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
In 2008, Tanner crab male mature biomass (MMB) and at the time of the survey was estimated at 143.1 million pounds. This represented a 22.7% decrease in mature male biomass relative to 2007. Legal males were sparsely distributed in 2008 with regions of highest abundance in southern Bristol Bay. The total abundance index for legal males was 13.1 million crabs which represented a 9% increase over 2007. Legal males were distributed 69.0% east and 31.0% west of 166° West longitude which compared to 44.5% and 55.5% respectively in 2007. The abundance index for pre-recruit male crabs declined 16.0%, and that for small males declined 55.1% relative to 2007. Total male abundance declined 43.2% between 2007 and 2008. Comparison of the 2006-2008 male size frequency distributions reveal persistently declining abundance across all size ranges, a general failure for modes to persist inter-annually, and a relatively increasing percentage of old shell crabs in the mature male stock.

In 2008, a single station sampled in southern-most Bristol Bay was a high density station for Tanner male crab. The legal male abundance estimated at this station (6.1 million crabs) represented 67.8% of all legal male crab in the Eastern District. It exceeded by 2.1 million crab the number of legal males in the Western District, and it comprised 46.7% of all legal males estimated throughout the EBS. Considerable uncertainty exists in the apparent strength (+9.0%) of the 2008 legal male estimate relative to 2007.

Large female Tanner crab showed a 21.4% decrease over 2007, and these were dominated (71.1%) by old shell females. Small female Tanner crab declined 38.8% relative to 2007. Total 2008 female abundance declined 35.9%, and the total abundance of male and female combined declined 43.2% since 2007. The survey length frequency distributions of female Tanner crab from 2006-2008 reveal consistently declining abundance across the size modes and the general failure of modes of abundance to persist inter-annually.

Tanner crab is managed as a Tier-4 stock. The proxy B_{MSY} used in the OFL-setting process was B_{REF} = 178.2 million pounds male mature biomass estimated as the average MMB_{mating} for 1975-80. For Tier-4 stocks, the F_{OFL} is derived using and F_{OFL} Control Rule based on the relationship of current mature stock biomass to a reference biomass proxy for B_{MSY}. Here, $F_{OFL} = \gamma M$. The Amendment 24 and its associated EA defines a default value of gamma=1.0. Gamma is allowed to be less than or greater than unity resulting in overfishing limits more or less biologically conservative than fishing at M. However, Amendment 24 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 plus bycatch losses.

The value of M is 0.23 for eastern Bering Sea Tanner crab. For this analysis, gamma was set to 1.0. Relative to B_{REF} = 178.155 million pounds, the 2008 estimate of MMB at the time of mating (106.746 million pounds) represented B/B_{REF} = 0.599 resulting in and F_{OFL} = 0.128.

For the 2008 Tanner crab fishery, we estimated the Total Catch OFL = 15.273 million pounds. Directed and non-directed losses to MMB in 2008 are estimated to be 7.683 and 2.916 million pounds, respectively. After accounting for expected losses to MMB, the projected catch of legal-sized Tanner crab is 5.382 million pounds. The retained part of the catch of legal-sized crab (4,674 million pounds) accounts for expected directed and non-directed losses to LMB by the fisheries. In comparison to the overfishing limit (15.273 million pounds), retained legal catch would comprise 30.6% of the total male mature biomass losses. A significant component of the Total Catch OFL therefore results from non-targeted losses under current EBS fisheries.

Expected bycatch losses of female Tanner crab from the 2008 ground fish fishery were estimated at 0.732 million pounds. Therefore, total expected male plus female catch in 2008 is 16.369 million pounds. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.093 and 0.129 respectively.

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

The common name for *C. bairdi* of "Tanner crab" (Williams et al. 1989), was recently been modified to "southern Tanner crab" (McLaughlin et al. 2005). Prior to this change, the term "Tanner crab" has also been variously used to refer to other members of the genus, or the genus as a whole. Hereafter, the common name "Tanner crab" will be used in reference to "southern Tanner crab".

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), the Tanner crab distribution appears to be limited by water temperature (Somerton 1981a) (Figure 1). *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). The southern range of the cold water congener, *C. opilio*, the snow crab in the EBS is near the Pribilof Islands (Turnock et al. 2008). The distributions of snow and Tanner crab 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 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 observations are lacking for the eastern Bering Sea, seasonal differences have been observed 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) respectively (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 post 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 its EBS range. There is no more current information on EBS Tanner crab growth than that provided by Sommerton (1981b). 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 50% 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. He felt that because of net selectivity of the survey sampling gear, that age five Tanner crab (mean CW = 95 mm) were the first cohort to be fully recruited to the gear; he estimated an instantaneous natural mortality rate of 0.35 for this size class using catch curve analysis. Using a catch curve model with two different data sets, Somerton 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. Somerton concluded 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 in an assessment model incorporating survey and fishery data through 1996 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.

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 4). 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: $W=0.00019(CW)^{3.09894}$.

The Survey

The National Marine Fisheries Service conducts an annual trawl survey in the eastern Bering Sea to determine the distribution and abundance of commercially-important crab and groundfish fishery resources. The survey has been conducted since 1971 by the Resource Conservation and Engineering (RACE) Division of the Alaska Fisheries Science Center. It's been conducted annually since 1975 when it was also expanded into Bristol Bay and the majority of the Bering Sea continental shelf. Since 1988, 376 standard stations have been included in the survey covering a 150,776 nm^2 area of the EBS with station depths ranging from 20 to 150 meters depth. The annual collection of data on the distribution and abundance of crab and groundfish resources provides fishery-independent estimates of population metrics and biological data used for the management of target fishery resources. Crustacean fishery resources targeted by this survey and enumerated annually by NMFS are red king crab (*Paralithodes camtschaticus*), blue king crab (*P. platypus*), hair crab (*Erimacrus isenbeckii*), Tanner crab (*Chionoecetes bairdi*) and snow crab *(C. opilio*).

The 2008 trawl survey consisted of 378 bottom trawls taken over an area of approximately 139,548 nm^2. The survey was conducted onboard the FV *Arcturus* and FV *Aldebaran*, between 4 June and 24 July. Sampling methodology was identical to that of previous surveys since 1982, and most tows were made at the centers of squares defined by a 20 x 20 nmi (37 x 37 km) grid (Figure 1). Near St. Matthew Island and the Pribilof Islands, additional tows were made at the corners of squares that define high density sampling strata for blue king crab and red king crab. . The distribution of average bottom water temperatures across the area sampled in 2008 are is shown in Figure 1.

Both the FV *Arcturus* and FV *Aldebaran* fished an eastern otter trawl with an 83 ft (25.3 m) headrope and a 112 ft (34.1 m) footrope which has been the standard gear since 1982. Each tow was approximately 0.5 h in duration towed at 3 knot, and conducted in strict compliance with established NOAA groundfish bottom trawl protocols (Stauffer 2004). The average tow length of all tows taken in 2008 was 1.49 nmi (2.78 km). The mean bottom water temperature of all 378 trawls was 1.08 ^{o}C. Crabs were sorted by species and sex, and then a sample of the catch measured to the nearest millimeter to provide a size-frequency distribution. Population estimates are indices of relative population abundance and biomass and do not necessarily represent absolute abundance or biomass measures. They are most precise for large crabs, and are least precise for small crabs due to gear selectivity, and for females of some stocks due to differential crab behavior.

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). LMB data are currently available only for 1980-2008. 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 those 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 2008, MMB rose at a moderate rate from a low of 25.1 million pounds in 1997 to 185.2 million pounds in 2007 before falling to 143.1 million pounds in 2008 . 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.

The legal minimum size of 5.5 in cw (spine tip to spine tip) is equivalent to 138 mm cw measured between the spines. Legal males were sparsely distributed with regions of highest abundance in southern Bristol Bay and south of the Pribolof Islands (Figure 2). In 2005, the ADF&G stratified the management of the Bering Sea Tanner crab stock into two subareas, east and west of 166^{o}W longitude, hereafter Eastern and Western Districts respectively. The abundance index for legal male C. bairdi for both Districts combined was 13.1 million crabs, a 9% increase over 2007. This abundance was distributed between management districts according to 69.0% Eastern and 31.0% Western compared to 44.5% and 55.5%, respectively in 2007. The abundance index (77.7 million crabs) for pre-recruit male crabs (110-137 mm cw) showed a 16.0% decrease, and the index of 186.8 million for small males (< 110 mm cw) showed a 55.1% decrease relative to 2007 for all areas combined (Figure 10).. The 2006 male size-frequency revealed a prominent mode in the 70-75 mm cw range, which persisted to 2007 at

90 mm cw (Figure 11). However, this mode is absent from the 2008 male length frequency and total male abundance was observed to decline 46.7% between 2007 and 2008 (Figures 10 and 11). Legal-sized males represent only a small portion (8.9%) of total male abundance in 2008. Among legal males, 91.3% were new-hardshells, and 8.7% were oldshell and older. Pre-recruit Tanner crab in 2008 were widely distributed across the range of the survey from southern Bristol Bay northwest to St. Matthew Island (Figure 2).

