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# Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

L. Rugolo, J. Turnock, and E. Munk
Alaska Fisheries Science Center
NOAA Fisheries

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## Introduction

*Scientific name and general distribution*

Originally described by Rathbun (1924), *Chionoecetes bairdi* is one of five species in the genus *Chionoecetes*. The taxonomic classification attributable to Garth (1958) has been revised (see McLaughlin et al. 2005) to include name changes for a number of hierarchical categories:

| | |
|---|---|
| Class | Malacostraca |
| Order | Decapoda |
| Infraorder | Brachyura |
| Superfamily | Majoidea |
| Family | Oregoniidae |
| Genus | Chionoecetes |

Additionally, the common name for *C. bairdi* of "Tanner crab" (Williams et al. 1989), has recently been modified to "southern Tanner crab" (McLaughlin et al. 2005). In the past the term "Tanner crab" has also been variously used to refer to other members of the genus, or the genus as a whole.

Tanner crabs are generally found in continental shelf waters of the north Pacific. In the east, their range extends as far south as Oregon (Hosie and Gaumer 1974) and in the west as far south as Hokkaido, Japan (Kon 1996). The northern extent of their range is in the Bering Sea (Somerton 1981a) where they are found along the Kamchatka peninsula (Slizkin 1990) to the west and in Bristol Bay to the east.

In the eastern Bering Sea (EBS), Tanner crab distribution appears to be limited by water temperature (Somerton 1981a) (Figure 1). Here, *C. bairdi* is common in the southern half of Bristol Bay, around the Pribilof Islands, and along the shelf break where water temperatures are generally warmer (Figures 2 and 3). A cold water congener, *C. opilio*, the snow crab, finds the southern extent of its range (in the EBS) around the Pribilof Islands. Their distributions overlap on the shelf from approximately 56° to 58°N, and in this area, the two species hybridize (Karinen and Hoopes 1971).

*Management units*

Fisheries have historically taken place for Tanner crab throughout their range in Alaska, but currently only the fishery in the Bering Sea is managed under a federal fisheries management plan (FMP). The FMP defers Bering Sea Tanner crab management to the state of Alaska with federal oversight (Bowers et al. 2008). The state manages Tanner crab based on registration areas, divided into districts. Under the FMP, the state can adjust or further subdivide these districts as needed to avoid overharvest in a particular area, change size limits from other stocks in the registration area, change fishing seasons, or encourage exploration (NPFMC 1998).

The Bering Sea District of Tanner crab Registration Area J (Figure 4) includes all waters of the Bering Sea north of Cape Sarichef at 54° 36' N lat. and east of the U.S.-Russia Maritime Boundary Line of 1991. This district is divided into the Eastern and Western Subdistricts at 173° W long. The Eastern Subdistrict is further divided at the Norton Sound Section north of the latitude of Cape Romanzof and east of 168° W long. and the General Section to the south and west of the Norton Sound Section (Bowers et al. 2008).

*Stock structure*

Tanner crabs in the eastern Bering Sea are considered to be a separate stock and distinct from Tanner crabs in the eastern and western Aleutian Islands (NPFMC 1998)**.** The eastern Bering Sea stock is managed as a single unit, but may consist of two groups in the east and west that differ biologically (see Somerton 1981a).

*Life history*

Reproduction

In most majid crabs, it is thought that the molt to maturity is the final or terminal molt. For *Chionoecetes bairdi* specifically it is now generally accepted that both males (Tamone et al. 2007) and females (Donaldson and Adams 1989) undergo a terminal molt. Females terminally molt from their last juvenile, or pubescent, instar usually while being grasped by a male (Donaldson and Adams 1989). Subsequent mating takes place annually in a hard shell state (Hilsinger 1976) and after extruding their second clutch of eggs. While mating involving old-shell adult females has been documented (Donaldson and Hicks 1977), fertile egg clutches can be produced in the absence of males by using stored sperm from the spermathacae (Adams and Paul 1983, Paul and Paul 1992). At least 2 consecutive egg fertilization events can follow a single copulation (Paul 1982, Adams and Paul 1983), however, egg viability decreases with time and age of the stored sperm (Paul 1984).

Maturity in males can be classified either physiologically or morphometrically. Physiological maturity refers to the presence or absence of spermataphores in the male gonads whereas morphometric maturity refers to the presence or absence of a large claw (Brown and Powell 1972). During the molt to morphometric maturity, there is a disproportionate increase in the size of the chelae in relation to the carapace (Somerton 1981a). While many earlier studies on Tanner crabs assumed that morphometrically mature male crabs continued to molt and grow, there is now substantial evidence supporting a terminal molt for males also (Otto 1998, Tamone et al. 2007). A consequence of the terminal molt in male Tanner crab is that a substantial portion of the population may never reach the legal harvest size (NPFMC 2007).

Although evidence is lacking for the eastern Bering Sea, seasonal differences exist between mating periods for pubescent and multiparous Tanner crab females in the Gulf of Alaska (GOA) and PWS. There, pubescent molting and mating takes place over a protracted period from winter through early summer, whereas multiparous mating occurs over a relatively short period during mid April to early June (Hilsinger 1976, Munk et al. 1996, and Stevens 2000). In the eastern Bering Sea egg condition for multiparous Tanner crabs assessed between April and July 1976 also suggested that hatching and extrusion of new clutches for this maturity status began in April and ended sometime in mid June (Somerton 1981a).

Fecundity

A variety of factors affect female Tanner crab fecundity including female size, maturity status (primiparous vs multiparous), age post terminal molt, and egg loss (NMFS 2004a). Of these factors, female size is the most important, with estimates of 89 to 424 thousand eggs for EBS females 75 to 124 mm carapace width (CW) (Haynes et al. 1976). Maturity status is another significant factor affecting fecundity with EBS primiparous females being only ~70% as fecund as equal size multiparous females (Somerton and Meyers 1983). The number of years after the maturity molt, and whether or not, a female has had to use stored sperm from that first mating can also affect egg counts (Paul 1984, Paul and Paul 1992). Additionally, older or senescent females in the EBS often carry small clutches or no eggs at all suggesting that Tanner crabs may have only 2 or 3 primary reproductive years (NMFS 2004a). Donaldson et al. (1981) inferred a maximum age of 6 years after terminal molt for female Tanner crab.

Size at Maturity

Somerton (1981b) noted differences in the size of Tanner crab female maturity across the EBS. For the 5 survey years from 1975 to 1979, east of 167° 15’ W longitude, the mean size of mature females ranged from 92.0 to 93.6 mm CW. West of that longitude, the size of female maturity ranged from 78.0 to 82.0 mm CW. For harvest strategy purposes, mature females are defined as females >=80mm CW (Bowers et al. 2008). For male Tanner crab during the same survey years and using the same longitude to partition the EBS, the estimated size at 50% maturity was 117.0 mm CW east of the partition, and 108.9 mm CW west of the partition (Somerton 1981b).

Mortality

Due to a lack of reliable age information, Somerton (1981a) estimated mortality separately for individual EBS cohorts of juveniles (pre recruits) and adults larger than a certain size. He felt that, because of net selectivity (survey sampling gear) that age five Tanner crab (95 mm CW) were the first cohort to be fully recruited to the sampling gear, and estimated an instantaneous

natural mortality rate of 0.35 for this size class. Using two different models, he then estimated natural mortality rates of adults (fished population) from data from the EBS population survey of 0.20 to 0.28. When using CPUE data from the Japanese fishery the estimated rates were 0.13 to 0.18. He felt that estimates (0.22 to 0.28) from models that used both the survey and fishery data were the best.

Zheng et al. (1998) used a nonlinear least-squares approach to estimate abundance, recruitment, and natural mortality for Bristol Bay Tanner crab. They limited their scope to crabs >=93 mm CW, also due to survey catchability concerns. Model estimates of natural mortality (2 scenarios) for males were 0.489 and 0.495 and for females 0.5231 and 0.551.

**Fishery**

The domestic Tanner crab (*Chionoecetes bairdi*) pot fishery rapidly developed in the mid-1970s (Table 1, Figures 5 and 6). Unites States landings were first reported for Tanner crab in 1968 at 1.01 million pounds taken incidentally to the eastern Bering Sea red king crab fishery. Tanner crab was targeted thereafter by the domestic fleet and landings rose sharply in the early-1970s, reaching a high of 66.6 million pounds in 1977. Landings fell precipitously after the peak in 1977 through the early 1980s, and domestic fishing was closed in 1985 and 1986 as a result of depressed stock status. In 1987, the fishery reopened and landings rose again in the late-1980s to a second peak in 1990 at 40.1 million pounds, then fell sharply through the mid-1990s. The domestic Tanner crab fishery closed between 1997 and 2004 as a result of severely depressed stock condition. Landings of Tanner crab in the foreign Japanese pot and tangle net fisheries were reported between 1965-1978, peaking at 44.0 million pounds in 1969 (Table 1, Figure 6). The Russian tangle net fishery was prosecuted between 1965-1971 with peak landings in 1969 at 15.6 million pounds. Both the Japanese and Russian Tanner crab fisheries were displaced by the domestic fishery by the late-1970s.

Discard and bycatch losses of Tanner crab originate from the directed pot fishery, the non-directed pot fisheries (notably, snow crab and red king crab), and the groundfish trawl fisheries (Table 2). Historical discard and bycatch data on Tanner crab were integrated from a variety of sources; missing data in some years and categories were derived based on relationships among data categories. Discard/bycatch mortalities were estimated using post-release handling mortality rates (HM) of 0.50 for pot fishery discards and 0.80 for trawl fishery bycatch. Total Tanner crab discard and bycatch losses by sex are shown in Table 2 for 1965-2007. The pattern of total discard/bycatch losses is similar to that of the retained catch (Table 1). These losses were persistently high during the late-1960s through the late-1970s; male losses peaked in 1970 at 44.5 million pounds (Table 2). A subsequent peak mode of discard/bycatch losses occurred in the late-1980s through the early-1990s which, although briefer in extent, revealed higher losses for males than the earlier mode; peak=49.2 million pounds in 1990. From 1965-1975, the groundfish trawl fisheries contributed significantly to total bycatch losses, although the combined pot fisheries are the principal source of contemporaneous non-retained losses to the stock (Table 2). Total Tanner crab retained catch plus non-directed losses of males and females (Table 3, Figure 5a) reflect the performance patterns in the directed and non-directed fisheries. Total male catch rose sharply with the fishery development in the early 1960s and reveals a bimodal distribution between 1965 and 1980 with peaks of 104.7 million pounds in 1969 and 115.5 million pounds in 1977 (Table 3, Figure 5a). Total male catch rose sharply after the

directed domestic fishery reopened in 1987 and reached a peak of 89.3 million pounds in 1990. Total male and female catch fell sharply thereafter with the collapse of the stock and the fishery closure in 1997.

**Data**

*Growth and Age*

Somerton (1981a) studied growth of Tanner crab in the eastern Bering Sea and used size frequency data to estimate growth per molt. Because of a lack data on smaller instars and no estimates of molt frequency, he combined size at age estimates from Kodiak crab (Donaldson et al. 1981) to construct a growth and age schedule for EBS Tanner crabs (Table 1). Radiometric ageing has suggested that age after terminal molt may be 6 to 7 years (Nevisi et al. 1996).

*Weight at length*

Growth in weight data was collected during the 1975 EBS crab survey (Somerton 1981a). Carapace width and total weight were measured on 243 male Tanner crab. Only clean shell 2 or 3 crab were selected with no missing or regenerating appendages. The fitted equation was: $W=0.00019(CW)^{3.09894}$.

