# 2011 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

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**Status of the 2010/11 Stock**

Tanner crab MMB in 2009/10 declined substantially from previous years and fell below the minimum stock size threshold at survey time (MSST=0.5 $B_{MSY\ Proxy}$) (Rugolo and Turnock 2010). MMB at the time of the 2010 survey declined further by 8.3% relative to the 2009 survey. Under the plan, MMB estimated at the time of mating (mid-February) is gauged against the MSST to determine its status relative to the overfished criterion. This accounts for losses due to natural morality (M) from the survey to mating and losses due to directed and non-directed fishing. For the status determination, $B_{MSY\ Proxy}$=83.80 thousand metric tonnes (t) and the overfished status criterion, MSST, is 41.90 thousand t. After accounting for stock losses from M and those in the 2009/10 fisheries, the 2010 MMB at the time of mating was 28.44 thousand t. This represented a ratio of 0.34 relative to $B_{MSY\ Proxy}$ which is below the limit that defines an overfished stock. The 2009/10 Tanner crab stock was determined to be overfished by NOAA Fisheries based on the 2010 stock assessment (Rugolo and Turnock 2010).

For 2010/11, the State of Alaska closed directed commercial fishing for Tanner crab east and west of $166^0$ W longitude (Pengilly 2010). The SOA's harvest strategy level of opening the Bering Sea District to fishing is 21 million pounds (9.5 thousand t) of mature female biomass in the Eastern Subdistrict at the time of the survey. Mature female biomass relative to this threshold is defined as the estimated biomass of females greater than 79 mm carapace width (cw). The 2010 survey estimate of total mature female Tanner crab biomass was 15.1 million pounds (6.8 thousand t).

For the current 2010/11 stock status determination, losses from the time of the 2010 survey to mating in 2011, plus losses from non-directed fishing are considered. There stock losses to directed fishing in 2010/11 due to the closure. After accounting for losses from M and the 2010/11 non-directed pot and groundfish fisheries, the 2011 MMB at the time of mating was 26.73 thousand t (-6.4% relative to 2010). This represents a ratio of 0.32 relative to $B_{MSY\ Proxy}$ which is below the limit that defines an overfished stock. There is no change in the 2010/11 stock relative to the overfished determination made in 2010.

The management plan stock data table requested by the CPT is shown in Table A-1 of Appendix A.

**Executive Summary**

In 2011, Tanner crab MMB at the time of the survey was estimated at 41.8 thousand t representing a 23.2% increase relative to 2010. Mature male abundance rose 34.2% relative to 2010 and legal males were sparsely and patchily distributed throughout the survey range with regions of highest abundance in southwestern Bristol Bay and the Pribilof Islands. The total abundance index for legal males increased 41.5% to 13.7 million crabs between 2010 and 2011owing largely to a high-density station in the area of the Pribilof Islands and the elimination of the 'hot-spot' re-sampling protocol in 2011. As a result, the 2011 survey male abundance and biomass estimates may be biased high relative to previous years that employed this re-sampling protocol. Legal males were distributed 37.1% (5.1 million crabs) east and 62.9% (8.6 million crabs) west of $166^0$ W longitude compared to 56.1% (east) and 43.9% (west) in 2010 (Rugolo and Turnock 2010). The 2011 abundance index for pre-recruit male crabs (110-137 mm cw) was relatively unchanged (+0.1%) relative to 2010, and that for small males (<110 mm cw) increased 49.6% relative to 2010. Total male abundance increased 44.3% between 2010 and 2011 influenced by the increase in small and in legal-sized males. MMB in 2011 increased 23.2% relative to 2010. Compared to that estimated at the time of the 2010 survey, male recruit biomass (<110 mm cw) increased 47.8%, pre-recruit biomass (110-137 mm cw) decreased 0.9%, legal male biomass increased 44.2% and total male biomass increased 30.1%. Total male biomass in 2011 was comprised of 76.6% immature, 9.8% new shell mature and 13.5% old shell mature males.

Comparison of the male size frequency distributions between 2006 and 2011 revealed a decline in male abundance above 70 mm cw between 2006 and 2010, and relatively increasing percentage of old shell crabs in the mature male stock (Figures 10 a-f). The male size frequency distribution in 2011 (Figure 10 f) reveals an apparent increase in pre-recruit abundance between 25-70 mm cw. The recruit mode (20-40mm cw) seen in 2009 (Figure 10 d) grew to 30-50 mm cw in 2010 (Figure 10 e) and to 55-65 mm cw in 2011 (Figure 10 f). The increase in male abundance in 2011 if real and not biased high due to the change in sampling design, particularly for recruit-sized crab (<110 mm cw), is an encouraging sign. The relatively high percentage of old and very old shell males in the mature stock, however, may remain a concern regarding future reproductive potential of this stock.

Large female (>=85 mm cw) Tanner crab increased 8.7% in abundance in 2011 relative to 2010. Total female biomass in 2011 was comprised of 79.5% immature, 13.9% new shell mature and 6.6% old shell mature females. Among all female Tanner crab in 2011, 6.6% were collectively old shell and 91.1% new-hard shell. Small females (<85 mm cw) increased by 44.2% relative to 2010. Total 2011 female abundance increased 42.4% largely influenced by the increase in small females <85 mm cw. Total survey abundance of males and females combined increased 9.3% over that in 2010 driven by the increase in both small male and small female crabs. The survey length frequency distributions of female Tanner crab from 2006-2011 revealed consistently declining abundance across the size modes and the general failure of modes of abundance to persist inter-annually (Figures 11 a-e). The prominent length mode between 65-75 mm cw seen in 2006 did not persist in expected levels of abundance in 2007 through 2010. The moderate mode of female abundance above 60 mm cw seen in 2009 (Figure 11 d), which was dominated by old and very old shell females, declined substantially in 2010 (Figure 11 e). A modest mode of new shell recruits seen in 2009 at 25-30 mm cw persists in 2010 at 35-50 mm cw. A relatively strong recruit mode (35-50 mm cw) is apparent in the 2010 survey data (Figure 11 e) which grew to 55-70 mm cw in 2011 (Figure 11 f). The female size frequency distribution in 2011 (Figure 11 f) reveals an apparent strong pre-recruit abundance mode between 30-50 mm cw. The increase in pre-recruit sized female abundance in 2011 is an encouraging in terms of future reproductive potential.

Tanner crab is managed as a Tier-4 stock. The proxy $B_{MSY}$ for OFL-setting is the reference biomass ($B_{MSY\ Proxy}$)=83.33 thousand t of MMB at the time of mating estimated as the average survey male mature biomass at mating from 1974-1980 inclusive. The bias-corrected proxy $B_{MSY}$ mean 1974-1980 MMB at mating is 93.24 thousand t. For Tier-4 stocks, the $F_{OFL}$ is derived using an $F_{OFL}$ Control Rule based on the relationship of current male mature biomass to the $B_{MSY\ Proxy}$ where, $F_{OFL}=\gamma M$**.** 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. Amendment 24 also cautions 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 ($F_{OFL}$) for Tier-4 stocks is specified in terms of a Total Catch OFL that includes all stock losses (retained catch, discard and bycatch mortalities) for males and females combined by the directed and all non-directed fisheries.

Using the bias-corrected 1974-1980 proxy $B_{MSY}$=93.24 thousand t, the estimated the 2011/12 Total Catch OFL=1,367.83 t for males and females combined. Total projected losses to MMB are 1,248.86 t. Conditioned on the 2011/12 snow crab retained catch OFL=24.61 thousand t, directed and non-directed discard losses to MMB in 2011/12 are estimated to be 117.61 t and 910.73 t, respectively. The retained part of the catch OFL of legal-sized crabs is 220.52 t. At a 2011/12 snow crab retained catch OFL= 35.88 thousand t, the 2011/12 retained Tanner crab catch OFL is zero. At values of 2011/12 snow crab retained catch OFL > 35.88 thousand t, the 2011/12 Total Catch OFL would be exceeded and overfishing occur even if the directed fishery was closed. Assuming that the 2011/12 snow crab retained catch OFL≤35.88 thousand t, the projected 2011/12 estimate of MMB at the time of mating is 26.27 thousand t which yields a $MMB_{2011/12}/B_{MSY\ Proxy}$=0.28 and the 2011/12 $F_{OFL}$=0.05. Expected female discard losses in the 2011/12 groundfish fishery and the directed pot fishery was estimated at 118.97 t. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.06 and 0.04 respectively.

Using the non bias-corrected 1974-1980 proxy $B_{MSY}$=83.33 thousand t, the estimated the 2011/12 Total Catch OFL=1,578.48 t for males and females combined. Total projected losses to MMB are 1,456.33 t. Conditioned on the 2011/12 snow crab retained catch OFL=24.61 thousand t, directed and non-directed discard losses to MMB in 2011/12 are estimated to be 189.75 t and 910.77 t, respectively. The retained part of the catch OFL of legal-sized crabs is 355.80 t. At a value of 2011/12 snow crab retained catch OFL= 42.77 thousand t, the 2011/12 retained Tanner crab catch OFL is zero. At values of 2011/12 snow crab retained catch OFL > 42.77 thousand t, the 2011/12 Total Catch OFL would be exceeded and overfishing occur even if the directed fishery was closed. Assuming that the 2011/12 snow crab retained catch OFL≤42.77 thousand t, the projected 2011/12 estimate of MMB at the time of mating is 26.06 thousand t which yields a $MMB_{2011/12}/B_{MSY\ Proxy}$=0.31 and the 2011/12 $F_{OFL}$=0.05. Expected female discard losses in the 2011/12 groundfish fishery and the directed pot fishery was estimated at 122.15 t. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.08 and 0.05 respectively.

Status and catch specifications (1000 t) for EBS Tanner crab.

| Year | MSST | Biomass (MMB) | OFL | TAC [E+W] | Retained Catch | Total Catch |
|---|---|---|---|---|---|---|
| 2005/06[1/] | | 39.28 | | 0.73 | 0.43 | 1.61 |
| 2006/07[1/] | | 59.18 | | 1.35 | 0.96 | 3.15 |
| 2007/08[1/] | | 68.76 | | 2.55 | 0.96 | 3.63 |
| 2008/09[1/] | 43.04 | 53.63 | 7.04 | 1.95 | 0.88 | 2.25 |
| 2009/10 | 41.90 | 28.44 | 2.27 | 0.61 | 0.60 | 1.69 |
| 2010/11 | 41.90 | 26.73 | 1.45 | 0.0 | 0.0 | 0.87 |
| 2011/12 | 41.67[2/] | 26.06[3/] | 1.46[4/] | | | |

Notes:
1/ Biomass and threshold definitions based on survey estimates derived using fixed 50 ft net width area-swept calculations.
2/ Non bias-corrected mean 1974-1980 MMB at mating using revised survey biomass estimates
3/ Projected 2011/12 MMB at mating after extraction of the estimated total catch OFL using non bias-corrected proxy $B_{MSY}$
4/ Total catch OFL for 2011/12 fishery based non bias-corrected proxy $B_{MSY}$

In 2010/11, Tanner crab MMB was below the MSST at the time of the 2010 survey, below MSST at the time of the 2010/11 fishery, and below MSST at the time of mating in mid-February 2011. Overfishing did not occur during the 2010/11 fishing year as total catch losses (0.87 thousand t) did not exceed the total catch OFL (1.45 thousand t). The 2010/11 MMB at the time of mating represented a ratio of 0.32

relative to $B_{MSY\ Proxy}$. The 2010/11 Tanner crab stock is determined to be overfished. In 2011 at the time of the survey, Tanner crab MMB increased 23.2% relative to 2010. Under a zero retained catch harvest strategy in 2011/12, there will be no change in the 2011/12 stock status relative to the overfished determination reached in September 2010.

## *A. Summary of Major Changes*

### *1. Management of Fishery:*

In March 2011, the Alaska Board of Fisheries approved a new minimum size limit strategy for Tanner crab that will be in effect for the 2011/12 fishery. The previous minimum legal size limit was 5.5" (138 mm cw) throughout the Eastern Subdistrict. The new regulations established different minimum size limits east and west of $166^0$ W longitude. That for the fishery to the east will be 4.8" (122 mm cw), and that to the west will be 4.4" (112 mm cw). The industry may self-impose retention of crab above 5.5" (138 mm cw) and 5" (127 mm cw) east and west of $166^0$ W longitude, respectively.

### 2. *Input Data*:

This assessment examined area-swept biomass estimates from the NMFS bottom trawl survey for 1969-1975. Data for years 1969-1973 are not used in the OFL analysis. Previous survey data for 1969, 1970 and 1972-1975 for males and 1974-1975 for females were extracted form historical International Pacific Fisheries Commission (INPFC) documents.

### *3. Assessment Methodology:*

There are no major changes to assessment methodology in this 2011 SAFE relative to the 2010 SAFE (Rugolo and Turnock 2010) in determining stock status or estimating the $F_{OFL}$ and the catch components comprising the Total Catch OFL. Two additional approaches are added to this assessment to address management strategy changes and MSA requirements:

1. To address the new size limit strategies in effect for the 2011/12 fishery, we show an example of a method to derive guideline harvest levels that apportions the retained catch component of the OFL to the areas east and west of $166^0$ W longitude (*see* Section F).
2. To address the requirement of the MSA to establish ACLs based on an ABC control rule that accounts for scientific uncertainty in the OFL, we develop a Tier-4 approach to derive an ACL=ABC for the 2011/12 fishery (*see* Section G).

## *B. Responses to SSC and CPT Comments*

### *1. SSC Comments:*

**<u>June 2011 Meeting</u>:**

In their review of the 2011 crab draft SAFE report, the SSC made the following general comments on eastern Bering Sea Tanner crab:

- *Authors Rugolo and Turnock developed a draft assessment in which they responded to changes suggested by the CPT and SSC in 2010, and to recommendations of the Crab Workshop (February 2011) and the SSC in April 2011. The CPT was encouraged by the changes and felt progress was being made, although the model is not yet ready for use in the stock assessment. The strategy is to continue improvements and evaluate it for assessment purposes in May 2012. Following a recommendation from the Crab Workshop, years 1969 through 1974 were not used for data quality reasons. The period 1974 through 1980 is now the period used for determining reference biomass; given the shortness of this period, the SSC recommends strongly that this time period be evaluated as intended by the authors.*
- *The main issues that have arisen in past reviews were discussed:*

  - *Hybrids: previous reviews were concerned that misidentification of hybrids might have degraded data quality. However only 1 hybrid has been seen in the survey in the last 8 years of legal Tanner size. The authors did not think this is a big issue in recent years.*
  - *Early bycatch data in groundfish fishery. Specifically, why is bycatch estimated to be so high in 1973/74 and 1974/75. Concerns were raised about mis-identification of snow crabs in previous SSC comments. The authors are examining this issue.*
  - *Patterns in survey length frequency. See model scenarios below.*
  - *Lack of fit to survey biomass between 1983 and 1987. See model scenarios below.*
- *The following model scenarios were decided at the CPT meeting:*
  - *Estimate survey catchability, Q, to see if this improves survey biomass fit in mid 1980s.*
  - *Include the underbag data.*
  - *Estimate growth and natural mortality with priors (especially important since growth data is borrowed from Kodiak).*
  - *Try different selectivity periods based on fishery changes.*
  - *Try dynamic initial biomass estimation.*
- *The SSC agrees with this plan of action.*
- *The CPT would wants to use the Tanner model for population projections despite its lack of approval for assessment. The SSC urges caution in proceeding in this direction. It's more appropriate that a model is accepted for assessment and then used for the projection. The CPT requested the authors to go ahead with the rebuilding model for evaluation in September 2011 if it can produce plausible results. Rebuilding scenarios would include no catch, bycatch only, different percentages of $F_{35\%}$, and the SOA harvest strategy. Recruitment scenarios could include random, a spawner-recruit relationship (SRR) model, a SRR with autocorrelation, an SRR with periodic behavior, and others. The SSC will review these scenarios and the performance of the model in September, 2011.*

These SSC comments and recommendations pertain to the Tanner crab stock assessment model (TCSAM) rather than to this Tier-4 assessment and 2011 SAFE report. The authors have addressed these comments in the separate TCSAM report that will be presented to the CPT and SSC in September 2011. The authors agree with and have addressed the SSC recommendations pertaining to the model.

The TCSAM has been extensively revised since the May 2011 CPT meeting. The authors formulated several model configurations to show the effects of principal changes to the model, and recommend a *Base Model* that attends to virtually all of the recommendations of the Crab Workshop, the SSC and plan team. The model is significantly improved over earlier intermediate versions seen by the Crab Workshop and SSC in April 2011. In the author's view, the *Base Model* represents the best available science and, while not perfect, a level of performance in modeling stock and fishery dynamics that may be acceptable to status of stock determination, OFL-setting and projection analysis. The authors will present the model to the CPT and SSC in September 2011 for review. Approval of the model for assessment will be made at the May 2012 CPT and June 2012 SSC meeting under the Council process. If it's approved, the model will apply to OFL-setting and stock status determination in the 2012/13 assessment cycle.

**October 2010 Meeting:**
In their review of the 2010 SAFE reports, the SSC made the following general comments on eastern Bering Sea Tanner crab:

- *The authors were responsive to SSC comments from June 2010. Lacking an assessment model, the authors continue to base stock status determination on results from the annual summer trawl survey. This year, the revised survey estimates were corrected based on survey net width for the first time and included the 2010 summer survey. The latest results confirm that* *estimated Tanner crab abundance has fallen below the MSST, which will require a rebuilding plan to be developed by October 1, 2012. The SSC noted a sharp one-year decline in the estimated abundance of mature females. Here, and in similar instances, the SSC would like the authors to report whether such declines are statistically significant.*

- *A stock assessment model is under development, but not yet ready for review. It's imperative that the model be completed for use as a projection model in the rebuilding analysis. A workshop on crab model development, held in February 2011 will be helpful in this regard. As noted in the June 2010 SSC report, the SSC would like the authors to develop a model capable of handling two different minimum size limits in the eastern and western areas, because the Alaska Board of Fisheries may take such an action at their next meeting on BSAI crabs. Also, the SSC looks forward to a model that considers recent results on gear selectivity.*
- *As indicated in the SSC's June 2010 report, the SSC concurs with the CPT that the years used for status determination should be investigated with respect to potential changes in productivity, and a rationale provided for the selected choice. In addition, the issue of Tanner/snow crab hybrids should be examined. Apparently, the hybrids are allocated to one species or the other based on eye color and mouth shape in the landings, but are identified as hybrids in the surveys and not counted toward the survey estimates for Tanner and snow crab. While in practice this could be a conservative approach, it would be useful to know how the current practice affects species-specific catches relative to the specified harvest strategy and whether some species-specific accounting needs to be better reconciled between stock assessments and catch reporting.*

The Tanner crab stock is currently managed under Tier-4 designation using trawl survey biomass estimates to gauge stock status. The Tanner crab stock was determined to be overfished based on the final 2010 stock assessment (Rugolo and Turnock 2010).

A stock assessment model for Tanner crab is in development. Results on the performance of the model were presented to the Crab Modeling Workshop in February 2011, to the SSC in March 2011 and to the CPT in May 2011. The Workshop reported that, "As currently formulated, the model is not sufficient for use in rebuilding analysis." The SSC reported in March 2011 that, while improvements to the model following the Workshop "…resulted in noted improvements in model fits, much work remains to be done and the current model is not yet ready for use in stock assessment or stock rebuilding analysis." We agree with those conclusions. The assessment model has been further developed since the May 2011 CPT meeting and will be presented to the CPT and SSC in September 2011 for review and acceptance for rebuilding analysis and for consideration of its use in stock assessment and OFL-setting. Approval of the model for assessment will be made at the May 2012 CPT and June 2012 SSC meeting under the Council process. If its approved, the model will apply to OFL-setting and stock status determination in the 2012/13 assessment cycle.

This assessment will propose an approach for review by the CPT and SSC to accommodate the new size limit strategy in the eastern and western areas under Tier-4. The years selected for determination of biomass reference points is an action item for the May CPT meeting (see response to September 2010 CPT recommendations). As indicated, Tanner-snow crab hybrids are enumerated in survey data although it's uncertain as to the level of accuracy in this designation or its consistency over the time series. The frequency of hybrids in the catch data is unknown and it's not apparent how the catch data can be retrospectively partitioned into non-hybrid and hybrid catch.

We expect the effect of Tanner-snow crab hybrids in the Tanner crab catch data to be negligible as somatic growth would need to approximated that of Tanner crab to result in hybrids retained by the directed Tanner fishery at legal size (138 mm cw). The largest size bin used in modeling snow crab is 130-135 mm cw plus group as snow crab larger than 135 mm cw are exceedingly uncommon. We examined the sizes of Tanner-snow crab hybrids observed in the survey data for 2004-2008 as an example. For these years, the largest and next largest size (mm cw) hybrid crab observed were: 2004 (126, 123), 2005 (133, 105), 2006 (138, 121), 2007 (133, 130), 2008 (149, 135). Only in 2008 was a single hybrid crab observed larger than 138 mm cw. We'll examine extant survey data to more completely understand the potential impact of the occurrence of hybrid crab in the Tanner retained catch. The authors recommend that improved species-specific accounting protocols be implemented to reconcile stock assessments and catch reporting.

**June 2010 Meeting:**
In their review of the crab SAFEs and OFLs, the SSC made the following general comments on eastern Bering Sea Tanner crab:

- *Tanner crab abundance has fallen below the MSST which will require a rebuilding plan to be developed. A stock assessment model is under development but not yet ready for review. The plan is to get CPT and SSC review in September / October 2010 for use in the rebuilding plan to be drafted by May 2011. The SSC would like the authors to develop a model capable of handling two different minimum size limits in the eastern and western areas as the BOF may take such action; this might be beneficial for optimal harvesting.*
- *Lacking a stock assessment model, stock status determination continues to be based on the trawl survey. This year the revised survey estimates corrected for survey net width were used for the first time. Final determination will be made after the summer survey.*
- *The SSC concurs with the CPT that the stock is in Tier 4, given the survey series and an estimate of M, and with the use of a default value for gamma of 1 to set OFL. The SSC requests that the authors and CPT reconsider the choice of years to be used in calculating $B_{MSY}$, currently 1969–1980. The issues of data quality and regime shift need to be more fully addressed. The SSC commented that it's possible that the generally warmer Bering Sea is in a new regime, with more groundfish predators (e.g., cod) and competitors (e.g., flatfish), which has caused a change in Tanner crab productivity. Two options might be to extend the time period to the current time or start the time period later, depending on identification of the shift.*
- *The CPT recommended that the text for OFL calculation should be revised to represent what was actually done. It might be helpful for the CPT to elaborate on what was incorrect in the SAFE, so that the authors can make the appropriate changes*.

As shown in this assessment, the 2009/10 Tanner crab stock is below the MSST and determined to be overfished. A length-based stock assessment model is in development. The current goal is to complete model development and have it approved by the CPT in May 2012 and by the SSC in June 2012 for application in 2012/13 OFL-setting. The model will be presented to the CPT in September 2011 for consideration of its use in developing the rebuilding plan. The timing of the start of the two year time frame for implementing the rebuilding plan by the Council is uncertain. Neither has it been specified when the draft the rebuilding plan will be required, nor the dates of the plan amendment process regarding review, comment and finalization of the rebuilding plan by the Council. The CPT discussed the requirements of for draft completion in May 2011 and will revisit this issue at the September 2011 meeting. The authors will have a better understanding of the requirements of rebuilding analysis once the elements of the rebuilding plan are identified and the required benchmark dates identified.

At the May 2010 meeting, the CPT considered genetic evidence presented in support of partitioning the EBS Tanner crab population into two stocks east and west of $166^0$ W longitude. The CPT found this evidence lacking. The authors have found no evidence to support the argument that the eastern Bering

Sea shelf is member to two distinct, non-intermixing, non-interbreeding stocks of Tanner crab in which the linked population and fisheries dynamics are bifurcated east and west of $166^0$ W longitude. The authors will consider approaches to handle different minimum size limits for the eastern and western areas consistent with the total catch OFL that may underlie optimum harvest strategies.

The authors agree that the stock status determination is based on trawl survey biomass and that these estimates are based on revised bottom trawl survey data using measured net widths beginning in 2010/11.

The authors agree that Tanner crab is a Tier-4 stock in which the OFL is based on M using a gamma of 1.0. As a general observation, we agree that over the time period 1960s to present, there has been an apparent shift in the eastern Bering Sea from a more decapod-dominated ecosystem to a more teleost-dominated ecosystem. We examined and could find no evidence of a change in Tanner crab productivity over this period, nor of changes in reproductive dynamics or life-history characteristics which would reveal temporal changes in recruitment success resulting from the "*generally warmer Bering Sea*". The authors have shown (Rugolo and Turnock 2010) that the historical patterns of fishery exploitation on MMB from the late 1960s to the present exceeded rates that we would deem biologically reasonable for this stock. Exploitation rates on MMB rose in the late 1970s and peaked at 0.69, then declined with the collapse in stock biomass through the mid-1980s, then rose again to 0.45 following the build up in the stock in the late1980s to early-1990s. At these rates, the Tanner crab stock would not be expected to persist at sustainable levels in the short-term, nor modulate around $B_{MSY}$ in the long-term.

