2012 Stock Assessment and Fishery Evaluation Report for the Tanner Crab Fisheries of the Bering Sea and Aleutian Islands Regions

Louis J. Rugolo and Benjamin J. Turnock
Alaska Fisheries Science Center
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Overview of Model Development

The Tanner Crab Stock Assessment Model (TCSAM) was presented for review in February 2011 to the Crab Modeling Workshop (Martel and Stram 2011), to the SSC in March 2011, to the CPT in May 2011, and to the CPT and SSC in September 2011. The model was revised after May 2011 and the report to the CPT in September 2011 (Rugolo and Turnock 2011a) described the developments in the model per recommendations of the CPT, SSC and Crab Modeling Workshop through September 2011. In January 2012, the TCSAM was reviewed at a second Crab Modeling Workshop. Model revisions were made during the Workshop based on consensus recommendations. The model resulting from the Workshop was presented to the SSC in January 2012. Review findings and recommendations by the January 2012 Workshop and SSC, as well as the author's research plan guided changes to the model. A model incorporating all revisions recommended by the CPT, SSC and both Crab Modeling Workshops was presented to the SSC in March 2012.

In May 2012 and June 2012, respectively, the TCSAM was presented to the CPT and SSC to determine its suitability for stock assessment and the rebuilding analysis (Rugolo and Turnock 2012). The CPT agreed that the model could be accepted for management of the stock in the 2012/12 cycle, and that the stock should be promoted to Tier-3 status. The CPT also agreed that the TCSAM could be used as the basis for rebuilding analysis to underlie a rebuilding plan scheduled for developed in 2012. In June 2012, the SSC reviewed the model and accepted the recommendations of the plan team. The Council approved the SSC recommendations in June 2012. For 2011/12, the Tanner crab is assessed as a Tier-3 stock and the model will be used to estimate status determination criteria and overfishing levels.

Review of Status of the Stock

Tanner crab male mature biomass (MMB) in 2009/10 declined 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 by 8.3% relative to 2009. Under the plan, MMB estimated at the time of mating accounts for losses due to natural morality from survey time to mating and losses due to directed and non-directed fishing. For the 2009/10 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 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 was below the limit that defined 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, plus losses from non-directed fishing were considered. No directed fishing occurred in 2010/11 due to a 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 represented a ratio of 0.32 relative to $B_{MSY\ Proxy}$ which remained below the limit (41.67 thousand t) that defines an overfished stock (Rugolo and Turnock 2011b). Thus, there was no change in the 2010/11 stock relative to the overfished determination made in 2010.

For the current 2011/12 stock status determination under Tier-4 management, losses from the time of the 2011 survey to mating in 2012, plus losses from non-directed fishing were considered. The directed fishery in 2011/12 was again closed to fishing. After accounting for losses from M and the 2011/12 non-directed pot and groundfish fisheries, the 2012 MMB at the time of mating is 34.67 thousand t (+29.7% relative to 2011). This represents a ratio of 0.42 relative to $B_{MSY\ Proxy}$ which remains below the limit of 41.67 thousand t that defines an overfished stock based on the Tier-4 assessment (Rugolo and Turnock 2011a). There was no change in the 2011/12 stock relative to the overfished determination made in 2010.

The status of the 2011/12 Tanner crab stock under Tier-3 management is yet to be determined. It is unclear how results of the model that will be implemented for the 2012/13 fisheries can be applied retroactively for the 2011/12 stock status determination since the 2011/12 benchmark reference points and overfishing definitions were based on the survey-based Tier-4 assessment. For the 2012/13 fisheries, a Tier-3 status determination will depend on the value of the $B_{35\%}$ proxy for B_{MSY} adopted by the Council in October 2012.

In Appendix A, we present results of a rebuilding analysis using output from *Model (0)* and *Model (1)* as inputs to a stock projection model in order to evaluate the consequences of alternative harvest strategies on stock rebuilding and fishery performance.

EXCUTIVE SUMMARY

In 2012, Tanner crab MMB at the time of the survey was estimated at 45.8 thousand t representing a 9.7% increase relative to 2011. Mature male abundance rose 40.6% relative to 2011 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 (Figure 1). Legal male abundance decreased 48.2% to 7.1 million crabs between 2011 and 2012 Legal males were distributed 63.1% (4.5 million crabs) east and 36.9% (2.6 million crabs) west of 166^0 W longitude compared to 37.1% (east) and 62.9% (west) in 2011 (Rugolo and Turnock 2011b). The 2012 abundance index for pre-recruit male crabs (110-137 mm cw) increased 4.6% relative to 2011, and that for small males (<110 mm cw) increased 19.2% relative to 2011 (Figure 2). Total male abundance increased 15.3% between 2011 and 2012. MMB in 2012 increased 9.7% relative to 2011. Compared to the 2011 survey, male recruit biomass (<110 mm cw) increased 89.7%, pre-recruit biomass (110-137 mm cw) decreased 0.6%, legal male biomass decreased 49.8% and total male biomass increased 26.2%. Total male abundance in 2012 was comprised of 60.6% immature, 30.8% new shell mature and 8.6% old shell mature males. Among all legal-sized males, 64.2% were old shell and 35.8% new shell.

Comparison of the male size frequency distributions between 2006 and 2012 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 3 a-g). The male size frequency distribution in 2011 (Figure 3 f) illustrates an apparent increase in pre-recruit abundance between 25-70 mm cw. The recruit mode (20-40mm cw) seen in 2009 (Figure 3 d) grew to 30-50 mm cw in 2010 (Figure 3 e) and to 55-65 mm cw in 2011 (Figure 3f). The increase in male abundance in 2011 is encouraging particularly for recruit-sized crab (<110 mm cw). The percentage of old and very old shell males in the 2012 mature stock declined relative to 2011. The size frequency distribution in 2012 (Figure 3 g) reveals a strong 55-65 mm mode of abundance which is consistent with that seen in 2011.

Large female (>=85 mm cw) Tanner crab increased 75.5% in abundance in 2012 relative to 2011 (Figure 2). Total female abundance in 2012 was comprised of 60.6% immature, 30.8% new shell mature and 8.6% old shell mature females. Among all female Tanner crab in 2012, 7.8% were collectively old shell and 92.2% new-hard shell. Small females (<85 mm cw) decreased by 10.7% relative to 2011. Total 2012 female abundance decreased 6.2%. Total survey abundance of males and females combined increased 6.2% over that in 2011 driven by the increase in small male and large female crabs. The distribution of ovigerous, barren and immature female Tanner crab is shown in Figure 4. The survey length frequency distributions of female Tanner crab from 2006-2012 reveals consistently declining abundance across the size modes and the general failure of modes of abundance to persist inter-annually (Figures 5 a-g). 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 5 d), which was dominated by old and very old shell females, declined substantially in 2010 (Figure 5 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 5 e) which grew to 55-70 mm cw in 2011 (Figure 5 f). The female size frequency distribution in 2011 (Figure 11 f) reveals an apparent strong pre-recruit abundance mode between 30-50 mm cw. This mode did not persist into 2012 (Figure 5 g).

The 5 mm length frequency abundance observed in the survey for male and female crab from 1969/70 to 2011/12 is shown in Figures 6 and 7 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	41.67[2/]	26.73	1.45	0	0	0.87
2011/12	41.67	33.20[3/]	2.63[4/]	0	0	1.24

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 2011/12, Tanner crab MMB was below the Tier-4 MSST at the time of the 2011 survey, and at the time of the 2011/12 fishery, and at the time of mating in February 2012. Overfishing did not occur in 2011/12 as total catch (1.24 thousand t) did not exceed the total catch OFL (2.63 thousand t). The 2011/12 MMB at the time of mating represented a ratio of 0.42 relative to $B_{MSY\ Proxy}$. The 2011/12 Tanner crab stock is overfished based on the Tier-4 assessment. In 2012 at the time of the survey, Tanner crab MMB increased 9.7% relative to 2011.

A. SUMMARY OF MAJOR CHANGES

1. Management of Fishery:

No changes relative to the 2011 Tanner crab SAFE (Rugolo and Turnock 2011b).

2. Input Data:

No changes with the exception of the inclusion with the 2011/12 survey and fishery data.

3. Assessment Methodology:

This stock assessment and fishery evaluation report is based on a length-based stock assessment model. The model was approved by the Council in June 2012 for use in stock status determination, setting overfishing definitions, and rebuilding analysis. For the 2011/12 stock status determination and the 2012/13 OFL-setting, the Tanner crab stock is promoted to Tier-3 status.

B. RESPONSES to SSC and CPT COMMENTS

During the development of the TCSAM, we implemented extensive revisions following review comments and recommendations of the CPT, SSC and two Crab Modeling Workshops. Two periods of model revisions are described: the first, from May to September 2011, and the second from September 2011 to

May 2012. Rugolo and Turnock (2011a) reported on model developments in this first period per reviews of the Crab Modeling Workshop (Martel and Stram 2011), SSC in March 2011, CPT in May 2011, and CPT and SSC in September 2011. The TCSAM was reviewed at a second Crab Modeling Workshop in January 2012 and revisions made based on consensus recommendations. Rugolo and Turnock (2012) reported on model developments in the model during this second period per reviews of the January 2012 Workshop.

1. Responses to SSC and CPT Comments

June 2011 SSC Meeting

In their review of the 2011 draft crab SAFE report, the SSC made the following 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 (model) reviews were discussed:*
    - *Hybrids: 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 significant 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 raised about misidentification of snow crabs. 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 (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 Tanner model for population projections despite its lack of approval for assessment. The SSC urges caution 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 proceed 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.*

The TCSAM has been extensively revised since the May 2011 CPT meeting. We formulated several model configurations to show the effects of principal changes to the model, and recommend a model that attended to 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. The CPT and SSC will review the model in September 2011.

The potential degradation of the Tanner retained catch by misidentification of hybrid crab was addressed. The early bycatch data in the groundfish fishery was validated. The *Base Model* estimates survey selectivity in the period (1982-1987) to improve survey biomass fit in the mid-1980s. The model estimates growth, natural morality on immature and mature male and female crab, and includes different directed and non-directed fishery selectivity periods to improve model performance.

May 2011 CPT Meeting
In their review of the draft 2011 SAFE, the CPT made the following comments and recommendations. Only comments on the assessment model are included here:

- *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*
    - *examine dynamic B_0, i.e. what would have happened has the fishery never occurred*
- *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 TCSAM has been extensively revised since the May 2011 CPT meeting and showed improved performance over earlier intermediate versions seen by the Crab Workshop, SSC in April 2011 and CPT in May 2011. The authors recommend a *Base Model* of demonstrating improved performance modeling stock and fishery dynamics and presented results of a stock projection model run using the *Base Model* configuration as a case example of its utility for rebuilding analysis.

In the *Base Model*, survey Q is freed in the three time periods and informed by the results of the underbag study. Male and female growth, and immature and mature male and female natural mortality are estimated. We examined the length compositions and all data to evaluate survey data fit, and modified the model accordingly. We implemented several selectivity time-blocks in the directed and non-directed fisheries to explore data fits and adopted time-blocks as required.

May 2012 CPT and June 2012 SSC Meetings
In their review of the TCSAM, the CPT and SSC made the following comments and recommendations for September 2012. Recommendations are grouped in two categorizes – those related to model output or presentation, and those related to model code revisions. The Council recommended a set of '*Longer-Term Tasks*' that the authors should consider as long-term research goals.

1. *Model Output or Presentation Issues:*

- *Update the weights in Table 8 (all LF weights = 1.0) and replace weights by CVs where possible.*
- *Plot input sample sizes for LF data vs. effective sample sizes inferred by the fit of the model.*
- *Indicate reference size for survey Q on plots of survey Q vs. length.*
- *Include a summary of the Somerton and Otto (1999) underbag experiment. Confirm the variance of survey Q matches that assumed in model.*
- *Add an appendix which details the effort series and their derivation.*
- *Add formulae used to calculate input sample sizes.*
- *Add equations on how full-selection F is calculated for years without catch using effort and a fishing mortality relationship.*
- *Update the plot of M vs. time for Bristol Bay red king crab.*
- *Check bubble plots are based on Pearson residuals and add key to indicate what largest circle means.*
- *Check that summary plots are sums over observed and predicted proportions.*
- *Add confidence intervals on the data to the summary plots for the compositional data.*
- *Label selectivity pattern plots better to indicate which curve applies to which year.*
- *Clearly indicate the current year on OFL Control Rule Figure 39.*
- *Add horizontal lines to effective sample size Figure 1 of the average input effective sample size by fleet.*
- *The model estimate of population biomass at the time of the survey should be a dotted line while the model estimate of survey biomass should be a solid line for Figures 17 & 18.*
- *Include a plot of the fits to survey biomass from reference model presented to September 2011 CPT meeting, the model at the end of the January 2012 workshop, and the May 2012 reference model.*
- *Since there are potentially a large number of runs, the document should contain results and diagnostics for reference model, as well as plots of recruitment and MMB time-series, and tables of likelihood components for the remaining runs. The full set of diagnostic plots should be made available electronically (e.g., using a "Dropbox")*

We've completed all output and presentation recommendations with the exception of the #5 and #11. The authors did not derive the time series of pot effort from the BSAI crab fisheries (#5). Data should be provided from its source and we recommend that persons contact the SOA for details and to obtain the effort data. We've not yet added CIs to the summary plots of length compositions (#11) and will do so in the next release of the document.

2. *Model Code Revisions:*

- *Use ADMB derivative checker to check for impacts of non-differentiability of objective function implemented in the code.*
- *Explore sensitivity of dropping lower bound for input sample sizes (a lower bound of 4 was imposed for reference model).*
- *Explore sensitivity of allowing input sample sizes for survey LF to vary over time – if there's basis that some years better estimate of length composition than other years.*
- *Allow for a difference in selectivity by sex for groundfish fishery**;** resolves poor residual pattern.*
- *Allow M for immature as well as mature males to change during 1980-83.*
- *Include the following model runs for September 2012:*
    - *The current reference model (as modified by 3rd and 4th bullet).*
    - *Alternative specifications related to Ms (1-run as modified by 5th bullet).*

- *A likelihood profile for survey-q for males.*
- *Alternative specification related to dropping lower bound for input sample sizes.*
- *Runs identified in ToR (e.g., retrospective patterns & runs based on changing emphasis on different likelihood components).*

We've completed all model code revisions with the exception of the last sub-bullet to #6. We've not conducted retrospective analysis of the models presented here nor conducted runs based on changing emphasis on different likelihood components.

3. Long-Term Research:

- *Consider implementing changing penalty weight on F-deviations as function of estimation phase.*
- *Consider treating all of F-deviations (except for which catch is known to be zero) as parameters, and include the fishing mortality-effort relationship as a prior.*
- *Consider different input sample sizes for each category of survey compositional data (e.g., males, females, mature, immature).*
- *Consider fitting to total biomass (by sex?) and compositional data rather than mature biomass, and include the fit to the mature biomass by sex as a diagnostic.*
- *Do not fit to male compositional data by maturity state for the years for which chela height – maturity relationships are not available.*
- *Base the assessment on code which is fully documented and for which the objective function is differentiable.*

The Council recommended that the authors should consider these items as as long-term research goals for the model. The objective function of the assessment model is fully differentiable (#6).

C. INTRODUCTION

Tanner crab *Chionoecetes bairdi* is one of five species in the 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, although sub-legal sized males (≤138 mm cw) and ovigerous and immature females of all sizes are distributed broadly from southern Bristol Bay northwest to St. Matthew Island (Rugolo and Turnock 2011a). The southern range of the cold water congener the snow crab, *C. opilio*, in the EBS is near the Pribilof Islands (Turnock and Rugolo 2011b). The distributions of snow and Tanner crab overlap on the shelf from approximately 56° to 60°N, and in this area, the two species hybridize (Karinen and Hoopes 1971).

1. 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 (Figure 8). Somerton (1981a) suggests that clinal differences in some biological characteristics may exist across the range of the unit stock. These conclusions may be limited since terminal molt at maturity in this species was not recognized at the time of that analysis, nor was stock movement with ontogeny considered. Biological characteristics estimated based on comparisons of length frequency distributions across the range of the stock, or on modal length analysis over time may be confounded as a result.

Despite the custom of setting management controls for this stock east and west of 166° W longitude, the unit stock of Tanner crab in the EBS comprises crab throughout the geographic range of the NMFS bottom trawl survey. Evidence is lacking that the EBS shelf is member to two distinct, non-intermixing, non-interbreeding stocks that can be assessed and managed separately.
Given the distribution 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 area fisheries consistent with the total catch OFL.

D. FISHERY HISTORY

1. 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 State of Alaska (SOA) with federal oversight (Bowers et al. 2008). The SOA 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 8) 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 effective for the 2011/12 fishery. The 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° West 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° West longitude, respectively.

The domestic Tanner crab pot fishery rapidly developed in the mid-1970s (Table 1, Figure 9). For stock biomass and fishery data tabled in this document, the convention is that ‘year’ refers to the survey year (t), and fishery data are those subsequent to the survey (t+1) through prior to year t+1 – e.g., 2008/09 is the 2008 summer survey and the winter 2009 fishery. Other notation is explicit. 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 1). 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 1, Figure 9). Landings fell sharply after the peak in 1977 through the early 1980s, and domestic fishing was closed in 1985 and 1986 due to 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. The domestic Tanner crab fishery closed between 1997 and 2004 as a result of conservation concerns regarding depressed stock status. The domestic Tanner crab fishery re-opened in 2005 and has averaged 0.77 thousand t retained catch between 2005-2009/10 (Table 1). Landings of Tanner crab in the Japanese pot and tangle net fisheries were reported between 1965-1978, peaking at 19.95 thousand t in 1969. 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 (Table 1, Figure 9).

For the 2010/11 and 2011/12 seasons, the SOA closed directed commercial fishing for Tanner crab due to estimated female stock metrics threshold in the state strategy.

Discard and bycatch losses of Tanner crab originate from the directed pot fishery, non-directed snow crab and Bristol Bay red king crab pot fisheries, and the groundfish fisheries (Table 2). Discard mortalities were estimated using post-release handling mortality rates (HM) of 50% for pot fishery discards and 80% for groundfish fishery bycatch (NPFMC 2008). The pattern of total discard/bycatch losses is similar to that of the retained catch (Table 1). Losses were persistently high during the early-1970s; a subsequent peak mode of discard losses occurred in the early-1990s. In the early-1970s, 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. Tanner crab predicted retained plus discard catch in the directed fishery (Table 3, Figure 10) and bycatch losses of male and female crab in the non-directed fisheries (Table 4) 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 (Table 5, Figure 10). Total male catch rose sharply after the directed domestic fishery reopened in 1987 and reached a peak of 45.07 thousand t in 1990 (Table 5). Total male and female catch fell sharply thereafter with the collapse of the stock and the fishery closure in 1997.

After the Tanner crab stock declined to low levels by the early-1980s, retained catches were low and variable. Since the re-opening in 2005, retained catch has routinely been below the total catch OFL. A specialized directed Tanner crab fishery has not developed since 2005 due to low quota sizes, and the majority of catch is taken incidentally in the Bristol Bay red king crab fishery and the snow crab fishery that hold Tanner shares. After the development of the domestic fleet in late-1970s, the contribution to total catch from a specialized directed fleet versus incidental catch by the snow and red king crab fisheries is not well understood and, unlike the snow crab and Bristol Bay red king crab fisheries with defined fishing practices (e.g., seasons, areas and gear), the current directed Tanner crab fishery is much less defined.

2. Exploitation Rates

The historical patterns of fishery exploitation on legal male biomass and male mature biomass were derived. The exploitation rate on LMB was estimated as the predicted retained catch biomass divided by the estimated legal male biomass at the time of the fishery, while that on MMB as the predicted total catch biomass (retained plus discard) divided by the estimated male mature biomass at the time of the fishery. The patterns of exploitation rates on LMB and MMB are similar over the period of record, 1969-2011 (Figure 11). Exploitation rates were high in the late-1970s to early-1980s and fell with stock condition through the mid-1980s, followed by a second period of prominent rates during the early-1990s. The pattern of fishery exploitation of this stock coincides with the modes of high catches in the late-1970s and the early-1990s (Table 5, Figure 10). These high rates of exploitation on MMB and LMB exceed the mortality at M=0.23 for this stock; the EBS Tanner crab stock did not persist at sustainable levels subjected to these rates. Rugolo and Turnock (2011b) discuss the history of exploitation rates on the male Tanner crab stock based on observed survey data and conclude that these exceeded rates would be deemed biologically reasonable, and led to the erosion of stock biomass. Exploitation rates on mature and legal male biomass since the start of the rebuilding plan in 1998 have been low (Table 6).

E. DATA

1. The Survey

The NMFS conducts an annual bottom trawl survey in the EBS to determine the distribution and abundance of commercially-important crab and groundfish fishery resources (Foy and Armistead 2012). The survey has been conducted since 1968 by the Resource Conservation and Engineering Division of the Alaska Fisheries Science Center. In 1975, it was 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 (Chilton et al. 2011). Near St. Matthew Island and the Pribilof Islands, additional tows are made at the corners of squares that define high density sampling strata for blue king crab and red king crab.

The 83-112 eastern otter trawl (83 ft/25.3 m headrope and 112 ft/34.1 m footrope) has been the standard gear since 1982. Each tow is approximately 0.5 h in duration towed at 3 knots conducted in accordance with established NMFS groundfish bottom trawl protocols (Stauffer 2004). Between 1968-1981, the 400 eastern otter trawl was the survey gear deployed and towed for approximately 1.0 h at 2.0 knots. 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 behavior. The observed male, female and total mature biomass, and observed abundance of legal male Tanner crab are shown in Table 7).

2. Data Sources

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 for 1974-2012. As recommended by the Crab Workshop (Martel and Stram 2011), 1969-1973 survey data are excluded from the analysis. The pre-1974 survey did not consistently sample Tanner habitat which resulted in variable and biased low biomass estimates and length frequency distributions. Each year from 1969-1973 represented a unique coverage ranging from 25% to 72% of the total Tanner distribution sampled since 1978 (Foy, pers. comm.). The male and female 5 mm length frequency abundance observed in the survey for 1969-2012 are shown in Figure 6 and Figure 7, respectively.

Size frequency data on retained Tanner crab in the directed fishery from 1981-1996 and 2005/06 to 2011/12 seasons were used in the analysis. Observers were placed on board directed crab vessels starting in 1990, and dockside sampling of the retained catch began in 1981. Length frequency data on the total catch and the retained catch in the directed fishery were available from 1991-2011/12 and 1981-2011/12 absent fishery closures. Retained catch data were available for 1974-2011/12. Total discard catch biomass was estimated from observer data from 1991 to 2011/12. The discard male catch was estimated from 1969-1990/91 in the model using the estimated fishery selectivity based on observer data from 1991-2011/12 and an applied post-release mortality rate of 50% for pot released crab. Male and female length frequency and catch biomass data in the snow crab fishery were available from 1989-2011/12.

Male and female length frequency and catch biomass data in the Bristol Bay red king crab fishery were available from 1989-1993 and 1996-2011/12. Trawl discard catch biomass estimates and the length frequency of discard crab included in the model were from 1973 to 2011/12.

The following table contains the various Tanner crab data components used in the model,

Data Component	Years
Retained length frequency by shell condition of male crab in directed fishery	1981-1996, 2005-2011/12
Total catch length frequency of male and female crab in directed fishery	1991/92-1996/97, 2005/06-2011/12
Male and female length frequency and catch in snow crab fishery	1989/90-2011/12
Male and female length frequency and catch in red king crab fishery	1989-1993, 1996-2011/12
Retained catch in directed fishery	1969-2011/12
Trawl discard catch and length frequency	1973-2011/12
Survey length frequency by sex and shell condition	1974-2012
Survey biomass estimates and coefficients of variation	1974-2012

F. LIFE HISTORY

1. 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 recruit to legal size (NPFMC 2007).

Although observations are lacking in the EBS, seasonal differences have been observed between mating periods for pubescent and multiparous 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).

2. Fecundity

A variety of factors affect female fecundity including somatic size, maturity status (primiparous vs. multiparous), age post terminal molt, and egg loss (NMFS 2004a). Of these factors, somatic size is the most important, with estimates of 89 to 424 thousand eggs for females 75 to 124 mm cw respectively (Haynes et al. 1976). Maturity status is another important 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 crab reproductive output is a declining function of age (NMFS 2004a).

The fraction of barren mature females by shell condition (Figure 12) and the fraction of mature females with clutches one-half full or less by shell condition (Figure 13) 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 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 14). Figure 14 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.

3. Size at Maturity

We estimated the maturity at length schedules for male and female Tanner crab from extant trawl survey data. For females, egg and maturity code information collected on the survey from 1976-2009 was analyzed to estimate the maturity curves for new shell females, and for the aggregate class of females all shell conditions combined (Figure 15). $SM_{50\%}$ 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 2008 collection of morphometric measurements taken at 0.1 mm in 2008 on the NMFS survey served 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. These rules were then applied to historical survey data from 1990-2007 to apportion male crab to immature and mature population mature at length. 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. $SM_{50\%,}$ 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 (Figure 16). By comparison, Zheng (1999) in development of the current SOA harvest strategy used knife-edge maturity at >79 mm cw for females and >112 mm cw for males.

The maturity curve for new shell females can be considered to represent the conditional probability of new shell immature females maturing given a representative sample of the length composition in the stock by shell condition class and no error in shell classification. For the *Model(0)* run presented here, the probability of maturing by size for males and females was estimated in the model with the constraint to be a smooth function (Figure 17). For comparison, the probability of new shell immature males maturing used by Zheng in the Amendment 24 analysis of overfishing definitions is shown in which $SM_{50\%}$=130.9 mm cw (NPFMC 2007) (Figure 17). We allow the assessment model to estimate a smooth function for both sexes that represents the probability that a new shell immature crab will molt to maturity which is distinguished from the average fraction of new shell mature crabs in the stock.

4. Mortality

Due to the lack of age information, Somerton (1981a) estimated mortality separately for individual EBS cohorts of juvenile (pre-recruit) and adult Tanner crab. Somerton postulated that because of net selectivity, age five 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 this analysis with two different data sets, Somerton estimated natural mortality rates of adult male crab from the fished stock to range from 0.20 to 0.28. When using CPUE data from the Japanese fishery, estimates 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 reliable estimates of oldest observed age for male Tanner crab. Unlike its congener the snow crab, information on longevity of the Tanner crab is lacking. We reasoned that longevity in a virgin population of Tanner crab would be analogous to that of the snow crab (Turnock and Rugolo 2011) given the close analogues in population dynamic and life-history characteristics, where longevity would be at least 20 years. Employing 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 if observable, 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. We adopted M=0.23 for both male and female Tanner crab in this analysis. This value corresponds with the range estimated by Somerton, and to the value used in the analysis to estimate new overfishing definitions which underlie Amendment 24 to the management plan (NPFMC 2007).

In the *Base Model (0)*, we allow the model to estimate M mature male crab, mature female crab, and for immature crab pooled by sex.

5. Growth

We derived 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). Growth relationships were based on observed growth data for males to approximately 140 mm cw and for females to approximately 115 mm cw (Figure 10). Somerton (1981a) estimated growth for EBS Tanner crab based on modal size frequency analysis of Tanner crab in survey data assuming no terminal molt at maturity. This approach did not directly measure molt increments and Somerton's findings are constrained by not considering that the progression of modal lengths between years was biased since 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. We found that the pattern of gpm for both males and females is characterized by a higher rate of growth to an intermediate size (90-100 mm cw) followed by a decrease in growth rate from that size thereafter (Figure 18). Such shaped growth curves are corroborated in work of Stone et al. (2003), Somerton (1981), Donaldson et al. (1981) and in the data of Munk. We modeled the relationship between pre-molt and post-molt size for males and females as a two parameter exponential function of the general form $y=ax^b$ where y=post-molt and x=pre-molt carapace width. The fitted growth relationship for males is $y=1.550x^{0.949}$, and that for females is $y=1.760x^{0.913}$.

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 summer trawl survey in 2006, 2007 and

2009 (Figure 19). 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 $W=0.00034(cw)^{2.956}$.

G. THE MODEL

We formulated a length-based assessment model for Tanner crab to characterize the performance of the stock and serve in estimating overfishing definitions. The model was initiated in 1950 to estimate recruitments to build the stock to fit initial observed biomass and length frequencies starting in 1974. Thirty-two 5mm length bins from 25-29 mm to a cumulative plus-group at 180-184 mm are modeled.

Fishery-independent estimates of biomass, population metrics and length frequency distributions used in the analysis were from NMFS trawl survey for 1974-2012. We estimated biological characteristics of male and female crab such as weight-length relationships, maturity schedules and growth functions from extant survey and experimental data, and from the literature to complete model parameterization. All component fishery-dependent data on Tanner crab were employed. Retained catch data in the domestic and foreign fisheries were available for 1965-2012. Retained male length-frequency by shell condition (1981-2012) and discard length frequency (1991-2012) for male and female crab in the directed fishery were incorporated. Sex-specific length frequencies of discarded crab in the snow crab and Bristol Bay red king pot fisheries (1989-2012), and from groundfish fisheries (1973-2012) were used to characterize non-directed stock losses and fishery performance.

Male and female survey selectivity were estimated for two time periods (1974-1981, 1982-2012) to address survey design and gear changes. Survey selectivity was estimated for each sex in both periods. In the most recent period, a prior on Q of 0.88 (cv-0.05) was used to inform male and female selectivity based on the net selectivity experiment of Somerton and Otto (1999). Fishery selectivity curves for the directed and all non-directed fleets were estimated for males and females over various periods. Post-release mortality for the pot discarded crab was set at 50%, and that for trawl discards set at 80%. Population dynamics in the model are separated by maturity status, shell condition class and sex. Estimated survey mature biomass is fit to observed mature biomass by sex, and survey length frequency is fit to immature and mature crab separately for each sex for the combined shell condition class. Model performance is evaluated by the fit to observed survey and fishery data.

The target biomass reference point of $B_{35\%}$ can be derived using model estimates of MMB over a reference time period (e.g., 1974-1980) representative of the proxy B_{MSY}, or as the product of mean recruitment (e.g., 1962-1974) which gave rise to the reference biomass and spawning biomass per recruit fishing at $F_{35\%}$. Mature male biomass at the nominal time of mating is the population metric used to gauge stock status relative to the limit reference point (B_{MSY} or proxy B_{MSY}) and to derive the overfishing limit (F_{OFL}) from the control rule. The Tanner crab stock declined from high biomass levels early-1970s to low levels in the 1980s. The stock was under a rebuilding plan from 1999-2007 and the fishery closed in 1985-1986, 1997-2004, 2010 and 2011 due to conservation concerns. The stock was declared overfished in 2010. A rebuilding plan must be implemented in 2012 for the 2012/13 fishing season.

For the *Base Model (0)*, we estimated $B_{35\%}$=161.37 thousand t and $F_{35\%}$=0.612. The model estimate of 2010/11 MMB at mating (65.40 thousand t) represents $0.41B_{35\%}$. The model estimate of 2011/12 MMB at mating (58.59 thousand t) represents $0.36B_{35\%}$.

H. MODEL CONFIGURATION

We formulated a *Base Model (0)* that attends to recommendations of the CPT through May 2012 and SSC through June 2012. The base model represents the best available science in modeling the Tanner crab stock and fishery dynamics in the author's view. We formulated one alternative *Model (1)* to address discussion of the CPT (May 2012) to explore the sensitivity of allowing natural mortality to be estimated on immature male and female crab during 1980-84. *Model (2)* is presented for reference as it's the unmodified *Base Model (0)* that uses the earlier scaled sample size weights in the length-frequency multinomial likelihood with the minimum constraint n=4.

Model (0) is the model approved by the CPT (May 2012) and SSC (June 2012) for assessment and OFL-setting. For *Model (1),* the issue of whether M increased on immature crab during 1980-84 bears further examination. Table 14 presents the change in male and female biomass of Tanner crab observed in the bottom trawl survey in 1980-1985 for customary size groups. The change in biomass in the smallest groups (males≤109 mm cw, and females <85 mm cw) implies an increase in mortality of immature crabs although that's not demonstrated in these data. At 109 mm cw, males are approximately 70% mature, and at 85 mm cw females are approximately 98% mature. Thus, a relatively large percentage of mature individuals comprise these smallest size groups for both sexes.

Analysis is required to examine the status of immature biomass over 1980-85 which should address the issue of errors in shell aging and survey selectivity at small size. A consideration in interpreting *Model (1)* results is that since the model is fit to mature biomass, it can account for the decline in mature biomass by an increase in mortality on immature crab that recruit to the mature stock. Such an increase does not necessarily reflect a change in environmental processes that increase natural mortality on immature crabs.

The argument for including the 1980-84 mortality period in the assessment model was that, given their co-occurrence, the processes operating on Bristol Bay red king crab in these years also operate on Tanner crab. As shown (Section H. Results), estimating immature M in *Model (1)* affects the estimate of mature M on males in 1980-84 but not that on mature females relative to *Model (0)* (*see* Figure 22). Estimated mortality on mature males in *Model (0)* (0.72) correspond to that estimated on mature male red king crab (0.74) (*see* Figure 23), while M on mature male Tanner estimated in *Model (1)* (0.44) is lower. In terms of environmental processes, we lack understanding as to why M on mature male crab would decline between *Model (0)* and *Model (1)* in 1980-84 (0.74 to 0.44) but remain unchanged on mature females (0.25 to 26) other than *Model (1)* sufficiently accounts for the decline in mature male biomass by increasing immature M. This is contrary to the assumption that equivalent processes affect Bristol Bay red king crab and Tanner crab.

Results of *Model (1)* or derivative configurations to *Model (0)* bear further examination. One question is that if environmental processes modulating natural mortality are indiscriminate with respect to sex (e.g., predation, temperature effects, habitat change), it's unclear as to why *Model (0)* and *Model (1)* produce identical estimates of mature female M during 1980-84 and outside this period, while that for immature pooled sexes differs dramatically between *Model (0)* and *Model (1)* (*see* Figure 22).

The summary specification of the ***Base Model (0)*** is:

i. Survey Selectivity:
The 50%, Q and difference (95%-50%) parameters of the logistic function are estimated for both males and females in 2 periods, 1974-1981, 1982-2011.

ii. Directed Fishery Selectivity:
A retention function and total selectivity are estimated in 2 periods: retention function (1981-1990 and 1991-2010); total selectivity (1991-1996 and 2005-2010) with annual varying mean (50%) in periods 1991-1996 and 2005-2010/11.

iii. Snow Crab Fishery Discard Selectivity:
Selectivity is estimated in 3 periods, 1989-1996, 1997-2004 and 2005-2011/12. In each period, one selectivity curve for males and females.

iv. Bristol Bay Red King Crab Fishery Discard Selectivity:
Selectivity is estimated in 3 periods, 1989-1996, 1997-2004 and 2005-2011/12. In each period, one selectivity curve for males and females.

v. Groundfish Fishery Discard Selectivity:
Selectivity is estimated in 3 periods, 1973-1986, 1987-1996 and 1997-2012. In each period, one selectivity curve for males and females.

vi. Growth:
The *a* and *b* parameters of exponential growth for males and females are estimated, all years.

vii. Natural Mortality:
Immature M (pooled sexes), mature male M and mature female M are estimated, all years.

viii. Recruitment Periods:
Recruitment is estimated in 2 periods, 1950-1973 and 1974-2012 with a first-difference penalty in the early period.

ix. Maturity:
A maturity function that defines the probability of an immature crab molting to maturity for males and females is estimated, all years.

x. Sample Size Weights on LFs:
Annual sample sizes (n) for the directed retained fishery were estimated based a factor which scaled the overall mean to 200. All annual fleet samples sizes were scaled using this factor with the constraint not to exceed n=200. Ns for survey LFs=200 for male and female.

xi. Additional Mortality Episode:
Implemented for mature male and female crab during 1980-84 in a manner analogous to the 2011/12 Bristol Bay red king crab assessment (Zheng 2011).

xii. Non-directed Pot Fishery Effort Data:
Snow crab and Bristol Bay red king crab fishery pot lift data used to estimate Tanner crab discards pre-1992 prior to the availability of discard data.

xiii. Penalty on Directed Fishing Mortality Deviations: the F penalty is set to 1.0.

Specifications for the two model configurations in this analysis are:

Model 0: *Base Model*

Model 1: *Base Model* modified such that additional mortality is estimated for immature male and female crab (pooled) during 1980-84.

Model 2: *Base Model* unmodified but uses old scaled sample size weights on the length-frequency multi nomial likelihood with the minimum constraint n=4.

Model:	Specification
0	Base Model
1	Base Model *but* M estimated immature males and females in 1980-84.
2	Base Model *but* M uses sample size weights with minimum n=4.

I. MODEL APPROACH

History of Approaches

Tier-4 Stock Designation

Through the 2011/12 season, Tanner crab was managed as a Tier-4 stock using a survey-based assessment approach (Rugolo and Turnock 2011b). In 2010, MMB fell below the minimum stock size threshold at survey time (MSST=0.5 $B_{MSY\ Proxy}$) (Rugolo and Turnock 2010). The status determination criterion, $B_{MSY\ Proxy}$, was 83.80 thousand t and the overfished status criterion, MSST, 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 and represented a ratio of 0.34 relative to $B_{MSY\ Proxy}$. The Tanner crab stock was determined to be overfished in 2019 by NOAA Fisheries and in need of a rebuilding plan.

For the 2010/11 status determination, the status criterion, $B_{MSY\ Proxy}$, was 83.33 thousand t and the overfished criterion, MSST, 41.67 thousand t (Rugolo and Turnock 2011 b). After accounting for stock losses due to M and the 2010/11 non-directed pot and groundfish fisheries, the 2011 MMB at the time of mating was 26.73 thousand t. This represented a ratio of 0.32 relative to $B_{MSY\ Proxy}$ which remained below the limit that defines an overfished stock. There was no change in the 2010/11 stock relative to the overfished determination made in 2010.

For the current 2011/12 stock status determination under Tier-4 management, after accounting for losses from M and the 2011/12 non-directed pot and groundfish fisheries, the 2012 MMB at the time of mating is 34.67 thousand t. This represents a ratio of 0.42 relative to $B_{MSY\ Proxy}$ which remains below the limit of 41.67 thousand t that defines an overfished stock based on the Tier-4 assessment (Rugolo and Turnock 2011b). There is no change in the 2011/12 stock relative to the overfished determination made in 2010.

In Tier-4, a default value of M and a Gamma (γ) are used in OFL setting. The proxy for B_{MSY} is the level of equilibrium stock biomass yielding MSY to fisheries whose mean performance is at F_{MSY}. For Tier-4 stocks, the $B_{MSY\ Proxy}$ is the average biomass over a specified period that satisfies the expectation of equilibrium biomass yielding MSY at F_{MSY}. It can be estimated as a percentage of pristine biomass (B_0) of an unfished or lightly exploited stock where data exist. 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 Environmental Assessment (NPFMC 2008) define a default value of gamma=1.0. Gamma can be less than or greater than 1.0 resulting in overfishing limits more or less biologically conservative than fishing at M. Since Tier-4 stocks are information-poor by definition, the EA states that γ should not be 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 (B) belongs to 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. 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
		$F_{OFL} \leq F_{MSY}$

Tier-3 Stock Designation

This stock assessment and fishery evaluation report is based on a length-based stock assessment model (TCSAM). The model was approved by the Council in June 2012 for use in stock status determination, setting overfishing definitions, and rebuilding analysis. For the 2012/13 stock status determination and OFL-setting, the Tanner crab stock is promoted to Tier-3 status.

The status of the 2011/12 Tanner crab stock under Tier-3 management is yet to be determined. It is unclear how results of the model that will be implemented for the 2012/13 fisheries can be applied retroactively for the 2011/12 stock status determination since the 2011/12 benchmark reference points and overfishing definitions were based on the survey-based Tier-4 assessment. For the 2012/13 fisheries, a Tier-3 status determination will depend on the value of the $B_{35\%}$ proxy for B_{MSY} adopted by the Council in October 2012.

In Tier-3, the $B_{MSY\ Proxy}$ is estimated using results of a spawning stock biomass-per-recruit (spr) analysis as the product of $SPR_{\%MSP}$ and mean recruitment over a selected period representative of $B_{\%MSP}$. The management target, %MSP, is a specified level of maximum spawning potential, SPR_0. Through simulation, SPR_0 is estimated fishing at F=0, then $F_{\%MSP}$ found as that level resulting in the specified proportion (%MSP) of SPR_0. 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-3 stocks under the plan, the $B_{MSY\ Proxy}$ is $B_{35\%}$ and $F_{MSY\ Proxy}$ is $F_{35\%}$.

Model Description

In this analysis, we developed a length-, sex-, maturity- and shell condition-structured model to characterize stock performance and serve the basis of estimating overfishing definitions. The model structure was developed following the methods of Fournier and Archibald's (1982) with many similarities to Methot (1990). The model was implemented using automatic differentiation software developed as a set of libraries under C++ (ADModel Builder). ADModel Builder can estimate a large number of parameters in a non-linear model using automatic differentiation software extended from Greiwank and Corliss (1991) and developed into C++ class libraries. This software provides the derivative calculations needed to find the objective function via a quasi-Newton function minimization routine (e.g., Press et al. 1992). The model implementation language (ADModel Builder) gives simple and rapid access to these routines and provides the ability to estimate the variance-covariance matrix for all parameters of interest.

The model estimates recruitments beginning in 1950 to build the stock to fit initial observed survey data biomass and length frequency estimates beginning in 1974. This results in 20 additional recruitment parameters. There are 32, 5mm length bins in the model starting from 25-29 mm up to a cumulative bin at 180-184 mm.

1. Recruitment

Recruitment is determined from the estimated mean recruitment, the yearly recruitment deviations and a gamma function that describes the proportion of recruits by length bin,

$$N_{t,1} = pr_l \, e^{R_0^l + \tau_t}$$

where,

R_0^l Mean recruitment

pr_l Proportion of recruits for each length bin

τ_t Recruitment deviations by year.

Recruitment numbers are estimated equal for males and females in the model.

Crab were distributed into 5mm CW length bins based on a pre-molt to post-molt length transition matrix. For immature crab, the number of crabs in length bin *l* in year *t-1* that remain immature in year *t* is given by,

$$N_{t,l}^{s} = (1 - \phi_l^s) \sum_{l=l_1}^{l'} \psi_{l',l}^{s} \, e^{-Z_{l'}^{s}} N_{t-1,l'}^{s}$$

$\psi_{l',l}^{s}$	growth transition matrix by sex, pre-molt and post-molt length bins which defined the fraction of crab of sex *s* and pre-molt length bin *l'*, that moved to length bin *l* after molting,
$N_{t,l}^{s}$	abundance of immature crab in year *t*, sex *s* and length bin *l*,
$N_{t-1,l'}^{s}$	abundance of immature crab in year *t-1*, sex s and length bin *l'*,
$Z_{l'}^{s}$	total instantaneous mortality by sex *s* and length bin *l'*,
ϕ_l^s	fraction of immature crab that became mature for sex *s* and length bin *l*,
l'	pre-molt length bin,
l	post-molt length bin.

2. Growth

Growth was modeled using a fixed non-linear exponential function to estimate the mean post-molt carapace width (*Y*) given the mean pre-molt carapace width (*X*),

$$Y_{t+1} = aX_t^b$$

Parameters values used in the model and whether parameters were estimated in the model, excluding recruitments and fishing mortality parameters are listed in Table 8.

Assignment to length bins was made using a two-parameter gamma distribution with mean equal to the growth increment by sex and length, over the 25-185 mm CW range, and a beta parameter which determines the variance,

$$\psi_{l',l}^{s} = \int_{l-2.5}^{l+2.5} gamma(l / \alpha_{s,l'}, \beta_s)$$

where,
$\alpha_{s,l'}$ expected growth interval for sex *s* and size *l'* divided by the shape parameter β,
$\psi^{s}_{l',l}$ growth transition matrix for sex, *s* and length bin *l'* (pre-molt size), and post-molt size *l*.

The Gamma distribution was,

$$gamma(l/\alpha_{s,l},\beta_s)=\frac{l^{\alpha_{s,l}-1}e^{-\frac{l}{\beta_s}}}{\beta^{\alpha_{s,l}}\Gamma(\alpha_{s,l})}$$

where *l* is the length bin, β was set equal to 0.75 for both males and females as estimated from growth data on EBS Tanner and king crab due to the scant amount of growth data available for snow crab.