*Stock Biomass*

Tanner crab male mature biomass (MMB) and legal male biomass (LMB) exhibited periods of peak biomass in the early to mid-1970s and the early to mid-1990s (Table 5, Figures 5b and 7). At this writing, LMB data are available only for 1980-2007. Although MMB estimates date to 1969, the variation in annual estimates between 1969-1975 reflect data availability and retrospective analysis of the historical NMFS trawl survey data is required to complete the time series record. The components of MMB and LMB at the time the survey, at the time of the fishery and at the time of mating are shown in Table 5 and Figure 7. The historical bimodal distribution in male biomass reflects that of the attendant directed fisheries with peak modes in the mid-1960s through mid-1970s and in the early-1990s (Table 5, Figure 7), and collapsed stock status following these respective modes. MMB at the survey revealed an all-time high of 623.9 million pounds in 1975, and a second peak of 255.7 million pounds in 1991. From late-1990s through 2007, MMB has risen at a moderate rate from a low of 25.1 million pounds in 1997 to its current level of 185.2 million pounds in 2007. Under the former BSAI King and Tanner Crab fishery management plan (NPFMC 1998) and overfishing definitions, the Tanner crab stock was above the $B_{MSY}$ level indicative of a restored stock for the second consecutive year in 2007 and declared rebuilt.

*Exploitation Rates*
The historical pattern of fishery exploitation on LMB and MMB were derived (Table 6, Figures 8a and 8b). The exploitation rate on LMB was estimated as the proportion of retained catch to LMB at the time of the fishery, while that on MMB as the proportion of total male catch to MMB at the time of the fishery. At this writing, estimates of LMB are available only for 1980-2007. During that period, exploitation rate ($\mu$) on LMB was highest in 1980 at 0.49 and fell with stock condition through the mid-1980s. LMB exploitation rate revealed a second prominent mode during 1987-1995, peaking at 0.39 in 1990 and averaging 0.27 (Table 6, Figure 8b). The pattern of $\mu$ on MMB from 1969-2007 reveals two high periods: one associated with the high total catches between 1969-1980; the other coincident with the mode of high catches in the late-1980s through early-1990s. The variability in $\mu$ on MMB during the early period (1969-1980) occurs as a result of the uncertainty in biomass estimates which require re-estimation. Exploitation rate on MMB during the 1990s peaked at 0.42 in 1990, averaged 0.20 between 1986-1998, and closely followed the build up in stock biomass during that period.

**Analytic Approach**

## *Tier-4 OFL Control Rule and OFL-Determination*

In the Environmental Assessment proposed as Amendment 24 to the BSAI King and Tanner Crab fishery management plan (NPFMC 2008), Tier-4 stocks are characterized as those where essential life-history information and understanding are lacking. Although a full assessment model cannot be specified for Tier-4 stocks, or stock-recruitment relationship defined, sufficient information is available for simulation modeling that captures essential population dynamics of the stock as well as the performance of the fisheries. Such modeling approaches serve the basis for deriving the annual status determination criteria to assess stock status and to establish harvest control rules.

In Tier-4, a default value of M and a scaler Gamma ($\gamma$) are used in OFL setting. The proxy $B_{MSY}$ represents the level of equilibrium stock biomass indicative of providing maximum sustainable yield (MSY) to the fisheries exploited at $F_{MSY.}$ $B_{MSY}$ can be estimated as the average biomass over a specified period that satisfies these conditions (i.e., equilibrium biomass yielding MSY by an applied $F_{MSY}$). We also consider its estimation as a percentage of pristine biomass ($B_0$) of the unfished or lightly exploited stock. In Tier-4, the $F_{OFL}$ is calculated as the product of $\gamma$ and M, where M is the instantaneous rate of natural mortality. The EA defines a default value of gamma = 1.0. Gamma is allowed to be less than or greater than unity and, in such instances, the resultant overfishing limit can be more or less biologically conservative than fishing at the rate M. Use of the scaler $\gamma$ is intended to allow adjustments in the overfishing definitions to account for differences in the biomass measures used in the EA analyses. However, since Tier-4 stocks are information-poor by definition, the EA states that $\gamma$ should not be set to a value that would provide less biological conservation and more risk-prone overfishing definitions without defensible evidence that the stock could support fishing at levels in excess of M. The resultant overfishing limit for Tier-4 stocks is the total catch OFL that includes expected retained plus discard/bycatch losses. For Tier-4 stocks, a minimum stock size threshold (MSST) is specified; if current MMB drops below MSST, the stock is considered to be overfished.

For Tier-4 stocks, the $F_{OFL}$ is derived using and $F_{OFL}$ Control Rule (Figure 9) according to whether current mature stock biomass metric (B) is a member of 1 of 3 stock status levels (a, b or

c) in the following algorithm. The stock biomass level beta (β) represents a minimum threshold below which directed fishing mortality is set to zero. The parameter alpha (α) moderates the slope of the non-constant portion of the control rule. For biomass levels levels $\beta < B \leq B_{MSY}$, the $F_{OFL}$ is estimated as a function of the ratio $B/B_{MSY}$. The value of M is 0.23 for eastern Bering Sea Tanner crab. In the EA analysis for Tier-3 stocks (*Chionoecetes opilio* and *Paralithodes camtschaticus*), a $B_{MSY}$ proxy reference value ($B_{REF}$) equal to 35% of the maximum spawning potential of the unfished stock was specified. For Tier-4 stocks, a reference biomass value ($B_{REF}$) must be specified. The OFL algorithm is:

| Stock Status Level: | | $F_{OFL}$: |
|---|---|---|
| a. | $B/B_{REF} > 1.0$ | $F_{OFL} = \gamma \cdot M$ |
| b. | $\beta < B/B_{REF} \leq 1.0$ | $F_{OFL} = \gamma \cdot M\ [(B/B_{REF} - \alpha)/(1 - \alpha)]$ |
| c. | $B/B_{REF} \leq \beta$ | Directed Fishery F=0 |
| | | $F_{OFL} \leq F_{MSY}$ |

***OFL Model Structure***

In this Tier-4 OFL-setting approach, LMB at the time of the fishery ($LMB_{Fishery}$) and MMB at both the time of the fishery ($MMB_{Fishery}$) and mating ($MMB_{Mating}$) are estimated as:

$$LMB_{Fishery} = LMB_{Survey} \cdot e^{-PM(sf)} \quad (1)$$

$$MMB_{Fishery} = MMB_{Survey} \cdot e^{-PM(sf)} \quad (2)$$

$$MMB_{Mating} = MMB_{Survey} \cdot e^{-PM(sm)} - Catch_{MMB}\ OFL \quad (3)$$

where,

$LMB_{Survey}$ is the legal male biomass at the time of the survey,
$LMB_{Fishery}$ is the legal male biomass at the time of the fishery,
$MMB_{Survey}$ is the mature male biomass at the time of the survey,
$MMB_{Fishery}$ is the mature male biomass at the time of the fishery,
PM(sf) is the partial M from the time of the survey to the fishery (6 months),
PM(sm) is the partial M from the time of the survey to mating (8 months),
$e^{-PM(sf)}$ is the survival rate from the survey to the fishery,
$e^{-PM(sm)}$ is the survival rate from the survey to mating.

The projected catch limit and the projected buffered catch limit on LMB are calculated as:

$$\text{Catch OFL} = [1 - e^{-Fofl}] \cdot LMB_{Fishery} \quad (4)$$

$$\text{Buffered Catch OFL} = P_{Buffer} \cdot [1 - e^{-Fofl}] \cdot LMB_{Fishery} \quad (5)$$

where,

$P_{Buffer}$ is the proportion of the Catch OFL set as a catch target,
$[1 - e^{-Fofl}]$ is the annual fishing mortality rate.

Exploitation rates on legal male biomass ($\mu_{LMB}$) and mature male biomass ($\mu_{MMB}$) at the time of the fishery are calculated as:

$$\mu_{LMB} = [\text{Total LMB Losses}] / LMB_{Fishery} \quad (6)$$

$$\mu_{MMB} = [\text{Total MMB Losses}] / MMB_{Fishery} \quad (7)$$

where,

[Total LMB Losses] is the total directed + non-directed losses to LMB,
[Total MMB Losses] is the total directed + non-directed losses to MMB.

Using the $F_{OFL}$ Control Rule (Figure 9), $F_{OFL}$ is determined based on MMB at time of mating after extraction of total catch. Since the ratio of $B/B_{REF}$ is dependent on the magnitude of the extracted catch and the catch OFL upon the estimated $F_{OFL}$, an iterative solution is found that maximizes the $F_{OFL}$ and catch based on the relationship of MMB at mating to $B_{REF}$. The total catch OFL includes all sources of fishery-induced removals from the stock – that is, directed retained catch, directed discards, and non-directed pot and trawl bycatch mortalities. Given specification of all component losses, the retained portion of the catch OFL and/or the retained portion of the buffered catch OFL is set as the limit for the directed fishery given the expected non-retained losses.

***OFL-Setting Results***

Estimation of overfishing limits for Tier-4 stocks in any fishing year requires the availability of the previous-most NMFS summer survey estimates of LMB and MMB. Since, at this writing, the 2008 eastern Bering Sea trawl survey is yet to be conducted, we're unable to estimate overfishing limits for the upcoming 2008/09 Tanner crab fishery. To illustrate the performance of this OFL-setting method for Tanner crab, we estimated the 2007/08 catch OFL and compared these results to the 2007/08 TAC estimated by the ADF&G fishery management threshold and harvest strategy analysis. Our proposed OFL-setting approach explicitly accounts for discard/bycatch mortalities which was not required previously.

We defined two types of proxy $B_{MSY}$ values for this analysis. In the first type, $B_{REF}$ is estimated as 35% of $B_0$, where $B_0$ is a proxy level of pristine male mature biomass indicative of equilibrium unfished or lightly exploited stock. The multiplier 35% is an approximation which originates from the EA simulation analysis which proposed $B_{35\%}$ as a proxy for $B_{MSY}$. $B_{35\%}$ is a spawning biomass per recruit value which does not necessarily equal 35% of $B_0$. The fraction of $B_0$ represented by $B_{35\%}$ will depend on the shape of the stock recruitment relationship. The second type of $B_{REF}$ is estimated as the average male mature biomass over a specified time period thought to be representative of life at $B_{MSY}$. For 2007, there levels of $B_{REF}$ are defined (Table 7). $B_{REF1}$ = 140.0 million pounds derived as $0.35 \cdot B_0$, where $B_0$ is the mean of the high 3 years of mature male biomass (1969, 1974 and 1975). $B_{REF2}$ = 154.4 million pounds derived as $0.35 \cdot B_0$, where $B_0$ is the mean of the high 2 years of mature male biomass (1969 and 1975). $B_{REF3}$ = 178.2 million pounds derived as the mean 1975-80 male mature biomass as a proxy for $B_{MSY}$. We acknowledge that these two proxy $B_0$ values underestimate pristine male mature biomass since the stock was contemporaneously exploited at levels among the highest on record

(Tables 1 and 3, Figure 5). Similarly, use of the average 1975-80 as a proxy for $B_{MSY}$ is confounded by contemporaneous and antecedent high exploitation rates (Table 6, Figure 8a). Therefore, we believe that $B_{REF3}$ underestimates the capacity of this stock to persist at $B_{MSY}$ and provide maximum sustainable yield to the fisheries.

We used a buffer value of 0.80 to illustrate a level of catch OFL that reduces the risk of exceeding the overfishing limit. For each of the 3 model scenarios (i.e., $B_{REF1}$, $B_{REF2}$ and $B_{REF3}$), gamma was set to 1.0. The catch OFL in this analysis does not incorporate fishery selectivity or market preferences for components of the legal male biomass. Here, LMB includes all legal-sized males regardless of shell condition class. If fishery selectivity is employed as an argument for setting gamma in excess of 1.0, then the measure of LMB used in this analysis to estimate catch OFLs would need to be depreciated by the old shell components of LMB not targeted by the fishery. In this instance, discard mortalities would also have to be applied.

