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

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Executive Summary

Stock: Tanner crab, *Chionoecetes bairdi*

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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
<u>Reproduction</u>
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 (μ) 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 μ 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 μ 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 (**γ**) 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 **γ** 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 **γ** 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 **γ** 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. $B/B_{REF} \leq \beta$	$F_{OFL} = 0$

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:

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

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

$$MMB_{Mating} = MMB_{Survey} \cdot e^{-PM(sf)} \quad (3)$$

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 overfishing limit and the projected buffered catch overfishing limit 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 (μ_{LMB}) and mature male biomass (μ_{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 5.8, 5.3 and 4.6 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: 4.0, 3.5 and 2.8 million pounds respectively. For the 3 model scenarios, the corresponding B/B_{REF} ratios and F_{OFLs} were: [B/B_{REF1}=1.05, F_{OFL}=0.23]; [B/B_{REF2}=0.91, F_{OFL}=0.21]; [B/B_{REF3}=0.79, F_{OFL}=0.18]. Projected buffered catch OFLs, and the retained portions of the buffered catch OFLs shown in parentheses for these three scenarios were 4.7 (2.8), 4.2 (2.4) and 3.7 (1.9) 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: [$\mu_{LMB} = 0.21$; $\mu_{MMB} = 0.10$]; [$\mu_{LMB} = 0.19$; $\mu_{MMB} = 0.10$] and [$\mu_{LMB} = 0.16$; $\mu_{MMB} = 0.09$] (Table 7).

Inspection of the discard and bycatch losses under each model scenario reveals that the retained component of the catch OFL comprises only 23.5%, 21.1% and 17.9% respectively of the total male mature biomass losses to the stock. A significant component of MMB catch is therefore allocated to non-targeted losses. 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). Under scenario 2, a μ=0.10 on MMB (Table 7) compares to 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.

Literature Cited

Adams, A. E. and A. J. Paul. 1983. Male parent size, sperm storage and egg production in the Crab *Chionoecetes bairdi* (DECAPODA, MAJIDAE). International Journal of Invertebrate Reproduction. 6:181-187.

Aydin, Kerim and Franz Mueter. 2007. The Bering Sea--A dynamic food web perspective. Deep-Sea Research II 54:2501-2525.

Barnard, D. R. 2008. Biodegradable twine report to the Alaska Board of Fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 08-05, Anchorage.

Barnard, D. R. and R. Burt. 2007. Alaska Department of Fish and Game summary of the 2005/2006 mandatory shellfish observer program database for the rationalized crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 07-02, Anchorage.

Barnard, D. R. and R. Burt. 2008. Alaska Department of Fish and Game summary of the 2006/2007 mandatory shellfish observer program database for the rationalized crab fisheries. Alaska Department of Fish and Game, Fishery Data Series No. 08-17, Anchorage. Bowers, F. R., M. Schwenzfeier, S. Coleman, B. J. Failor-Rounds, K. Milani, K. Herring, M.

Salmon, and M. Albert. 2008. Annual management report for the commercial and subsistence shellfish fisheries of the Aleutian Islands, Bering Sea and Westward Region's Shellfish Observer Program, 2006/07. Alaska Department of Fish and Game, Fishery Management Report No. 08-02, Anchorage.

Brown, R. B. and G. C. Powell. 1972. Size at maturity in the male Alaskan Tanner crab, *Chionoecetes bairdi*, as determined by chela allometry, reproductive tract weights, and size of precopulatory males. Journal of the Fisheries Research Board of Canada. 29:423-427.

Byersdorfer, S. C., and D. R. Barnard. 2002. Summary of crab injury assessment and aerial exposure sample results from selected 1998/1999 Bering Sea/Aleutian Islands king and Tanner crab fisheries and the 1999 Pribilof Islands hair crab fishery. Alaska Department of Fish and Game. Regional Information Report 4K02-29.

Carls, M. G. 1989. Influence of cold air exposures on ovigerous red king crab (*Paralithodes camtschatica*) and Tanner (*Chionoecetes bairdi*) crabs and their offspring. Proceedings of the International Symposium on king and Tanner crabs, Anchorage, AK, November 1989.

Conners, M.E., A.B Hollowed, and E. Brown. 2002. Retrospective analysis of Bering Sea bottom trawl surveys: regime shift and ecosystems reorganization. Prog. Oceanogr. 55:209-222.

Donaldson, W .E. and D. M. Hicks. 1977. Technical report to industry on the Kodiak crab population surveys. Results, life history, information, and history of the fishery for Tanner crab. Alaska Dept. Fish and Game, Kodiak Tanner crab research. 46 p.

Donaldson, W. E., and A. A. Adams. 1989. Ethogram of behavior with emphasis on mating for the Tanner crab *Chionoecetes bairdi* Rathbun. Journal of Crustacean Biology. 9:37-53.

Donaldson, W. E., R. T. Cooney, and J. R. Hilsinger. 1981. Growth, age, and size at maturity of Tanner crab *Chionoecetes bairdi* M. J. Rathbun, in the northern Gulf of Alaska. Crustaceana. 40:286-302.

Garth, J. S. 1958. Brachyura of the Pacific Coast of America. Oxyrhyncha. Allen Hancock Pacific Expeditions. 21 (1 and 2). 854 p.

Haynes, E., J. F. Karinen, J. Watson, and D. J. Hopson. 1976. Relation of number of eggs and egg length to carapace width in the brachyuran crabs *Chionoecetes baridi* and *C. opilio* from the southeastern Bering Sea and *C. opilio* from the Gulf of St. Lawrence. J. Fish. Res. Board Can. 33:2592-2595.

Hilsinger, J. R. 1976. Aspects of the reproductive biology of female snow crabs, *Chionoecetes bairdi*, from Prince William Sound and the adjacent Gulf of Alaska. Marine Science Communications. 2:201-225.

Hosie, M. J. and T. F. Gaumer. 1974. Southern range extension of the Baird crab *(Chionoecetes bairdi* Rathbun). Calif. Fish and Game. 60:44-47.

Hunt, G. L. Jr., P. Stabeno, G. Walters, E. Sinclair, R. D. Brodeur, J. M. Napp and N. A Bond. 2002. Climate change and control of the southeastern Bering Sea pelagic ecosystem. Deep-Sea Res. 49: 5821-5853.

ICES. 2002. The effects of Fishing on the Genetic Composition of Living Marine Resources. ICES Council Meeting Documents. Copenhagen.

Incze, L. S., Armstrong, D. A., and S. L. Smith. 1987. Abundance of larval Tanner crabs (*Chionoecetes* spp.) in relation to adult females and regional oceanography of the southeastern Bering Sea. Can. J. Fish. Aquat. Sci. 44:1143-1156.

