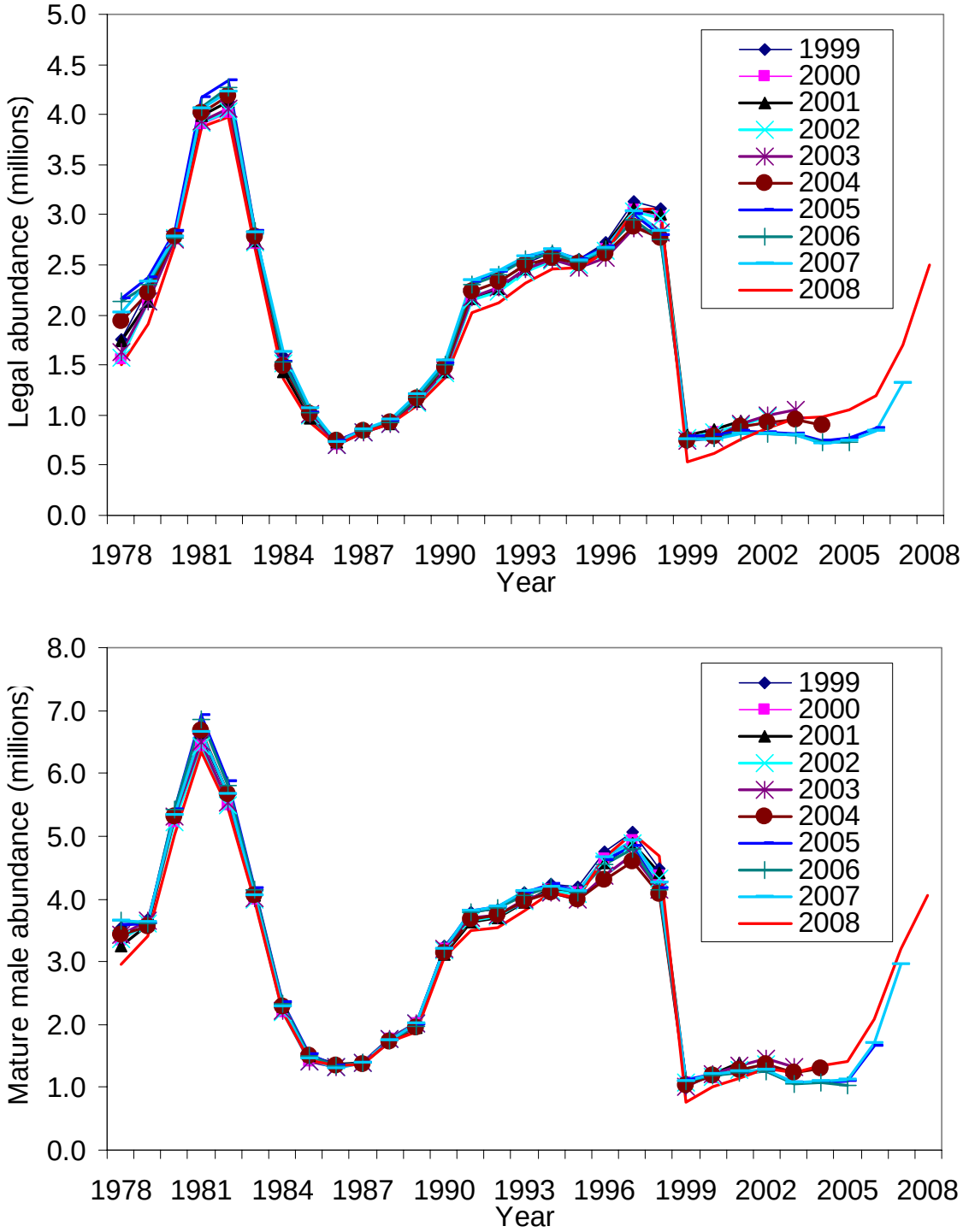



Figure 14. Comparison of estimates of legal male abundance and relative mature male abundance of St. Matthew Island blue king crab with terminal years 1999-2008. The 2008 model was with a fixed *M*=0.18 and *Q*=1.0. These are results of historical assessments. Legend shows the year in which the assessment was conducted.