3. Maturity

The probability of an immature crab becoming mature by size was applied to the post-molt size. Crab that matured and underwent their terminal molt in year *t* were mature new shell (SC2) by definition during their first year of maturity. The abundance of newly mature crab ($\Omega^{s}_{t,l}$) in year *t* is given by,

$$\Omega^{s}_{t,l} = \phi^{s}_{l} \sum_{L=l_1}^{l'} \psi^{s}_{l',l}\, e^{-Z^{s}_{l'}} N^{s}_{t-1,l'}$$

Crab that were mature SC2 in year *t-1* no longer molt and move to old shell mature crab (SC3+) in year *t* ($\Lambda^{s}_{t,l}$). Crab that are SC3+ in year *t-1* remained old shell mature for the rest of their lifespan. The total old shell mature abundance ($\Lambda^{s}_{t,l}$) in year *t* is the sum of old shell mature crab in year *t-1* plus previously new shell (SC2) mature crabs in year *t-1*,

$$\Lambda^{s}_{t,l} = e^{-Z^{s,old}_{l}} \Lambda^{s}_{t-1,l} + e^{-Z^{s,new}_{l}} \Omega^{s}_{t-1,l}$$

The fishery is prosecuted in early winter prior to growth in the spring. Crab that molted in year *t-1* remain as SC2 until after the spring molting season. Crab that molted to maturity in year *t-1* are SC2 through the fishery until the spring molting season after which they become old shell mature (SC3).

4. Male Mature Biomass

Mature male biomass (MMB) was calculated as the sum of all mature males at the time of mating multiplied by respective weight at length.

$$B_t = \sum_{L=1}^{lbins} (\Lambda^{males}_{tm,l} + \Omega^{males}_{tm,l})\, W^{males}_{l}$$

tm	nominal time of mating after the fishery and before molting,
lbins	number of length bins in the model,
$\Lambda^{males}_{tm,l}$	abundance of mature old shell males at time of mating in length bin *l*,
$\Omega^{males}_{tm,l}$	abundance of mature new shell males at the time of mating in length bin *l*,
W_1	mean weight of a male crab in length bin *l*.

5. Catch

Catch of male Tanner crab was taken as a pulse fishery on February 15 (0.62 y) after the beginning of the assessment year (July 1),

$$\hat{C}_t = \sum_l (1 - e^{-(F_{red} * Sel_l^{red} + F_{snow} * Sel_l^{snow} + F_{tanner} * Sel_l^{tanner} + F_{trawl} Sel_l^{trawl})}) w_l N_{t,l}^{males} e^{-M 0.62}$$

F_{tanner}	full selection fishing mortality (y^{-1}) determined from the control rule using biomass including assessment error,
F_{trawl}	fishing mortality (y^{-1}) for trawl bycatch fixed at 0.01 (average *F*),
F_{red}	fishing mortality (y^{-1}) for red king crab fishery trawl bycatch,
Sel_l^{tanner}	directed fishery selectivity for shell condition and length bin *l* for male crab,
Sel_l^{red}	red king bycatch fishery selectivity for shell condition and length bin *l* for male crab,
Sel_l^{snow}	snow bycatch fishery selectivity for shell condition and length bin *l* for male crab,
Sel_l^{trawl}	trawl bycatch fishery selectivity for shell condition and length bin *l* for male crab,
w_l	mean weight of male crab in length bin *l*,
$N_{t,l}^{males}$	numbers by length for shell condition class and length bin *l*,
M	instantaneous natural mortality rate.

6. Selectivity

The selectivity curves for the total catch, the retention curve, catch in the red king crab fishery, catch in the snow crab fishery, and catch in the groundfish fisheries, were estimated as two-parameter ascending logistic curves,

$$Sel_l = \frac{1}{1 + e^{(-a(l-b))}}$$

Where *a* is slope and *b* is length at 50% selectivity. Separate selectivity curves for males and females were estimated for the directed, snow and red king crab fisheries.

The probability of retaining crabs by size in the directed fishery with combined shell condition was estimated as an ascending logistic function. The selectivities for the retained catch were estimated by multiplying a two parameter logistic retention curve (same logistic equation as the total selectivity) by the selectivity ties for the total catch,

$$S_{ret,l} = (selectivity\ total)(retention)$$

The selectivity for the survey was estimated with three-parameter, ascending logistic functions.

$$Sel_l = \frac{Q}{1 + e^{\left\{\frac{-\ln(19)(l - l_{50\%})}{(l_{95\%} - l_{50\%})}\right\}}}$$

Survey selectivity was estimated for 2 periods, 1974-1981, 1982-2012 to address evolving survey design and gear changes. The spatial coverage of the survey was standardized in 1978 with the exception of the addition of some stations in the northwestern survey area, well outside the distribution of EBS Tanner crab. Years 1974-1981 were considered to have similar coverage of the Tanner crab distribution. In 1974-1981, the survey used a 400 eastern otter trawl which was changed to the current 83-112 otter trawl in 1982. Years prior to 1974 had unique coverage temporally and spatially relative to Tanner crab and not included in the analysis as recommended by the Crab Modeling Workshop (Martel and Stram 2011). All three parameters (50%, 95% and Q) of the logistic function for both males and females are estimated in the three periods. For males in period-3, we inform Q based on results of the Somerton and Otto (1999) underbag study (Q=0.88; sd=0.05).

7. Likelihood Equations

Weighting values (λ) for each likelihood equation are shown in Table 9.

Catch biomass for the directed fishery, snow crab fishery, red king crab fishery and groundfish fishery is assumed to have a normal distribution,

$$\lambda \sum_{t=1}^{T} \left[(C_{t,fishery}) - (\hat{C}_{t,fishery}) \right]^2$$

There are separate likelihood components for the retained catch, discard in the directed fishery, discard in the snow crab fishery, discard in the red king crab fishery and groundfish bycatch.

The robust multinomial likelihood is used for length frequencies from the survey for the fraction of animals by sex in each 5mm length interval. The number of samples measured in each year is used to weight the likelihood. However, since thousands of crab are measured annually, the sample size was set at 200. Likelihood weights for the length frequencies of catch from the directed and non-directed fleets were scaled by a factor equal to the mean number of crab retained in the directed fishery over all years divided by 200. The scaled weight in any year for any fleet is the ratio of the number of crab measured to this factor with the constraint that the ratio is capped at 200. Let Λ be the mean of the number of retained crab measured for all years, t. Let Φ be a constant equal to Λ/200. Then, the weighted sample size weight, $nsampwt_{jt}$, in any fleet j in year t is the number of measured crab fleet j in year t divided by the constant Φ; thus, $nsampwt_{jt}=nsamp_{t,j}/\ \Phi$.

$$Length\ Likelihood = -\sum_{t=1}^{T} \sum_{l=1}^{L} nsampwt_t * p_{t,l} \log(\hat{p}_{t,l} + o) - Offset$$

$$Offset = \sum_{t=1}^{T} \sum_{l=1}^{L} nsamp_t * p_{t,l} \log(p_{t,l})$$

Where, T is the number of years, $p_{t,l}$ is the proportion in length bin *l*, an *o* is fixed at 0.001.

The survey biomass assumes a lognormal distribution with the inverse of the standard deviation of the log(biomass) in each year used as a weight,

$$\lambda \sum_{t=1}^{ts} \left[\frac{\log(SB_t) - \log(\hat{SB}_t)}{sqrt(2) * s.d.(\log(SB_t))} \right]^2$$

$$s.d.(\log(SB_t)) = sqrt(\log((cv(SB_t))^2 + 1))$$

Recruitment deviations likelihood equation is (t is year),

$$\lambda \sum_{t=1}^{T} \tau_t^2$$

First difference constraint on early recruitments (years (t) from 1950 to 1973)

$$\sum_{t=1}^{T} (first\ differences(\tau_t))^2$$

Smooth constraint on probability of maturing by sex and length

$$\sum_{S=1}^{2} \sum_{l=1}^{L} (first\ differences(first\ differences(PM_{s,l}))^2$$

where, $PM_{s,l}$ is a vector of parameters that define the probability of molting.

Fishery CPUE in average number of crab per pot lift (currently not fit in the model),

$$\sum_{t=1}^{tf} \left[\frac{\log(CPUE_t) - \log(\hat{C}PUE_t)}{sqrt(2) * s.d.(\log(CPUE_t))} \right]^2$$

Penalties on fishing mortality deviations,

$$\lambda \sum_{t=1}^{T} \varepsilon_t^2$$

Growth parameters likelihood,

$$0.5(\frac{\tau - \mu}{\sigma})^2$$

M penalty, sd = 0.05,

$$0.5\left(\frac{M-0.23}{\sigma}\right)^2$$

Penalty on survey Q for 1982-present (2 period model), sd = 0.05, prior is from underbag experiment,

$$0.5\left(\frac{Q-0.88}{\sigma}\right)^2$$

Constraint on annual survey Q deviations (when estimated),

$$\lambda \sum_{t=1}^{T} \varepsilon_t^2$$

Snow crab and red king crab fisheries discard catch of Tanner crab for years when discard data are not available was estimated from the relationship between the retained catch of snow crab (or red king crab) and the bycatch of Tanner crab in the directed snow crab (or red king crab) fishery for years with observer data,

$$R = mean\left[\frac{F_{Tanner\,bycatch}}{\text{Re}tained\ Directed\ catch}\right]$$

Fishing mortality for Tanner crab bycatch for years when no observer data are available is estimated using R above with the retained catch of snow crab (or red king crab, C_R),

$F = R\, C_R$

A first difference penalty on annual deviations in the size at 50% selected for the total male catch in the directed Tanner fishery,

$$\sum_{t=1}^{T} (first\ differences(\tau_t))^2$$

In *Model (0)*, a total of 296 parameters for the 38 years of data (1974-2012) were estimated in the model (Table 8). The 97 fishing mortality parameters (one for the directed fishery deviations, 1970-2012, and one mean value), one set for the snow crab fishery, 1992-2012, one set for the red king crab fishery, 1992-2012, and one set for the trawl fishery bycatch, 1973-2012) estimated in the model were constrained so that the estimated catch fit the observed catch closely. There were 62 recruitment deviation parameters estimated in the model, 2 mean recruitments in 2 periods (male and female recruitment were fixed to be equal). There were 62 fishery selectivity parameters. Male and female survey selectivity was estimated for 3 periods resulting in 18 parameters estimated. A total of 64 parameters were estimated for the probability of maturing smooth constrained functions.

Molting probabilities for mature males and females were fixed at 0, i.e., growth ceases at maturity which is consistent with the terminal molt paradigm (Otto 1998, Tamone et al. 2005). Molting probabilities were fixed at 1.0 for immature females and males. The a and b parameters of the exponential model of post-molt size relative to pre-molt size describing growth of male and female were estimated in the model. A gamma distribution was used in the growth transition matrix with the beta parameters fixed at 0.75 for males and females. We modeled the variance of the distribution of post-molt size given pre-molt size bin using growth data on male and female GOA Tanner crab and found that a beta of 0.75 resulted in good approximation of the distribution of post-molt sizes over all size bins.

The model separates male and female crab into mature, immature, new shell and old shell for the population dynamics. The model estimate of survey mature biomass is fit to the observed survey mature biomass time series by sex. The model fits the size frequencies of the survey by immature and mature separately for each sex and shell condition combined. The model fits the size frequencies for the pot fishery catch by sex.

Crabs 25 mm cw and larger were included in the model, divided into 32 size bins of 5 mm each, from 25-29 mm to a plus group at 180-184 mm. In this report the term size as well as length will be considered synonymous with cw. Recruits were distributed in the first few size bins using a two parameter gamma distribution with the parameters estimated in the model. The alpha parameter of the distribution was fixed at 11.5 and the beta parameter fixed at 4.0. No spawner-recruit relationship was used in the population dynamics part of the model; annual recruitments were estimated in the model to fit the data.

The NMFS trawl survey occurs in summer each year, generally in June-August. In the model, the time of the survey (July) is considered to be the start of the year rather than January. The modern directed Tanner crab pot fishery has occurred generally in the winter months (January to February) over a contracted time period. In contrast, in the early years the fishery occurred over a more protracted period of time. Natural mortality is applied to the population from the time the survey occurs until the fishery occurs, then catch is extracted instantaneously. The fishing mortality was applied as a pulse fishery at the mean time for that year. After the fishery, growth and recruitment take place in spring, with the remainder of losses due to natural mortality through the end of the year.

8. Discard mortality

Pot fishery discard mortality was assumed to be 50% for this assessment. The fishery for snow crabs occurs in winter when low temperatures and wind may result in freezing of crabs on deck before they are returned to the sea. Short-term mortality may occur due to exposure, which has been demonstrated in laboratory experiments by Zhou and Kruse (1998) and Shirley (1998), where 100% mortality occurred under temperature and wind conditions that may occur in the fishery. Even if damage did not result in short term mortality, immature crabs that are discarded may experience mortality during molting some time later in their life.

9. Estimation of F Using Non-Directed Pot Fishery Effort

Fishing mortality from discards in the snow crab and Bristol Bay red king crab fisheries for years when no discard catch data are available (pre-1992) were estimated using the effort (pot lifts) data in the snow crab and Bristol Bay red king crab directed fisheries, and the relationship between the model estimates of discard Fs and effort for years with bycatch data.

If Ω is the mean ratio of discard F to effort for each fishery from 1992 to end year except years when the fishery was closed, then the component fishing mortality in each discard fishery in year t is estimated pre-1992 as the product of Ω and effort, f_t, in year t:

$$F_t = \Omega \cdot f_t$$

For the Bristol Bay red king crab fishery, the effort time series includes pot lifts from both the Japanese and the domestic US pot fisheries. Effort data through 1965 is only for the Japanese fleet, 1966 through 1972 is combined Japanese and domestic effort, and 1973 to 1991 is domestic pot effort only.

10. Overfishing Control Rule

Amendment 24 to the NPFMC fishery management plan (NPFMC 2007) introduced revised the definitions for overfishing for EBS crab stocks. The information provided in this assessment is sufficient to estimate overfishing limits for Tanner crab under Tier 3b. The OFL control rule for Tier 3b is based on spawning biomass-per-recruit reference points (NPFMC 2007).

$$F = \begin{cases} Bycatch\ only,\ Directed\ F = 0, & if\ \dfrac{B_t}{B_{REF}} \le \beta \\ \dfrac{F_{REF}\left[\dfrac{B_t}{B_{REF}} - \alpha\right]}{(1-\alpha)} & if\ \beta < \dfrac{B_t}{B_{REF}} < 1 \\ F_{REF} & if\ B_t \ge B_{REF} \end{cases} \quad (12)$$

where,

B_t	mature male biomass at time of mating in year t
B_{REF}	proxy for B_{MSY} defined as mature male biomass at time of mating resulting from fishing at F_{REF} (proxy F_{MSY})
F_{REF}	F_{MSY} proxy defined as the fishing mortality that reduces mature male biomass at the time of mating-per-recruit to specified percent of its unfished level
α	fraction of B_{REF} where the harvest control rule intersects the x-axis if extended below β
β	fraction of B_{REF} below which directed fishing mortality is 0

The total catch, including all bycatch of both sexes from all fisheries, is estimated by the following equation,

$$catch = \sum_f \sum_s \sum_l \frac{F_{f,s,l}}{F_{tot,s,l}}(1 - e^{-(F_{tot,s,l})}) w_{s,l} N_{s,l}\, e^{-M*.62}$$

where, $N_{S,l}$ is the 2012 numbers in length bin *l* and sex *s* at the time of the survey estimated from the population dynamics model, M_s is natural mortality by sex, 0.625 is the time elapsed (in years) from when the survey occurs to the fishery, F_{tot} is the value estimated from the OFL control rule using the 2012 mature male biomass projected forward to the time of mating time (February 2013), $F_{f,s,l}$ is partial value for each directed and non-directed fishery component in length bin *l* by sex, and $w_{s,l}$ is the mean weight in length bin *l* by sex. Fishery selectivity by length for the total catch (retained plus discard) and retained catch estimated from the population dynamics model (Figures 16 and 17).

11. Projection Model Structure

Variability in recruitment, as well as assessment error, was simulated with temporal autocorrelation. Recruitment was generated from a Beverton-Holt stock-recruitment model,

$$R_t = \frac{0.8\, h\, R_0\, B_t}{0.2\ spr_{F=0}\ R_0(1-h) + (h-0.2)B_t}\ e^{\varepsilon_t - \sigma_R^2/2} \qquad (1)$$

$spr_{F=0}$	mature male biomass per recruit fishing at F=0. $B_0 = spr_{F=0}\ R_0$,
B_t	mature male biomass at time t,
h	steepness of the stock-recruitment curve defined as the fraction of R_0 at 20% of B_0,
R_0	recruitment when fishing at F=0,
σ_R	standard deviation for recruitment deviations, estimated at 0.86 from the assessment model.

The temporal autocorrelation error (ε_t) was estimated as,

$$\varepsilon_t = \rho_R \varepsilon_{t-1} + \sqrt{1+\rho_R^2}\ \ \eta_t \qquad where\ \eta_t \sim N(0;\sigma_R^2) \qquad (2)$$

ρ_R	temporal autocorrelation coefficient for recruitment, set at 0.6.

Recruitment variability and autocorrelation were estimated using recruitment estimates from the stock assessment model. R_0 and steepness were estimated such that $F_{35\%} = F_{MSY}$ and $B_{35\%} = B_{MSY}$ using a Beverton-Holt stock recruitment relationship.

Assessment error was modeled as a lognormal autocorrelated error on the mature male biomass used to determine the fishing mortality rate in the harvest control rule,

$$B_t^{'} = B_t\, e^{\phi_t - \sigma_I^2/2}\ ;\ \ \phi_t = \rho_I \phi_{t-1} + \sqrt{1+\rho_I^2}\ \ \varphi_t \qquad where\ \varphi_t \sim N(0;\sigma_I^2)$$

$B_t^{'}$	mature male biomass in year t with assessment error input to the harvest control rule,
B_t	mature male biomass in year t,
ρ_I	temporal autocorrelation for assessment error, set at 0.6 (estimated from the recruitment time series),

σ_I standard deviation of φ, which determines the magnitude of the assessment error, set at the estimate of variance of ending biomass from the assessment model plus additional uncertainty.

Assessment error in mature male biomass resulted in fishing mortality values applied to the population that was either higher or lower than the values without assessment error. The autocorrelation was assumed to be the same value as that estimated for recruitment. Assessment autocorrelation was used to more closely approximate the process of estimating a biomass time series from within a stock assessment model. The variability in biomass of the simulated population resulted from the variability in recruitment and variability in full selection *F* arising from implementation error on biomass. Uncertainty in initial numbers by length was added using a lognormal distribution with cv of ending biomass from the assessment model. The population dynamics equations were identical to those presented for the assessment model in the model structure section of this assessment.

12. State of Alaska Harvest Strategy Prior to 2011/12

The SOA harvest strategy (Zheng and Kruse 2000) in effect prior to the change in 2011/12 was: Let MFB_t be the estimate of mature female biomass in the Eastern Subdistrict (i.e., the waters of the Bering Sea District east of 173^0 W longitude) at the time of the survey in year *t* defined as the estimated biomass of females > 79 mm carapace width (cw), MFB_{t-1} be the estimate of mature female biomass in the Eastern Subdistrict at the time of the survey in the previous year (*t-1*), $MMMA_t$ be the molting mature male abundance in each area east and west of 166^0 W longitude within the Eastern Subdistrict at the time of the survey in year *t* defined as the estimated abundance of all new-shell males > 112-mm cw plus 15% of the estimated abundance of old-shell males > 112-mm cw, $ELMA_t$ be the exploitable legal male abundance in each area east and west of 166^0 W longitude within the Eastern Subdistrict at the time of the survey in year *t* defined as the estimated abundance of all new-shell legal males ≥ 138 mm cw plus 32% of the estimated abundance of old-shell legal males ≥ 138 mm cw, W_t be the average weight of legal males in the Eastern Subdistrict east or west of 166^0 W longitude in year *t* estimated by applying a weight-length relationship to the survey size-frequency data for legal (≥ 138 mm cw) males, HG_{COMP} be the total allowable catch computed for each area east and west of 166^0 W longitude in the Eastern Subdistrict, HG_{CAP} be the capped total allowable catch derived for each area east and west of 166° W longitude in the Eastern Subdistrict. In applying the control rule, [i] a separate *HG* is determined as the minimum of the HG_{COMP} and the HG_{CAP} for each area east and west of 166^0 W longitude, and [ii] the *HG* of legal males in each area east or west of 166^0 W longitude in the Eastern Subdistrict is capped at 50% of the exploitable legal male abundance.

The control rule for the HG during year *t* in each area east and west of 166^0 W longitude in the Eastern Subdistrict is as follows: (mp=million pounds).

1. If $MFB_{t-1} < 21.0$ mp and $MFB_t < 21.0$ mp, then $HG_{COMP}=0$ and $HG_{CAP}=0$.
2. If $MFB_{t-1} < 21.0$ mp and 21.0 mp $\leq MFB_t < 45.0$ mp, then $HG_{COMP}=0.05MMMA_tW_t$ and $HG_{CAP}=0.25ELMA_tW_t$.
3. If $MFB_{t-1} < 21.0$ mp and $MFB_t \geq 45.0$ mp, then $HG_{COMP}=0.1MMMA_tW_t$ and $HG_{CAP}=0.25ELMA_tW_t$.
4. If $MFB_{t-1} \geq 21.0$ mp and $MFB_t < 21.0$ mp, then $HG_{COMP}=0$ and $HG_{CAP}=0$.
5. If $MFB_{t-1} \geq 21.0$ mp and 21.0 mp $\leq MFB_t < 45.0$ mp, then $HG_{COMP}=0.1MMMA_tW_t$ and $HG_{CAP}=0.5ELMA_tW_t$.
6. If $MFB_{t-1} < 21.0$ mp and $MFB_t \geq 45.0$ mp, then $HG_{COMP}=0.2MMMA_tW_t$ and $HG_{CAP}=0.5ELMA_tW_t$.

13. New Size Limits Strategy and Fishery Selectivity

In March 2011, the Alaska Board of Fisheries approved a new minimum size limit strategy for Tanner crab effective 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° West 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° West longitude, respectively. The operational framework of the these new regulations will be incorporated in stock projections.

The SOA closed the directed Tanner crab fishery in the 2010/11 and 2011/12 seasons. For stock projections, since fishery performance has not been observed under the new size limit regime, we would initially approximate east-west fishery selectivity and the catch splits in the projection model framework. As a first approximation, total selectivity is unchanged and applied to the east-west fisheries given that no gear changes accompanied the regulatory change in size limit. Retained selectivity for the eastern and western districts would be formulated based on the industry imposed size limits of 138 mm (east) and 127 mm (west). For the eastern fishery, retained selectivity would be unchanged. For the western fishery, the retained selectivity curve would be shifted 10 mm to the proposed 127 mm minimum size limit. The split in the catch east-west would be approximated by the 3-year average proportion of the abundance of crab observed in the 2010 to 2012 surveys east and west of 166^0 W longitude.

J. RESULTS

This analysis presents results of the *Base Model (0)* and two alternative models – *Model (1) and Model (2)*. Specification of the base model configuration is described in Section H (Model Configuration). Alternative *Model (1)* is the base model modified such that additional mortality is estimated for immature male and female crab (pooled) during the 1980-84 period. *Model (2)* is the base model, and results differ relative to the base model only by a change in the input data. Here, the scaled sample weights to the multinomial likelihood have a minimum constraint of n=4 for any fleet-year. The minimum constraint of n=4 was a decision in earlier model testing and the CPT (May 2012) requested it be removed. Model (2) results are presented only as a reference to what the CPT reviewed in May 2012.

Model:	Specification
0	Base Model
1	Base Model *but* M estimated immature males and females in 1980-84.
2	Base Model *but* M uses sample size weights with minimum n=4.

Table 1 provides the fishery history of observed retained catch in the domestic and foreign Tanner crab fisheries from 1965/66 to 2011/12. The total biomass of discard catch of Tanner crab in the domestic pot fisheries and groundfish fisheries for 1973/74 through 2011/12 is shown in Table 2. *Model (0)* estimates of predicted retained and discard catch of Tanner crab by sex in the directed fishery for 19674/75 through 2009/10 is shown in Table 3. Table 4 shows the discard catch in the non-directed pot and groundfish fisheries by sex estimated in the *Model (0)* for 19674/75 through 2011/12. The *Model (0)* predicted total (retained plus discard) Tanner crab catch biomass from the directed and all non-directed fisheries combined for years 19674/75 through 2011/12 is presented in Table 5. Table 6 presents the observed survey female, male and total spawning biomass, and observed abundance of legal male crab (≥ 138 mm cw) for 1974-2011. *Model (0)* estimates of population biomass and abundance, male, female and total mature biomass, abundance of legal males, recruitment to the population, male mature biomass at mating and full-selection fishing mortality rates are presented in Table 7. Table 8 provides the parameter values and whether the parameters were estimated in the model, excluding recruitments and fishing mortality parameters for *Model (0)*. The weighting factors for the likelihood equations used for all models is shown in Table 9. Table 10 shows the likelihood values by component for *Model (0)* through *Model (2)*. The values of natural morality (M) estimated or fixed for *Model (0)* through *Model (6)* are shown in Table 11. The total likelihood, maximum survey selectivity Q, and survey Q at a reference size for male (140 mm) and female (100 mm) crab are shown versus Q for the *Model (0)* in Table 12.

Figure 21 (a) and (b) show the sample sizes used in the multinomial likelihood in fitting the fishery length compositions by fleet and the resulting mean fleet samples sizes for comparison. The *Model (0)* and *Model (1)* estimates of natural morality for immature male and female (pooled) crab, and for mature males and females, and the estimated rate of additional mortality over 1980-84 are shown in Figure 22. The estimated rate of additional morality on mature male crab over 1980-84 is 3.2 times the baseline natural mortality of 0.23, equaling 0.74 (Table 11). By comparison, the values of fixed and estimated rates of natural mortality for male and female crab in the current Bristol Bay red king crab assessment (Zheng 2011) are shown in Figure 23. Over the period 1980-84, estimated M on male crab is 3.0M, where M represents the fixed life-history based value of 0.18, equaling 0.72.

Figure 24 presents a comparison of four reference model fits to the observed survey male mature biomass and the predicted population male mature biomass. This figure was requested by the CPT (May 2012), and the reference models are: #1=3-period model presented to CPT in September 2011, #2=2-perod model resulting from January 2012 Crab Workshop; #3=2-period model presented to CPT in May 2012; and (#4=2-period model approved by the CPT in May, 2012. Figure 25 presents this same comparison of reference model fits but to mature female biomass.

***Model (0)*:**
Figure 10 presents predicted retained male catch and predicted retained plus discarded catches of male Tanner crab in the directed fishery, and total male catch in all fisheries combined. Predicted Mature male biomass declined sharply from its high in 1974 to the mid-1980s, increased modestly to a secondary mode in 1990, then declined thereafter through the early-2000s (Table 7, Figure 26). The model does not fit the increasing survey biomass trend in 2005-2008 but better fits the 2011-2012 observed biomass. The increasing trend in 2005-2008 was driven principally by hot-spot tows which inflated total biomass estimates (Rugolo and Turnock 2008). Exploitation rates on legal and mature male biomass demonstrated two peaks: the first in the late-1970s through early-1980s and the second in the mid-1990s (Figure 11).

Estimated total selectivity in the directed fishery for combined shell condition male Tanner crab in the directed fishery was estimated in three periods (1981-1990, 1991-1996 and 2005-2010). Figure 27 (a) shows the estimated total selectivity in 2008 as a reference for the shape of the function, where (b) shows the change in the mean (50%) of total selectivity over 1990-2010. The estimated fraction of total catch retained by size for male crab in the directed fishery for all shell condition classes combined estimated in three periods (1981-1990, 1991-1996 and 2005-2010). Figure 28 presents the retained selectivity curves for a year in each of these three periods. All three parameters (50%, 95% and Q) of the logistic function for male (Figure 29) and female (Figure 30) survey selectivity was estimated in two periods (1974-1981, 1982-2012). For males in period-2, we inform Q based on the 1999 Somerton and Otto underbag study (Q=0.88, sd=0.05). The profile of survey Q versus total likelihood, and survey selectivity at reference sizes (male=140 mm, female=100 mm) are presented in Figures 31 (a) and (b).

Male and female Tanner crab fishery selectivity in the Bristol Bay red king crab fishery (Figure 32) and in the snow crab fishery (Figure 33) were estimate in three periods (1989-1996, 1997-2004 and 2005-2011). Selectivity of Tanner crab in the groundfish fisheries was estimated for three periods (1973-1986, 1987-1996 and 1997-2010) (Figure 34).

Model fits to mature female biomass is shown in Figure 35. Observed female mature biomass is relatively more variable than male mature biomass (Figure 26) and the model does not fit these female data as well in the early-1980s and early-1990s. Model fits to the survey length frequencies for males and females including observed survey biomass are shown in Figure 36 and Figure 38 respectively. Standardized Pearson residuals of model fits to the male survey length frequencies are shown in Figure 37, and those for mature females in Figure 39. A summary plot of the model fit to the survey length frequencies for males and females over all years is shown in Figure 40. Observed survey numbers of legal males (Table 6) and model estimates of the population of legal males (Table 7) are scaled by the model estimates survey Q.

The relationships of pre-molt length to post-molt length for male and female Tanner crab estimated in the model are shown in Figure 41. Figure 42 illustrates the estimated recruitment to model of crab 25 mm to 50 mm by fertilization year which are distributed by carapace width to the model as shown in Figure 43. Model fits to the retained male size frequency data in the 1981-2009/10 directed fishery, and the summary fit to the retained male size frequencies over all years are shown in Figure 44 and Figure 45 respectively. The model fits to the total male size frequency data for 1981-2009/10 in all fisheries combined, and the summary fit to the total male size frequencies over all years are shown in Figure 46 and Figure 47 respectively. Figure 48 presents the summary fit to the discard female size frequency data in the directed fishery. Figures 49 through 51 present the summary model fits to the size frequencies of male and female Tanner crab discards in the snow crab fishery, in the Bristol Bay red king crab fishery and in the EBS groundfish fisheries.

Full-selection fishing mortality rates varied from near zero to 2.2 (Figure 52, Table 7). Full-selection fishing mortality rates concur with a history of excessive exploitation, averaging 1.1 (1977/78-1981/82) peaking in 1979/80 at 2.2, and averaging 0.9 (1990/91-1993/94) peaking in 1992/93 at 1.2 coincident with peak extraction of catch and decline in stock biomass. Figure 53 shows realized instantaneous fishing morality rate versus male mature biomass at mating by fishing year where $F_{35\%}$=0.61 and $B_{35\%}$=161.37 thousand t. The pattern of recruitment to the model vs. male mature biomass is illustrated in Figure 54. Figure 55 presents the trajectory of estimated male mature biomass at the time of mating from 1974-2012. From the high biomass in 1974, MMB at mating has demonstrated a one-way trip of sharply declining biomass through 2000 and remaining at low levels thereafter. A modest mode of MMB was observed in the late-1980s to early-1990s, peaking in 1990 (Figure 55, Table 7), but this peak represented half of the male mature biomass estimated in 1974-1980. The observed male size frequencies from 1974-2012 (Figure 6) reveals a contraction of the distribution and a length shift to smaller sizes coincident with the decline; the modest increase in biomass associated with the 1990 mode is seen in the progression of lengths from 1987 through 1992. The 2012 observed length frequency reveals a relatively prominent mode of recruit-sized crab which is encouraging if it recruits to the mature stock. Inspection of the metrics of stock and fishery performance of Tanner crab over its history from indicate a severe stock decline.

The relative productivity of a stock is expressed as index based on the number of recruits per spawner – e.g., as the natural log of recruitment divided by spawning stock biomass. Figure 56 shows Tanner crab production index versus male mature biomass over 1968 to 2012. The stock production index versus the predicted exploitation rate on male mature biomass over 1968 to 2012 is shown in Figure 57.

Alternative Models:

For alternative *Model (1)*, we present nine figures representative of model performance. For females, these are the estimated population of mature female biomass with model fit to survey mature biomass, the model fit to the survey size frequency data, and the residual plot of model fit to the survey size frequency data. We repeat this set of three figures for males. Lastly, the summary plot of model fit to the survey male and female size frequency data, and the model estimates of male and female survey selectivity are given. The remaining plots for *Model (1)* are provided electronically in a Drop Box established by the CPT as a repository for model output. Similarly, the complete set of model plots for *Model (2)* are provided electronically.

Model (1):

Model fits to mature male biomass and to mature female biomass and the respective estimates of the population of mature biomass are shown in Figure 58 and Figure 61, respectively. Figure 59 and Figure 62 show the model fit to the survey size frequencies for males and females respectively, including the observed survey biomass data. Residuals of model fits to the male survey size frequency data are shown in Figure 60, and those for mature females in Figure 63. The summary plot of the model fit to the survey size frequencies for females and males over all years is shown in Figure 64. The model estimates of survey selectivity for male (Figure 65) and female (Figure 66) are shown for the two periods (1974-1981, 1982-2012) along with the survey selectivity estimated by Somerton and Otto (1999).

K. Calculation of the 2012/13 OFL

Average Recruitment Options

We estimated the Total Catch OFL and associated catch components for the 2012/13 Tanner crab fishery for *Model (0)* and *Model (1)* at four levels of the $B_{35\%}$ proxy for B_{MSY} resulting from four levels of mean recruitment. Here, year represents the recruitment year to the model.

1. ***R1 = 1966-1972 average recruitment.*** This represents the recruitment that 'gave rise to the biomass estimated in 1974-1980' – the reference biomass period used in the survey-based Tier-4 assessment. Requested by the Crab Modeling Workshop (Martel and Stram, 2011); SSC (March 2012) and CPT (June 2012).
2. ***R2 = 1966-1988 average recruitment.*** This alternative is a range of years that, although it includes recruitments that did not result from a stock at B_{MSY} nor that subsequently yielded B_{MSY}, it captures the mode of secondary MMB in 1990 but not beyond mid-1990 when the stock was declared overfished. These years include wider variability in recruitment than R1. It accepts the fact that the stock declined to low levels in the mid-1980s, and the fishery closed (1986 and 1987) due to conservation concerns. In the author's opinion, 1988 is the last recruitment year to include as recruitments after 1988 are inconsistent with basic theory of a stock living at B_{MSY}, or a level of production that either maintained the stock at equilibrium B_{MSY} or provided for its recovery to B_{MSY} from overfished state.
3. ***R3 = 1982-2012 average recruitment.*** A 'bookend' range of recruitment requested by the Crab Modeling Workshop (Martel and Stram, 2011) and reaffirmed by the SSC (March 2012) and CPT (June 2012).
4. ***R4 = 1966-2012 average recruitment.*** A range of recruitment that include 'all years' requested by the SSC (March 2012).

The authors recommend the use of average recruitment over 1966-1972 (R1). It's the recruitment that produced mature male biomass considered the benchmark reference point B_{MSY}. Average recruitment over 1966-1988 (R2) is an alternative that includes a longer range of recruitment that may not represent B_{MSY}. R2 is a level of mean recruitment that is seemingly inadequate to have led to recovery to B_{MSY} following the stock decline in the 1970s. We don't consider average recruitment over 1982-2012 (R3) or 1966-2012 (R4) to represent the production of recruitment from a stock at B_{MSY} given the overfished stock declarations and fishery closures during 1986-1987, 1997-2004 and again in 2011-2012 (Table 3, Figures 26 and 42).

Changes in Stock Productivity
The relative productivity of a stock is commonly expressed as index based on the number of recruits per spawner – e.g., as the natural log of recruitment divided by spawning stock biomass. Changes in this index over time may reflect a shift in the productivity of the stock which may be associated with a change in the environmental regime the stock inhabits. Directional trends or punctuated changes in the production index may be indicative of environmental shifts that would factor into decisions on the selection of years included in the estimation of proxy reference points. Figure 56 shows the Tanner crab production index versus male mature biomass over 1968 to 2012. The production index versus predicted exploitation rate on male mature biomass over 1968 to 2012 is shown in Figure 57. Although male mature biomass varied widely over the time period, the production index displays no directional trend or abrupt change in magnitude that would support splitting the time-series in order to calculation $B_{35\%}$.

The lack of change in the rate of production over time does not by default argue for the inclusion of all years in the average used to calculate the $B_{35\%}$ proxy. Total recruitment, the product of the recruitment rate and total spawning stock biomass, is also a governing factor. The expectation is that lower levels of stock biomass will produce lower recruitments even at the same productivity level. Following the stock decline in the mid-1970s, recruitment has been insufficient to maintain the stock, or to provide for its recovery. With the exception of the early time period, we have not observed recruitments from a stock living at the proxy B_{MSY} level. Neither has total recruitment following the decline led to recovery to the proxy B_{MSY}.

The Tanner crab stock experienced a one-way trip from high biomass levels in the late-1960s and early-1970s to low levels in the 1980's to the present. The performance of stock and fishery reveal that the Tanner crab experienced a severe stock decline over the period of record. The stock was declared overfished in 2010 by the NOAA Fisheries and in need of a rebuilding plan (Rugolo and Turnock 2010). The historical bimodal distribution in male mature biomass (Figure 26) reflects that of the attendant directed fisheries (Figure 10) with peak modes in the early- and late-1970s and early-1990s, and depressed stock status subsequent to these modes. Full-selection fishing mortality rates estimated in the model concur with a history of excessive exploitation (Figure 52, Table 7). If the $F_{35\%}$ OFL control rule established by Amendment 24 had been in effect from 1974/75-2011/12, in approximately one-half of the 44 years, the realized F would have exceeded the overfishing limit (Figure 53). Fishing mortality rates on male Tanner crab have often exceeded the F_{OFL}, however, this did not constitute overfishing in the past because Amendment 24 was implemented in 2008.

Recruitment to the model at 25 mm to 50 mm fluctuated widely from 1950-2007 (fertilization year) displaying a prominent period of moderately high recruitment in the early-to-mid-1960s (Figure 42). These recruitments gave rise to the peak male mature biomass levels in the early-1970s. Recruitments to the stock following the decline in stock biomass from the 1970s have been low and insufficient to maintain the stock at levels observed pre-1980 or provide for stock growth.

The EBS Tanner crab stock was under a rebuilding plan for 1999-2009 and the directed fishery closed from 1997 to 2004 as a result of depressed stock status. The fishery was also closed in 1985 and 1986 due to conservation concerns, and the SOA again in 2010 and 2011 as stock biomass was the minimum threshold in the harvest strategy for opening. 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. However, the increase in observed biomass in 2005-2008 was driven principally by hot-spot tows that inflated total biomass estimates (Rugolo and Turnock 2008). It was doubtful that MMB increased as suggested by estimated survey biomass. MMB declined in 2008-2010 from the apparent 2007 level and the stock was declared overfished in 2010 (Rugolo and Turnock 2010) and deemed in need of a rebuilding plan.

Status of 2011/12 Stock and 2012/13 OFL

1. R1 Recruitment:

Model (0)

$B_{35\%}$=161.37 thousand t and $F_{35\%}$=0.61. The model estimate of 2011/12 MMB at mating (58.59 thousand t) represents 0.36$B_{35\%}$. The total catch OFL is 9.29 thousand t, and the ACL=9.28 thousand t for a P*=0.49 and cv=0.077.

Model (1)

$B_{35\%}$=157.48 thousand t and $F_{35\%}$=0.59. The model estimate of 2011/12 MMB at mating (58.59 thousand t) represents 0.37$B_{35\%}$. The total catch OFL is 9.14 thousand t, and the ACL=9.12 thousand t for a P*=0.49 and cv=0.077.

2. R2 Recruitment:

Model (0)

$B_{35\%}$=90.14 thousand t and $F_{35\%}$=0.61. The model estimate of 2011/12 MMB at mating (58.59 thousand t) represents 0.65$B_{35\%}$. The total catch OFL is 12.71 thousand t, and the ACL=12.39 thousand t for a P*=0.49 and cv=0.077.

Model (1)

$B_{35\%}$=97.57 thousand t and $F_{35\%}$=0.59. The model estimate of 2011/12 MMB at mating (58.59 thousand t) represents 0.60$B_{35\%}$. The total catch OFL is 11.70 thousand t, and the ACL= 11.69 thousand t for a P*=0.49 and cv=0.077.

3. R3 Recruitment:

Model (0)

$B_{35\%}$= 33.45 thousand t and $F_{35\%}$=0.61. The model estimate of 2011/12 MMB at mating (58.59 thousand t) represents 1.75$B_{35\%}$. The total catch OFL is xx.xx thousand t, and the ACL= xx.xx thousand t for a P*=0.49 and cv=0.077.

Model (1)

$B_{35\%}$= 35.60 thousand t and $F_{35\%}$=0.59. The model estimate of 2011/12 MMB at mating (58.59 thousand t) represents 1.65$B_{35\%}$. The total catch OFL is xx.xx thousand t, and the ACL= xx.xx thousand t for a P*=0.49 and cv=0.077.

4. R4 Recruitment:

Model (0)

$B_{35\%}$= 56.00 thousand t and $F_{35\%}$=0.61. The model estimate of 2011/12 MMB at mating (58.59 thousand t) represents 1.05$B_{35\%}$. The total catch OFL is xx.xx thousand t, and the ACL= xx.xx thousand t for a P*=0.49 and cv=0.077.

Model (1)

$B_{35\%}$= 59.55 thousand t and $F_{35\%}$=0.59. The model estimate of 2011/12 MMB at mating (58.59 thousand t) represents 0.98$B_{35\%}$. The total catch OFL is xx.xx thousand t, and the ACL= xx.xx thousand t for a P*=0.49 and cv=0.077.

L. CALCULATION OF THE 2011/12 ABC=ACL

Amendments 38 and 39 to the plan (NPFMC 2010) established methods for the Council to set Annual Catch Limits (ACLs). The Magnuson-Stevens 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 Council's SSC.

Two methods for establishing the ABC control rule are: 1) a constant buffer where the ABC is set by applying a multiplier to the OFL to meet a specified buffer below the OFL; and 2) a variable buffer where the ABC is set based on a specified percentile (P*) of the distribution of the OFL that accounts for uncertainty in the OFL. P* is the probability that ABC would exceed the OFL and overfishing occur. In 2010, the NPFMC prescribed that ABCs for BSAI crab stocks be established at P*=0.49. Annual ACL=ABC levels are established such that the risk of ovefishing, P[ABC>OFL], is 49%.

Two sources of uncertainty are considered in setting the ABC: 1) σ_w, or within assessment uncertainty; and 2) σ_b , additional uncertainty. The EA recommends that some level of additional uncertainty be used in computing ABCs for all stocks. Within assessment uncertainty, σ_w, in a Tier-3 stock is the coefficient of variation in the estimate of end year mature male biomass. Sources of additional uncertainty, σ_b , are: pre-specified population dynamic parameters and life-history rates such as natural mortality, size-weight, maturity; the assumption that F_{MSY}=$F_{35\%}$ when applying the OFL control rule; estimates of the OFL; and the assumption that B_{MSY} is represented by $B_{35\%}$ derived using average recruitment over a time period representative of a stock at B_{MSY} via spawning stock biomass-per-recruit analysis.

The ABC=ACL for the 2012/13 fishery is estimated using the constant buffer approach. For the 2011/12 crab ABCs, the SSC utilized a buffer of 10% for all crab stocks.

1. R1 Recruitment:

Model (0)

OFL=9.29 thousand t, ACL=9.28 thousand t and ABC=8.36 thousand t.

Model (1)

OFL=9.14 thousand t, ACL=9.12 thousand t and ABC=8.20 thousand t.

2. R2 Recruitment:

Model (0)

OFL=12.71 thousand t, ACL=12.69 thousand t and ABC=11.44 thousand t.

Model (1)

OFL=11.70 thousand t, ACL=11.69 thousand t and ABC=10.53 thousand t.

3. R3 Recruitment:

Model (0)

OFL=19.00 thousand t, ACL=18.99 thousand t and ABC=17.10 thousand t.

Model (1)

OFL=18.40 thousand t, ACL=18.39 thousand t and ABC=16.56 thousand t.

4. R4 Recruitment:

Model (0)

OFL=16.30 thousand t, ACL=16.29 thousand t and ABC=14.67 thousand t.

Model (1)

OFL=15.10 thousand t, ACL=15.09 thousand t and ABC=13.59 thousand t.

M. DATA GAPS and RESEARCH PRIORITIES

Long-term research associated with the length-based stock assessment model is required as itemized under Section B.2. Analysis to derive model inputs, parameters and schedules including growth, maturity, survey selectivity, and fishing power are require to improve model performance. Also required is the reformulation of length-weight relationships, molting probability schedules and growth transition matrices.

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Table 1. Eastern Bering Sea Tanner crab retained catch in the United States pot, the Japanese tangle net and pot, and the Russian tangle net fisheries, 1965/66-2011/12.

Eastern Bering Sea *Chionoecetes bairdi* Retained Catch (1000T)				
Year	US Pot	Japan	Russia	Total
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
2011/12	0			0

Table 2. Eastern Bering Sea Tanner crab discards (1000 t) in the domestic pot fisheries and groundfish fisheries, 1973/74-2011/12. No discard mortality applied.