If there have been effects of "*generally warmer*" ambient temperatures on Tanner crab productivity or from increased competition and predation on survival, empirical data don't exist to demonstrate these effects nor would the magnitude of such effects, if any, be readily separable from the effects of excessive fishing mortality on the stock. The former range of years (1969-1980) used for estimating $B_{MSY\ Proxy}$ included a five year period (1976-1980) of sharply declining and low male mature biomass. Inclusion of these years was required by the SSC in 2009. The authors do not believe that these that these five years represent levels of male mature biomass that, if fished at $F_{MSY}$, would yield MSY to the fishery. The revised range of years (1974-1980) for estimating $B_{MSY\ Proxy}$ also includes this five years of declining and low male mature biomass. Extending the time period to the current time would include time periods where the stock had collapsed and the fishery closed due to conservation concerns. The time period from 1980 to present is characterized by exceedingly low and unsustainable levels of stock biomass, punctuated by periods (late-1970s to mid-1980s, and early-1990s to present) of collapsed stock. Inclusion of years in which stock biomass had fallen to levels requiring fishery closures in an estimate of proxy $B_{MSY}$ would be inconsistent with the tenet of selection of a range of years that represent the stock living dynamically at $B_{MSY}$ while being fished at rates approximating $F_{MSY}$, and thereby yielding MSY to the fisheries.

The OFL calculation in this and previous assessments represents what is done. In this assessment, the authors revised Section E.2 (Model Description) to clarify the computational logic used in OFL-setting.

### *2. CPT Comments:*

**<u>May 2011 Meeting</u>:**

In their review of the draft 2011 SAFE, the CPT made the following comments and recommendations:

- *The team had no recommendations on the proposed approach for estimating retained catch OFLs for the areas east and west of $166^0$ W longitude.*
- *The team recommends the assessment include an author's recommended ABC and a rationale for the recommended ABC. How the OFL is calculated should not change but rather be reflected*

*in the rationale for the lower ABC which accounts for a source of uncertainty not reflected in the standard calculation process.*

- *On the stock assessment model, the team encourages development and an update on the model in September 2011 focusing on model fits and to move forward as quickly as possible. Suggestions on the model by the team:*
  - *free up Q to address the residual pattern*
  - *include underbag data as it pertains to this assessment*
  - *free up as many parameters (e.g., growth, M) as possible perhaps – e.g., growth data are not from the Bering Sea*
  - *examine length compositions and other data sources to evaluate model fit to the survey data, particularly in the early years.*
  - *consider a large number of selectivity time-blocks to see what the data want, then explore if reasons to justify choices of selectivity time-blocks. (Doug noted Bristol Bay was closed in mid-1990s for RKC so no bycatch occurred in BBRKC fishery, thus entire catch in west*
  - *examine dynamic $B_0$, i.e. what would have happened has the fishery never occurred*
- *The team discussed base years for estimating $B_{MSY}$ proxy for this stock. The team noted that it's now a very limited number of years, and questioned why this stock has such a different year-set than all others. There should be some common productivity periods for all stocks. The stock with the most similar catch history is BBRKC. The assessment document needs to justify the assumed change in production change. In particular, there needs to be more information on recruitment and trends in recruitment over time.*
- *Possibilities for the years used to estimate the $B_{MSY}$ proxy include: (a) 1974-1980; (b) early 1990's when stock higher (than now); (c) years in which F was at a reasonable level; and (d) the entire time-period. The team recommended that the author consider all four options and that the assessment document argue why each option is and is not appropriate. The authors should also consider the status of the fishery historically.*
- *The team discussed how to develop and analyze rebuilding plan alternatives in absence of a model. Without an approved assessment model, it's not possible to estimate the required pieces of a rebuilding plan: minimum time to rebuild, target time to rebuild, and harvest rate that would achieve rebuilding in the target time period. Or to evaluate different rebuilding options. The team will develop rebuilding plan alternatives in September 2011 as the structure of the alternatives will be driven by whether the assessment model can be used. The model could be used for initial projection of the time frame to rebuild and which can be updated as the model improves. The team recommended going forward with projection model focusing on recruitment; it should be possible to use the model to develop a rebuilding plan if the model is sufficiently close to acceptance in September.*

The approach presented in the document to apportion the retained catch OFL into TACs east and west of $166^0$ W. longitude is for illustration. The illustrated TACs are not area-specific retained catch OFLs. The sum of all stock losses in the eastern and western areas is gauged against the Total Catch OFL to assess if overfishing occurred.

The authors will recommend an ABC and the rationale for the additional uncertainty in the calculation.

The authors have addressed the team's recommendations on the Tanner crab stock assessment model, in the separate TCSAM report that will be presented to the CPT and SSC in September 2011.

The authors considered the team's comments on the base years for estimating the $B_{MSY}$ proxy for this stock. The team's observation that there should be a common productivity period for all stocks is unfounded, presumes that the principal driver of crab reproductive potential is the environment, and that the latter has changed magnitude and direction sufficient to explain observed crab stock history. Each crab stock has experienced its own exploitation history, expresses its own unique reproductive dynamics, and its own compensatory mechanisms and responses to external forces. There should be no *a priori* expectation that all crab stocks in the eastern Bering Sea should have the same reproductive history or change in productivity, if any, as a result of forces operating against equilibrium such as exploitation or elements embodied in natural mortality. The authors have not assumed a "*change in production*" in the assessment. The authors have noted that they find no evidence of a change in Tanner crab productivity, nor of changes in reproductive dynamics or life-history characteristics which would reveal temporal changes in recruitment success consistent with the so-called '*regime shift*' paradigm.

The authors have considered the suggested possibilities for the years to estimate the $B_{MSY}$ proxy. This assessment presents results of Total Catch OFL based on the status quo period 1974-1980 (SSC 2009) and the entire time period for comparison. We considered and found no intermediate period (e.g., 1990s when the stock was higher than now, or years in which F was at a reasonable level) that represents, or resulted in biomass that is consistent with $B_{MSY}$. The secondary mode of mature male biomass in the late-1980s and early-1990s was affected by contemporaneous and antecedent high exploitation rates. A $B_{MSY}$ proxy estimated using these years would underestimate the capacity of this stock to persist at $B_{MSY}$ and provide maximum sustainable yield to the fisheries. While exploitation rates were low in the early-to-mid-1980s, the duration is insufficient given the 'k' reproductive strategy of Tanner crab to have resulted in the stock reaching equilibrium in the early-1990s which, coupled with the rise in exploitation in the 1990s that eroded stock biomass. The period 1980 to 2010 is characterized by exceedingly low and unsustainable levels of stock biomass, and punctuated by periods (late-1970s to mid-1980s, and early-1990s to 2010) of collapsed stock. During this period, the stock experienced exploitation rates in excess of current $F_{MSY}$ estimates – at approximately 3M in the late-1970s, and 2M in the late-1980s preceding the collapses. During 1980-2009, the stock has not maintained itself at a level that could be reasonably construed as in dynamic equilibrium or at a level indicative of $B_{MSY}$ capable of providing maximum sustainable yield to the fisheries by definition. Inclusion of years in which stock biomass had fallen to levels requiring fishery closures in an estimate of a proxy $B_{MSY}$ is inconsistent with the tenet of selection of a range of years that represent the stock living at $B_{MSY}$, being fished at rates approximating $F_{MSY}$, and thereby yielding MSY to the fisheries.

The TCSAM has been extensively revised since the May 2011 CPT meeting, and significantly improved over earlier intermediate versions seen by the Crab Workshop, SSC in April 2011 and CPT in May 2011. The CPT will review the model for the purpose of use in stock assessment and the rebuilding analysis. In the author's view, the recommended *Base Model* represents the best available science and a level of performance in modeling stock and fishery dynamics that may be acceptable to assessment and projection analysis. The authors will present the CPT results of a stock projection model run using the *Base Model* configuration as a case example of the utility of the model for rebuilding plan analysis.

**<u>September 2010 Meeting:</u>**
In their review of the 2010 stock assessment, the CPT made the following recommendations related to Tanner crab rebuilding plan and stock assessment:

- *The rebuilding plan will need to consider and address possible effects of groundfish fisheries and may need to recommend controls on the mortality to EBS Tanner crab due to bycatch in the groundfish fisheries.*
- *The time period for computing $B_{REF}$ should be reviewed and evaluated in the rebuilding plan; options for that time period should be considered and evaluated for review by the SSC. The CPT*

*received public testimony recommending a reconsideration of the validity of the period used to compute $B_{REF}$ in the September 2010 assessment (i.e., 1969-1980).*

The authors agree that the Tanner crab rebuilding plan must address the effects of bycatch from the groundfish fisheries. To the extent that non-directed stock losses may affect stock recovery, the plan may need to recommend controls on the mortality of Tanner crab resulting from these fisheries.

The time period of years selected for determining the biomass reference point is an action item for the May CPT meeting. Based on the outcome of the Crab Modeling Workshop (February 2011) and recommendations of the SSC (March 2011), the 1969-1973 survey biomass estimates will be excluded from the analysis. By this change, the revised time period for computing $B_{MSY\ Proxy}$ from 1974-1980 resulting in $B_{MSY\ Proxy}$=83.30 thousand t. The authors recommend this result.

The authors listened to the public testimony at the September 2010 CPT meeting that questioned the validity of the 1969-1980 period for computing $B_{MSY\ Proxy}$. Although the CPT minutes don't elaborate, the stated criticism was that the current environmental regime the eastern Bering Sea has resulted in a different production potential for the Tanner crab stock and that there should be no expectation that the stock could recover to levels observed during this period. This hypothesis is speculative and we suggest that it's incumbent on its advocates to provide the CPT results of an analysis that gives clear and convincing evidence for its support. Otherwise, we consider it capricious to employ inference from presumptive argument to lower the threshold biomass considered to represent a rebuilt stock particularly given the importance of this decision to the health of the ecosystem and the fisheries.

The testimony that the Tanner crab stock should not be expected to recover to levels observed prior to 1980 is inconsistent with the data. If we consider stock performance measured as MMB at the time of the fishery (i.e., prior to catch extraction), that mean quantity over the revised time period (1974-1980) for computing $B^*_{REF}$ is 123.2 thousand t (se=24.8). Even after experiencing excessive rates of exploitation prior to 1980 and the presumptive effects of the so-called '1*976 environmental regime change'*, the stock recovered to an average 1989-1992 MMB at fishery = 94.0 thousand t (se=0.9), or 76.3% of 123.2 thousand t. Extending this average one year on either side of the mode to 1988-1993, the mean MMB at fishery was 81.1 thousand t (se=8.2), or 65.8% of $B^*_{REF}$. Recruits which gave rise to this mode of MMB in the late-1980s to early-1990s were from cohorts produced in the early-1980s – thus, after the so-called '1*976 environmental regime change'* and any presumed change in reproductive potential. The Tanner crab stock demonstrated the ability to recover to greater than 75% of this reference biomass despite the collective effects of excessive exploitation and the theorized environmental regime change.

We observe that the current measure of $B_{MSY\ Proxy}$ employed for EBS crab stocks (i.e., MMB at mating) exempts excessive fishery exploitation in the measure of reproductive biomass since MMB at mating is tabulated after the extraction of the catch. The authors propose an alternative $B_{MSY\ Proxy}$ measure which adjusts for exploitation in excess of $F_{MSY}$. Using the 1974-1980 mean MMB at the time of the fishery ($B^*_{REF}$= 123.2 thousand t) as a proxy for $B_{MSY}$, if exploited at $F_{MSY}$=M=0.23 would yield a mean MSY catch of 28.3 thousand t. Extracting this catch from $B^*_{REF}$ gives an alternative proxy estimate of $B_{MSY}$=94.9 thousand t over 1974-1980 compared to 83.3 thousand t based on MMB at mating. The current $B_{MSY\ Proxy}$ based on MMB at mating is a biased low measure of reproductive potential in instances where fishery removals exceed those estimated using $F_{MSY}$. If recruitment was maintained despite excessive removals, the extent of this bias is proportional to the magnitude of the catch in excess of MSY.

As a general observation, we agree that from the 1960s to present, there has been an apparent shift in the eastern Bering Sea from a more decapod-dominated ecosystem to a more teleost-dominated ecosystem currently. We've not found evidence of a change in Tanner crab productivity over this period, nor of changes in reproductive dynamics or life-history characteristics which reveal temporal changes in recruitment resulting from the purported '1*976 environmental regime change*'. The authors have shown (Rugolo and Turnock 2010) that the historical patterns of fishery exploitation on MMB from the late 1960s to the present exceeded rates that we would now deem biologically reasonable for this stock. Exploitation rates on MMB rose in the late 1970s and peaked at 0.69 in 1978, then declined with the collapse in stock biomass through the mid-1980s, then rose again to 0.45 and followed the build up in the stock in the late-1980s to early-1990s. The exploitation rate on legal male biomass in 1978 was estimated in this assessment was 0.94. At these rates, the Tanner crab stock would not be expected to persist at sustainable levels in the short-term, nor modulate around $B_{MSY}$ in the long-term.

If there have been effects of a change in environmental regime on Tanner crab productivity or from increased competition and predation on survival, empirical data have not shown those effects. Neither would the magnitude of those effects, if any, be easily separable from those of excessive fishing mortality on the stock. The revised range of years (1974-1980) used to estimate $B_{MSY\ Proxy}$ includes a five year period (1976-1980) of sharply declining and low male mature biomass. Inclusion of these five years was required by the SSC in 2009. The authors do not believe that these that these five years represent levels of mature male biomass that, if fished at $F_{MSY}$, would yield MSY to the fishery. Extending the time period to present would include time periods where the stock had collapsed and the fishery closed due to conservation concerns. The time period from 1980 to present is characterized by exceedingly low and unsustainable levels of stock biomass, and punctuated by periods (late-1970s to mid-1980s, and early-1990s to present) of collapsed stock. Inclusion of years in which stock biomass had fallen to levels requiring fishery closures in an estimate of $B_{MSY\ Proxy}$ would be inconsistent with the tenet of selection of a range of years that represent the stock living at $B_{MSY}$, being fished at rates approximating $F_{MSY}$, and thereby yielding MSY to the fisheries.

**<u>May 2010 Meeting</u>:**
In their stock assessment review, the CPT made the following comments concerning the Tanner crab Tier-4 stock assessment:

- *The current assessment estimates a likely upper limit on MMB at time of mating. Final results depend on fishery performance. It is estimated from the 2009 survey that the stock was below the MSST at that time, and the catches during the 2009/10 fishery will have led to the MMB at mating in 2010 being lower. A formal determination of the stock being overfished will occur with the Fall 2010 assessment.*

The CPT had the following recommendations for the authors:

- *Include CV's with point estimates in the tables.*
- *Determine whether groundfish discards are based on all groundfish fisheries or only trawl fisheries.*
- *Revise the text for OFL calculation (Eq. 3 and 4) to represent what was actually done.*
- *Remove Appendix A as it came from a prior assessment.*
- *Provide the September meeting with a summary of progress with the new model. The CPT may recommend that additional planning meeting may be necessary depending on progress given the necessity of this model for the rebuilding plan.*

In this document, the authors provide a final assessment of the status of the 2009/10 Tanner crab stock based on estimated MMB at mating in mid-February 2010. The 2009/10 stock is below the status determination criterion indicative of an overfished stock. The authors made best attempts to address the recommendations of the CPT in this assessment. Developing the time-series of CVs for metrics tabled in this document has proven more involved than anticipated given the change in survey data based on measured net widths used in this assessment. We'll continue to make best efforts to develop these data and work with the Shellfish Assessment Program who is lead concerning data verification and re-estimation of the historical time series. As we previously reported to the CPT, groundfish discards are based on all groundfish fisheries. The OFL calculation in this and previous assessments represents what is done. The authors revised Section E.2 (Model Description) to clarify the computational logic used in OFL-setting. Appendix A is removed in this assessment. The authors will discuss progress on the new model at the September 2010 meeting.

## *C. Introduction*

### *1. Scientific Name and General Distribution*

Tanner crab *Chionoecetes bairdi* originally described by Rathbun (1924) 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 | Brachyra |
| Superfamily | Majoidea |
| Family | Oregoniidae |
| Genus | Chionoecetes |

The common name for *C. bairdi* of "Tanner crab" (Williams et al. 1989) was recently modified to "southern Tanner crab" (McLaughlin et al. 2005). Prior to this change, the term "Tanner crab" has also been 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 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 may be limited by water temperature (Somerton 1981a). *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. The southern range of the cold water congener the snow crab, *C. opilio*, in the EBS is near the Pribilof Islands (Turnock and Rugolo 2010). 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).

### *2. Stock structure*

Tanner crabs in the EBS are considered to be a separate stock distinct from Tanner crabs in the eastern and western Aleutian Islands (NPFMC 1998)**.** The unit stock is that defined across the geographic range of the EBS continental shelf, and managed as a single unit. Somerton (1981a) suggests that clinal differences in some biological characteristics may exist across the range of the unit stock. Somerton's conclusions are limited since he did not recognize that terminal molt at maturity is a characteristic of this species, nor consider stock movement with ontogeny. Thus, biological characteristics estimated based on comparisons of length frequency distributions across the range of the stock, or on modal length analysis over time are confounded by these omissions.

Despite the custom of setting management controls for this stock east and west of $166^0$ W longitude, the unit stock of Tanner crab in the EBS comprises crab throughout the geographic range of the NMFS trawl survey. No evidence supports partitioning the unit stock into discrete, non-interbreeding, non-mixing sub-populations which can be assessed and managed separately. Given requisite understanding of the geographic fidelity of the stock over its range and its availability to the fisheries, partitioning the total catch OFL may be possible to allow setting TACs or issuing of IFQs for the Eastern and Western District fisheries consistent with the total catch OFL.

## *D. Data*

### *1. The Survey*

The NMFS conducts an annual trawl survey in the EBS to determine the distribution and abundance of commercially-important crab and groundfish fishery resources (Chilton et al. 2011). The survey has been conducted since 1968 by the Resource Conservation and Engineering (RACE) Division of the Alaska Fisheries Science Center. It's been conducted annually since 1975 when it 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 resources targeted by this survey 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 sampling methodology specifies the majority of tows made at the centers of squares defined by a 20 x 20 nmi (37 x 37 km) grid (Figures 1 and 2). 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 eastern otter trawl with an 83 ft (25.3 m) headrope and a 112 ft (34.1 m) footrope has been the standard gear since 1982. Each tow was approximately 0.5 h in duration towed at 3 knots, and conducted in strict compliance with established NMFS groundfish bottom trawl protocols (Stauffer 2004). Crabs are sorted by species and sex, and then a sample of the catch measured to the nearest millimeter to provide a size-frequency distribution. Derived population metrics are indices of relative abundance and biomass and do not necessarily represent absolute abundance or biomass. 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.

Estimates of Tanner crab stock biomass, population metrics and length frequencies from the trawl survey used in this assessment were based on area-swept calculations using measured net widths spreads for 1969-2010. Survey for 1969-1973 are not used in the OFL analysis. Previous survey data for 1969, 1970 and 1972-1975 for males and 1974-1975 for females were extracted form historical International Pacific Fisheries Commission (INPFC) documents. Figures 1 and 2 present the distribution catch-per-unit effort by tow for legal males, sublegal males, ovigerous females, barren mature females and immature females from the 2011 survey. The highest abundance of males and females occurs from 163 to 170 degrees W longitude with the distinction that males also reveal moderate levels of abundance in the area of the Pribilof Islands. Areas of highest abundance of male and female Tanner crab in 2011 occurred from southwestern Bristol Bay northeastward to the Pribilof Islands. Figures 13 and 14 show the 5 mm size frequency abundance estimated in the survey for male and female Tanner crab from 1969-2011.

*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, Figure 4b). LMB and MMB estimates in this analysis date to 1974. 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 6. The historical bimodal distribution in male biomass (Figure 4) is also reflected in the pattern of the directed fisheries with peak modes in the mid-1960s through mid-1970s and in the late-1980s to early-1990s (Table 5, Figure 5), and collapsed stock status following those modes. MMB at the survey revealed an all-time high of 257.0

thousand t in 1975, and a second peak of 108.3 thousand t in 1991 (Figure 4). From the late-1990s through 2008, MMB rose at a moderate rate from a low of 10.4 thousand t in 1997 to 73.6 thousand t in 2007 before falling to 32.1 thousand t in 2010. 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. Tanner crab MMB at the time of mating in mid-February 2010 fell below the MSST resulting Tanner crab being declared overfished in September 2010.

In 2011, Tanner crab MMB at the time of the survey was estimated at 41.8 thousand t representing a 23.2% increase relative to 2010. Mature male abundance rose 34.2% relative to 2010 and legal males were sparsely and patchily distributed throughout the survey range with regions of highest abundance in southwestern Bristol Bay and the Pribilof Islands. Legal males were sparsely and patchily distributed throughout the survey range with an area of moderate abundance in southern Bristol Bay and an area of high density near the Pribilof Islands (Figure 1). The total abundance index for legal males increased 41.5% to 13.7 million crabs between 2010 and 2011owing largely to a high-density station in the area of the Pribilof Islands and the elimination of the 'hot-spot' re-sampling protocol in 2011. As a result, the 2011 survey male abundance and biomass estimates are biased high relative to all previous years that employed this re-sampling protocol. Legal-sized males represent only a small portion (3.6%) of total male abundance in 2011. Legal males were distributed 37.1% (5.1 million crabs) east and 62.9% (8.6 million crabs) west of $166^0$ W longitude compared to 56.1% (east) and 43.9% (west) in 2010 (Rugolo and Turnock 2010). The 2011 abundance index for pre-recruit male crabs (110-137 mm cw) was relatively unchanged (+0.1%) relative to 2010, and that for small males (<110 mm cw) increased 49.6% relative to 2010 for all areas combined (Figure 9). Pre-recruit crab in 2011 were widely distributed across the range of the survey from southern Bristol Bay northwest to St. Matthew Island (Figure 1). Regions of highest abundance of pre-recruit males in 2010 were seen in southwestern Bristol Bay and the surrounding area of the Pribilof Islands (Figure 1). Total male abundance increased 44.3% between 2010 and 2011 influenced by the increase in small and in legal-sized males (Figure 9). MMB in 2011 increased 23.2% relative to 2010. Compared to that estimated at the time of the 2010 survey, male recruit biomass (<110 mm cw) increased 47.8%, pre-recruit biomass (110-137 mm cw) decreased 0.9%, legal male biomass increased 44.2% and total male biomass increased 30.1%. Total male biomass in 2011 was comprised of 76.6% immature, 9.8% new shell mature and 13.5% old shell mature males.

Comparison of the male size frequency distributions between 2006 and 2011 revealed a decline in male abundance above 70 mm cw between 2006 and 2010, and relatively increasing percentage of old shell crabs in the mature male stock (Figures 10 a-f). The male size frequency distribution in 2011 (Figure 10 f) reveals an apparent increase in pre-recruit abundance between 25-70 mm cw. The recruit mode (20-40mm cw) seen in 2009 (Figure 10 d) grew to 30-50 mm cw in 2010 (Figure 10 e) and to 55-65 mm cw in 2011 (Figure 10 f). Among all male Tanner crab in 2011, 13.5% were old shell in all categories combined, and 86.5% were comprised of molting, new-soft and new-hard shell (85.1%) categories combined. Among legal-sized males, 52.7% were old shell all categories combined relative to 42.2% in 2010, and 47.1% were new-hard shells. The increase in male abundance in 2011 if not biased high due to the change in sampling design, particularly for recruit-sized crab (<110 mm cw), is an encouraging sign. The relatively high percentage of old and very old shell males in the mature stock, however, may remain a concern regarding future reproductive potential of this stock.

Large female (>=85 mm cw) Tanner crab increased 8.7% in abundance in 2011 relative to 2010. Total female biomass in 2011 was comprised of 79.5% immature, 13.9% new shell mature and 6.6% old shell mature females. Among all female Tanner crab in 2011, 6.6% were collectively old shell and 91.1% new-hard shell. Small females (<85 mm cw) increased by 44.2% to 269.5 million crabs relative to 2010 and comprise 94.7% of total female abundance. Total 2011 female abundance increased 42.4% to 284.6 million crabs largely influenced by the increase in small females <85 mm cw (Figure 9). Total survey abundance of males and females combined increased 9.3% over that in 2010 driven by the increase in both small male and small female crabs. Ovigerous females were distributed from southern Bristol Bay at relatively highest abundance northwestward to south of St. Matthew Island with an area of moderate density near the Pribilof Islands (Figure 2). Immature female Tanner crab displayed a similar distribution to mature females although they were slightly more densely distributed relative to matures along the southeast-northwest cline from southwestern Bristol Bay, north of the Pribilof Islands to west and south of St. Matthew Island (Figure 2). The survey length frequency distributions of female Tanner crab from 2006-2011 revealed consistently declining abundance across the size modes and the general failure of modes of abundance to persist inter-annually (Figures 11 a-e). The prominent length mode between 65-75 mm cw seen in 2006 did not persist in expected levels of abundance in 2007 through 2010. The moderate mode of female abundance above 60 mm cw seen in 2009 (Figure 11 d), which was dominated by old and very old shell females, declined substantially in 2010 (Figure 11 e). A modest mode of new shell recruits seen in 2009 at 25-30 mm cw persists in 2010 at 35-50 mm cw. A relatively strong recruit mode (35-50 mm cw) is apparent in the 2010 survey data (Figure 11 e) which grew to 55-70 mm cw in 2011 (Figure 11 f). The female size frequency distribution in 2011 (Figure 11 f) reveals an apparent strong pre-recruit abundance mode between 30-50 mm cw. The increase in pre-recruit sized female abundance in 2011 is an encouraging in terms of future reproductive potential.

## *2. The Fishery*

*Management Unit*

Fisheries have historically taken place for Tanner crab throughout their range in Alaska, but currently only the fishery in the EBS is managed under a federal fisheries management plan (NPFMC 1998). The plan defers certain management controls for Tanner crab to the SOA with federal oversight (Bowers et al. 2008). The state manages Tanner crab based on registration areas divided into districts. Under the plan, the state can adjust or further subdivide 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 3) 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 longitude. The Eastern Subdistrict is further divided at the Norton Sound Section north of the latitude of Cape Romanzof and east of 168° W longitude and the General Section to the south and west of the Norton Sound Section (Bowers et al. 2008).