In our OFL analysis, we accounted for discard/bycatch mortalities from the directed and non-directed pot fisheries and the groundfish trawl fisheries. By comparison, since the EA simulations did not equivalently account for non-retained losses, it's uncertain what, if any, multiplier of M is appropriate or would be suggested by the relationship of M to full-selection $F_{35\%}$ rates from EA simulations. Further confounding specification of gamma in excess of 1.0 is the fact that the MMB currency derived in this analysis employs a maturity schedule vs that of the EA simulations which employed knife-edge sex-specific maturity at size. The EA prescribes that gamma should not be set to a level that would provide for more risk-prone overfishing definitions without defensible evidence that the stock could support at levels in excess of M. Examination of the historical performance of the fishery (Figure 5a) and stock biomass (Figure 7) reveals that the Tanner crab stock has not been able to maintain itself in dynamic equilibrium over any sustained period, nor persist in the face of exploitation rates (Table 6, Figures 8a and 8b) in excess of M. Differences between fishery selectivity and maturity in eastern Bering Sea crab stocks have also been suggested as a reason to allow gamma to exceed unity. This latter argument relies on theoretical mass-balance considerations in mature male biomass which are violated given the unique reproductive dynamic features of the stocks (e.g., male-female size dependencies for successful copulation, male guarding and competition). Since a fundamental precept of precautionary fishery management is that no stock component should be exploited at a rate in excess of the $F_{OFL}$, we find no evidence that would justify a gamma in excess of 1.0 or fishing at an $F_{OFL}$ rate greater than M.

<u>The 2007/08 OFLs</u>:
For the 2007 Tanner crab fishery, we estimated catch OFLs of 5.4, 4.8 and 4.3 million pounds of legal male biomass for the respective 3 model scenarios (i.e., $B_{REF1}$, $B_{REF2}$ and $B_{REF3}$) (Table 7). By comparison, the 2007 Tanner crab TAC estimated by the ADF&G harvest control strategy was 5.6 million pounds. After adjusting for projected directed discard and non-directed discard/bycatch losses to LMB, the retained portion of the catch OFLs are: 2.5, 2.1 and 1.6 million pounds respectively. For the 3 model scenarios, the corresponding $B/B_{REF}$ ratios and $F_{OFLs}$ were: [$B/B_{REF1}$=0.94, $F_{OFL}$=0.21]; [$B/B_{REF2}$=0.83, $F_{OFL}$=0.19]; [$B/B_{REF3}$=0.74, $F_{OFL}$=0.16]. Projected buffered catch OFLs, and the retained portions of the buffered catch OFLs shown in parentheses for these three scenarios were 3.6 (2.5), 3.0 (2.1) and 2.5 (1.6) million pounds, respectively (Table 7). The expected exploitation rates on LMB and MMB associated with the

$F_{OFL}$ for each model scenario after accounting for all catch components were, respectively, 0.19, 0.17 and 0.15 (Table 7).

In comparison the catch limit representing the overfishing status determination criterion, the permitted non-directed mortalities to MMB under each model scenario reveals that the retained catch limit would comprise only 10.2%, 9.7% and 9.0% respectively of the total male mature biomass losses to the stock. A significant component of MMB OFL is therefore subject to non-targeted losses under this OFL definition. Although its biomass currency is not directly comparable, the EA simulation analysis found that the Bristol Bay portion of the 2007 Tanner crab MMB was approximately 0.95 $B_{REF}$ which compares to the $B_{REF2}$ results of this analysis (0.91). The exploitation rates under all scenarios exceed the ADF&G harvest strategy goal of 10% harvest rate on molting mature male biomass.

**Ecosystem Considerations**

**Ecosystem Effects on Stock**

*Prey availability or abundance trends*

Tanner crab food habits in the EBS are largely unstudied, but a study near Kodiak (Jewett and Feder 1983) examined stomach contents from 1,025 Tanner crab > 40 mm CW Arthropods (mainly juvenile Tanner crab) dominated by weight; fishes and mollusks (mainly *Macoma* spp. and *Yoldia* spp.) were the second and third-most important food groups, by weight. In the western Bering Sea, the ascidian *Halocynthia autantium* is preyed upon by snow and Tanner crabs (Ivanov 1993). While the trends in EBS Tanner crab prey are largely unknown, it is thought that recent warmer temperatures may have put the Bering Sea food web into a top-down control regime (Hunt et al. 2002, Aydin and Mueter 2007) and so prey availability would not be limiting adult Tanner abundance. The relative importance, however, of climate effects is uncertain (Aydin and Mueter 2007).

*Predator population trends*

Several fishes, most notably Pacific cod (*Gadus macrocepahalus*), are documented as predators of Tanner crab in the eastern Bering Sea, Pacific halibut (*Hippoglossus stenolepis*) and skates (*Raja* sp.) being minor predators (Livingston 1989, Livingston et al. 1993, Lang et al. 2005). Pacific cod biomass increased steadily from 1978 through 1983, remained relatively constant from 1983 through 1988, fluctuated slightly from 1988 through 1994 (the highest observation) and in general has steadily declined since then with 2007 estimates being the lowest estimate in the time series (Thompson et al. 2007). Halibut biomass was lowest in 1982, fluctuated from 1983 through 1988, peaked in 1988, dropped in 1989 and increased from 1990 through 1996 when the highest biomass of the time series was observed, after 1998 biomass has fluctuated (personal communication, Steven Hare, IPHC). Biomass estimates of all skate species in the eastern Bering Sea are not reported, however biomass has been estimated for the Alaska skate (*Bathyraja parmifera*) since 1982. Estimated biomass for the Alaska skate fluctuated from 1982 through 1986, from 1986 through 1990 biomass in general increased and peaked in 1990, from 1991 through 1999 biomass tended to decrease and beginning in 1999 to the present biomass has been increasing (Ormseth and Matta 2007).

*Disease effects on the stock*
Bitter crab syndrome (BCS) is caused by a non-motile single celled protistan blood parasite *Hematodinium* sp. and is uniformly lethal to crab (Meyers et al. 1990). BCS has been detected in EBS Tanner crab for 20 years with no clear trends in prevalence. As discussed at a recent international workshop on the disease ("Hematodinum Associated Diseases: Research Status and Future Directions", Charlottetown, Prince Edward Island, Canada, Sept. 20-22, 2007), the long term effect of the disease on the crab populations is not well understood. Another potentially serious Tanner crab disease is black mat syndrome (BMS). BMS is a systemic fungal infection caused by *Trichomaris invadens* and is lethal to crab. Infection prevents molting therefore infected sublegal crabs would never grow to enter the fishery (Sparks 1982). BMS, however, has never been an important issue in the EBS (F. Morado, NOAA Fisheries, AFSC, Seattle, personal communication)

*Changes in habitat quality*
The ecosystem reorganization following the 1976/77 regime shift and to a lesser degree the 1998/1999 shift (Connors et al. 2002, Litzow 2006), have not in general favored Tanner populations in the EBS, but the exact nature of the biological response to these climate changes is poorly understood (Litzow 2006). In addition, it is proposed that future temperature increases and ocean acidification may directly affect the growth and survival of larval crab (M. Litzow, unpublished data, AFSC NOAA Fisheries), as well as causing drastic changes to the phytoplankton community in the Bering Sea (Hare et al. 2007) upon which larval Tanner crab are dependent (Incze et al. 1987, Incze and Paul 1983). The current effects of temperature increases and ocean acidification on Tanner crab are unknown.

***Tanner Crab Fishery Effects on the Bering Sea Ecosystem***
*Fishery contribution to bycatch*
The ADF&G observer program collects bycatch data on observed vessels (Table 8). Non-targeted sublegal male and female Tanner crab made up the largest number of bycatch followed by snow crab bycatch. Fish, including a number of crab predators, especially Pacific cod, Pacific halibut, yellowfin sole, and sculpin (*Myoxocephalus* spp.) were also caught (Barnard and Burt 2007, 2008, NMFS 2004). Invertebrates include sea stars, snails, hermit crabs, lyre crab, and others captured at low rates.

*Handling mortality*
It is generally accepted that there is a certain amount of mortality inflicted on the non-target species captured during fishing operations. Captured animals can die from handling stress, windchill, or while trapped in lost gear. Studies have been done to simulate handling injury but subsequent mortality was low and not significantly greater than controls (MacIntosh et al. 1996). Freezing due to windchill causes significant mortality to Tanner crabs (Carls 1989) and can result in leg loss or immediate mortality for Tanner crabs. Stevens and MacIntosh (1992) found average overall mortality of 11% for Tanner crab on one commercial crab vessel. Although it has been conclusively shown that windchill can effect high rates of mortality in Tanner crabs, there is also evidence that exposure of captured crabs to such windchill may not be common during actual fishing. The Crab Plan Team has estimated bycatch mortality to be higher in the snow and

Tanner crab fisheries (24% and 20%, respectively) than in the king crab fisheries (8%) and that has been supported by higher incidence of pre-discard injuries during the snow crab fishery than in the red king crab fishery (Tracy and Byersdorfer 2000, Byersdorfer and Barnard 2002). Despite the research on handling mortality, the EIS for Bering Sea and Aleutian Islands (BSAI) crab fisheries (NMFS 2004) concludes there is not a good understanding of the effects of handling on crab bycatch mortality.

Increased mortality to fish and non-target invertebrates from ghost pot fishing in the Bering Sea has not been fully studied. ADF&G strictly enforces the requirement for a biodegradeable twine in each crab pot at the time vessels register for the fishery. The biodegrading twine requirement is intended to disable the ability of lost pots to fish after approximately 30 days but recent work indicates that the twine may stay intact for as long as 89 days in lost pots (Barnard 2008), much longer than the 30 days that was found to cause irreversible starvation effects in the laboratory (Paul et al. 1994).

*Benthic species and habitat impacted by pot gear*

In the final environmental impact statement for the BSAI crab fisheries the impact of pot gear on benthic species is discussed (NMFS 2004). These benthic species include fish, gastropods, coral, echinoderms (sea stars and sea urchins), non-FMP crab, and other invertebrates (sponges, octopuses, anemones, tunicates, bryozoans, hydroids, and jellyfish). Physical damage to the habitat by pot gear is dependent on habitat type. Sand and soft sediments where the Tanner crab fishery occurs are less likely to be impacted, whereas coral, sponge, and gorgonian habitats are more likely to be damaged (Quandt 1999, NMFS 2004). Despite the large number of pot lifts that occur during the fishery, the actual footprint impacted by the pots is much less than 1% of the Bering Sea shelf (NMFS 2004). It was concluded that the BSAI crab fisheries have an insignificant effect on benthic habitat. Since the bycatch species are widespread across the Bering Sea shelf, the impacts of pot gear on overall populations would also be minimal.

*ESA and non-ESA marine mammals and seabirds*

According to the ESA EIS report, crab fisheries do not adversely affect ESA listed species, destroy or modify their habitat, or comprise a measurable portion of the diet (NMFS 2004) including listed marine mammals or seabirds, although the possibility of strikes of listed seabirds with crab fishing vessels exists (NMFS 2000).

Of the marine mammals not listed under the ESA, the bearded seals (*Erignathus barbatus*) are the only marine mammal potentially impacted by the crab fisheries because crab are a measurable portion of the diet of these species (Lowry et al. 1980, NMFS 2004). No current data or information regarding bearded seal populations or conflicts or interactions with crab fisheries is available. For non-listed seabirds, the Alaska Groundfish Fisheries Final Programmatic SEIS (NMFS 2004b) provides life history, population biology and foraging ecology for marine birds. The SEIS concludes that the crab species under the FMP, including Tanner crab, have very limited interaction with non-listed seabirds.

*Fishery Effects on Amount of Large Size Target Crab*
While there have been some documented changes in the size of large fish available to fisheries as a result of removals of the fastest growing components of the population (ICES 2002), this phenomena has not been demonstrated in crustaceans.