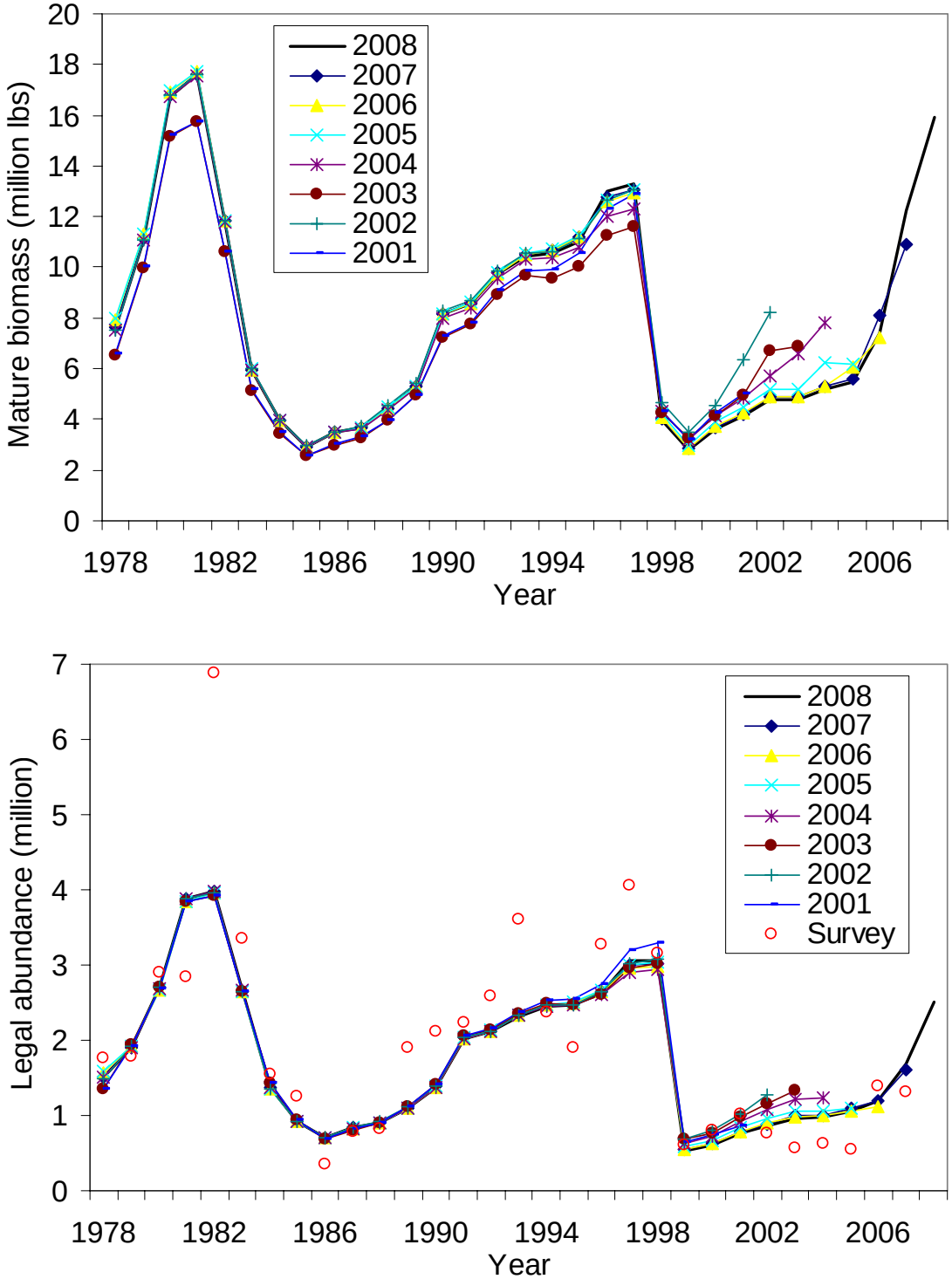



Figure 15. Comparison of estimates of legal male abundance (upper plot) and mature male biomass (lower plot) of St. Matthew Island blue king crab from 1978 to 2008 made with terminal years 2001-2008. These are results of the 2008 model with a fixed *M*=0.18 and *Q*=1.0. The abundances in the terminal years were one-year-ahead projection. Legend shows the year in which the assessment was conducted.