In March 2011, the Alaska Board of Fisheries approved a new minimum size limit strategy for Tanner crab that will be in effect for the 2011/12 fishery. The previously minimum legal size limit was 5.5" (138 mm cw) throughout the Eastern Subdistrict. The new regulations established different minimum size limits east and west of $166^0$ W longitude. That for the fishery to the east will be 4.8" (122 mm cw), and that to the west will be 4.4" (112 mm cw). The industry may self-impose retention of crab above 5.5" (138 mm cw) and 5" (127 mm cw) east and west of $166^0$ W longitude, respectively.

The domestic Tanner crab (*C. bairdi*) pot fishery rapidly developed in the mid-1970s (Table 2, Figures 5). For stock biomass and fishery data tabled in this document, we adopted the convention that 'year' refers to the survey year, and fishery data are those subsequent to the survey, through prior to the survey in the following year. Other notation is explicit – e.g., 2008/09 is the 2008 summer survey and the winter 2009 fishery. United States landings were first reported for Tanner crab in 1968 at 0.46 thousand t taken incidentally to the EBS red king crab fishery (Table 2). Tanner crab was targeted thereafter by the domestic fleet and landings rose sharply in the early-1970s, reaching a high of 30.21 thousand t in 1977 (Table 2, Figure 5). 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 18.19 thousand t, and then fell sharply through the mid-1990s (Figure 5). 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 0.77 thousand t retained catch between 2005-2009/10 (Table 2). Landings of Tanner crab in the foreign Japanese pot and tangle net fisheries were reported between 1965-1978, peaking at 19.95 thousand t in 1969 (Table 2, Figure 5). The Russian tangle net fishery was prosecuted between 1965-1971 with peak landings in 1969 at 7.08 thousand t. Both the Japanese and Russian Tanner crab fisheries were displaced by the domestic fishery by the late-1970s.

For the 2010/11 fishery, the SOA closed directed commercial fishing for Tanner crab. The SOA's harvest strategy for opening the fishing is 21 million pounds (9.5 thousand t) of mature female biomass in the Eastern Subdistrict at the time of the survey. The 2010 survey estimate of total mature female Tanner crab biomass was 15.1 million pounds (6.8 thousand t).

Discard and bycatch losses of Tanner crab originate from the directed pot fishery, non-directed pot fisheries (notably, for snow crab and red king crab), and the groundfish fisheries (Table 3). Discard/bycatch mortalities were estimated using post-release handling mortality rates (HM) of 50% for pot fishery discards and 80% for groundfish fishery bycatch (NPFMC 2008). Total Tanner crab discard and bycatch losses by sex are shown in Table 3 for 1965-2011. The pattern of total discard/bycatch losses is similar to that of the retained catch (Table 2). These losses were persistently high during the late-1960s through the late-1970s; male losses peaked in 1970 at 20.17 thousand t (Table 3). A subsequent peak mode of discard/bycatch losses occurred in the late-1980s through the early-1990s which, although briefer in duration, revealed higher losses for males than the earlier mode, peaking at 22.82 thousand t in 1990. From 1965-1975, the groundfish fisheries contributed significantly to total bycatch losses, although the combined crab pot fisheries are the principal source of contemporary non-retained losses to the stock (Table 3). Total Tanner crab retained catch plus non-directed losses of males and females (Table 4, Figure 4a) reflect the performance patterns in the directed and non-directed fisheries. Total male catch rose sharply with fishery development in the early-1960s and reveals a bimodal distribution between 1965 and 1980 with peaks of 47.48 thousand t in 1969 and 52.30 thousand t in 1977 (Table 4, Figure 4a). Total male catch rose sharply after the directed domestic fishery reopened in 1987 and reached a peak of 41.01 thousand t in 1990. Total male and female catch fell sharply thereafter with the collapse of the stock and the fishery closure in 1997.

Since re-opening of the domestic fishery in 2005, the relationship of total male discard/bycatch losses by non-directed crab pot and groundfish fisheries to retained catch shifted relative to that between 1980-1996 (Tables 2 and 3). For 2005-2009, the ratio of total male discard losses to retained catch was 2.2, 1.8, 2.5,1.3, and 1.6 respectively, and averaged 1.9 (ser=0.2). The majority of these male losses are sub-legal sized crab, and the principal contributor to these non-retained losses is the non-directed snow crab fishery (Table 7a). This contrasts the pre-closure performance of the domestic fishery (1980-1996) which averaged 1.3 (se=0.1) pounds of non-retained male losses to each pound of retained catch. Corresponding ratios in terms of numbers of non-retained male losses to retained legal crab are more striking due to the contribution of sub-legal sized crab to total male discards. Discard and bycatch losses of male and female Tanner crab (Table 3) 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 fisheries.

*Exploitation Rates*

The historical patterns of fishery exploitation on LMB and MMB were derived (Table 6, Figures 7a and 7b). 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. During 1974-2009, exploitation rate ($\mu$) on LMB was highest in 1979 at 0.94 and second highest in 1981 at 0.54; thereafter, it fell with stock condition through the mid-1980s. LMB exploitation rates revealed a second prominent mode during 1989-1993, peaking at 0.46 in 1991 and averaging 0.44 during those five years (Table 6, Figure 7b). At these rates of exploitation on LMB, the Tanner crab was not expected to persist at maximum sustainable levels even in the short-term, nor modulate around $B_{MSY}$ in the long-term. The pattern of μ on MMB from 1974-2009 reveals two analogous high periods: one associated with the high total catches in the mid-1970s to 1980; the other coincident with the mode of high catches in the late-1980s through early-1990s. Exploitation rates on MMB peaked at 0.69 in 1979 and at 0.44 in 1990, averaged 0.23 over 1986-1997 and followed the build up in stock biomass during that period.

## *3. Life-History*

*Reproduction*

In most majid crabs, the molt to maturity is the final or terminal molt. For *C. bairdi*, it's now accepted that both males (Tamone et al. 2007) and females (Donaldson and Adams 1989) undergo terminal molt at maturity. 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 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). Two or more consecutive egg fertilization events can follow a single copulation using stored sperm to self-fertilize the new clutch (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 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 (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 EBS, seasonal differences have been observed between mating periods for pubescent and multiparous Tanner crab females in the Gulf of Alaska and Prince William Sound. 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 EBS 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 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 senescent females often carry small clutches or no eggs (i.e., barren) suggesting that female Tanner crab reproductive output is a declining function of age (NMFS 2004a).

The fraction of barren mature females by shell condition (Figure 15) and the fraction of mature females with clutches one-half full or less by shell condition (Figure 16) are shown. After 1991, 20-40% of new shell females brooded clutches less than or equal to 50% full, and in 2009 this number was approximately 23%. We developed a Tanner crab Egg Production Index (EPI) by female shell condition that incorporates observed clutch size measurements taken on the survey and fecundity by carapace width for 1976-2009 (Figure 17). Figure 17 also presents estimates of male and female mature biomass relative to the shell condition class EPIs in these years. Although male and female mature biomass increased after 2005, egg production does not increase proportionally to mature biomass (Figure 17).

*Size at Maturity*

Maturity at length (cw) schedules were estimated for male and female Tanner crab from extant NMFS trawl survey data. For females, we used egg and maturity code information collected on the survey from 1976-2009 to estimate the maturity curves for new shell females, and for the aggregate class of females all shell conditions combined. SM50%, for females all shell classes combined was estimated to be 68.8 mm cw, and that for new shell females was 74.6 mm cw. For males, data from the special collection of morphometric measurements taken to the 0.1 mm in 2008 on the NMFS survey was used to derive the classification rules between immature and mature crab based on chela allometry using the mixture-of-two-regressions analysis. We estimated classification lines between chela height and carapace width defining morphometric maturity for the unit Tanner crab stock, and for the sub-stock components east and west of $166^0$ W longitude. We then applied these rules to historical survey data from 1990-2007 to apportion male crab to the immature and mature populations. We examined and found no significant differences between the classification lines of the sub-stock components (E and W of $166^0$ W longitude), or between the sub-stock components and that of the unit stock classification line. SM50%, for males all shell condition classes combined was estimated to be 91.9 mm cw, and that for new shell males was 104.4 mm cw. By comparison, Zheng (1999) in development of the current SOA harvest strategy used knife-edge maturity of >79 mm cw for females and >112 mm cw for males. For harvest strategy purposes, mature females are defined as females >=80 mm cw (Bowers et al. 2008).

Somerton (1981b) noted differences in the size of Tanner crab female maturity across the range of the unit stock. As previously noted, Somerton's interpretations were limited since he did not recognize that terminal molt at maturity is a characteristic of this species, nor did he consider the pattern of ontogenous stock movement. Thus, maturity estimated based on comparisons of the proportions of mature individuals at length in any area, or on changes in the proportion of mature individuals at length over time are confounded by these omissions. Nonetheless, we report that for the 5 survey years from 1975 to 1979, east of 167° 15' W longitude, Somerton (1981a) estimated that 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 male Tanner crab during the same survey years, he estimated size at 50% maturity was 117.0 mm cw and 108.9 mm cw east and west of 167° 15' W longitude, respectively.

*Mortality*

Due to a lack of reliable age information, Somerton (1981a) estimated mortality separately for individual EBS cohorts of juvenile (pre-recruits) and adult Tanner crab. Somerton postulated that because of net selectivity of the survey sampling gear, 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 catch curve analysis with two different data sets, Somerton estimated natural mortality rates of adult male crab from the fished EBS stock to range from 0.20 to 0.28. When using CPUE data from the Japanese fishery the estimated rate of M ranged from 0.13 to 0.18. Somerton concluded that M estimates of 0.22 to 0.28 estimated from models that used both the survey and fishery data were the most representative.

We examined empirical evidence for estimates of oldest observed age for male Tanner crab. Unlike its congener the snow crab, estimates of longevity of Tanner crab are lacking. We reasoned that longevity in a virgin population of Tanner crab would be analogous to that of the snow crab (Turnock and Rugolo

2010) given the analogues in population dynamic and life-history characteristics between these species, where longevity would be at least 20 years. Using 20 years as a proxy for longevity and assuming that this age represents the upper $98.5^{th}$ percentile of the distribution of ages in an unexploited population, M is estimated to be 0.23 (Hoenig 1983). If 20 years is assumed to represent the 95% percentile of the distribution of ages in an unexploited stock, M is estimated to be 0.15. The natural mortality rate (M) of EBS Tanner crab is set at 0.23 for assessing stock status and OFL-setting based on the current expectation of longevity of at least 15 y. This rate of M=0.23 is consistent with that used in Amendment 24 and its associated EA that established new overfishing definitions for crab stocks under the plan.

*Growth and Age*

Rugolo and Turnock (2010) derived the growth relationships for male and female Tanner crab using data collected in the Gulf of Alaska near Kodiak (Munk pers. comm., Donaldson et al. 1981), and examined growth relationships developed by Zheng and Kruse (1999). Somerton (1981a) estimated growth for EBS Tanner crab based on modal size frequency analysis of survey data assuming no terminal molt at maturity. Somerton's approach did not directly measure molt increments and his findings were confounded by not recognizing that inter-annual modal length progression was biased sicne male and female crab ceased growing after their maturity molt. We compared our growth per molt (gpm) relationships with those of Stone et al. (2003) for Tanner crab in southeast Alaska in terms of the overall pattern of gpm over the size range of crab. Initial results suggest that gpm is expressed by two distinct rates of growth for both males and females – a higher rate of growth to an intermediate size in the area 90-100 mm cw, coupled with a decrease in growth rate from that intermediate size thereafter. Such 'dog-leg' shaped growth curves are corroborated in work of Stone et al. (2003), Somerton (1981), Donaldson et al. (1981) and in the data of Munk. Work on the growth relationships is ongoing and we intend to examine curvilinear functions to fit the observed pattern of growth.

Somerton (1981a) studied growth of Tanner crab in the EBS and used modal length analysis 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 the terminal molt to maturity may be 6-7 years (Nevisi et al. 1996). If mean age at maturity is 8-10 y, these results suggest that maximum age of an exploited stock is 14-17 y.

*Weight at Length*

We derived weight at length relationships for male, immature female and mature female Tanner crab based on special collections of length and weight data on the NMFS trawl survey in 2006, 2007 and 2009 (Figure 15). The fitted weight (kg)-length (mm cw) relationship for males of shell condition classes 2 (SC2) through class 5 (SC5) inclusive is: $W=0.00016(cw)^{3.136}$. Those for immature (SC2) and mature (SC2-SC4) females are, respectively, $W=0.00064(cw)^{2.794}$ and $W=0.00034(cw)^{2.956}$.

***E. The Analytic Approach***

***1. History of Modeling Approaches***

*Tier-4 OFL Control Rule*

*Old Survey Data:*

Tanner crab is managed as a Tier-4 stock. Through the 2009 assessment, the proxy $B_{MSY}$ for management is the reference biomass ($B_{MSY\ Proxy}$)=86.80 thousand t MMB at the time of mating estimated as the average observed $MMB_{mating}$ from the time period of 1969-80. As reported in Rugolo and Turnock (2009), Tanner crab MMB in 2009 declined to 39.74 thousand t and even at the time of the survey it was below the minimum stock size threshold MSST=0.5 $B_{MSY\ Proxy}$=43.04 thousand t. After accounting for all losses to the stock from the 2009/10 fisheries and natural mortality, the 2009/10 MMB at mating was 32.52 thousand t. This represented a ratio of 0.38 relative to $B_{MSY\ Proxy}$ which was below the limit that defines an overfished stock. The 2009/10 Tanner crab stock was deemed approaching an overfished condition as determined using stock relative to $B_{MSY\ Proxy}$ and MSST computed using survey MMB estimates based on the fixed 50 ft net width area-swept calculations.

*New Survey Data:*

Beginning with the 2010 assessment, all stock metrics, as well as overfishing definitions were based on survey estimates derived using the measured net width area-swept calculations. This resulted in changes in the historical time series data. Using the revised survey data, the equivalent proxy $B_{MSY}$=83.80 thousand t and MSST=41.90 thousand t. After accounting for all losses to the stock from natural mortality and the 2009/10 fisheries, the 2009/10 MMB at the time of mating was 28.44 thousand t. This represented a ratio of 0.34 relative to $B_{MSY\ Proxy}$ which is below the limit that defines an overfished stock. The 2009/10 Tanner crab stock was determined to be overfished by NOAA Fisheries based on the 2010 stock assessment (Rugolo and Turnock 2010). For the 2011 assessment, $B_{MSY\ Proxy}$ estimated over the revised period (1974-1980) is 83.33 thousand t and MSST=41.67 thousand t. The bias-corrected $B_{MSY\ Proxy}$ estimated over 1974-1980 is 93.24 thousand t and MSST=46.62 thousand t.

MMB at the time of the 2010 survey declined 8.3% relative to that in 2009. Under the plan, MMB estimated at the time of mating (mid-February) is gauged against the MSST to determine its status relative to the overfished criterion after accounting for all stock losses due to M and directed and non-directed fishing. After accounting for stock losses from M and those in the 2009/10 fisheries, the 2010 MMB at the time of mating was 28.44 thousand t. This represented a ratio of 0.34 relative to $B_{MSY\ Proxy}$ which is below the limit that defines an overfished stock. The 2009/10 Tanner crab stock was determined to be overfished by NOAA Fisheries based on the 2010 stock assessment (Rugolo and Turnock 2010).

For the 2010/11 stock status determination, losses from the time of the 2010 survey to mating in 2011 and those from non-directed fishing are considered. The directed fishery was closed in 2010/11. Considering stock losses from M and the 2010/11 non-directed pot and groundfish fisheries, the 2011 MMB at the time of mating was 26.73 thousand t (-6.4% relative to 2010). This represents a ratio of 0.32 relative to $B_{MSY\ Proxy}$ and a ratio of 0.29 relative to the bias-corrected $B_{MSY\ Proxy}$ which are both below the limit that defines an overfished stock. Thus, there is no change in the 2010/11 stock relative to the overfished determination made in 2010.

In the Environmental Assessment associated with 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 may be available for simulation modeling that captures essential population dynamics of the stock as well as the performance of the fisheries. Such modeling approaches can 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 whose mean performance exploits the stock at $F_{MSY.}$ For Tier-4 stocks, the proxy $B_{MSY}$ is commonly estimated as the average biomass over a specified period that satisfies the expectation of equilibrium biomass yielding MSY at $F_{MSY}$. 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 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. The specification of the scaler **γ** in the EA was intended to allow adjustments in the overfishing definitions to account for differences in the biomass measures used in EA simulation 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 and bycatch losses. For Tier-4 stocks, a minimum stock size threshold (MSST) is specified; if current MMB is below MSST, the stock is overfished.

For Tier-4 stocks, the $F_{OFL}$ is derived using and $F_{OFL}$ Control Rule (Figure 8) according to whether current mature stock biomass metric (B) belongs to stock status levels a, b or c in the algorithm below. The stock biomass level beta (β) represents a minimum threshold below which directed fishing mortality is set to zero. The $F_{OFL}$ Control Rule sets β=0.25. The parameter alpha moderates the slope of the non-constant portion of the control rule. For biomass levels where $\beta < B \leq B_{MSY}$, 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 analysis of Tier-3 for snow crab, *C. opilio,* and red king crab, *P. camtschaticus*, a $B_{MSY}$ proxy reference value ($B_{MSY\ Proxy}$) 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 ($B_{MSY\ Proxy}$) must is specified consistent with the expectation of a measure of equilibrium stock biomass ($B_{MSY}$) capable of yielding MSY to the fisheries operating at $F_{MSY}$.

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

## *2. Model Description*

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 approach used for OFL-setting based on these metrics.

A. Definition of Terms:

The following terms will be used in the illustration of our Tier-4 OFL-setting approach.

Let:

| | | |
|---|---|---|
| $B_1$ | = | male mature biomass at the time of the survey |
| $B_2$ | = | male mature biomass at the time of the fishery |
| $B_3$ | = | male mature biomass at the time of mating |
| $L_1$ | = | legal male biomass at the time of the survey |
| $L_2$ | = | legal male biomass at the time of the fishery |
| $L_3$ | = | legal male biomass at the time of mating |
| $S_1$ | = | survival rate after 6 months of M = $e^{-M/2}$ from survey time to the nominal start of the fishery. (Not used in OFL-setting calculations). |
| $S_2$ | = | survival rate from the time of the survey to mating ($\Delta$=8 months) = $e^{-2M/3}$ |
| M | = | instantaneous rate of natural mortality = 0.23 |
| $\gamma$ | = | scaler on M = 1.0 |
| $\alpha$ | = | location parameter that determines intersection of sloping part of OFL control rule and the x-axis |
| $\beta$ | = | minimum stock biomass threshold below which directed fishing is set to zero |
| $B_{MSY\ Proxy}$ | = | reference biomass value proxy for $B_{MSY}$ |
| $B_{MSY}$ | = | equilibrium biomass that yields maximum sustainable yield to the fisheries under an applied $F_{OFL}$ |
| $F_{OFL}$ | = | fishing mortality rate proxy for $F_{MSY}$ that yields the Total Catch OFL ($TC_{OFL}$) using the $F_{OFL}$ control rule |
| $U_{OFL}$ | = | exploitation rate at the applied $F_{OFL}$ = $(1-e^{-FOFL})$ |
| $TC_{OFL}$ | = | total catch overfishing limit corresponding to the $F_{OFL}$ applied to male mature biomass at mating = $B_3S_2U_{OFL}$ |
| $C_1$ | = | total catch losses to MMB from retained + non-retained mortalities. Will equal $TC_{OFL}$ if all projected catch losses are realized. |
| $C_2$ | = | total catch losses to LMB from retained + non-retained mortalities |
| $C_{RET}$ | = | retained catch of male mature biomass in the directed fishery in 2010/11 |
| $C_{3RET}$ | = | 3-year average (2007-09) retained catch of male mature biomass in the directed fishery |
| $CO_{RET}$ | = | projected 2010/11 snow crab retained catch OFL |
| $D_1$ | = | discard mortality of MMB by the directed fishery |
| $D_2$ | = | discard mortality of MMB by the non-directed snow crab fishery |
| $D_3$ | = | discard mortality of MMB by the EBS groundfish fisheries |
| $R_1$ | = | 3-year average (2007-09) ratio of discarded mature male biomass per retained catch biomass in the directed fishery |
| $R_2$ | = | 3-year average (2007-09) rate of discarded mature male biomass per retained snow crab catch in the non-directed snow crab fishery |
| $R_3$ | = | 3-year average (2007-09) groundfish fishery discards of mature male biomass |
| $HM_1$ | = | post-release mortality rate for pot discarded crab (0.50) |
| $HM_1$ | = | post-release mortality rate for groundfish discarded crab (0.80) |
| $TC_{PART}$ | = | residual part of the $TC_{OFL}$ available to the directed fishery |

B. OFL-Setting:

Determination of the total catch OFL ($TC_{OFL}$), $F_{OFL}$, resultant measures of stock biomass and the various catch components is a straightforward process given the $F_{OFL}$ control rule and an estimate of MMB at the time of mating. The following prescription illustrates the logic of the computational approach, the arithmetic employed and formulae used in the estimation of all stock metrics an catch components:

1. Finding $F_{OFL}$:

Given $B_{MSY\ Proxy}$ and the estimate of mature male biomass at the time of mating, $B_3$, the overfishing limit $F_{OFL}$ is found using the FOFL control rule algorithm:

$$F_{OFL} = \gamma M\ [(B_3/\ B_{MSY\ Proxy} - \alpha)/(1 - \alpha)] \quad (1)$$

2. Finding the $TC_{OFL}$:

Given the $F_{OFL}$, we can estimate the total catch OFL ($TC_{OFL}$) that results from applied fishing at the $F_{OFL}$ on $B_3$ by:

$$TC_{OFL} = (B_1 S_2 U_{OFL}) \quad (2)$$

$$= (B_1 S_2 (1\text{-}e^{-\ FOFL})) \quad (3)$$

3. Finding $B_3$:

In the current directed fishery, catches occur mainly in January and February, and in March to a lesser extent. Retained catches coincide with the nominal time of mating (mid-February) eight months from the mid-point survey (mid-June), and span the nominal time of mating. We treat survival from survey to mating as a Type I process in which the stock is depreciated by M through mid-February then the catch is extracted instantaneously.

Thus, the estimate of male mature biomass at the time of mating ($B_3$) results from the combined survival of crab from the time of the survey to mating after natural morality, less the extraction of the total catch OFL ($TC_{OFL}$).

$$B_3 = (B_1 S_2) - TC_{OFL} \quad (4)$$

$$= (B_1 S_2) – (B_1 S_2 U_{OFL}) \quad (5)$$

$$= (B_1 S_2) – B_1 S_2 (1\text{-}e^{-\ FOFL}) \quad (6)$$

Replacing $B_3$ in (1) with equations (3) and (6) gives:

$$F_{OFL} = \gamma M\ [[[(B_1 S_2) – B_1 S_2 (1\text{-}e^{-\ FOFL})]/\ B_{MSY\ Proxy}] – \alpha]/(1 - \alpha)] \quad (7)$$

Since there are unknowns on either side of the equality in equation (7), there is no analytical solution and it must be solved iteratively. This is because the $F_{OFL}$ rate depends on the level of mature male biomass at mating ($B_3$) which, in turn, depends on the extracted $TC_{OFL.}$ Thus, we can't know the $F_{OFL}$ until we extract the total catch OFL using the $F_{OFL}$ control rule, and we can't estimate the $TC_{OFL}$ until we have know the $F_{OFL}$. An iterative flow to solve for the $F_{OFL}$ and $TC_{OFL}$ is shown:

i. Initial guess at the $F_{OFL-1}$ using $B_1$ in the $F_{OFL}$ control rule. If $B_1$ is on the sloping part of the control rule, $F_{OFL-1}$ will be too large by definition since $B_1 > B_3$.
ii. Estimate $TC_{OFL}$ using this $F_{OFL-1}$.
iii. Estimate $B_3$ using equation (4).
iv. Re-estimate the $F_{OFL-2}$ using $B_3$ in the $F_{OFL}$ control rule.
v. Test if $F_{OFL-1}$-$F_{OFL-2}$ =0. If yes, set the final $F_{OFL}$=$F_{OFL-2}$. If no, depreciate $F_{OFL-2}$ by a small increment resulting in $F_{OFL-3}$.
vi. Repeat using $F_{OFL-3}$ in step ii to estimate the $TC_{OFL}$ using $F_{OFL-3}$ and end the iteration when the test in step v. is yes.

At the termination of the iteration, the final $F_{OFL}$ for the OFL-setting will be known. Given that $F_{OFL}$, estimate the $TC_{OFL}$ using equation (3) and the $B_3$ using equation (4).