Incze, L. S., and A. J. Paul. 1983. Grazing and predation as related to energy needs of stage I zoeae of the Tanner crab *Chionoecetes bairdi* (Brachyura, Majidae). Biological Bulletin 165:197-208.

Ivanov, B. G. 1993. An interesting mode of feeding snow crabs, *Chionoecetes* spp.(Crustacea, Decapoda, Majidae), on the ascidian *Halocynthia aurantium*. Zool. Zh. 72:27-33.

Jewett, S. C., and H. M. Feder. 1983. Food of the Tanner Crab *Chionoecetes bairdi* near Kodiak Island, Alaska. J. Crust. Biol. 3(2):196-207.

Karinen, J. F. and D. T. Hoopes. 1971. Occurrence of Tanner crabs (*Chionoecetes* sp.) in the eastern Bering Sea with characteristics intermediate between *C. bairdi* and *C. opilio*. Proc. Natl. Shellfish Assoc. 61:8-9.

Kon, T. 1996. Overview of Tanner crab fisheries around the Japanese Archipelago, p. 13-24. *In* High

Latitude Crabs: Biology, Management and Economics. Alaska Sea Grant Report, AK-SG-96-02, Universityof Alaska Fairbanks.

Lang, G. M., P. A. Livingston, and K. A. Dodd. 2005. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1997 through 2001. United States Department of Commerce, NOAA Technical Memorandum NMFS-AFSC-158, 230 p.

Litzow, M.A. 2006. Climate shifts and community reorganization in the Gulf of Alaska: how do recent shifts compare with 1976/1977? ICES J. of Mar. Sci. 63:1386-1396.

Livingston, P. A. 1989. Interannual trends in Pacific cod, *Gadus macrocephalus*, predation on three commercially important crab species in the eastern Bering Sea. Fishery Bulletin. 87:807-827.

Livingston, P. A., A. Ward, G. M. Lang, and M. S. Yang. 1993. Groundfish food habitsand predation on commercially important prey species in the eastern Bering Sea from 1987 to 1989. NOAA Technical Memorandum, NMFS-AFSC-11, DOC, NOAA, NMFS, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, 192 p.

Lowry, L. F., K. H. Frost, and J. J. Burns. 1980. Feeding of bearded seals in the Bering and Chukchi seas and trophic interaction with Pacific walruses. Arctic 33:330-342.

MacIntosh, R. A., B. G. Stevens, J. A. Haaga, and B. A. Johnson. 1996. Effects of handling and discarding on mortality of Tanner crabs, *Chionoecetes bairdi*. p. 577-590, *In* High Latitude

Crabs: Biology, Management, and Economics, , Alaska Sea Grant College Program Report, AK-SG-96-02, University of Alaska Sea Grant Program, Anchorage, AK.
McLaughlin, P. A. and 39 coauthors. 2005. Common and scientific names of aquatic invertebrates from the United States and Canada: crustaceans. American Fisheries Society Special Publication 31. 545 p.
Meyers, T. R., B. Eaton, S. Short, C. Botelho, T. Koeneman, A. Sparks, and F. Morado. 1990. Bitter crab dinoflagellate disease: overview of the causative agent and its importance and distribution in the Alaskan Tanner crab (*Chionoecetes bairdi, C. opilio*) fisheries. p. 405 (abstract only), *In* Proceedings of the International Symposium on King and Tanner Crabs. Lowell Wakefield Fisheries Symposium Series., Alaska Sea Grant Report, 90-04, University of Alaska Fairbanks, Alaska Sea Grant College, Fairbanks.
Munk, J. E., S. A. Payne, and B. G. Stevens. 1996. Timing and duration of the mating and molting season for shallow water Tanner crab (*Chionoecetes bairdi*), p. 341 (abstract only). *In* High Latitude Crabs: Biology, Management and Economics. Alaska Sea Grant Report, AK-SG-96-02, University of Alaska Fairbanks.
Nevisi, A., J. M. Orensanz, A. J. Paul, and D. A. Armstrong. 1996. Radiometric estimation of shell age in *Chionoecetes* spp. from the eastern Bering Sea, and its use to interpret shell condition indices: preliminary results, p. 389-396. *In* High Latitude Crabs: Biology, Management and Economics. Alaska Sea Grant Report, AK-SG-96-02, University of Alaska Fairbanks.
NMFS. 2000. Endangered Species Act Section 7 Consultation - Biological Assessment for listed marine mammals. Activities Considered: Crab fisheries authorized under the Fishery Management Plan for Bering Sea/Aleutian Islands King and Tanner Crabs, DOC, NOAA, July 18, 2000.
NMFS. 2004a. Final Environmental Impact Statement for Bering Sea and Aleutian Islands Crab Fisheries. National Marine Fisheries Service, P.O. Box 21668, Juneau, AK 99802-1668.
NMFS. 2004b. Alaska Groundfish Fisheries Final Programmatic Supplemental Environmental Impact Statement, DOC, NOAA, National Marine Fisheries Service, AK Region, P.O. Box 21668, Juneau, AK 99802-1668. Appx 7300 p.
NPFMC. 1998. Fishery Management Plan for the King and Tanner Crab Fisheries of the Bering Sea and Aleutian Islands. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite, 306, Anchorage, AK 99501.
NPFMC. 1999. Environmental Assessment/Regulatory Impact Review/Initial Regulatory Flexibility analysis for Amendment 11 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs. North Pacific Fishery Management Council, 605 W. 4th Avenue, Suite, 306, Anchorage, AK 99501.
NPFMC. 2007. Initial Review Draft Environmental Assessment, Amendment 24 to the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner crabs to Revise Overfishing Definitions. North Pacific Fishery Management Council, 605 W. 4th Avenue, 306, Anchorage, AK 99501.