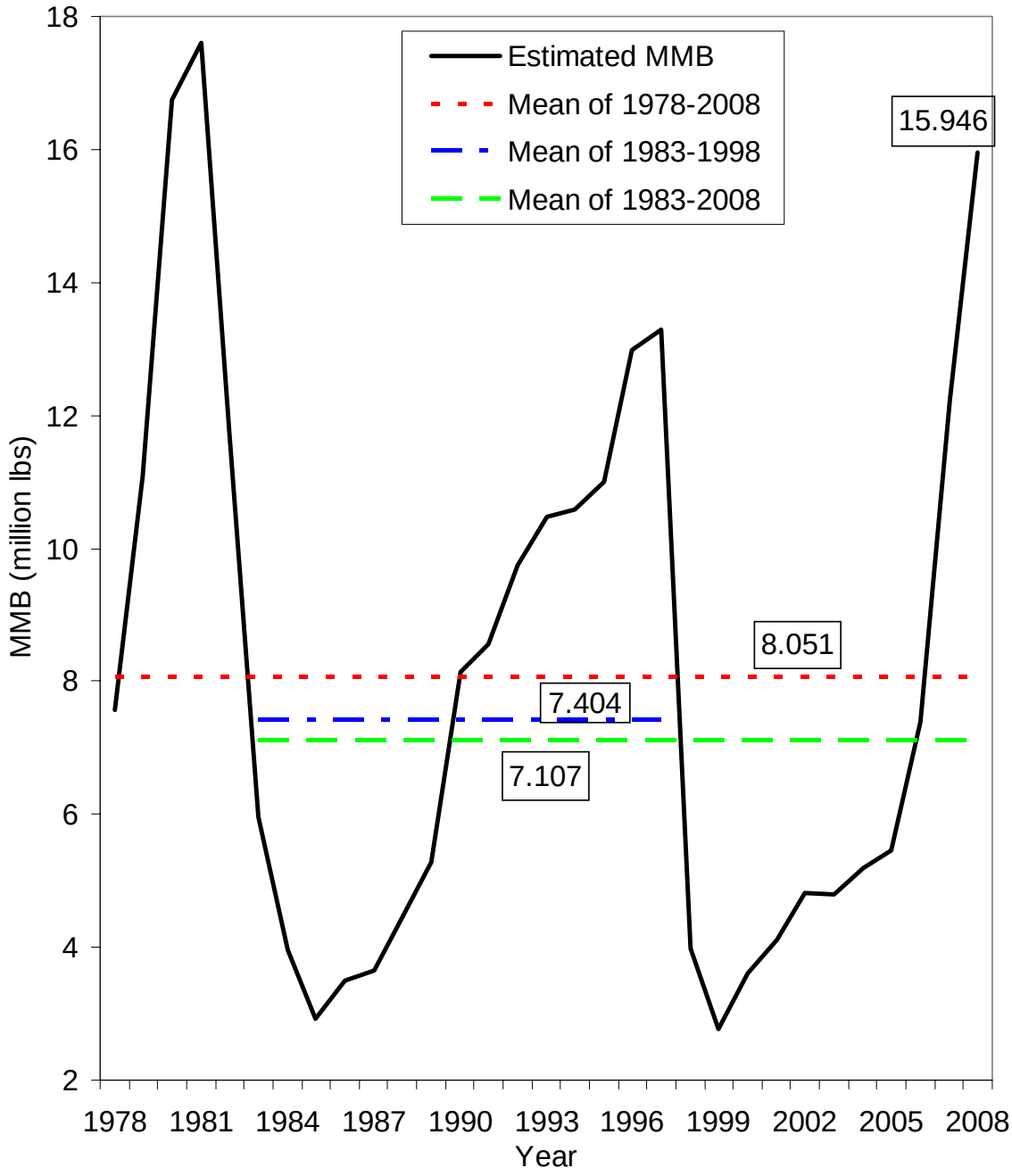



Figure 16. Comparison of estimated mean mature male biomasses during different periods of St. Matthew Island blue king crab. The model was with a fixed *M*=0.18 and *Q*=1.0. Zero catch was assumed for the 2008 fishery to project mature male biomass in 2008.