Discards (1000 t) of Tanner Crab by Fishery							
	Tanner Crab		Snow Crab		Red King Crab		Groundfish
Year	Male	Female	Male	Female	Male	Female	♀+♂
1973/74							17.737
1974/75							24.450
1975/76							9.410
1976/77							4.700
1977/78							2.776
1978/79							1.868
1979/80							3.395
1980/81							2.114
1981/82							1.472
1982/83							0.449
1983/84							0.672
1984/85							0.646
1985/86							0.397
1986/87							0.650
1987/88							0.638
1988/89							0.464
1989/90							0.672
1990/91							0.945
1991/92							2.543
1992/93	10.986	1.787	25.759	1.787	1.188	0.029	2.760
1993/94	6.831	1.814	14.530	1.814	2.967	0.198	1.758
1994/95	3.130	1.270	7.124	1.271	0.000	0	2.096
1995/96	2.762	1.760	4.797	1.759	0.000	0	1.525
1996/97	0.236	0.091	0.833	0.229	0.027	0.004	1.594
1997/98	0	0	1.750	0.226	0.165	0.003	1.180
1998/99	0	0	1.989	0.175	0.119	0.003	0.935
1999/00	0	0	0.695	0.145	0.076	0.004	0.631
2000/01	0	0	0.146	0.022	0.067	0.002	0.742
2001/02	0	0	0.323	0.011	0.043	0.002	1.185
2002/03	0	0	0.557	0.037	0.062	0.003	0.719
2003/04	0	0	0.193	0.026	0.056	0.003	0.424
2004/05	0	0	0.078	0.014	0.048	0.003	0.675
2005/06	0.286	0.027	0.968	0.043	0.042	0.002	0.621
2006/07	1.243	0.322	1.462	0.169	0.026	0.003	0.717
2007/08	2.100	0.100	1.872	0.102	0.056	0.009	0.695
2008/09	0.431	0.014	1.119	0.050	0.270	0.004	0.533
2009/10	0.071	0.002	1.324	0.014	0.150	0.001	0.321
2010/11	0	0	1.344	0.016	0.033	0.001	0.217
2011/12	0	0	2.119	0.014	0.010	0.000	0.208

Table 3. *Base Model (0)* predicted retained and discard catch (1000 t) by sex in the directed Tanner crab pot fishery, 1974/75-2011/12.

Directed Fishery Predicted Retained and Discard Catch Biomass (1000 t)				
Year	Retained	Discard Catch		Total
	Male Catch	Male	Female	Male Catch
1974/75	15.23	6.90	0.58	22.12
1975/76	17.65	8.00	0.67	25.65
1976/77	30.01	14.77	1.27	44.78
1977/78	35.52	20.78	1.99	56.30
1978/79	21.09	15.84	1.81	36.93
1979/80	18.97	23.93	3.44	42.89
1980/81	13.44	16.38	2.35	29.82
1981/82	5.03	3.09	0.48	8.13
1982/83	2.47	1.13	0.19	3.60
1983/84	0.79	0.28	0.06	1.07
1984/85	1.50	0.48	0.13	1.97
1985/86	0	0	0	0
1986/87	0	0	0	0
1987/88	1.02	0.54	0.08	1.56
1988/89	3.10	1.59	0.20	4.70
1989/90	11.02	6.17	0.72	17.19
1990/91	18.09	10.25	1.26	28.34
1991/92	14.31	8.70	1.11	23.01
1992/93	15.32	6.42	1.56	21.74
1993/94	7.48	3.74	0.72	11.23
1994/95	3.46	1.76	0.30	5.22
1995/96	1.84	1.62	0.13	3.46
1996/97	0.80	0.36	0.06	1.16
1997/98	0	0	0	0
1998/99	0	0	0	0
1999/00	0	0	0	0
2000/01	0	0	0	0
2001/02	0	0	0	0
2002/03	0	0	0	0
2003/04	0	0	0	0
2004/05	0	0	0	0
2005/06	0.43	0.43	0.01	0.86
2006/07	0.93	0.81	0.03	1.74
2007/08	1.04	1.06	0.03	2.10
2008/09	0.92	0.34	0.03	1.26
2009/10	0.69	0.04	0.06	0.73
2010/11	0	0	0	0
2011/12	0	0	0	0

Table 4. *Base Model (0)* predicted discard catch (1000 t) by sex in the non-directed domestic pot and groundfish fisheries by sex, 1974/75-2011/12.

Non-Directed Fishery Predicted Discard Catch Biomass (1000 t)					
Year	Snow Crab Fishery		Red King Crab Fishery		GF Fishery
	Male	Female	Male	Female	Male + Female
1974/75	2.11	0.18	2.76	8.5E-05	19.56
1975/76	1.81	0.15	2.29	7.0E-05	7.53
1976/77	1.51	0.13	2.86	9.3E-05	3.76
1977/78	1.13	0.11	2.74	1.0E-04	2.23
1978/79	2.65	0.28	1.52	7.0E-05	1.52
1979/80	3.24	0.35	0.73	4.2E-05	2.71
1980/81	5.56	0.58	1.33	7.5E-05	1.70
1981/82	4.85	0.62	1.46	8.1E-05	1.21
1982/83	2.27	0.35	0.57	3.2E-05	0.49
1983/84	0.84	0.18	0.46	3.0E-05	0.59
1984/85	1.08	0.32	0	0	0.56
1985/86	1.28	0.42	0	0	0.40
1986/87	2.37	0.48	0.22	1.7E-05	0.54
1987/88	4.68	0.67	0.36	2.0E-05	0.55
1988/89	6.03	0.72	0.50	2.2E-05	0.47
1989/90	10.33	1.13	0.65	2.7E-05	0.61
1990/91	15.50	1.76	0.84	3.8E-05	0.79
1991/92	12.57	1.51	0.65	3.2E-05	2.03
1992/93	12.71	1.63	0.24	1.3E-05	2.22
1993/94	7.19	1.00	0.18	1.0E-05	1.45
1994/95	3.52	0.52	0	0	1.74
1995/96	2.44	0.37	0	0	1.32
1996/97	0.44	0.07	0.08	4.3E-06	1.43
1997/98	0.76	0.33	0.04	1.1E-05	1.02
1998/99	0.71	0.28	0.04	8.1E-06	0.70
1999/00	0.24	0.08	0.04	7.0E-06	0.47
2000/01	0.18	0.06	0.04	7.3E-06	0.58
2001/02	0.23	0.07	0.05	8.5E-06	0.94
2002/03	0.29	0.08	0.06	9.8E-06	0.58
2003/04	0.25	0.07	0.07	1.2E-05	0.41
2004/05	0.24	0.06	0.09	1.5E-05	0.57
2005/06	0.46	0.11	0.07	2.1E-07	0.54
2006/07	0.68	0.18	0.08	2.4E-07	0.63
2007/08	0.88	0.23	0.09	2.7E-07	0.63
2008/09	0.59	0.14	0.10	3.1E-07	0.53
2009/10	0.64	0.15	0.11	3.2E-07	0.39
2010/11	0.63	0.15	0.11	2.8E-07	0.33
2011/12	0.95	0.23	0.09	2.4E-07	0.32

Table 5. *Base Model (0)* predicted total (retained + discard) Tanner crab catch biomass (1000 t) in the directed and non-directed fisheries, 1973/74-2010/11. Post-release discard mortality rates applied (0.50=pot and 0.80=groundfish).

Year	Total Catch Biomass (1000 t)	
	Male	Female
1973/74	36.78	10.53
1974/75	33.51	4.58
1975/76	51.03	3.28
1976/77	61.30	3.21
1977/78	41.85	2.84
1978/79	48.22	5.14
1979/80	37.56	3.79
1980/81	15.04	1.71
1981/82	6.68	0.78
1982/83	2.67	0.53
1983/84	3.33	0.73
1984/85	1.48	0.62
1985/86	2.85	0.75
1986/87	6.88	1.03
1987/88	11.46	1.16
1988/89	28.48	2.15
1989/90	45.07	3.43
1990/91	37.24	3.63
1991/92	35.80	4.30
1992/93	19.32	2.45
1993/94	9.62	1.69
1994/95	6.56	1.16
1995/96	2.40	0.84
1996/97	1.30	0.84
1997/98	1.10	0.63
1998/99	0.51	0.32
1999/00	0.51	0.35
2000/01	0.75	0.54
2001/02	0.64	0.37
2002/03	0.53	0.27
2003/04	0.61	0.35
2004/05	1.66	0.40
2005/06	2.81	0.52
2006/07	3.38	0.57
2007/08	2.22	0.44
2008/09	1.68	0.41
2009/10	0.90	0.31
2010/11	1.20	0.39
2011/12	1.12	0.63

Table 6. Observed survey female, male and total spawning biomass (1000 t) and observed abundance of legal male crab ≥ 138mm (million crab), 1974-2012.

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	212.01	55.76	267.77	87.53
1975	265.07	38.76	303.83	151.45
1976	152.09	45.99	198.08	86.07
1977	130.41	47.59	177.99	68.49
1978	80.62	26.43	107.06	37.65
1979	47.82	20.43	68.25	21.33
1980	86.33	70.42	156.76	28.53
1981	50.67	45.24	95.91	10.14
1982	49.67	64.76	114.43	6.82
1983	29.04	20.72	49.76	4.70
1984	26.15	14.72	40.87	6.19
1985	11.71	5.68	17.39	3.54
1986	13.18	3.49	16.67	2.27
1987	24.18	5.27	29.46	5.73
1988	59.51	25.57	85.08	15.60
1989	101.48	25.47	126.96	32.73
1990	103.17	36.36	139.52	42.93
1991	110.82	45.56	156.37	33.89
1992	108.12	27.76	135.88	39.65
1993	62.12	11.91	74.03	18.22
1994	44.55	10.37	54.92	14.81
1995	33.86	13.44	47.30	9.45
1996	27.32	9.80	37.12	8.56
1997	11.07	3.53	14.60	3.24
1998	10.56	2.31	12.87	1.97
1999	12.40	3.81	16.21	2.07
2000	16.45	4.17	20.63	4.60
2001	18.20	4.61	22.81	5.97
2002	18.23	4.48	22.71	5.94
2003	23.71	8.35	32.06	6.31
2004	25.56	4.70	30.26	4.50
2005	43.99	11.62	55.61	10.41
2006	66.89	15.79	82.68	13.36
2007	72.63	13.33	85.97	10.90
2008	59.70	11.33	71.03	14.39
2009	37.60	8.22	45.82	6.91
2010	36.14	5.44	41.59	8.01
2011	46.30	8.67	54.97	13.68
2012	15.83	43.15	58.97	7.09

Table 7. *Base Model (0)* estimates of population biomass and abundance, male, female and total mature biomass, abundance of legal (≥ 138mm) males, recruitment to the population, male mature biomass at mating, and full-selection fishing mortality rate. (Biomass in 1000 t, abundance in 10^6 crab).

Year	Population ≥ 25mm		Mature Biomass (1000 t)			Males ≥ 138 mm	R > 25-30mm	MMB @Mating	Full-Selection
	1000 t	10^6 crab	Female	Male	Total	10^6 crab	10^6 crab	1000 t	F
1974/75	622.03	2396.92	116.72	417.70	534.41	161.67	170.91	317.24	0.19
1975/76	528.29	2070.50	98.93	362.18	461.11	140.35	392.90	275.01	0.22
1976/77	451.90	2302.84	83.68	308.44	392.12	116.99	272.24	212.46	0.45
1977/78	368.19	2237.05	68.95	237.37	306.32	83.73	251.58	141.90	0.85
1978/79	295.95	2138.16	58.75	160.42	219.17	45.67	67.39	96.08	0.98
1979/80	268.35	1713.19	57.40	126.13	183.53	27.78	13.53	62.39	2.20
1980/81	243.07	1247.01	57.41	114.56	171.98	23.73	53.48	47.16	1.53
1981/82	200.18	941.15	57.27	95.81	153.09	29.02	20.99	50.71	0.31
1982/83	163.65	687.83	52.68	86.12	138.80	33.00	204.83	49.86	0.12
1983/84	127.54	885.08	44.04	65.70	109.73	29.76	172.65	39.56	0.05
1984/85	100.76	993.78	35.75	40.94	76.68	19.29	361.45	23.53	0.11
1985/86	98.91	1466.08	30.45	26.41	56.86	11.30	287.01	21.52	0.01
1986/87	126.26	1696.07	29.32	33.59	62.92	12.59	277.72	26.91	0.02
1987/88	167.70	1851.78	33.62	53.16	86.78	17.92	200.09	40.52	0.10
1988/89	210.91	1807.34	41.23	80.57	121.79	28.08	111.48	59.82	0.18
1989/90	245.30	1586.51	49.17	112.42	161.59	39.49	47.42	71.57	0.49
1990/91	245.37	1256.65	52.68	125.88	178.56	45.05	23.79	67.73	0.80
1991/92	208.36	922.89	50.49	111.39	161.87	37.95	18.75	61.85	0.73
1992/93	166.30	664.09	43.97	95.04	139.00	32.65	15.50	48.34	1.17
1993/94	115.41	460.68	33.95	67.40	101.35	21.95	15.21	39.46	0.69
1994/95	81.48	337.18	25.27	48.37	73.64	15.91	21.55	32.00	0.39
1995/96	59.80	273.93	18.46	35.53	53.99	11.87	24.17	23.95	0.24
1996/97	44.77	238.63	13.56	25.70	39.26	8.82	62.21	19.50	0.18
1997/98	38.50	296.60	10.28	21.17	31.45	7.29	26.33	16.70	0.05
1998/99	35.58	273.75	8.09	18.56	26.66	6.62	81.78	14.75	0.04
1999/00	37.33	368.78	7.20	17.64	24.84	6.36	47.37	14.55	0.03
2000/01	42.53	376.72	7.65	19.60	27.25	6.93	148.01	16.22	0.03
2001/02	52.34	583.78	8.54	24.19	32.73	8.76	56.60	19.86	0.04
2002/03	61.57	560.65	9.73	28.70	38.43	10.91	100.79	23.88	0.02
2003/04	73.88	631.53	11.68	34.78	46.46	13.01	198.12	29.20	0.01
2004/05	91.01	881.36	14.49	43.45	57.94	16.40	57.63	36.50	0.02
2005/06	106.23	793.51	17.04	55.01	72.05	20.92	47.15	45.40	0.04
2006/07	117.40	701.68	19.10	63.40	82.50	25.61	36.38	51.43	0.06
2007/08	125.03	605.69	22.10	70.02	92.13	26.98	40.30	56.65	0.06
2008/09	128.24	536.41	23.40	81.58	104.98	32.04	194.21	67.49	0.05
2009/10	126.32	792.75	21.33	85.39	106.72	36.54	246.71	71.23	0.08
2010/11	123.43	1099.44	18.39	77.65	96.03	33.84	131.29	65.40	0.01
2011/12	127.23	1109.73	17.39	69.96	87.35	30.32	32.39	58.59	0.01
2012/13	139.88	918.99	20.79	68.98	89.76	27.71	-	-	-

Table 8. *Base Model (0)* parameter values and whether parameters were estimated in the model, excluding recruitments and fishing mortality parameters.

Parameter	Value	S.Deviation	Estimated?
Natural Mortality - immature male and female	0.249	0.01	Y
Natural Mortality - mature male	0.252	0.01	Y
Natural Mortality - mature female	0.337	0.01	Y
Additional 1980-84 Mortality - mature male	0.737	0.11	Y
Additional 1980-84 Mortality - mature female	0.280	0.04	Y
Female (a) parameter of exponential growth	1.98	0.05	Y
Female (b) parameter of exponential growth	0.89	0.01	Y
Male (a) parameter of exponential growth	1.56	0.02	Y
Male (b) parameter of exponential growth	0.97	0.01	Y
Alpha for gamma distribution of recruits	11.5		N
Beta for gamma distribution of recruits	4.0		N
Beta for gamma distribution female growth	0.75		N
Beta for gamma distribution male growth	0.75		N
Fishery selectivity total male slope - 1991-1996	0.13	0.01	Y
Fishery selectivity total male slope - 2005-2011	0.13	0.01	Y
Fishery selectivity total male length at 50%, 1991	132.94	0.31	Y
Fishery selectivity total male length at 50%, 1992	139.78	0.31	Y
Fishery selectivity total male length at 50%, 1993	136.81	0.31	Y
Fishery selectivity total male length at 50%, 1994	135.02	0.31	Y
Fishery selectivity total male length at 50%, 1995	123.34	0.31	Y
Fishery selectivity total male length at 50%, 1996	134.72	0.32	Y
Fishery selectivity total male length at 50%, 2005	118.26	0.31	Y
Fishery selectivity total male length at 50%, 2006	118.39	0.31	Y
Fishery selectivity total male length at 50%, 2007	116.14	0.31	Y
Fishery selectivity total male length at 50%, 2008	135.84	0.31	Y
Fishery selectivity total male length at 50%, 2009	159.37	0.31	Y
Fishery retention curve male slope, 1991-1996	0.74	0.14	Y
Fishery retention curve male length at 50%, 1991-1996	137.95	0.40	Y
Fishery retention curve male slope, 2005-2010	1.02	0.28	Y
Fishery retention curve male length at 50%, 2005-2011	137.70	0.24	Y
Directed Fishery discard selectivity female slope	0.13	0.01	Y
Directed Fishery discard selectivity female length at 50%	115.93	2.86	Y
Snow crab male selectivity slope ascending, 1989-1996	0.05	0.00	Y
Snow crab male selectivity length at 50% ascending, 1989-1996	118.81	5.84	Y
Snow crab male selectivity slope descending, 1989-1996	0.22	0.13	Y
Snow crab male selectivity length at 50% descending, 1989-1996	80.59	5.98	Y
Snow crab male selectivity slope ascending, 1997-2004	0.14	0.05	Y
Snow crab male selectivity length at 50% ascending, 1997-2004	87.45	7.84	Y
Snow crab male selectivity slope descending, 1997-2004	0.32	0.10	Y
Snow crab male selectivity length at 50% descending, 1997-2004	88.00	1.99	Y
Snow crab male selectivity slope ascending, 2005-2011	0.12	0.07	Y
Snow crab male selectivity length at 50% ascending, 2005-2011	135.79	6.31	Y
Snow crab male selectivity slope descending, 2005-2011	0.25	0.09	Y
Snow crab male selectivity length at 50% descending, 2005-2011	92.53	3.01	Y

Table 8. (continued)

Parameter	Value	S.Deviation	Estimated?
Snow crab fishery female selectivity slope, 1989-1996	0.17	0.11	Y
Snow crab fishery female selectivity length at 50%, 1989-1996	141.72	5.41	Y
Snow crab fishery female selectivity slope, 2005-2011	0.23	0.05	Y
Snow crab fishery female selectivity length at 50%, 2005-2011	137.39	1.63	Y
Red king crab fishery male selectivity slope, 1989-1996	0.17	0.04	Y
Red king crab fishery male selectivity length at 50%, 1989-1996	150.00	1.17	Y
Red king crab fishery male selectivity slope, 1997-2004	0.14	0.07	Y
Red king crab fishery male selectivity length at 50%, 1997-2004	150.00	2.95	Y
Red king crab fishery male selectivity slope, 2005-2011	0.17	0.07	Y
Red king crab fishery male selectivity length at 50%, 2005-2011	169.96	245.05	Y
Red king crab fishery female selectivity slope, 1989-1996	0.18	0.07	Y
Red king crab fishery female selectivity length at 50%, 1989-1996	115.64	5.36	Y
Red king crab fishery female selectivity slope, 1997-2004	0.09	0.03	Y
Red king crab fishery female selectivity length at 50%, 1997-2004	134.27	14.68	Y
Red king crab fishery female selectivity slope, 2005-2011	0.07	0.01	Y
Red king crab fishery female selectivity length at 50%, 2005-2011	150.00	0.00	Y
Groundfish Fishery male selectivity slope, 1973-1986	0.14	0.03	Y
Groundfish Fishery male selectivity length at 50%, 1973-1986	42.30	2.00	Y
Groundfish Fishery male selectivity slope, 1987-1996	0.18	0.08	Y
Groundfish Fishery male selectivity length at 50%, 1987-1996	40.00	0.00	Y
Groundfish Fishery male selectivity slope, 1997-2011	0.10	0.01	Y
Groundfish Fishery male selectivity length at 50%, 1997-2011	67.70	3.13	Y
Groundfish Fishery female selectivity slope, 1973-1986	0.15	0.03	Y
Groundfish Fishery female selectivity length at 50%, 1973-1986	47.02	1.96	Y
Groundfish Fishery female selectivity slope, 1987-1996	0.15	0.12	Y
Groundfish Fishery female selectivity length at 50%, 1987-1996	41.86	5.19	Y
Groundfish Fishery female selectivity slope, 1997-2011	0.08	0.01	Y
Groundfish Fishery female selectivity length at 50%, 1997-2011	81.21	4.74	Y
Survey Q 1974-1981 – male	0.53	0.04	Y
Survey 1974-1981 difference in length (95%-50%) of Q – male	21.51	3.53	Y
Survey 1974-1981 length at 50% of Q – male	45.36	1.92	Y
Survey Q 1982-2012 – male	0.72	0.04	Y
Survey 1982-2012 difference in length (95%-50%) of Q – male	61.79	9.31	Y
Survey 1982-2012 length at 50% of Q – male	30.14	3.56	Y
Survey Q 1974-1981 – female	0.71	0.20	Y
Survey 1974-1981 difference in length (95%-50%) of Q – female	55.07	19.84	Y
Survey 1974-1981 length at 50% of Q – female	60.63	13.91	Y
Survey Q 1982-2012 – female	0.56	0.04	Y
Survey 1982-2012 difference in length (95%-50%) of Q – female	100.00	0.00	Y
Survey 1982-2012 length at 50% of Q – female	7.90	14.03	Y
Fishery cpue q	0.00055		N

Table 9. Weighting factors for likelihood equations for *Base Model (0),* and *Model (1)* through *Model (6)*. Sample sizes for all length components were set at 200.

Likelihood Component	Weight
retained + discard male catch, male and female discards in snow and red king fisheries	10.0
directed fishery female discards	10.0
groundfish catch	10.0
total catch length composition	1.0
retained catch length composition	1.0
female directed fishery length composition	1.0
survey length composition	1.0
groundfish fishery length composition	1.0
snow and red king fishery length composition	1.0
survey biomass	1.0
recruitment deviations	1.0
directed fishing mortality deviations	1.0
snow fishing mortality deviations	0.5
red king crab fishing mortality deviations	3.0
trawl fishing mortality deviations	0.5
fishery cpue	0
natural mortality penalty standard deviation	0.05
growth penalty male a standard deviation	0.025
growth penalty male b standard deviation	0.1
growth penalty female a standard deviation	0.1
growth penalty female b standard deviation	0.025
penalty on first-difference early recruitment	1.0
penalty on second-difference maturity probability males	0.5
penalty on second-difference maturity probability females	1.0
penalty on survey Q annual deviations	0.05
survey Q standard deviation penalty	10.0

Table 10. Likelihood values by component for the Tanner crab assessment model shown for *Base Model (0), Model (1)* and *Model (2)*.

Likelihood Component	Likelihood Value		
	Model 0	*Model 1*	*Model 2*
recruitment deviations	1.9	1.7	1.9
probability of maturity smooth constraint	1.6	1.6	1.6
Survey q penalty	26.0	17.8	26.0
F penalty	65.2	65.3	65.4
retained length	39.4	38.4	39.7
total directed length	56.9	58.4	57.1
female directed length	9.1	9.7	9.7
survey length	829.4	827.3	830.0
groundfish fishery length	35.7	29.9	40.4
snow fishery length	44.6	45.8	51.0
red king fishery length	27.6	27.6	51.7
survey biomass	186.6	171.4	186.5
fishery cpue	-	-	-
directed fishery male discard catch	3.7	3.8	3.8
directed fishery male retained catch	5.4	5.3	5.4
directed fishery female discard catch	11.8	12.0	11.8
groundfish fishery male + female catch	1.9	2.0	1.9
snow fishery male + female catch	13.3	14.4	13.6
red king fishery male + female catch	18.7	19.2	18.7
natural mortality penalty	46.0	49.7	46.2
Total Likelihood	1426.0	1403.1	1463.7

Table 11. Natural mortality rates on immature male and female, mature female and mature male Tanner crab estimated in *Base Model (0)* and *Model (1)*.

Category	*Base Model (0)*		*Model (1)*	
	Pre-1984 + 1985-P	1980-84	Pre-1984 + 1985-P	1980-84
Immature M-F	0.249	0.249	0.246	0.689
Mature Male	0.252	0.737	0.251	0.436
Mature Female	0.337	0.280	0.342	0.258

Table 12. Total likelihood, maximum survey Q and survey Q at reference size for male (140 mm cw) and female (100 mm cw) Tanner crab versus Q for *Base Model (0)*.

Q	TL	Male		Female	
		maxQ	Q@140 mm	maxQ	Q@100 mm
0.1	1740.6	0.10	0.10	0.193	0.139
0.2	1579.6	0.20	0.20	0.198	0.175
0.3	1515.0	0.30	0.30	0.263	0.246
0.4	1472.3	0.40	0.40	0.356	0.328
0.5	1446.5	0.50	0.50	0.434	0.398
0.6	1431.5	0.60	0.60	0.494	0.457
0.7	1426.1	0.70	0.70	0.546	0.511
0.8	1428.4	0.80	0.79	0.592	0.559
0.9	1437.3	0.90	0.89	0.631	0.600
1.0	1451.9	0.99	0.95	0.642	0.611

Table 13. Likelihood components at fixed values of survey Q for the *Base Model (0)*.

Likelihood Component	Q									
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
recruitment deviations	3.4	2.8	2.3	2.2	2.0	1.9	1.9	1.8	1.8	1.8
probability of maturity smooth constraint	1.5	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Survey q penalty	214.2	185.0	143.0	100.5	68.1	45.0	28.3	17.6	12.2	13.9
F penalty	92.6	74.3	73.3	69.1	66.9	65.4	65.2	65.2	65.1	64.8
retained length	41.9	41.4	42.4	41.6	40.2	39.4	39.4	39.4	39.4	39.4
total directed length	61.2	47.9	52.3	53.7	53.6	55.0	56.7	58.3	59.7	60.1
female directed length	7.9	8.4	8.7	8.8	8.9	9.0	9.1	9.2	9.3	9.4
survey length	825.0	792.8	778.1	792.4	808.6	819.4	827.9	836.1	844.8	853.6
groundfish fishery length	10.4	20.3	25.1	26.6	29.3	32.3	35.2	38.0	40.6	42.1
snow fishery length	42.1	43.0	44.6	44.3	44.2	44.2	44.5	45.0	45.5	45.9
red king fishery length	28.8	27.6	27.4	27.3	27.7	27.7	27.6	27.6	27.6	27.7
survey biomass	296.6	245.6	230.6	212.7	201.1	192.4	187.3	184.2	182.6	182.6
fishery cpue	-	-	-	-	-	-	-	-	-	-
directed fishery male discard catch	5.9	5.1	4.7	4.5	4.1	3.8	3.7	3.6	3.4	3.4
directed fishery male retained catch	10.7	7.3	6.1	6.2	5.2	5.3	5.4	5.5	5.6	5.7
directed fishery female discard catch	11.6	11.3	11.1	11.3	11.3	11.5	11.7	12.0	12.3	12.4
groundfish fishery male + female catch	1.7	1.5	1.6	1.6	1.7	1.8	1.9	2.0	2.2	2.3
snow fishery male + female catch	9.9	10.0	10.4	11.0	11.5	12.2	13.1	14.2	15.3	15.7
red king fishery male + female catch	20.3	11.7	12.8	14.9	16.2	17.5	18.5	19.3	20.0	20.4
natural mortality penalty	53.2	41.5	37.9	41.6	43.8	45.2	45.9	46.5	46.9	47.5
Total Likelihood	1740.6	1579.6	1515.0	1472.3	1446.5	1431.5	1426.1	1428.4	1437.3	1451.9

Table14. Percent change in male and female biomass of Tanner crab estimated in the NMFS bottom trawl survey, 1980-1985, for customary survey size groupings.

Percent Change in Tanner Crab Biomass, 1980-1985	
Males:	%
Recruit (<=109 mm)	-93.7
Pre-Recruit (110-137 mm)	-84.7
Legal (>=138 mm)	-90.9
Mature (All Sizes)	-88.5
Females:	
Small (<85 mm)	-94.6
Large (>=85 mm)	-85.3
Mature (All Sizes)	-91.3

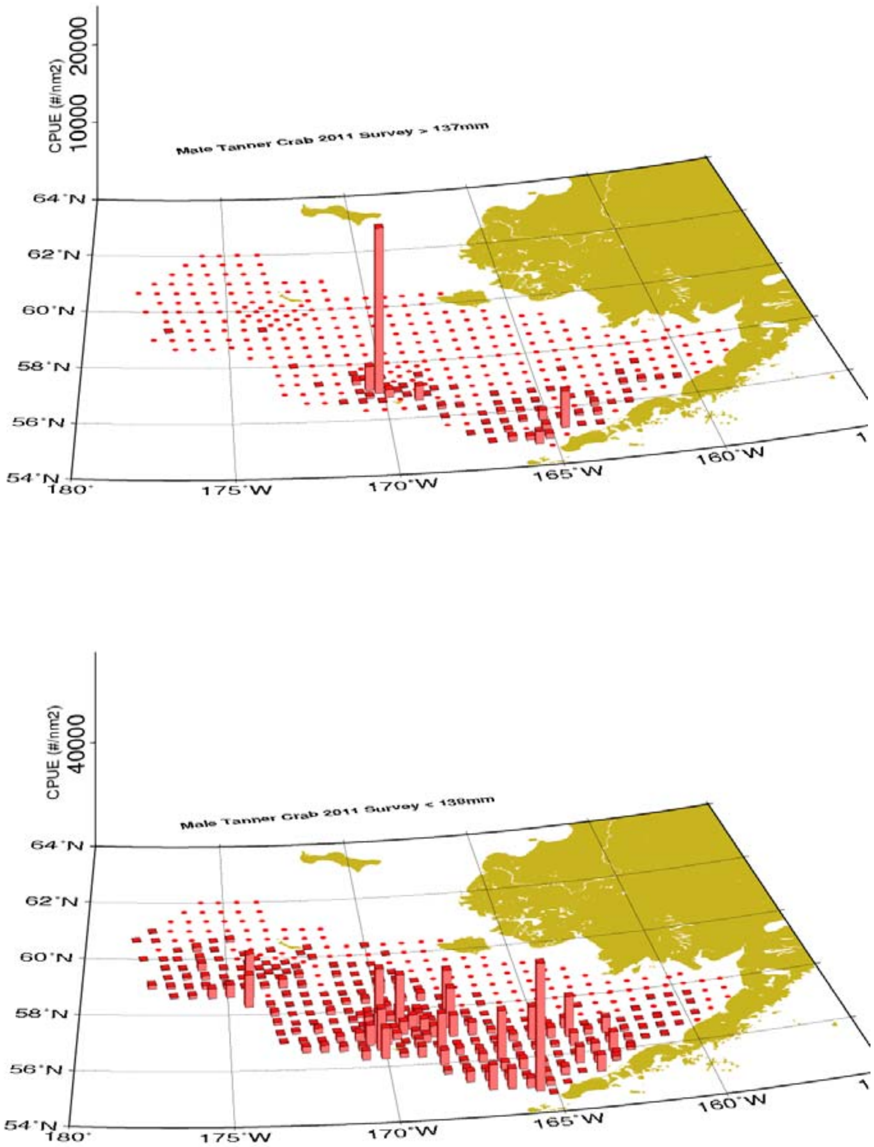


Figure 1. Distribution and abundance of legal (>= 138 mm cw) (top) and sublegal (< 138 mm cw) (bottom) male Tanner crab in the summer 2011 NMFS bottom trawl survey.

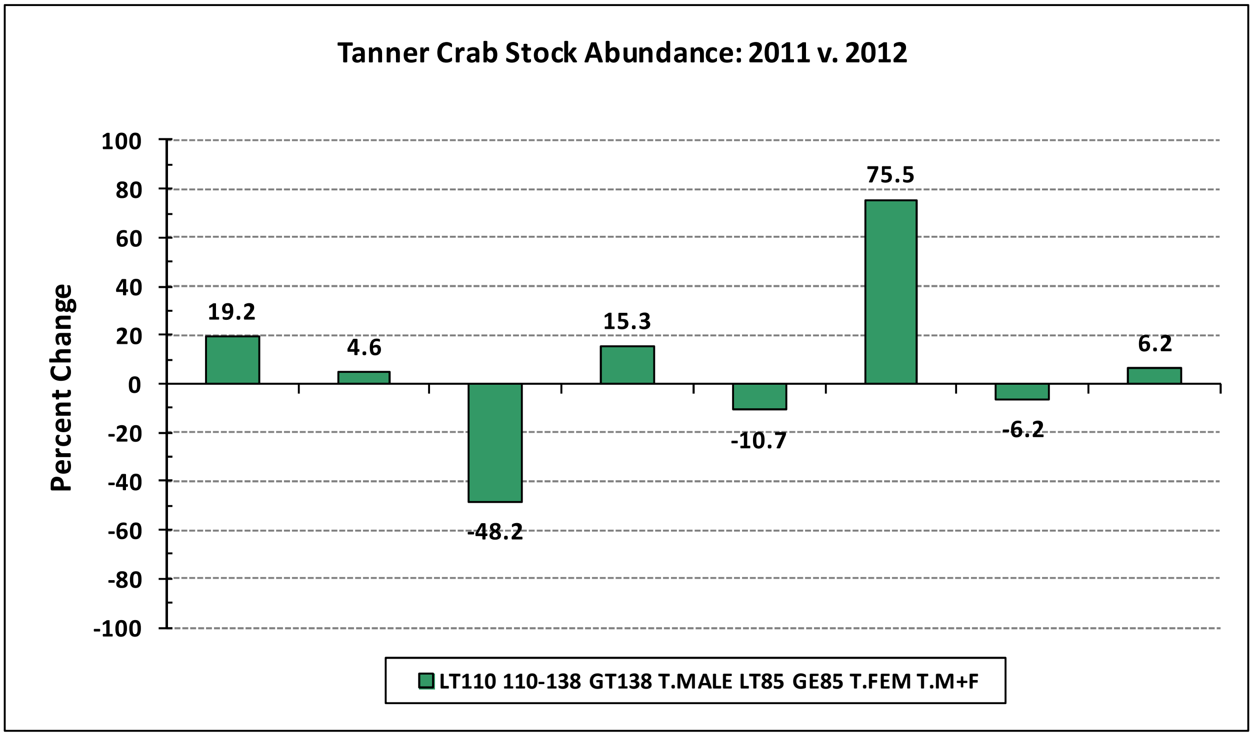
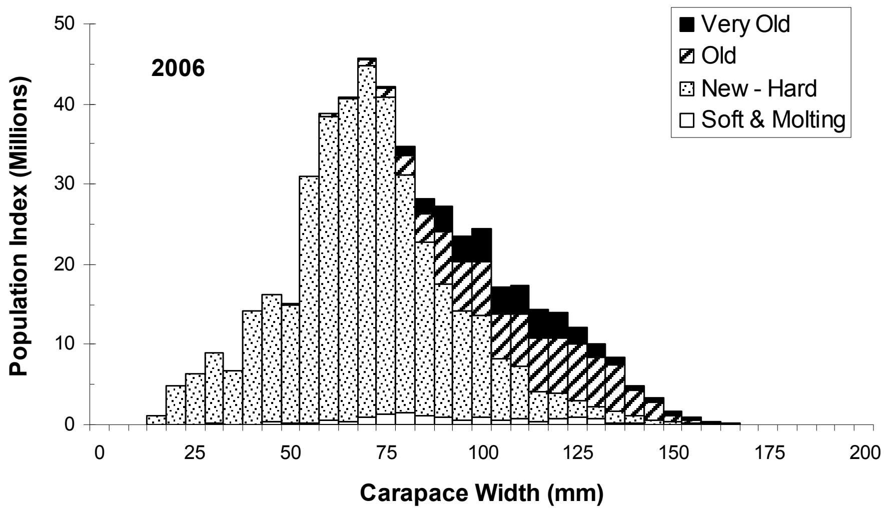


Figure 2. Percent change in Tanner crab stock abundance between the 2010 and 2011 summer trawl survey for males (< 110 mm cw, 110-137 mm cw, >= 138 mm cw and total males), females (<85 mm cw, >=85 mm cw and total females), and for total males + females combined.

(a)



(b)

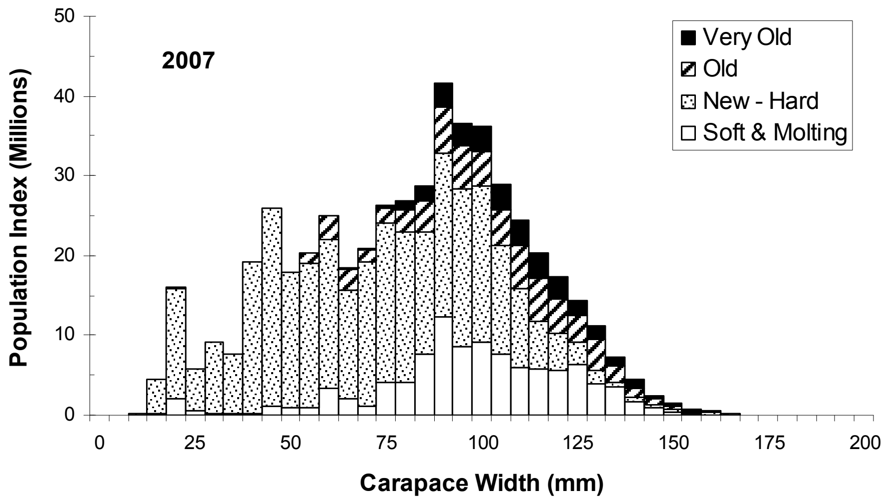
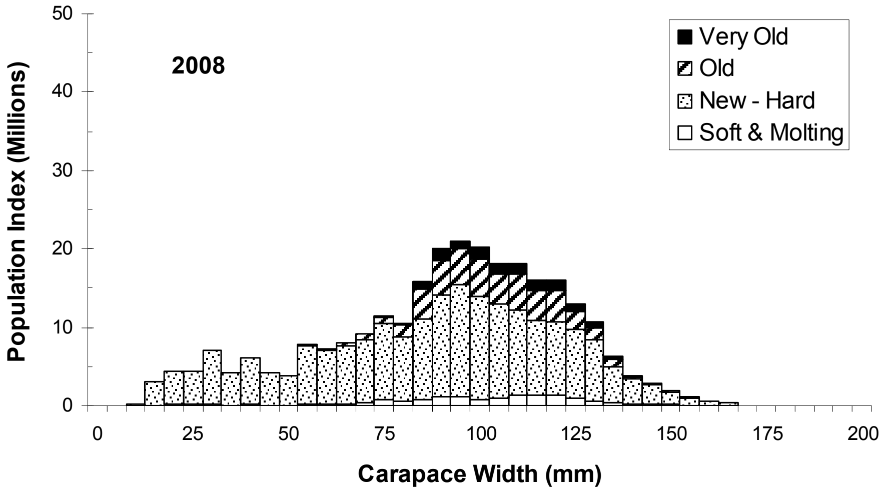


Figure 3 (a-b). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006/07 to 2007/08.

(c)



(d)

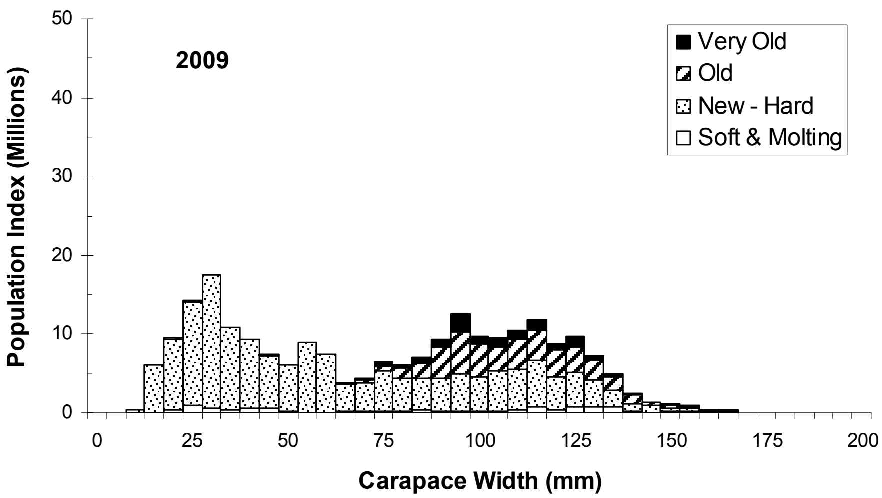
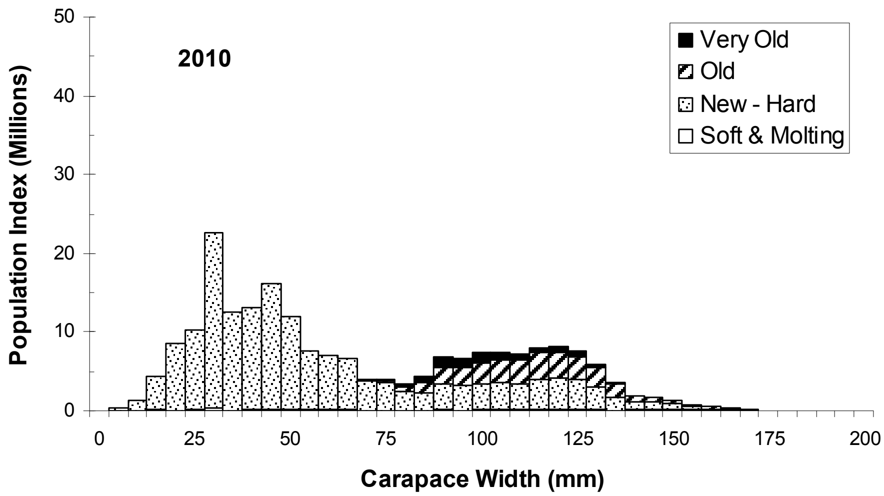


Figure 3 (c-d). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2008/09 to 2009/10.

(e)



(f)

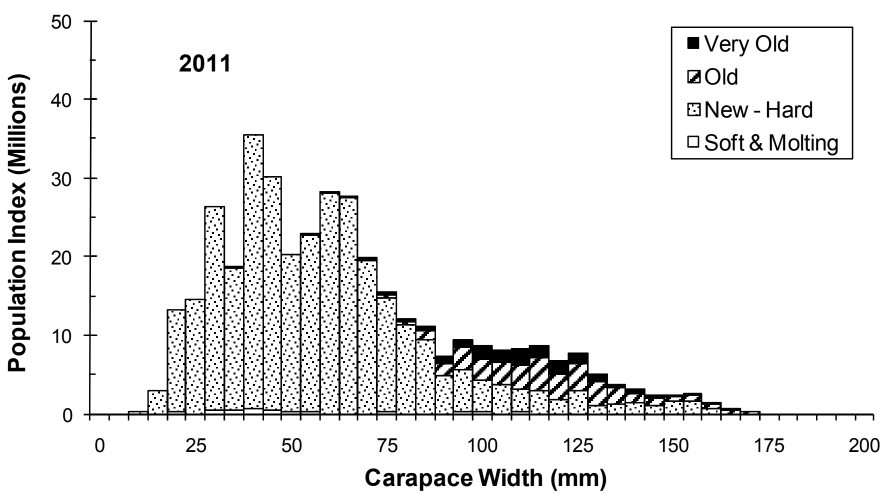


Figure 3 (e-f). Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2010/11 to 2011/12.

(g)

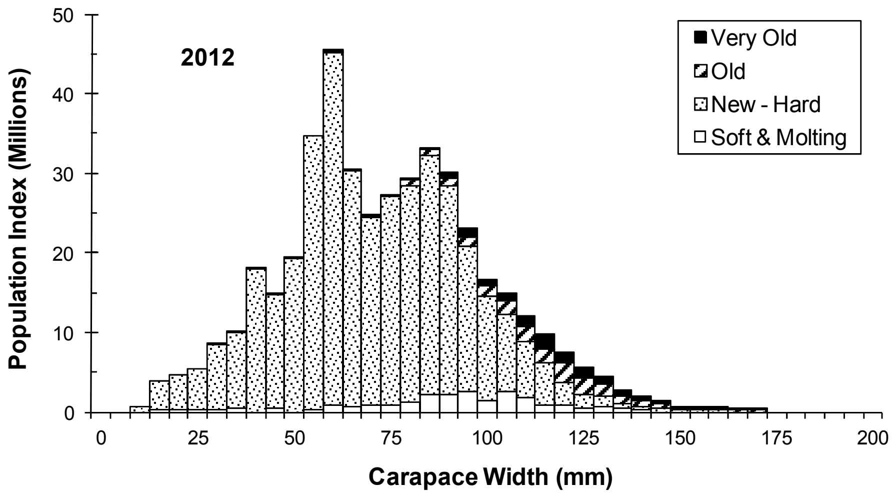


Figure 3 g. Male Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2012/13.