Orensanz, J. M. L., J. Armstrong, D. Armstrong, and R. Hilborn. 1998. Crustacean resources are vulnerable to serial depletion - the multifaceted decline of crab and shrimp fisheries in the Greater Gulf of Alaska. Reviews in Fish Biology and Fisheries 8: 117-176.
Ormseth, O. and B. Matta. 2007. Chapter 17: Bering Sea and Aleutian Islands Skates. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering

Sea/Aleutian Islands Regions, North Pacific Fishery Management Council, Anchorage 909-1010 p.
Otto, R. S. 1998. Assessment of the eastern Bering Sea snow crab, *Chionoecetes opilio*, stock under the terminal molting hypothesis, p. 109-124. *In* G. S. Jamieson and A. Campbell, (editors), Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management. Canadian Special Publication of Fisheries and Aquatic Sciences.
Paul, A. J. 1982. Mating frequency and sperm storage as factors affecting egg production in multiparous *Chionoecetes bairdi,* p. 273-281. *In* B. Melteff (editor), Proceedings of the International Symposium on the Genus *Chionoecetes:* Lowell Wakefield Symposium Series, Alaska Sea Grant Report, 82-10. University of Alaska Fairbanks.
Paul, A. J. 1984. Mating frequency and viability of stored sperm in the Tanner crab *Chionoecetes bairdi* (DECAPODA, MAJIDAE). Journal of Crustacean Biology. 4:375-381.
Paul, A. J. and J. M. Paul. 1992. Second clutch viability of *Chionoecetes bairdi* Rathbun (DECAPODA: MAJIDAE) inseminated only at the maturity molt. Journal of Crustacean Biology. 12:438-441.
Paul, J.M., A.J. Paul, and A. Kimker. 1994. Compensatory feeding capacity of 2 brachyuran crabs, Tanner and Dungeness, after starvation periods like those encountered in pots. Alaska Fish. Res. Bull. 1:184-187.
Paul, A. J. and J. M. Paul. 1996. Observations on mating of multiparous *Chionoecetes bairdi* Rathbun (DECAPODA: MAJIDAE) held with different sizes of males and one-clawed males. Journal of Crustacean Biology. 16:295-299.
Quandt, A. 1999. Assessment of fish trap damage on coral reefs around St. Thomas, USVI. Independent Project Report, UVI Spring 1999. 9 p.
Rathbun, M. J. 1924. New species and subspecies of spider crabs. Proceedings of U.S. Nat. Museum. 64:1-5.
Slizkin, A. G. 1990. Tanner crabs *(Chionoecetes opilio*, *C. bairdi*) of the northwest Pacific: distribution, biological peculiarities, and population structure, p. 27-33. *In* Proceedings of the International Symposium on King and Tanner Crabs. Lowell Wakefield Fisheries Symposium Series, Alaska Sea Grant College Program Report 90-04. University of Alaska Fairbanks.
Somerton, D. A. 1980. A computer technique for estimating the size of sexual maturity in crabs. Can. J. Fish. Aquat. Sci. 37:1488-1494.
Somerton, D. A. 1981a. Life history and population dynamics of two species of Tanner crab, *Chionoecetes bairdi* and *C. opilio*, in the eastern Bering Sea with implications for the management of the commercial harvest, PhD Thesis, University of Washington, 220 p.
Somerton, D. A. 1981b. Regional variation in the size at maturity of two species of Tanner Crab (*Chionoecetes bairdi* and *C. opilio*) in the eastern Bering Sea, and its use in defining management subareas. Canadian Journal of Fisheries and Aquatic Science. 38:163-174.
Somerton, D. A. and W. S. Meyers. 1983. Fecundity differences between primiparous and multiparous female Alaskan Tanner crab (*Chionoecetes bairdi*). Journal of Crustacean Biology. 3:183-186.
Sparks, A.K. 1982. Observations on the histopathology and probable progression of the disease caused by *Trichomaris invadens* in the Tanner crab, *Chionecetes bairdi*. J. Invertebr. Pathol. 34:184-191.

Stevens, B. G. 2000. Moonlight madness and larval launch pads: tidal synchronization of Mound Formation and hatching by Tanner crab, *Chionoecetes bairdi*. Journal of Shellfish Research. 19:640-641.

Stevens, B. G., and R. A. MacIntosh. 1992. Cruise Results Supplement, Cruise 91-1 Ocean Hope 3: 1991 eastern Bering Sea juvenile red king crab survey, May 24-June 3, 1991., DOC, NOAA, NMFS, Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, 13 p.

Tamone, S. L., S. J. Taggart, A. G. Andrews, J. Mondragon, and J. K. Nielsen. 2007. The relationship between circulating ecdysteroids and chela allometry in male Tanner crabs: Evidence for a terminal molt in the genus *Chionoecetes*. J. Crust. Biol. 27:635-642.

Thompson, G. J. Ianelli, M. Dorn, D. Nichol, S. Gaichas, and K. Aydin. 2007. Chapter 2: Assessment of the Pacific cod stock in the eastern Bering Sea and Aleutian Islands Area. Stock Assessment and Fishery Evaluation Report for the Groundfish Resources of the Bering Sea/Aleutian Islands Regions, North Pacific Fishery Management Council, Anchorage, 209-328 p.

Tracy, D. A., and S. C. Byersdorfer. 2000. Summary of crab injury assessment and aerial exposure sample results from selected 1997/1998 Bering Sea/Aleutian Islands king and Tanner crab fisheries and the 1998 Pribilof Islands hair crab fishery. Alaska Department of Fish and Game. Regional Information Report 4K00-52.

Williams, A. B., L. G. Abele, D. L. Felder, H. H. Hobbs, Jr., R. B. Manning, P. A. McLaughlin, and I. Perez Farfante. 1989. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. American Fisheries Society Special Publication 17. 77 p.

Zheng, J., G. H. Kruse, and M. C. Murphy. 1998. A length based approach to estimate population abundance of Tanner, *Chionoecetes bairdi*, crab in Bristol Bay, Alaska, p. 97-105. G. S. Jamieson and A. Campbell (editors), *In* Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment. Canadian Special Publication of Fisheries and Aquatic Sciences.

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	8.98
1981	158.07	140.90	116.68	31.08	27.71	7.75
1982	113.32	101.01	88.11	21.72	19.36	9.53
1983	65.70	58.56	53.23	13.18	11.75	8.19
1984	45.41	40.48	32.63	11.73	10.45	3.73
1985	26.01	23.19	20.87	9.68	8.63	6.85
1986	35.49	31.64	28.30	6.83	6.09	3.72
1987	63.93	56.99	47.59	16.25	14.48	6.68
1988	139.55	124.39	100.95	36.60	32.62	12.63
1989	231.48	206.34	148.28	83.11	74.08	21.00
1990	240.30	214.20	116.87	114.64	102.19	9.07
1991	255.73	227.95	140.59	92.81	82.73	0.84
1992	246.92	220.09	147.39	104.50	93.15	25.22
1993	144.40	128.71	90.47	56.00	49.91	14.63
1994	95.02	84.70	64.74	40.79	36.35	18.22
1995	71.65	63.87	50.79	26.46	23.58	12.02
1996	58.64	52.27	46.27	24.47	21.81	16.96
1997	25.13	22.40	18.50	8.66	7.72	4.37
1998	25.35	22.60	18.69	5.89	5.25	1.99
1999	43.87	39.11	36.48	4.89	4.36	3.05
2000	39.24	34.98	33.05	11.42	10.18	9.18
2001	43.65	38.91	36.45	15.19	13.54	12.04
2002	44.53	39.70	36.80	16.71	14.90	12.94
2003	61.29	54.63	50.99	18.78	16.74	14.53
2004	65.48	58.36	55.08	14.04	12.52	10.96
2005	104.50	93.15	86.24	29.32	26.14	21.75
2006	158.95	141.68	125.98	37.48	33.41	21.78
2007	185.19	165.07	140.30	31.75	28.30	8.67