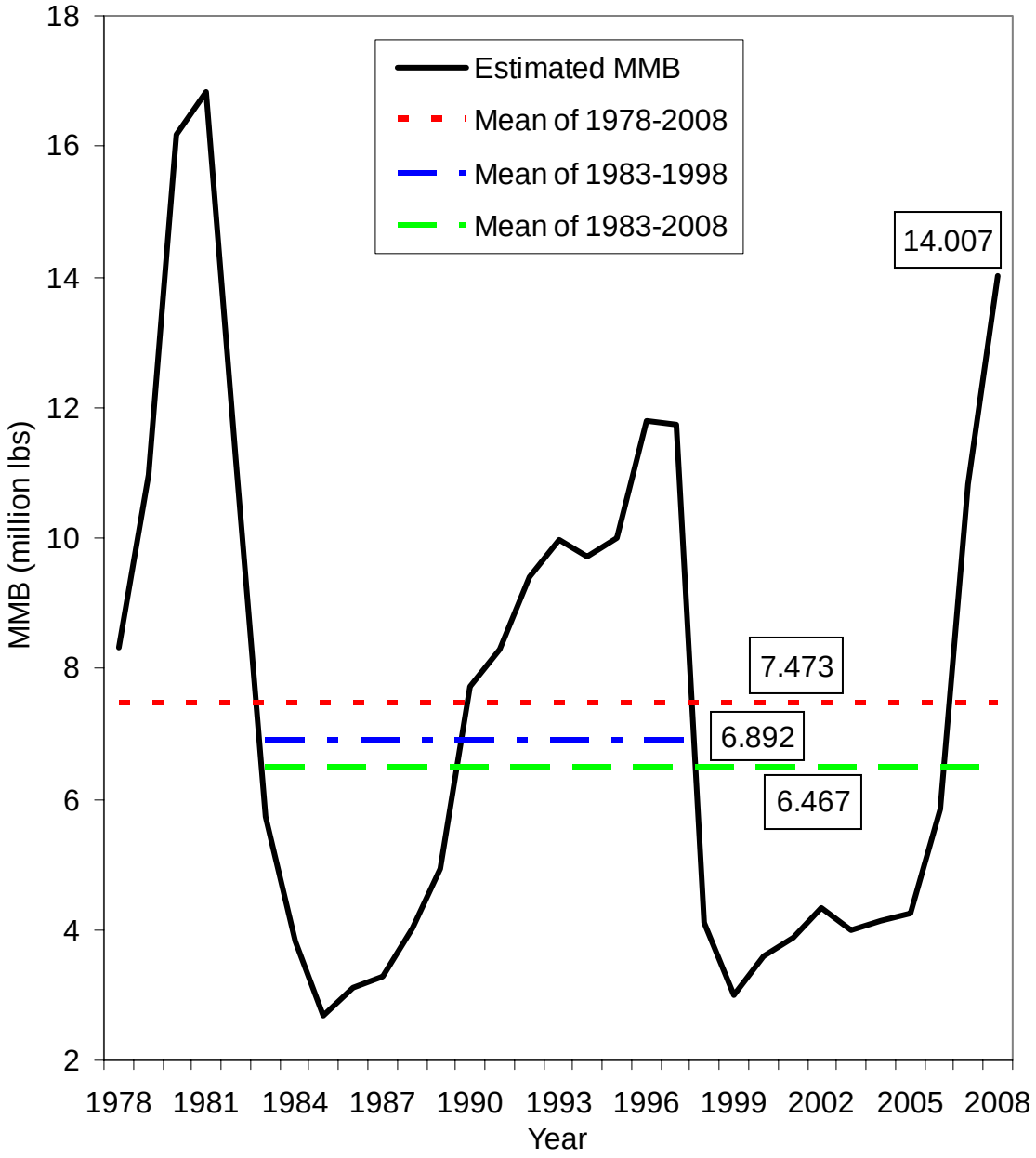



Figure 17. Comparison of estimated mean mature male biomasses during different periods of St. Matthew Island blue king crab. The model was with a fixed *Q*=1.0 and estimating *M*. Zero catch was assumed for the 2008 fishery to project mature male biomass in 2008.