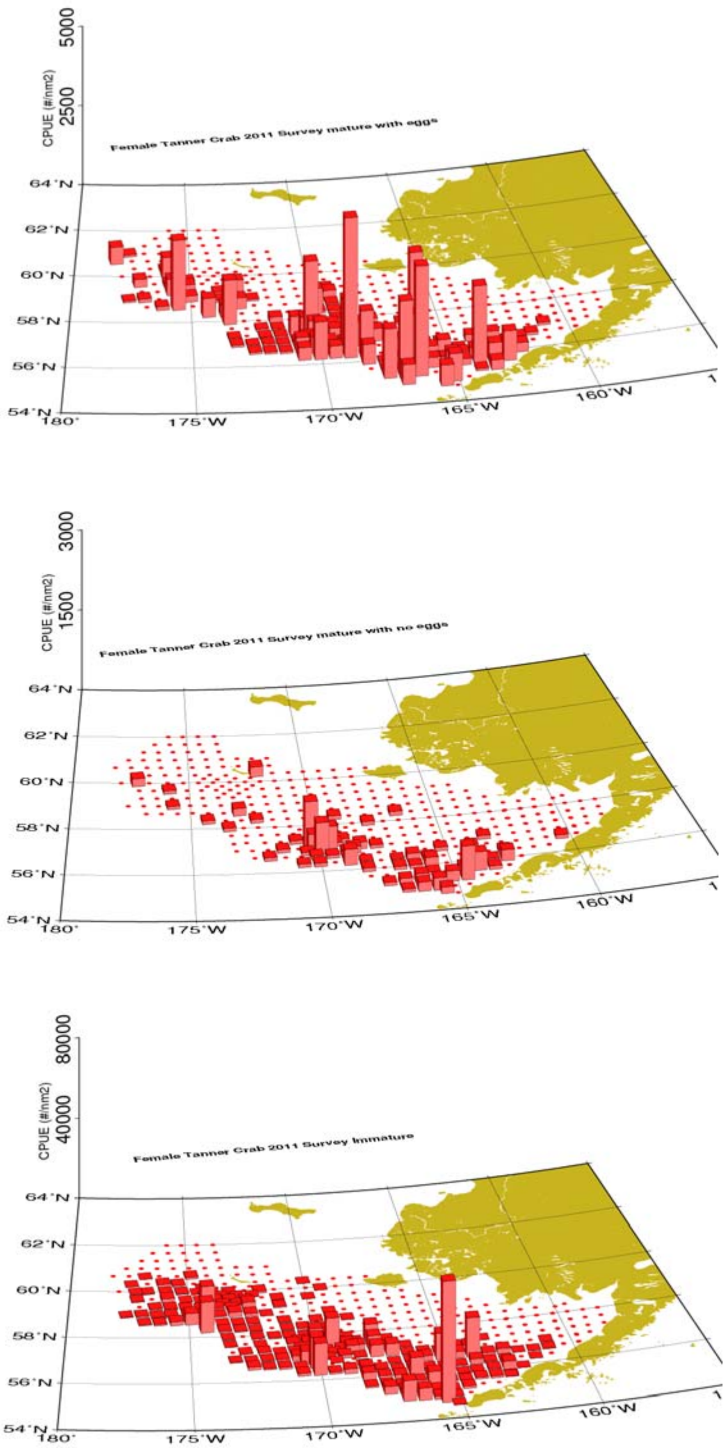
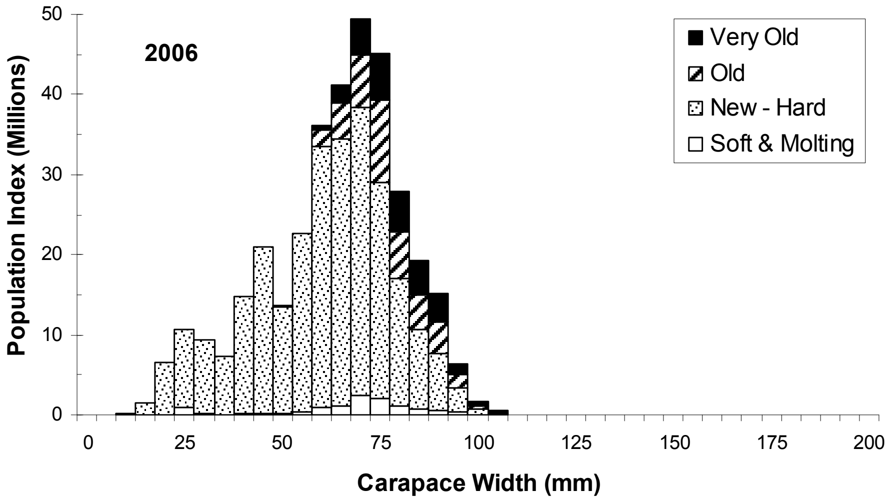


Figure 4. Distribution and abundance of ovigerous (top), barren mature (middle), and immature (bottom) female Tanner crab in the summer 2011 NMFS bottom trawl survey.

(a)



(b)

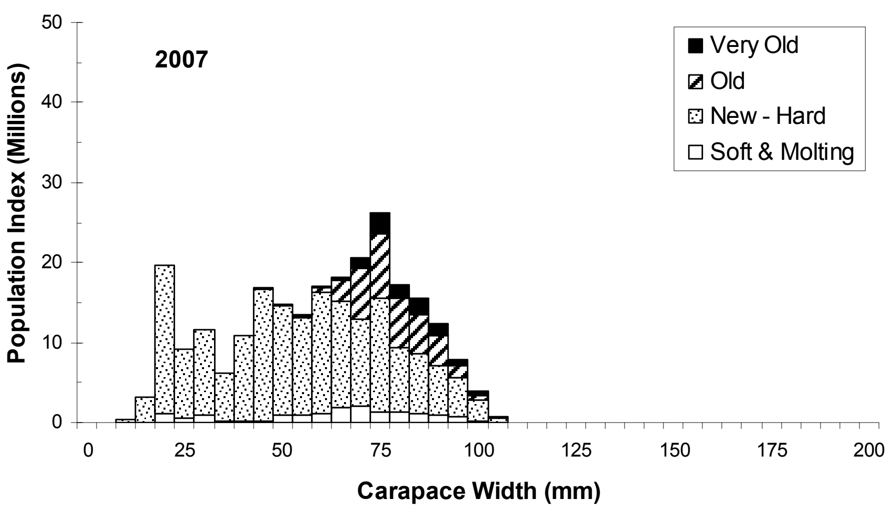
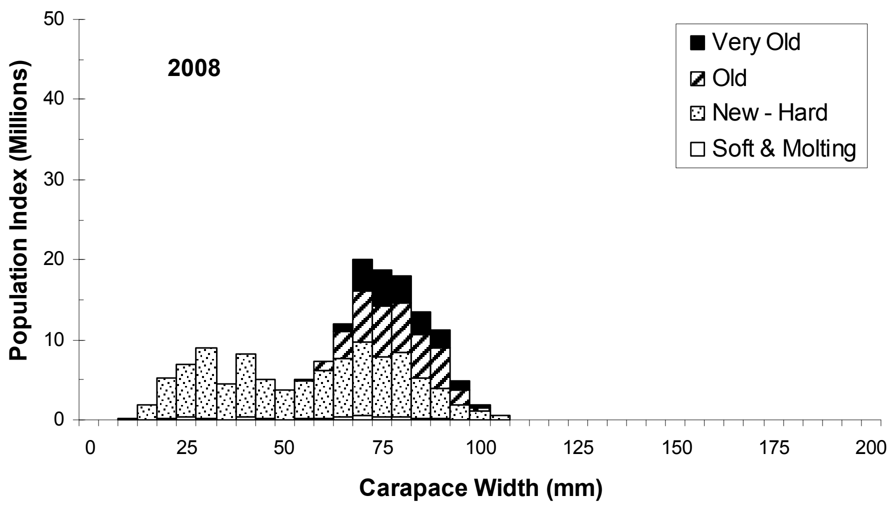


Figure 5 (a-b). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2006/07 to 2007/08.

(c)



(d)

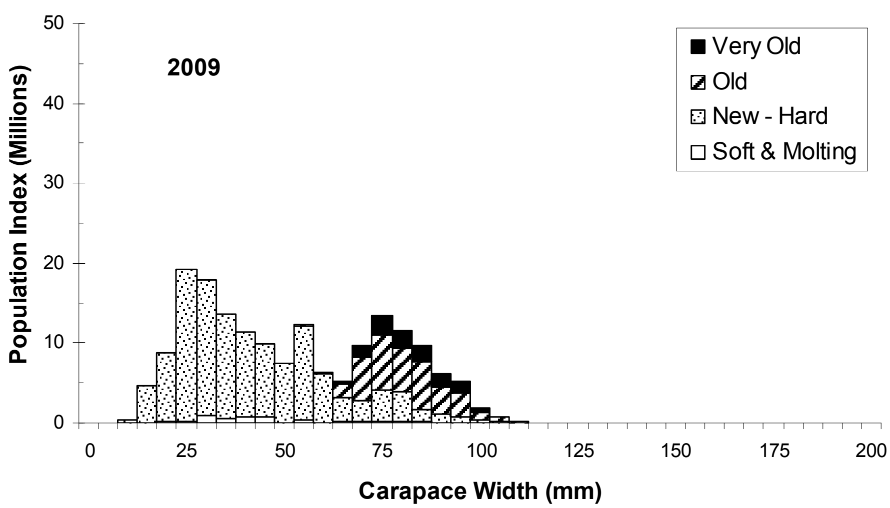
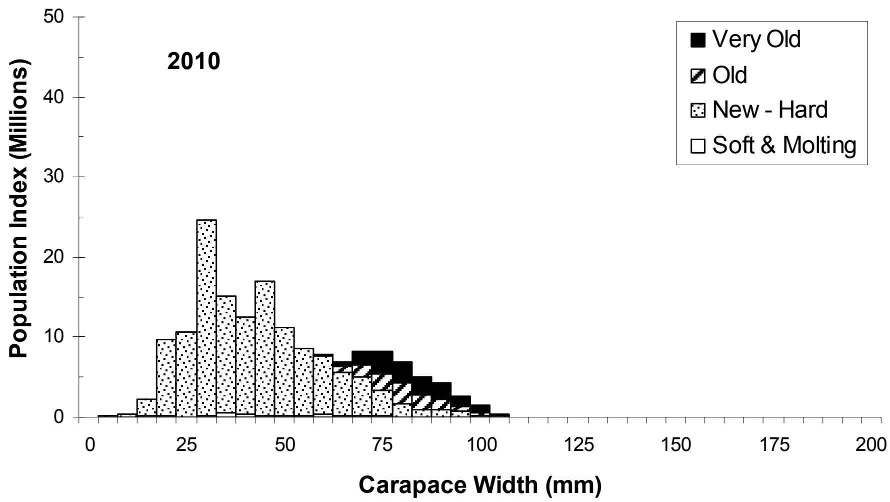


Figure 5 (c-d). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2008/09 to 2009/10.

(e)



(f)

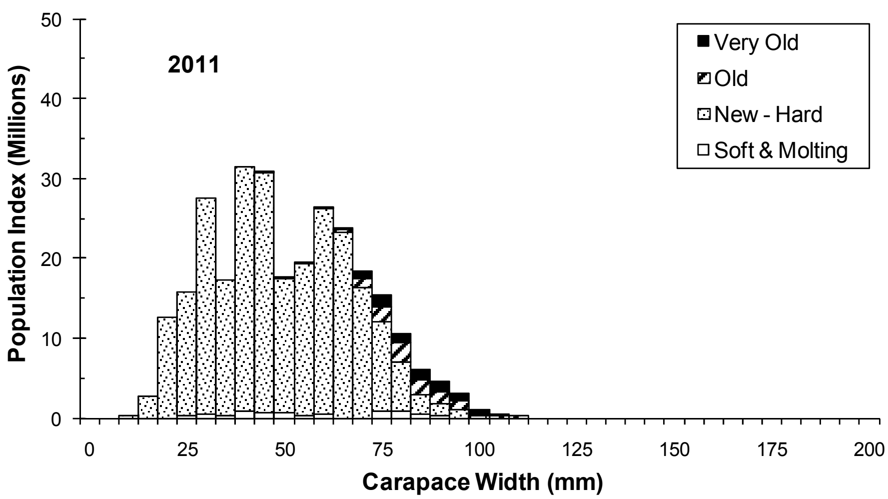


Figure 5 (e-f). Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2010/11 to 2011/12.

(g)

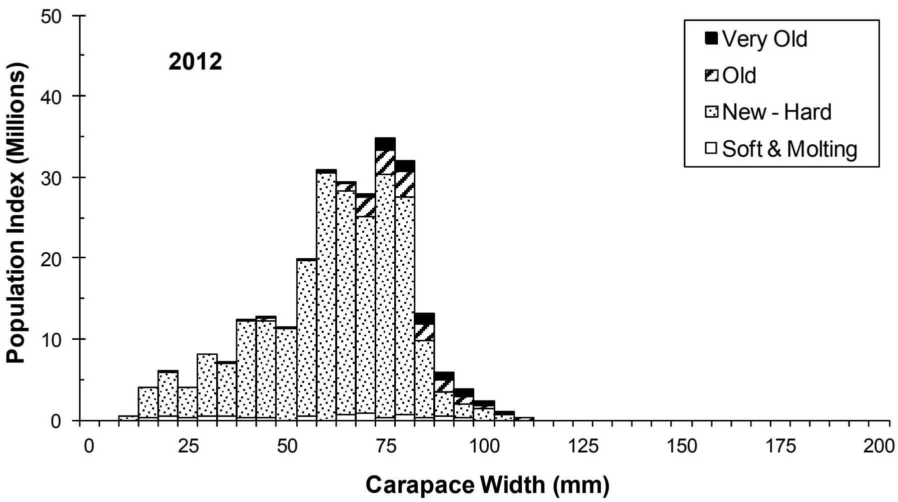


Figure 5 g. Female Tanner crab length frequency by shell class condition sampled by the EBS trawl survey, 2012/13.

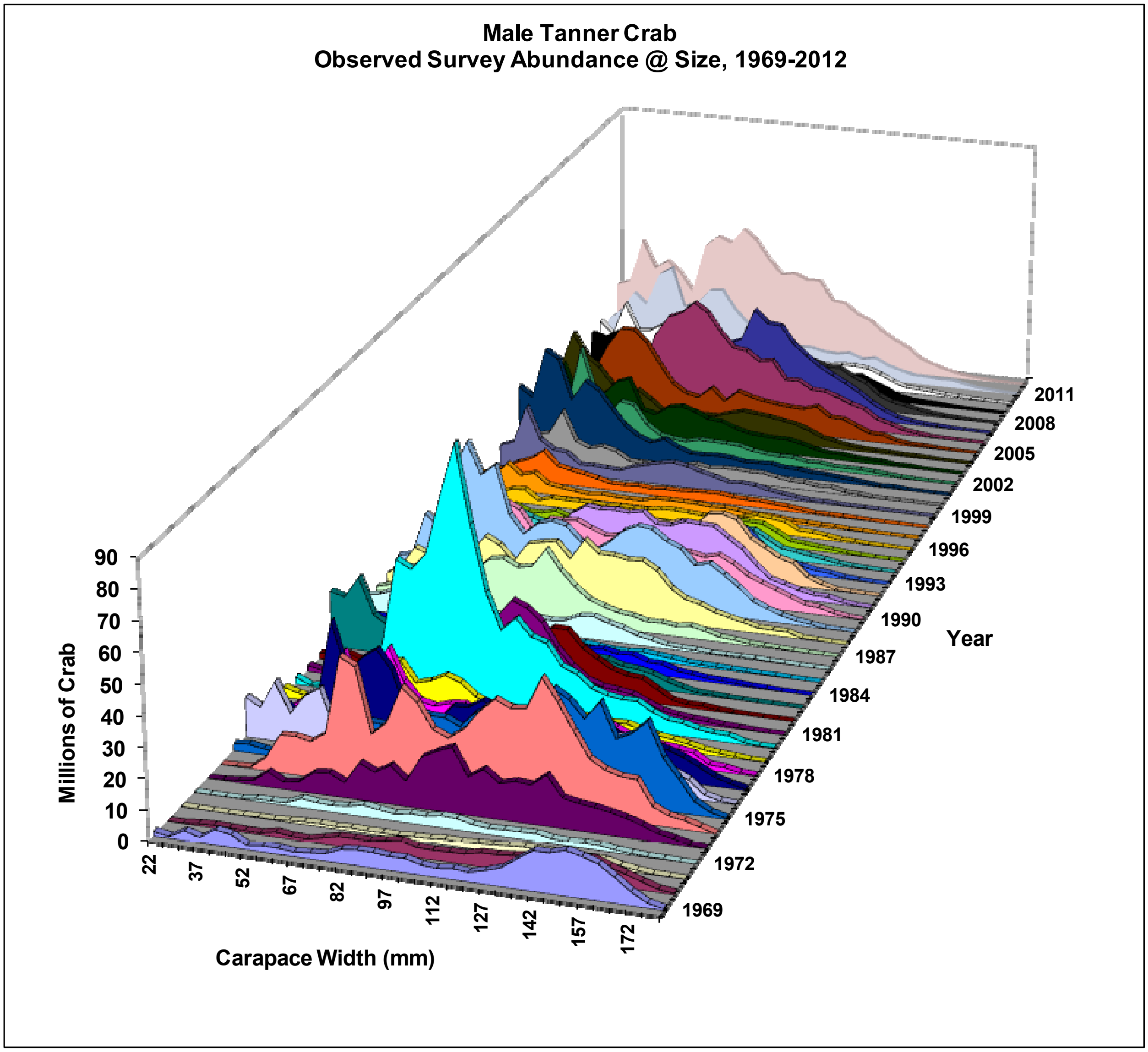


Figure 6. Observed male Tanner crab survey abundance (millions of crab) by carapace width for 1969/70 to 2011/12.

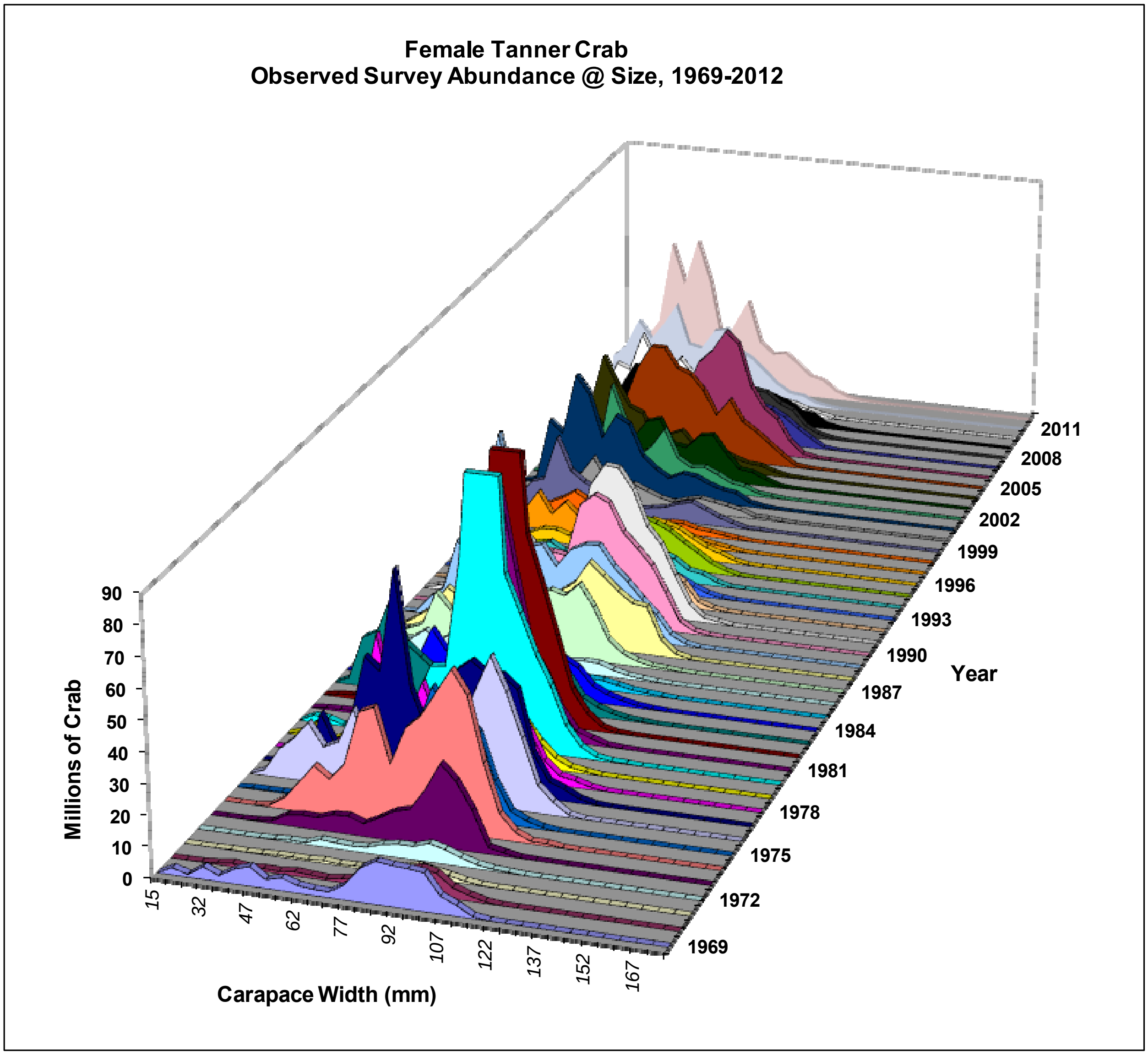


Figure 7. Observed female Tanner crab survey abundance (millions of crab) by carapace width for 1969/70 to 2011/12.

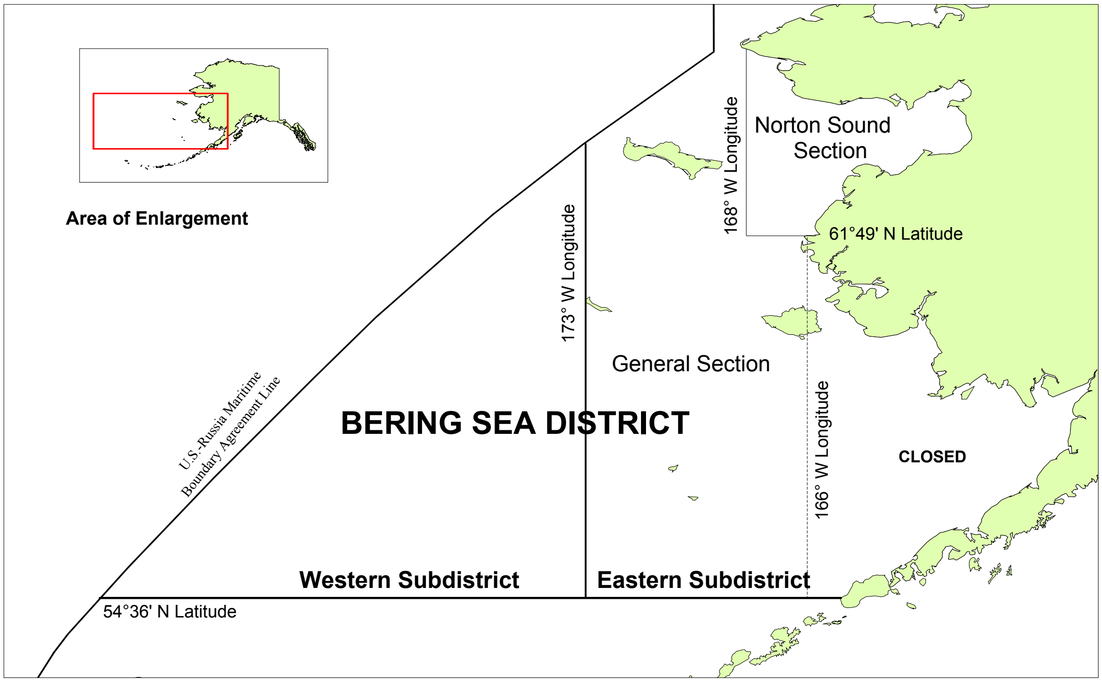


Figure 8. Eastern Bering Sea District of Tanner crab Registration Area J including subdistricts and sections (From Bowers et al. 2008).

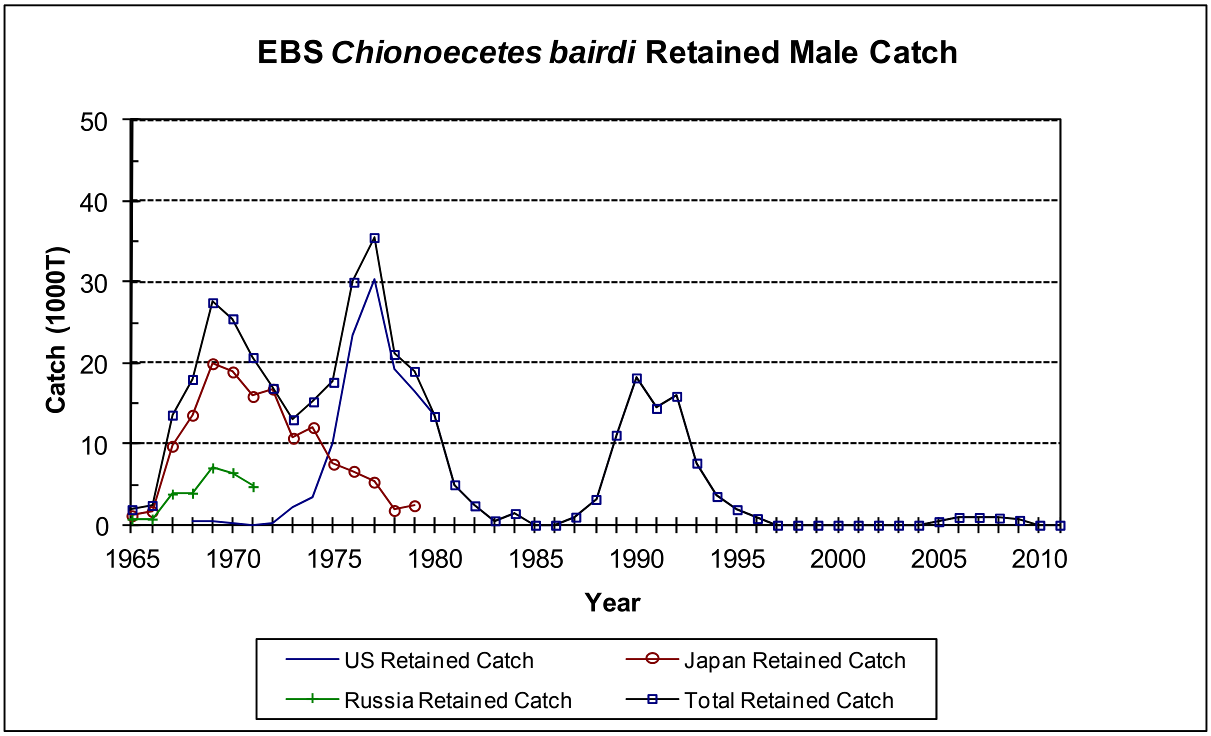


Figure 9. Eastern Bering Sea *C. bairdi* retained male catch in the directed United States, Russian and Japanese fisheries, 1965/66-2011/12.

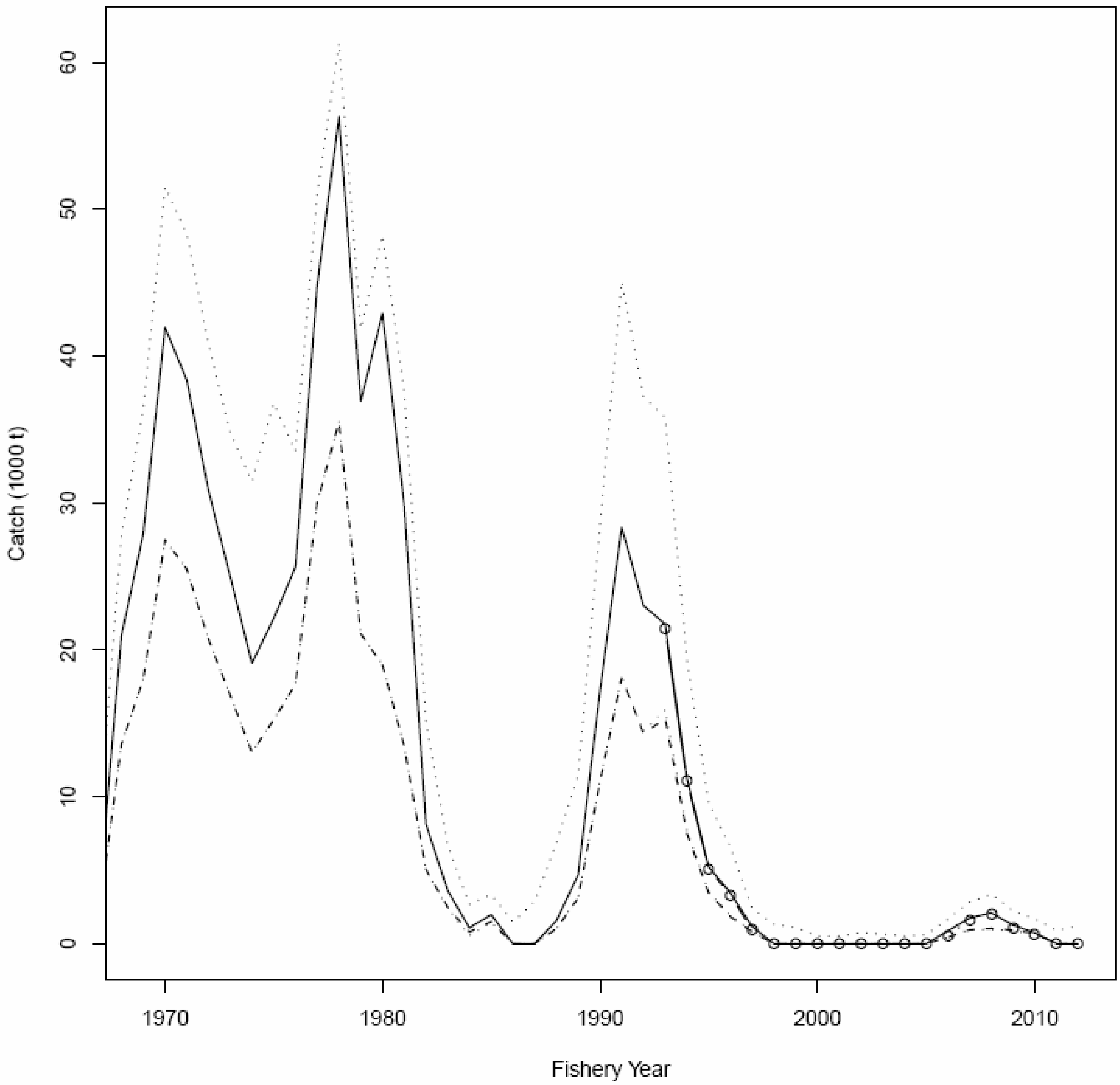


Figure 10. *Base Model (0)* predicted catch history of male Tanner crab catch by survey year. [solid line=predicted retained plus discard catch in the directed fishery; dashed line=predicted retained catch in the directed fishery; dotted line=predicted total male catch from all sources].

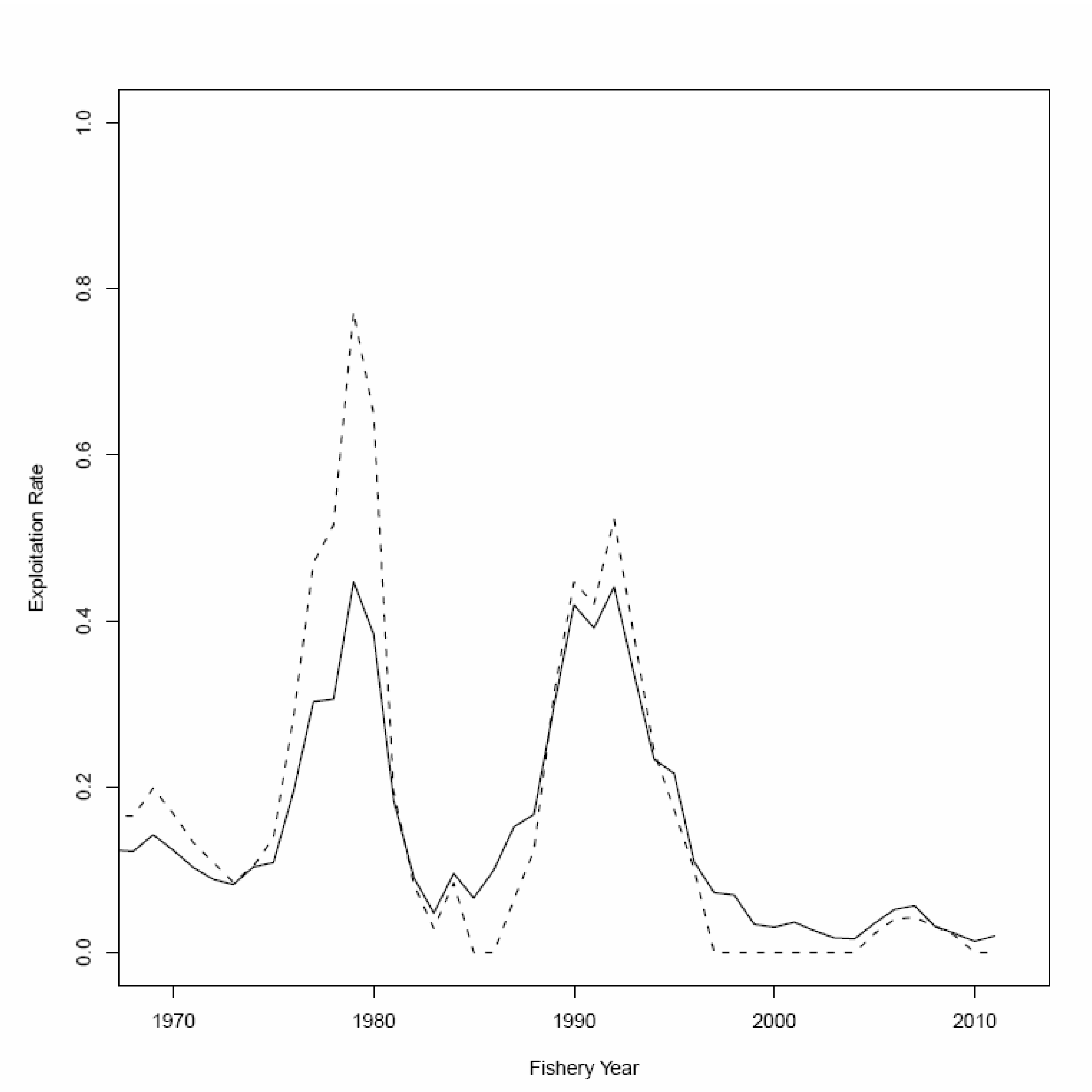


Figure 11.. *Base Model (0)* exploitation fraction estimated as the predicted catch biomass of legal males in all fisheries divided by the estimated legal male biomass at the time of the fishery (solid), and the predicted total catch (retained plus discard) divided by the estimated male mature biomass at the time of the fishery (dotted). Year is the year of the fishery.

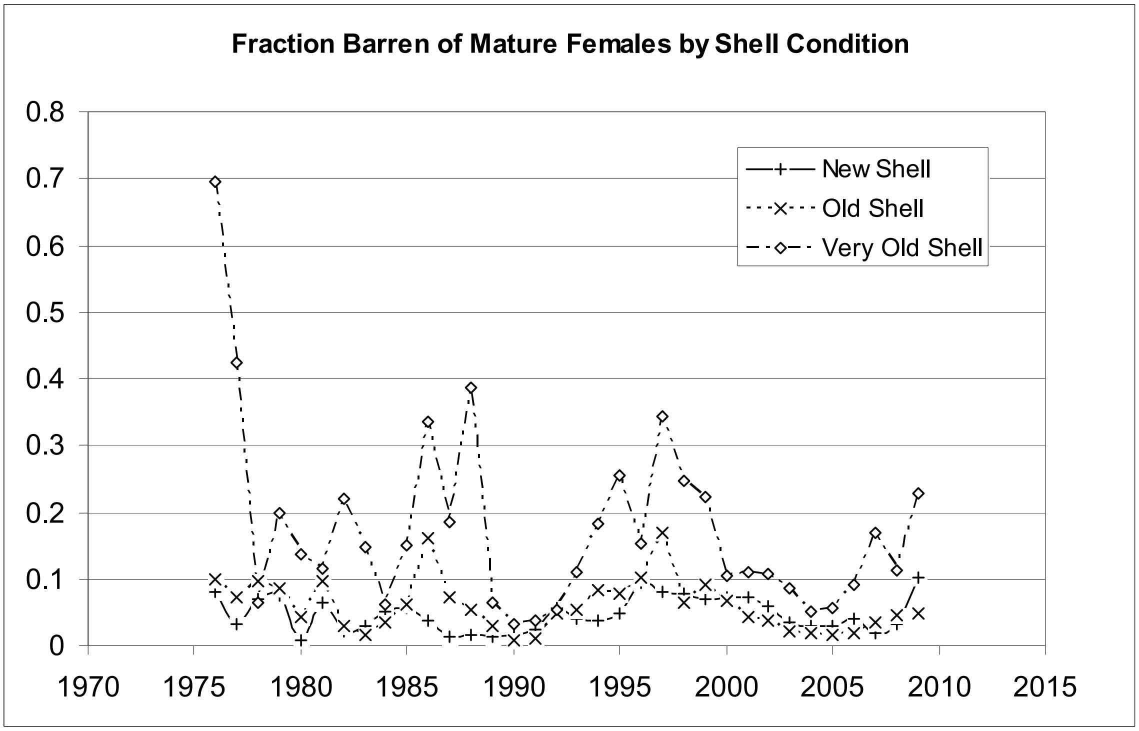


Figure 12. Proportion of female Tanner crab with barren clutches by shell condition from survey data for 1976/77 to 2009/10.

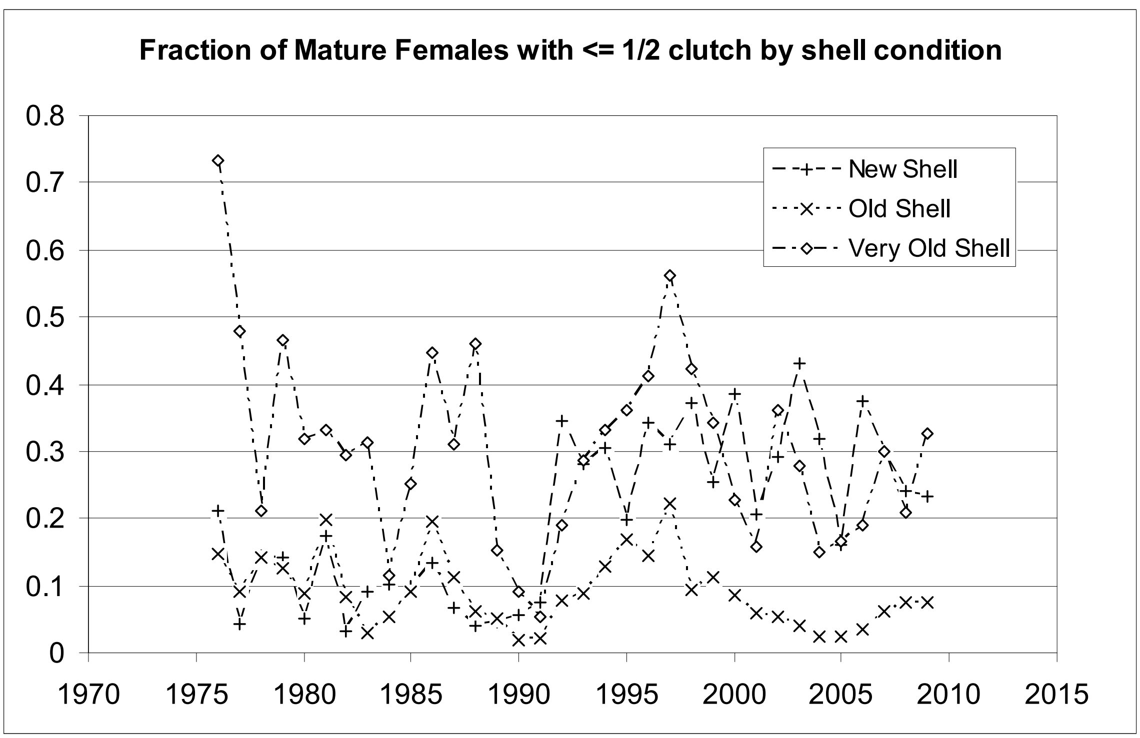


Figure 13. Proportion of female Tanner crab with less than or equal to one-half full clutch by shell condition from survey data 1976/77 to 2009/10.

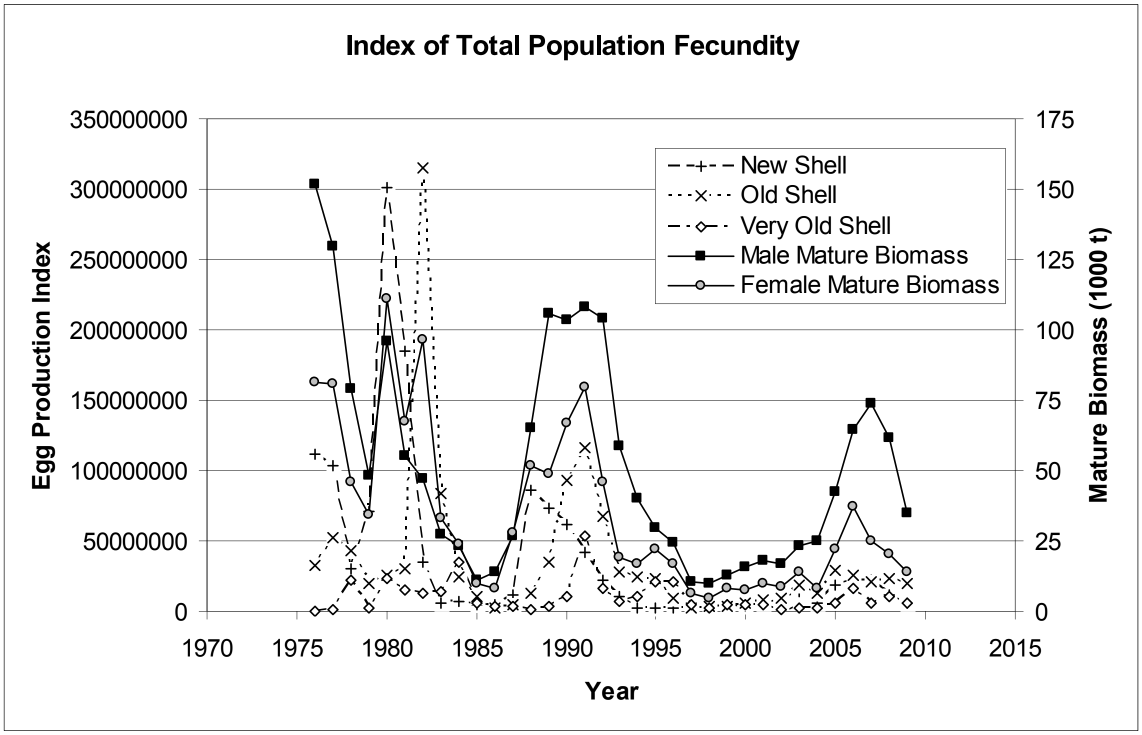


Figure 14. Tanner crab female egg production index (EPI) by shell condition, survey estimate of male mature biomass (1000 t), and survey estimate of female mature biomass (1000 t) from survey data for 1976/77 to 2009/10.

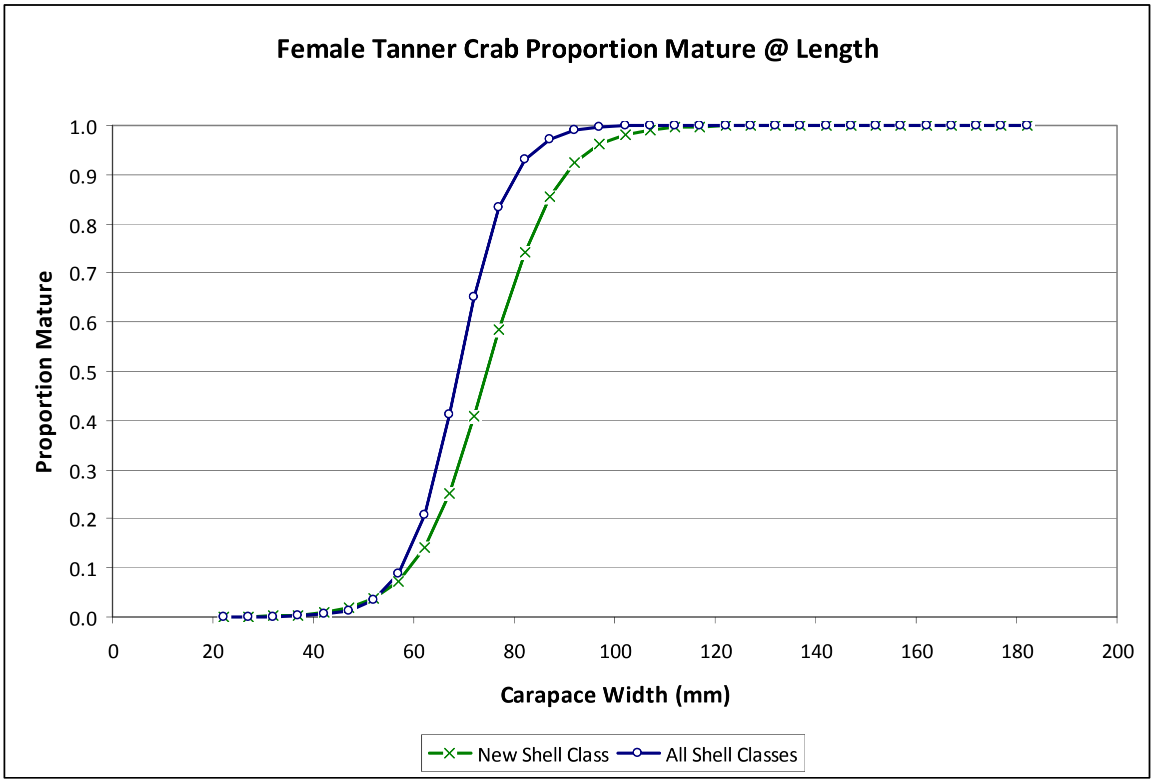


Figure 15. Fitted logistic functions of proportion mature in the stock for new shell and old shell female Tanner crab based on egg code classification of new and old shell crab in 1976-2009 survey data.