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 and Fishery Metrics

[MFMT=F_{MSY}= γ M; B_{REF}=B_{MSY} or Proxy B_{MSY}; B=MMB @ Mating]

	B_{REF1}, TAC/OFL=0.8	B_{REF2}, TAC/OFL=0.8	B_{REF3}, TAC/OFL=0.8
Metrics (10^6lb):			
Projected Catch OFL:	5.814	5.295	4.594
Projected Buffered Catch OFL:	4.651	4.236	3.675
B_{REF}:	133.987	154.424	178.155
MMB @ Mating:	140.103	140.622	141.322
B/B_{REF}:	1.046	0.911	0.793
F_{OFL}:	0.230	0.207	0.177
Catch Components (10^6lb):			
Directed Discard Losses ♀:	0.106	0.096	0.084
Directed Discard Losses MMB:	1.116	1.016	0.882
Non-Directed Discard Losses MMB:	11.866	11.866	11.866
Directed Discard Losses LMB:	0.013	0.011	0.010
Non-Directed Discard Losses LMB:	1.808	1.808	1.808
Total ♂ Discard + Bycatch Losses:	12.944	12.944	12.944
Total Male Catch:	16.975	16.357	15.524
Total Male + Female Catch:	17.081	16.453	15.607
OFL Split (10^6lb):			
Retained Part of Catch OFL:	3.994	3.475	2.776
Retained Part Buffered Catch OFL:	2.831	2.416	1.858
Rates:			
Catch OFL/MMB @ Fishery:	0.035	0.032	0.028
μ on LMB @ Fishery:	0.205	0.187	0.162
μ on MMB @ Fishery:	0.103	0.099	0.094

$B_{REF1} = 0.35 \cdot B_O$, where B_O is proxy for pristine male mature biomass. B_O = mean 1969 and 1974-75 MMB @ mating.

$B_{REF2} = 0.35 \cdot B_O$, 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 2005/06	Total Catch 2006/07	Species	Total Catch 2005/06	Total Catch 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

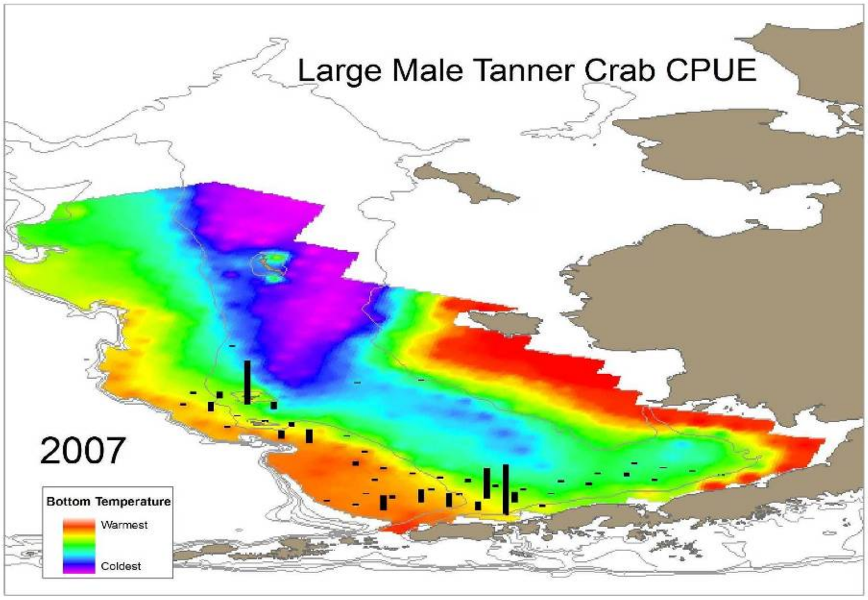


Figure 1. Distribution and abundance of large male Tanner crab with bottom temperature from the 2007 EBS crab-ground fish survey.