4. Find Discard Catches in Non-Directed Fisheries:
Discard losses of male mature biomass are attributed to losses from the non-directed EBS crab pot fisheries and the groundfish fisheries. In practice, the discard catch components are estimated from past performance in the respective fisheries considered to be most representative of current conditions.

a. Non-Directed Pot Fishery Discard Mortalities:
Non-directed pot fishery discard losses to male mature biomass are principally attributed to the snow crab fishery and to the Bristol Bay red king crab fishery to a lesser extent. For example, the 2010/11 Tanner crab discards by the snow crab fishery comprised 98.3% of all pot discards from the snow crab and red king crab fisheries combined. In this analysis, we used data from the previous three fishing seasons (2008, 2009 and 2010) to estimate of the 3-year average ratio of Tanner crab mature male biomass discards in the snow crab fishery to snow crab retained catch ($R_2$) (Table 7b). Discard mortality of MMB by the non-directed snow crab fishery ($D_2$) in the 2010/11 $TC_{OFL}$ is derived as the product of $R_2$ and the projected 2010/11 snow crab retained catch OFL ($CO_{RET}$) (Turnock and Rugolo 2011) given by:

$$D_2 = R_2 \, CO_{RET} \, HM_1 \qquad (8)$$

b. Groundfish Fisheries Discard Mortalities:
Discard losses to male mature biomass resulting from bycatch in the groundfish fisheries ($D_3$) was estimated using the average groundfish bycatch of Tanner crab over 2008-10 ($R_3$) (Table 7c) supplied by the Alaska Regional Office, 08/11. We assumed that this average bycatch of Tanner crab would occur in the 2011/12 fishery. Reported bycatch are for males and females combined. The sex distribution of this bycatch is unavailable for this analysis. The proportion of males in the groundfish fisheries bycatch ($P_M$) 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 groundfish fishery discards, a post-release handling mortality rate of 0.80 was used ($HM_2$). Discard mortality of MMB by the groundfish fisheries ($D_3$) in the 2010/11 $TC_{OFL}$ is given by:

$$D_3 = R_3 \, P_M \, HM_2 \qquad (9)$$

5. Partial $TC_{OFL}$ Available to Directed Tanner Crab Fishery:
Through this stage in the analysis, we've computed the total catch OFL ($TC_{OFL}$) for the 2011/12 fisheries which represents the threshold level of MMB catch beyond which constitutes overfishing. We have also computed the expected discard mortalities of MMB in the $TC_{OFL}$ from the non-directed crab pot fisheries and the groundfish fisheries. These latter losses to male mature biomass can be considered fixed costs to MMB. They would occur whether or not a directed fishery is allowed, and are independent to an extent of the status of the Tanner crab stock ($B_3$) in 2011/12. They depend on the expected performance of the respective non-directed fisheries whose mean performance in terms of discards is not expected to change markedly in the 2011/12 fishing season. Projected discard mortalities depend on the relationship between Tanner male mature biomass and average discards being representative of current conditions – that, neither Tanner MMB nor the operations of the non-directed fisheries will change substantially so as make the relationships between recent 3-year performance and discards invalid.

6. Find Directed Tanner Crab Fishery Discard Mortalities:
The residual part ($TC_{PART}$) of the $TC_{OFL}$ available to the directed fishery is estimated by extraction of the projected discard mortalities in the non-directed pot ($D_2$) and groundfish ($D_3$) fisheries by:

$$TC_{PART} = TC_{OFL} - (D_2 + D_3) \qquad (10)$$

However, since the directed Tanner fishery also contributes to discard mortalities of male mature biomass, the residual part ($TC_{PART}$) of the $TC_{OFL}$ available to the directed fishery must be partitioned to allow for retained catch biomass ($C_{RET}$) and discard mortalities of male mature biomass ($D_1$). After accounting for discard losses by the directed fishery, the retained catch component of the OFL is by:

$$C_{RET} = TC_{PART} - D_1 \qquad (11)$$

Discard losses of mature male biomass by the directed 2011/12 fishery ($D_1$) was estimated using data from the most recent three Tanner crab fisheries, for which there were fisheries, supplied by D. Pengilly, ADF&G (08/24/09) and B.Gaeuman (ADF&G, 07/02/10) (Table 7a). (The directed fishery was closed in 2010/11.) The average ratios of legal and sublegal male and female discards to the average retained catch in the 2007/08, 2008/09 and 2009/10 fisheries are used to project discard losses in the 2011/12 fishery. Here, $R_1$ is the 3-year average rate of discarded mature male biomass per retained catch biomass in the 2007-09 directed Tanner fisheries. For all pot discards, a post-release mortality rate of 0.50 was used ($HM_1$=0.50). Directed fishery discard losses ($D_1$) to male mature biomass is given by:

$$D_1 = C_{RET}\, R_1\, HM_1 \qquad (12)$$

Substituting for $D_1$ in equation (11) with equation (12), gives:

$$C_{RET} = TC_{PART} - C_{RET}\, R_1\, HM_1 \qquad (13)$$

At this stage in the analysis, $TC_{PART}$ is known from equation (10). Also, known are $R_1$ and $HM_1$. However, $C_{RET}$ is unknown and $D_1$ depends on $C_{RET}$. As with equation (7), there are unknowns on either side of the equality; there's no analytical solution and equation (13) which must be solved iteratively. This is readily accomplished by substitution of $C_{RET}$ in equation (12) to estimate $D_1$ until the sum of $C_{RET} + D_1 = TC_{PART}$ which is known.

C. Exploitation Rates:

Exploitation rates on legal male biomass ($\mu_L$) and mature male biomass ($\mu_M$) at the time of the fishery are calculated as the ratio of total directed plus non-directed losses to legal male biomass ($M_L$) and mature male biomass ($M_M$) to the respective legal and mature male biomass at the time of the fishery ($L_2$ and $M_2$, respectively).

$$\mu_L = M_L/L_2 \quad (14)$$

$$\mu_M = M_M/M_2 \quad (15)$$

### *3. Model Selection*

In May 2008, the CPT requested that the authors examine the feasibility of estimating $F_{35\%}$ for the Tanner crab stock using fishery selectivity. The SSC had recommended using fishery selectivity and maturity to estimate $F_{35\%}$ as the proxy $F_{OFL}$, and to estimate gamma as the ratio of $F_{35\%}$ to M. Results of that study are presented in Rugolo and Turnock (2009). In summary, fishery selectivity for Tanner crab used in the EA analysis were estimated on historical fishery performance data prior to the 1997 closure. We estimated selectivity for the contemporary fishery following its reopening in 2005 and found that the current selectivity for the directed and non-directed pot fisheries differed from those used in the EA. While it's desirable for Tier-4 stocks to employ the $F_{35\%}$ proxy for $F_{MSY}$ where reliable data on fishery performance exist, the authors and SSC considered it premature to employ this approach for the Tier-4 Tanner assessment given these changes in performance observed in 2005-2007 versus those of the pre-1997 closure. Since the EA selectivity patterns no longer applied, their use in estimating $F_{35\%}$ and a factor in estimating gamma, may provide misleading and incorrect results in terms of management controls. The SSC concurred with the author's findings and recommended the $F_{35\%}$ not be used in OFL-setting since it could provide misleading results, and to set gamma=1.0.

In this assessment, gamma is set to 1.0, and discard mortalities from the directed and non-directed pot fisheries and the groundfish fisheries are included in OFL-setting. Even if pot fishery selectivities did not change after the reopening in 2005 relative to pre-1997, the EA simulations which suggest that $F_{35\%}$ may be a suitable $F_{MSY}$ proxy for snow crab and Bristol Bay red king crab did not account for non-retained stock losses. Thus, it's uncertain what scaler of M is appropriate to relate M to full-selection $F_{35\%}$ rates in EA simulations. A further consideration in the estimation of gamma as the ratio of the EA $F_{35\%}$ to M is the fact that the MMB metric used in this assessment employs a maturity schedule, whereas the EA simulations employed knife-edge maturity at size. Thus, currency differences in the measure of reproductive biomass are potentially confounding.

The EA guidance 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 4a) and stock biomass (Figure 6) reveals that the Tanner crab stock has not been maintained in dynamic equilibrium over any sustained period, nor persisted in the face of exploitation rates (Table 6, Figures 7and 7b) that exceed levels we would consider biologically meaningful for this stock. The difference between fishery selectivity and maturity in EBS crab stocks has been suggested as a reason to allow gamma to exceed unity. Notwithstanding the technical challenges noted in estimating current fishery selectivity, this relies on theoretical population dynamic 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 on this stock.

### *4. Results*

This assessment uses the proxy $B_{MSY}$ ($B_{MSY\ Proxy}$) calculated as the average MMB at the time of mating over 1974-1980 inclusive. Formerly, $B_{MSY\ Proxy}$ was estimated as the average over 1969-1980 as requested by the SSC in 2009. As a result of recommendations of the Crab Workshop (Martel and Stam 2011) and the SSC in April 2011, 1969-1973 revised survey data are excluded from the analysis. The 1969-1973 survey did not consistently sample Tanner habitat which resulted in variable and biased low biomass estimates. The revised years (1974-1980) is a period of initially high then sharply declining male mature biomass resulting in a biased low proxy $B_{MSY}$. The production of stock biomass over 1974-1980 was affected by contemporaneous and antecedent high exploitation rates (Table 6, Figure 7a). This proxy $B_{MSY}$ may underestimate the capacity of this stock to persist at $B_{MSY}$ and provide maximum sustainable yield to the fisheries if fished at $F_{MSY}$.

The time period from 1980 to present is characterized by low and unsustainable levels of stock biomass, and punctuated by periods (late-1970s to mid-1980s, and early-1990s to present) of collapsed stock and the imposition of a rebuilding plan by the NPFMC in 1999. During this period, the stock experienced exploitation rates in excess of current $F_{MSY}$ estimates – at approximately 3M in the late-1970s, and 2M in the late-1980s preceding the collapses. During 1980-2009, the stock has not maintained itself at a level that could be reasonably construed as in dynamic equilibrium or at a level indicative of $B_{MSY}$ capable of providing maximum sustainable yield to the fisheries. Inclusion of years in which stock biomass had fallen to levels requiring fishery closures in an estimate of $B_{MSY\ Proxy}$ would be inconsistent with the tenet of selection of a range of years that represent the stock living at $B_{MSY}$, being fished at rates approximating $F_{MSY}$, and yielding MSY to the fisheries. The authors will revisit the choice of a proxy $B_{MSY}$ with the development of the Tanner crab stock assessment model.

## *F. Calculation of the 2011/12 OFL*

We estimated the Total Catch OFL and associated catch components for the 2011/12 Tanner crab fishery at three levels of proxy $B_{MSY}$: [1] bias-corrected 1974-1980 MMB at mating (93.24 thousand t); [2] non bias-corrected mean 19674-1980 MMB at mating (83.33 thousand t); and [3] mean 1974-2010 MMB at mating (37.01 thousand t) requested by the CPT (May 2011). Bias-correction of the indices of MMB at mating follows the method proposed by Rugolo and Turnock (2011), and reviewed by the CPT in May 2011. The non bias-corrected and bias-corrected estimates of MMB are shown in Table 8 columns 3 and 6, respectively, along with the respective mean values. For each proxy $B_{MSY}$ values, we estimated 2011/12 catch components at three levels of projected 2011/12 snow crab retained catch OFL. While the Total Catch OFL, $F_{OFL}$ and $MMB_{2011/12}/B_{MSY\ Proxy}$ at each proxy $B_{MSY}$ is unaffected by the level of 2011/12 snow crab retained catch, the Tanner retained catch OFL changes as a result of expected discard losses in the 2011/12 snow crab fishery.

At this writing, the 2011/12 snow crab retained catch OFL is unknown. To complete the 2011/12 OFL-setting analysis, we assumed the 2011/12 snow crab retained catch OFL at three levels: [1] 2010/11 realized snow crab retained catch of 24.61 thousand t (54.26 million pounds); [2] projected 57.30 thousand t (126.3 million pounds) equal to the 75%$F_{OFL}$ model scenario where mature male M is estimated; and [3] either 35.88 thousand t (79.10 million pounds) or 42.77 thousand t (94.30 million pounds) which produce discard losses of Tanner crab in the snow crab fishery at a level resulting in zero Tanner 2011/12 retained catch OFL under the bias-corrected [1] and non bias-corrected [2] proxy $B_{MSY}$ values, respectively.

The authors recommended the use of bias-corrected proxy $B_{MSY}$. A proxy $B_{MSY}$ based on 1974-2010 is fundamentally inconsistent with a measure of stock biomass indicative of $B_{MSY}$ that would provide maximum sustainable yield to the fisheries if fished at $F_{MSY}$. It's for illustration per CPT request.

Here, we discuss only the OFL-setting results for the bias-corrected (Table 9) and non bias-corrected (Table 10) proxy $B_{MSY}$ for the assumed levels of 2011/12 snow crab retained catch OFL. Results assuming a proxy $B_{MSY}$ based on 1974-2010 are shown in Table 11.

Using the bias-corrected 1974-1980 proxy $B_{MSY}$=93.24 thousand t, the estimated the 2011/12 Total Catch OFL=1,367.83 t for males and females combined (Table 9). Total projected losses to MMB are 1,248.86 t. Conditioned on the 2011/12 snow crab retained catch OFL=24.61 thousand t, directed and non-directed discard losses to MMB in 2011/12 are estimated to be 117.61 t and 910.73 t, respectively. The retained part of the catch OFL of legal-sized crabs is 220.52 t. At a 2011/12 snow crab retained catch OFL= 35.88 thousand t, the 2011/12 retained Tanner crab catch OFL is zero. At values of 2011/12 snow crab retained catch OFL > 35.88 thousand t, the 2011/12 Total Catch OFL would be exceeded and overfishing occur even if the directed fishery was closed. Assuming that the 2011/12 snow crab retained catch OFL$\leq$35.88 thousand t, the projected 2011/12 estimate of MMB at the time of mating is 26.27 thousand t which yields a $MMB_{2011/12}/B_{MSY\ Proxy}$=0.28 and the 2011/12 $F_{OFL}$=0.05. Expected female discard losses in the 2011/12 groundfish fishery and the directed pot fishery was estimated at 118.97 t. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.06 and 0.04 respectively.

Using the non bias-corrected 1974-1980 proxy $B_{MSY}$=83.83 thousand t, the estimated the 2011/12 Total Catch OFL=1,578.48 t for males and females combined (Table 10). Total projected losses to MMB are 1,456.33 t. Conditioned on the 2011/12 snow crab retained catch OFL=24.61 thousand t, directed and non-directed discard losses to MMB in 2011/12 are estimated to be 189.75 t and 910.77 t, respectively. The retained part of the catch OFL of legal-sized crabs is 355.80 t. At a value of 2011/12 snow crab retained catch OFL= 42.77 thousand t, the 2011/12 retained Tanner crab catch OFL is zero. At values of 2011/12 snow crab retained catch OFL > 42.77 thousand t, the 2011/12 Total Catch OFL would be exceeded and overfishing occur even if the directed fishery was closed. Assuming that the 2011/12 snow crab retained catch OFL$\leq$42.77 thousand t, the projected 2011/12 estimate of MMB at the time of mating is 26.06 thousand t which yields a $MMB_{2011/12}/B_{MSY\ Proxy}$=0.31 and the 2011/12 $F_{OFL}$=0.05. Expected female discard losses in the 2011/12 groundfish fishery and the directed pot fishery was estimated at 122.15 t. Estimated exploitation rates on LMB and MMB associated with these projected catches are 0.08 and 0.05 respectively.

### *1. The 2011/12 OFL Apportioned E-W of* **$166^0$** *W Longitude:*

In March 2011, the BOF approved a new minimum size limit strategy for Tanner crab effective for the 2011/12 fishery. The new regulations established different minimum size limits east and west of $166^0$ W longitude. That for the fishery to the east will be 4.8" (122 mm cw), and that to the west will be 4.4" (112 mm cw). The industry may self-impose retention of crab above 5.5" (138 mm cw) and 5" (127 mm cw) east and west of $166^0$ W longitude, respectively.

An approach to accommodate the new harvest regulations in the eastern and western areas under Tier-4 is proposed for illustration. For Tier-4 stocks, the $F_{OFL}$ is specified using an $F_{OFL}$ control rule according to whether projected mature male biomass at mating belongs to one of three stock status levels. If MMB is greater than the minimum stock size threshold beta ($\beta$), the Total Catch OFL is derived as the product of MMB and the $F_{OFL}$. Since fishery selectivity is not factored in the Tier-4 process, the biomass of all mature males is used in the calculation of the Total Catch OFL. Thus, mature male crab of all sizes are vulnerable to the $F_{OFL}$ and no additional adjustment is required for a minimum legal size limit in an area – i.e., mature male fishery selectivity=1.0 for all sizes.

A basis to apportion the Total Catch OFL into guideline harvest levels (GHLs) in the areas east and west of $166^0$ W longitude would be the relative proportion of MMB in those areas estimated at the time of the survey. An assumption of this approach is that movement of crab from the time of the survey to the fishery is negligible or, alternatively, movement does not occur predominately from one area to the other. If so, a $GHL_E$ and a $GHL_W$ can be established with the following provisos:

1. The $GHL_E$ and a $GHL_W$ are not area-specific total catch OFLs. They're guidelines for harvest to be taken under the size limit strategy implemented in each area.
2. The Total Catch OFL remains as the status determination criterion. The sum of all stock losses to the east and west of $166^0$ W longitude will be gauged against the Total Catch OFL to assess overfishing.
3. In setting harvest policies for the new size limit strategy, the aim is not to exceed $GHL_E$ and $GHL_W$. While there is no rule against setting $GHL_E$ or $GHL_W$ to the retained component of the Total Catch OFL, doing so would exploit MMB in that area at a rate that exceeds the $F_{OFL}$ which could lead to unintended consequences on the reproductive potential of the stock as a whole.

Once the retained catch component ($C_{RET}$) of the total catch OFL is known from Eq. 13, the guideline harvest level for the area east of $166^0$ W longitude ($GHL_E$) and for the area west of $166^0$ W longitude ($GHL_W$) can be estimated as the product of $C_{RET}$ and the proportion of MMB estimated in the respective areas ($P_{MMB\text{-}E}$, $P_{MMB\text{-}W}$) at the time of the survey by:

$$GHL_E = C_{RET}\, P_{MMB\text{-}E} \qquad (16)$$

$$GHL_W = C_{RET}\, P_{MMB\text{-}W} \qquad (17)$$

In the 2011 survey, MMB was distributed 35.8% to the east and 64.2% to the west of $166^0$ W longitude.

## *G. Calculation of the 2010/11 ACL=ABC*

*Background*

The Environmental Assessment for amendments 38 and 39 to the management for the BSAI KTC stocks (NPFMC 2010) established methods by which the Council will set Annual Catch Limits (ACLs) to meet the requirements of the Magnuson-Stevens Act. The Act requires that ACLs be established based upon an acceptable biological catch (ABC) control rule that accounts for scientific uncertainty in the OFL such that ACL=ABC and the total allowable catch (TAC) and guideline harvest levels (GHLs) be set below the ABC so as not to exceed the ACL. ABCs must be recommended annually by the NPFMC's SSC.

Two methods for establishing the ABC control rule were considered: 1) a constant buffer approach where the ABC is set by applying a multiplier (M) to the OFL to meet a pre-specified buffer below the OFL; and 2) a variable buffer approach where the ABC is set based upon a pre-specified percentile (P*) of the distribution for the OFL that accounts for uncertainty in the OFL. P* is the probability that the ABC would exceed the OFL and overfishing occur. Two sources of uncertainty were used in setting the ABC for each stock: 1) $\sigma_w$, or within assessment uncertainty; and 2) $\sigma_b$ , additional uncertainty, where total uncertainty $\sigma_{total}=\sigma_w+\sigma_b$. For all stocks, the EA recommended that some level of additional uncertainty be used in computing ABCs. An additional level of uncertainty equal to 0.30 is recommended for Tanner in this Tier-4 analysis.

*Uncertainty in the Assessment*

Additional uncertainty in this Tier-4 assessment is associated with estimates of stock biomass and the OFL which may be high relative to more well-studied BSAI crab stocks. Potential sources of additional uncertainty considered in formulating the ABC were: 1) pre-specified population dynamic parameters and life-history rates such as natural mortality, size-weight, maturity; 2) the assumption that $F_{msy}=F_{35\%}$ when applying the OFL control rule; and 3) the assumption that $B_{msy}$ is represented by $B_{35\%}$ with an average biomass corresponding to MSY calculated over 1974-1980 using survey MMB at mating. The coefficient of variation (0.13) for the observed survey estimate of mature male biomass for 2011 is taken as the measure of within assessment uncertainty ($\sigma_w$).

*Approach*

The ABC=ACL for the 2011/12 fishery is estimated based on the Tier-4 control rule. Uncertainty was incorporated in the 2011/12 ABC in the estimation of survey biomass from the log-normal distribution incorporating $\sigma_w$=0.13 at two levels of additional uncertainty, $\sigma_b$=0 and $\sigma_b$=0.30 ($\sigma_{total}$=0.13 and $\sigma_{total}$=0.33, respectively) using the notation of the EA, and in the estimation of $B_{MSY\ Proxy}$ from the distribution based on non-parametric bootstrapping of the 1974-80 survey estimates of MMB at mating.

In 2010, the NPFMC prescribed that ABCs be established for all BSAI crab stocks at P*=0.49. Under this prescription, annual ACL=ABC levels are established such that the risk of ovefishing, P[ABC>OFL], equals 49%. We derived the relationship between the probability of overfishing and the OFL multiplier (M) via simulation and found the value of M corresponding to P*=0.49 at the specified levels of total scientific uncertainty, $\sigma_{total}$=0.13 and $\sigma_{total}$=0.33.

| P[ABC > OFL] = 0.49 | |
|---|---|
| $\sigma_{TOTAL}$ | Multiplier (M) |
| 0.13 | $M_1$=1.0 |
| 0.33 | $M_2$=0.82 |

*Results*

Given the retained catch component ($C_{RET}$) of the total catch OFL from Eq. 13, if $M_1$ is the OFL multiplier under $\sigma_{total}$=0.13 and $M_2$ is the multiplier under $\sigma_{total}$=0.33, the respective retained catch components at these levels of total scientific uncertainty ($C_{RET,0.13}$ and $C_{RET,0.33}$) are given by:

$$C_{RET,0.13} = C_{RET}\, M_1 \quad (18)$$

$$C_{RET,0.33} = C_{RET}\, M_2 \quad (19)$$

The revised guideline harvest levels for the areas east and west of $166^0$ W longitude under $\sigma_{total}$=0.13 ($GHL_{E,0.13}$, $GHL_{W,0.13}$) are estimated as the product of $C_{RET,0.13}$ and the proportion of MMB estimated in the respective areas ($P_{MMB\text{-}E}$, $P_{MMB\text{-}W}$) at the time of the survey. The revised guideline harvest levels for the areas east and west of $166^0$ W longitude under $\sigma_{total}$=0.33 ($GHL_{E,0.33}$, $GHL_{W,0.33}$) are estimated as the product of $C_{RET,0.33}$ and the proportion of MMB estimated in the respective areas ($P_{MMB\text{-}E}$, $P_{MMB\text{-}W}$) at the time of the survey.

$$GHL_{E,0.13} = C_{RET,0.13}\, P_{MMB\text{-}E} \quad (20)$$

$$GHL_{W,0.13} = C_{RET,0.13}\, P_{MMB\text{-}W} \quad (21)$$

$$GHL_{E,0.33} = C_{RET,0.33}\, P_{MMB\text{-}E} \quad (22)$$

$$GHL_{W,0.33} = C_{RET,0.33} P_{MMB\text{-}W} \quad (23)$$

We recommend the use of a total uncertainty of 0.33 in this Tier-4 assessment, resulting in a multiplier of 0.82. Based on the bias-corrected proxy $B_{MSY}$ and conditioned on the 2011/12 snow crab retained catch OFL=24.61 thousand t, the retained part of the 2011/12 Tanner catch OFL=0.82·220.52 t=180.83 t. Based on the non bias-corrected proxy $B_{MSY}$ and conditioned on the 2011/12 snow crab retained catch OFL=24.61 thousand t, the retained part of the 2011/12 Tanner catch OFL=0.82 ·355.80 t=291.76 t.

The ABC equivalent of any projected retained catch OFL is calculated as the product of the multiplier $M_2$=0.82 and the tabled retained catch OFL shown in Tables 9 through 11.

### *H. Data Gaps and Research Priorities*

A length-based stock assessment model (TCSAM) for this stock is being developed. The TCSAM will incorporate population and survey performance metrics from time series survey data from 1974-2010. The goal is to promote the Tanner crab stock to a Tier-3 management status and to formulate OFLs based on the TCSAM. Antecedent analysis is being preformed to derive model inputs, parameters and schedules. For both males and females, these include the estimation of growth, maturity, survey selectivity, and fishing power. Also required is the reformulation of length-weight relationships, molting probability schedules and growth transition matrices.