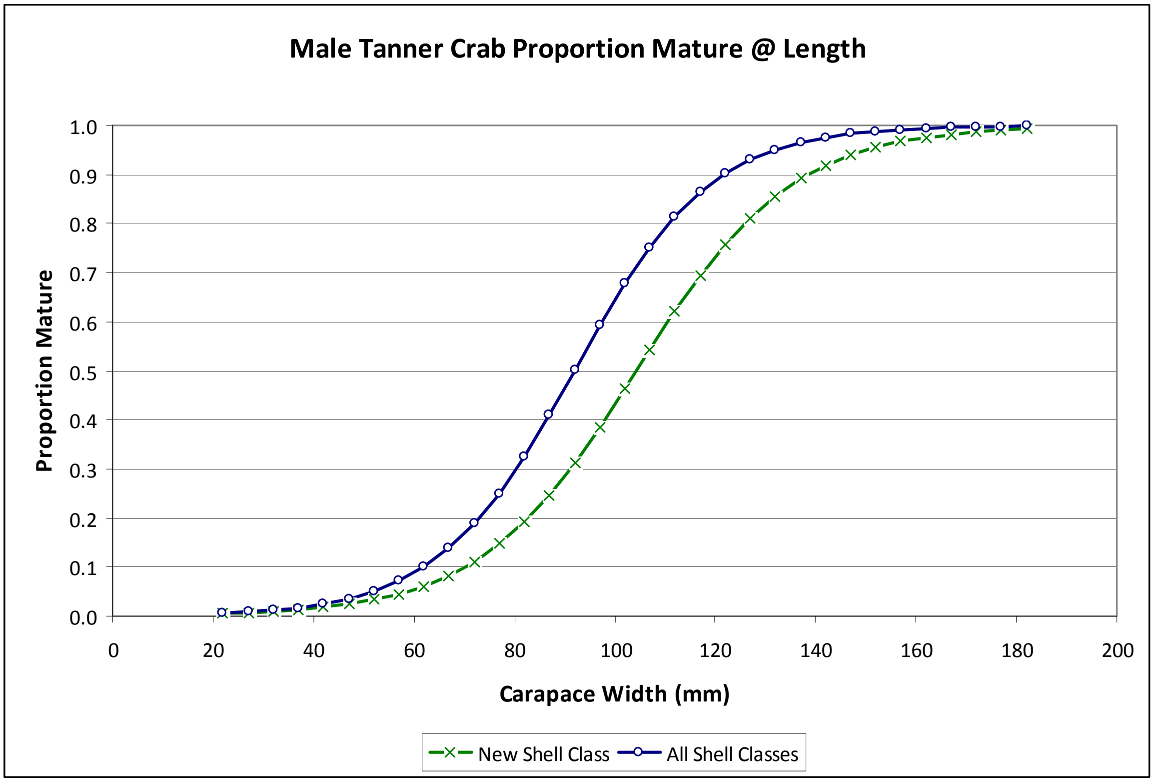


Figure 16. Fitted logistic functions of proportion mature in the stock for new shell and old shell male Tanner crab based on classification of new and old shell crab in 1990-2007 survey data.

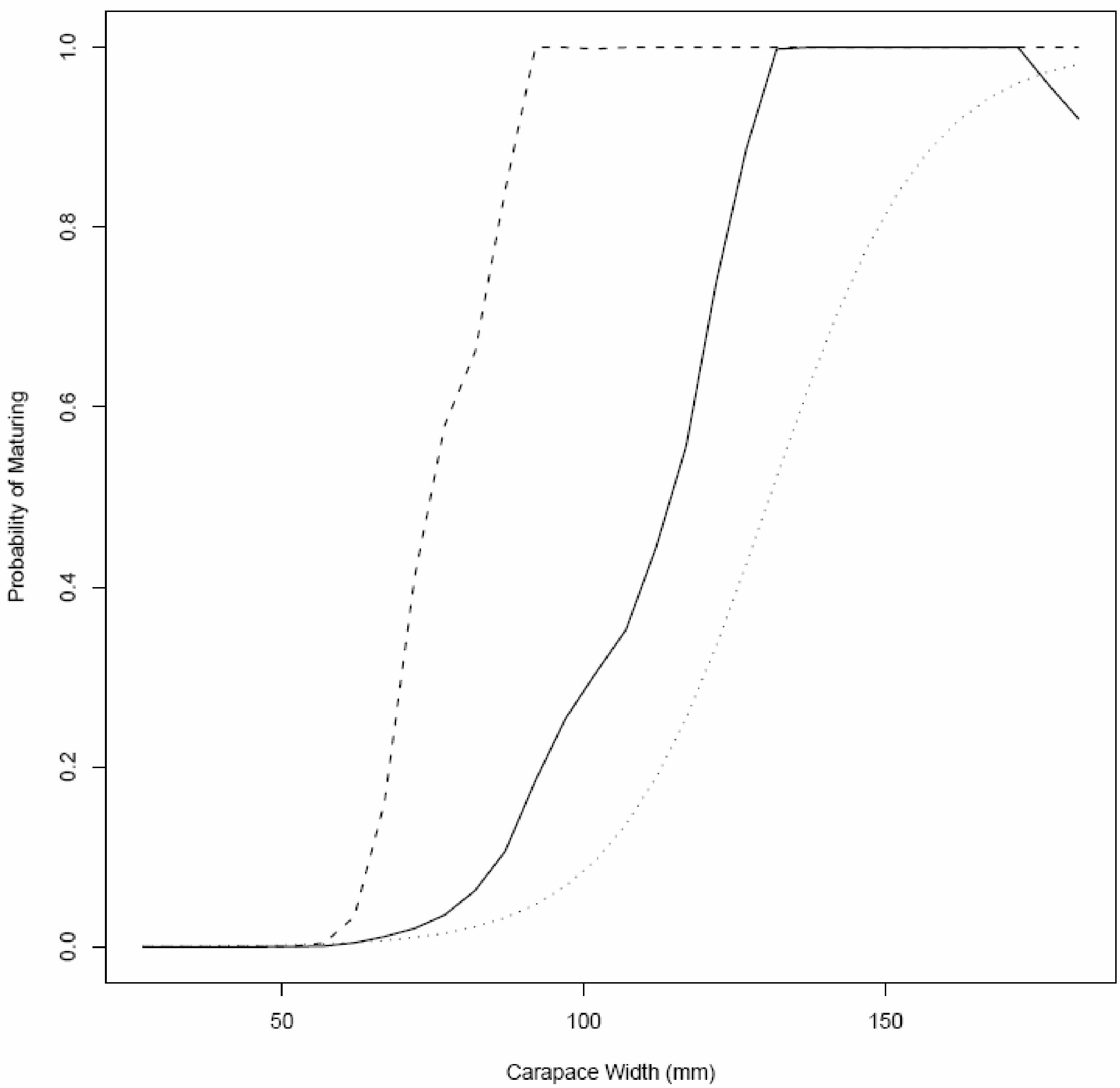
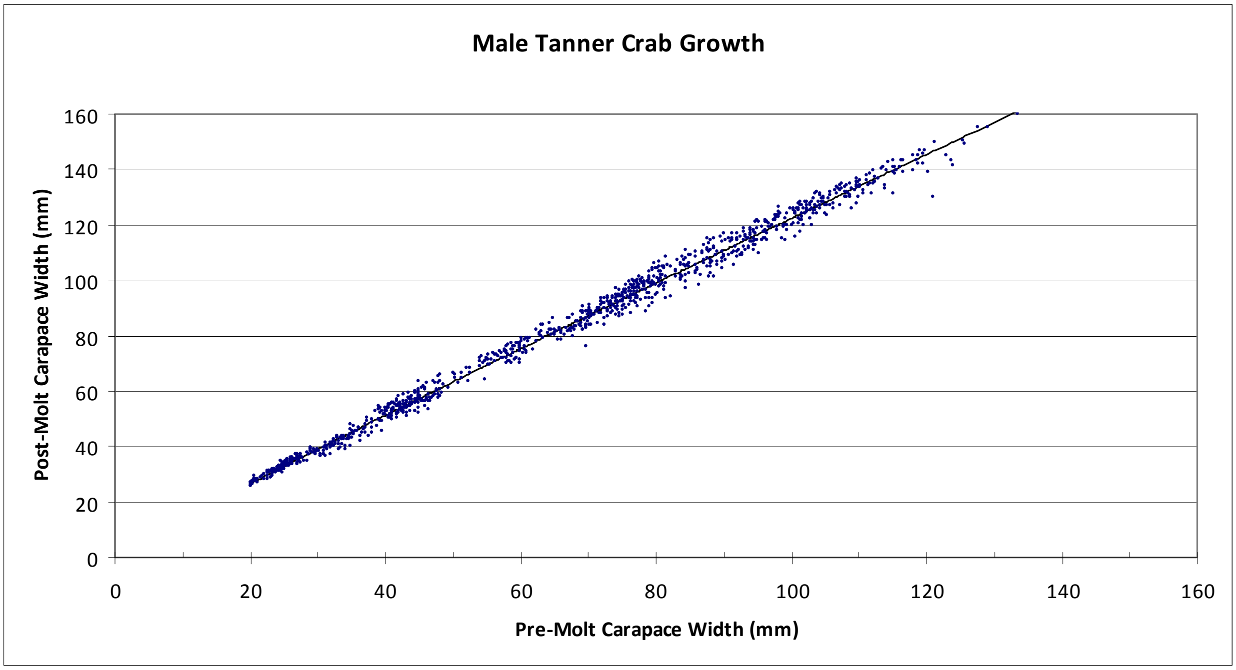


Figure 17. *Base Model (0)* estimate of probability of maturing by size for male (solid) and female (dashed) Tanner crab (not average fraction mature), and male probability of maturing by size used in Amendment #24 OFL analysis (dotted) (NPFMC 2007).

(a)



(b)

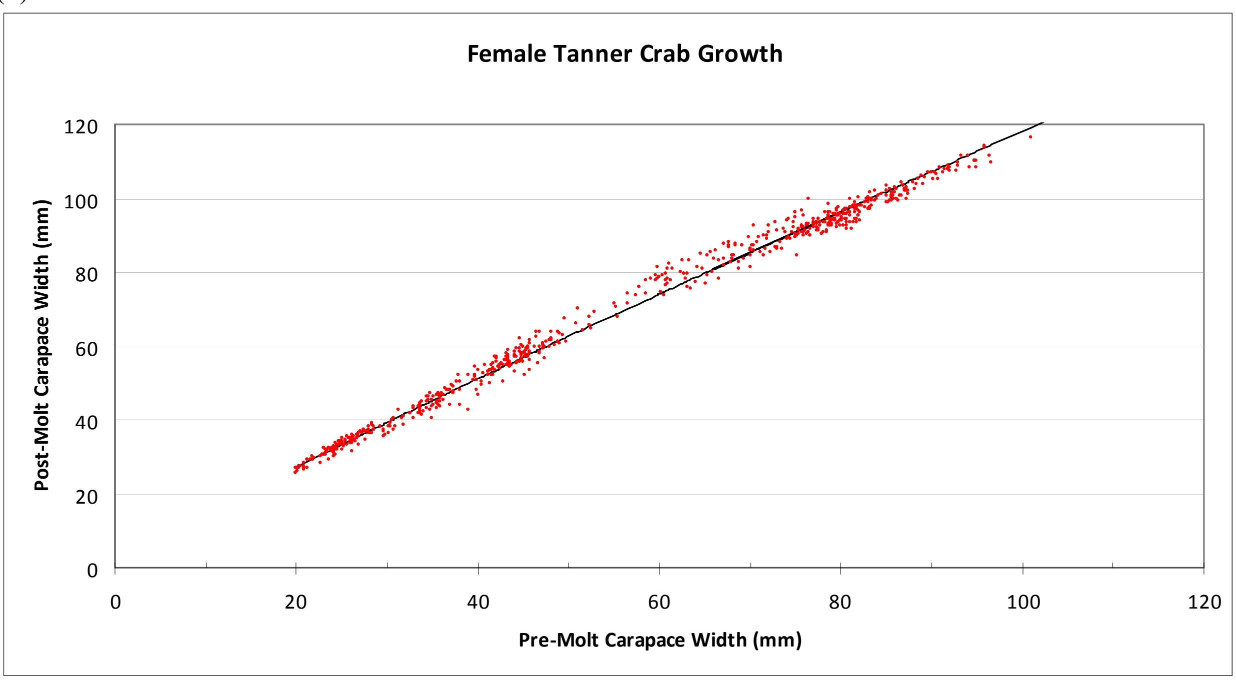


Figure 18. Growth of male (a) and female (b) Tanner crab as a function of premolt size. Estimated by Rugolo and Turnock 2010 based on data from GOA Tanner crab (Munk, unpublished data).

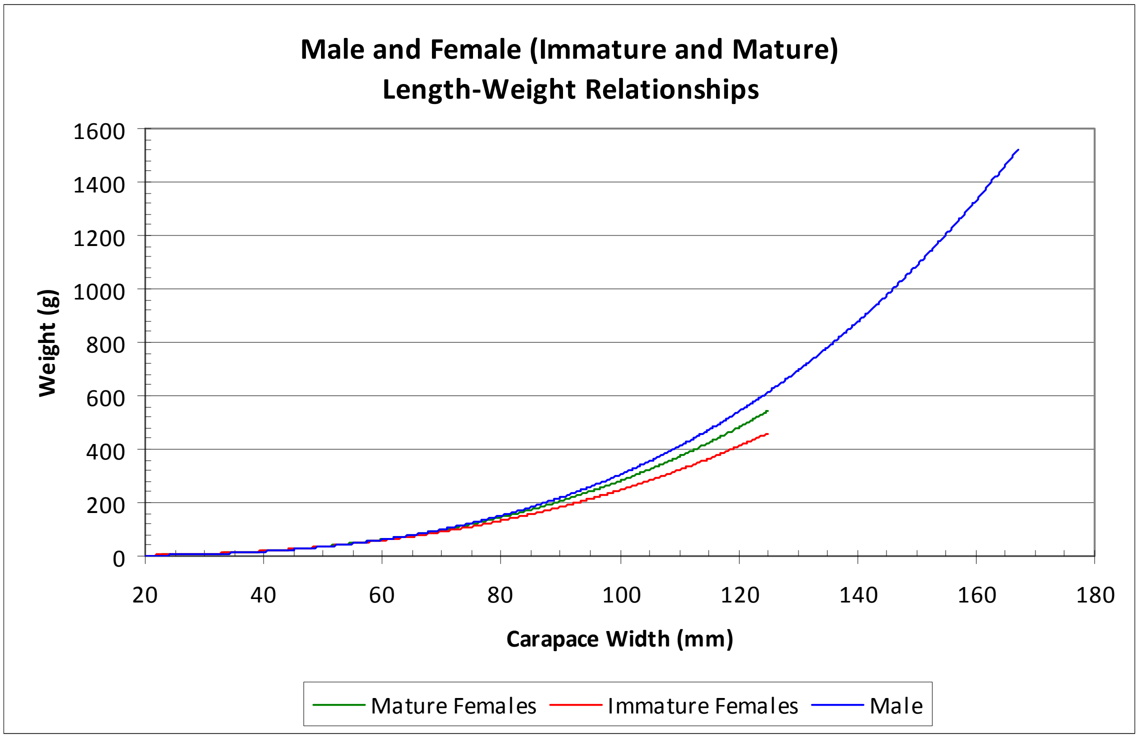


Figure 19. Weight (kg) – size (mm) relationship for male (top), mature female (middle) and immature female (bottom) Tanner crab.

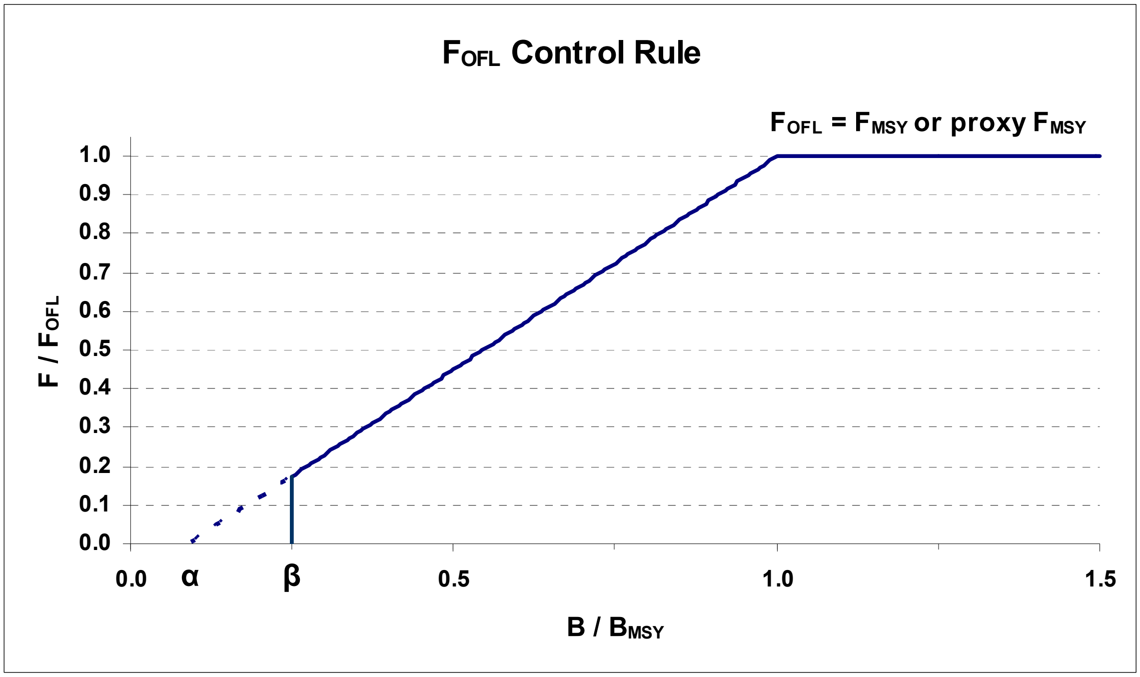
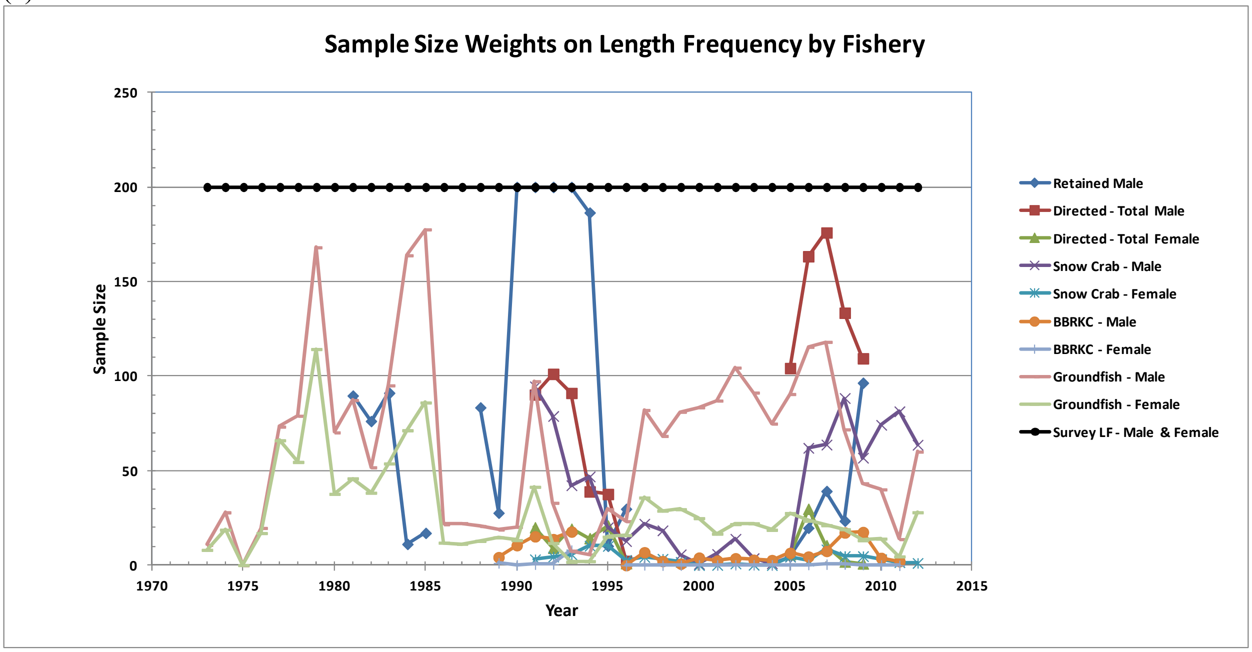


Figure 20. F_{OFL} Control Rule for Tier-4 stocks under Amendment 24 to the BSAI King and Tanner Crabs fishery management plan. Directed fishing mortality is set 0 below β.

(a)



(b)

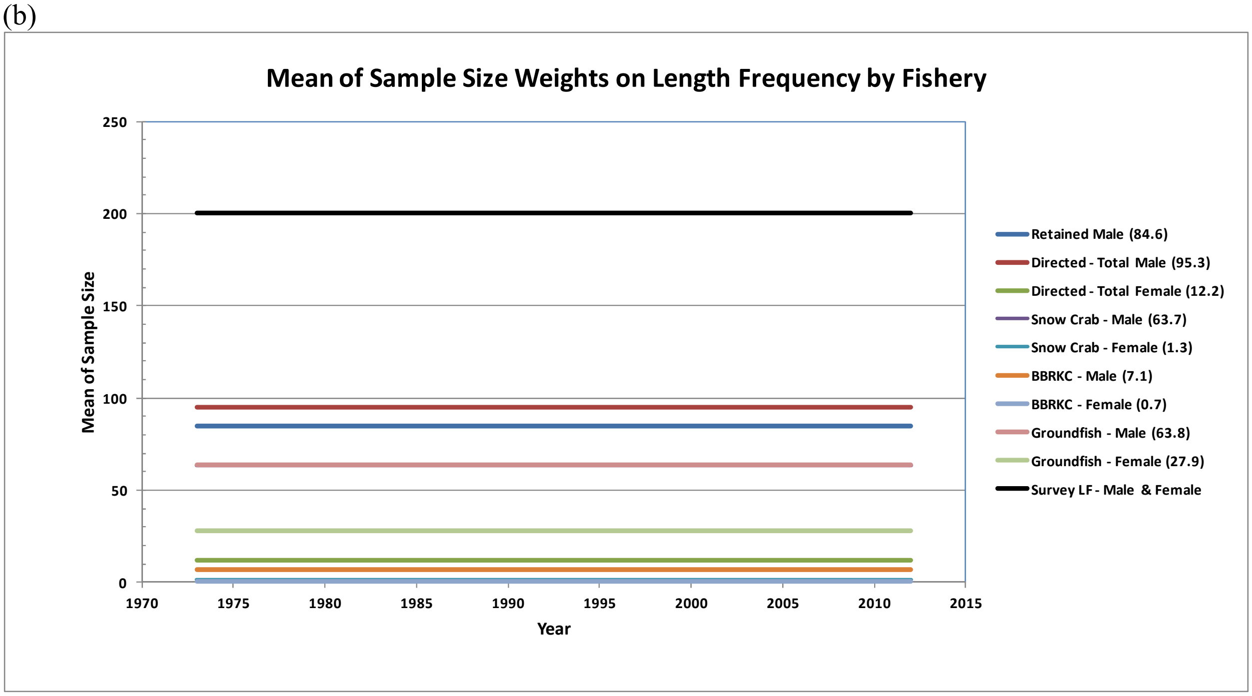
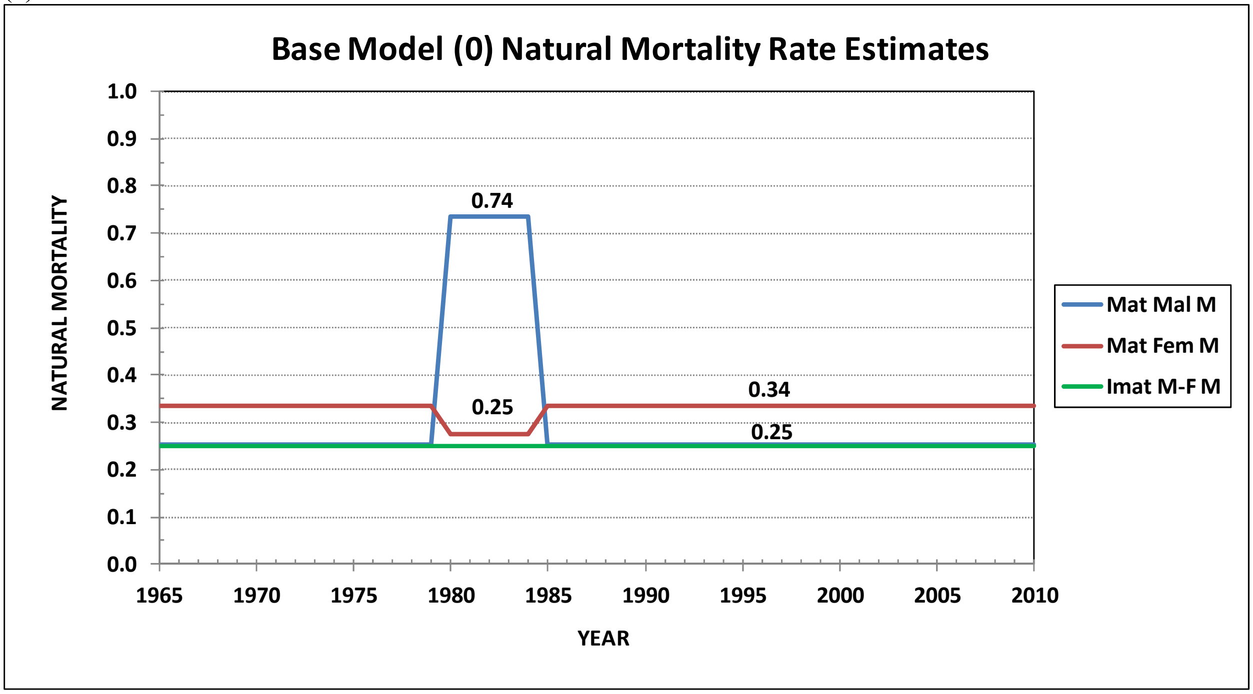


Figure 21. Sample sizes (a) used in the fitting of the fishery length compositions by fleet, and (b) meanof the fleet sample sizes for comparison.

(a)



(b)

i

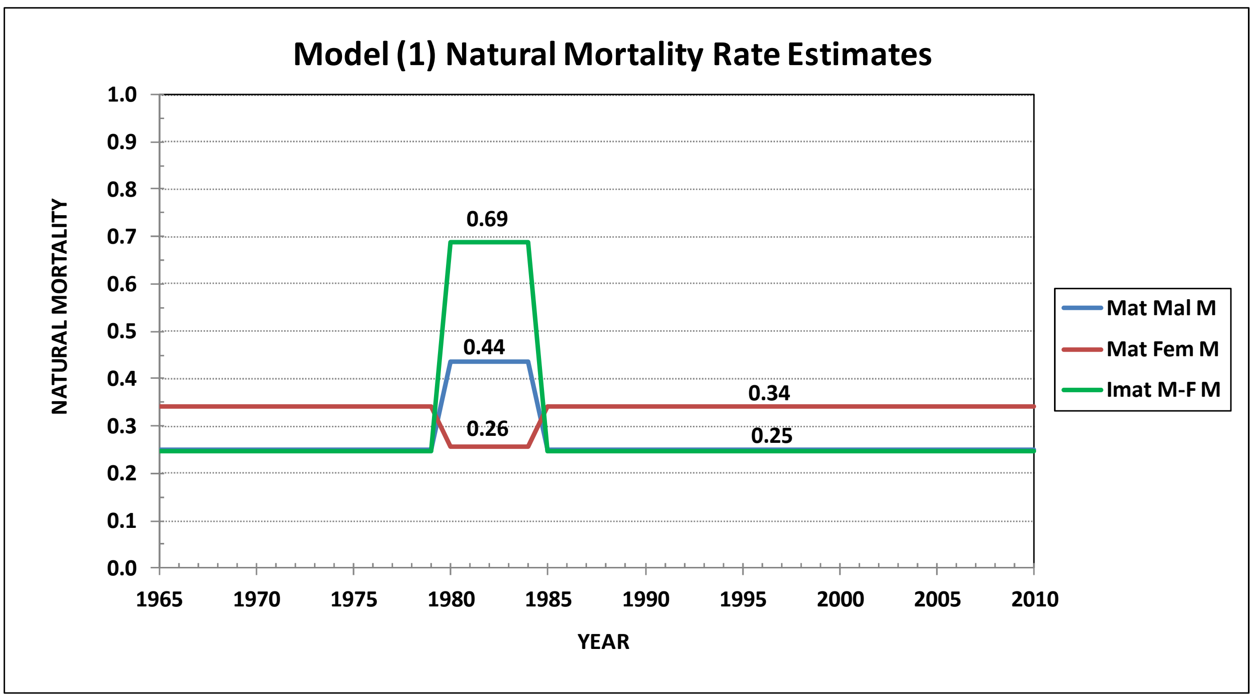


Figure 22. *Base Model(0)* (a) and *Model (1)* (b) estimates of the natural mortality rate for immature male and female, mature female and mature male Tanner crab, 1965-2012. In *Model (1)*, immature male-female M is estimated in 2-periods: 1980-84 and all other years combined.

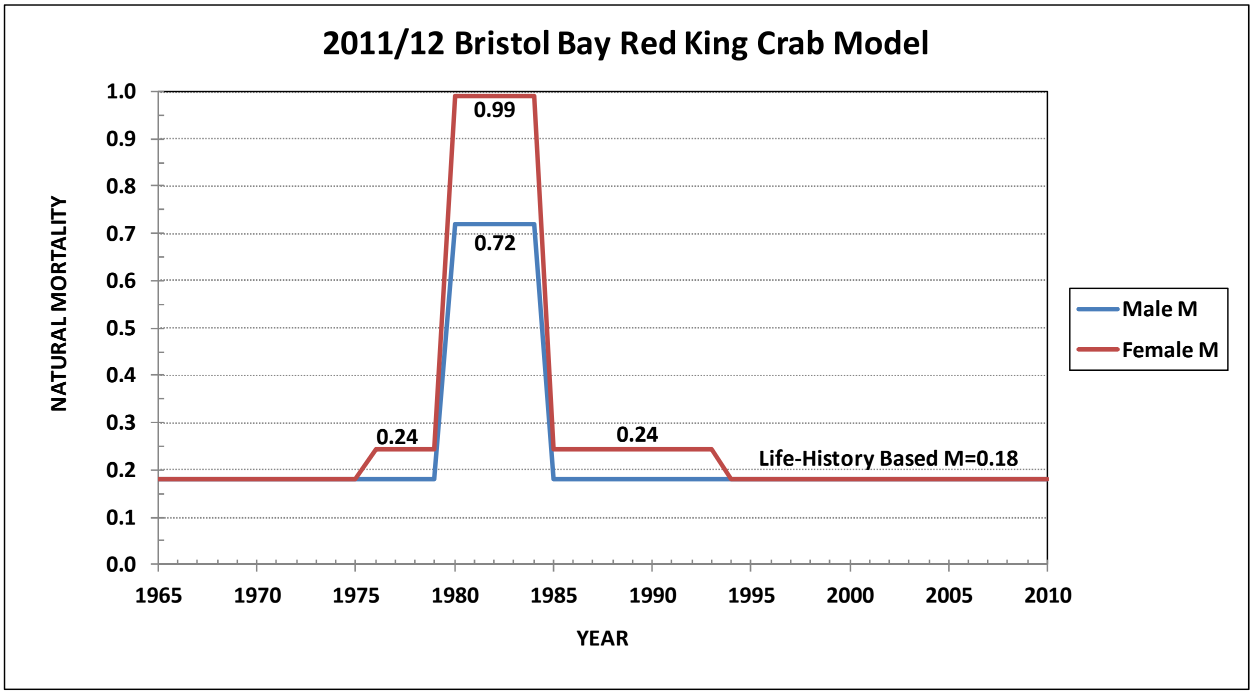


Figure 23. Model estimates of natural mortality rate for male (1980-1984) and female (1976-1993) Bristol Bay red king crab, and fixed M for remaining years in the 2011/12 stock assessment model (Zheng 2011).

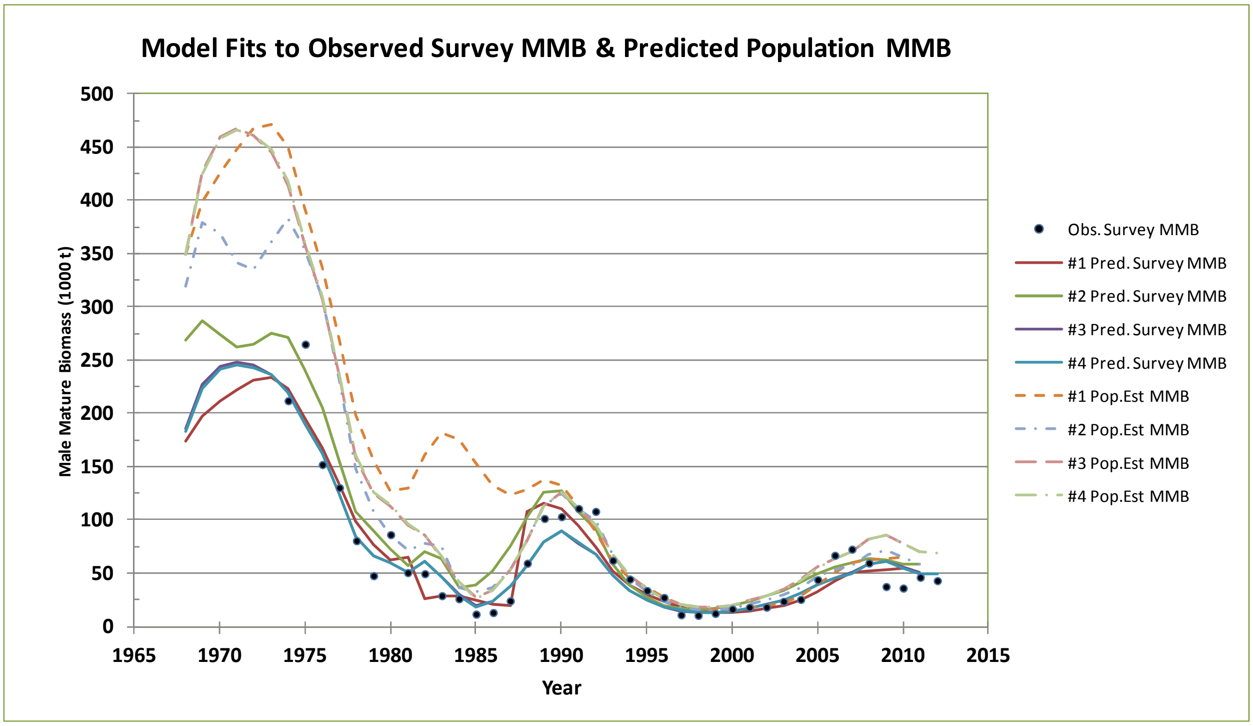


Figure 24. Comparison of past reference models performance in terms of fit (solid) to observed survey mature male biomass (points), and population mature male biomass (dotted line). Key: #1=3-period model presented to CPT (09/11); #2=2-perod model resulting from 01/2012 Crab Workshop; #3=2-period model presented to CPT (05/12); and #4=2-period model approved by the CPT (05/12).

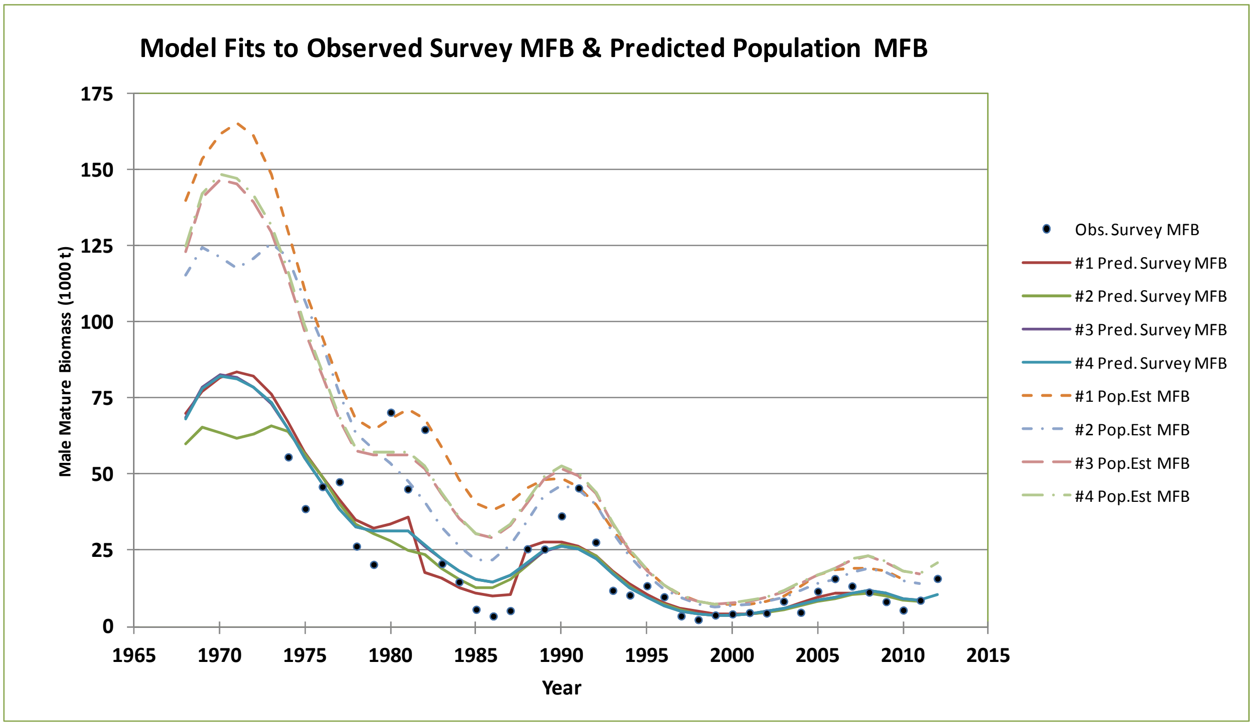


Figure 25. Comparison of past reference models performance in terms of fit (solid) to observed survey mature female biomass (points), and population mature female biomass (dotted line). Key: #1=3-period model presented to CPT (09/11); #2=2-perod model resulting from 01/2012 Crab Workshop; #3=2-period model presented to CPT (05/12); and #4=2-period model approved by the CPT (05/12).

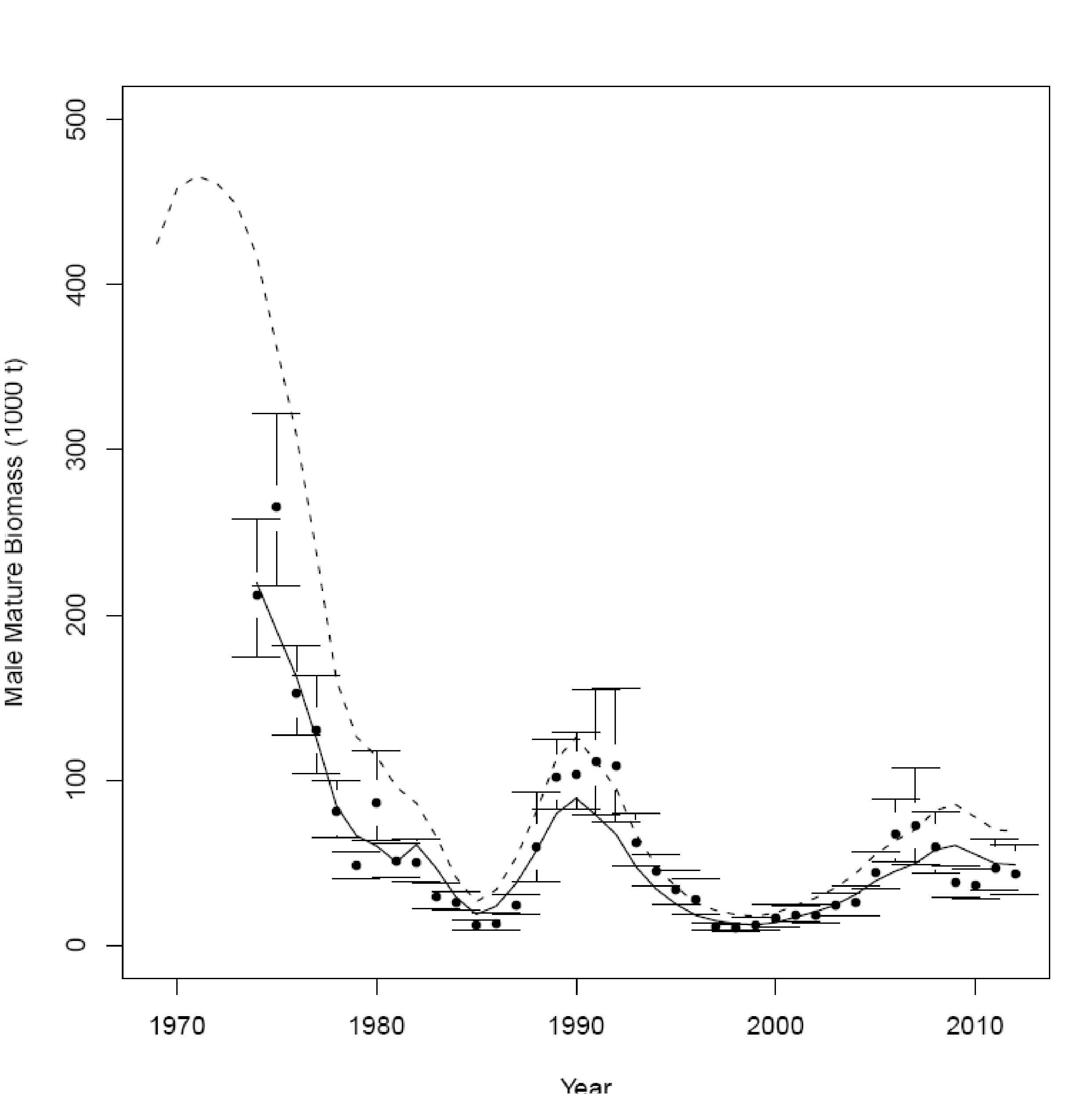
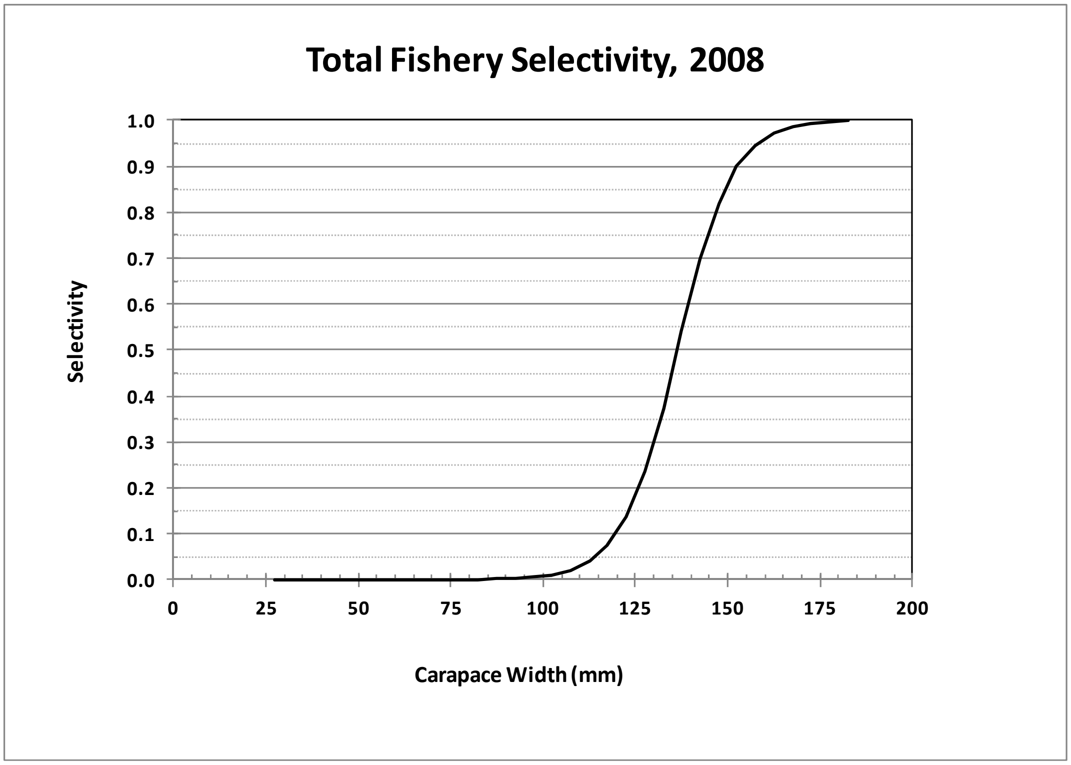


Figure 26. *Base Model (0)* population mature male biomass (1000 t, dotted line) at the time of the survey, model estimate of survey mature biomass (solid line) and observed survey mature male biomass with approximate lognormal 95% confidence intervals.