*Fishery Contribution to Discards and Offal Production*
The EIS for the BSAI Crab Fisheries summarizes some of the effects of discards and offal production (NMFS 2004). Returning discards, process waste, and the contents of used bait containers to the sea provides energy to scavenging birds and animals that may not have access to those energy resources. The total offal and discard production as a percentage of the unused detritus already going to the bottom has not been estimated for the crab fisheries.

*Fishery Effects on Age-At-Maturity and Fecundity*
No effects of overfishing on fecundity or size at maturity in female crabs would be expected in a crab fishery that targets only mature males (Orensanz et al. 1998) with little bycatch of females.

Ecosystem effects on the eastern Bering Sea Tanner crab stocks and fishery effects on the ecosystem are interpreted and evaluated in Table 9.

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Table 1. Eastern Bering Sea *Chionoecetes bairdi* retained catch in the United States pot, the Japanese tangle net and pot, and the Russian tangle net fisheries, 1965-2007.

| | Eastern Bering Sea *Chionoecetes baridi* Retained Catch ($10^6$ lb) | | | | |
|---|---|---|---|---|---|
| | US Pot Fishery | | Japan | Russia | Total |
| Year | | [Crabs/Pot] | | | |
| 1965 | | | 2.58 | 1.66 | 4.24 |
| 1966 | | | 3.73 | 1.66 | 5.39 |
| 1967 | | | 21.50 | 8.48 | 29.98 |
| 1968 | 1.01 | 12.00 | 29.95 | 8.73 | 39.69 |
| 1969 | 1.02 | 29.00 | 43.98 | 15.61 | 60.60 |
| 1970 | 0.17 | 8.00 | 41.73 | 14.31 | 56.20 |
| 1971 | 0.11 | 10.00 | 35.04 | 10.51 | 45.66 |
| 1972 | 0.23 | 6.00 | 37.04 | | 37.27 |
| 1973 | 5.04 | 115.00 | 23.67 | | 28.72 |
| 1974 | 7.03 | 72.00 | 26.58 | | 33.60 |
| 1975 | 22.30 | 63.00 | 16.62 | | 38.92 |
| 1976 | 51.50 | 68.00 | 14.67 | | 66.17 |
| 1977 | 66.60 | 51.00 | 11.72 | | 78.32 |
| 1978 | 42.50 | 42.00 | 4.00 | | 46.50 |
| 1979 | 36.60 | 30.00 | 5.30 | | 41.90 |
| 1980 | 29.60 | 21.00 | | | 29.60 |
| 1981 | 11.00 | 10.00 | | | 11.00 |
| 1982 | 5.27 | 8.00 | | | 5.27 |
| 1983 | 1.21 | 8.00 | | | 1.21 |
| 1984 | 3.15 | 12.00 | | | 3.15 |
| 1985 | 0 | 0 | | | 0 |
| 1986 | 0 | 0 | | | 0 |
| 1987 | 2.20 | 8.00 | | | 2.20 |
| 1988 | 7.01 | 16.00 | | | 7.01 |
| 1989 | 24.50 | 15.00 | | | 24.50 |
| 1990 | 40.10 | 19.00 | | | 40.10 |
| 1991 | 31.80 | 10.00 | | | 31.80 |
| 1992 | 35.10 | 13.00 | | | 35.10 |
| 1993 | 16.90 | 13.00 | | | 16.90 |
| 1994 | 7.80 | 13.00 | | | 7.80 |
| 1995 | 4.23 | 8.00 | | | 4.23 |
| 1996 | 1.81 | 5.00 | | | 1.81 |
| 1997 | 0 | 0 | | | 0 |
| 1998 | 0 | 0 | | | 0 |
| 1999 | 0 | 0 | | | 0 |
| 2000 | 0 | 0 | | | 0 |
| 2001 | 0 | 0 | | | 0 |
| 2002 | 0 | 0 | | | 0 |
| 2003 | 0 | 0 | | | 0 |
| 2004 | 0 | 0 | | | 0 |
| 2005 | 0.95 | 0.00 | | | 0.95 |
| 2006 | 2.12 | 13.77 | | | 2.12 |
| 2007 | 5.62 | 17.00 | | | 5.62 |

Table 2. Eastern Bering Sea *Chionoecetes bairdi* total discard and bycatch losses by sex in the directed plus non-directed pot and the groundfish trawl fisheries, 1965-2007.

Eastern Bering Sea *Chionoecetes bairdi* Discard and Bycatch Losses ($10^6$ lb)
[$HM_{Pot}$=0.50; $HM_{GF}$=0.80]

| | All Pot | | Groundfish | | Total | |
|---|---|---|---|---|---|---|
| Year | Male | Female | Male | Female | Male | Female |
| 1965 | 1.73 | 0.48 | 6.15 | 4.07 | 7.88 | 4.56 |
| 1966 | 2.20 | 0.62 | 11.16 | 7.38 | 13.36 | 8.00 |
| 1967 | 12.23 | 3.42 | 17.37 | 11.50 | 29.60 | 14.92 |
| 1968 | 16.20 | 4.53 | 13.18 | 8.72 | 29.37 | 13.25 |
| 1969 | 24.73 | 6.92 | 19.35 | 12.81 | 44.08 | 19.73 |
| 1970 | 22.94 | 6.42 | 21.52 | 14.24 | 44.46 | 20.66 |
| 1971 | 18.63 | 5.21 | 24.15 | 15.98 | 42.78 | 21.19 |
| 1972 | 15.21 | 4.25 | 13.86 | 9.18 | 29.07 | 13.43 |
| 1973 | 12.28 | 3.33 | 18.97 | 12.55 | 31.25 | 15.89 |
| 1974 | 14.52 | 3.91 | 26.25 | 17.37 | 40.77 | 21.29 |
| 1975 | 17.95 | 4.64 | 10.16 | 6.73 | 28.12 | 11.37 |
| 1976 | 28.29 | 7.68 | 4.40 | 2.91 | 32.70 | 10.59 |
| 1977 | 34.22 | 9.15 | 2.98 | 1.97 | 37.20 | 11.13 |
| 1978 | 22.76 | 5.67 | 3.42 | 2.27 | 26.18 | 7.93 |
| 1979 | 20.77 | 5.13 | 2.73 | 1.81 | 23.50 | 6.94 |
| 1980 | 17.62 | 3.91 | 2.24 | 1.48 | 19.86 | 5.39 |
| 1981 | 6.36 | 1.43 | 1.56 | 1.03 | 7.92 | 2.47 |
| 1982 | 3.34 | 0.72 | 0.48 | 0.32 | 3.82 | 1.03 |
| 1983 | 1.20 | 0.21 | 0.71 | 0.47 | 1.92 | 0.68 |
| 1984 | 2.49 | 0.47 | 0.69 | 0.45 | 3.18 | 0.93 |
| 1985 | 1.03 | 0.10 | 0.42 | 0.28 | 1.45 | 0.38 |
| 1986 | 1.46 | 0.14 | 0.69 | 0.46 | 2.15 | 0.60 |
| 1987 | 4.38 | 0.58 | 0.68 | 0.45 | 5.06 | 1.03 |
| 1988 | 11.26 | 1.60 | 0.49 | 0.33 | 11.75 | 1.93 |
| 1989 | 25.08 | 4.23 | 0.71 | 0.47 | 25.80 | 4.70 |
| 1990 | 48.17 | 7.60 | 1.00 | 0.66 | 49.17 | 8.27 |
| 1991 | 45.45 | 6.72 | 1.54 | 1.02 | 46.98 | 7.73 |
| 1992 | 27.25 | 2.41 | 2.07 | 1.37 | 29.32 | 3.78 |
| 1993 | 14.86 | 2.72 | 1.65 | 1.09 | 16.51 | 3.81 |
| 1994 | 7.74 | 2.34 | 1.23 | 0.81 | 8.97 | 3.15 |
| 1995 | 5.33 | 2.61 | 1.11 | 0.73 | 6.44 | 3.34 |
| 1996 | 1.21 | 0.36 | 1.02 | 0.68 | 2.23 | 1.03 |
| 1997 | 2.11 | 0.25 | 0.95 | 0.63 | 3.06 | 0.88 |
| 1998 | 2.32 | 0.20 | 0.73 | 0.48 | 3.06 | 0.68 |
| 1999 | 0.85 | 0.16 | 0.30 | 0.20 | 1.15 | 0.36 |
| 2000 | 0.23 | 0.03 | 0.38 | 0.25 | 0.62 | 0.28 |
| 2001 | 0.40 | 0.01 | 0.59 | 0.39 | 0.99 | 0.40 |
| 2002 | 0.68 | 0.04 | 0.72 | 0.47 | 1.40 | 0.52 |
| 2003 | 0.27 | 0.03 | 1.31 | 0.87 | 1.58 | 0.90 |
| 2004 | 0.14 | 0.02 | 0.95 | 0.63 | 1.09 | 0.65 |
| 2005 | 1.43 | 0.11 | 1.02 | 0.68 | 2.45 | 0.79 |
| 2006 | 6.61 | 0.20 | 1.64 | 1.09 | 8.25 | 1.29 |
| 2007 | 11.64 | 0.38 | 1.30 | 0.86 | 12.94 | 1.24 |

Table 3. Eastern Bering Sea *Chionoecetes bairdi* total catch in the directed (retained) and non-directed (discard + bycatch) fisheries, 1965-2007.

Eastern Bering Sea *Chionoecetes bairdi* Total Catch in the Directed + Non-Directed Fisheries ($10^6$ lb)

| Year | Male | Female | Total |
|---|---|---|---|
| 1965 | 12.12 | 4.56 | 16.68 |
| 1966 | 18.74 | 8.00 | 26.74 |
| 1967 | 59.58 | 14.92 | 74.50 |
| 1968 | 69.06 | 13.25 | 82.31 |
| 1969 | 104.68 | 19.73 | 124.41 |
| 1970 | 100.66 | 20.66 | 121.32 |
| 1971 | 88.44 | 21.19 | 109.63 |
| 1972 | 66.34 | 13.43 | 79.77 |
| 1973 | 59.97 | 15.89 | 75.85 |
| 1974 | 74.38 | 21.29 | 95.66 |
| 1975 | 67.03 | 11.37 | 78.40 |
| 1976 | 98.87 | 10.59 | 109.46 |
| 1977 | 115.52 | 11.13 | 126.64 |
| 1978 | 72.68 | 7.93 | 80.61 |
| 1979 | 65.40 | 6.94 | 72.34 |
| 1980 | 49.46 | 5.39 | 54.85 |
| 1981 | 18.92 | 2.47 | 21.39 |
| 1982 | 9.10 | 1.03 | 10.13 |
| 1983 | 3.12 | 0.68 | 3.80 |
| 1984 | 6.33 | 0.93 | 7.26 |
| 1985 | 1.45 | 0.38 | 1.82 |
| 1986 | 2.15 | 0.60 | 2.74 |
| 1987 | 7.26 | 1.03 | 8.29 |
| 1988 | 18.77 | 1.93 | 20.69 |
| 1989 | 50.30 | 4.70 | 55.00 |
| 1990 | 89.27 | 8.27 | 97.54 |
| 1991 | 78.78 | 7.73 | 86.52 |
| 1992 | 64.42 | 3.78 | 68.20 |
| 1993 | 33.41 | 3.81 | 37.22 |
| 1994 | 16.77 | 3.15 | 19.92 |
| 1995 | 10.68 | 3.34 | 14.02 |
| 1996 | 4.03 | 1.03 | 5.07 |
| 1997 | 3.06 | 0.88 | 3.94 |
| 1998 | 3.06 | 0.68 | 3.74 |
| 1999 | 1.15 | 0.36 | 1.52 |
| 2000 | 0.62 | 0.28 | 0.90 |
| 2001 | 0.99 | 0.40 | 1.39 |
| 2002 | 1.40 | 0.52 | 1.91 |
| 2003 | 1.58 | 0.90 | 2.48 |
| 2004 | 1.09 | 0.65 | 1.74 |
| 2005 | 3.41 | 0.79 | 4.19 |
| 2006 | 10.37 | 1.29 | 11.66 |
| 2007 | 18.57 | 1.24 | 19.81 |