In 2008, a single station sampled in southern-most central Bristol Bay revealed a high density of male Tanner crab. The legal male abundance estimated at this station (6.1 million crabs) represents 67.8% of all legal male crab in the Eastern District. It exceeded by 2.1 million crab the estimate of all legal males in the Western District, and it comprised 46.7% of all legal males estimated in all EBS areas combined. Therefore, considerable uncertainty exists in the apparent strength (+9.0%) of the 2008 estimate of legal male abundance relative to 2007.

The combined Eastern and Western Districts abundance index (32.1 million crabs) of large females ($\geq$ 85 mm cw) showed a 21.4% decrease over 2007 (Figure 10). Among sampled mature females, 1.8% were softshells; 27.0% were new-hardshell, of which 98.4% carried new eggs; and 71.1% were oldshell and older, of which 81.8% carried new eggs. The vast majority of mature females sampled had completed hatching by the time of the survey. The small (<85 mm cw) female Tanner crab abundance estimate in 2008 (125.6 million crab) showed a 38.8% decline relative to 2007. Total 2008 female abundance (157.7 million crab) declined 35.9% in from 2007, and the total abundance of male and female combined declined 43.2% since 2007 (Figure 10). Ovigerous females were sparsely distributed from southern Bristol Bay westward to south of St. Matthew Island (Figure 3). Immature female Tanner crab displayed a similar distribution to mature females with the exception of an area of relatively high concentration west of Bristol Bay and north of the Pribiolof Islands (Figure 3). Barren mature females were intermittently distributed (Figure 3). The survey length frequency distributions of female Tanner crab from 2006-2008 are shown in Figure 12. The prominent length mode between 65-75 mm cw seen in 2006 is not shown to persist through 2007 or 2008. Rather, it is shown in consistently declining abundance through 2008. A significant portion (71.1%) of mature female Tanner crab are in old or older shell class condition (Figure 12).

The Fishery

The domestic Tanner crab (*Chionoecetes bairdi*) pot fishery rapidly developed in the mid-1970s (Table 1, Figures 5 and 6). As a note, we adopted the convention for tables in this document presenting biomass or fishery data, the 'year' refers to the survey year, and fishery data are those subsequent to the survey that year through but prior to the survey in the following year. United 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, and 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. The domestic Tanner crab fishery re-opened in 2005 and has averaged 1.7 million pounds retained catch between 2005-2007. 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, for snow crab and red king crab), and the groundfish trawl fisheries (Table 2). Discard/bycatch mortalities were estimated using post-release handling mortality rates (HM) of 50% for pot fishery discards and 80% for trawl fishery bycatch (NPFMC 2008). 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.

Since the re-opening of the domestic fishery in 2005, the relationship of total male discard/bycatch mortalities by all pot and trawl fisheries combined to retained catch has shifted markedly relative to that between 1980-1996 (Tables 1 and 2). In the last three years, the ratio of total male non-retained losses to retained catch in terms of biomass is 4.4, 5.6 and 4.2 respectively. The majority of these male losses are sub-legal sized crab, and a principal contributor to these non-retained losses is the directed Tanner crab fishery itself (see Table 9a). This contrasts the pre-closure performance of the domestic fishery between 1980-1996 which averaged 1.1 (se=0.1) pounds of non-retained male mortalities to each 1.0 pound of retained catch. These ratios in terms of numbers of male non-retained losses to retained legal crab are more striking due to the contribution of sub-legal sized crab to total male discards. Note, discard and bycatch losses of male and female Tanner crab (Table 2) during the closures of the directed domestic fishery (1985-1986 and 1997-2004) reflect losses due to non-directed EBS pot fisheries and the domestic groundfish trawl fishery.

Exploitation Rates
The historical patterns 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. Estimates of LMB are available only for 1980-2008. During that period, exploitation rate (μ) on LMB was highest in 1980 at 0.19 and fell with stock condition through the mid-1980s. LMB exploitation rate revealed a second prominent mode during 1989-1993, peaking at 0.18 in 1991 and averaging 0.17 (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 0.21 between 1986-1997, and closely followed the build up in stock biomass during that period.

The 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 incomplete. Although a full assessment model cannot be specified for Tier-4 stocks or stock-recruitment relationship defined, sufficient information is customarily 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 estimating 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 maximum sustainable yield (MSY) to fisheries exploiting the stock at $F_{MSY.}$ For Tier-4 stocks, B_{MSY} is commonly estimated as the average biomass over a specified period that satisfies the conditions of equilibrium biomass yielding MSY by an applied F_{MSY}. It can also be estimated as a percentage of pristine biomass (B_0) of the unfished or lightly exploited stock where data exist. 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 Amendment 24 and its associated EA defines a default value of gamma = 1.0. Gamma is allowed to be less than or greater than unity resulting in overfishing limits more or less biologically conservative than fishing at 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 associated with Amendment 24 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_t) belongs to 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 where $\beta < B_t \leq B_{MSY}$, the F_{OFL} is estimated as a function of the ratio B_t/B_{MSY}. The value of M is 0.23 for eastern Bering Sea Tanner crab. In the analysis of Tier-3 for snow crab, *Chionoecetes opilio,* and red king crab, *Paralithodes camtschaticus*, a B_{MSY} proxy reference value (B_{REF}) equal to 35% of the maximum spawning potential of the unfished stock was specified (Annon 2008, EA associated with Amendment 24). For Tier-4 stocks, a reference biomass value (B_{REF}) must be specified.

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

OFL Model Structure

In the Tier-4 OFL-setting approach EBS Tanner crab, various measures of stock biomass and catch components are integrated in the overfishing level determination. Here, we define each component and illustrate the conceptual approach for OFL-setting based on these metrics.

Male Mature and Legal Biomass:

Annual estimates of male biomass are derived from the NMFS Eastern Bering Sea summer trawl survey. Two measures are specified: male mature biomass (MMB) and legal male biomass (LMB). From these measures derived at the time of the survey, we estimate MMB and LMB at the time of mating by depreciating survey biomass by the partial natural mortality rate (M) over 8 months from the survey to mating and extracting catch components (C_{MMB} or C_{LMB}).

$$MMB_{mating} = MMB_{survey}e^{-2M/3} - C_{MMB} \quad (1)$$

$$LMB_{mating} = LMB_{survey}e^{-2M/3} - C_{LMB} \quad (2)$$

Finding F_{OFL}:

Given MMB_{mating} (or B_t) and the specification of a biomass reference (B_{REF}) proxy for B_{MSY}, the overfishing limit F_{OFL} is found using the OFL algorithm. In the case where, for example, $\beta < B_t/B_{REF} \leq 1.0$, the overfishing limit is estimated, where α=0.1:

$$F_{OFL} = \gamma M\,((B_t/B_{REF} - 0.1)/(1 - 0.1)) \quad (3)$$

Total Catch OFL and Catch Components:

A total catch overfishing limit (Total Catch OFL) corresponding to the F_{OFL} can be estimated as the product of the annual fishing mortality rate ($1-e^{-Fofl}$) and the male mature biomass at the time of the fishery ($MMB_{survey}e^{-M/2}$). Here, the time lag from the survey to the fishery is 6 months.

$$\text{Total Catch OFL} = (1-e^{-Fofl})\,(MMB_{survey}e^{-M/2}) \quad (4)$$

This total catch overfishing limit includes all retained, plus discard and bycatch losses from the directed fishery and all non-directed fisheries (pot and groundfish trawl). These catch components are defined as:

i. $C_{ret,LMB}$ = retained legal male biomass by the directed fishery
ii. $C_{dir\text{-}dsc,MMB}$ = discard losses to MMB by the directed fishery
iii. $C_{non\text{-}dsc\text{-}pot,MMB}$ = discard losses to MMB by the non-directed pot fisheries
iv. $C_{non\text{-}dsc\text{-}gf,MMB}$ = discard losses to MMB by the non-directed trawl fisheries

Therefore, using these catch components,

$$\text{Total Catch OFL} = C_{ret,LMB} + C_{dir\text{-}dsc,MMB} + C_{non\text{-}dsc\text{-}pot,MMB} + C_{non\text{-}dsc\text{-}gf,MMB} \quad (5)$$

In practice, the catch components i-iv are estimated from past performance in the respective fisheries considered to be most representative of current conditions. Catch components i and iv are co-related, and the magnitude of the discard losses to MMB by the directed fishery is a function of the retained legal male biomass. In this case, $C_{ret,LMB}$ is found by iteration such that the Total Catch OFL (5) equated to that estimated in equation (4).