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Table 1. Age (months), mean size (mm cw) and instar number for male Tanner crab in Kodiak and the eastern Bering Sea.

| | Kodiak | | EBS |
|---|---|---|---|
| Instar Number | Mean Size (mm cw) | Mean Age (months) | Mean Size (mm cw) |
| 1 | 3.4 | 1.8 | - |
| 2 | 4.5 | 4.5 | - |
| 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 2. Eastern Bering Sea *C. bairdi* retained catch in the United States pot, the Japanese tangle net and pot, and the Russian tangle net fisheries, 1965/66-2010/11.

| | Eastern Bering Sea *Chionoecetes bairdi* Retained Catch (1000T) | | | |
|---|---|---|---|---|
| | US Pot | Japan | Russia | Total |
| Year | | | | |
| 1965/66 | | 1.17 | 0.75 | 1.92 |
| 1966/67 | | 1.69 | 0.75 | 2.44 |
| 1967/68 | | 9.75 | 3.84 | 13.60 |
| 1968/69 | 0.46 | 13.59 | 3.96 | 18.00 |
| 1969/70 | 0.46 | 19.95 | 7.08 | 27.49 |
| 1970/71 | 0.08 | 18.93 | 6.49 | 25.49 |
| 1971/72 | 0.05 | 15.90 | 4.77 | 20.71 |
| 1972/73 | 0.10 | 16.80 | | 16.90 |
| 1973/74 | 2.29 | 10.74 | | 13.03 |
| 1974/75 | 3.30 | 12.06 | | 15.24 |
| 1975/76 | 10.12 | 7.54 | | 17.65 |
| 1976/77 | 23.36 | 6.66 | | 30.02 |
| 1977/78 | 30.21 | 5.32 | | 35.52 |
| 1978/79 | 19.28 | 1.81 | | 21.09 |
| 1979/80 | 16.60 | 2.40 | | 19.01 |
| 1980/81 | 13.47 | | | 13.43 |
| 1981/82 | 4.99 | | | 4.99 |
| 1982/83 | 2.39 | | | 2.39 |
| 1983/84 | 0.55 | | | 0.55 |
| 1984/85 | 1.43 | | | 1.43 |
| 1985/86 | 0 | | | 0 |
| 1986/87 | 0 | | | 0 |
| 1987/88 | 1.00 | | | 1.00 |
| 1988/89 | 3.15 | | | 3.18 |
| 1989/90 | 11.11 | | | 11.11 |
| 1990/91 | 18.19 | | | 18.19 |
| 1991/92 | 14.42 | | | 14.42 |
| 1992/93 | 15.92 | | | 15.92 |
| 1993/94 | 7.67 | | | 7.67 |
| 1994/95 | 3.54 | | | 3.54 |
| 1995/96 | 1.92 | | | 1.92 |
| 1996/97 | 0.82 | | | 0.82 |
| 1997/98 | 0 | | | 0 |
| 1998/99 | 0 | | | 0 |
| 1999/00 | 0 | | | 0 |
| 2000/01 | 0 | | | 0 |
| 2001/02 | 0 | | | 0 |
| 2002/03 | 0 | | | 0 |
| 2003/04 | 0 | | | 0 |
| 2004/05 | 0 | | | 0 |
| 2005/06 | 0.43 | | | 0.43 |
| 2006/07 | 0.96 | | | 0.96 |
| 2007/08 | 0.96 | | | 0.96 |
| 2008/09 | 0.88 | | | 0.88 |
| 2009/10 | 0.60 | | | 0.60 |
| 2010/11 | 0 | | | 0 |

Table 3. Eastern Bering Sea *C. bairdi* total discard and bycatch losses by sex in the directed plus non-directed pot and the groundfish fisheries, 1965/66-2010/11.

Eastern Bering Sea *Chionoecetes bairdi* Discard and Bycatch Losses (1000T)

[HMPot=0.50; $HM_{GF}$=0.80]

| | All Pot | | Groundfish | | Total | |
|---|---|---|---|---|---|---|
| Year | Male | Female | Male | Female | Male | Female |
| 1965/66 | 0.78 | 0.22 | 2.79 | 1.85 | 3.58 | 2.07 |
| 1966/67 | 1.00 | 0.28 | 5.06 | 3.35 | 6.06 | 3.63 |
| 1967/68 | 5.55 | 1.55 | 7.88 | 5.21 | 13.43 | 6.77 |
| 1968/69 | 7.35 | 2.05 | 5.98 | 3.96 | 13.32 | 6.01 |
| 1969/70 | 11.22 | 3.14 | 8.78 | 5.81 | 20.00 | 8.95 |
| 1970/71 | 10.40 | 2.91 | 9.76 | 6.46 | 20.17 | 9.37 |
| 1971/72 | 8.45 | 2.36 | 10.95 | 7.25 | 19.41 | 9.61 |
| 1972/73 | 6.90 | 1.93 | 6.29 | 4.16 | 13.19 | 6.09 |
| 1973/74 | 5.59 | 1.51 | 8.60 | 5.69 | 14.20 | 7.21 |
| 1974/75 | 6.62 | 1.78 | 11.91 | 7.88 | 18.53 | 9.66 |
| 1975/76 | 8.23 | 2.11 | 4.61 | 3.05 | 12.84 | 5.16 |
| 1976/77 | 12.92 | 3.49 | 2.00 | 1.32 | 14.92 | 4.81 |
| 1977/78 | 15.42 | 4.14 | 1.35 | 0.89 | 16.78 | 5.04 |
| 1978/79 | 10.42 | 2.58 | 1.55 | 1.03 | 11.98 | 3.61 |
| 1979/80 | 9.34 | 2.32 | 1.24 | 0.82 | 10.58 | 3.14 |
| 1980/81 | 8.29 | 1.80 | 1.02 | 0.67 | 9.31 | 2.47 |
| 1981/82 | 2.75 | 0.64 | 0.71 | 0.47 | 3.46 | 1.11 |
| 1982/83 | 1.51 | 0.32 | 0.22 | 0.14 | 1.73 | 0.47 |
| 1983/84 | 0.54 | 0.09 | 0.32 | 0.21 | 0.87 | 0.31 |
| 1984/85 | 1.25 | 0.23 | 0.31 | 0.21 | 1.57 | 0.43 |
| 1985/86 | 0.47 | 0.05 | 0.19 | 0.13 | 0.66 | 0.17 |
| 1986/87 | 0.61 | 0.06 | 0.31 | 0.21 | 0.93 | 0.27 |
| 1987/88 | 2.00 | 0.27 | 0.31 | 0.20 | 2.30 | 0.47 |
| 1988/89 | 5.56 | 0.77 | 0.22 | 0.15 | 5.79 | 0.92 |
| 1989/90 | 12.04 | 1.98 | 0.32 | 0.21 | 12.36 | 2.20 |
| 1990/91 | 22.36 | 3.50 | 0.45 | 0.30 | 22.82 | 3.80 |
| 1991/92 | 20.88 | 3.07 | 1.22 | 0.81 | 22.10 | 3.88 |
| 1992/93 | 12.36 | 1.09 | 1.33 | 0.88 | 13.69 | 1.97 |
| 1993/94 | 6.74 | 1.23 | 0.85 | 0.56 | 7.59 | 1.79 |
| 1994/95 | 3.51 | 1.06 | 1.01 | 0.67 | 4.52 | 1.73 |
| 1995/96 | 2.42 | 1.18 | 0.73 | 0.49 | 3.15 | 1.67 |
| 1996/97 | 0.55 | 0.16 | 0.77 | 0.51 | 1.32 | 0.67 |
| 1997/98 | 0.96 | 0.11 | 0.57 | 0.38 | 1.53 | 0.49 |
| 1998/99 | 1.05 | 0.09 | 0.45 | 0.30 | 1.50 | 0.39 |
| 1999/00 | 0.39 | 0.07 | 0.30 | 0.20 | 0.69 | 0.28 |
| 2000/01 | 0.11 | 0.01 | 0.36 | 0.24 | 0.46 | 0.25 |
| 2001/02 | 0.18 | 0.01 | 0.57 | 0.38 | 0.75 | 0.38 |
| 2002/03 | 0.31 | 0.02 | 0.35 | 0.23 | 0.66 | 0.25 |
| 2003/04 | 0.12 | 0.01 | 0.20 | 0.14 | 0.33 | 0.15 |
| 2004/05 | 0.06 | 0.01 | 0.32 | 0.22 | 0.39 | 0.22 |
| 2005/06 | 0.65 | 0.04 | 0.30 | 0.20 | 0.95 | 0.23 |
| 2006/07 | 1.37 | 0.25 | 0.35 | 0.23 | 1.71 | 0.48 |
| 2007/08 | 2.01 | 0.10 | 0.33 | 0.22 | 2.35 | 0.33 |
| 2008/09 | 0.91 | 0.03 | 0.26 | 0.17 | 1.17 | 0.20 |
| 2009/10 | 0.82 | 0.01 | 0.15 | 0.10 | 0.97 | 0.11 |
| 2010/11 | 0.69 | 0.01 | 0.10 | 0.07 | 0.79 | 0.08 |

Table 4. Eastern Bering Sea *C. bairdi* total catch in the directed (retained) and non-directed fisheries, 1965/66-2010/11.

Eastern Bering Sea *Chionoecetes bairdi* Total Catch
(Retained + Non-Retained) (1000T)

| Year | Male | Female | Total |
|---|---|---|---|
| 1965/66 | 5.44 | 2.03 | 7.46 |
| 1966/67 | 8.37 | 3.54 | 11.91 |
| 1967/68 | 26.82 | 6.63 | 33.45 |
| 1968/69 | 31.17 | 5.91 | 37.08 |
| 1969/70 | 47.25 | 8.79 | 56.04 |
| 1970/71 | 45.41 | 9.20 | 54.61 |
| 1971/72 | 39.90 | 9.47 | 49.38 |
| 1972/73 | 29.98 | 6.02 | 35.99 |
| 1973/74 | 27.22 | 7.21 | 34.43 |
| 1974/75 | 33.77 | 9.66 | 43.43 |
| 1975/76 | 30.49 | 5.16 | 35.65 |
| 1976/77 | 44.93 | 4.81 | 49.74 |
| 1977/78 | 52.30 | 5.04 | 57.34 |
| 1978/79 | 33.07 | 3.61 | 36.68 |
| 1979/80 | 29.59 | 3.14 | 32.73 |
| 1980/81 | 22.73 | 2.47 | 25.21 |
| 1981/82 | 8.45 | 1.11 | 9.56 |
| 1982/83 | 4.12 | 0.47 | 4.59 |
| 1983/84 | 1.42 | 0.31 | 1.72 |
| 1984/85 | 3.00 | 0.43 | 3.43 |
| 1985/86 | 0.66 | 0.17 | 0.84 |
| 1986/87 | 0.93 | 0.27 | 1.19 |
| 1987/88 | 3.30 | 0.47 | 3.77 |
| 1988/89 | 8.97 | 0.92 | 9.88 |
| 1989/90 | 23.47 | 2.20 | 25.67 |
| 1990/91 | 41.01 | 3.80 | 44.81 |
| 1991/92 | 36.53 | 3.88 | 40.41 |
| 1992/93 | 29.61 | 1.97 | 31.58 |
| 1993/94 | 15.25 | 1.79 | 17.04 |
| 1994/95 | 8.06 | 1.73 | 9.79 |
| 1995/96 | 5.07 | 1.67 | 6.74 |
| 1996/97 | 2.13 | 0.67 | 2.81 |
| 1997/98 | 1.53 | 0.49 | 2.02 |
| 1998/99 | 1.50 | 0.39 | 1.89 |
| 1999/00 | 0.69 | 0.28 | 0.96 |
| 2000/01 | 0.46 | 0.25 | 0.71 |
| 2001/02 | 0.75 | 0.38 | 1.14 |
| 2002/03 | 0.66 | 0.25 | 0.90 |
| 2003/04 | 0.33 | 0.15 | 0.48 |
| 2004/05 | 0.39 | 0.22 | 0.61 |
| 2005/06 | 1.38 | 0.23 | 1.61 |
| 2006/07 | 2.67 | 0.48 | 3.15 |
| 2007/08 | 3.30 | 0.33 | 3.63 |
| 2008/09 | 2.05 | 0.20 | 2.25 |
| 2009/10 | 1.58 | 0.11 | 1.69 |
| 2010/11 | 0.79 | 0.08 | 0.87 |

Table 5a. Observed eastern Bering Sea *C. bairdi* male mature biomass and legal male (≥ 138mm cw) biomass at time of the survey, fishery and mating, 1974/75-2011/12.

| Eastern Bering Sea *Chionoecetes bairdi* Survey Biomass (1000T) | | | | | | |
|---|---|---|---|---|---|---|
| | Male Mature Biomass | | | Legal Male Biomass | | |
| Year | Survey | Fishery | Mating | Survey | Fishery | Mating |
| 1974/75 | 206.29 | 183.88 | 143.20 | 94.52 | 84.25 | 65.84 |
| 1975/76 | 257.02 | 229.10 | 189.99 | 168.79 | 150.46 | 127.14 |
| 1976/77 | 151.60 | 135.13 | 85.12 | 93.80 | 83.61 | 50.45 |
| 1977/78 | 129.63 | 115.54 | 58.90 | 77.66 | 69.22 | 31.09 |
| 1978/79 | 79.18 | 70.58 | 34.86 | 41.92 | 37.37 | 14.87 |
| 1979/80 | 48.14 | 42.91 | 11.71 | 22.69 | 20.22 | 0.46 |
| 1980/81 | 95.65 | 85.26 | 59.32 | 30.96 | 27.59 | 13.13 |
| 1981/82 | 55.51 | 49.48 | 39.17 | 10.40 | 9.27 | 3.93 |
| 1982/83 | 46.84 | 41.75 | 36.06 | 6.75 | 6.02 | 3.40 |
| 1983/84 | 27.22 | 24.27 | 21.94 | 4.40 | 3.92 | 3.22 |
| 1984/85 | 23.18 | 20.67 | 16.89 | 6.40 | 5.71 | 4.06 |
| 1985/86 | 11.01 | 9.81 | 8.78 | 3.81 | 3.40 | 3.27 |
| 1986/87 | 13.74 | 12.25 | 10.86 | 2.50 | 2.23 | 2.14 |
| 1987/88 | 26.76 | 23.85 | 19.66 | 5.79 | 5.16 | 3.97 |
| 1988/89 | 65.02 | 57.96 | 46.81 | 16.12 | 14.37 | 10.65 |
| 1989/90 | 105.65 | 94.18 | 67.16 | 32.41 | 28.89 | 16.69 |
| 1990/91 | 103.60 | 92.34 | 47.86 | 45.50 | 40.55 | 20.84 |
| 1991/92 | 108.34 | 96.57 | 56.41 | 35.15 | 31.33 | 15.73 |
| 1992/93 | 104.33 | 93.00 | 59.89 | 39.59 | 35.29 | 18.04 |
| 1993/94 | 58.76 | 52.38 | 35.16 | 18.80 | 16.76 | 8.46 |
| 1994/95 | 40.12 | 35.76 | 26.36 | 15.21 | 13.56 | 9.51 |
| 1995/96 | 29.62 | 26.40 | 20.34 | 9.47 | 8.44 | 6.20 |
| 1996/97 | 24.28 | 21.64 | 18.70 | 8.61 | 7.68 | 6.57 |
| 1997/98 | 10.43 | 9.30 | 7.42 | 3.32 | 2.96 | 2.85 |
| 1998/99 | 9.99 | 8.91 | 7.07 | 2.02 | 1.80 | 1.73 |
| 1999/00 | 12.80 | 11.41 | 10.29 | 2.14 | 1.91 | 1.84 |
| 2000/01 | 15.93 | 14.20 | 13.20 | 4.39 | 3.91 | 3.77 |
| 2001/02 | 17.79 | 15.86 | 14.51 | 5.90 | 5.26 | 5.06 |
| 2002/03 | 17.06 | 15.21 | 13.98 | 6.14 | 5.47 | 5.27 |
| 2003/04 | 23.19 | 20.67 | 19.56 | 6.61 | 5.89 | 5.67 |
| 2004/05 | 24.73 | 22.04 | 20.83 | 4.83 | 4.31 | 4.15 |
| 2005/06 | 42.40 | 37.80 | 34.99 | 10.28 | 9.16 | 8.39 |
| 2006/07 | 64.72 | 57.69 | 52.84 | 12.77 | 11.38 | 9.99 |
| 2007/08 | 73.56 | 65.57 | 59.80 | 10.48 | 9.34 | 8.03 |
| 2008/09 | 61.60 | 54.91 | 50.80 | 14.49 | 12.91 | 11.55 |
| 2009/10 | 34.99 | 31.19 | 28.44 | 7.03 | 6.26 | 5.43 |
| 2010/11 | 32.08 | 28.59 | 26.73 | 8.22 | 7.33 | 7.05 |
| 2011/12 | 41.78 | 37.24 | | 14.73 | 13.13 | |

Table 5b. Observed eastern Bering Sea *C. bairdi* survey female, male and total spawning biomass (1000 t) and observed abundance of legal male crab ≥ 138mm (million crab), 1974-2011.

Observed Survey Mature Male and Female Biomass and Legal Male Abundance

| Year | Mature Biomass (1000 t) | | | Male ≥ 138 mm ($10^6$ crab) |
|---|---|---|---|---|
| | Male | Female | Total | |
| 1974 | 206.3 | 94.9 | 301.2 | 87.53 |
| 1975 | 257.0 | 66.0 | 323.0 | 151.45 |
| 1976 | 151.6 | 81.1 | 232.7 | 86.07 |
| 1977 | 129.6 | 80.8 | 210.4 | 68.49 |
| 1978 | 79.2 | 45.9 | 125.1 | 37.65 |
| 1979 | 48.1 | 34.2 | 82.3 | 21.33 |
| 1980 | 95.6 | 111.3 | 207.0 | 28.53 |
| 1981 | 55.5 | 67.3 | 122.8 | 10.14 |
| 1982 | 46.8 | 96.6 | 143.5 | 6.82 |
| 1983 | 27.2 | 32.9 | 60.1 | 4.70 |
| 1984 | 23.2 | 23.9 | 47.1 | 6.19 |
| 1985 | 11.0 | 9.7 | 20.7 | 3.54 |
| 1986 | 13.7 | 7.8 | 21.6 | 2.27 |
| 1987 | 26.8 | 28.1 | 54.9 | 5.73 |
| 1988 | 65.0 | 51.6 | 116.7 | 15.60 |
| 1989 | 105.7 | 49.0 | 154.6 | 32.73 |
| 1990 | 103.6 | 66.7 | 170.3 | 42.93 |
| 1991 | 108.3 | 79.4 | 187.8 | 33.89 |
| 1992 | 104.3 | 45.7 | 150.0 | 39.65 |
| 1993 | 58.8 | 19.4 | 78.2 | 18.22 |
| 1994 | 40.1 | 17.1 | 57.2 | 14.81 |
| 1995 | 29.6 | 22.4 | 52.0 | 9.45 |
| 1996 | 24.3 | 17.0 | 41.3 | 8.56 |
| 1997 | 10.4 | 6.3 | 16.7 | 3.24 |
| 1998 | 10.0 | 4.7 | 14.7 | 1.97 |
| 1999 | 12.8 | 8.3 | 21.1 | 2.07 |
| 2000 | 15.9 | 7.8 | 23.7 | 4.60 |
| 2001 | 17.8 | 9.7 | 27.5 | 5.97 |
| 2002 | 17.1 | 8.9 | 26.0 | 5.94 |
| 2003 | 23.2 | 14.1 | 37.3 | 6.31 |
| 2004 | 24.7 | 8.1 | 32.8 | 4.50 |
| 2005 | 42.4 | 22.1 | 64.5 | 10.41 |
| 2006 | 64.7 | 37.1 | 101.8 | 13.36 |
| 2007 | 73.6 | 25.2 | 98.8 | 10.90 |
| 2008 | 61.6 | 20.6 | 82.2 | 14.39 |
| 2009 | 35.0 | 14.2 | 49.2 | 6.91 |
| 2010 | 32.1 | 10.3 | 42.3 | 8.01 |
| 2011 | 41.8 | 15.7 | 57.5 | 13.7 |

Table 6. Eastern Bering Sea *C. bairdi* fishery exploitation rate on male mature biomass (MMB) and legal mature biomass (LMB ), 1974/75-2010/11. 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* | | |
|---|---|---|
| | Exploitation Rate @ Time Fishery | |
| Year | MMB | LMB |
| 1974/75 | 0.18 | 0.18 |
| 1975/76 | 0.13 | 0.12 |
| 1976/77 | 0.33 | 0.36 |
| 1977/78 | 0.45 | 0.51 |
| 1978/79 | 0.47 | 0.56 |
| 1979/80 | 0.69 | 0.94 |
| 1980/81 | 0.27 | 0.49 |
| 1981/82 | 0.17 | 0.54 |
| 1982/83 | 0.10 | 0.40 |
| 1983/84 | 0.06 | 0.14 |
| 1984/85 | 0.14 | 0.25 |
| 1985/86 | 0.07 | 0.00 |
| 1986/87 | 0.08 | 0.00 |
| 1987/88 | 0.14 | 0.19 |
| 1988/89 | 0.15 | 0.22 |
| 1989/90 | 0.25 | 0.38 |
| 1990/91 | 0.44 | 0.45 |
| 1991/92 | 0.38 | 0.46 |
| 1992/93 | 0.32 | 0.45 |
| 1993/94 | 0.29 | 0.46 |
| 1994/95 | 0.23 | 0.26 |
| 1995/96 | 0.19 | 0.23 |
| 1996/97 | 0.10 | 0.11 |
| 1997/98 | 0.16 | 0 |
| 1998/99 | 0.17 | 0 |
| 1999/00 | 0.06 | 0 |
| 2000/01 | 0.03 | 0 |
| 2001/02 | 0.05 | 0 |
| 2002/03 | 0.04 | 0 |
| 2003/04 | 0.02 | 0 |
| 2004/05 | 0.02 | 0 |
| 2005/06 | 0.04 | 0.05 |
| 2006/07 | 0.05 | 0.08 |
| 2007/08 | 0.05 | 0.10 |
| 2008/09 | 0.04 | 0.07 |
| 2009/10 | 0.05 | 0.10 |
| 2010/11 | 0.03 | 0 |

Table 7. Data used to estimate discard and bycatch losses in the t 2011/12 fishery: (a) average directed fishery performance; (b) Tanner discards in non-directed EBS crab pot fisheries and snow crab retained catch, and (c) average Tanner crab bycatch in the EBS groundfish fisheries.

(a)

| Average Observer Fishery Data<br>EBS Tanner Crab Directed Fishery<br>[2007/08, 2008/09, 2009/10] | | | |
|---|---|---|---|
| Discard: | | 1000T | Ratio: |
| | S.Legal ♂: | 0.85 | 1.05 |
| | Legal ♂: | 0.02 | 0.02 |
| | All ♀: | 0.04 | 0.05 |
| Retained: | | 0.81 | 1.0 |
| | Total: | 1.72 | |

(b)

| Tanner Crab Non-Directed Pot Fishery Discards (1000T)<br>(Combined Opilio + RKC Pot Fisheries) | | | | |
|---|---|---|---|---|
| Year | Opilio Retained | | Bairdi Discard | Ratio |
| 2008/09 | 26.56 | | 1.93 | 0.07 |
| 2009/10 | 21.78 | | 1.39 | 0.05 |
| 2010/11 | 24.61 | | 1.57 | 0.07 |
| 2011/12 | 24.61 | 1/ | Average: | 0.06 |
| | 42.77 | 2/ | | |
| | 57.30 | 3/ | | |
| | Projected Bairdi Discards (1000T) 1/: | | | 1.48 |
| | Projected Bairdi Discards (1000T) 2/: | | | 2.57 |
| | Projected Bairdi Discards (1000T) 3/: | | | 3.44 |

1/ 2010/11 retained catch.
2/ Value at which 2011/12 Tanner retained catch OFL=0.
3/ Projected 2011/12 retained catch OFL @0.75F35%.