Table 4. Age, growth, and instar number for male Tanner crab in Kodiak and the eastern Bering Sea.

| Instar Number | Kodiak mean size (mm) | Kodiak age (months) | EBS mean size (mm) |
|---|---|---|---|
| 1 | 3.4 | 1.8 | - |
| 2 | 4.5 | 2.5 | - |
| 3 | 6.0 | 3.5 | - |
| 4 | 7.9 | 4.9 | - |
| 5 | 10.4 | 6.6 | - |
| 6 | 13.7 | 8.9 | - |
| 7 | 18.1 | 11.9 | 17.2 |
| 8 | 23.9 | 15.9 | 24.4 |
| 9 | 31.6 | 21.1 | 33.5 |
| 10 | 41.7 | 28.1 | 45.9 |
| 11 | 53.6 | 37.3 | 60.7 |
| 12 | 67.8 | 47.2 | 79.3 |
| 13 | 84.6 | 59.0 | 98.5 |
| 14 | 106.3 | 73.1 | 112.5 |
| 15 | 129.5 | 85.3 | 126.8 |
| 16 | 154.3 | 106.2 | 141.8 |
| 17 | 180.8 | 124.5 | 157.2 |

Table 5. Eastern Bering Sea *Chionoecetes bairdi* male mature biomass and legal male (≥ 138mm cw) biomass at time of the survey, fishery and mating, 1965-2007.

| | Eastern Bering Sea *Chionoecetes bairdi* Survey Biomass ($10^6$ lb) | | | | | |
|---|---|---|---|---|---|---|
| | Male Mature Biomass ($10^6$ lb) | | | Legal Male Biomass ($10^6$ lb) | | |
| Year | Survey | Fishery | Mating | Survey | Fishery | Mating |
| 1965 | | | | | | |
| 1966 | | | | | | |
| 1967 | | | | | | |
| 1968 | | | | | | |
| 1969 | 604.93 | 539.22 | 414.26 | | | |
| 1970 | 151.81 | 135.32 | 29.57 | | | |
| 1971 | | | | | | |
| 1972 | | | | | | |
| 1973 | 208.44 | 185.80 | 118.84 | | | |
| 1974 | 396.83 | 353.72 | 266.04 | | | |
| 1975 | 623.89 | 556.11 | 468.16 | | | |
| 1976 | 318.43 | 283.83 | 174.29 | | | |
| 1977 | 344.02 | 306.65 | 179.60 | | | |
| 1978 | 179.55 | 160.05 | 81.35 | | | |
| 1979 | 121.38 | 108.20 | 38.73 | | | |
| 1980 | 205.47 | 183.15 | 126.80 | 68.12 | 60.72 | 28.84 |
| 1981 | 158.07 | 140.90 | 116.68 | 31.08 | 27.71 | 15.67 |
| 1982 | 113.32 | 101.01 | 88.11 | 21.72 | 19.36 | 13.35 |
| 1983 | 65.70 | 58.56 | 53.23 | 13.18 | 11.75 | 10.10 |
| 1984 | 45.41 | 40.48 | 32.63 | 11.73 | 10.45 | 6.91 |
| 1985 | 26.01 | 23.19 | 20.87 | 9.68 | 8.63 | 8.30 |
| 1986 | 35.49 | 31.64 | 28.30 | 6.83 | 6.09 | 5.86 |
| 1987 | 63.93 | 56.99 | 47.59 | 16.25 | 14.48 | 11.74 |
| 1988 | 139.55 | 124.39 | 100.95 | 36.60 | 32.62 | 24.38 |
| 1989 | 231.48 | 206.34 | 148.28 | 83.11 | 74.08 | 46.80 |
| 1990 | 240.30 | 214.20 | 116.87 | 114.64 | 102.19 | 58.24 |
| 1991 | 255.73 | 227.95 | 140.59 | 92.81 | 82.73 | 47.82 |
| 1992 | 246.92 | 220.09 | 147.39 | 104.50 | 93.15 | 54.54 |
| 1993 | 144.40 | 128.71 | 90.47 | 56.00 | 49.91 | 31.14 |
| 1994 | 95.02 | 84.70 | 64.74 | 40.79 | 36.35 | 27.19 |
| 1995 | 71.65 | 63.87 | 50.79 | 26.46 | 23.58 | 18.46 |
| 1996 | 58.64 | 52.27 | 46.27 | 24.47 | 21.81 | 19.19 |
| 1997 | 25.13 | 22.40 | 18.50 | 8.66 | 7.72 | 7.43 |
| 1998 | 25.35 | 22.60 | 18.69 | 5.89 | 5.25 | 5.05 |
| 1999 | 43.87 | 39.11 | 36.48 | 4.89 | 4.36 | 4.20 |
| 2000 | 39.24 | 34.98 | 33.05 | 11.42 | 10.18 | 9.80 |
| 2001 | 43.65 | 38.91 | 36.45 | 15.19 | 13.54 | 13.03 |
| 2002 | 44.53 | 39.70 | 36.80 | 16.71 | 14.90 | 14.34 |
| 2003 | 61.29 | 54.63 | 50.99 | 18.78 | 16.74 | 16.11 |
| 2004 | 65.48 | 58.36 | 55.08 | 14.04 | 12.52 | 12.05 |
| 2005 | 104.50 | 93.15 | 86.24 | 29.32 | 26.14 | 24.20 |
| 2006 | 158.95 | 141.68 | 125.98 | 37.48 | 33.41 | 30.03 |
| 2007 | 185.19 | 165.07 | 140.30 | 31.75 | 28.30 | 21.61 |

Table 6. Eastern Bering Sea *Chionoecetes bairdi* fishery rate of exploitation on male mature biomass (MMB) and legal mature biomass (LMB ) at fishery time, 1965-2007.

| Eastern Bering Sea *Chionoecetes bairdi* Fishery Exploitation Rate @ Time Fishery | | |
|---|---|---|
| Year | MMB | LMB |
| 1965 | | |
| 1966 | | |
| 1967 | | |
| 1968 | | |
| 1969 | 0.19 | |
| 1970 | 0.74 | |
| 1971 | | |
| 1972 | | |
| 1973 | 0.32 | |
| 1974 | 0.21 | |
| 1975 | 0.12 | |
| 1976 | 0.35 | |
| 1977 | 0.38 | |
| 1978 | 0.45 | |
| 1979 | 0.60 | |
| 1980 | 0.27 | 0.49 |
| 1981 | 0.13 | 0.40 |
| 1982 | 0.09 | 0.27 |
| 1983 | 0.05 | 0.10 |
| 1984 | 0.16 | 0.30 |
| 1985 | 0.06 | 0 |
| 1986 | 0.07 | 0 |
| 1987 | 0.13 | 0.15 |
| 1988 | 0.15 | 0.21 |
| 1989 | 0.24 | 0.33 |
| 1990 | 0.42 | 0.39 |
| 1991 | 0.35 | 0.38 |
| 1992 | 0.29 | 0.38 |
| 1993 | 0.26 | 0.34 |
| 1994 | 0.20 | 0.21 |
| 1995 | 0.17 | 0.18 |
| 1996 | 0.08 | 0.08 |
| 1997 | 0.14 | 0 |
| 1998 | 0.14 | 0 |
| 1999 | 0.03 | 0 |
| 2000 | 0.02 | 0 |
| 2001 | 0.03 | 0 |
| 2002 | 0.04 | 0 |
| 2003 | 0.03 | 0 |
| 2004 | 0.02 | 0 |
| 2005 | 0.04 | 0.04 |
| 2006 | 0.07 | 0.06 |
| 2007 | 0.11 | 0.20 |

Table 7. Catch overfishing limits, stock and fishery metrics for three biomass reference values ($B_{REF}$) given current male mature biomass at mating for the 2007 Eastern Bering Sea *Chionoecetes bairdi* fishery. (Gamma=1.0 and TAC/OFL=1.0).

2007 Eastern Bering Sea Chionoecetes bairdi Status Determination Criteria, Stock & Fishery Metrics
[MFMT=FMSY=Γ M; BREF=BMSY or Proxy BMSY; B=MMB @ Mating]

| | $B_{REF1}$ TAC/OFL=0.8 | $B_{REF2}$ TAC/OFL=0.8 | $B_{REF3}$ TAC/OFL=0.8 |
|---|---|---|---|
| ***Metrics ($10^6$lb):*** | | | |
| Projected Catch OFL: | 5.439 | 4.841 | 4.278 |
| Projected Buffered Catch OFL: | 4.351 | 3.872 | 3.423 |
| $B_{REF}$: | 133.987 | 154.424 | 178.155 |
| MMB @ Mating: | 125.313 | 128.806 | 132.087 |
| $B/B_{REF}$: | 0.935 | 0.834 | 0.741 |
| $F_{OFL}$: | 0.213 | 0.188 | 0.164 |
| ***Catch Components ($10^6$lb):*** | | | |
| Directed Discard Losses ♀: | 0.099 | 0.088 | 0.078 |
| Directed Discard Losses MMB: | 1.044 | 0.929 | 0.821 |
| Non-Directed Discard Losses MMB: | 27.065 | 24.286 | 21.675 |
| Directed Discard Losses LMB: | 0.012 | 0.010 | 0.009 |
| Non-Directed Discard Losses LMB: | 1.808 | 1.808 | 1.808 |
| Total ♂ Discard + Bycatch Losses: | 28.109 | 25.214 | 22.495 |
| Total Male Catch: | 31.728 | 28.236 | 24.956 |
| Total Male + Female Catch: | 31.827 | 28.324 | 25.034 |
| ***OFL Split ($10^6$lb):*** | | | |
| Retained Part of Catch OFL: | 3.619 | 3.022 | 2.461 |
| Retained Part Buffered Catch OFL: | 2.532 | 2.054 | 1.605 |
| ***Rates:*** | | | |
| Catch OFL/MMB @ Fishery: | 0.033 | 0.029 | 0.026 |
| μ on LMB @ Fishery: | 0.192 | 0.171 | 0.151 |
| μ on MMB @ Fishery: | 0.192 | 0.171 | 0.151 |

$B_{REF1}$ = 0.35 * $B_O$, where $B_O$ is proxy for pristine male mature biomass. $B_O$ = mean 1969 and 1974-1975 MMB @ mating.

$B_{REF2}$ = 0.35 * $B_O$, where $B_O$ is proxy for pristine male mature biomass. $B_O$ = mean 1969 and 1975 MMB @ mating.

$B_{REF3}$ = mean of 1975-1980 MMB @ mating as proxy for $B_{MSY}$.