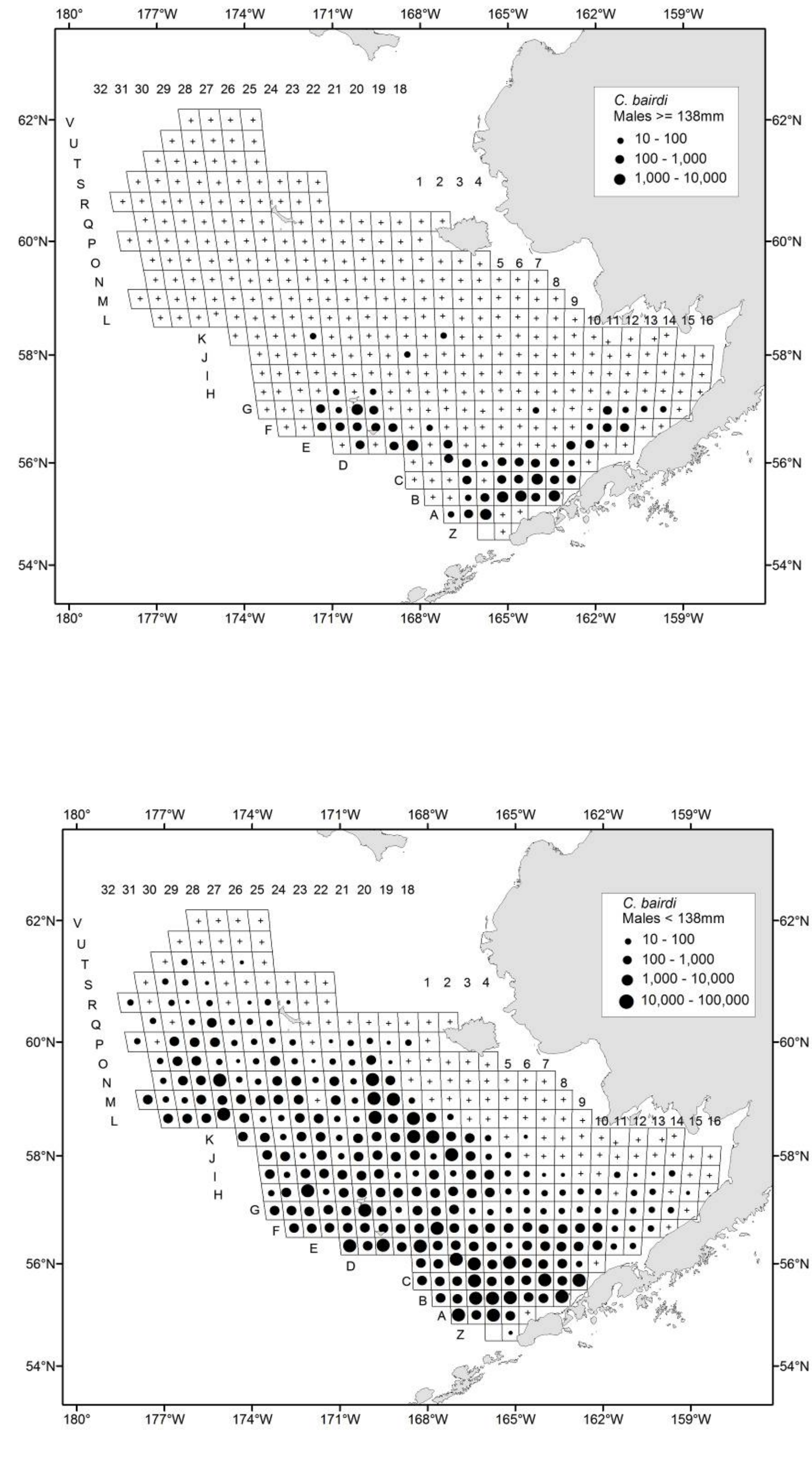


Figure 2. Distribution and abundance of legal (>= 138 mm CW) and sub legal (<138 mm CW) male Tanner crab in the summer 2007 EBS crab-ground fish survey.

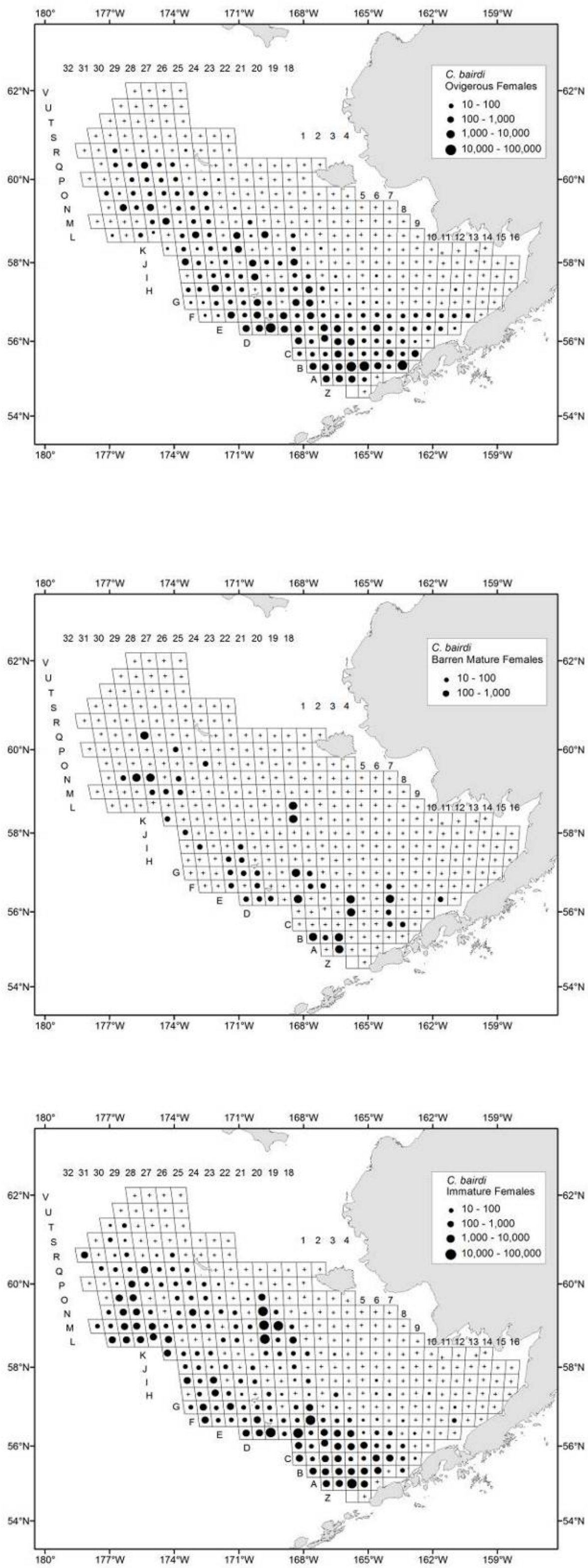


Figure 3. Distribution and abundance of ovigerous, barren mature, and immature female Tanner crab in the 2007 EBS crab-ground fish survey.