(a)



(b)

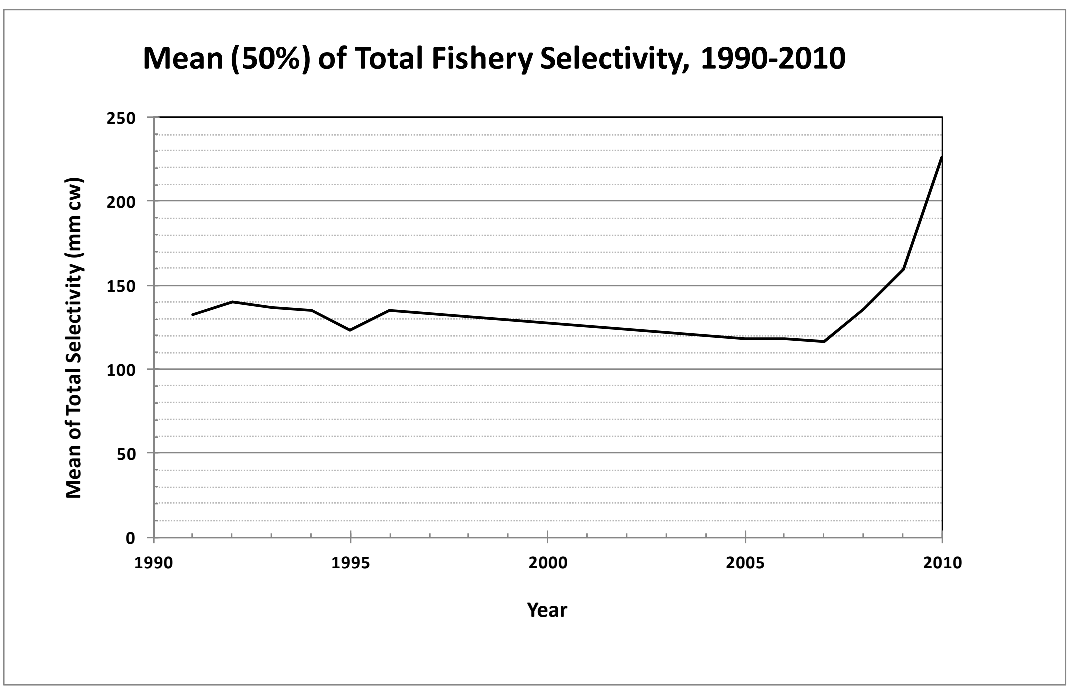


Figure 27. Estimated male total selectivity (a) in *Base Model (0)* in the 2008 (representative shape) and (b) change in the mean (50%) of total selectivity in the directed fishery for 1990-2010.

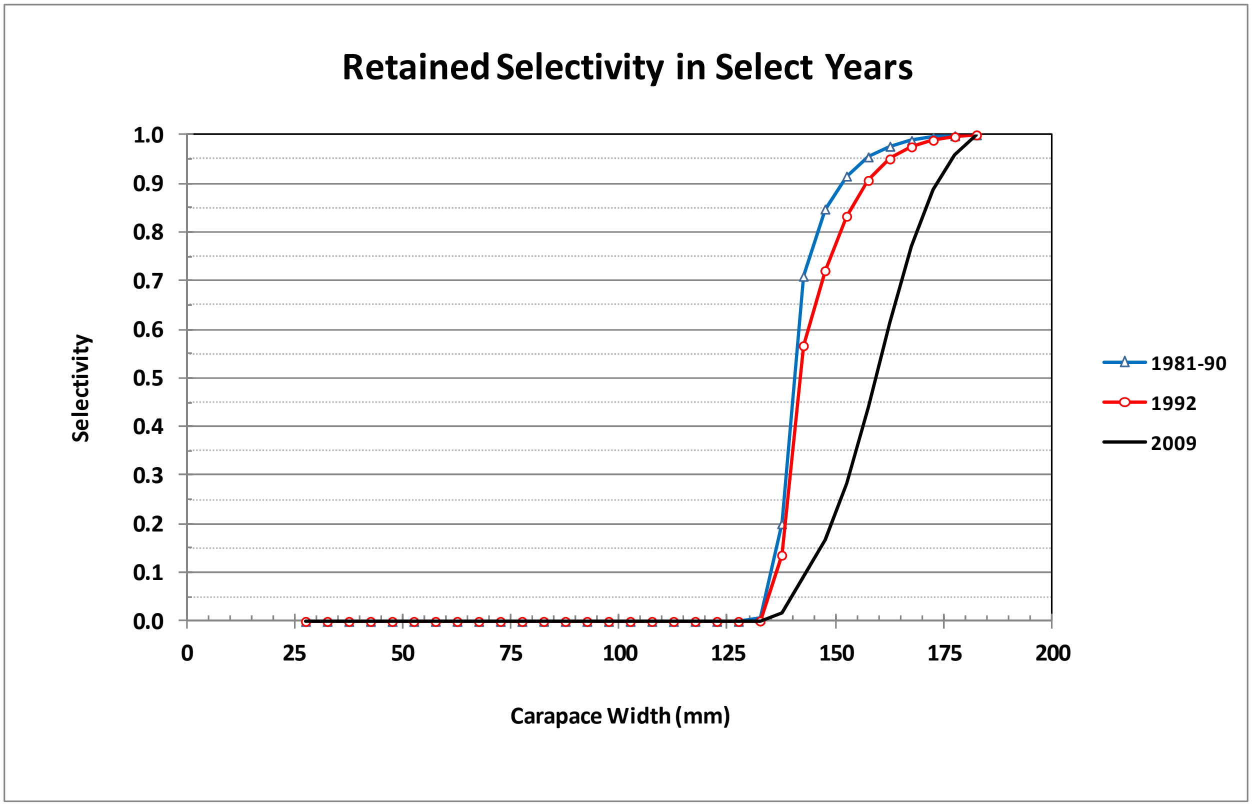


Figure 28. *Base Model (0)* fraction of total catch retained by size for male crab in the directed fishery, all shell conditions combined for 3 representative years-periods: mean of 1981-90, 1992 and 2009.

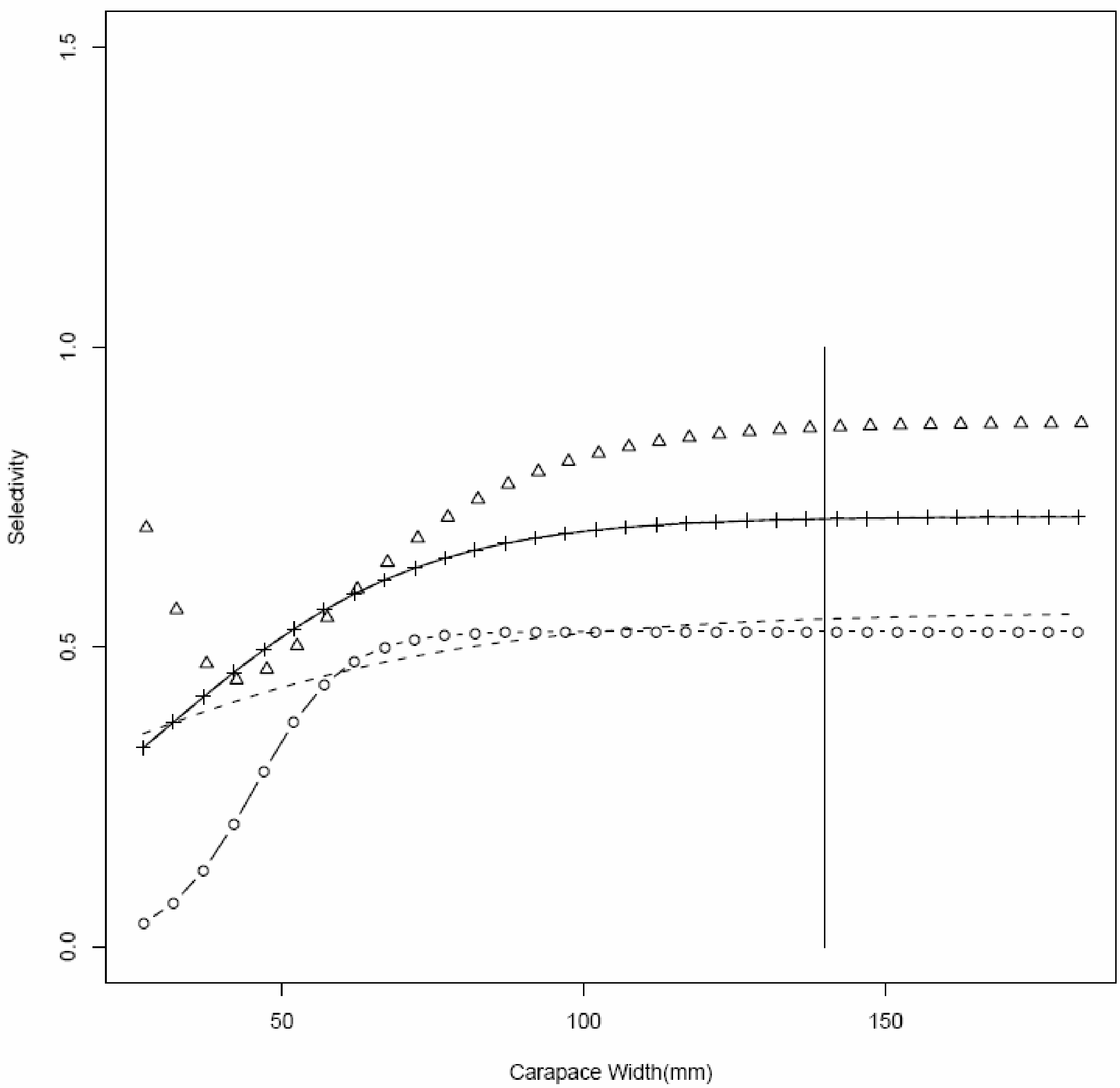


Figure 29. *Base Model(0)* survey selectivity curves for male Tanner crab estimated for 1974-1981 (dashed line with circles), 1982-2012 (solid line with pluses) with vertical reference line at 140 mm. Survey selectivity estimated by Somerton and Otto (1999) are triangle symbols, and female selectivity for 1982-2012 is dashed line for reference.

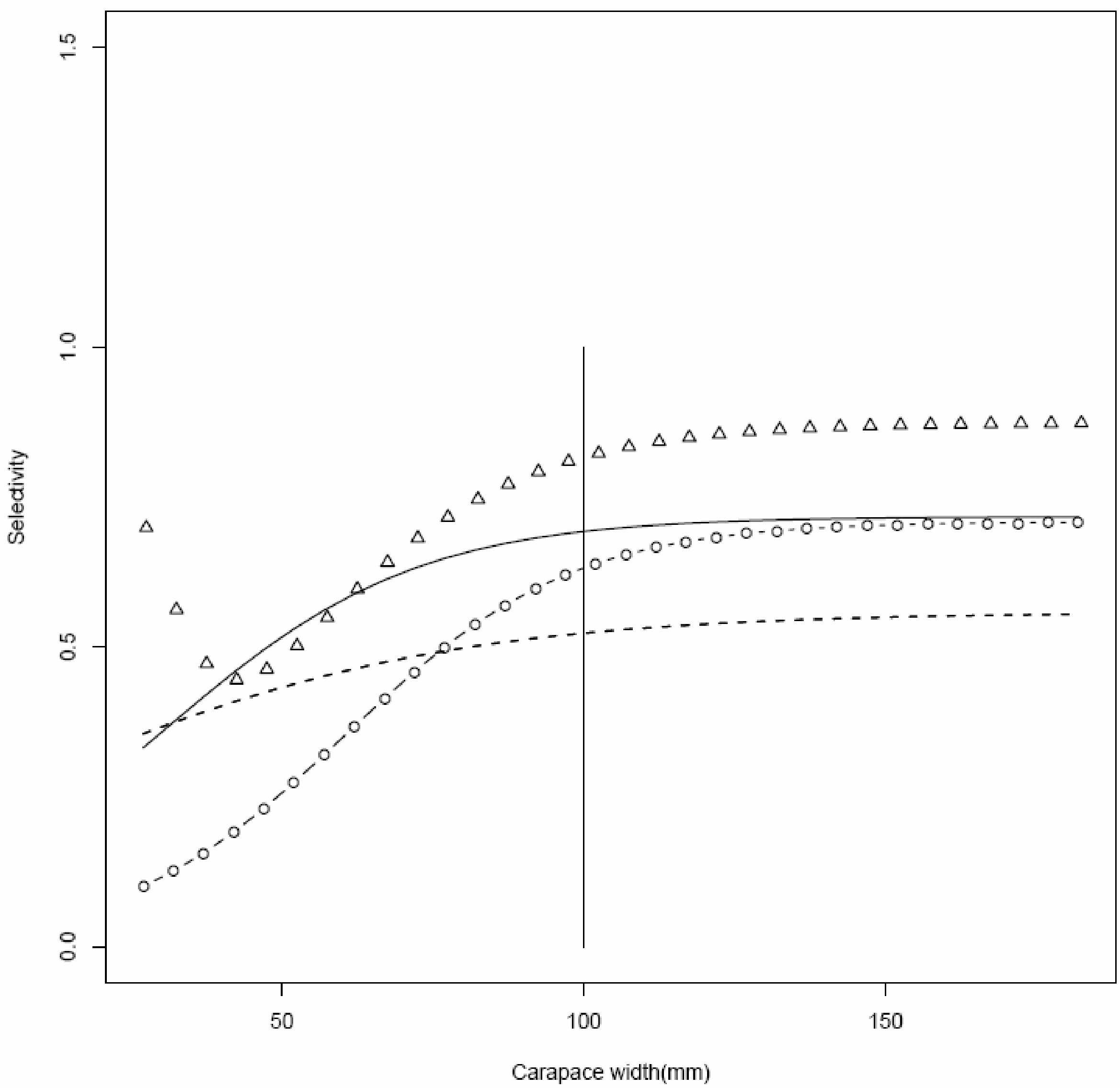
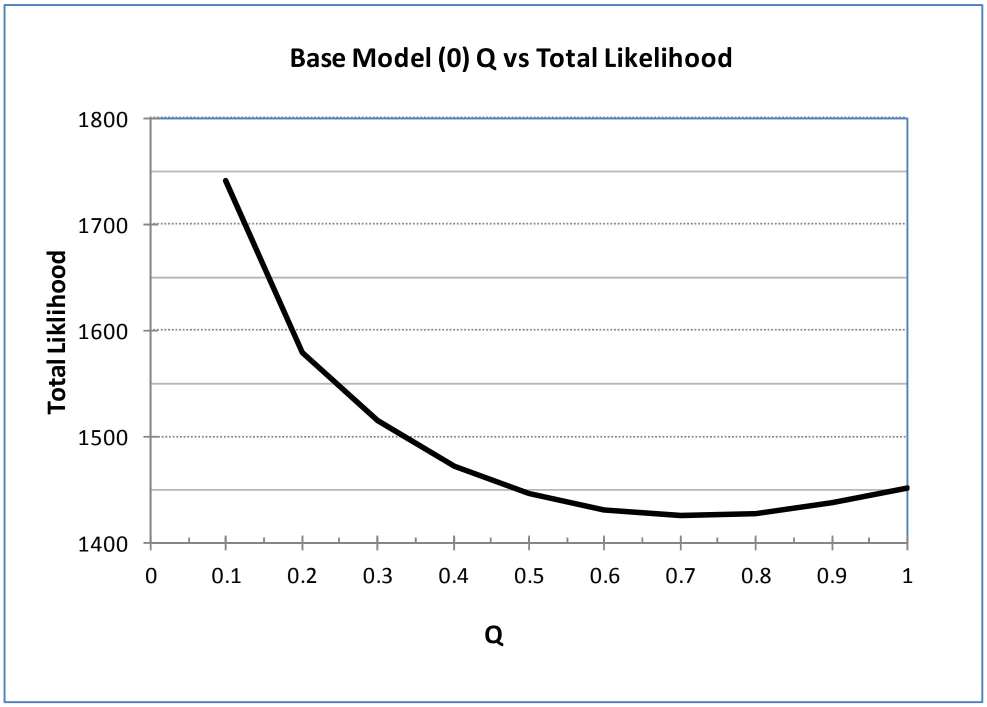


Figure 30. *Base Model (0)* survey selectivity curves for female Tanner crab estimated for 1974-1981 (dashed line with circles), 1982-2012 (dashed line) with vertical reference line at 100 mm. Survey selectivity estimated by Somerton and Otto (1999) are triangle symbols, and male selectivity for 1982-2012 is upper solid line for reference.

(a)



(b)

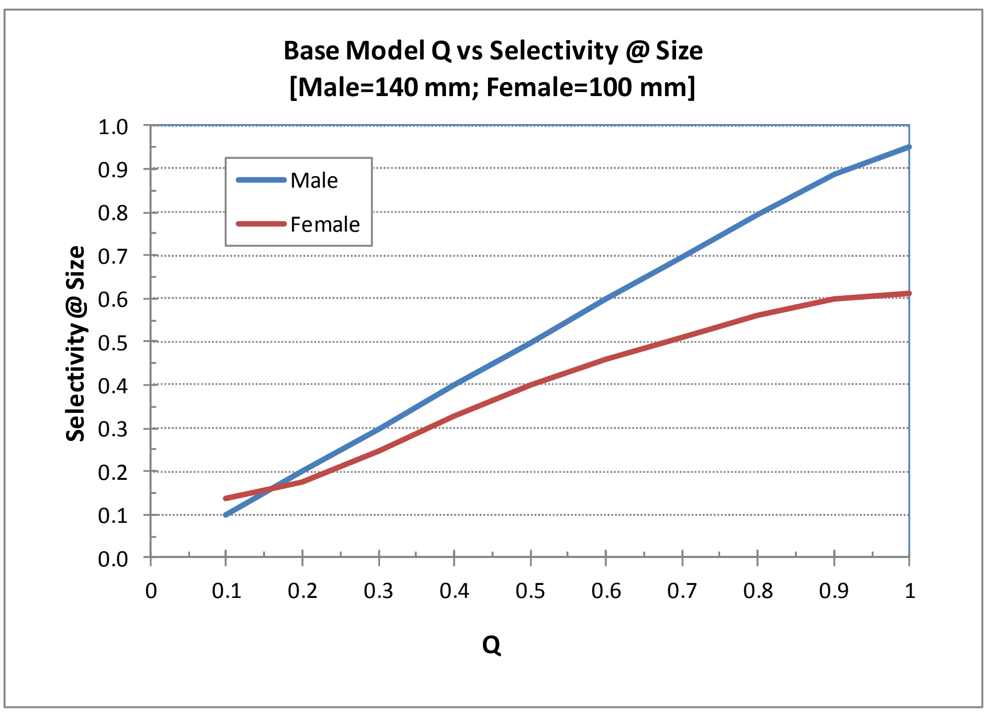


Figure 31. Survey Q profile versus total likelihood (a) and selectivity at reference size versus Q (b) for the *Base Model (0)*.

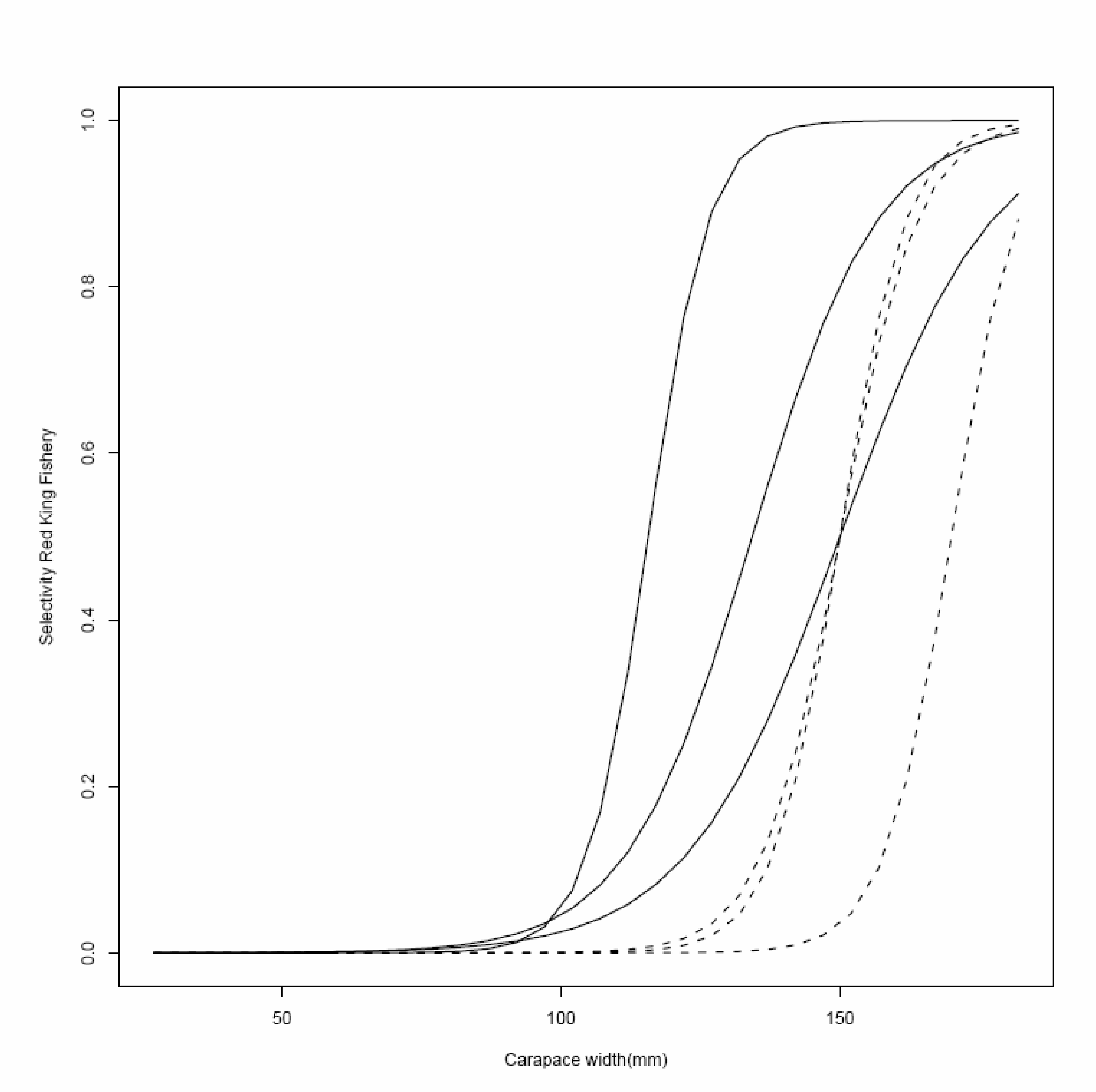


Figure 32. *Base Model (0)* selectivity curve estimated by the model for bycatch in the Bristol Bay red king crab fishery for females (dashed) and males (solid) for three periods: period-1 (1989-1996), period-2 (1997-2004) and period-3 (2005-P). The male and female curves for the three time periods are in chronological order from left to right – i.e., earliest to left, intermediate in center, and most recent to right.

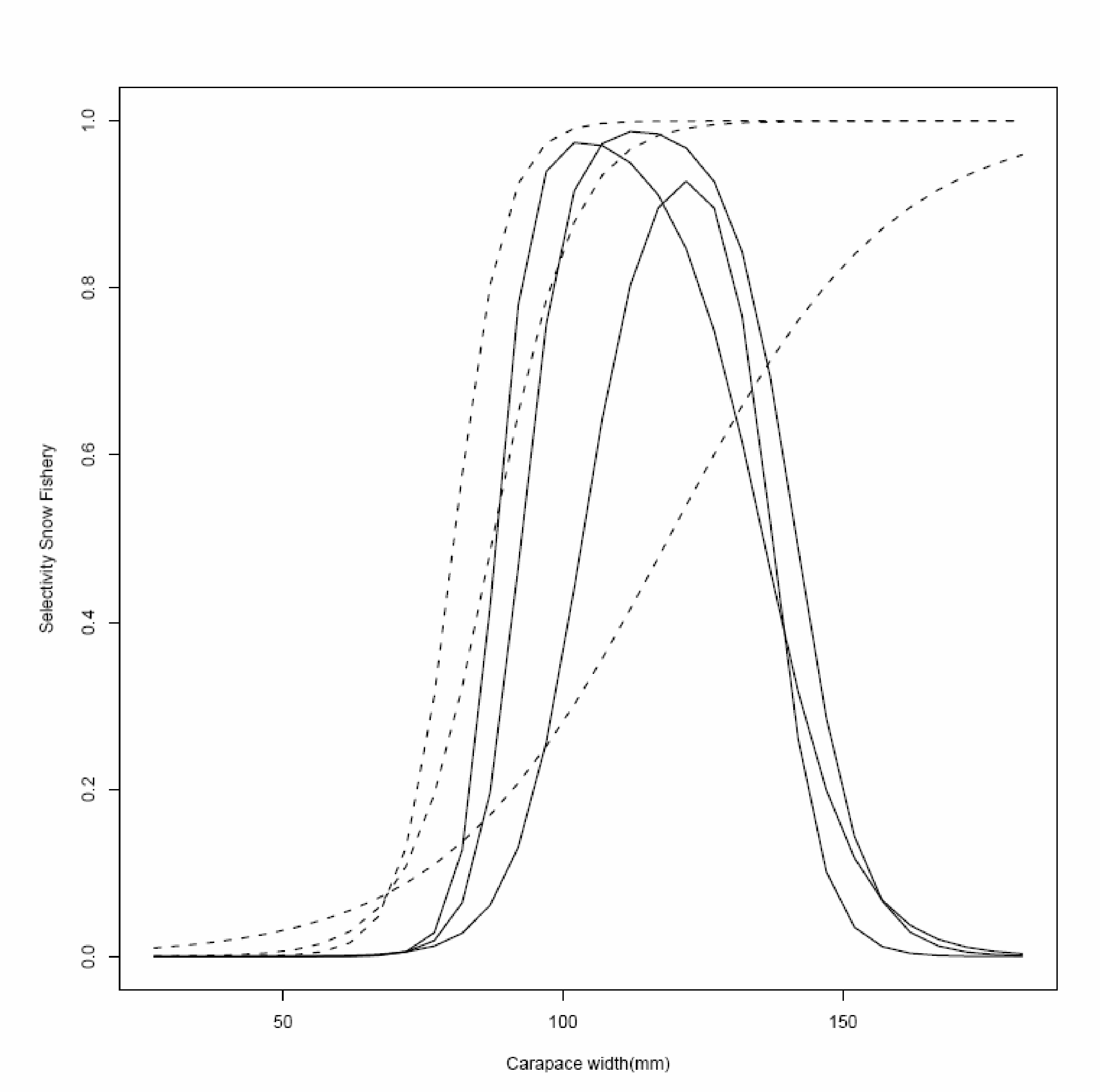


Figure 33. *Base Model (0)* selectivity curve estimated by the model for bycatch in the snow crab fishery for females (dashed) and males (solid) for three periods: period-1 (1989-1996), period-2 (1997-2004) and period-3 (2005-P). The curves for males: period-1 (left), period-2 (center) and period-3 (right). Curves for females: period-1 (right), period-2 (left) and period-3 (center).

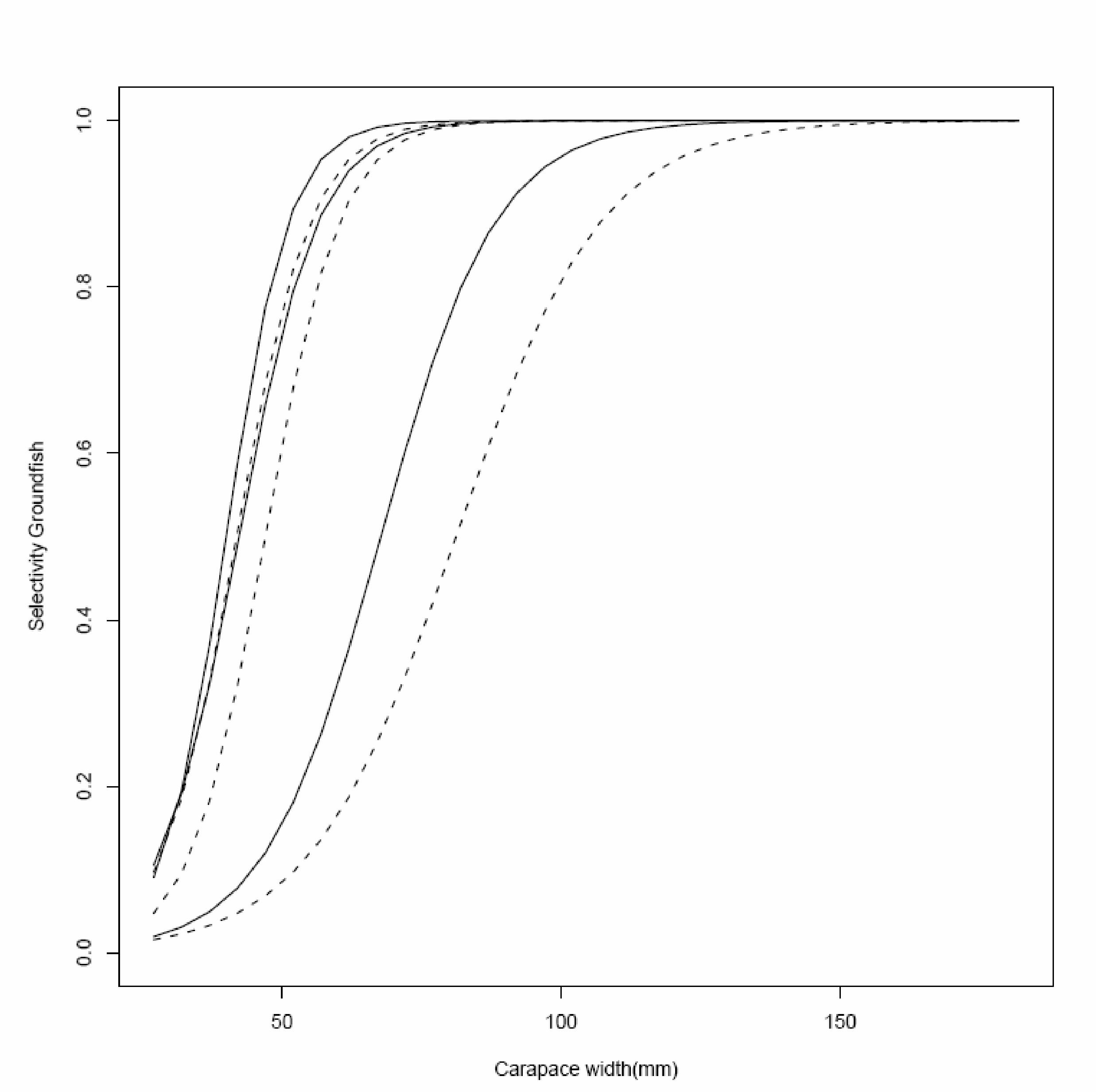


Figure 34. *Base Model (0)* selectivity curve estimated by the model for bycatch of males (dashed) and females (solid) in the groundfish fishery for three periods: period-1 (1973-1986), period-2 (1987-1996) and period-3 (1997-P). The curves for males: period-1 (left), period-2 (center) and period-3 (right). Curves for females: period-1 (left), period-2 (right) and period-3 (center).

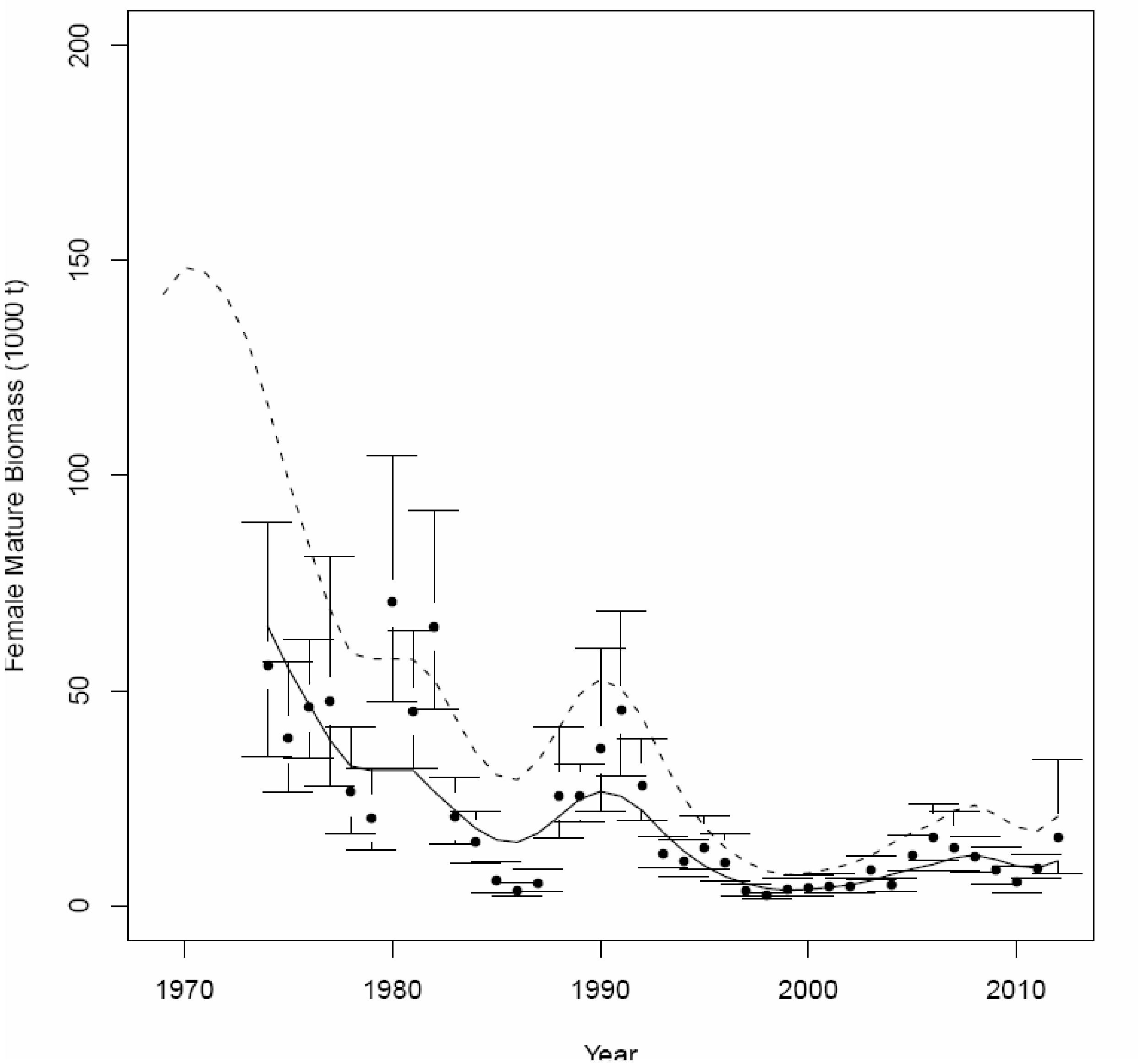


Figure 35. *Base Model (0)* population female mature biomass (1000 t, dotted line), model estimate of survey female mature biomass (solid line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

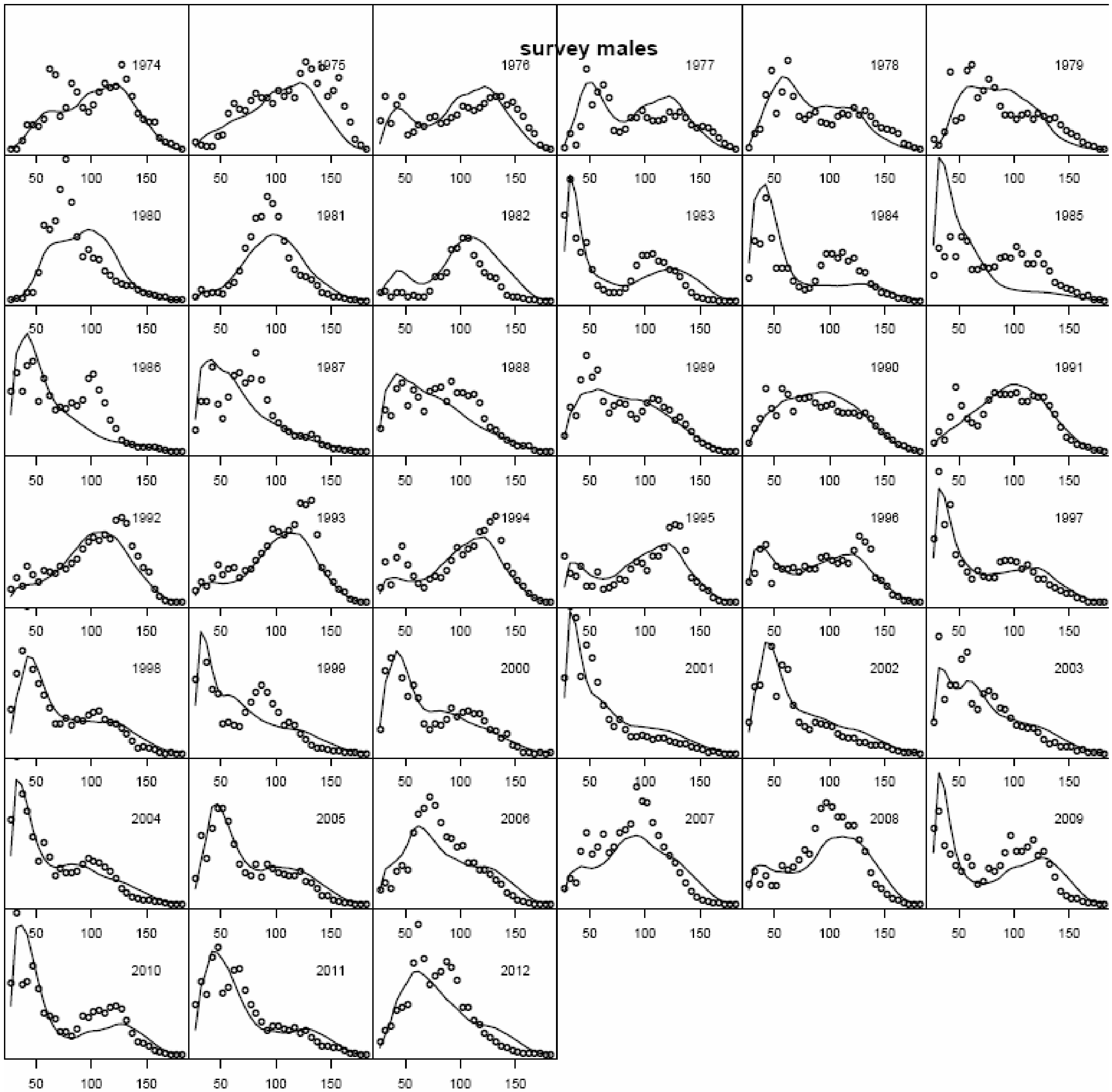


Figure 36. *Base Model (0)* fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

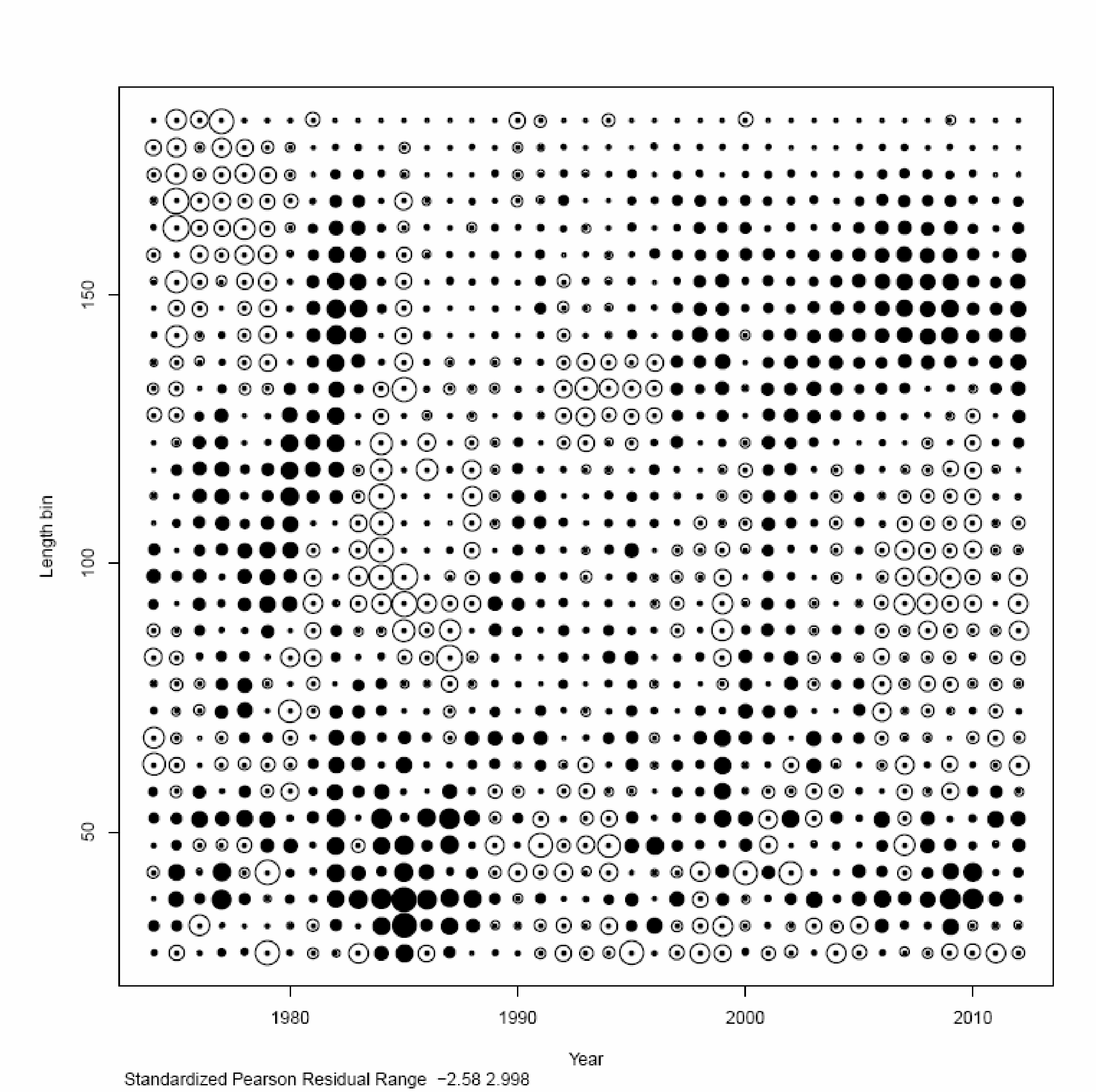


Figure 37. *Base Model (0)* standardized Pearson residuals of the model fit to the survey male size frequency data. Solid circles= overestimate and open circles=underestimate. Diameter of circle proportional to extent of lack of fit. Residual range shown at bottom.