Discard Catches:
Discard losses of mature male biomass by the directed fishery ($C_{dir\text{-}dsc,MMB}$) was estimated using data from the most recent 2007 Tanner crab fishery supplied by D. Barnard (ADF&G, 08/11/08) (Table 9a). The ratios of legal and sublegal male and female discards to the retained catch are used to project discard losses in the terminal 2008 OFL fishery. Here, DSC,MMB_{07} is the discarded mature male biomass by the directed 2007 Tanner crab fishery. For all pot discards, a post-release handling mortality rate of 50% was used (HM_{pot}=0.50). Directed fishery discard losses to MMB is given by:

$$C_{dir\text{-}dsc,MMB} = C_{ret,LMB} \left(DSC,MMB_{07} / C_{ret,LMB\ 07}\right) HM_{pot} \quad (6)$$

Non-directed pot fishery discard losses to male mature biomass ($C_{non\text{-}dsc\text{-}pot,MMB}$) are principally attributed to the EBS snow crab fishery and to the Bristol Bay red king crab fishery to al lesser extent. In this analysis, we used data from the previous two fishing seasons (2006 and 2007) to estimate of the average ratio of combined Tanner crab mature male discards to snow crab retained catch (Table 9b). $C_{ret,opilio\ 2008}$ is the projected 2008 retained catch OFL (Turnock, pers. Comm.). Using this ratio, projected non-directed pot fishery discard losses to MMB in the terminal OFL fishery is given by:

$$C_{non\text{-}dsc\text{-}pot,MMB} = C_{ret,Opilio\ 2008} \left(C_{non\text{-}dsc\text{-}pot,MMB} / C_{ret,opilio}\right)_{mean,07} HM_{pot} \quad (7)$$

Discard losses to MMB resulting from bycatch in the groundfish trawl fisheries ($C_{non\text{-}dsc\text{-}gf,MMB}$) was estimated using the average groundfish bycatch of Tanner crab over 2003-07 (Table 9c). We assumed that this average (5 y) bycatch of Tanner crab would occur in the 2008 OFL fishery. Reported bycatch are for males and females combined. The sex distribution and length frequency of this bycatch is unavailable for this analysis. The proportion of males in the bycatch was estimated assuming a sex ratio of 1:1 in the bycatch and apportioning the catch based on the ratio of mean weights of 120 mm cw male crab to 87.5 mm cw female crab resulting in a 60.2% v. 39.8% male to female split. For all trawl discards, a post-release handling mortality rate of 80% was used (HM_{gf}=0.80). Ground fish trawl fishery discard losses to MMB is given by:

$$C_{non\text{-}dsc\text{-}gf,MMB} \quad = \text{Mean}_{03\text{-}07,dsc,gf}\ \text{Porportion}_{male}\ HM_{gf} \qquad (8)$$

Exploitation rates on legal male biomass (μ_{LMB}) and mature male biomass (μ_{MMB}) at the time of the fishery are calculated as the ratio of total directed plus non-directed losses to LMB and MMB to respective legal and mature male biomass at the time of the fishery:

$$\mu_{LMB} \quad = \text{Total LMB Losses} / LMB_{fishery} \qquad (9)$$

$$\mu_{MMB} \quad = \text{Total MMB Losses} / MMB_{fishery} \qquad (10)$$

Using the F_{OFL} Control Rule (Figure 9), F_{OFL} is determined based on MMB at time of mating after extraction of the Total Catch OFL. 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 (directed retained catch, directed discards, and non-directed pot and trawl bycatch mortalities). Given specification of all component losses, the retained portion of the legal catch is a fishery control which could be set so as not to exceed the OFL if the non-retained losses in the terminal OFL year perform as expected.

OFL-Setting Results

The proxy B_{MSY} used in this analysis was B_{REF} = 178.2 million pounds male mature biomass estimated as the average MMB_{mating} for 1975-80 (CPT, May 2008). We acknowledge that 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). As a result, we believe that this B_{REF} underestimates the capacity of this stock to persist at B_{MSY} and provide maximum sustainable yield to the fisheries.

In May 2008, the CPT requested that an estimate of $F_{35\%}$ using fishery selectivity be presented to the SSC at its June 2008 meeting. Fishery selectivity used for the SSC analysis were those employed in the EA analysis and estimated based on historical fishery performance prior to 1997 closure. The SSC recommended using fishery selectivity and maturity to estimate $F_{35\%}$ as the proxy F_{OFL} and to use the ratio of $F_{35\%}$ to M as an estimate of gamma. We found this recommendation problematic on several grounds and have not adopted it in this OFL-setting analysis. One reason for our decision was that fishery data for the last 3 years reveal that current selectivity in both the directed fishery and the snow crab pot fishery differ profoundly from those employed in the EA analysis. Also, the CPT did not have an opportunity to review our $F_{35\%}$ analysis or the results presented to the SSC in June. To adopt the SSC recommendation in this OFL-setting analysis, fishery selectivity would have to be re-estimated without the benefit of an assessment model. Neither would these results be reviewed by the CPT prior to the September 2008 meeting. We considered it ill-advised to attempt to estimate fishery selectivity ad hoc without improved understanding of the current fisheries as well as discussion and consent by the CPT. Since the EA selectivity pattern no longer applies, its use may provide non-informative or misleading results. The development of a Tanner crab stock assessment model is currently planned in which fishery selectivity will be estimated with the benefit of more data from contemporaneous fisheries.

For this analysis, gamma was set to 1.0. We accounted for discard/bycatch mortalities from the directed and non-directed pot fisheries and the groundfish trawl fisheries. By comparison, the EA simulations did not equivalently account for non-retained losses, thus it's uncertain what scaler of M is appropriate to relate M to full-selection $F_{35\%}$ rates in EA simulations. Further confounding specification of gamma is the fact that the MMB measure 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 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 maintained itself in dynamic equilibrium over any sustained period, nor persisted 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. Notwithstanding the problems noted in estimating current fishery selectivity, this argument relies on theoretical reproductive dynamical considerations in mature male biomass which are violated given the unique reproductive dynamic features of this stock (e.g., male-female size dependencies for successful copulation, male guarding and competition). Since a fundamental precept of precautionary fishery management is that the stock should not 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.

The 2008 Overfishing Limits

For the 2008 Tanner crab fishery, we estimated the Total Catch OFL = 15.273 million pounds (Table 7). Relative to B_{REF} = 178.155 million pounds, the 2008 estimate of MMB at mating (106.746 million pounds) represents B/B_{REF} = 0.599 resulting in and F_{OFL} = 0.128.

Directed and non-directed losses to MMB in 2008 are estimated to be 7.683 and 2.916 million pounds, respectively. After accounting for expected losses to MMB, the projected catch of legal-sized Tanner crab is 5.382 million pounds. The retained part of the catch of legal-sized crab (4,674 million pounds) accounts for expected directed and non-directed losses to LMB by the fisheries. In comparison to the overfishing limit (15.273 million pounds), the retained legal catch would comprise 30.6% of the total male mature biomass losses. A significant component of the Total Catch OFL therefore results from non-targeted losses under current EBS fisheries.

Expected bycatch losses of female Tanner crab from the 2008 ground fish fishery were estimated at 0.732 million pounds. Therefore, total expected male plus female catch in 2008 is 16.369 million pounds. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.093 and 0.129 respectively.

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	2.11	17.00			2.11

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	5.41	0.28	0.61	0.40	6.01	0.68

Table 3. Eastern Bering Sea *Chionoecetes bairdi* total catch losses 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	9.77	2.17	11.95
2007	8.12	0.68	8.80

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, 1965-2008.

	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	170.86	152.30	116.97
1981	158.07	140.90	116.68	77.16	68.78	55.19
1982	113.32	101.01	88.11	55.67	49.62	42.48
1983	65.70	58.56	53.23	36.93	32.92	30.47
1984	45.41	40.48	32.63	31.97	28.49	24.27
1985	26.01	23.19	20.87	24.25	21.62	20.80
1986	35.49	31.64	28.30	17.09	15.23	14.66
1987	63.93	56.99	47.59	32.52	28.99	25.70
1988	139.55	124.39	100.95	78.81	70.25	60.60
1989	231.48	206.34	148.28	185.19	165.07	134.36
1990	240.30	214.20	116.87	248.57	221.57	173.13
1991	255.73	227.95	140.59	193.45	172.44	134.15
1992	246.92	220.09	147.39	230.38	205.35	162.53
1993	144.40	128.71	90.47	113.54	101.20	80.50
1994	95.02	84.70	64.74	84.88	75.66	65.01
1995	71.65	63.87	50.79	55.12	49.13	43.05
1996	58.64	52.27	46.27	50.71	45.20	41.69
1997	25.13	22.40	18.50	18.74	16.70	16.08
1998	25.35	22.60	18.69	12.13	10.81	10.40
1999	43.87	39.11	36.48	11.57	10.32	9.93
2000	39.24	34.98	33.05	27.56	24.56	23.64
2001	43.65	38.91	36.45	35.82	31.93	30.73
2002	44.53	39.70	36.80	38.58	34.39	33.10
2003	61.29	54.63	50.99	40.79	36.35	34.99
2004	65.48	58.36	55.08	29.76	26.53	25.53
2005	104.50	93.15	86.24	62.83	56.01	52.95
2006	158.95	141.68	126.58	80.19	71.48	66.67
2007	185.19	165.07	150.74	58.49	52.13	48.07
2008	143.06	127.52	122.73	64.80	57.76	51.49

Table 6. Eastern Bering Sea *Chionoecetes bairdi* fishery rate of exploitation on male mature biomass (MMB) and legal mature biomass (LMB) at the time of the fishery, 1965-2007. Exploitation rates are based on biomass; μ on MMB uses total catch losses while μ on LMB uses total retained legal catch.