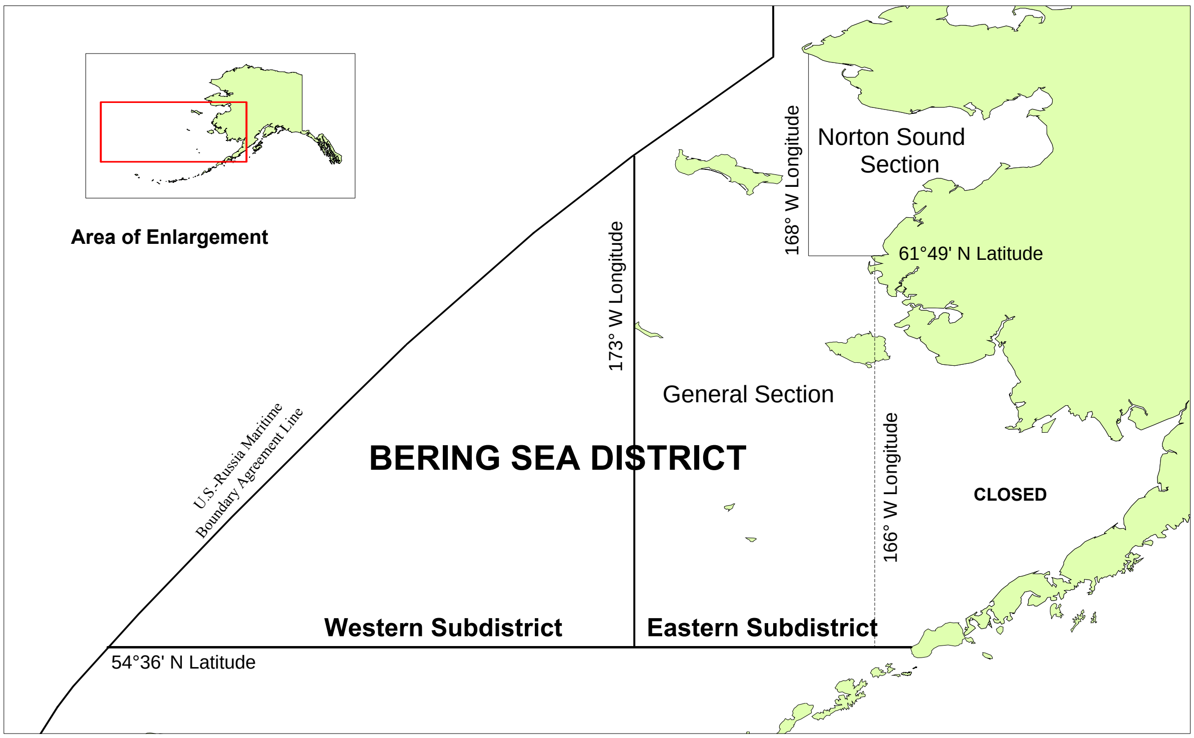
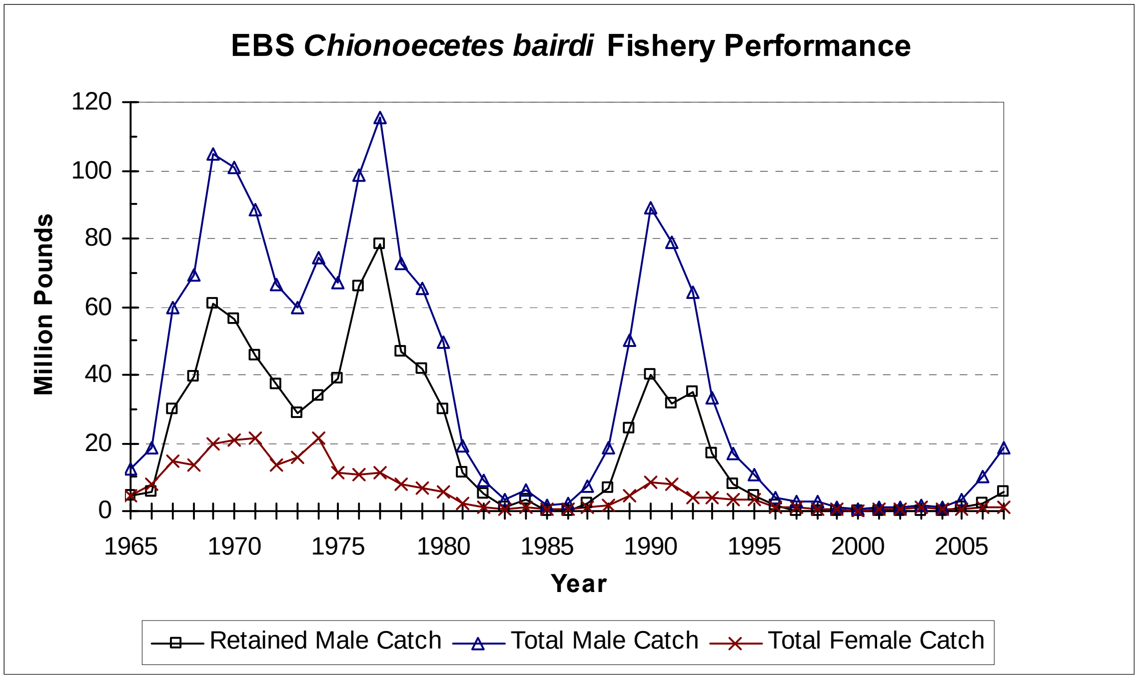


Figure 4. Bering Sea District of Tanner crab Registration Area J including sub districts and sections (from Bowers et al. 2008).

(a)



(b)

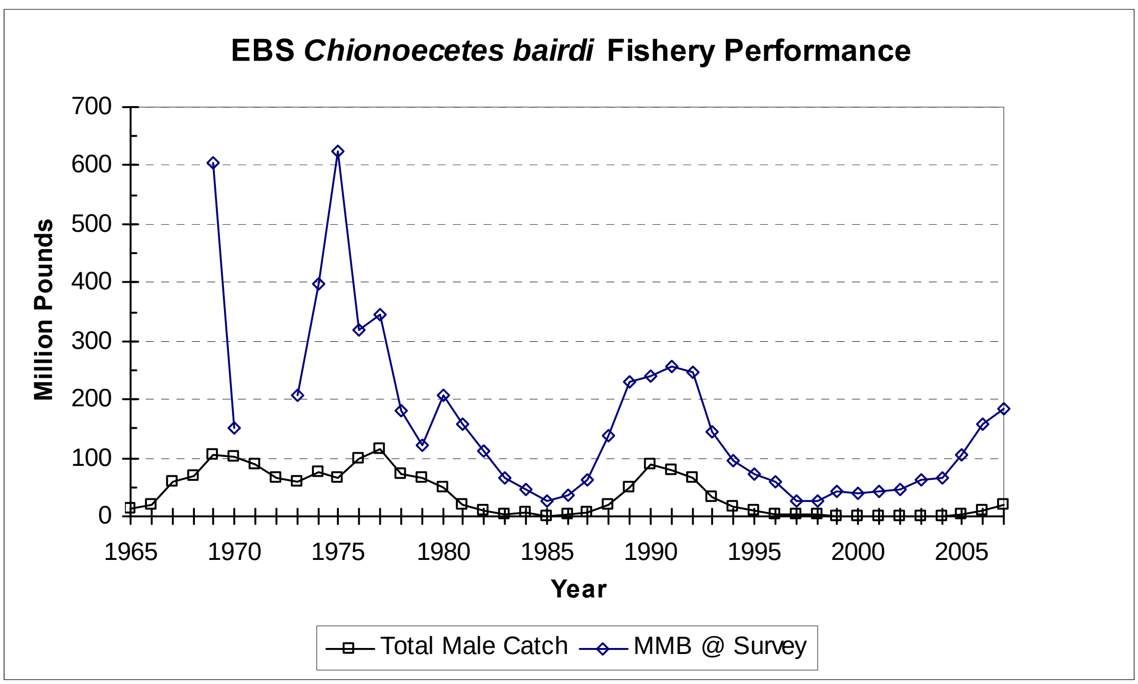


Figure 5. Eastern Bering Sea *Chionoecetes bairdi* retained male catch, total (retained + discard/bycatch) male catch and total female catch (a), and total male catch vs male mature biomass at the time of the survey (b), 1965-2007.