(c)

| Groundfish Fishery Tanner Crab Bycatch (1000 T)<br>(Male + Female Combined) | | |
|---|---|---|
| Year | | Bycatch |
| 2008 | | 0.53 |
| 2009 | | 0.32 |
| 2010 | | 0.22 |
| | Average: | 0.36 |

Table 8. Bias-correction of $B_{MSY}$ Proxy=mean 1974-1980 MMB at the time of mating. Correction of biased estimated $B_{MSY}$ at mating resulting from total observed catch losses greater or less than $F_{MSY}$ catch in fishing years 1974/75 through 1981/81. $F_{MSY}$=M=0.23.

| Bias Correction in Proxy $B_{MSY}$ Given Total Observed Catch ≠ $F_{MSY}$ Catch | | | | | |
|---|---|---|---|---|---|
| | Observed MMB | | Observed | Est. $F_{MSY}$ | Adj. MMB |
| Year | @Fishery | @Mating | Total Catch | Total Catch | @Mating |
| | | | (1000 T) | | |
| 1974/75 | 183.88 | 143.33 | 33.63 | 37.78 | 139.17 |
| 1975/76 | 229.10 | 190.07 | 30.41 | 47.07 | 173.40 |
| 1976/77 | 135.13 | 84.85 | 45.20 | 27.76 | 102.27 |
| 1977/78 | 115.54 | 58.91 | 52.28 | 23.74 | 87.45 |
| 1978/79 | 70.58 | 35.51 | 32.42 | 14.50 | 53.42 |
| 1979/80 | 42.91 | 11.32 | 29.98 | 8.82 | 32.48 |
| 1980/81 | 85.26 | 59.32 | 22.73 | 17.52 | 64.53 |
| | Mean | 83.33 | | Mean | 93.24 |

Table 9. Catch overfishing limits, stock and fishery metrics for the 2011/12 Eastern Bering Sea *C. bairdi* fishery. $B_{MSY}$ Proxy is the bias-corrected mean 1974-1980 MMB at the time of mating at three-levels of projected 2011/12 snow crab retained catch OFL. µ on MMB is Total Catch OFL/MMB at the time of the fishery.

| 2011/12 Eastern Bering Sea *Chionoecetes bairdi* | 2011/12 Opilio Retained Catch OFL (1000 t) | | |
|---|---|---|---|
| Catch OFL, Stock and Fishery Metrics | 24.61 | 35.88 | 57.30 |
| ***Metrics (1000T):*** | | | |
| $B_{REF}$: | 93.24 | 93.24 | 93.24 |
| MMB @ Mating: | 26.27 | 26.27 | 26.27 |
| $B/B_{REF}$: | 0.28 | 0.28 | 0.28 |
| $F_{OFL}$: | 0.05 | 0.05 | 0.05 |
| ***Catch Components (1000T):*** | | | |
| Total ♂ Catch OFL: | 1.25 | 1.25 | 1.25 |
| Directed Discard Losses MMB: | 0.12 | 0.00 | 0.00 |
| Non-Directed Discard Losses MMB: | 0.91 | 1.25 | 1.89 |
| Retained Part of Total ♂ Catch OFL: | 0.22 | 0.00 | 0.00 |
| Discard + Bycatch Losses ♀: | 0.12 | 0.11 | 0.11 |
| Total ♂ Catch OFL + ♀ Losses: | 1.37 | 1.36 | 2.01 |
| ***Rates:*** | | | |
| µ on MMB @ Fishery: | 0.044 | 0.044 | 0.044 |
| BREF=bias-corrected mean 1974-1980 MMB@mating | | | |

Table 10. Catch overfishing limits, stock and fishery metrics for the 2011/12 Eastern Bering Sea *C. bairdi* fishery. $B_{MSY}$ Proxy is the non bias-corrected mean 1974-1980 MMB at the time of mating at three-levels of projected 2011/12 snow crab retained catch OFL. µ on MMB is Total Catch OFL/MMB at the time of the fishery.

| 2011/12 Eastern Bering Sea *Chionoecetes bairdi* | 2011/12 Opilio Retained Catch OFL (1000 t) | | |
|---|---|---|---|
| Catch OFL, Stock and Fishery Metrics | 24.61 | 42.77 | 57.30 |
| ***Metrics (1000T):*** | | | |
| $B_{REF}$: | 83.33 | 83.33 | 83.33 |
| MMB @ Mating: | 26.06 | 26.06 | 26.06 |
| $B/B_{REF}$: | 0.31 | 0.31 | 0.31 |
| $F_{OFL}$: | 0.05 | 0.05 | 0.05 |
| ***Catch Components (1000T):*** | | | |
| Total ♂ Catch OFL: | 1.46 | 1.46 | 1.46 |
| Directed Discard Losses MMB: | 0.19 | 0.00 | 0.00 |
| Non-Directed Discard Losses MMB: | 0.91 | 1.46 | 1.89 |
| Retained Part of Total ♂ Catch OFL: | 0.36 | 0.00 | 0.00 |
| Discard + Bycatch Losses ♀: | 0.12 | 0.11 | 0.11 |
| Total ♂ Catch OFL + ♀ Losses: | 1.58 | 1.57 | 2.01 |
| ***Rates:*** | | | |
| µ on MMB @ Fishery: | 0.051 | 0.051 | 0.051 |
| BREF=mean 1974-1980 MMB@mating | | | |

Table 11. Catch overfishing limits, stock and fishery metrics for the 2011/12 Eastern Bering Sea *C. bairdi* fishery. $B_{MSY}$ Proxy is the mean 1974-2010 MMB at the time of mating at three-levels of projected 2011/12 snow crab retained catch OFL. µ on MMB is Total Catch OFL/MMB at the time of the fishery.

| 2011/12 Eastern Bering Sea *Chionoecetes bairdi* | 2011/12 Opilio Retained Catch OFL (1000 t) | | |
|---|---|---|---|
| Catch OFL, Stock and Fishery Metrics | 24.61 | 42.77 | 57.30 |
| ***Metrics (1000T):*** | | | |
| $B_{REF}$: | 37.01 | 37.01 | 37.01 |
| MMB @ Mating: | 23.93 | 23.93 | 23.93 |
| $B/B_{REF}$: | 0.65 | 0.65 | 0.65 |
| $F_{OFL}$: | 0.14 | 0.14 | 0.14 |
| ***Catch Components (1000T):*** | | | |
| Total ♂ Catch OFL: | 3.59 | 3.59 | 3.59 |
| Directed Discard Losses MMB: | 0.93 | 0.74 | 0.59 |
| Non-Directed Discard Losses MMB: | 0.91 | 1.46 | 1.89 |
| Retained Part of Total ♂ Catch OFL: | 1.75 | 1.39 | 1.11 |
| Discard + Bycatch Losses ♀: | 0.15 | 0.15 | 0.14 |
| Total ♂ Catch OFL + ♀ Losses: | 3.74 | 3.73 | 3.73 |
| ***Rates:*** | | | |
| µ on MMB @ Fishery: | 0.125 | 0.125 | 0.125 |
| BREF=mean 1974-2010 MMB@mating | | | |

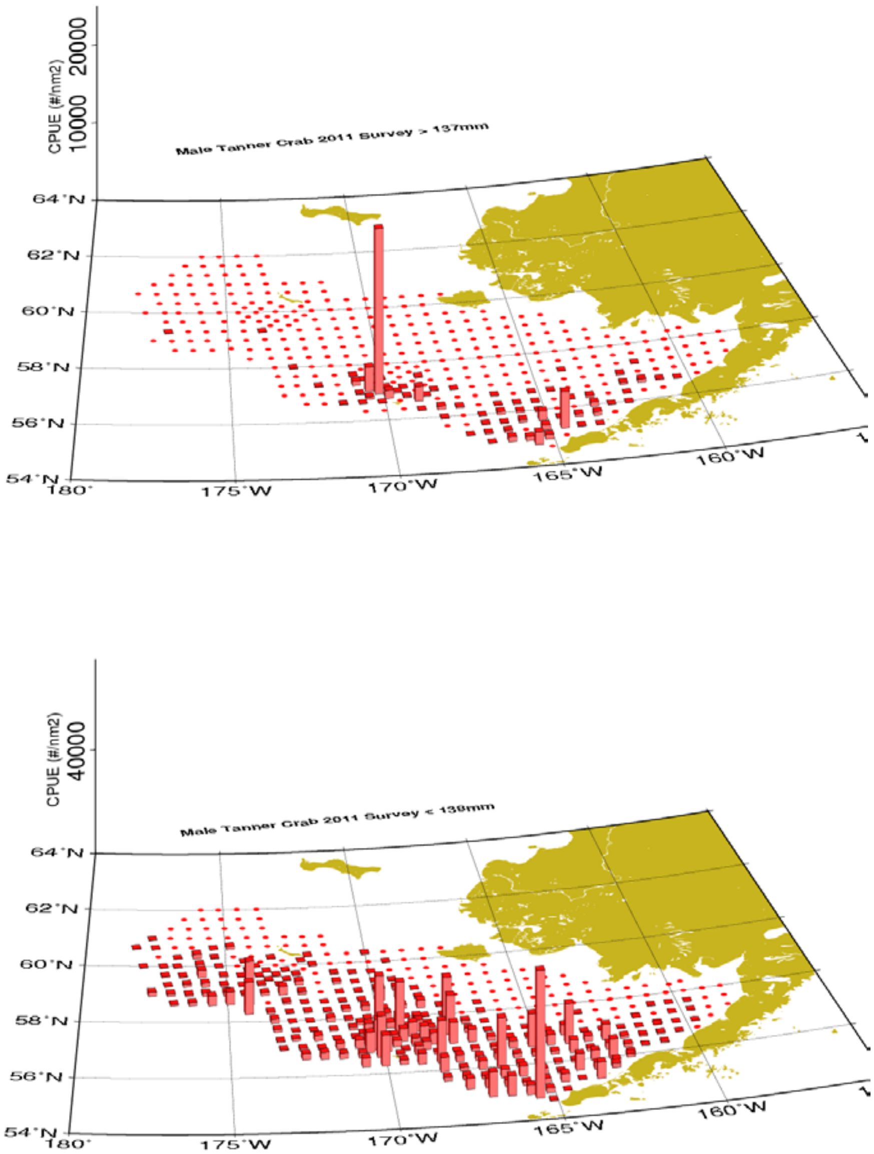



Figure 1. Distribution and abundance of legal (>= 138 mm cw) (top) and sublegal (< 138 mm cw) (bottom) male Tanner crab in the summer 2011 NMFS bottom trawl survey.

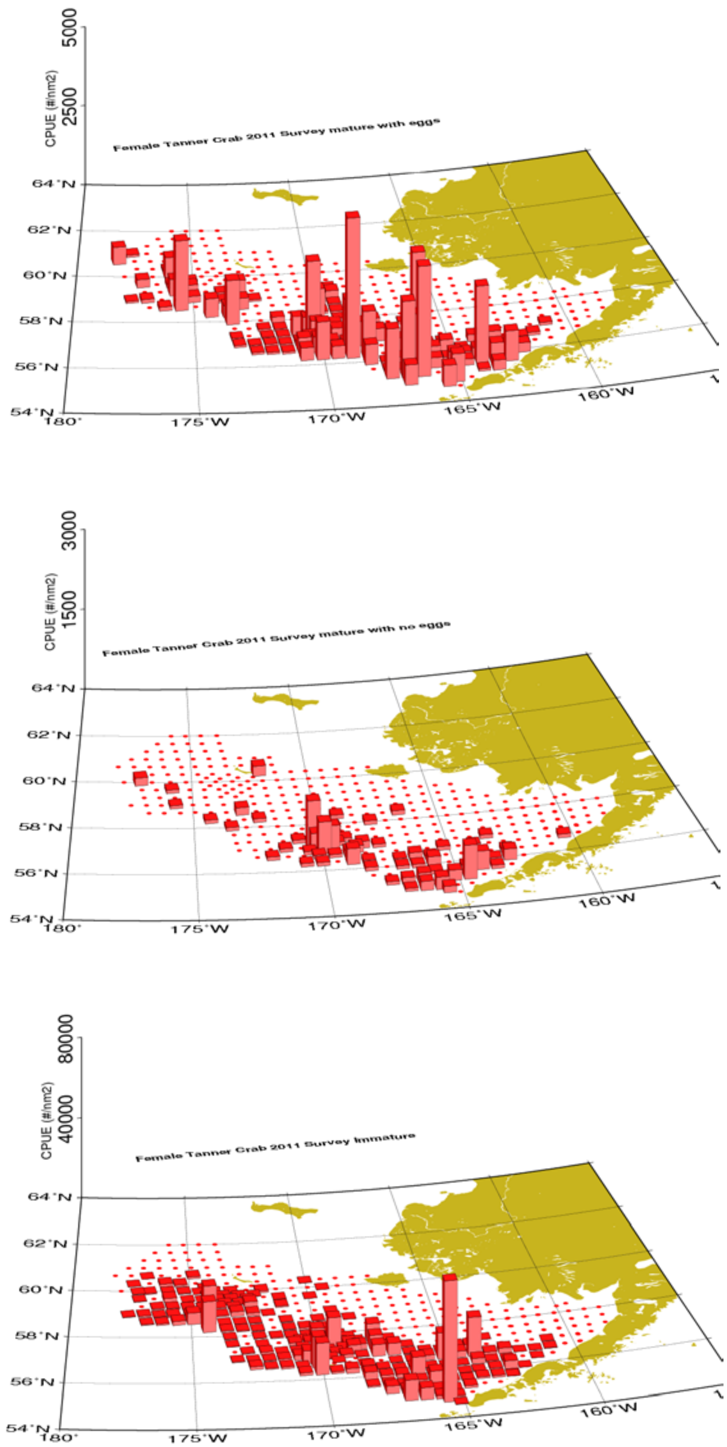



Figure 2. Distribution and abundance of ovigerous (top), barren mature (middle), and immature (bottom) female Tanner crab in the summer 2011 NMFS bottom trawl survey.

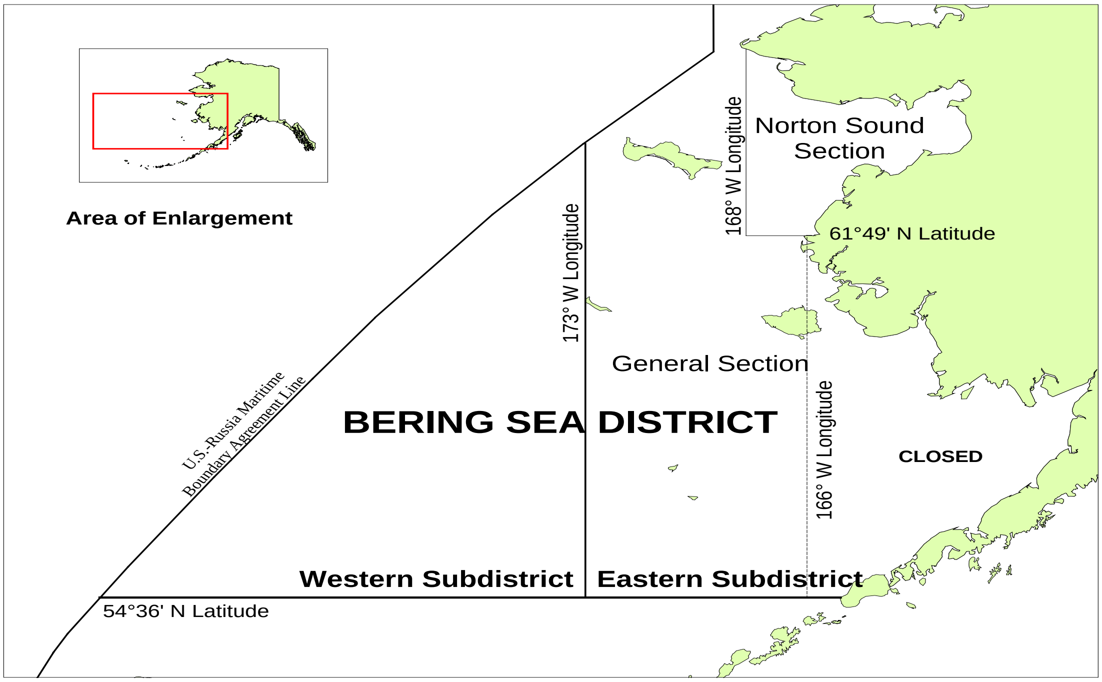
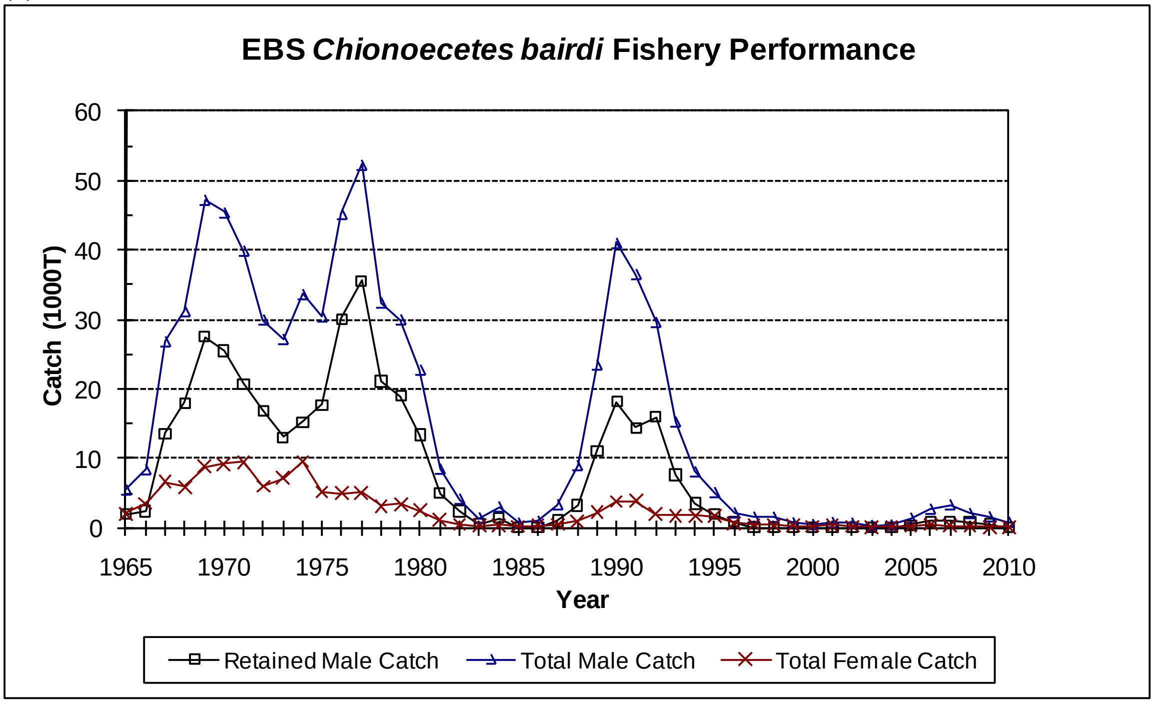



Figure 3. Eastern Bering Sea District of Tanner crab Registration Area J including subdistricts and sections (From Bowers et al. 2008).

(a)




(b)

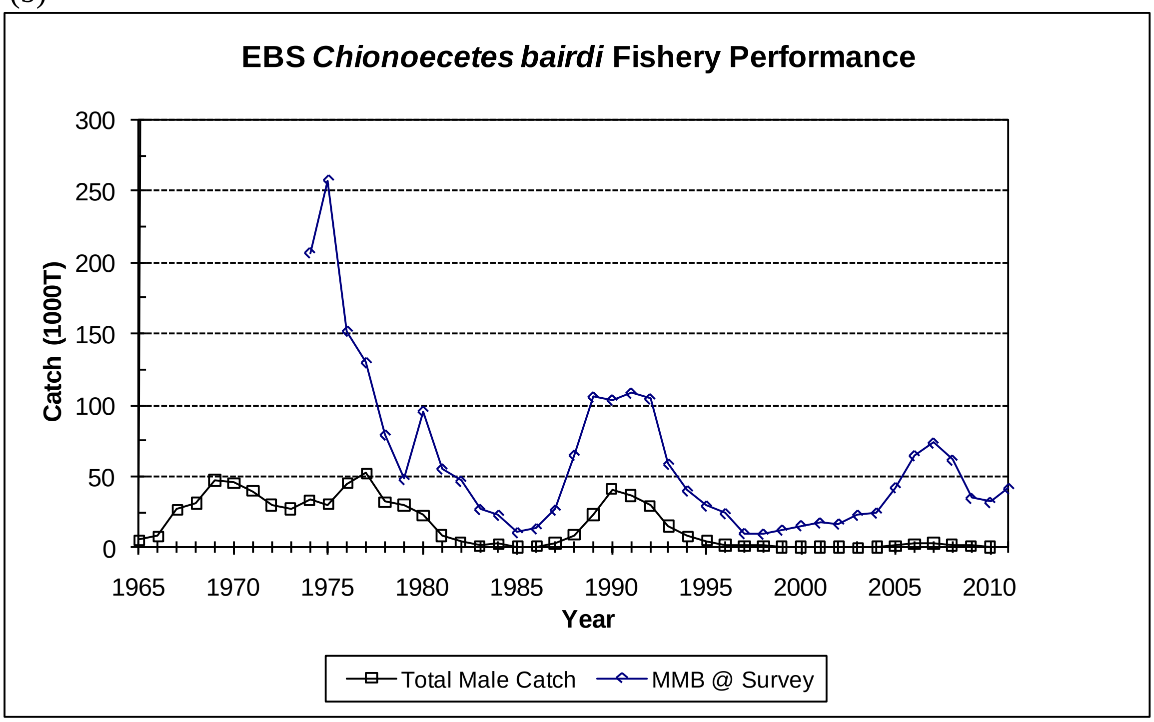



Figure 4. Eastern Bering Sea *C. bairdi* retained male catch, total (retained + bycatch) male catch and total female catch (a), and total male catch v. male mature biomass at the time of the survey (b) for years 1965/66 to 2010/11.

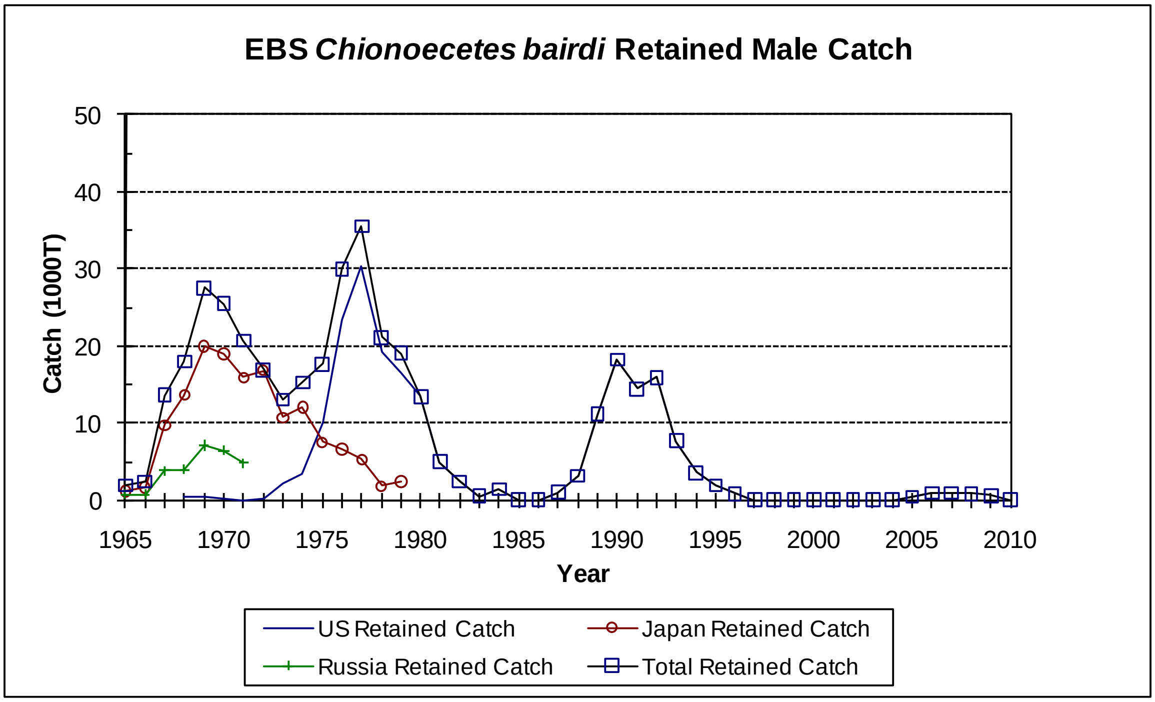



Figure 5. Eastern Bering Sea *Chionoecetes bairdi* retained male catch in the directed United States, Russian and Japanese fisheries, 1965/66 to 2010/11.

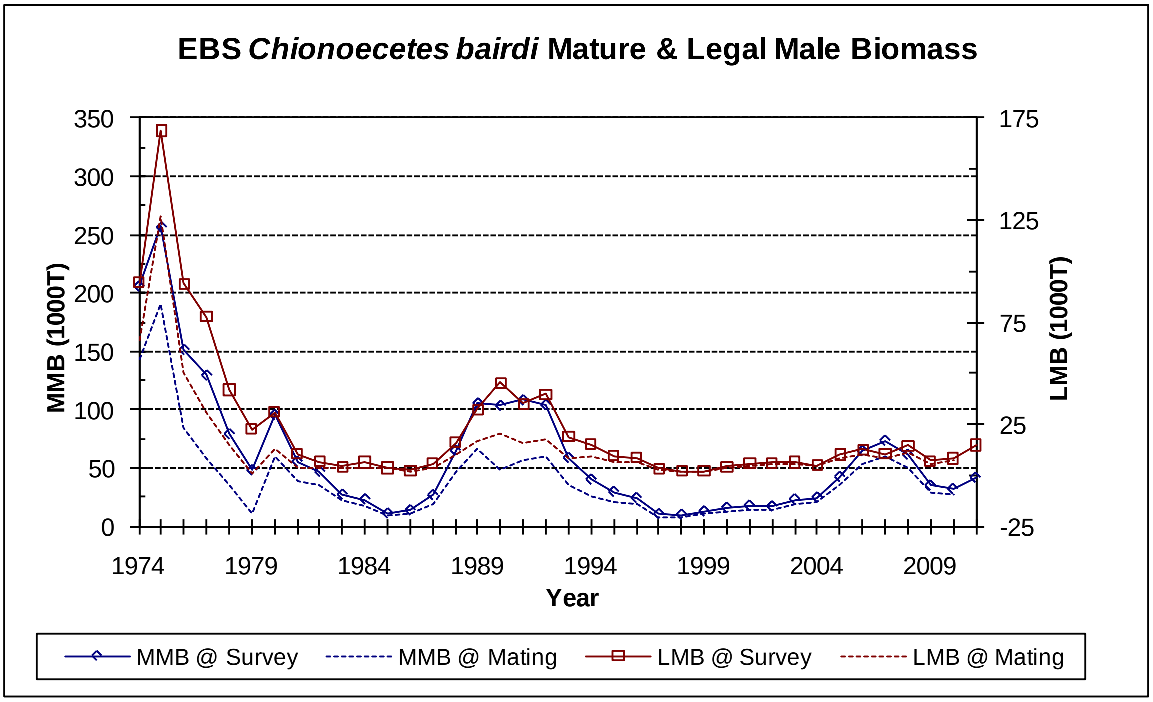
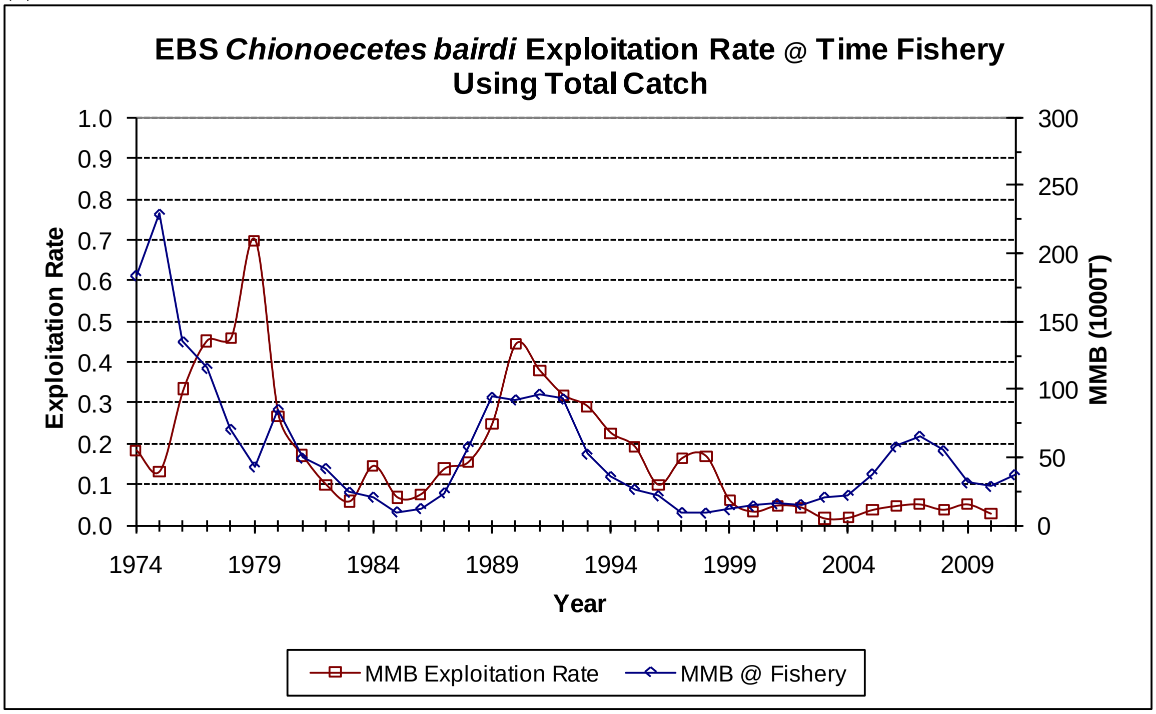



Figure 6. Eastern Bering Sea *C. bairdi* mature and legal male biomass at time of the survey and mating, 1974/75 to 2010/11.