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	0.05	0.04

Table 7. Catch overfishing limits, stock and fishery metrics for the 2008 Eastern Bering Sea *Chionoecetes bairdi* fishery. (μ on LMB is total legal retained catch/LMB at the time of the fishery, μ on MMB is Total Catch OFL/MMB at the time of the fishery).

2008 Eastern Bering Sea *Chionoecetes bairdi*
Catch OFL, Stock and Fishery Metrics

Metrics (10^6lb):	
B_{REF}:	178.155
MMB @ Mating:	106.746
B/B_{REF}:	0.599
F_{OFL}:	0.128
Catch Components (10^6lb):	
Total Catch OFL:	15.273
Directed Discard Losses MMB:	7.683
Non-Directed Discard Losses MMB:	2.916
Projected Legal Catch:	5.382
Directed Discard Losses LMB:	0.102
Non-Directed Discard Losses LMB:	0.606
Retained Part of Legal Catch:	4.674
Directed Discard Losses ♀:	0.364
Groundfish Bycatch Losses ♀:	0.732
Total Male + Female Catch:	16.369
Rates:	
μ on LMB @ Fishery:	0.093
μ on MMB @ Fishery:	0.120

B_{REF}=mean 1975-80 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

Table 9. Data used to estimate discard and bycatch losses projected in the terminal 2008/09 Bairdi OFL fishery: (a) 2007/08 Tanner crab fishery performance, (b) 2006/07 and 2007/08 Tanner crab discards in the EBS pot fisheries and snow crab retained catch, and (c) 2003-07 EBS groundfish trawl fishery Tanner crab bycatch.

(a)

2007/08 Observer Fishery Data
EBS Tanner Crab Directed Fishery

		LB	Ratio
Discard"			
	S.Legal ♂:	6,842,396	3.24799
	Legal ♂:	82,896	0.03935
	All ♀:	328,283	0.15583
Retained:		2,106,655	1.0
	Total:	9,360,230	

(b)

Tanner Crab Non-Directed Pot Fishery Bycatch
(Combined Opilio + RKC Pot Fisheries)

Year	Opilio Retained (10^6 LB)	Bairdi Discard (10^6 LB)	Ratio
2006/07	37.00	3.19	0.086103
2007/08	63.03	3.89	0.061657
2008/09	49.00 *		
		Average:	0.073880
Projected 2008/09 Bairdi Discard (10^6 LB):			3.620116

* Projected 2008/09 Opilio retained catch OFL

(c)

Trawl Fishery Tanner Crab Bycatch
(Male + Female Combined)

Year		Bycatch (10^6 LB)
2003		2.7151
2004		1.9751
2005		2.1226
2006		3.4113
2007		1.2594
	Average:	2.2967

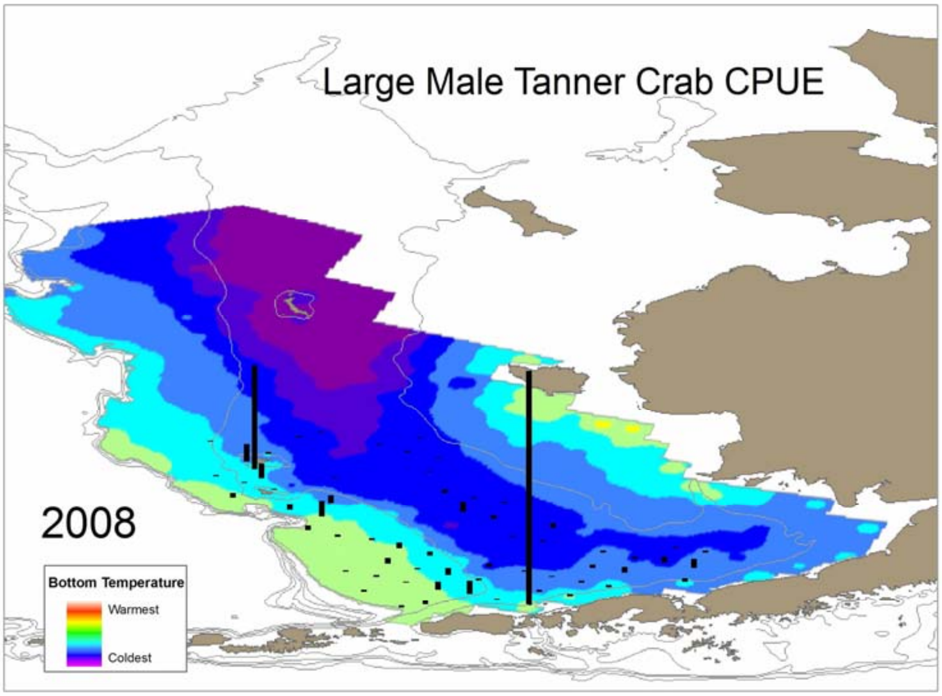
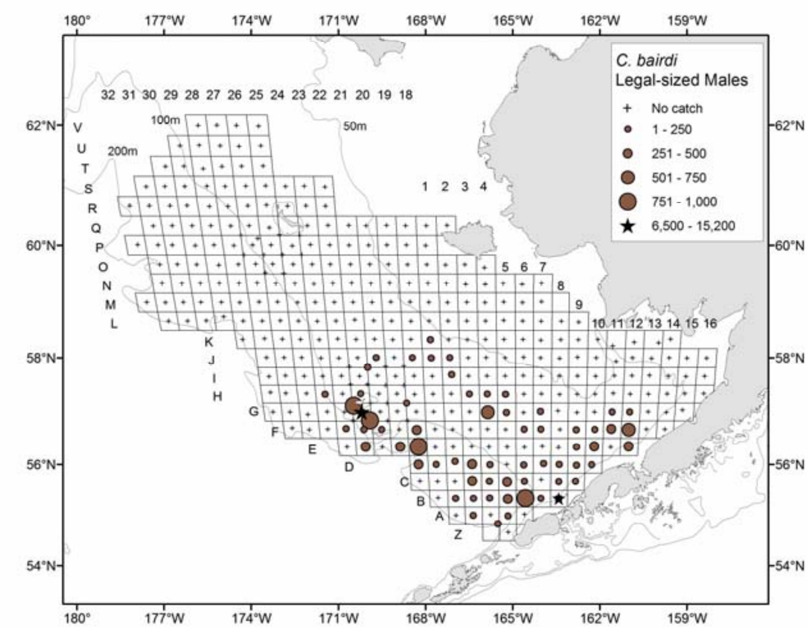


Figure 1. Distribution and abundance of large male Tanner crab with bottom temperature from the summer 2008 NMFS EBS trawl survey.



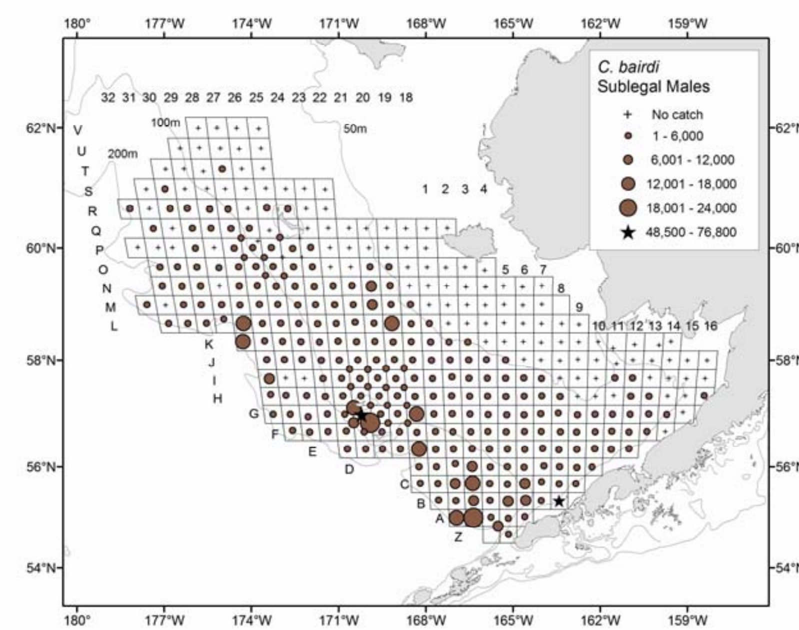


Figure 2. Distribution and abundance of legal (>= 138 mm cw) and sublegal (< 138 mm cw) male Tanner crab in the summer 2008 NMFS EBS trawl survey.