(a)

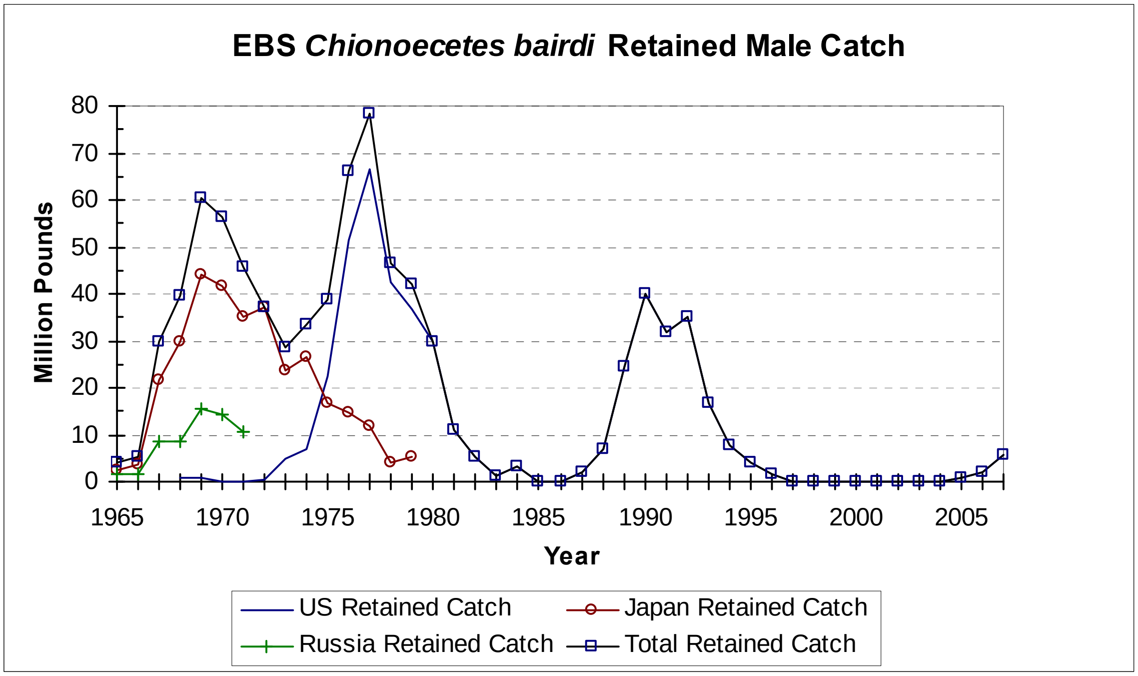


Figure 6. Eastern Bering Sea *Chionoecetes bairdi* retained male catch in the directed United States, Russian and Japanese fisheries, and 1965-2007.

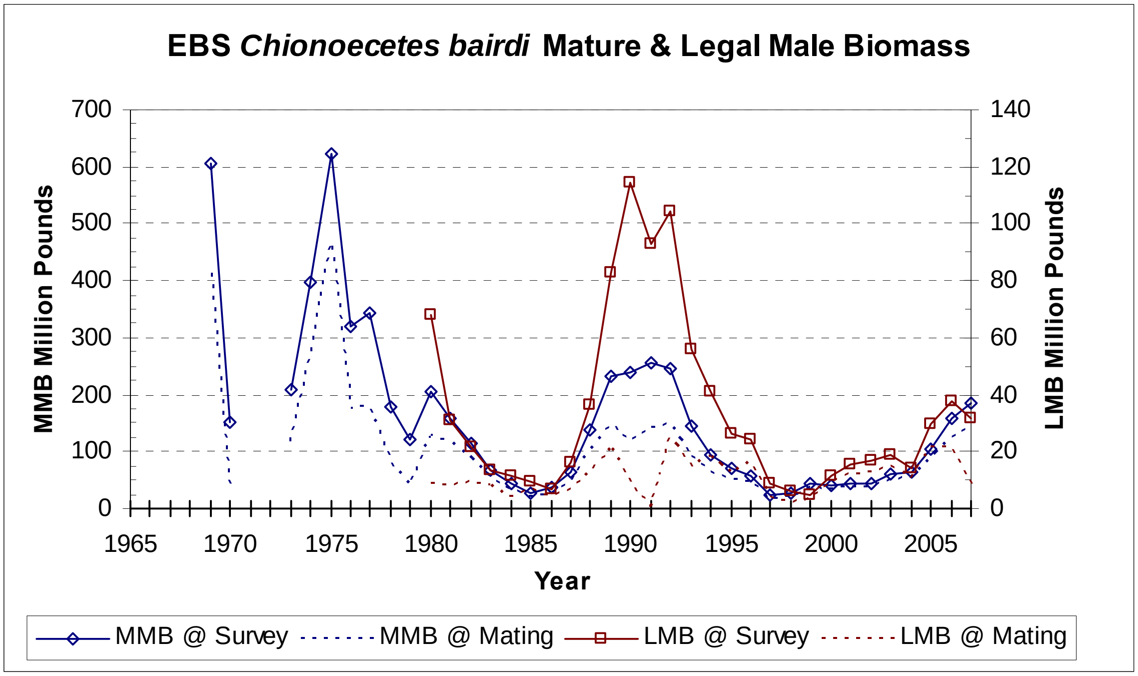
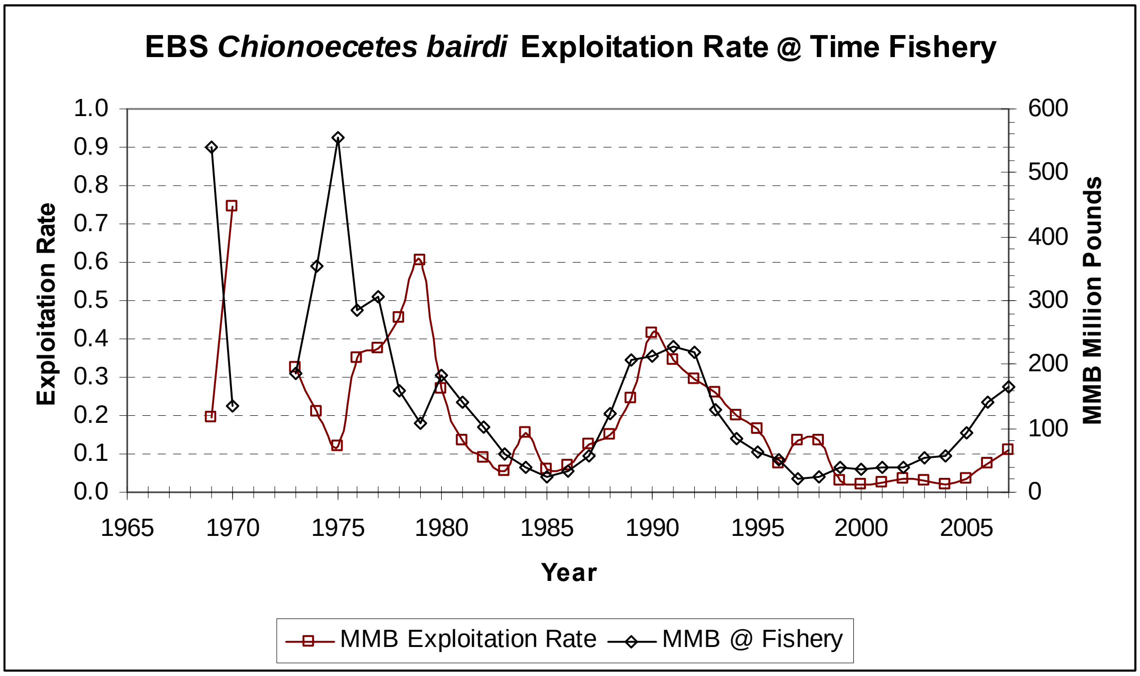