(a)




(b)

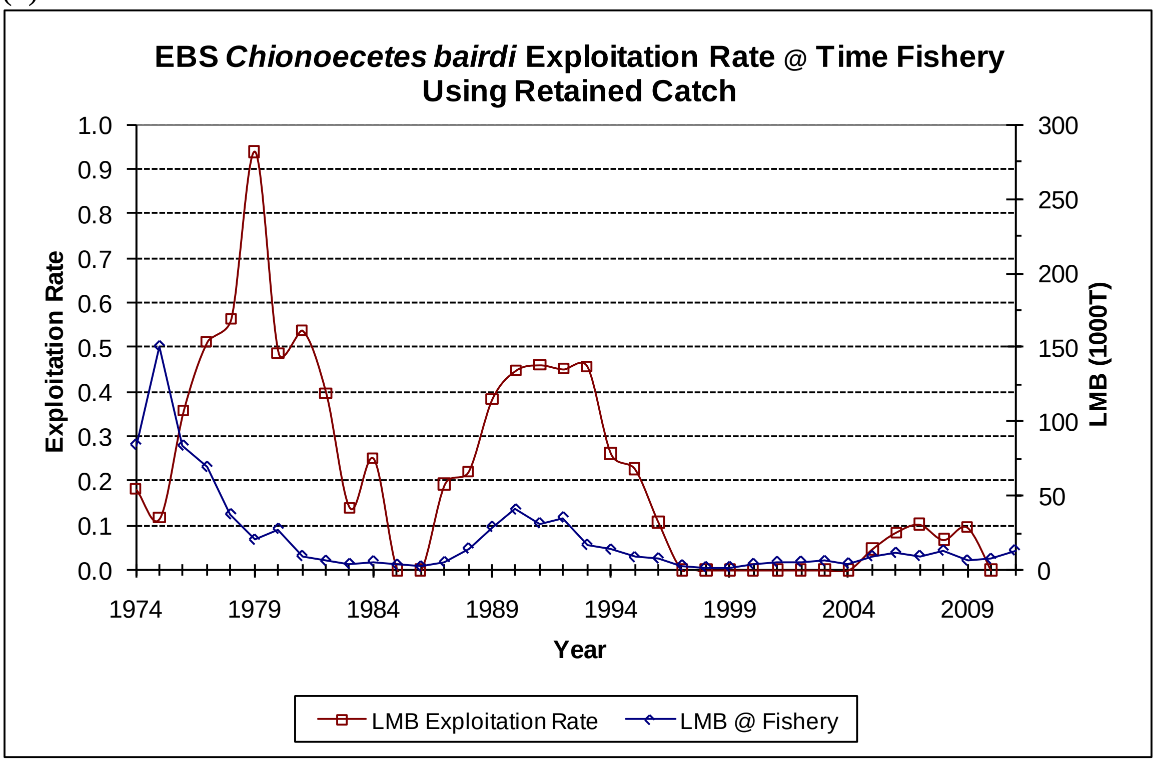



Figure 7. Eastern Bering Sea *C. bairdi* exploitation rate on mature (a) and legal (b) male biomass at the time of the fishery with associated male biomass metric, 1974/75 to 2010/11.

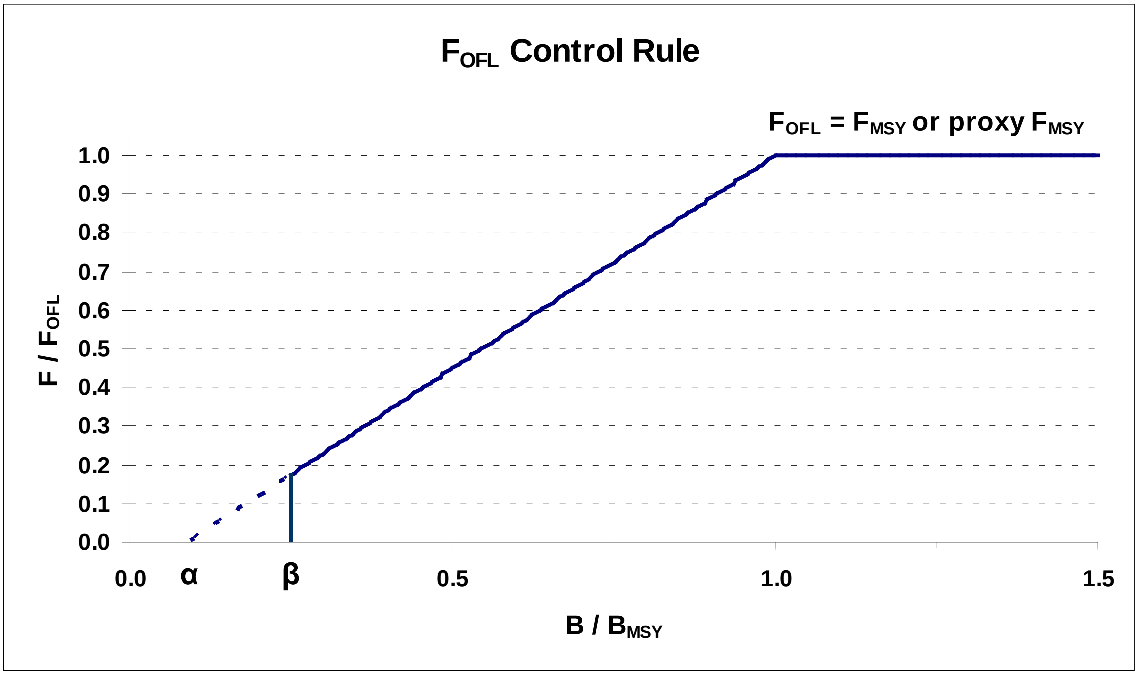



Figure 8. $F_{OFL}$ Control Rule for Tier-4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set 0 below β.

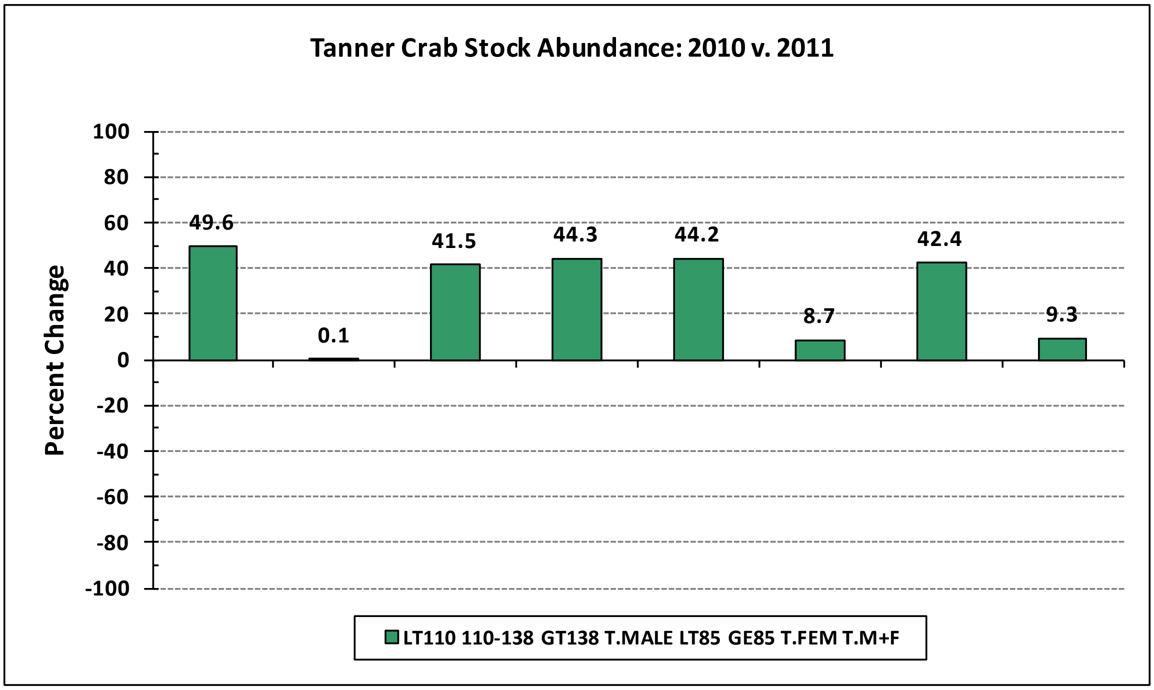
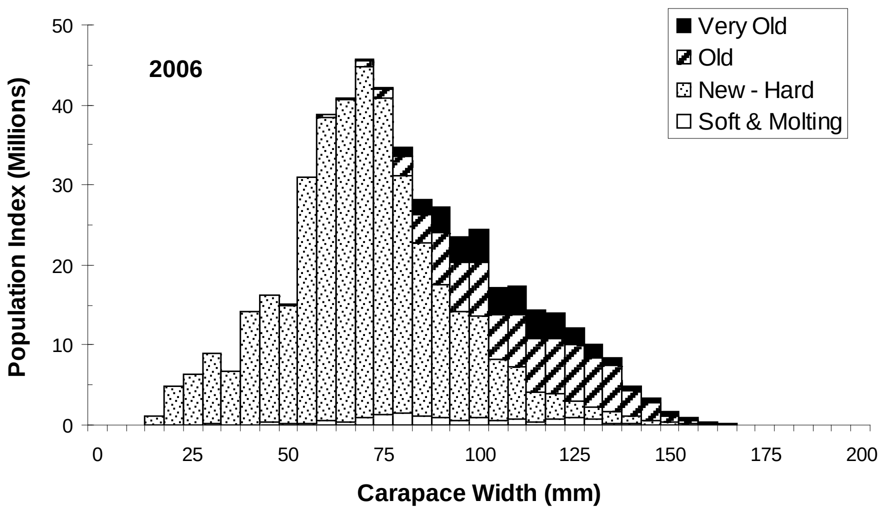



Figure 9. Percent change in Tanner crab stock abundance between the 2010 and 2011 summer trawl survey for males (< 110 mm cw, 110-137 mm cw, >= 138 mm cw and total males), females (<85 mm cw, >=85 mm cw and total females), and for total males + females combined.

(a)




(b)

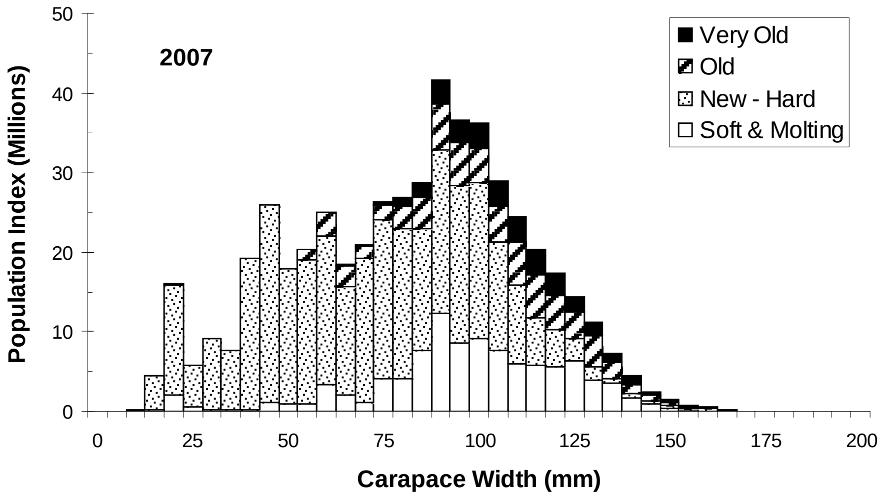
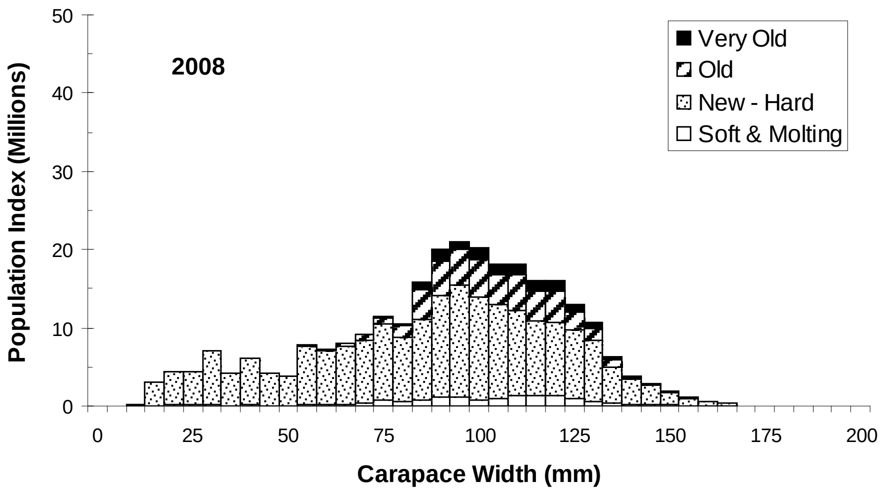



Figure 10 (a-b). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006/07 to 2007/08.

(c)




(d)

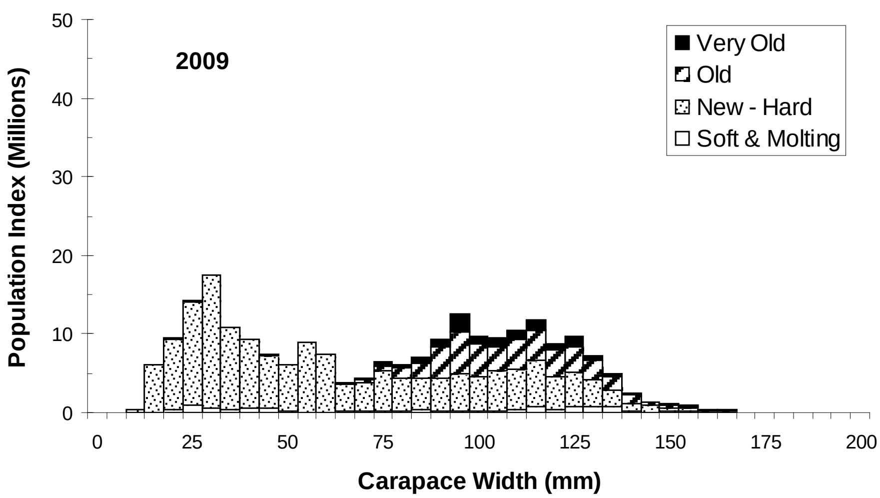
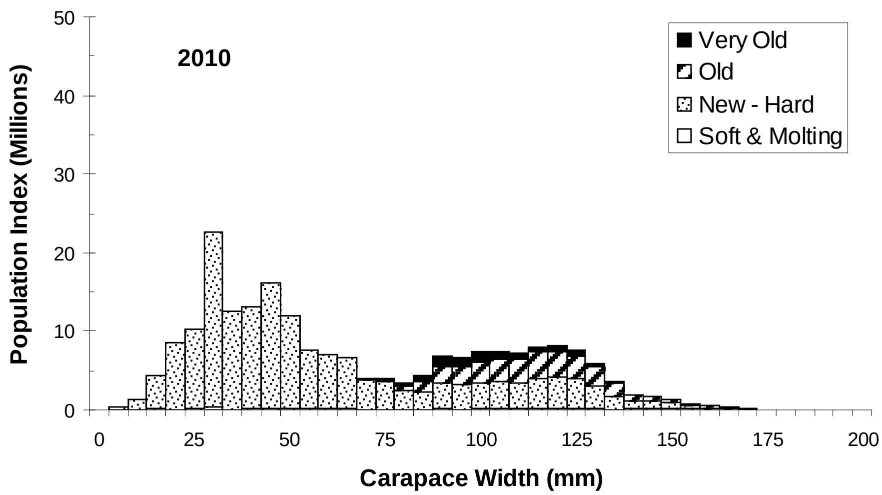



Figure 10 (c-d). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2008/09 to 2009/10.

(e)




(f)

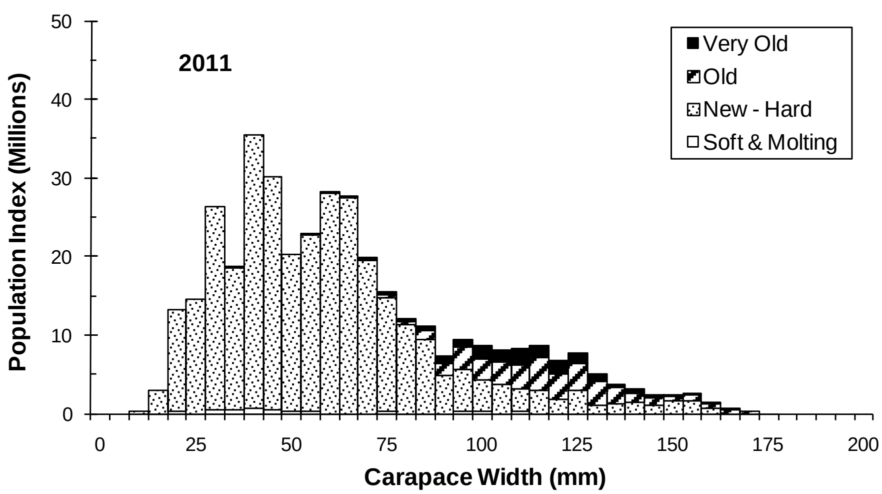
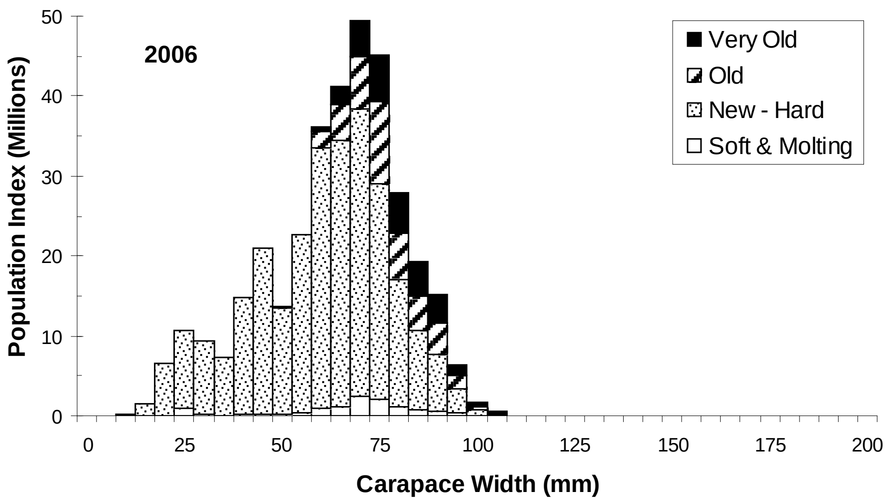



Figure 10 (e-f). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2010/11 to 2011/12.

(a)




(b)

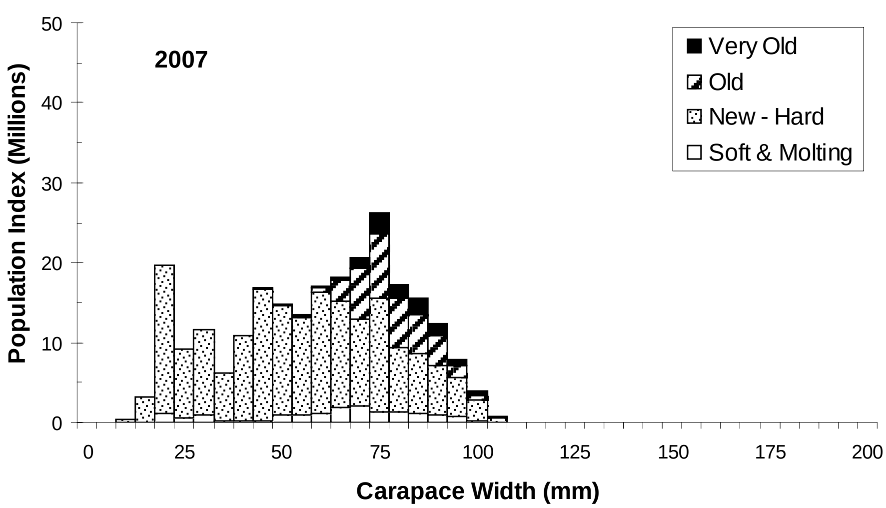
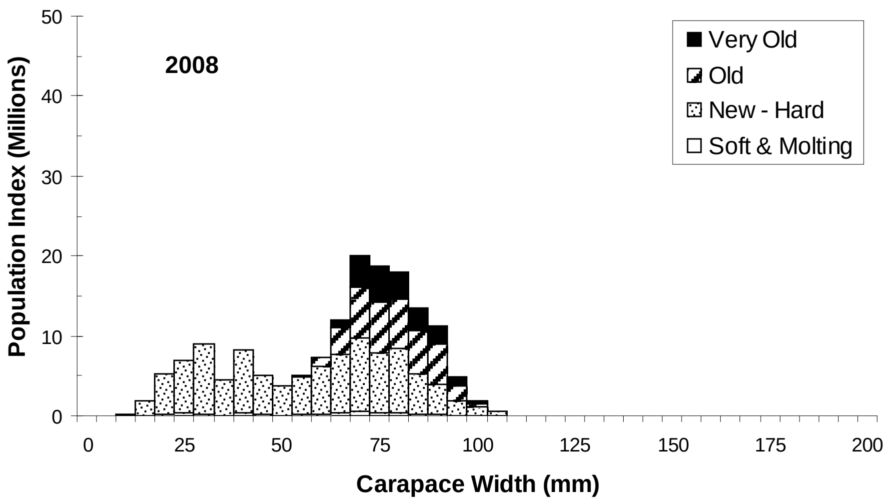



Figure 11 (a-b). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006/07 to 2007/08.

(c)




(d)

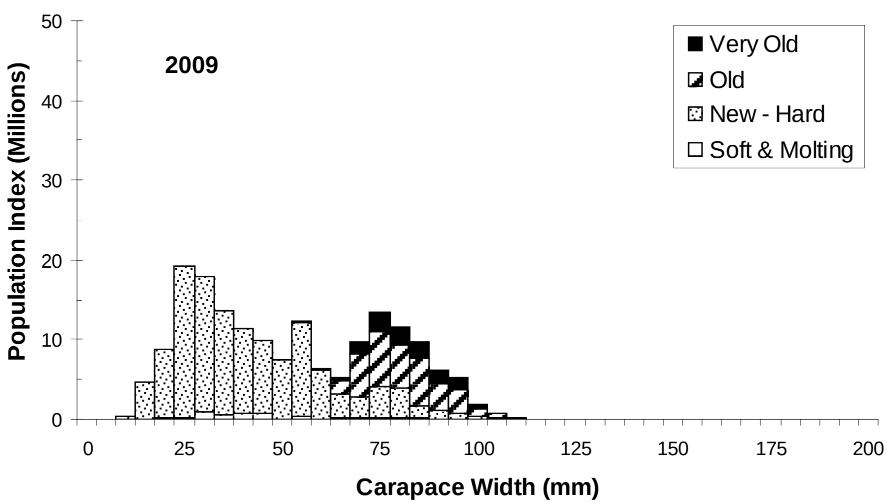
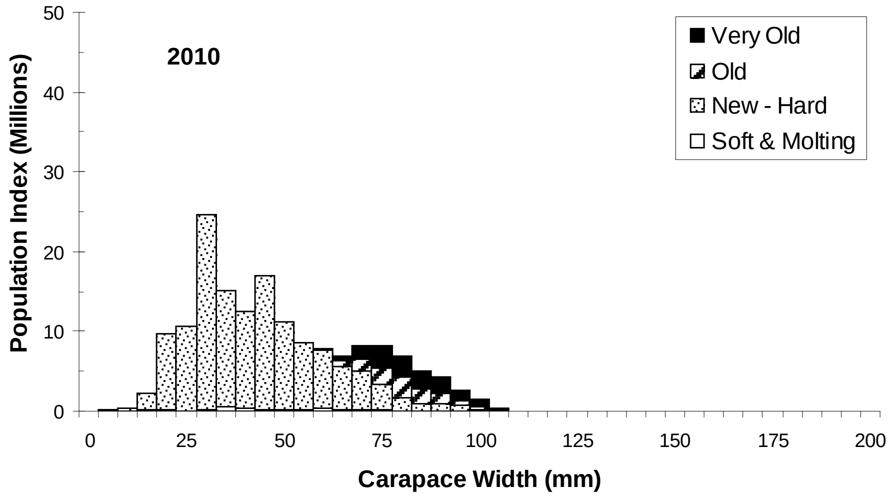



Figure 11 (c-d). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2008/09 to 2009/10.