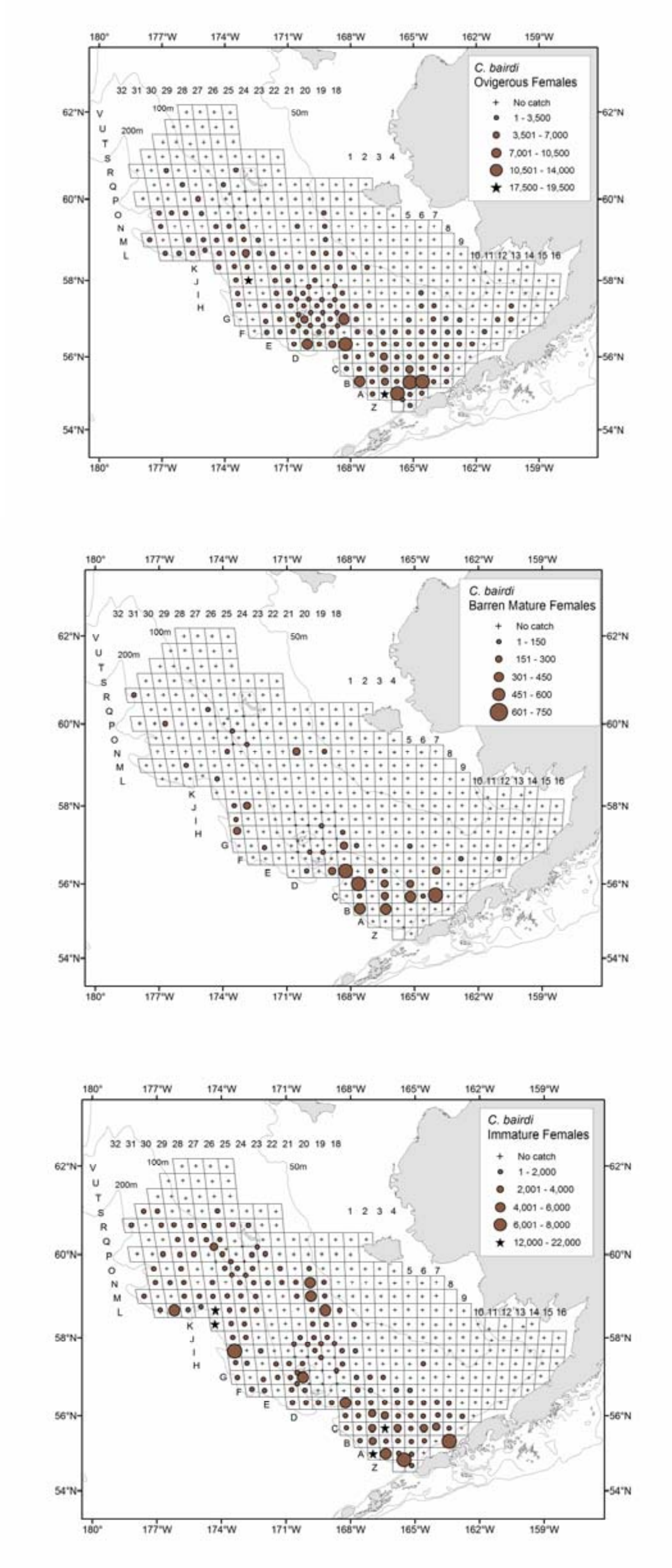


Figure 3. Distribution and abundance of ovigerous, barren mature, and immature female Tanner crab in the summer 2008 NMFS EBS trawl survey.

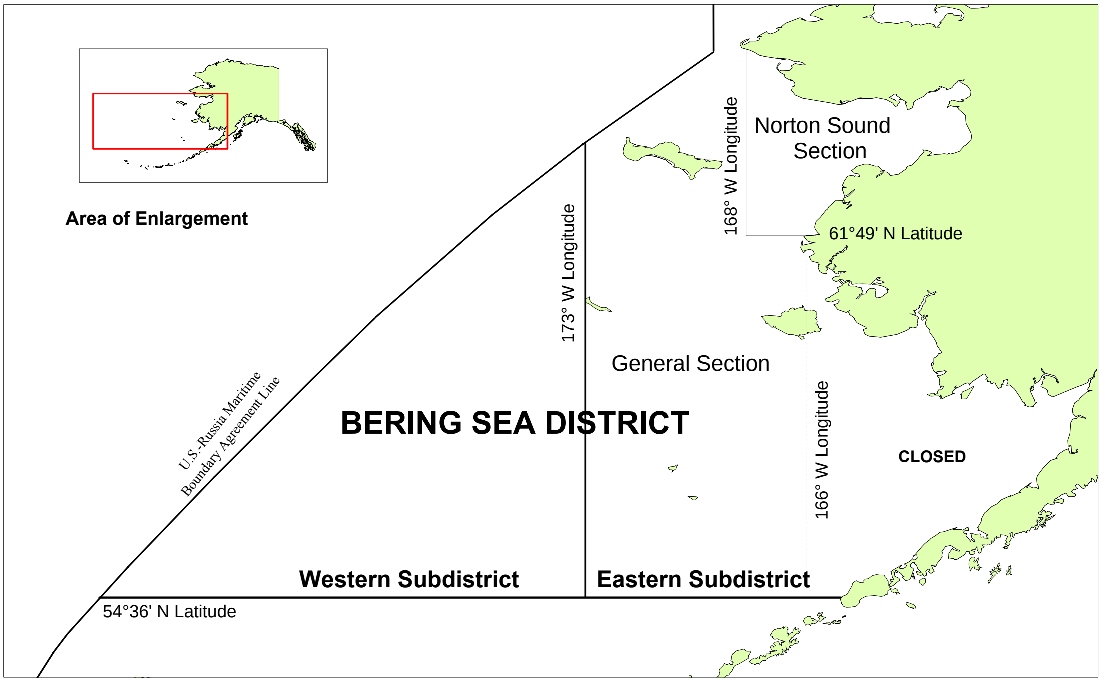
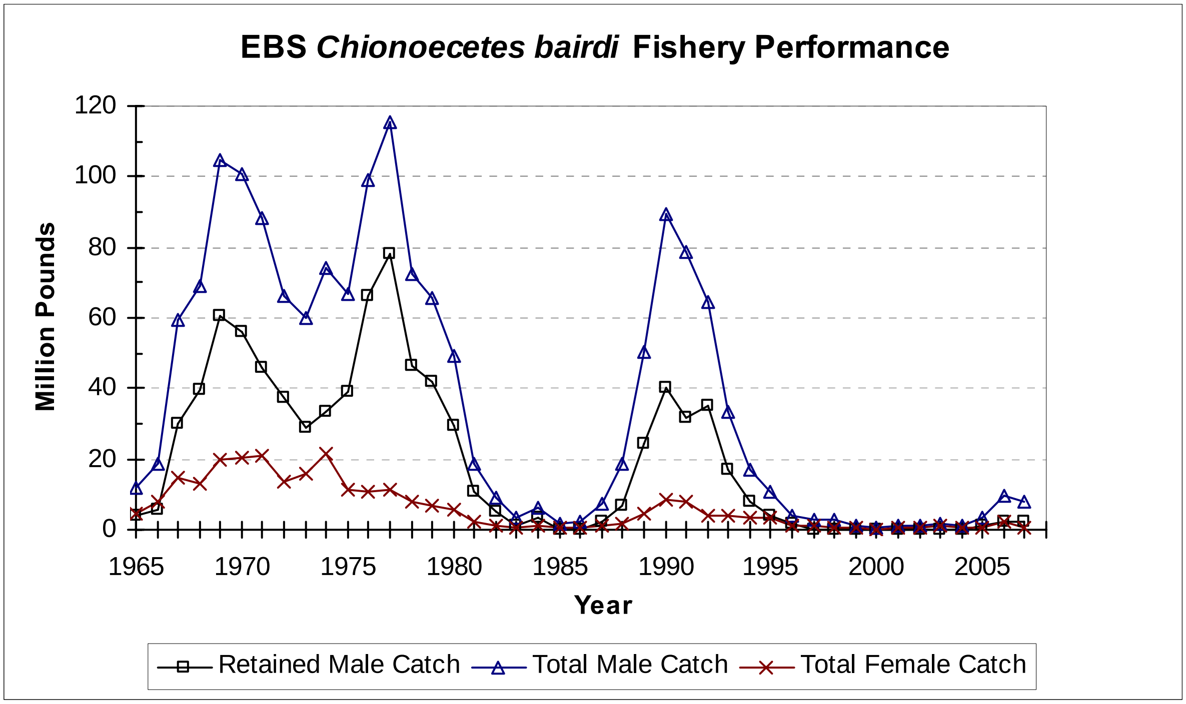


Figure 4. Eastern Bering Sea District of Tanner crab Registration Area J including subdistricts and sections (From Bowers et al. 2008).