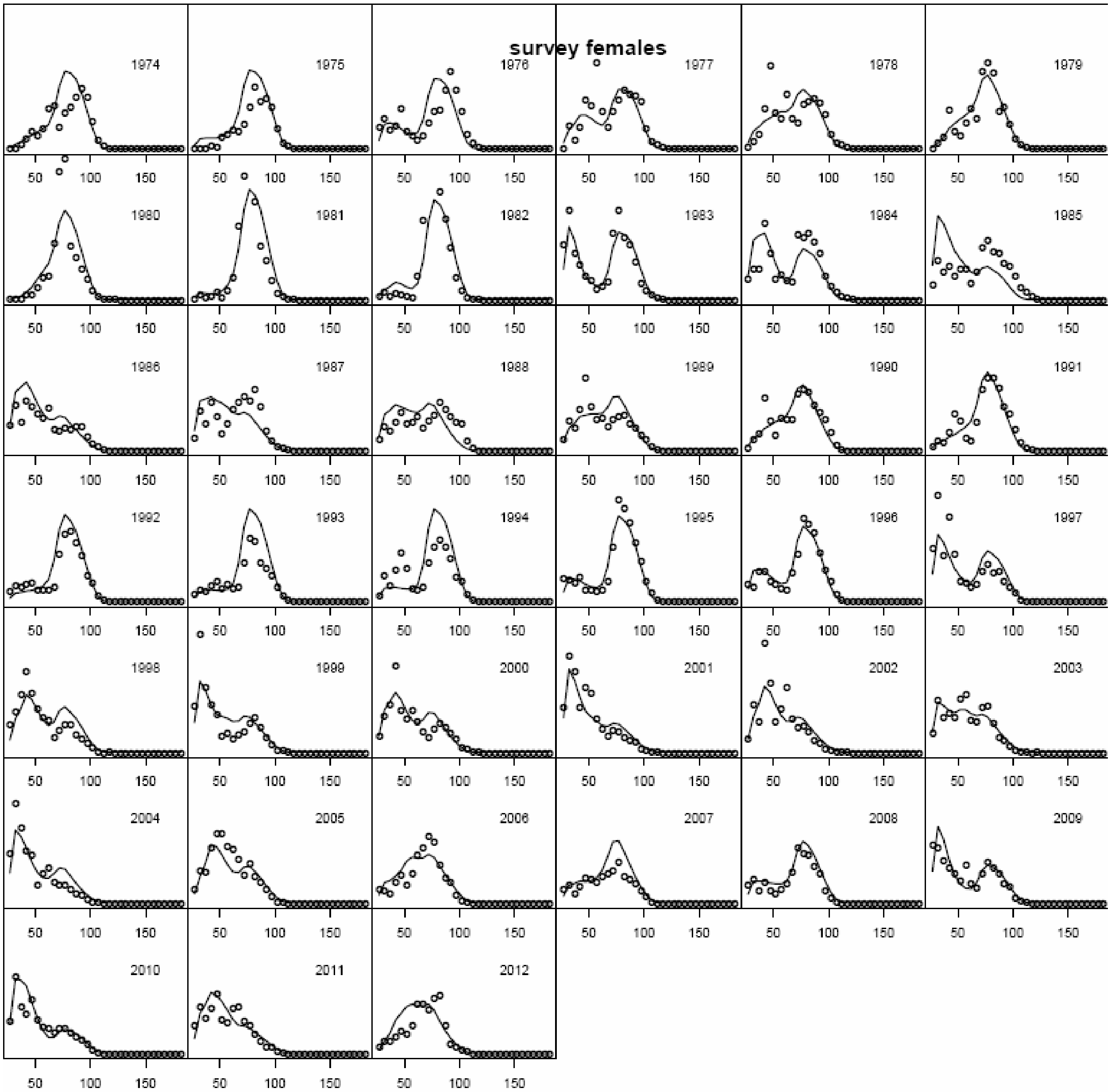


Figure 38. *Base Model (0)* fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

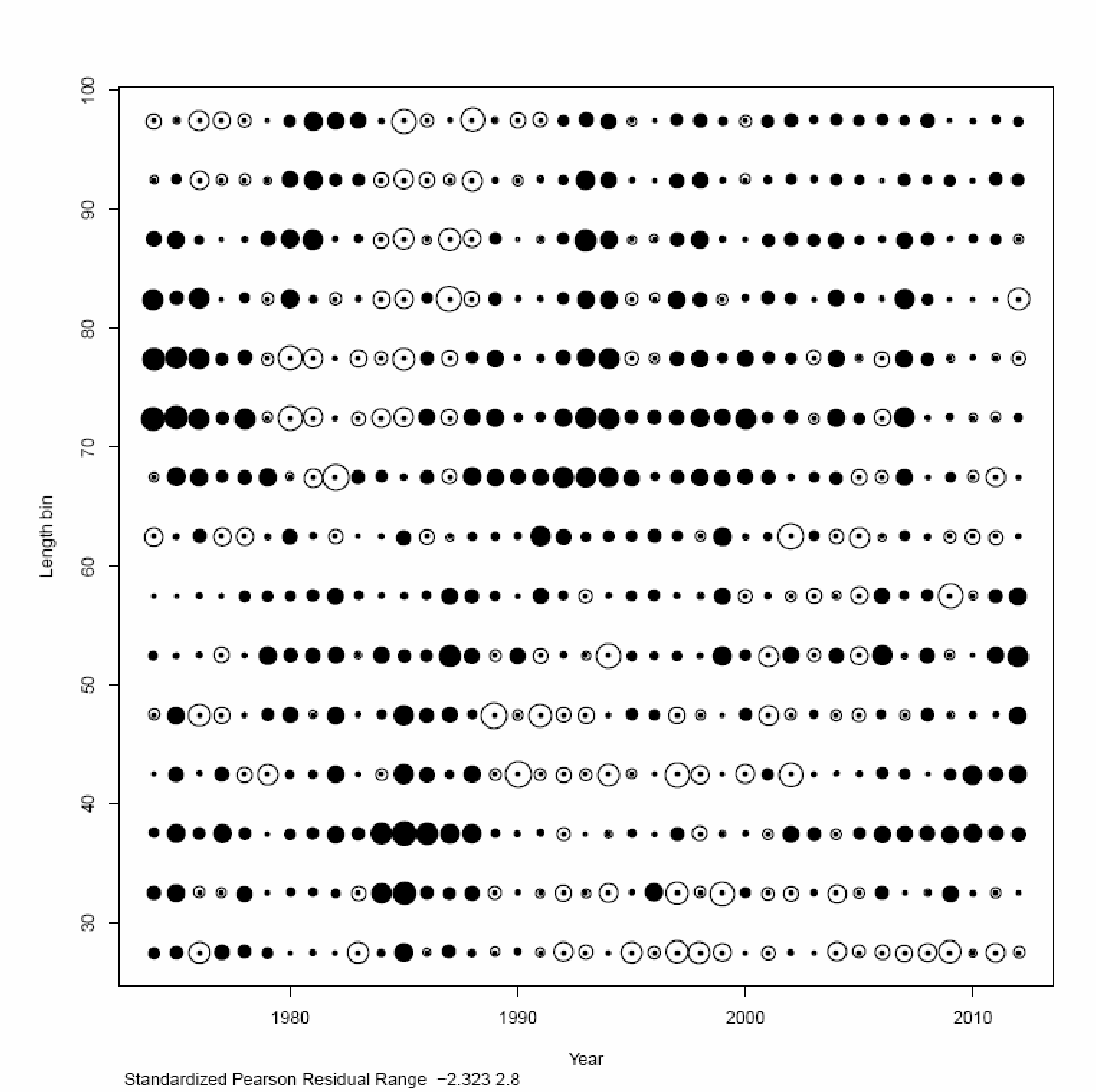


Figure 39. *Base Model (0)* standardized Pearson residuals of the model fit to the survey female size frequency data. Solid circles= overestimate and open circles=underestimate. Diameter of circle proportional to extent of lack of fit. Residual range shown at bottom.

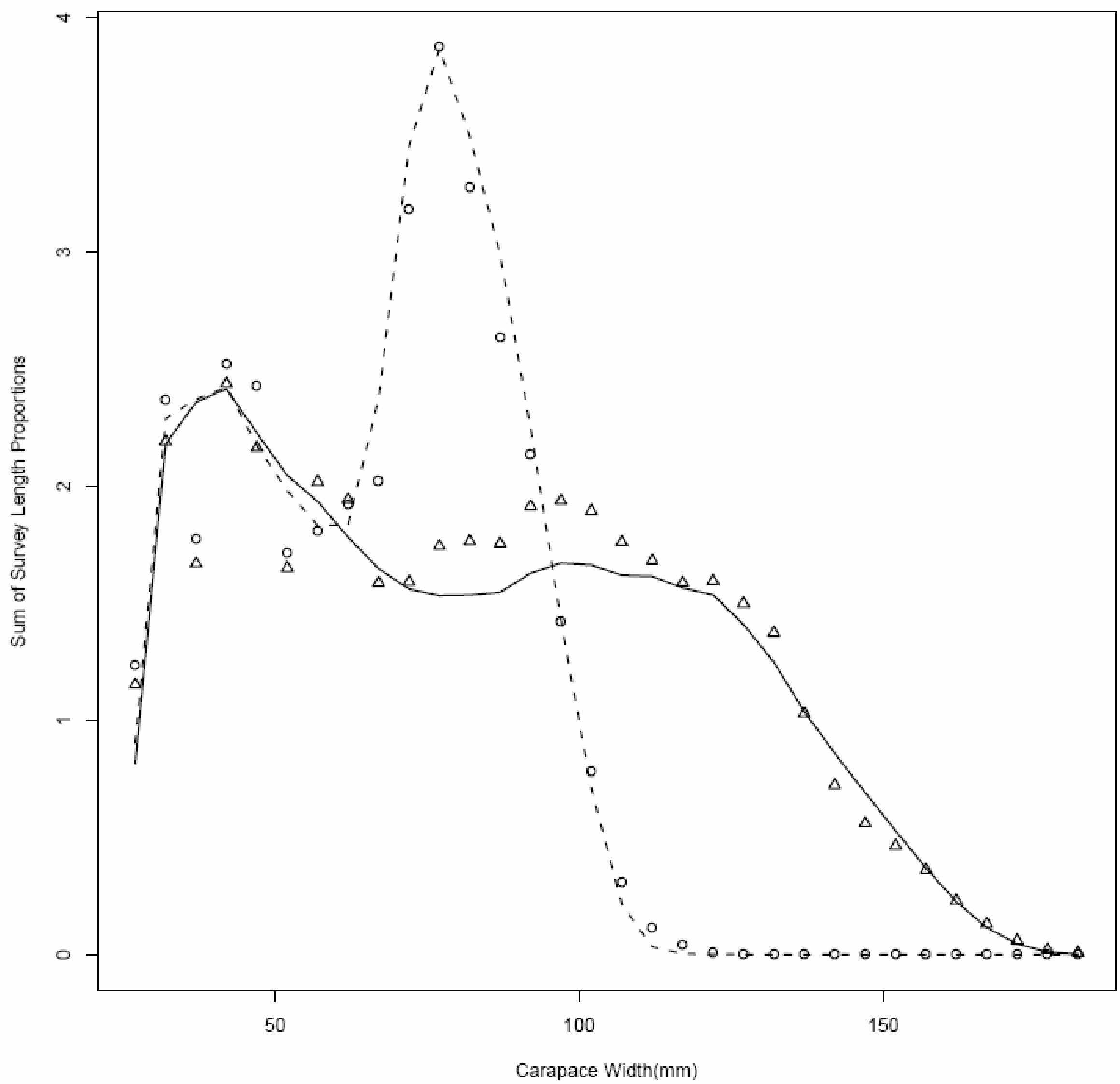


Figure 40. *Base Model (0)* summary fit to the survey male (solid line) and female (dotted line) size frequency data, all shell conditions combined. Symbols are observed data.

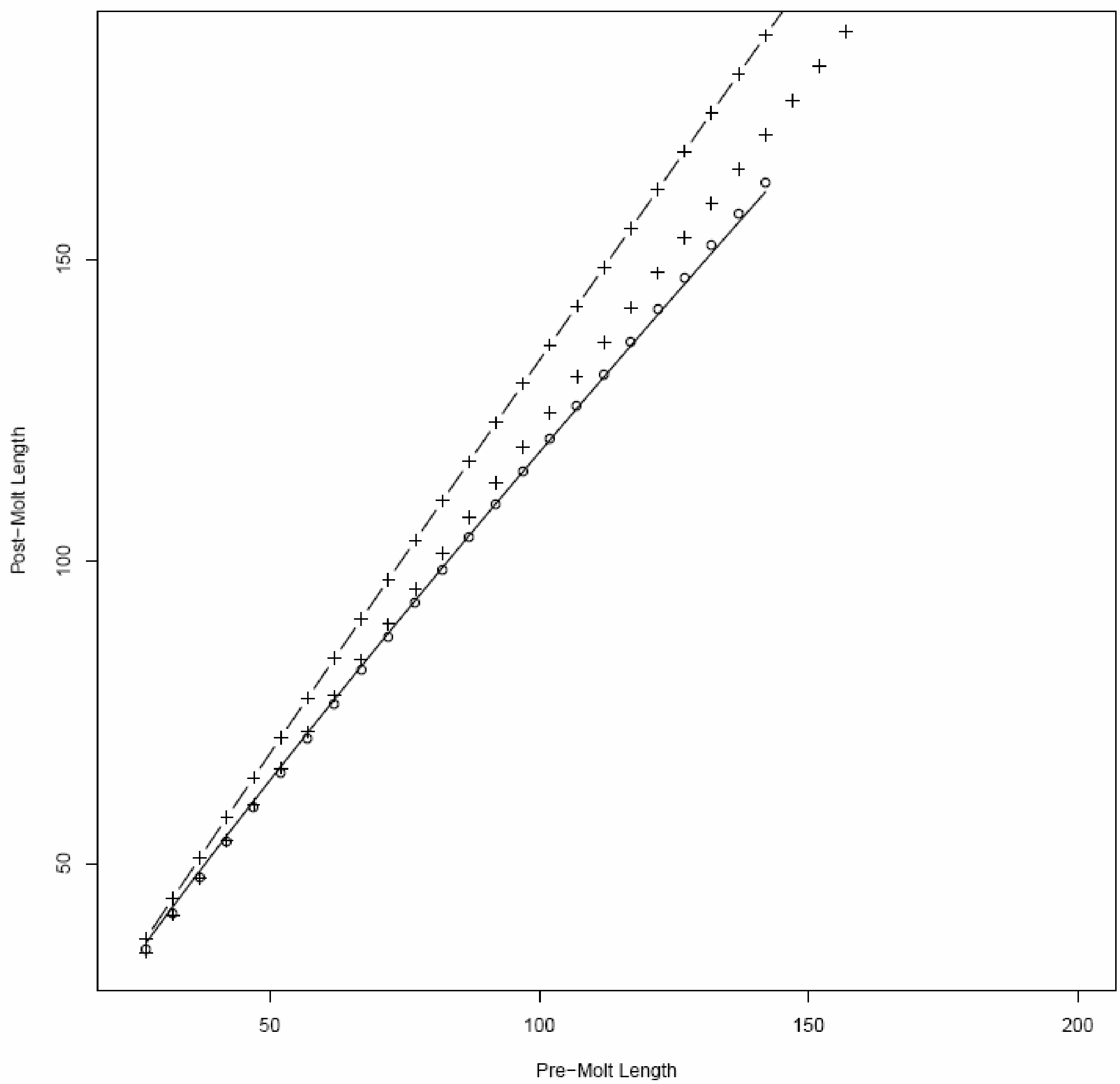


Figure 41. *Base Model (0)* estimated relationships of pre-molt length to post-molt length (mm cw) for male (dashed with pluses) and female (dashed with circles) eastern Bering Sea Tanner crab. The empirically-derived growth relationships for male (pluses) and female (circles) based on data collected near Kodiak Island in the Gulf of Alaska are shown for reference.

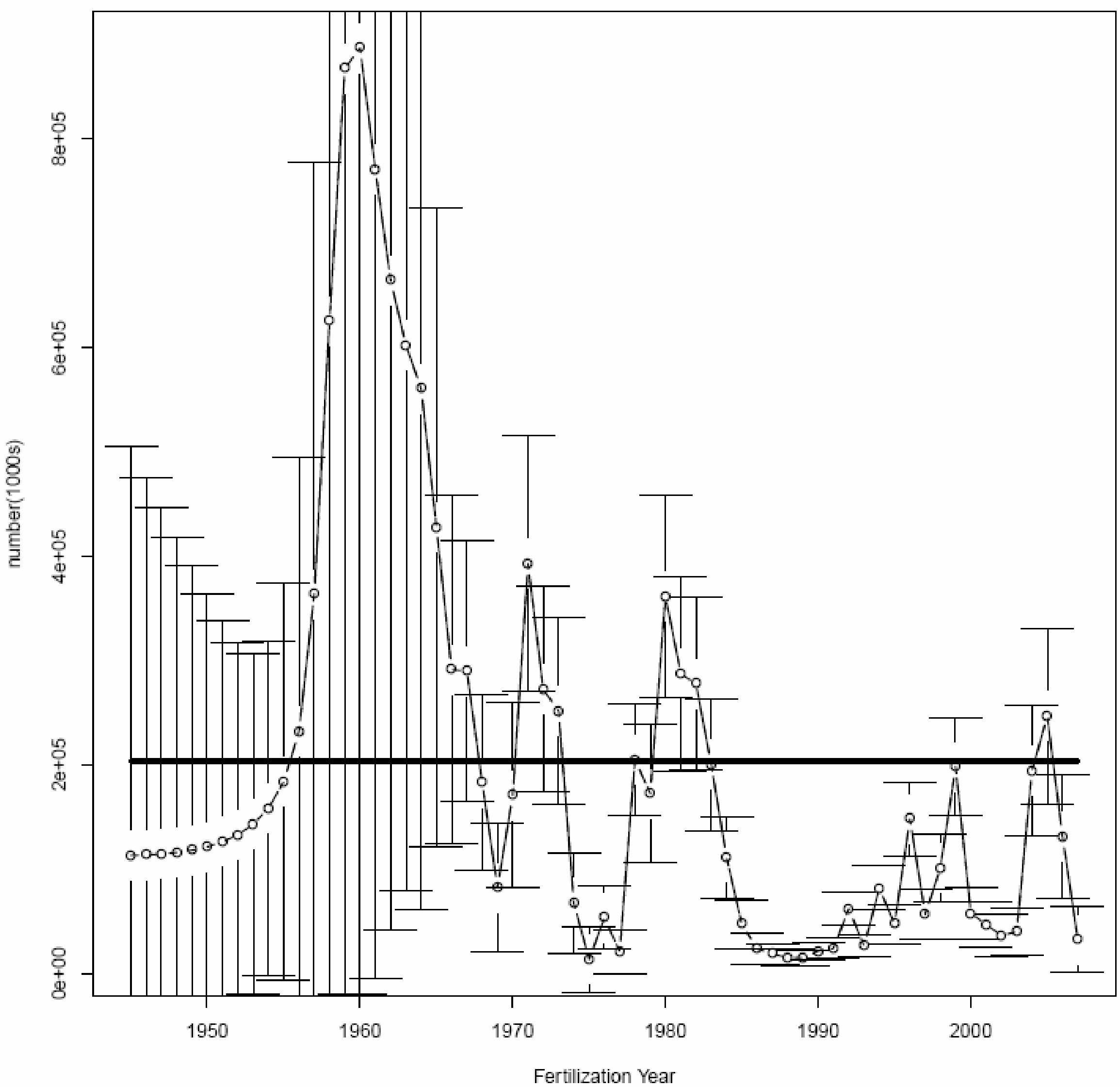


Figure 42. *Base Model (0)* recruitment to model of crab 25 mm to 50 mm by fertilization year. Total recruitment is 2 times recruitment in the plot given that male and female recruitment is set to be equal. Solid horizontal line is average recruitment.

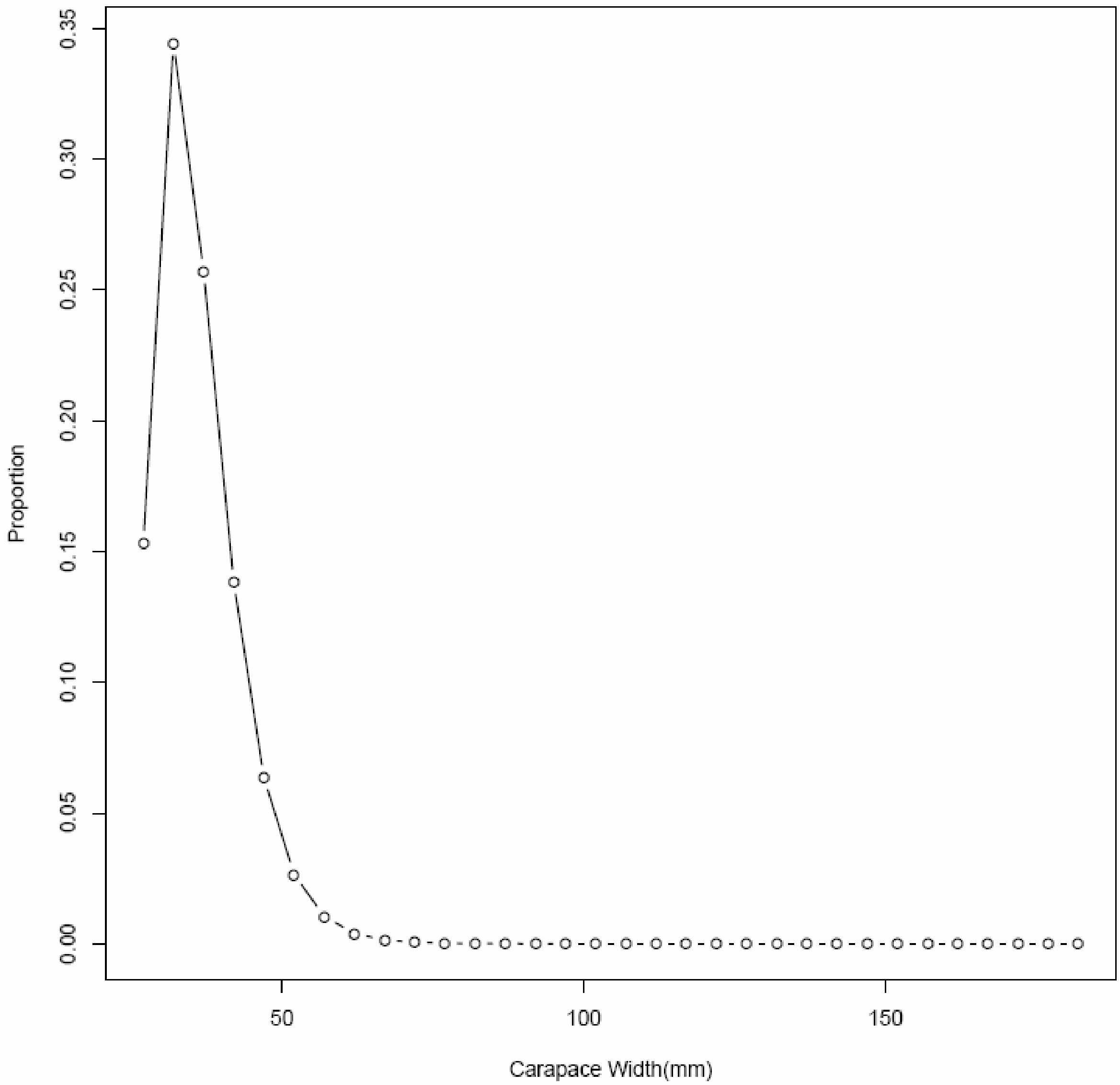


Figure 43. *Base Model (0)* distribution of recruits to length bins estimated by the model.

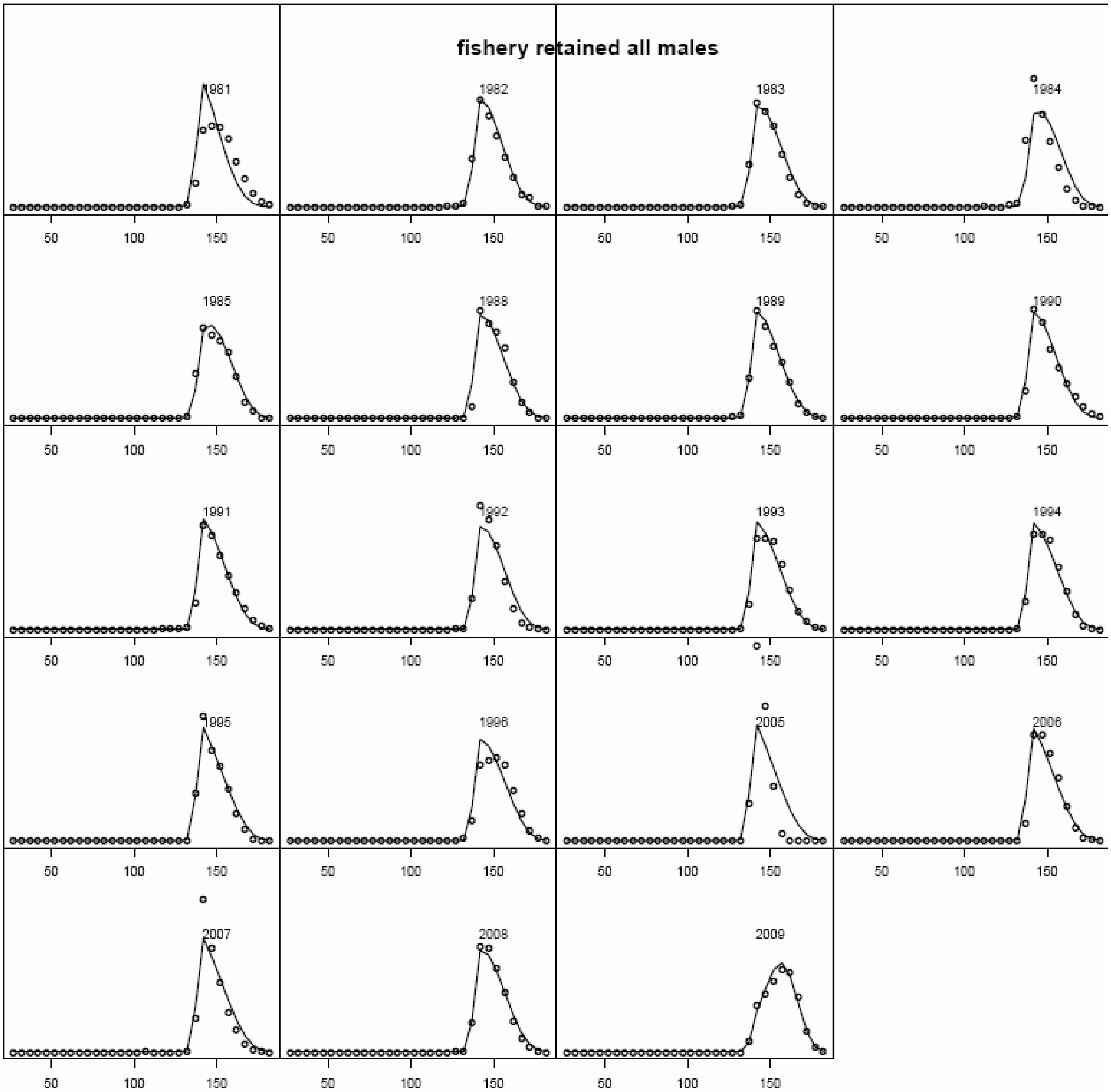


Figure 44. *Base Model (0)* fit to the retained male size frequency data in the directed fishery, shell condition combined. Circles are observed data.

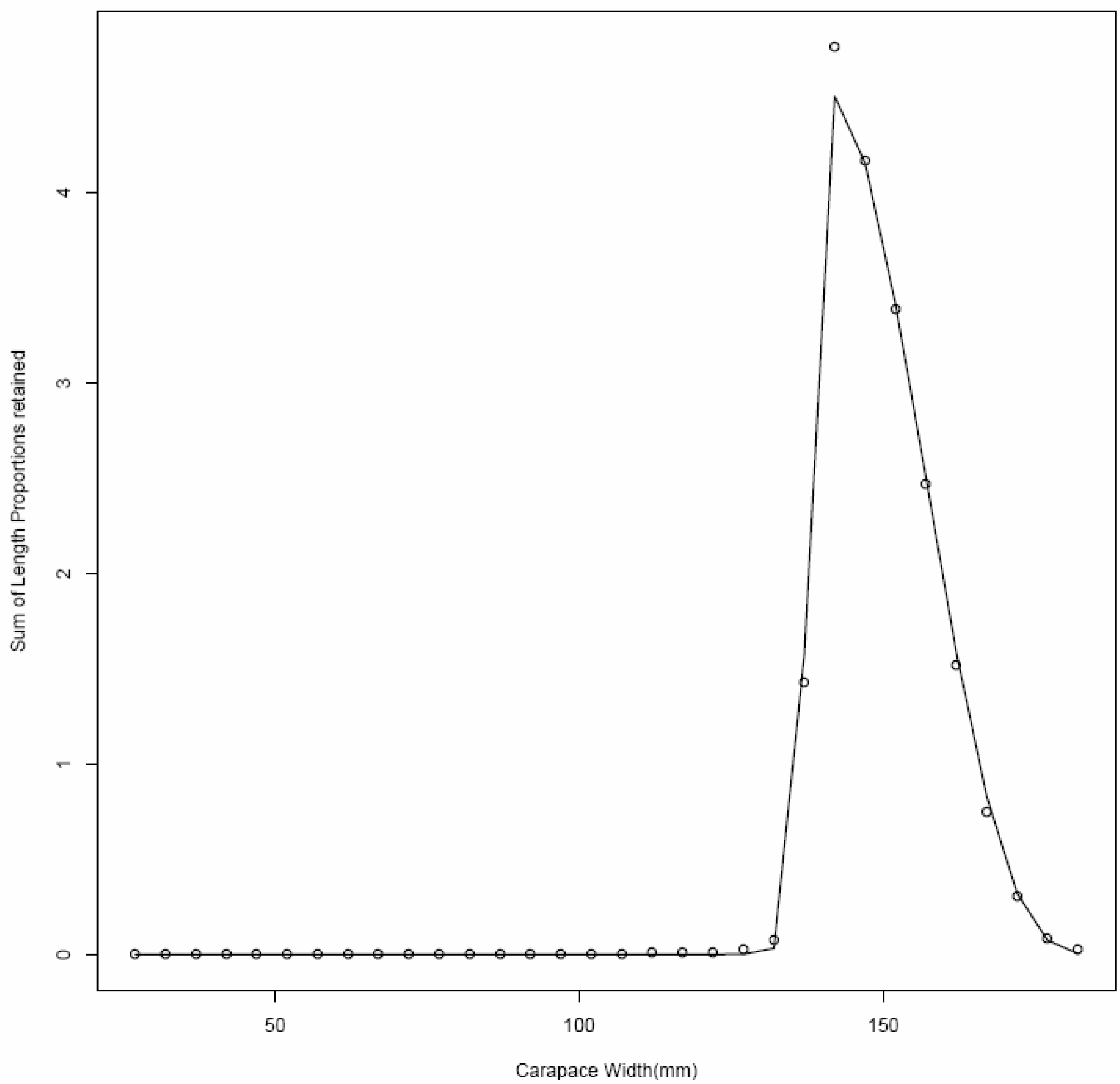


Figure 45. *Base Model (0)* summary fit to the retained male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data.

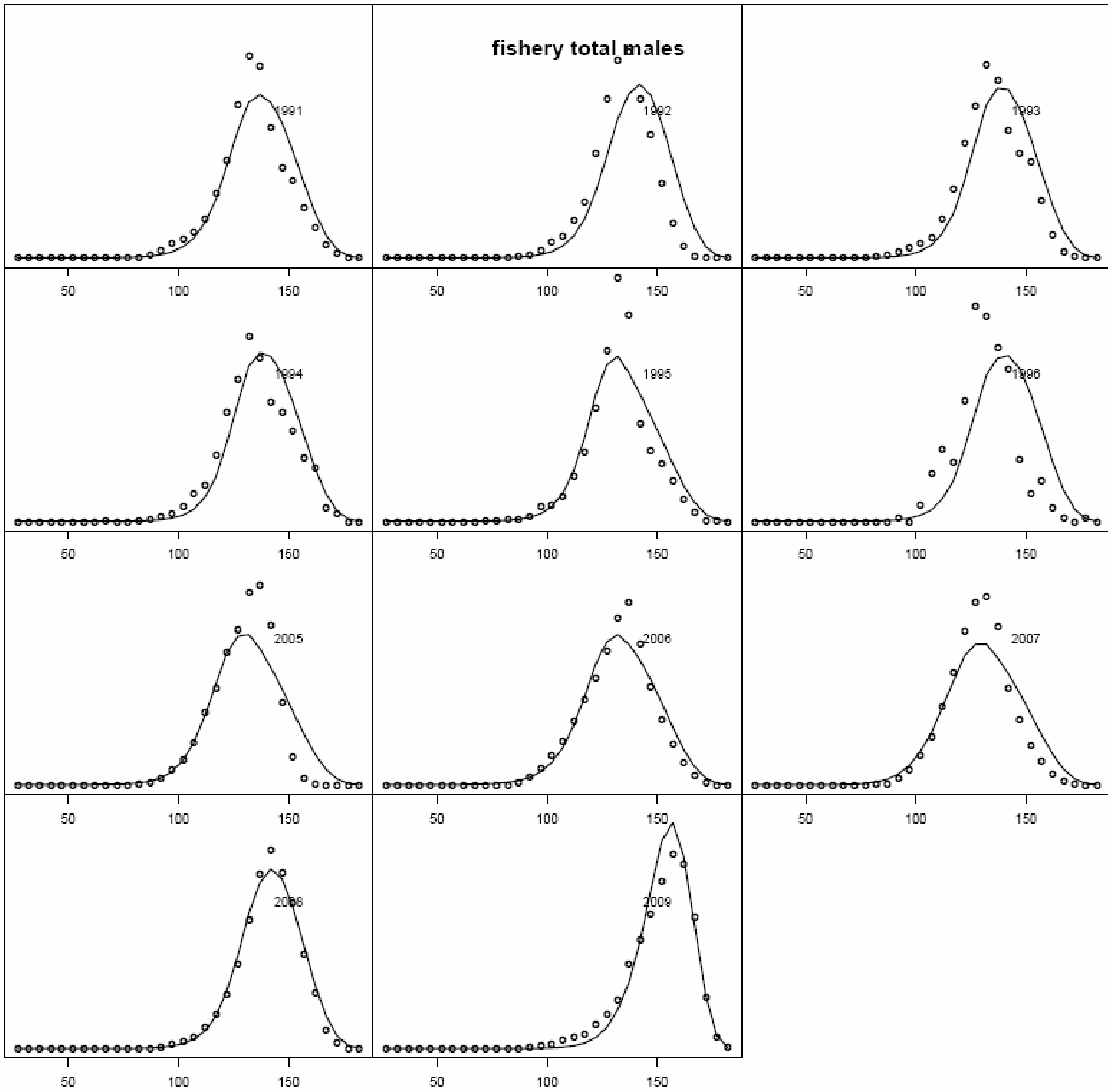


Figure 46. *Base Model (0)* fit to the total (discard plus retained) male size frequency data in all fisheries combined, shell condition combined. Circles are observed data.

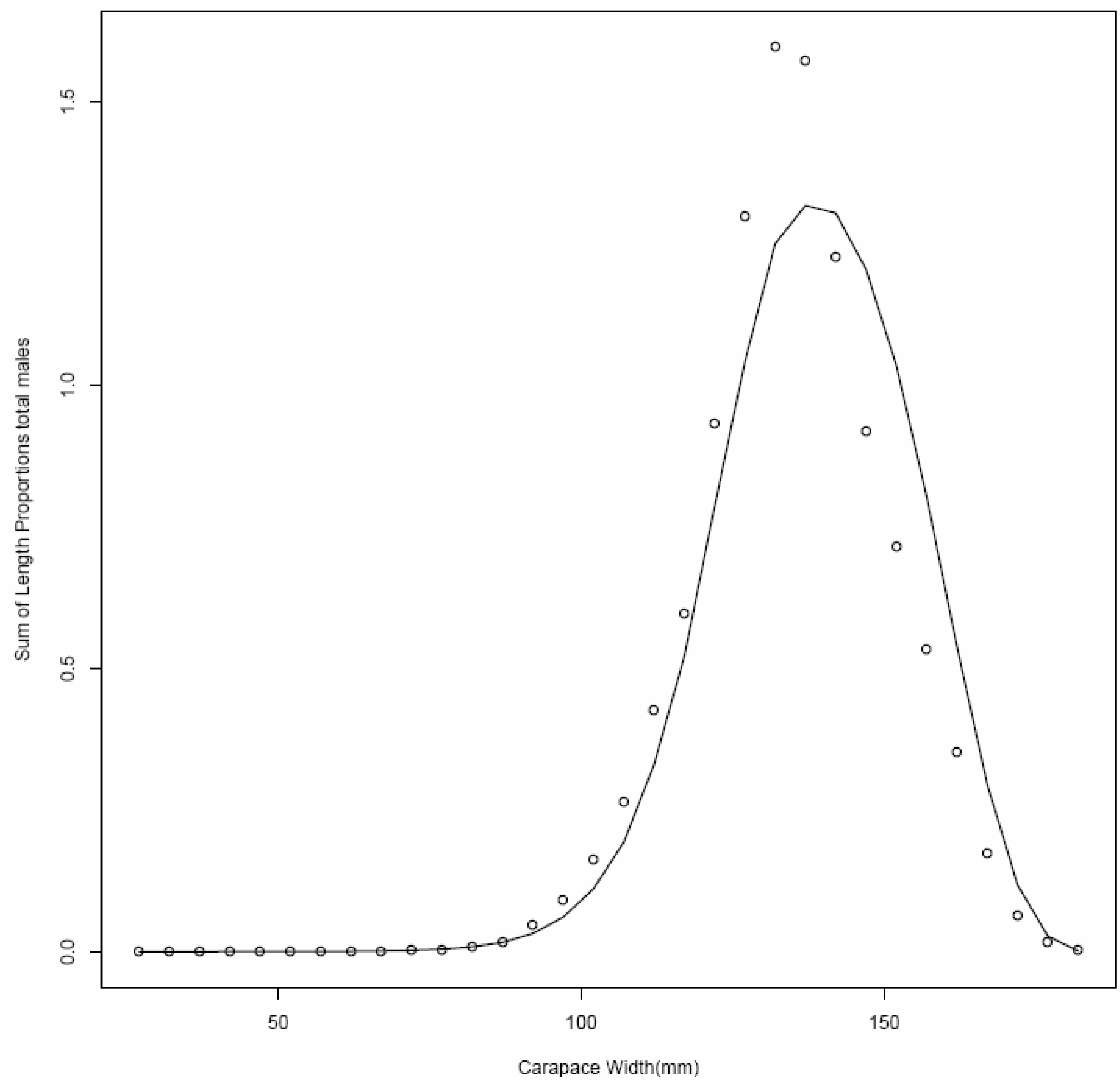


Figure 47. *Base Model (0)* summary fit to the total (discard plus retained) male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data.

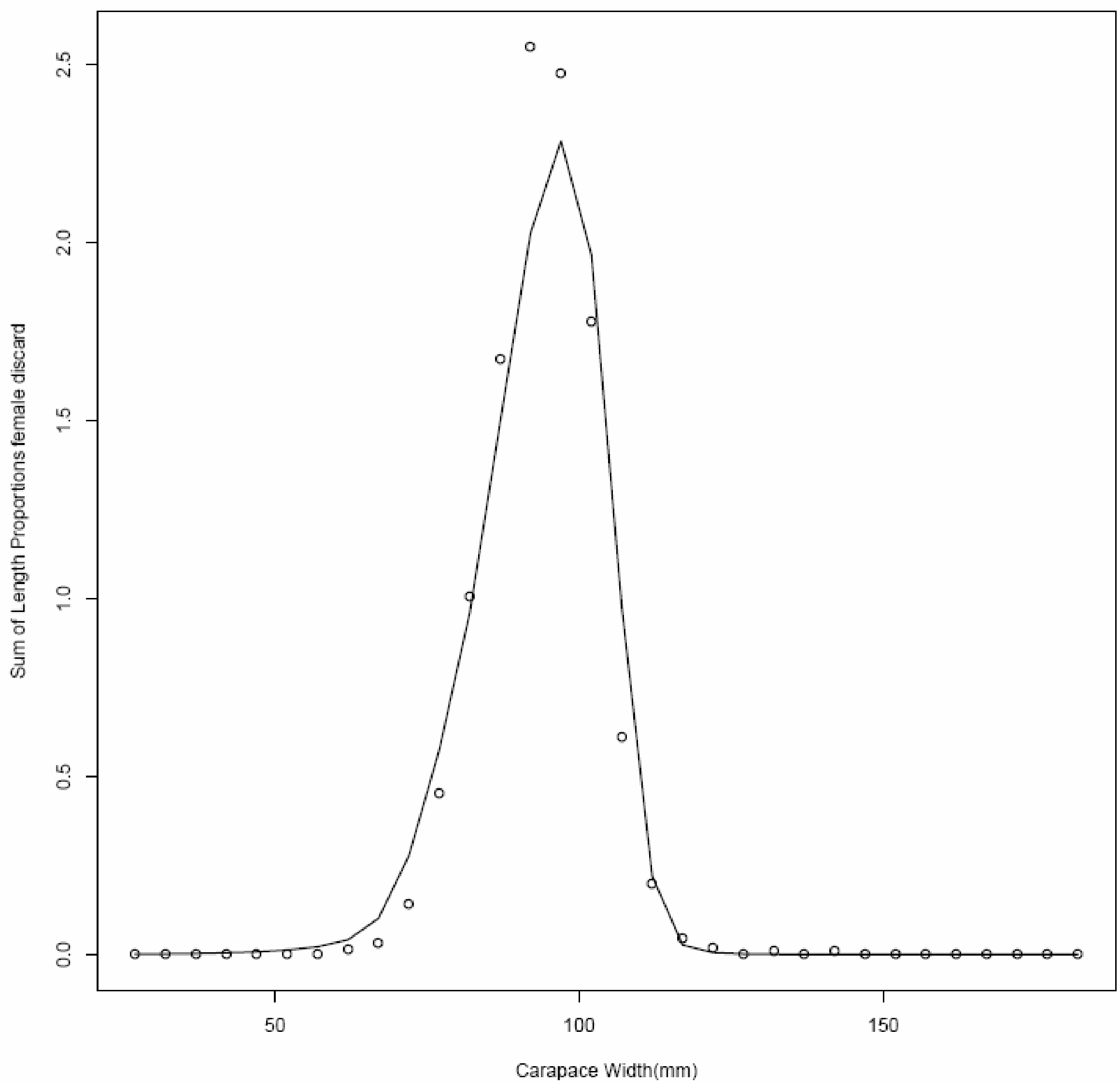


Figure 48. *Base Model (0)* summary fit to the discard female size frequency data in the directed fishery. Solid line is the model fit. Circles are observed data.

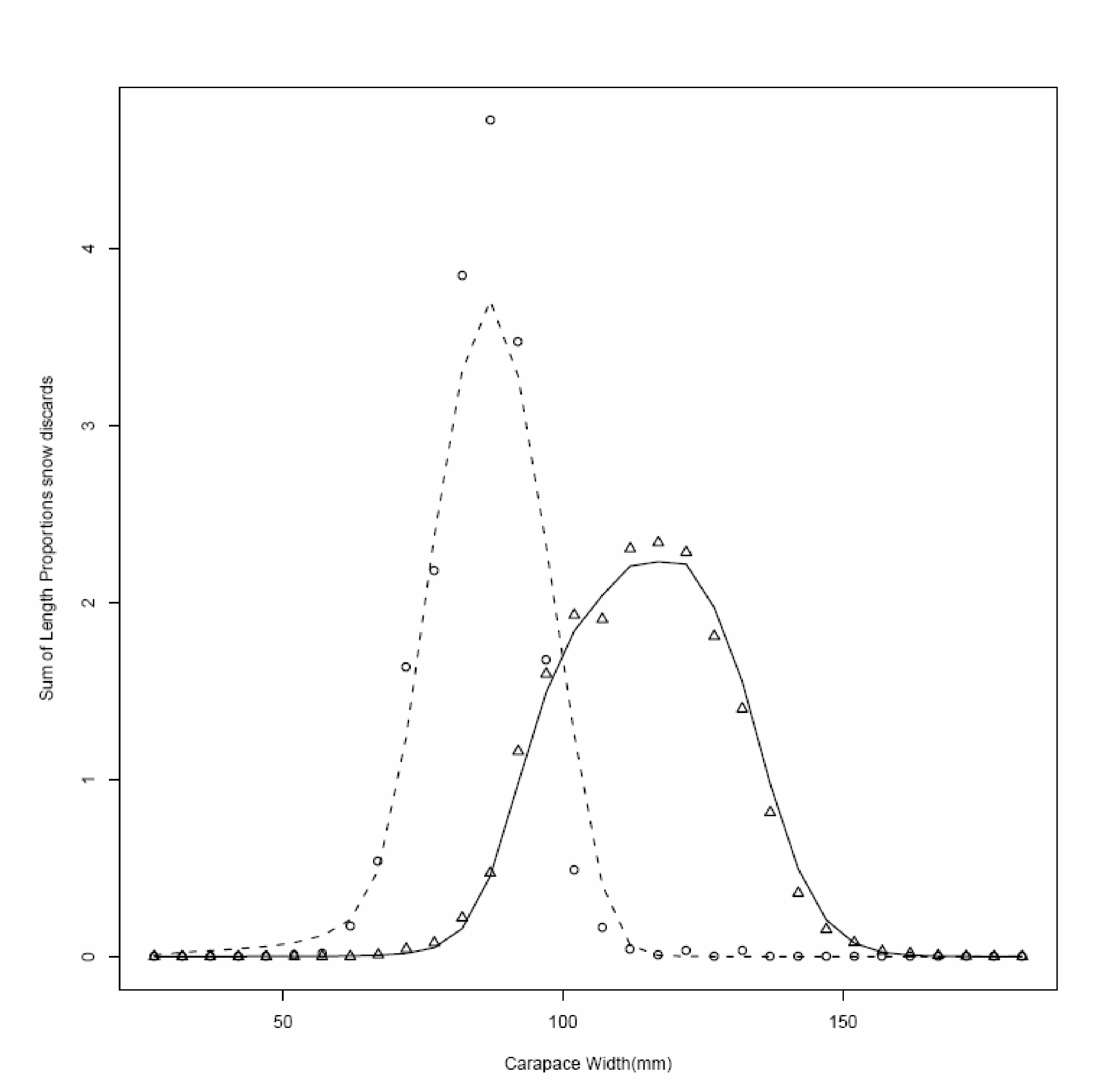


Figure 49. *Base Model (0)* summary fit to the discards in the snow crab fishery for males (solid line) and females (dotted line) size frequency data. Symbols are observed data.