(e)




(f)

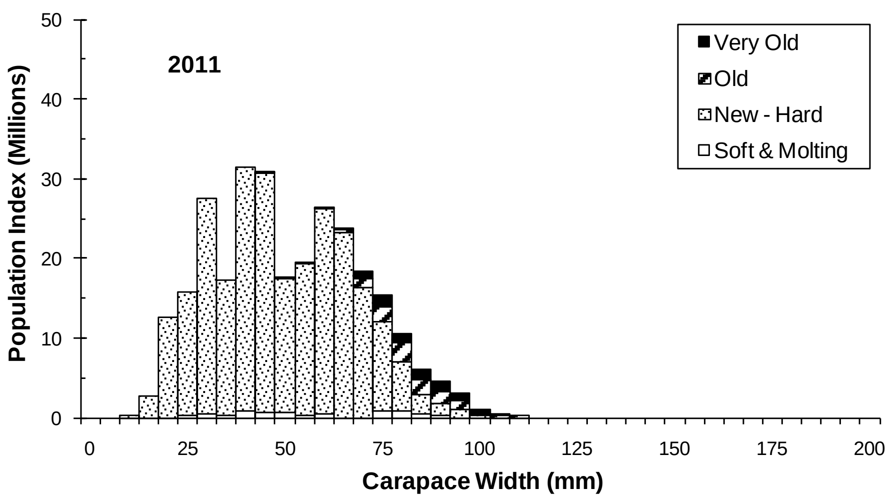



Figure 11 (e-f). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2010/11 to 2011/12.

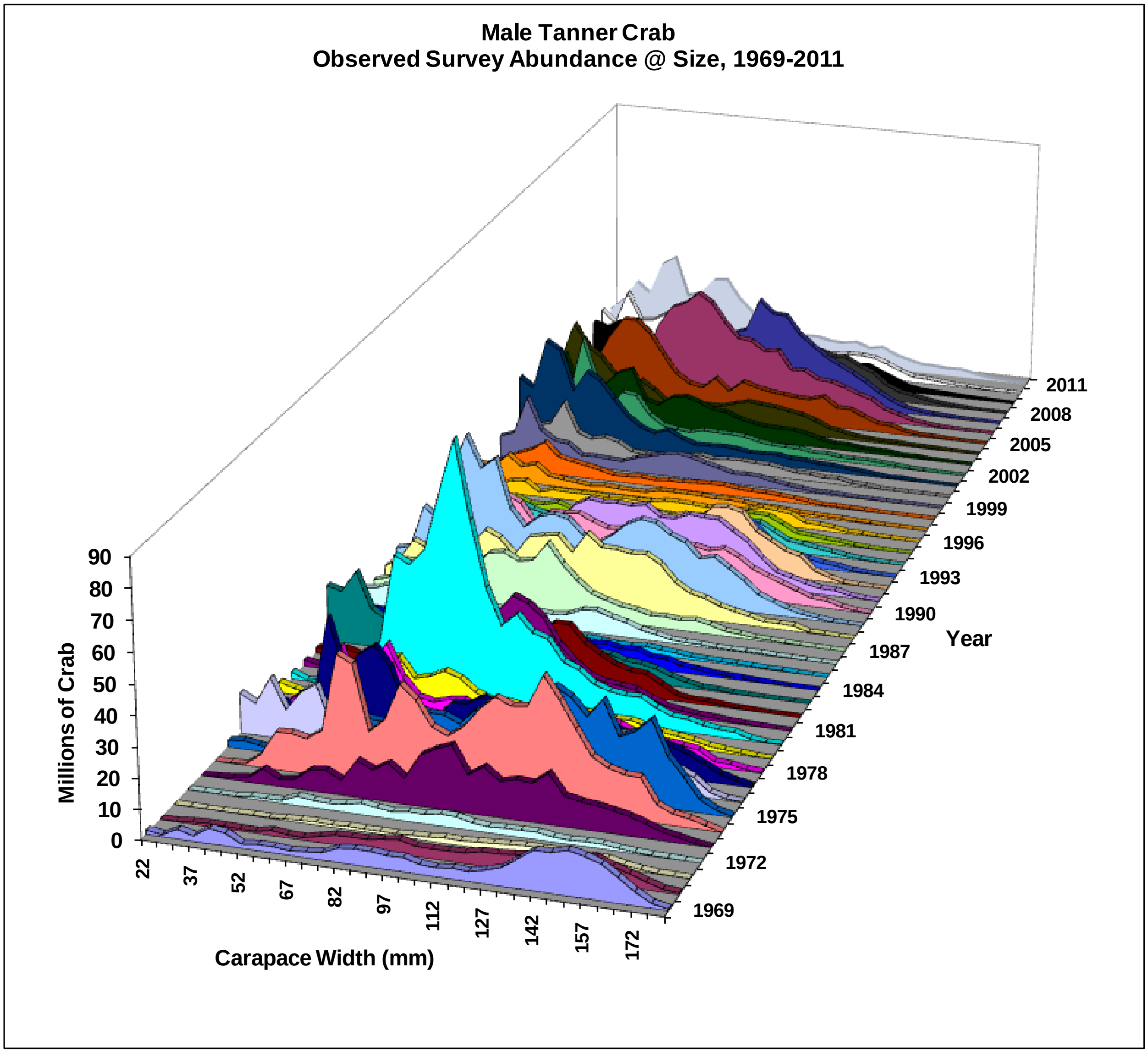



Figure 13. Observed male Tanner crab survey abundance (millions of crab) by carapace width for 1969/70 to 2010/11.

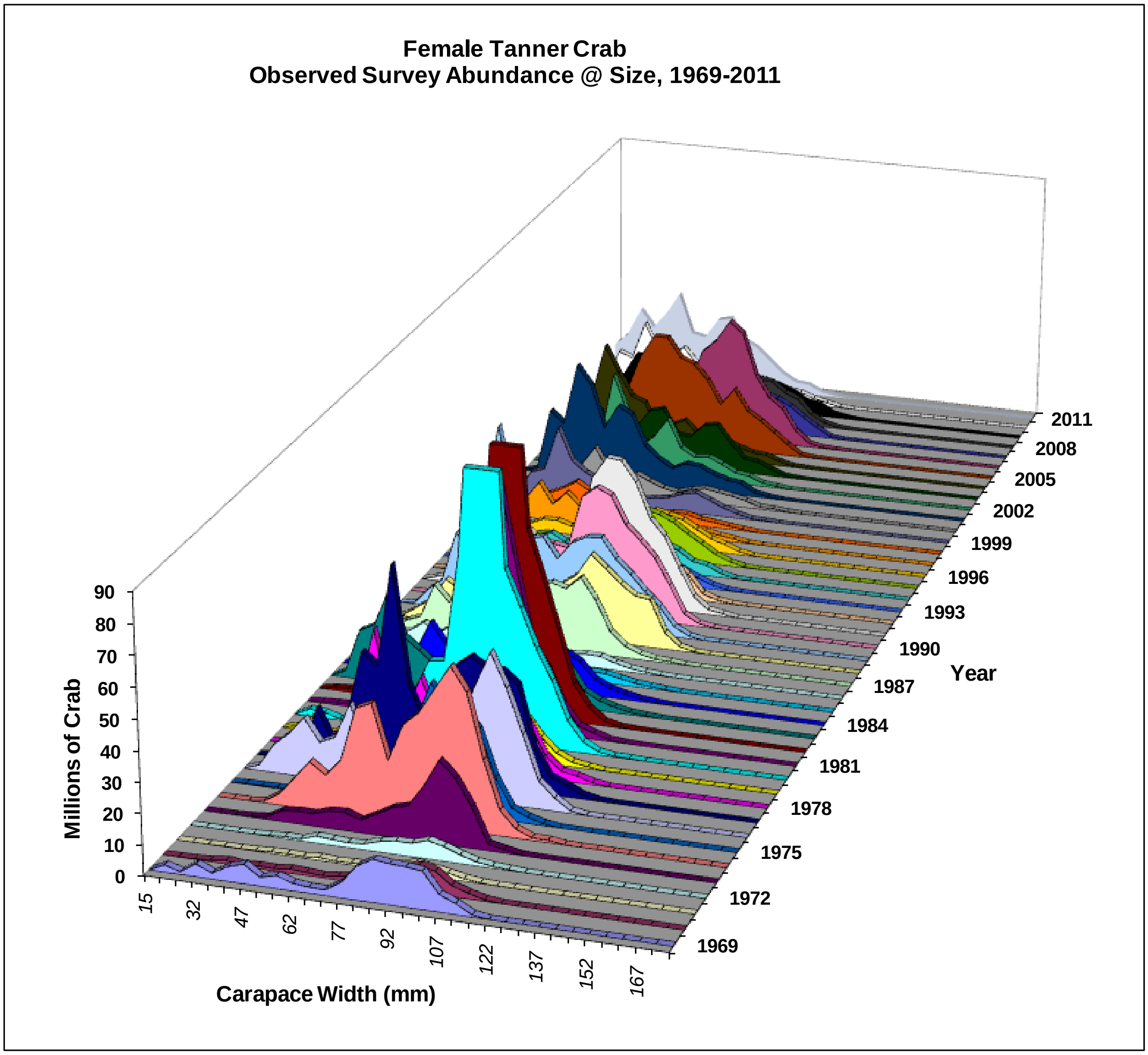



Figure 14 Observed female Tanner crab survey abundance (millions of crab) by carapace width for 1969/70 to 2010/11.

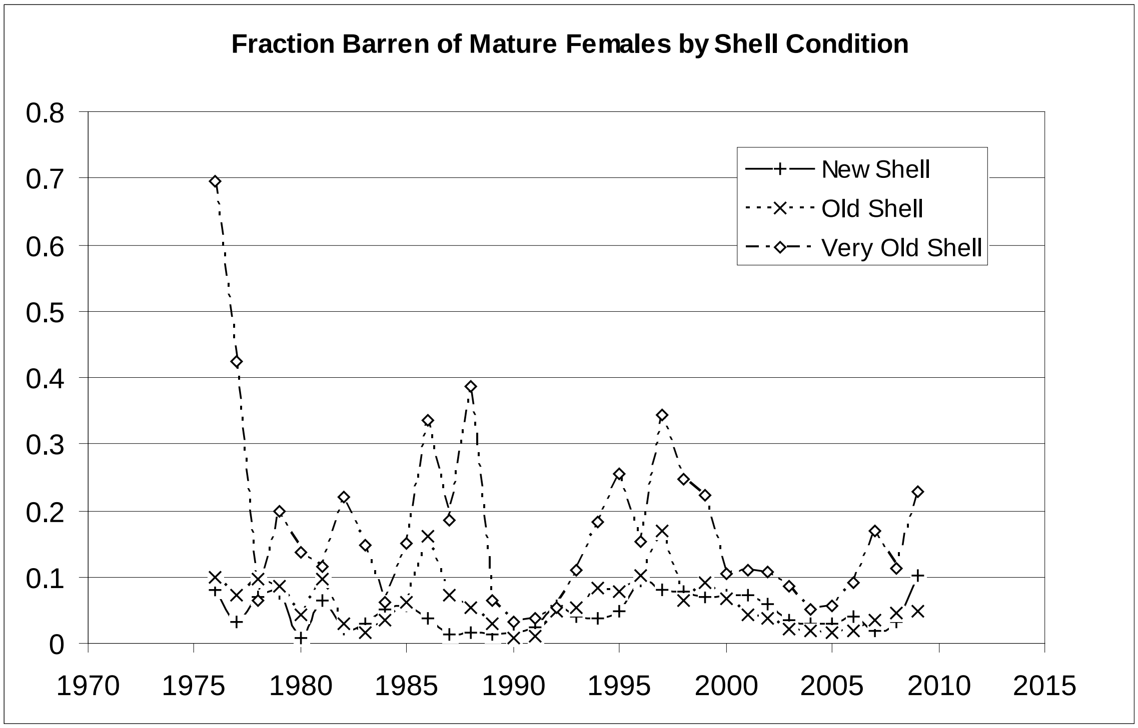



Figure 15. Proportion of female Tanner crab with barren clutches by shell condition from survey data for 1976/77 to 2009/10.

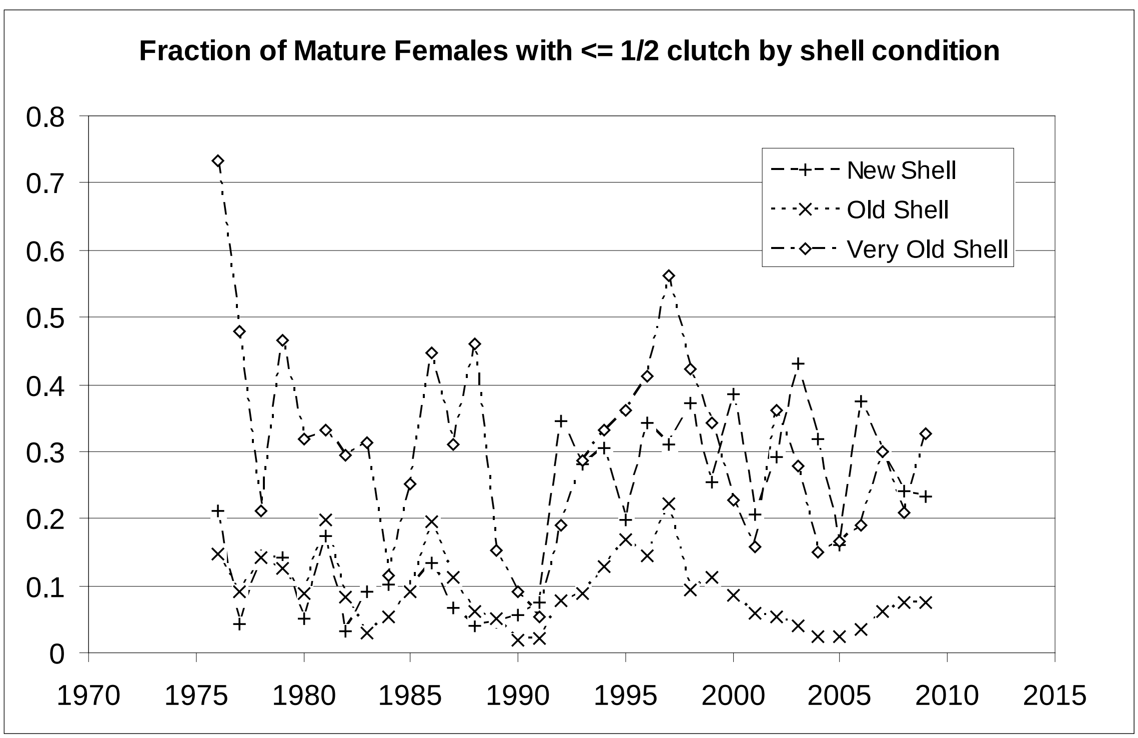



Figure 16. Proportion of female Tanner crab with less than or equal to one-half full clutch by shell condition from survey data 1976/77 to 2009/10.

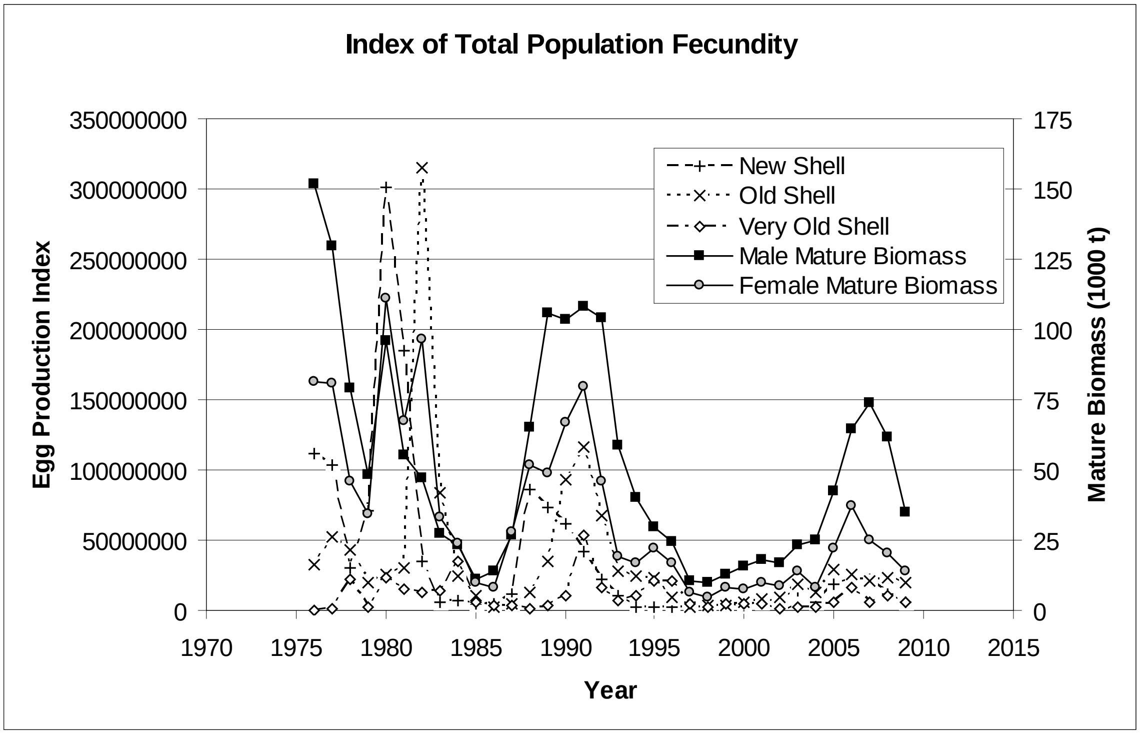



Figure 17. Tanner crab female egg production index (EPI) by shell condition, survey estimate of male mature biomass (1000 t), and survey estimate of female mature biomass (1000 t) from survey data for 1976/77 to 2009/10.

**Appendix A.**

Table A-1. Tanner crab management plan stock data table.

| Year | Survey Recruit Biomass (1000 t) | $MMB/B_{MSY}$ | Mature Biomass @Mating MMB (1000 t) | MFB (1000 t) | $\mu_{LMB}$ = Retained / LMB@ Fishery | Average F LMB@ Fishery (Retained) | Catch Biomass Retained (1000 t) | Total (1000 t) | Survey MMB Abundance ($10^6$ Crab) | Biomass (1000 t) | Survey FMB Abundance ($10^6$ Crab) | Biomass (1000 t) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1965/66 | | | | | | | 1.92 | 5.44 | | | | |
| 1966/67 | | | | | | | 2.44 | 8.37 | | | | |
| 1967/68 | | | | | | | 13.60 | 26.82 | | | | |
| 1968/69 | | | | | | | 18.00 | 31.17 | | | | |
| 1969/70 | | | | | | | 27.49 | 47.25 | | | | |
| 1970/71 | | | | | | | 25.49 | 45.41 | | | | |
| 1971/72 | | | | | | | 20.71 | 39.90 | | | | |
| 1972/73 | | | | | | | 16.90 | 29.98 | | | | |
| 1973/74 | | | | | | | 13.03 | 27.16 | | | | |
| 1974/75 | *n/a* | 1.72 | 143.20 | *n/a* | 0.18 | 0.20 | 15.24 | 33.63 | 349.84 | 206.29 | 276.35 | 94.87 |
| 1975/76 | | 2.28 | 189.99 | | 0.12 | 0.12 | 17.65 | 30.41 | 356.07 | 257.02 | 198.31 | 65.99 |
| 1976/77 | | 1.02 | 85.12 | | 0.36 | 0.44 | 30.02 | 45.20 | 221.89 | 151.60 | 222.97 | 81.13 |
| 1977/78 | | 0.71 | 58.90 | | 0.51 | 0.72 | 35.52 | 52.28 | 205.74 | 129.63 | 247.22 | 80.82 |
| 1978/79 | | 0.42 | 34.86 | | 0.56 | 0.83 | 21.09 | 32.42 | 135.50 | 79.18 | 142.24 | 45.89 |
| 1979/80 | | 0.14 | 11.71 | | 0.94 | 2.81 | 19.01 | 29.98 | 95.10 | 48.14 | 120.22 | 34.19 |
| 1980/81 | | 0.71 | 59.32 | | 0.49 | 0.67 | 13.43 | 22.73 | 260.96 | 95.65 | 420.27 | 111.32 |
| 1981/82 | | 0.47 | 39.17 | | 0.54 | 0.77 | 4.99 | 8.45 | 147.92 | 55.51 | 253.33 | 67.31 |
| 1982/83 | | 0.43 | 36.06 | | 0.40 | 0.51 | 2.39 | 4.12 | 107.93 | 46.84 | 369.80 | 96.63 |
| 1983/84 | | 0.26 | 21.94 | | 0.14 | 0.15 | 0.55 | 1.42 | 63.84 | 27.22 | 113.08 | 32.89 |
| 1984/85 | | 0.20 | 16.89 | | 0.25 | 0.29 | 1.43 | 3.00 | 49.19 | 23.18 | 77.64 | 23.92 |
| 1985/86 | | 0.11 | 8.78 | | 0 | 0 | 0 | 0.66 | 23.12 | 11.01 | 29.29 | 9.68 |
| 1986/87 | | 0.13 | 10.86 | | 0 | 0 | 0 | 0.93 | 40.46 | 13.74 | 25.54 | 7.85 |
| 1987/88 | | 0.24 | 19.66 | | 0.19 | 0.21 | 1.00 | 3.30 | 84.02 | 26.76 | 103.68 | 28.12 |

Table A-1. Tanner Crab management plan stock data table. (continued)

| Year | Survey Recruit Biomass (1000 t) | $MMB/B_{MSY}$ | Mature Biomass @Mating MMB (1000 t) | MFB (1000 t) | $\mu_{LMB}$ = Retained / LMB@ Fishery | Average F LMB@ Fishery (Retained) | Catch Biomass Retained (1000 t) | Total (1000 t) | Survey MMB Abundance ($10^6$ Crab) | Biomass (1000 t) | Survey FMB Abundance ($10^6$ Crab) | Biomass (1000 t) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1988/89 | | 0.56 | 46.81 | | 0.22 | 0.25 | 3.18 | 8.97 | 164.21 | 65.02 | 156.57 | 51.64 |
| 1989/90 | | 0.81 | 67.16 | | 0.38 | 0.49 | 11.11 | 23.47 | 237.22 | 105.65 | 163.65 | 48.96 |
| 1990/91 | | 0.57 | 47.86 | | 0.45 | 0.60 | 18.19 | 41.01 | 202.23 | 103.60 | 219.80 | 66.72 |
| 1991/92 | | 0.68 | 56.41 | | 0.46 | 0.62 | 14.42 | 36.53 | 218.32 | 108.34 | 254.94 | 79.42 |
| 1992/93 | | 0.72 | 59.89 | | 0.45 | 0.60 | 15.92 | 29.61 | 184.41 | 104.33 | 147.10 | 45.65 |
| 1993/94 | | 0.42 | 35.16 | | 0.46 | 0.61 | 7.67 | 15.25 | 104.46 | 58.76 | 62.91 | 19.41 |
| 1994/95 | | 0.32 | 26.36 | | 0.26 | 0.30 | 3.54 | 8.06 | 68.19 | 40.12 | 53.78 | 17.06 |
| 1995/96 | | 0.24 | 20.34 | | 0.23 | 0.26 | 1.92 | 5.07 | 51.80 | 29.62 | 72.51 | 22.37 |
| 1996/97 | | 0.22 | 18.70 | | 0.11 | 0.11 | 0.82 | 2.13 | 44.51 | 24.28 | 55.53 | 17.05 |
| 1997/98 | | 0.09 | 7.42 | | 0 | 0 | 0 | 1.53 | 24.41 | 10.43 | 21.06 | 6.26 |
| 1998/99 | | 0.08 | 7.07 | | 0 | 0 | 0 | 1.50 | 26.36 | 9.99 | 16.66 | 4.67 |
| 1999/00 | | 0.12 | 10.29 | | 0 | 0 | 0 | 0.69 | 40.36 | 12.80 | 29.30 | 8.29 |
| 2000/01 | | 0.16 | 13.20 | | 0 | 0 | 0 | 0.46 | 39.30 | 15.93 | 25.75 | 7.78 |
| 2001/02 | | 0.17 | 14.51 | | 0 | 0 | 0 | 0.75 | 54.49 | 17.79 | 37.44 | 9.74 |
| 2002/03 | | 0.17 | 13.98 | | 0 | 0 | 0 | 0.66 | 48.85 | 17.06 | 36.18 | 8.90 |
| 2003/04 | | 0.23 | 19.56 | | 0 | 0 | 0 | 0.33 | 68.02 | 23.19 | 55.82 | 14.13 |
| 2004/05 | | 0.25 | 20.83 | | 0 | 0 | 0 | 0.39 | 70.04 | 24.73 | 30.85 | 8.06 |
| 2005/06 | | 0.42 | 34.99 | | 0.05 | 0.05 | 0.43 | 1.38 | 109.17 | 42.40 | 86.31 | 22.06 |
| 2006/07 | | 0.63 | 52.84 | | 0.08 | 0.09 | 0.96 | 2.67 | 181.26 | 64.72 | 145.98 | 37.07 |
| 2007/08 | | 0.72 | 59.80 | | 0.10 | 0.11 | 0.96 | 3.30 | 195.38 | 73.56 | 88.99 | 25.23 |
| 2008/09 | | 0.61 | 50.80 | | 0.07 | 0.07 | 0.88 | 2.05 | 133.15 | 61.60 | 73.05 | 20.62 |
| 2009/10 | | 0.34 | 28.44 | | 0.10 | 0.10 | 0.60 | 1.58 | 77.35 | 34.99 | 48.35 | 14.17 |
| 2010/11 | | 0.32 | 26.73 | | 0 | 0 | 0 | 0.79 | 70.71 | 32.08 | 36.88 | 10.25 |
| 2011/12 | | | | | | | | | 107.39 | 41.78 | 64.11 | 15.70 |