(a)



(b)

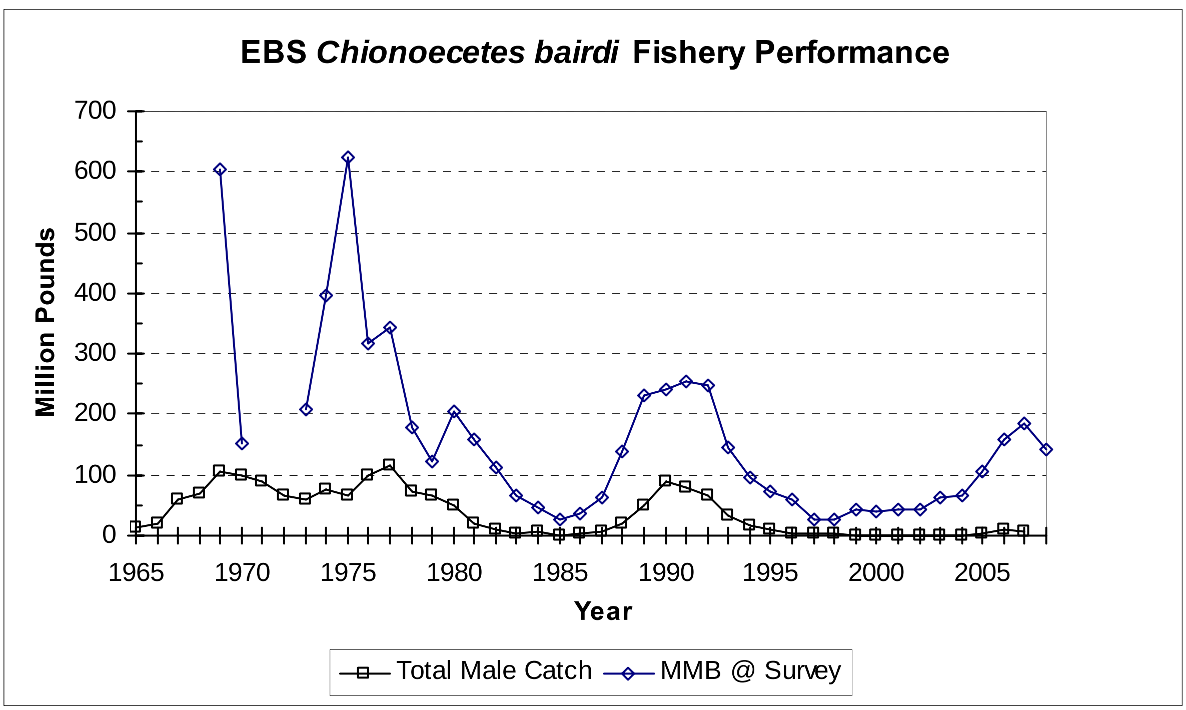


Figure 5. Eastern Bering Sea *Chionoecetes bairdi* retained male catch, total (retained + discard/bycatch) male catch and total female catch (a), and total male catch vs male mature biomass at the time of the survey (b), 1965-2008.

(a)

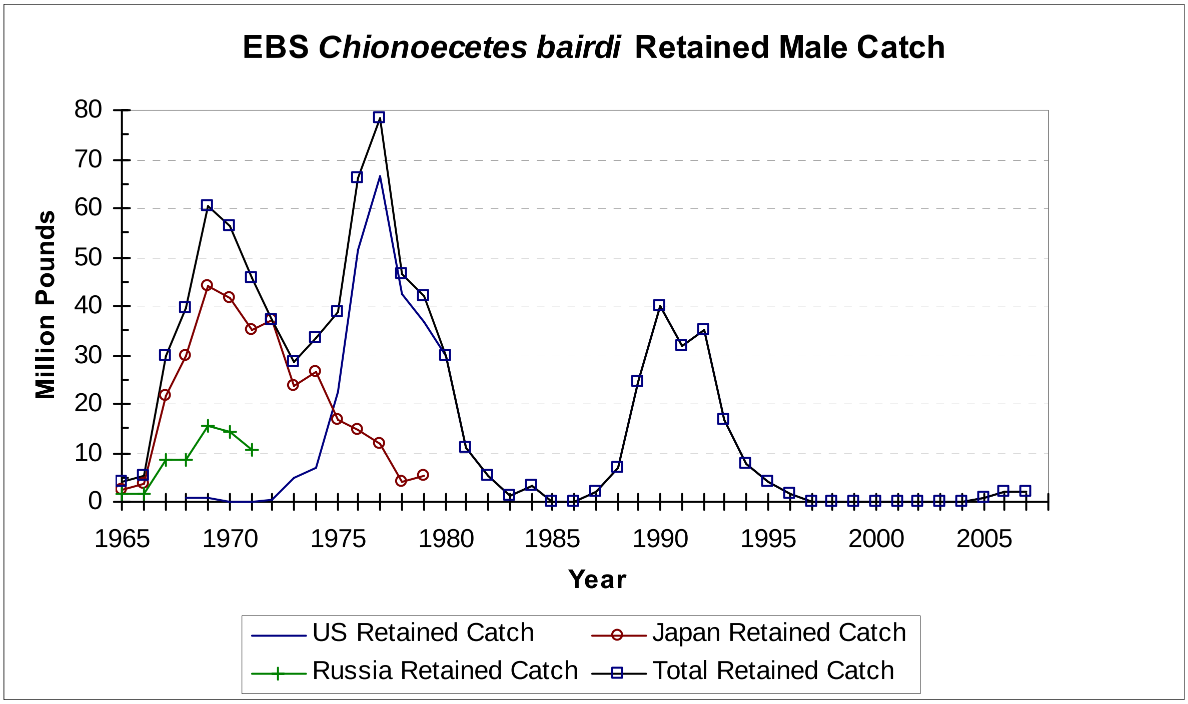


Figure 6. Eastern Bering Sea *Chionoecetes bairdi* retained male catch in the directed United States, Russian and Japanese fisheries, 1965-2007.

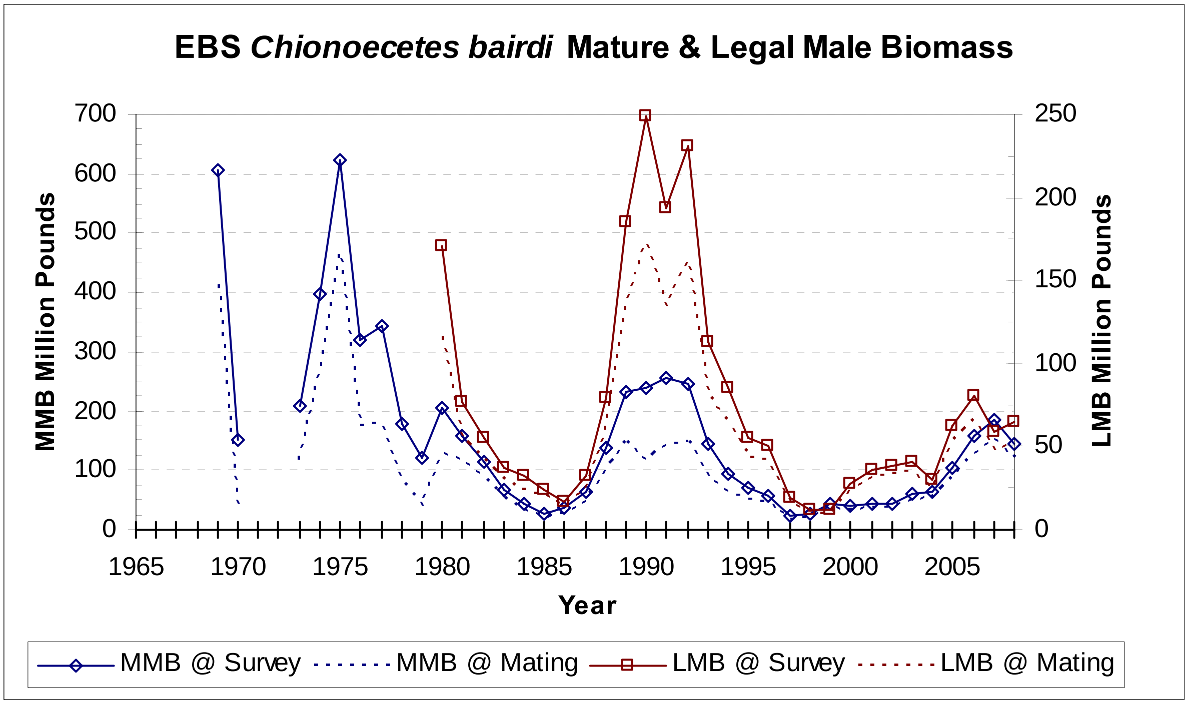
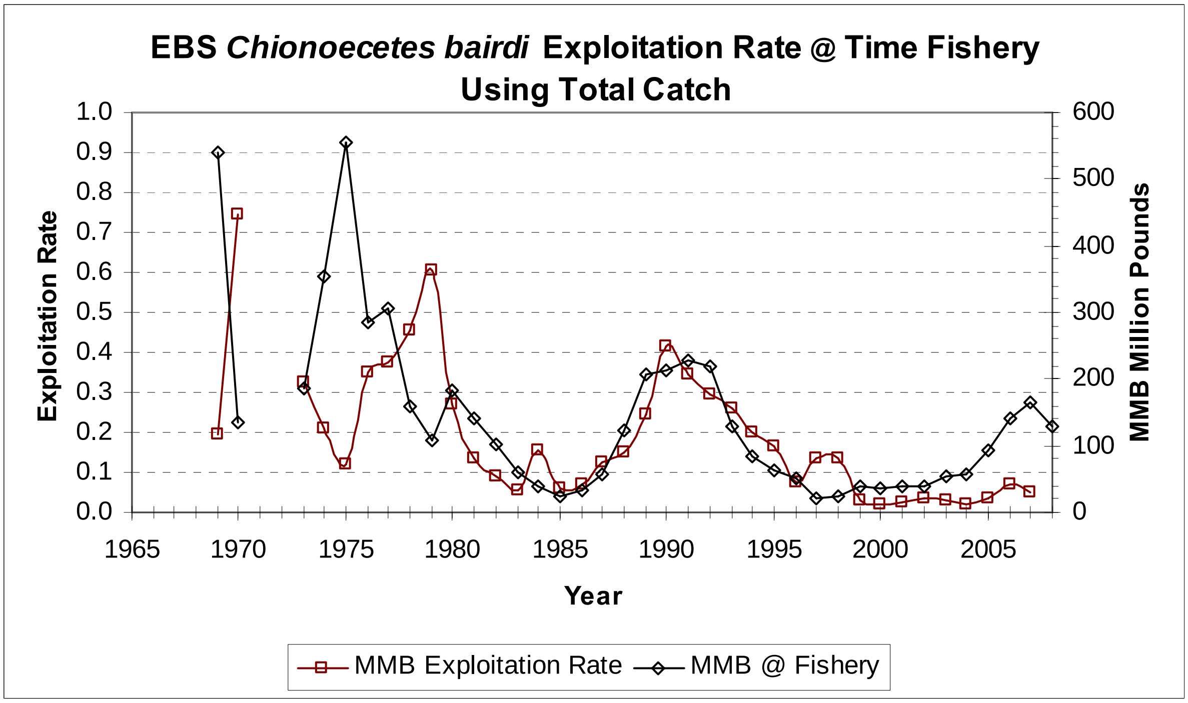