Table 8. Total pot lift contents for 160 pot lifts sampled during the 2005/2006 (160 pot lifts) 2006/2007 (141 pot lifts) Bering Sea Tanner crab fisheries (Barnard and Burt 2007, 2008). A total of 29,693 and 49,192 pots were lifted during the 2005/2006 and 2006/2007 fisheries respectively (Bowers et al. 2008).

| Species | Total Catch | | Species | Total Catch | |
|---|---|---|---|---|---|
| | 2005/06 | 2006/07 | | 2005/06 | 2006/07 |
| Tanner crab | | | Yellowfin sole | 270 | 123 |
| Legal male | 6,612 | 12,130 | Sea star (unidentified) | 156 | 317 |
| Sublegal male | 18,578 | 20,222 | Sculpin (inidentified) | 132 | 60 |
| Female | 2,838 | 10,768 | Snail (unidentified) | 129 | 23 |
| | | | Pribilof Neptune | 62 | 0 |
| Snow crab | | | Pacific cod | 55 | 31 |
| Legal male | 2,726 | 889 | Hermit crab (unidentified) | 27 | 3 |
| Sublegal male | 258 | 13 | Lyre crab | 18 | 23 |
| Female | 16 | 0 | Yellow Irish lord | 16 | 96 |
| | | | Jellyfish (unidentified) | 10 | 0 |
| Red King crab | | | Sea urchin (unidentified) | 8 | 0 |
| Legal male | 0 | 3 | Brittle star (unidentified) | 7 | 5 |
| Sublegal male | 29 | 1 | Pacific Halibut | 5 | 1 |
| Female | 137 | 9 | Arrowtooth flounder | 2 | 0 |
| | | | Bryozoan (unidentified) | 1 | 0 |
| Tanner x snow crab hybrid | | | Flatfish (unidentified) | 1 | 0 |
| Legal male | 107 | 2 | Prowfish | 1 | 0 |
| Sublegal male | 50 | 94 | Rock sole (unidentified) | 1 | 2 |
| Female | 2 | 3 | Sea cucumber | 1 | 2 |
| | | | Flathead sole | 0 | 2 |
| Blue King crab | | | Hydroid (unidentified) | 0 | 2 |
| Legal male | 8 | 0 | Decorator crab | 0 | 1 |
| Sublegal male | 112 | 0 | Snailfish (unidentified) | 0 | 1 |
| Female | 0 | 1 | | | |

Table 9. Ecosystem effects on the eastern Bering Sea Tanner crab stocks and fishery effects on the ecosystem.

| **Ecosystem effects on Bering Sea Tanner crab stocks** | | | |
|---|---|---|---|
| Indicator | Observation | Interpretation | Evaluation |
| *Prey availability or abundance trends* | | | |
| Plankton | During May spring bloom occurs during a seasonal thermocline along the north Aleutian Shelf in ice-free waters. | Promotes phytoplankton and *Pseudocalnus* production. | Concern |
| *Predator population trends* | | | |
| Fish predators (Pacific cod, arrwowtooth flounder, Pollock, sculpins) | Increase in Pacific cod, arrowtooth flounder, pollock, and juvenile sockeye salmon | Pacific cod predators of juvenile and adult Tanner crab. Juvenile sockeye feed on larval Tanner crab. Predation by planktivorous fishes may be significant in some years and seasons, but their overall effect on recruitment is unknown. Bottom temperatures during crab gonadal development and egg incubation may be more important. | Concern |
| *Disease* | | | |
| Britter crab syndrome | | Prevalences in legal crabs low. More prevalent in smaller crab < 50 mm CW. Could affect recruitment. | Concern affecting recruitment and potential impact if it becomes epidemic. |
| Black mat syndrome | No prevalence in EBS for 20 years | | No concern |
| *Changes in Habitat Quality* | | | |

| | | | |
|---|---|---|---|
| Temperature regime | Seasonal ice effects spring bloom. Early ice retreat then late bloom and more zooplankton, favors pelagic production and crab abundance goes down. Late ice retreat then early bloom and less zooplankton, favors benthic production and crab abundance goes up. Zooplankton biomass is declining. | Effect larval release, hatch timing, food availability for larvae, larval survival, recruitment success, and year class strength. Change in trophic structure and predator prey populations. Increase in predators- Pollock, cod, juvenile sockeye salmon, and arrowtooth flounder. Decreased crab abundance. | 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. Decalcification of calcifying plankton. | Concern |
| Winter-spring environmental conditions | Affects pre-recruit survival | Recruitment success correlated with strength of NE winds during May-June which promote retention and larval settlement in favorable mud-sand mid-shelf regions of EBS. | Causes natural variability. Concern. |
| Production | Fairly stable nutrient flow from upwelled BS Basin | Inter-annual variability and recruitment in year class strength | Concern |

| **Fishery effects on the eastern Bering Sea ecosystem** | | | |
|---|---|---|---|
| Indicator | Observation | Interpretation | Evaluation |
| *Fishery contribution to bycatch* | | | |
| Prohibitive species (blue king crab, pacific halibut) | Stable, heavily monitored. Sublegal male Tanner have a high rate of bycatch. | Minor contribution to mortality. Use of degradable mesh and rings, Tanner boards and observers. | Concern |

| | | | |
|---|---|---|---|
| Forage (Pacific cod, sculpin, yellowfin sole) | Stable, heavily monitored | Bycatch levels small relative to forage biomass | No concern |
| HAPC biota | Most HAPC biota are not concentrated in areas of fishery. | Low impact from pots. | No concern |
| ESA and non-ESA marine mammals and birds | | Crab fisheries do not adversely affect listed species or destroy or modify their habitat | No concern |
| Sensitive non-target species | Likely minor impact | Minor contribution to mortality | No concern |
| *Fishery concentration in space and time* | | | |
| *Fishery effects on amount of large size target crab* | Fishery targets legal size males only. | Some concern of reduction of sex ratio and mean size of male crab in a fishery that targets legal-size males and high bycatch of sublegal males. Other sources of bycatch. | Concern |
| *Fishery contribution to discards and offal production* | | | |
| *Fishery effects on age-at-maturity and fecundity* | Fishery targets legal size males only. | Little bycatch of females. Some concern for overharvesting legal males and high bycatch of sublegal males. Other sources of bycatch. | Concern |

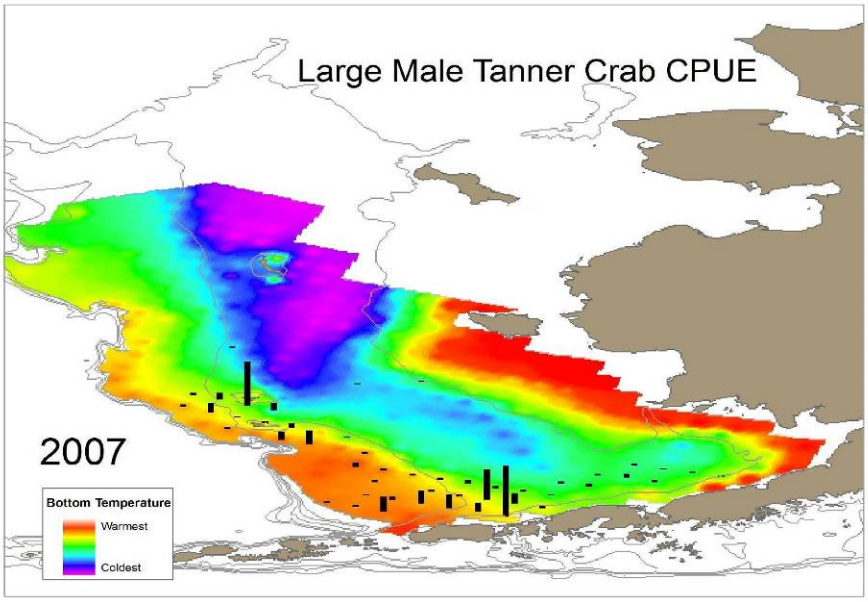



Figure 1. Distribution and abundance of large male Tanner crab with bottom temperature from the 2007 EBS crab-ground fish survey.

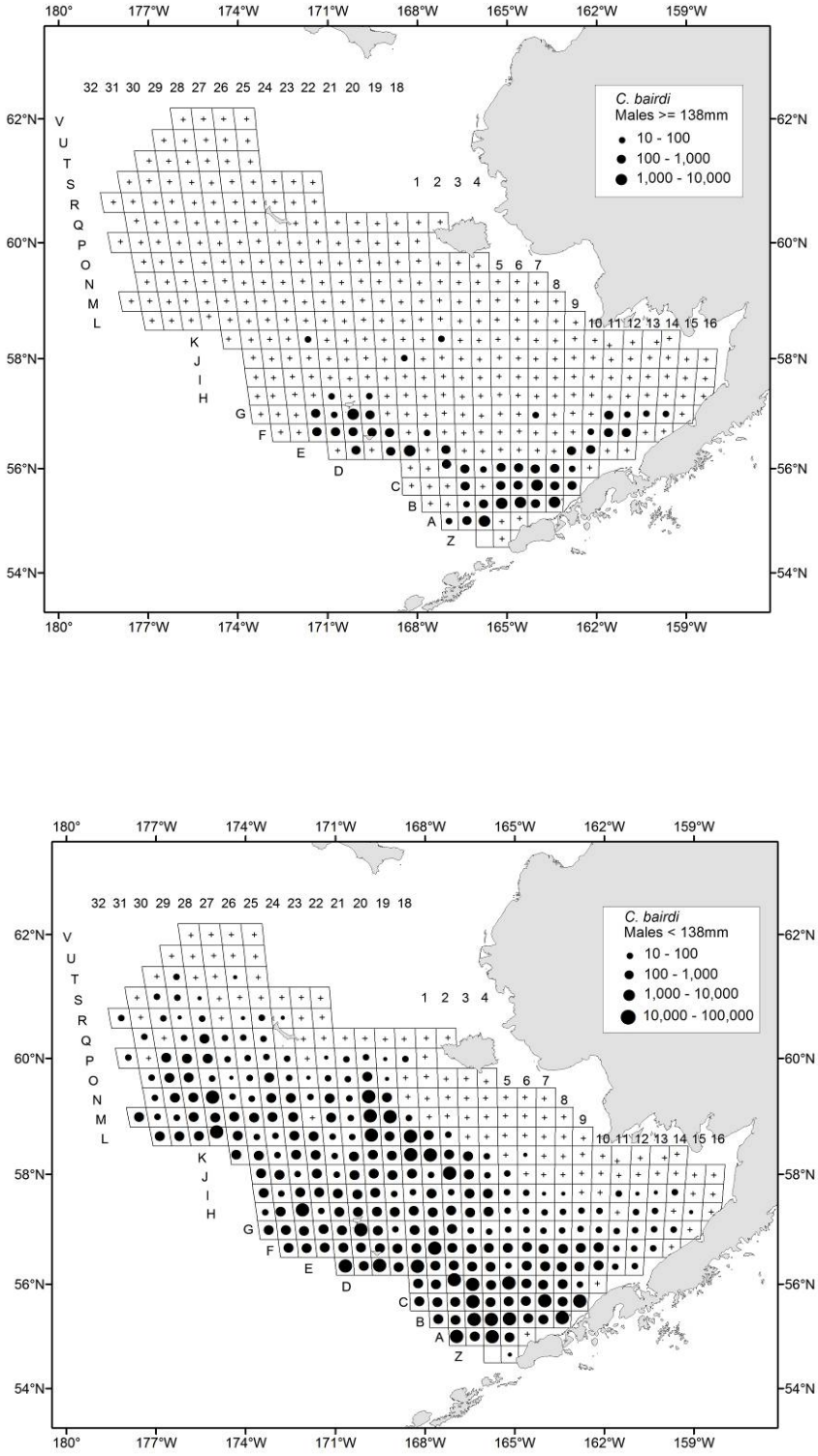



Figure 2. Distribution and abundance of legal (>= 138 mm CW) and sub legal (<138 mm CW) male Tanner crab in the summer 2007 EBS crab-ground fish survey.