Figure 7. Eastern Bering Sea *Chionoecetes bairdi* mature and legal male biomass at time of the survey and subsequent mating, 1965-2007.

(a)



(b)

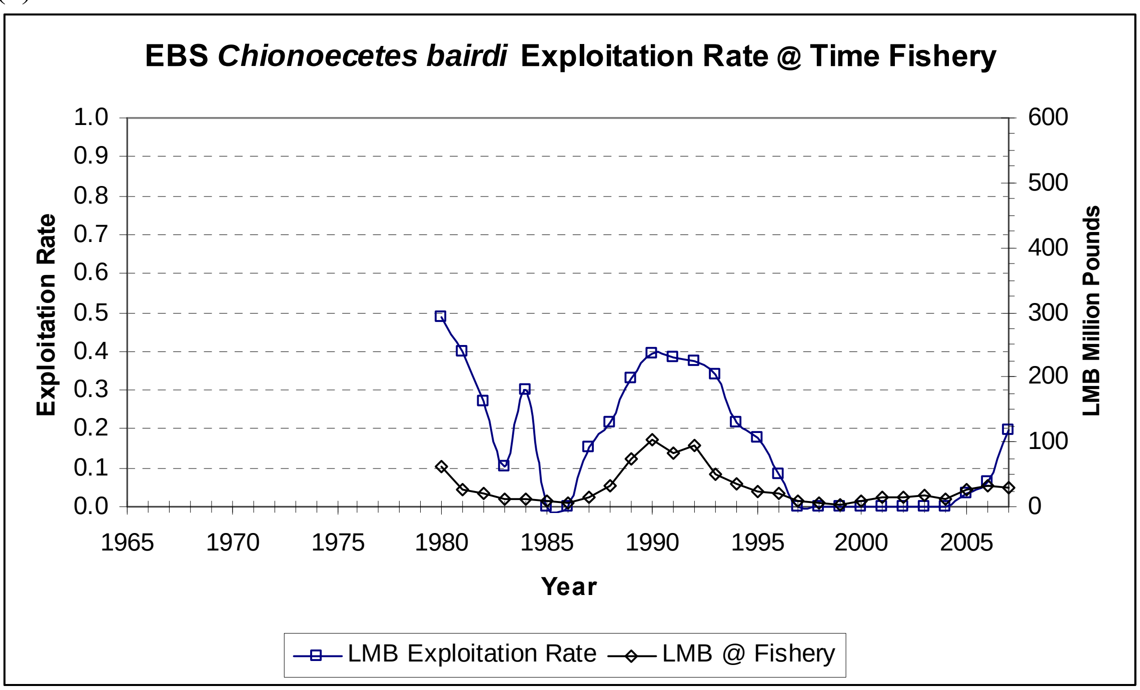


Figure 8. Eastern Bering Sea *Chionoecetes bairdi* exploitation rate on mature (a) and legal (b) male biomass at the time of the fishery with associated male biomass metric, 1965-2007.

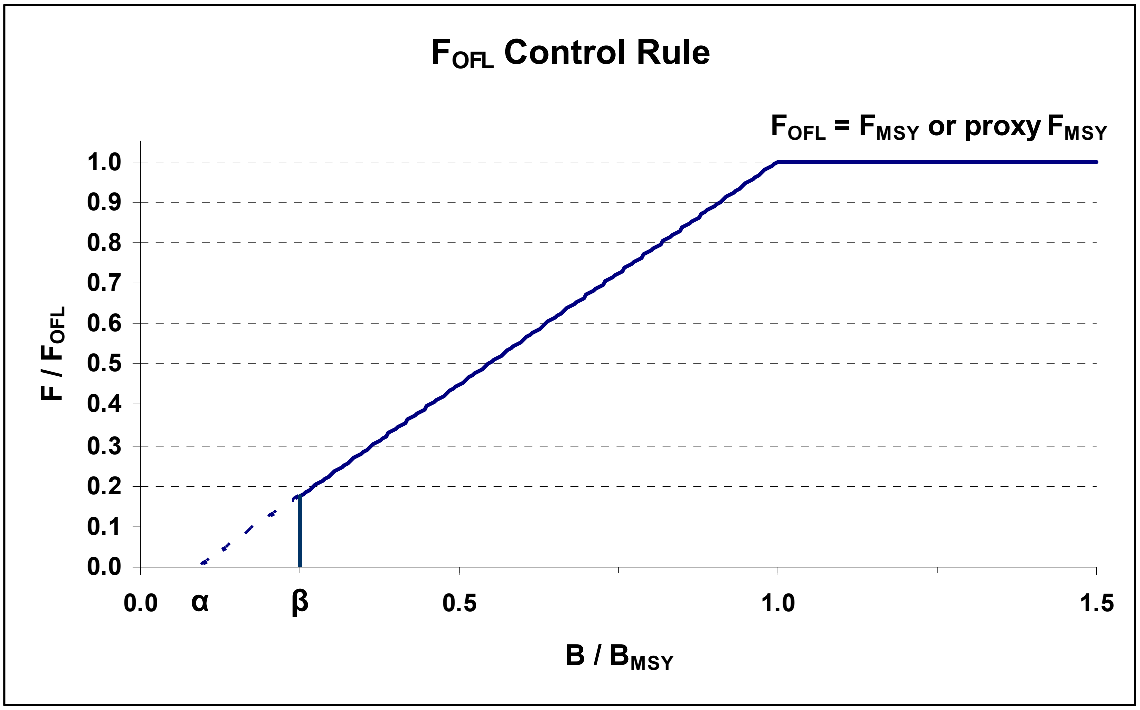


Figure 9. F_{OFL} Control Rule for Tier-4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set 0 below β.