Figure 7. Eastern Bering Sea *Chionoecetes bairdi* mature and legal male biomass at time of the survey and subsequent mating, 1965-2008.

(a)



(b)

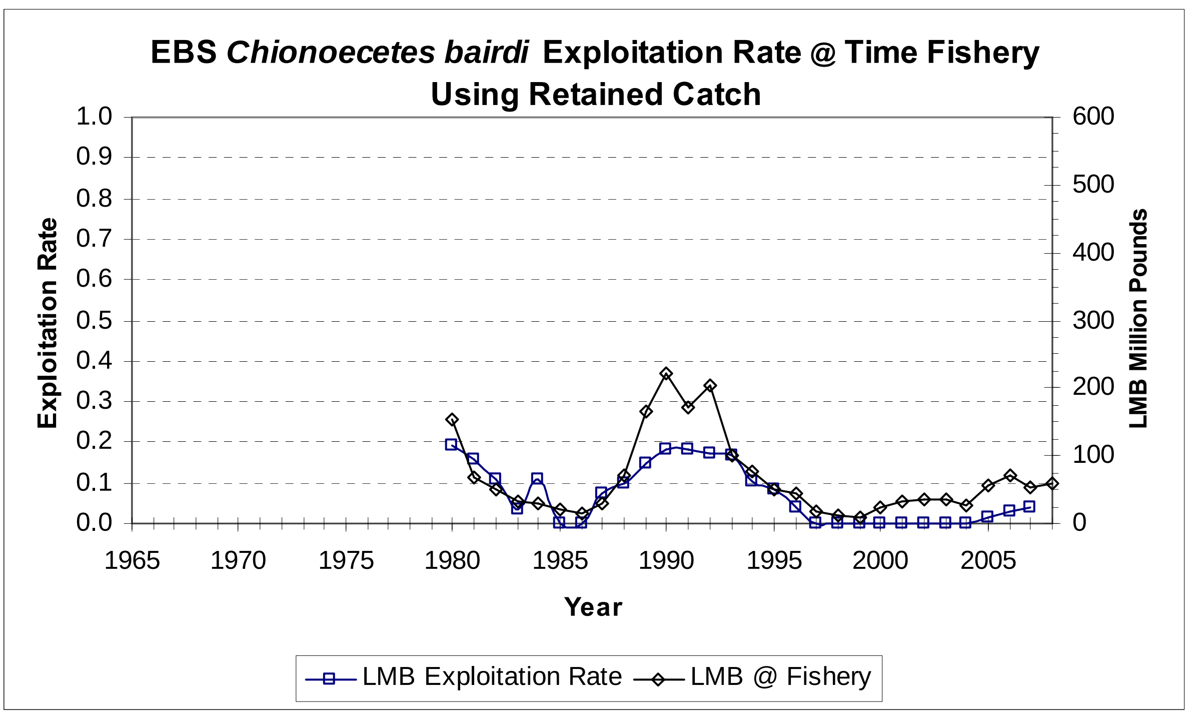


Figure 8. Eastern Bering Sea *Chionoecetes bairdi* exploitation rate on mature (a) and legal (b) male biomass at the time of the fishery with associated male biomass metric, 1965-2008.

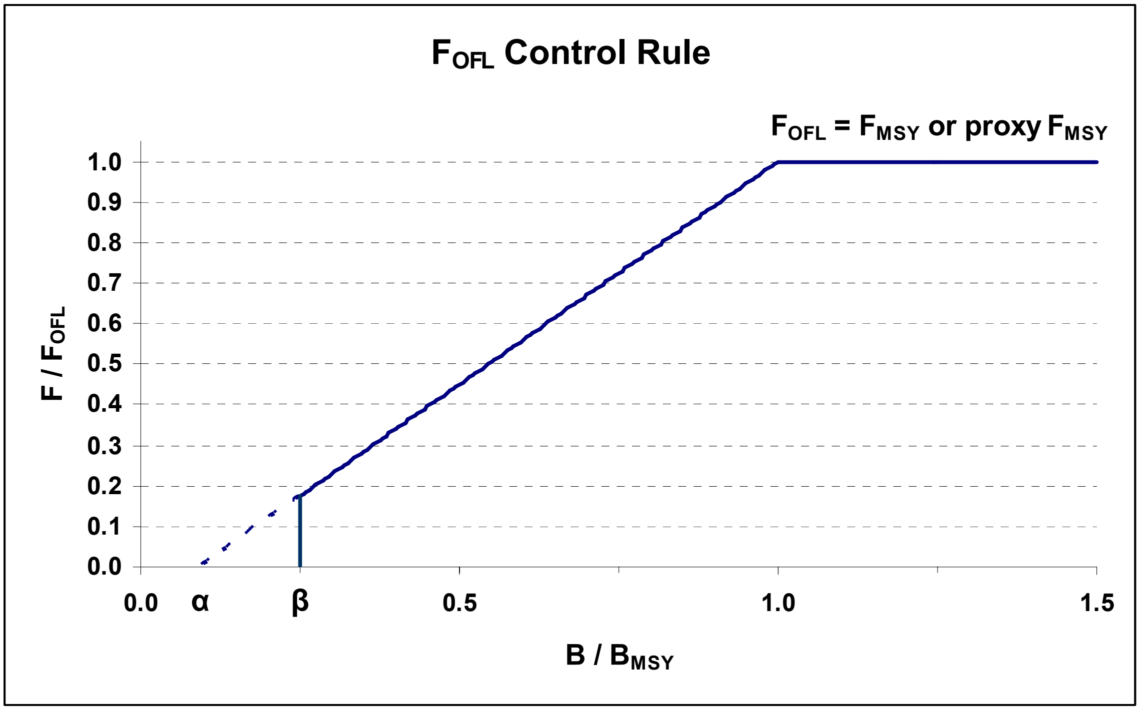


Figure 9. F_{OFL} Control Rule for Tier-4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set 0 below β.