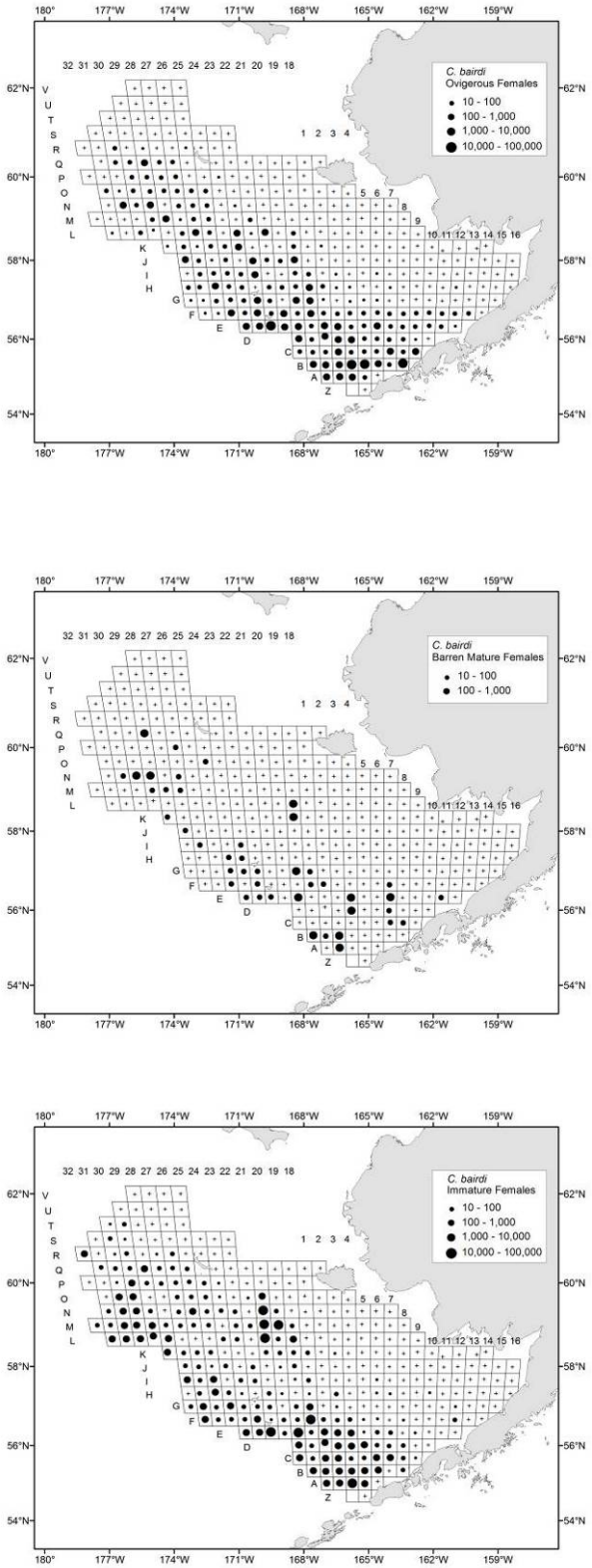



Figure 3. Distribution and abundance of ovigerous, barren mature, and immature female Tanner crab in the 2007 EBS crab-ground fish survey.

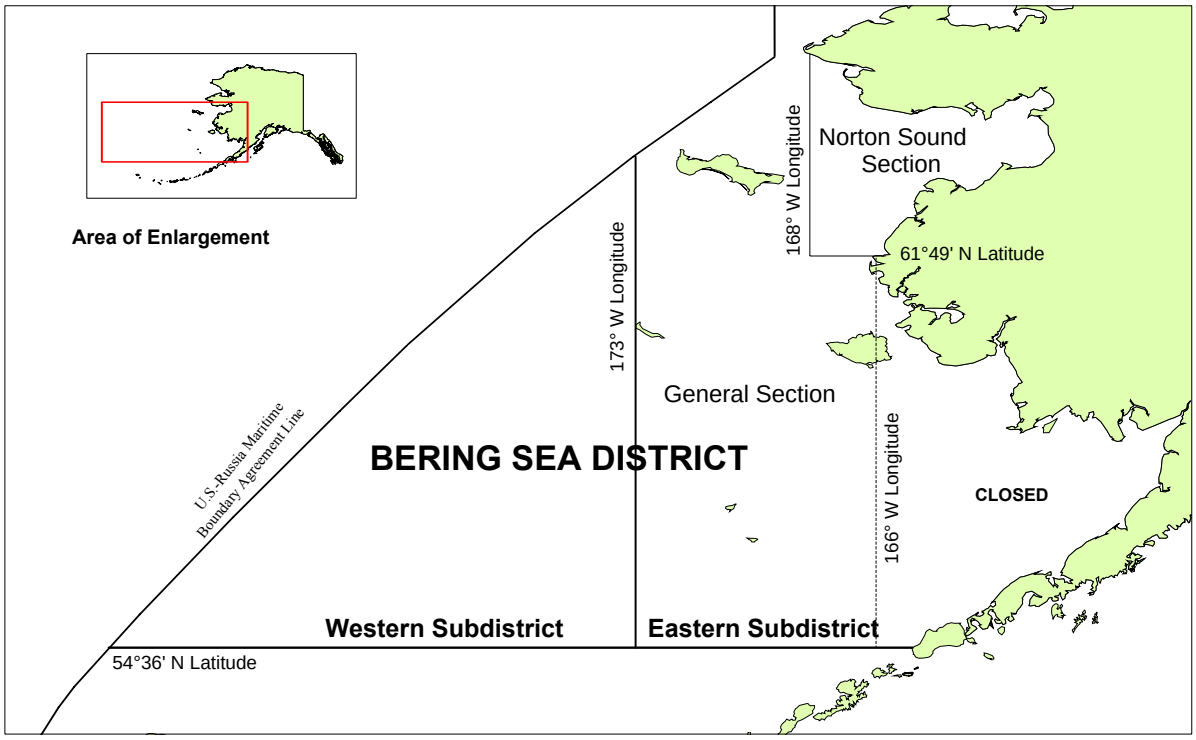
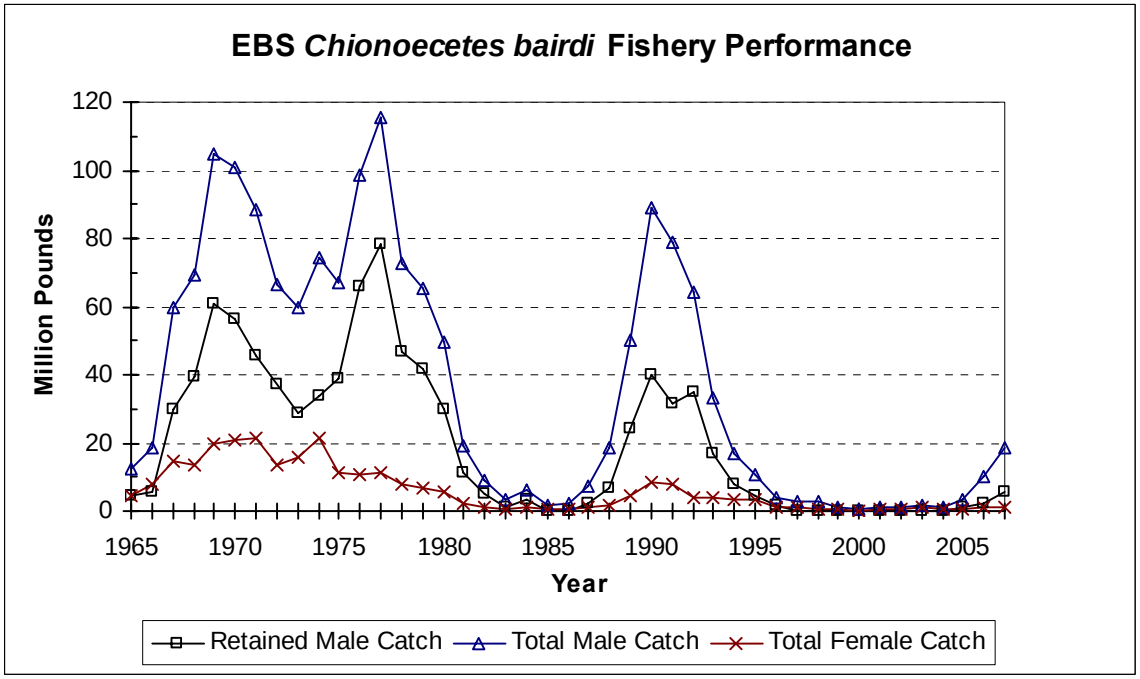



Figure 4. Bering Sea District of Tanner crab Registration Area J including sub districts and sections (from Bowers et al. 2008).

(a)




(b)

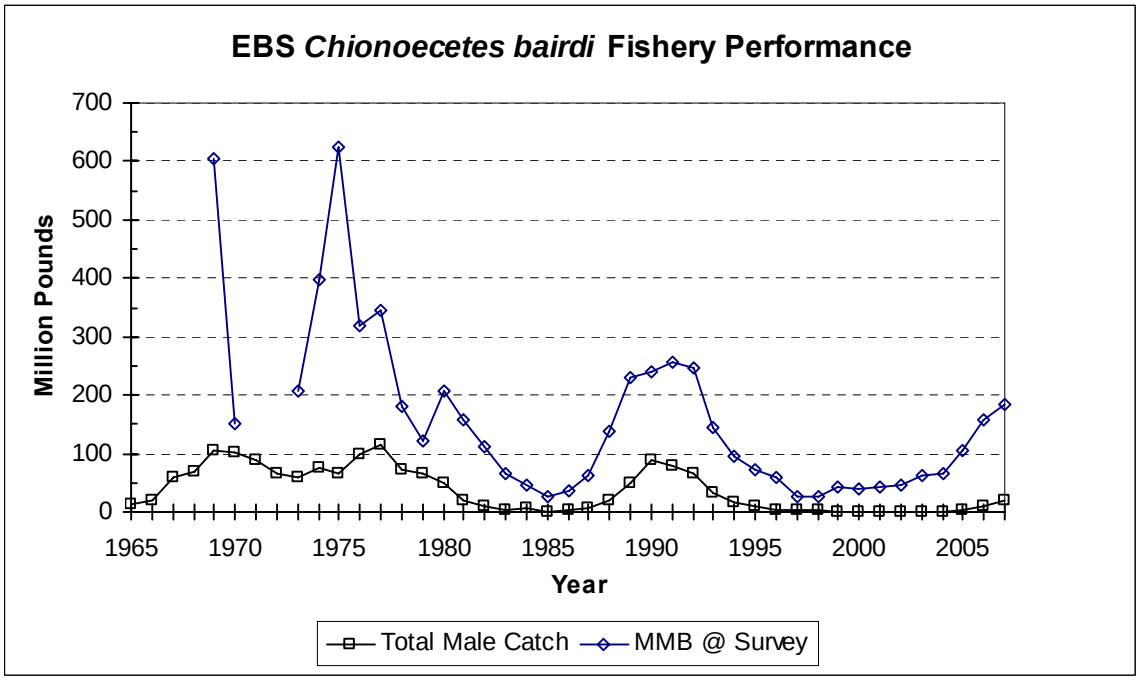



Figure 5. Eastern Bering Sea *Chionoecetes bairdi* retained male catch, total (retained + discard/bycatch) male catch and total female catch (a), and total male catch vs male mature biomass at the time of the survey (b), 1965-2007.

(a)

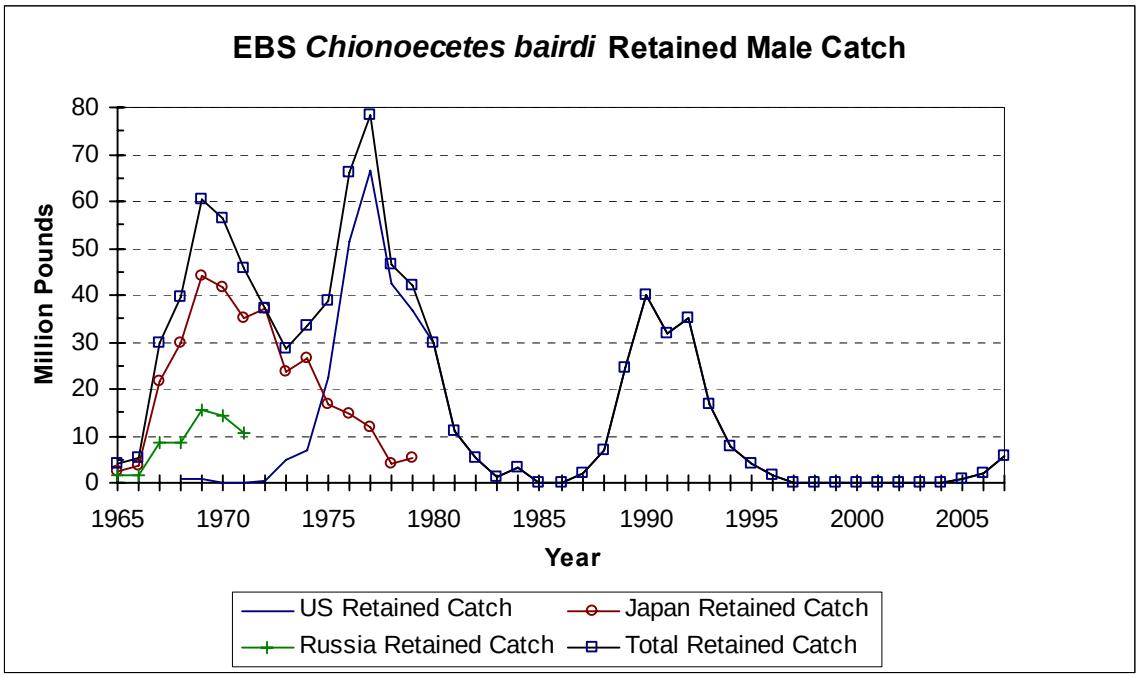



Figure 6. Eastern Bering Sea *Chionoecetes bairdi* retained male catch in the directed United States, Russian and Japanese fisheries, and 1965-2007.