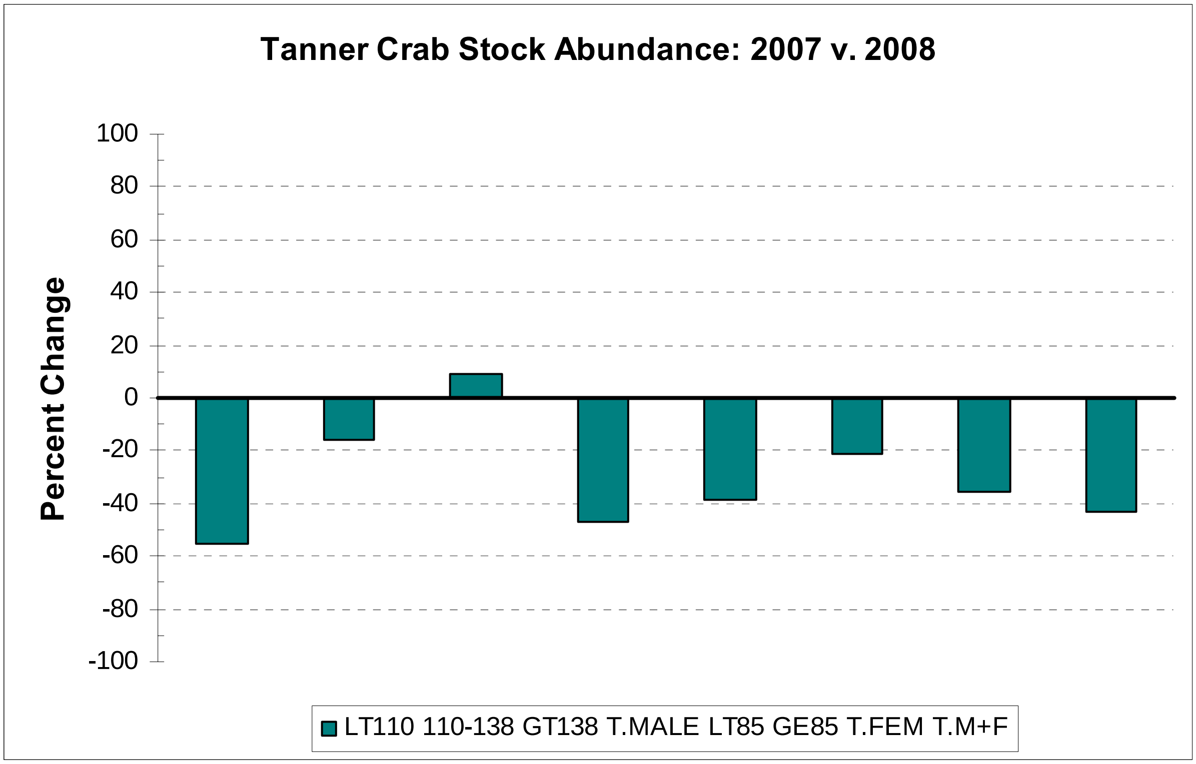
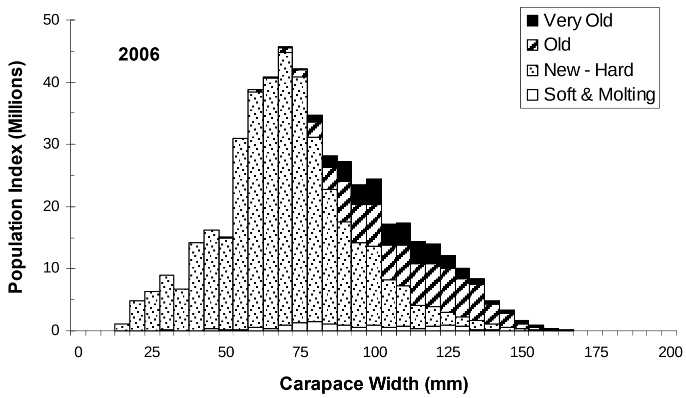
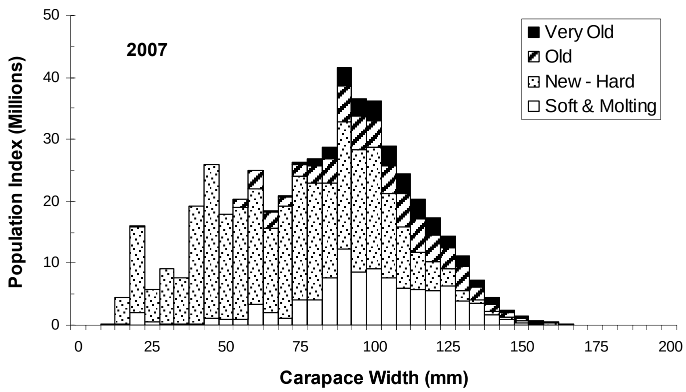


Figure 10. Percent change in Tanner crab stock abundance between 2007 and 2008 for males (< 110 mm cw, 110-137 mm cw, >= 138 mm cw and total males), females (<85 mm cw, >=85 mm cw and total females), and for total males + females combined.





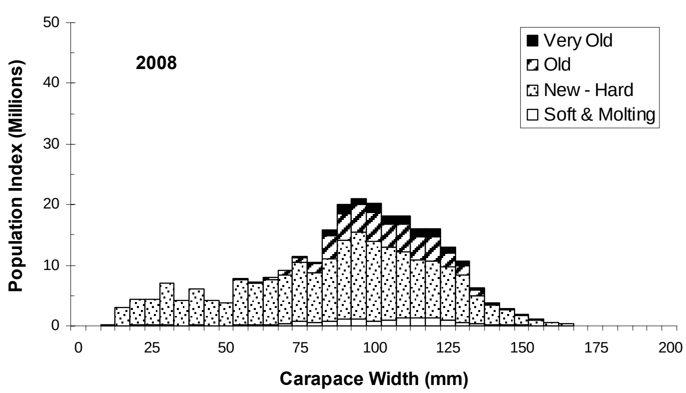


Figure 11. Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006-2008.

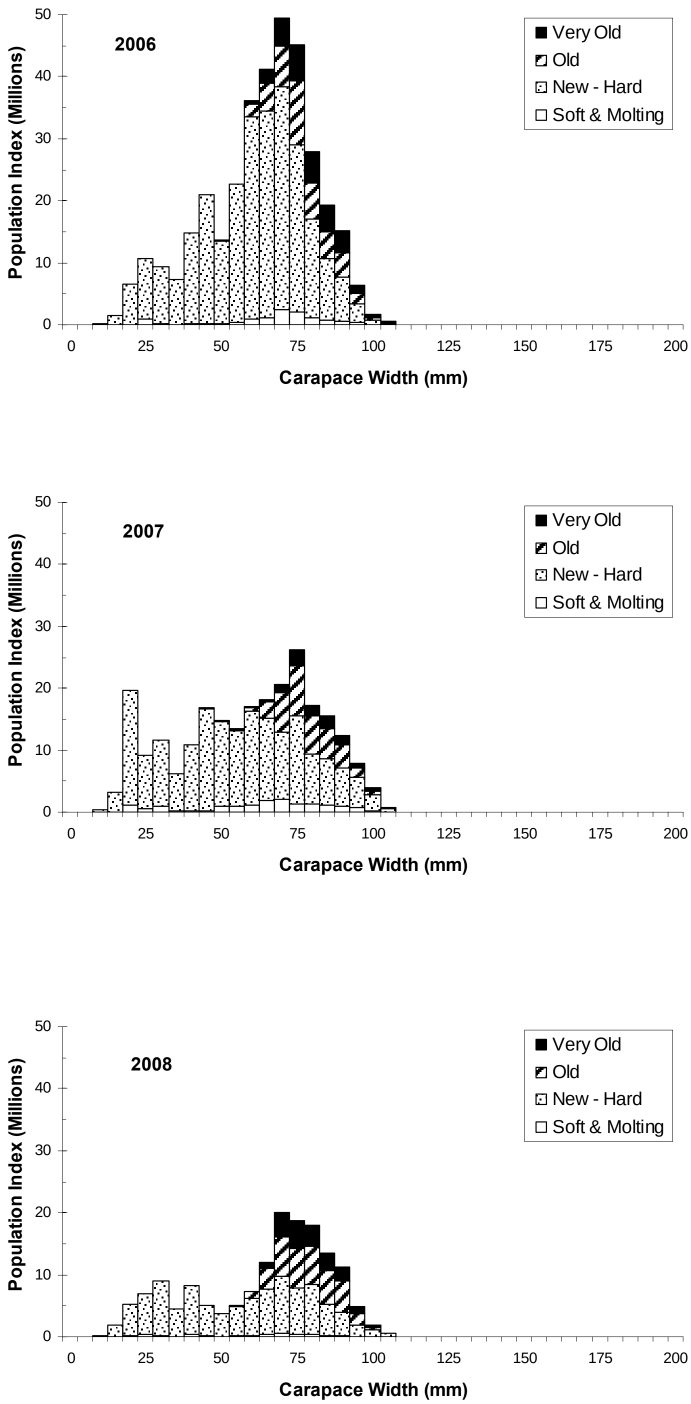


Figure 12. Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006-2008.