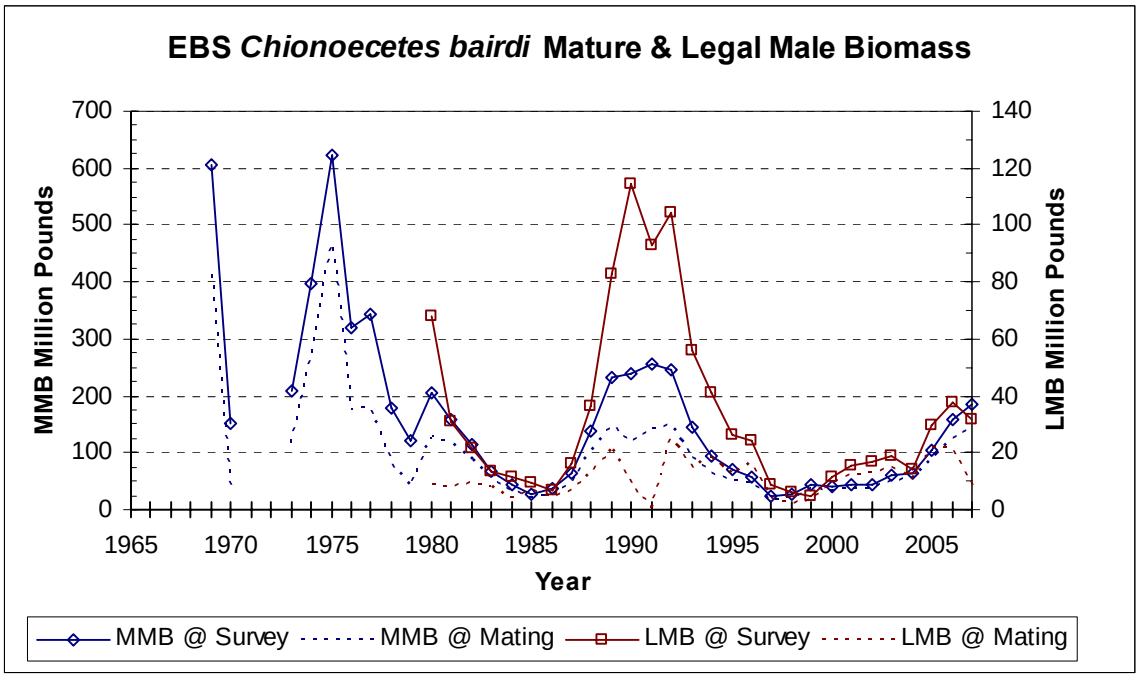
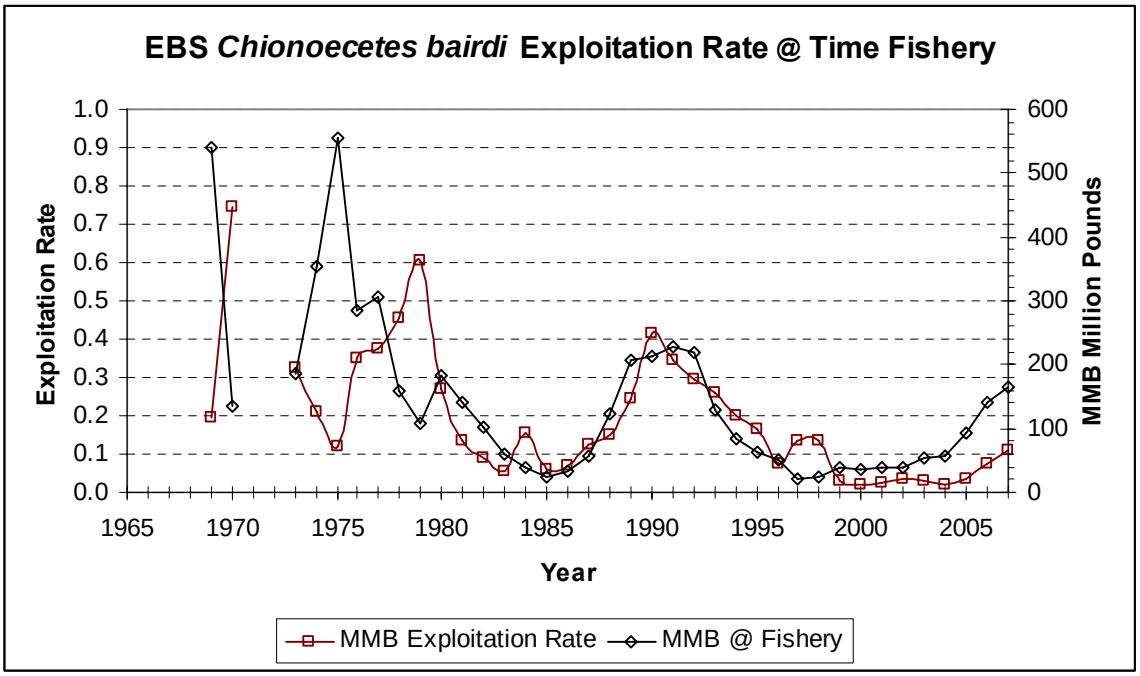



Figure 7. Eastern Bering Sea *Chionoecetes bairdi* mature and legal male biomass at time of the survey and subsequent mating, 1965-2007.

(a)




(b)

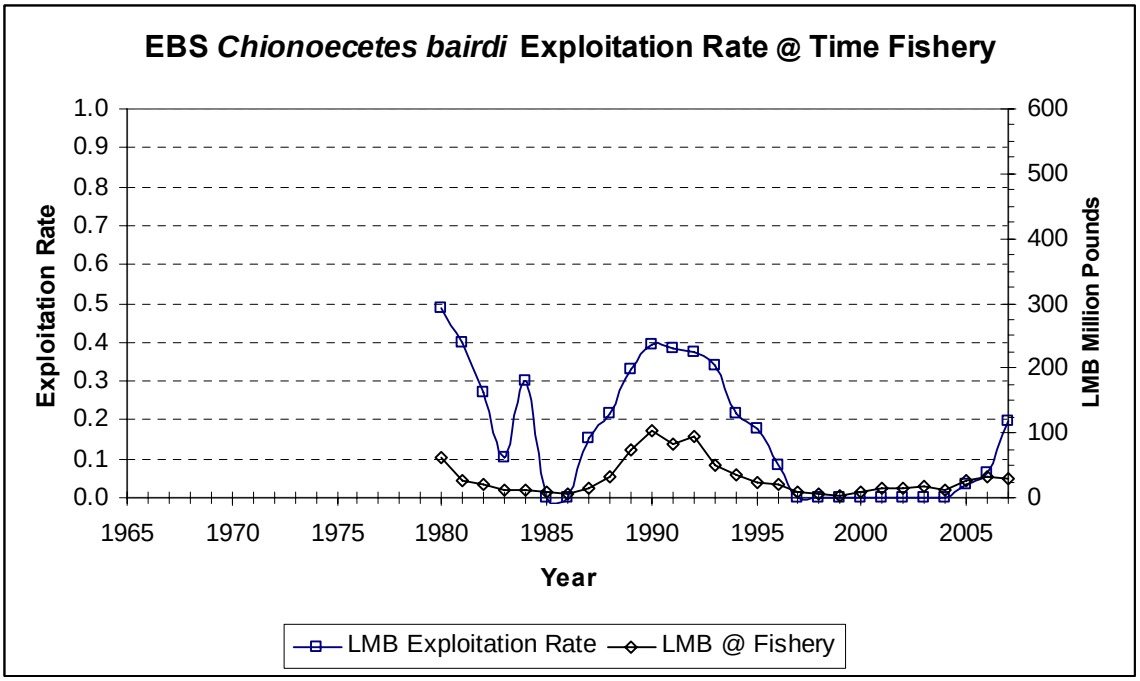



Figure 8. Eastern Bering Sea *Chionoecetes bairdi* exploitation rate on mature (a) and legal (b) male biomass at the time of the fishery with associated male biomass metric, 1965-2007.

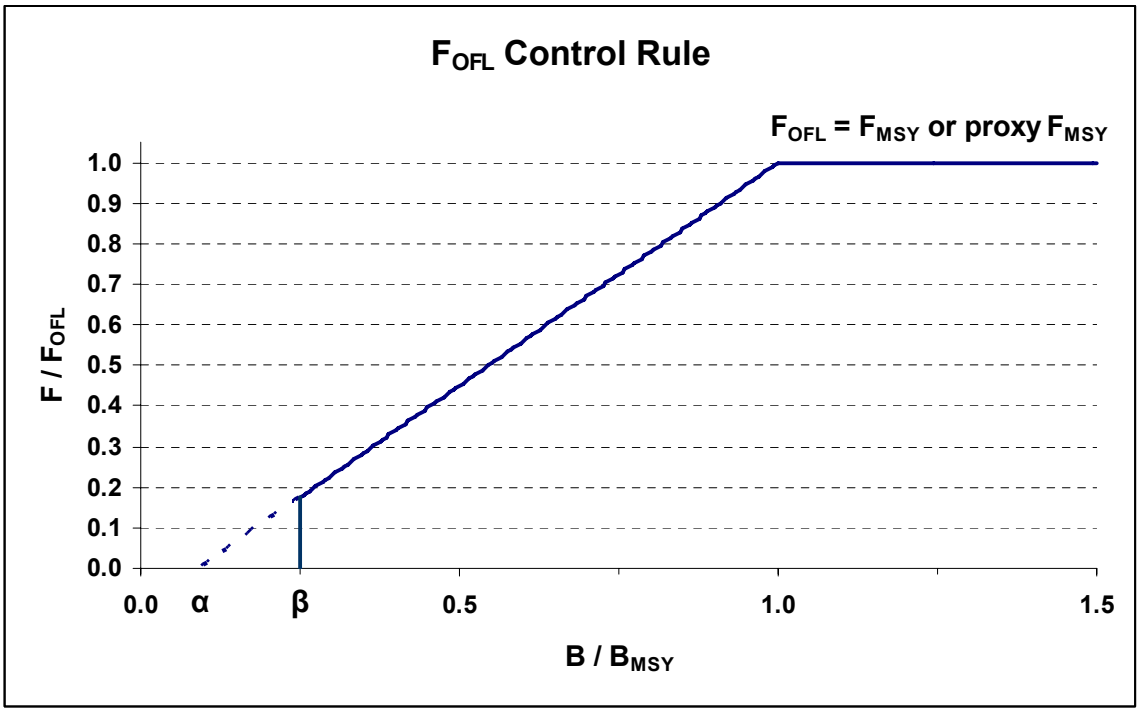



Figure 9. $F_{OFL}$ Control Rule for Tier-4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set 0 below β.