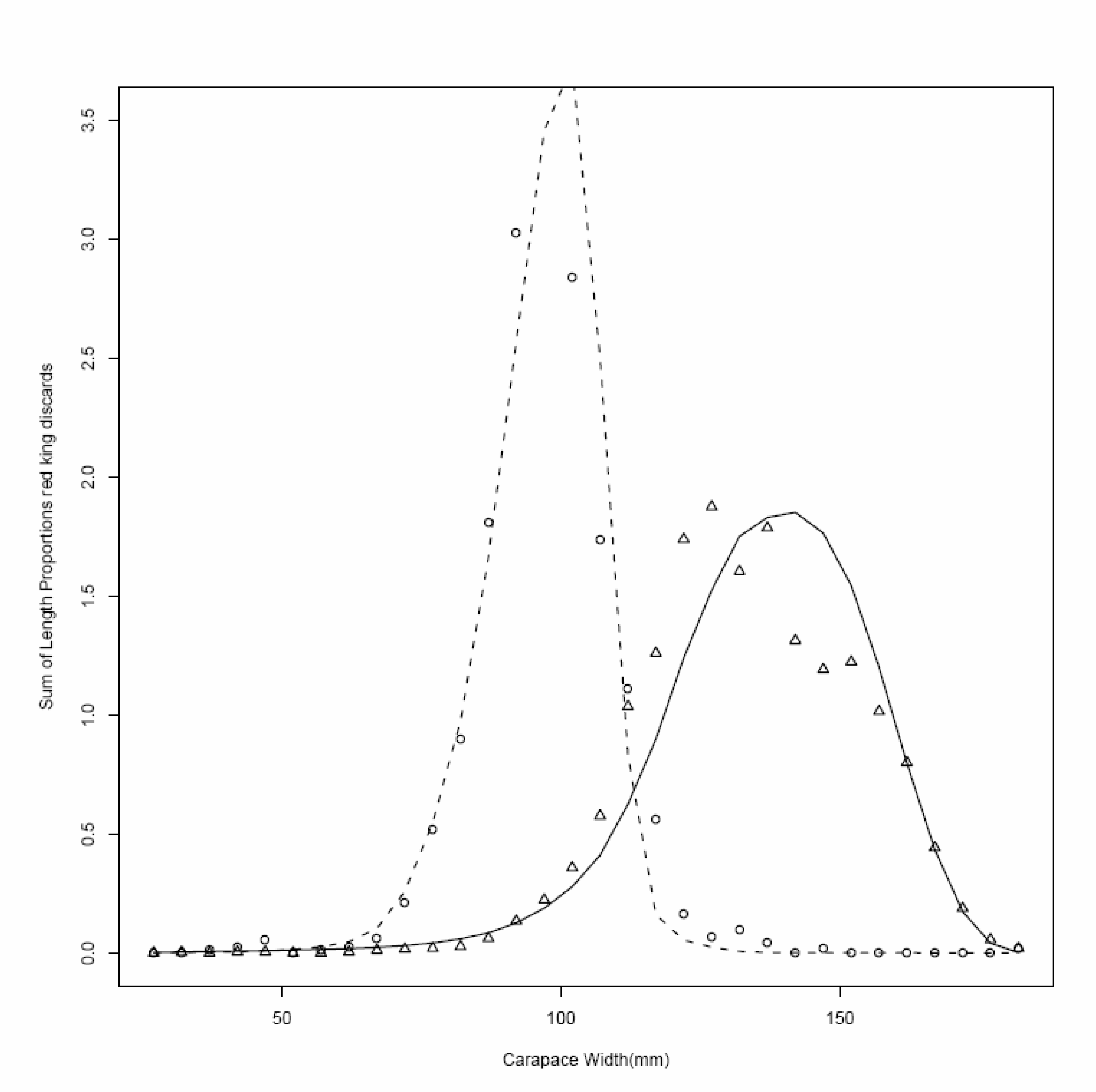


Figure 50. *Base Model (0)* summary fit to the discards in the Bristol Bay red king crab fishery for males (solid line) and females (dotted line) size frequency data. Symbols are observed data.

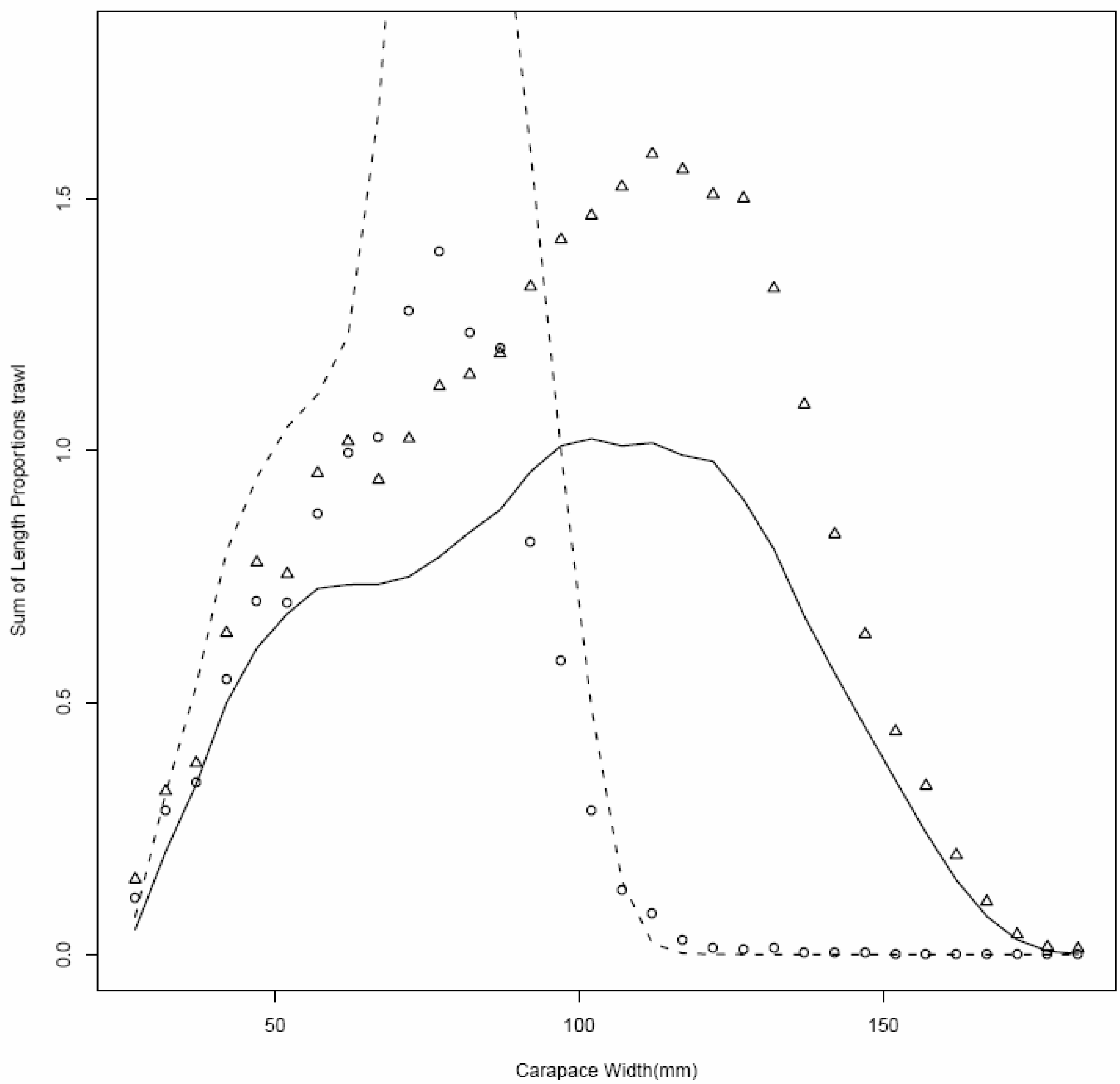


Figure 519. *Base Model (0)* summary fit to the discards in the eastern Bering Sea groundfish fisheries for males (solid line) and females (dotted line) size frequency data. Symbols are observed data.

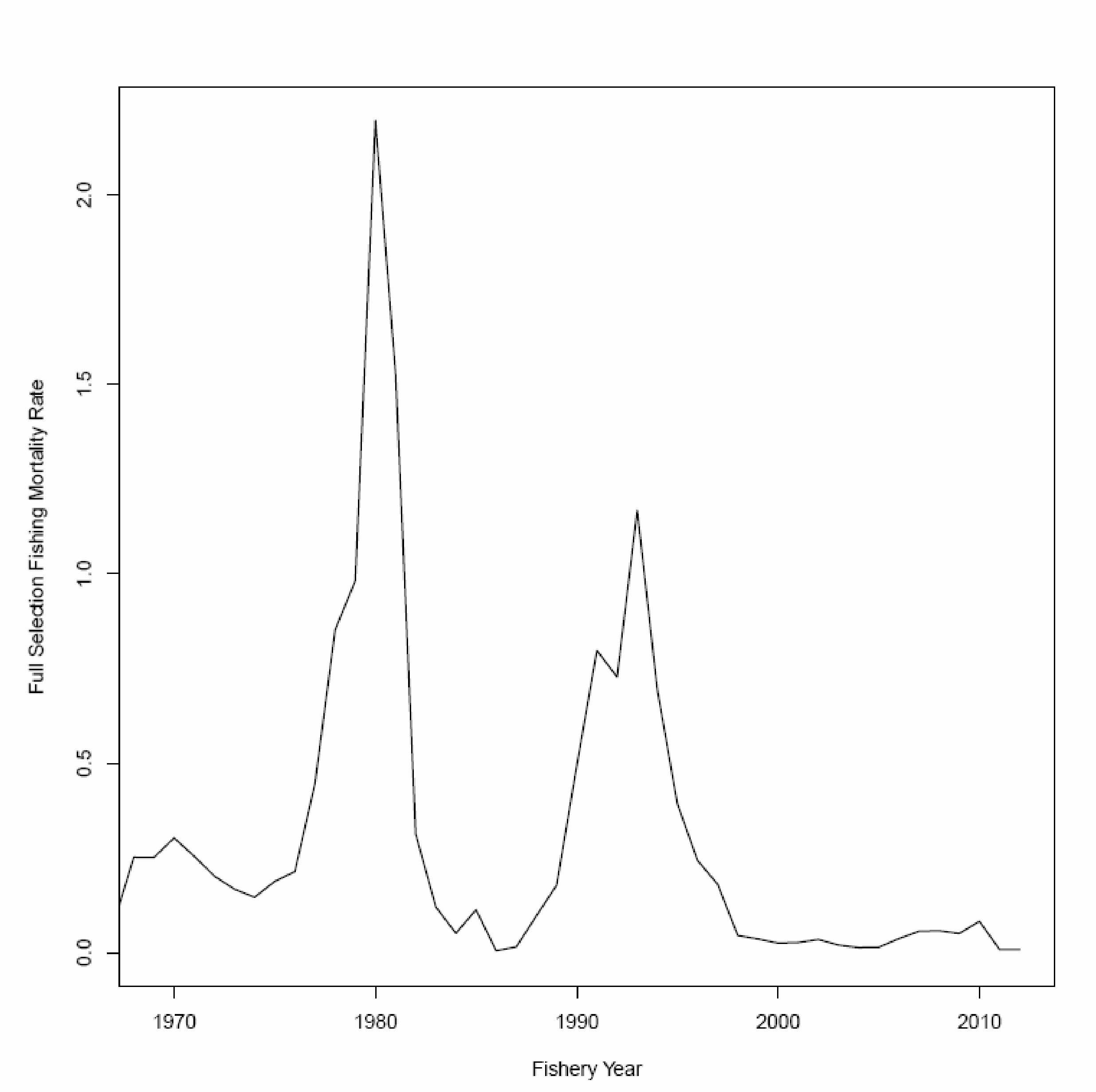


Figure 52. *Base Model (0)* full-selection total fishing mortality rates estimated in the model from 1970 to 2011 fishery seasons (1969 to 2010 survey years).

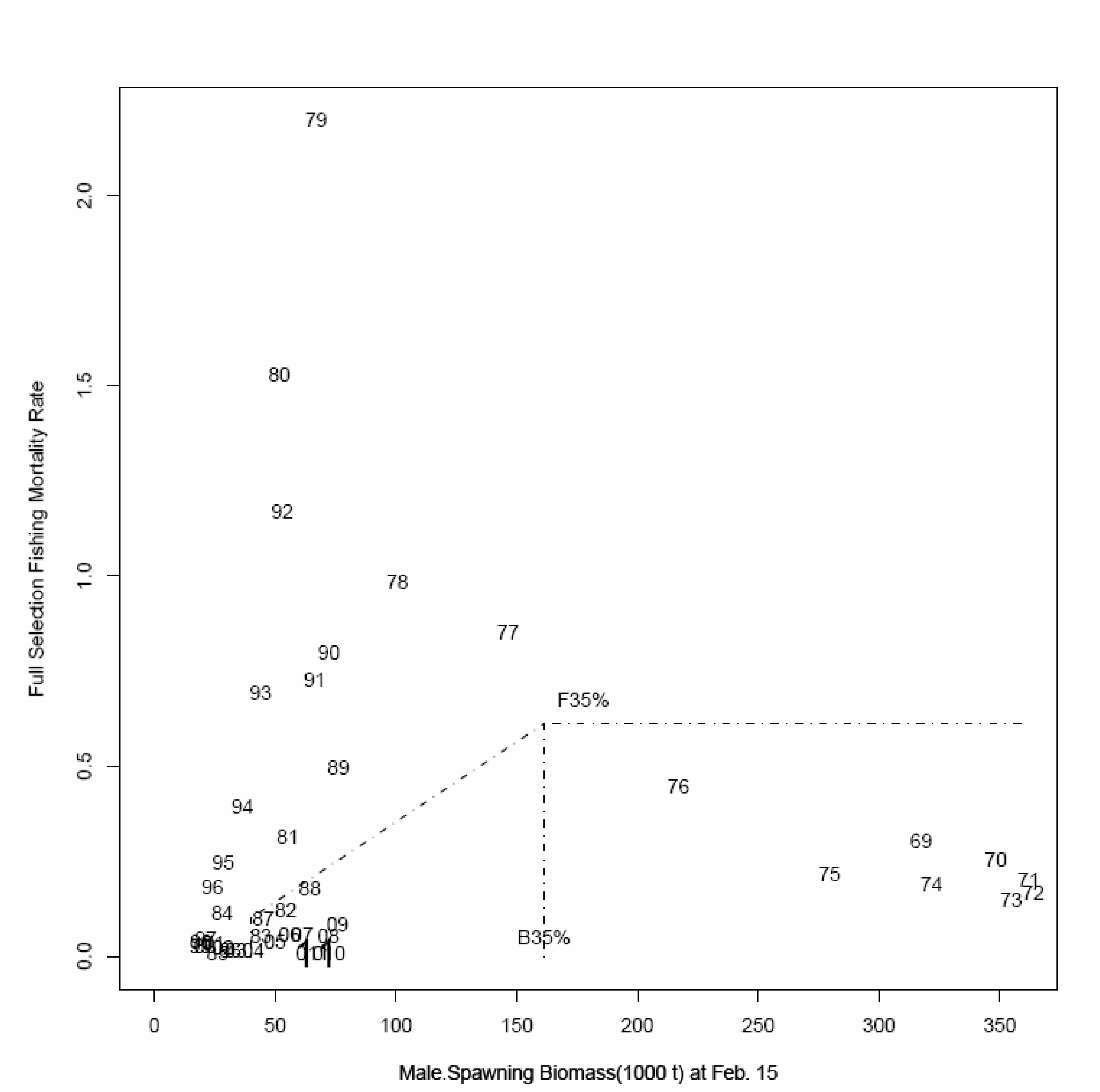


Figure 53. Full-selection fishing mortality versus male mature biomass at mating in fishing years 1967-2010/11. The *Base Model (0)* OFL control rule where $F_{35\%}$=0.612 and $B_{35\%}$=161.37 thousand t.

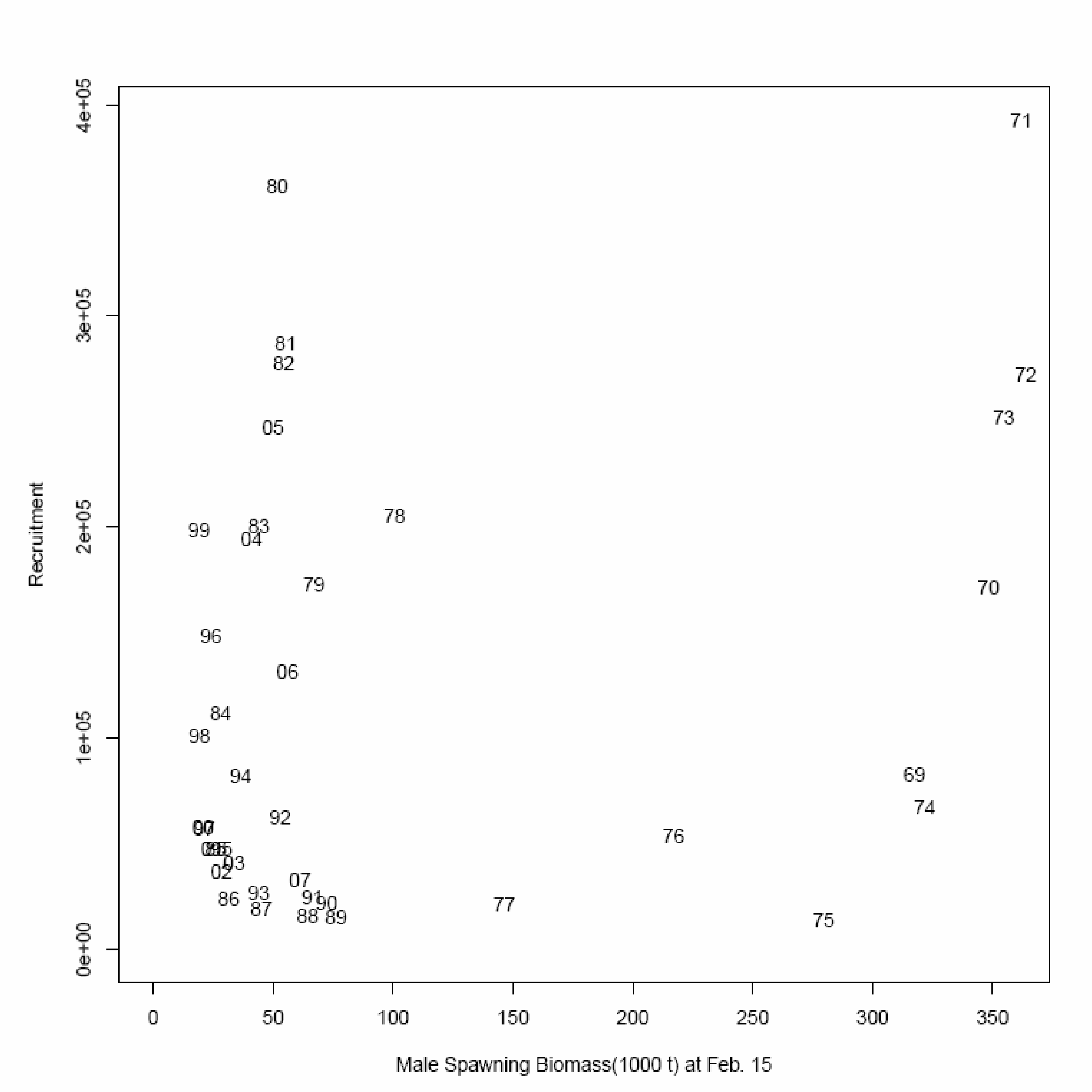


Figure 54. *Base Model (0)* recruitment (1000 crab) vs. male mature biomass at time of mating (1000 t). Two digit year numbers are fertilization year lagged 5 years. Recruitment is one-half of total recruits.

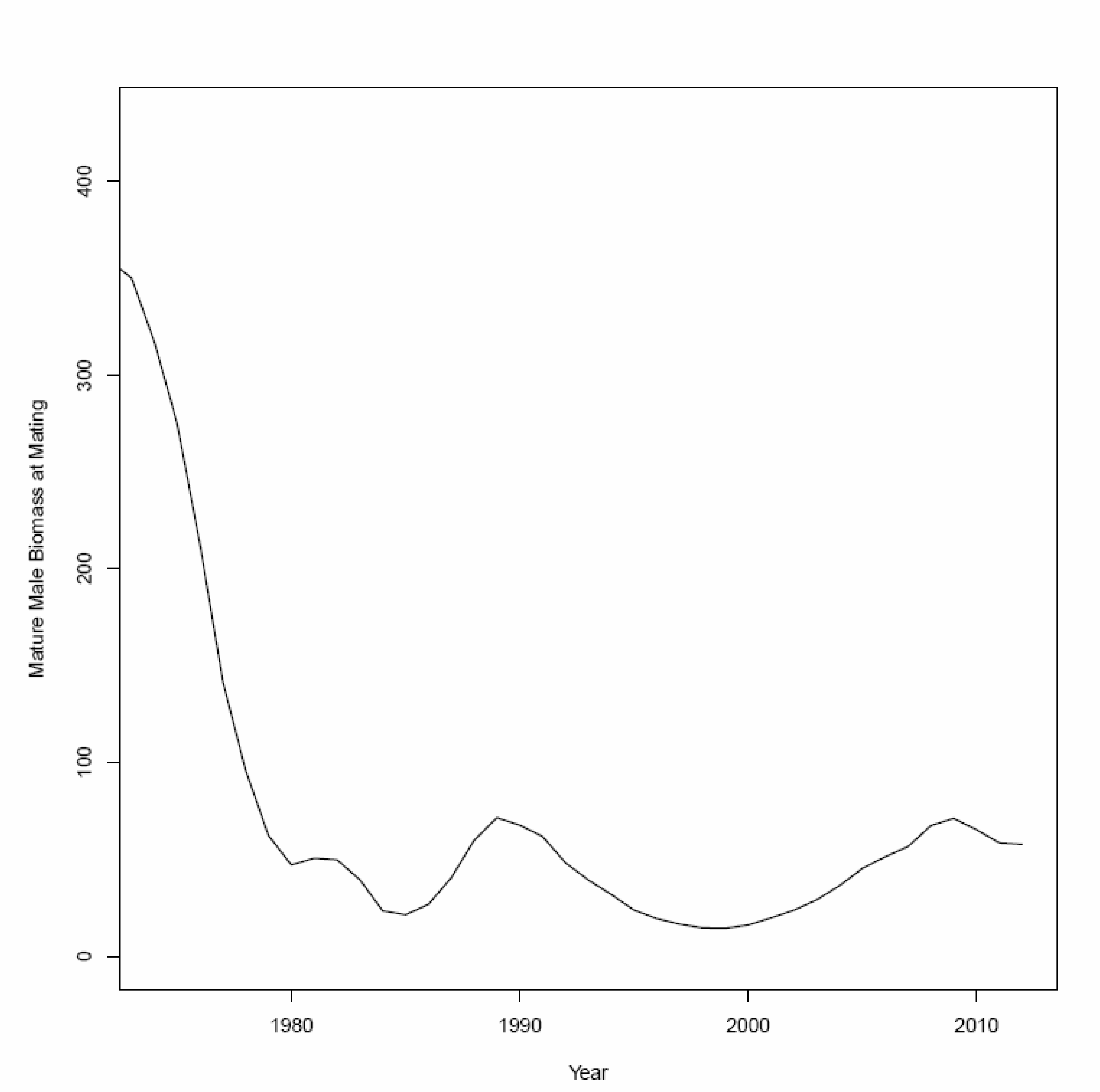


Figure 55. *Base Model (0)* time-trajectory of mature male biomass at the time of mating for EBS Tanner crab (1000 t) for years 1974-2012.

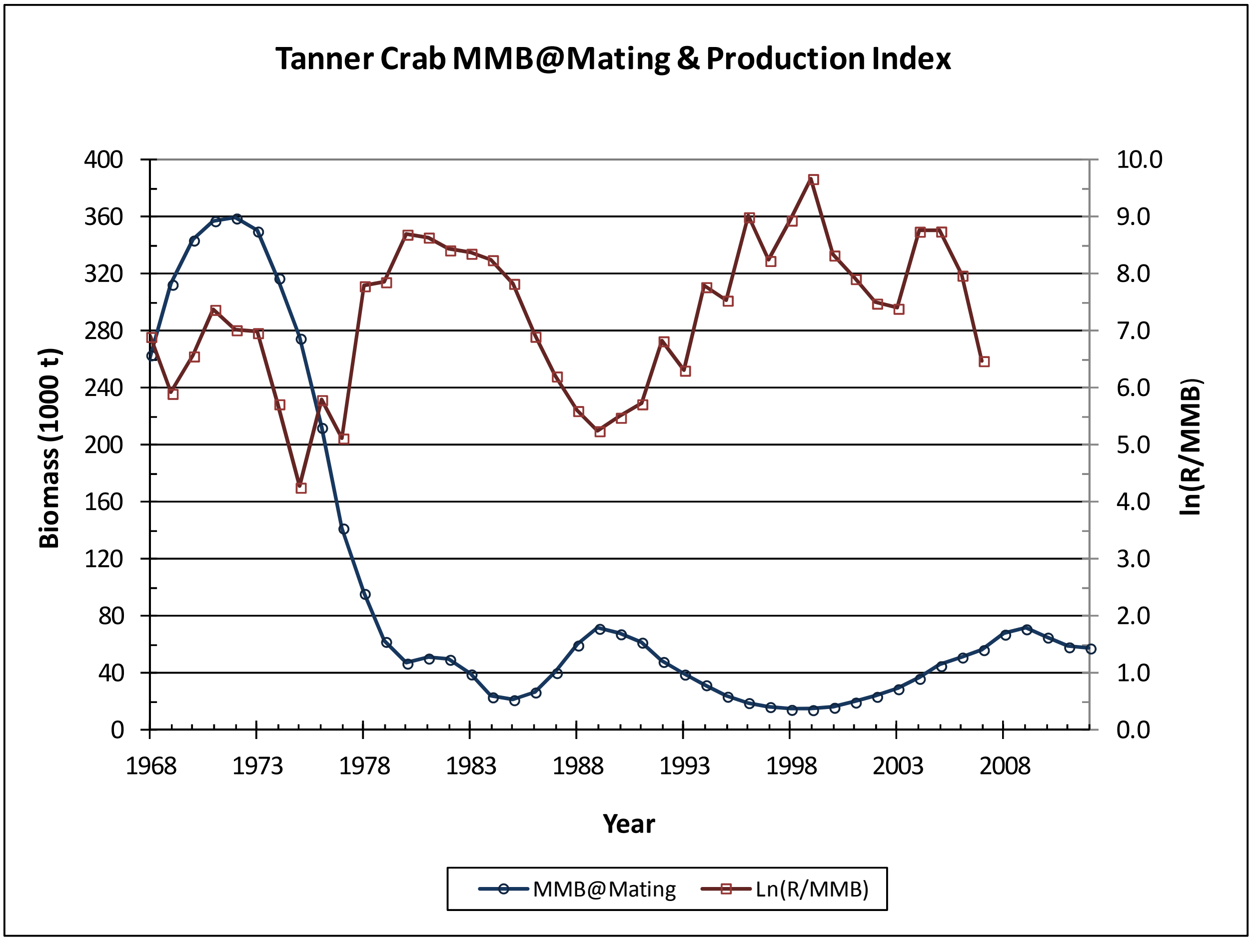


Figure 56. *Base Model (0)* estimate of male mature biomass at mating versus the stock production index, ln(R/MMB), for the Tanner crab stock, 1968-2012.

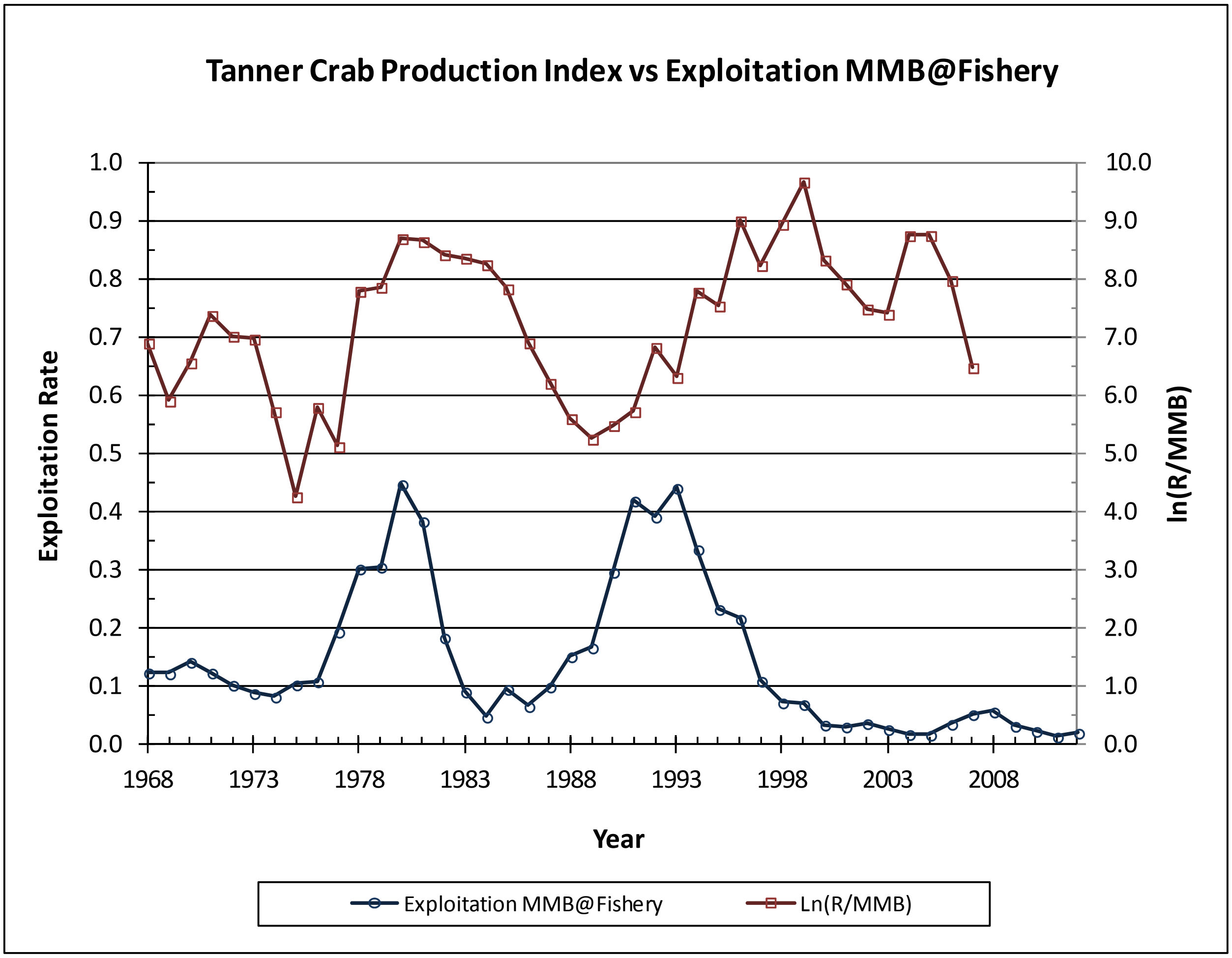


Figure 57. *Base Model (0)* exploitation rate history on Tanner crab male mature biomass at the time of the fishery versus the stock production index, ln(R/MMB), 1968-2012.

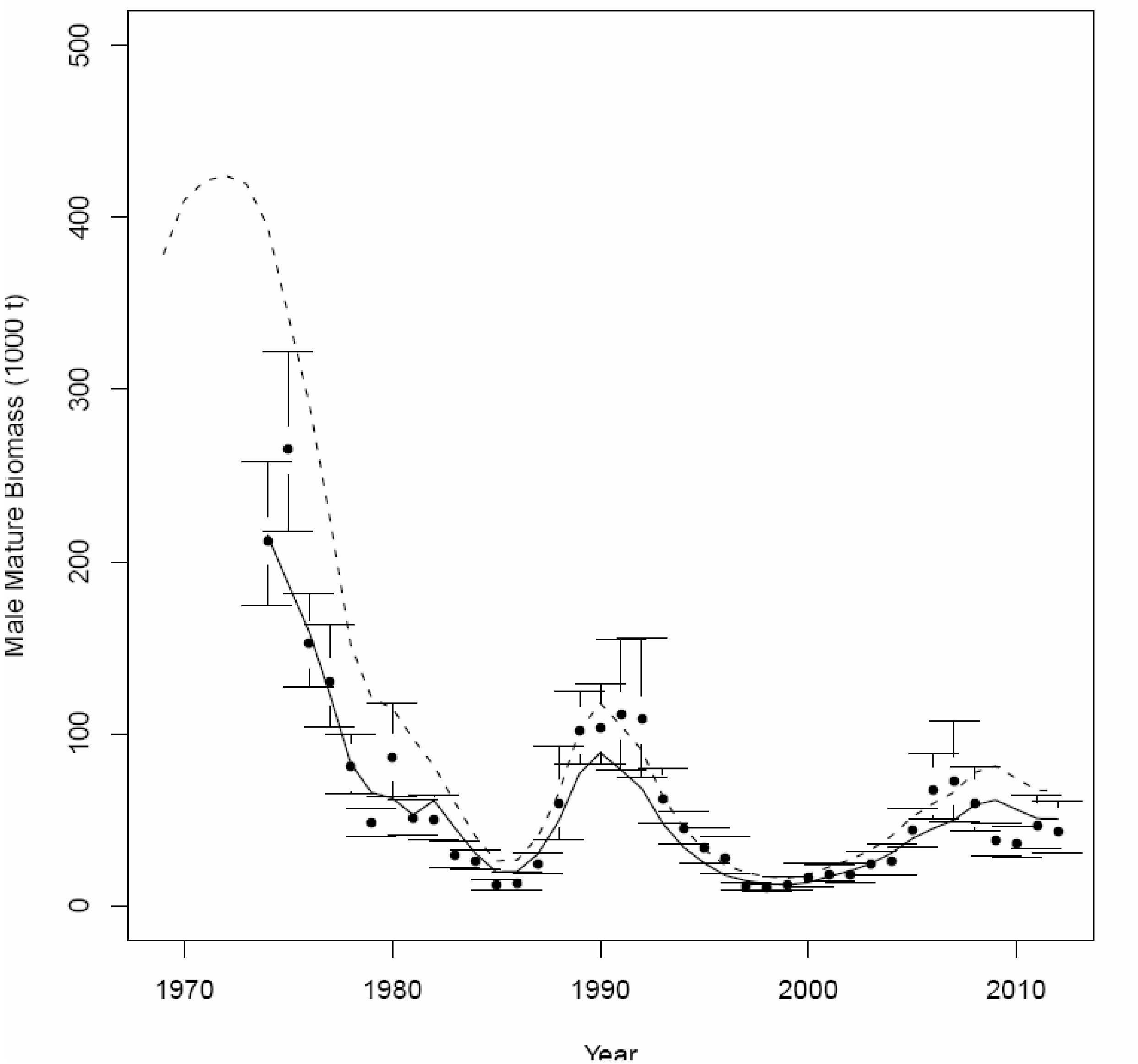


Figure 58. *Model (1)* population mature male biomass (1000 t, dotted line) at the time of the survey, model estimate of survey mature biomass (solid line) and observed survey mature male biomass with approximate lognormal 95% confidence intervals.

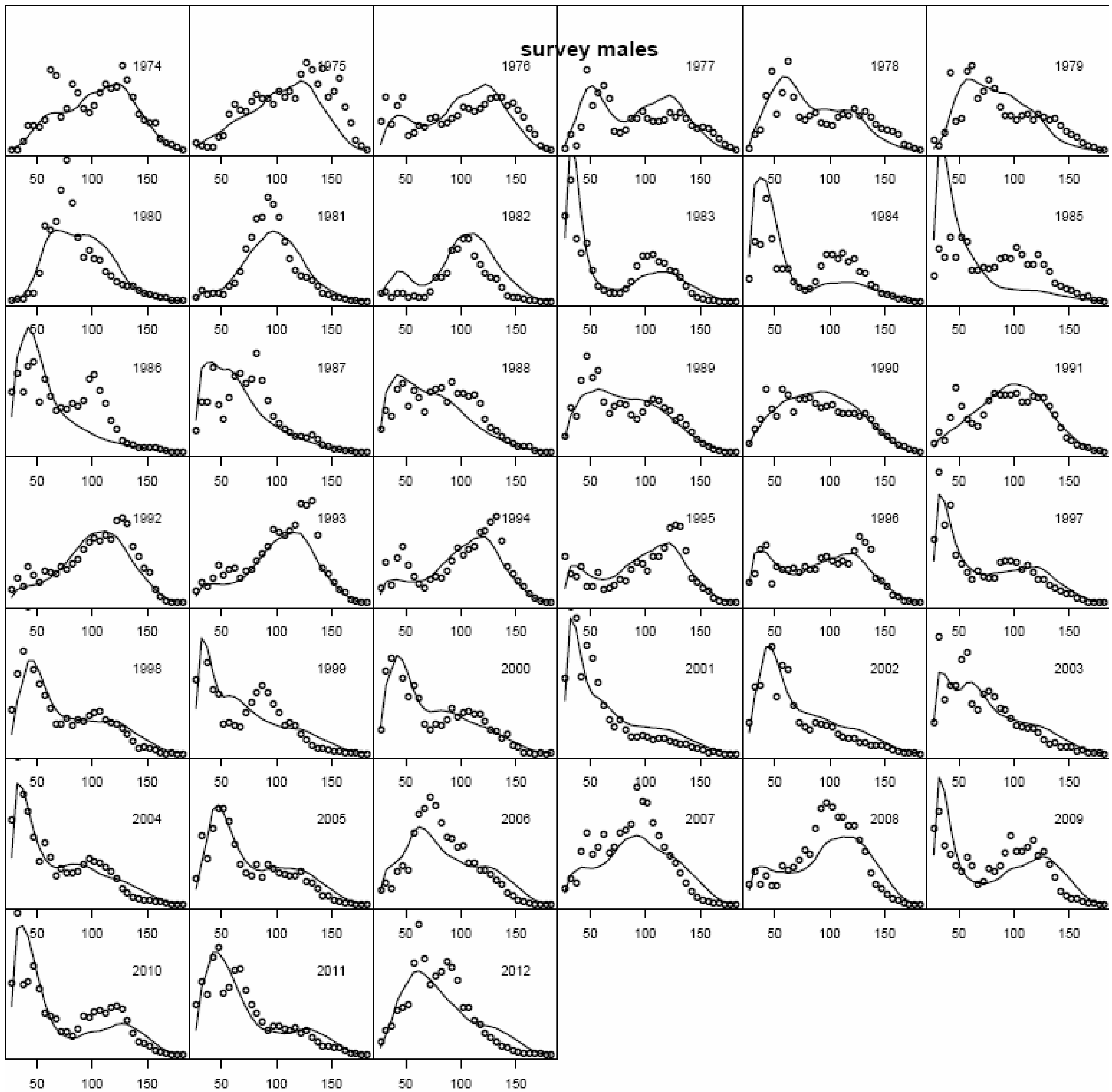


Figure 59. *Model (1)* fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

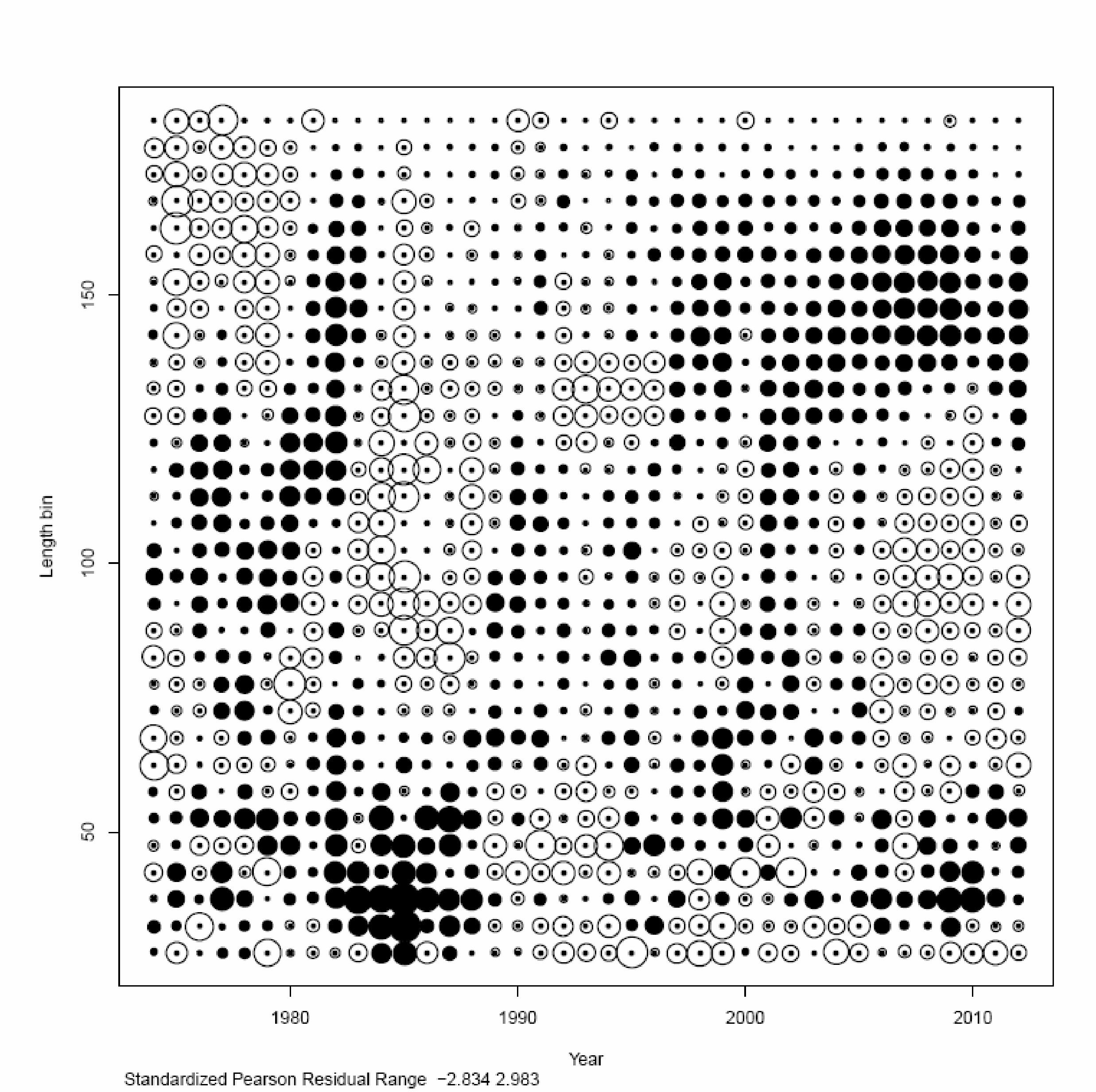


Figure 60. *Model (1)* standardized Pearson residuals of the model fit to the survey male size frequency data. Solid circles= overestimate and open circles=underestimate. Diameter of circle proportional to extent of lack of fit. Residual range shown at bottom.

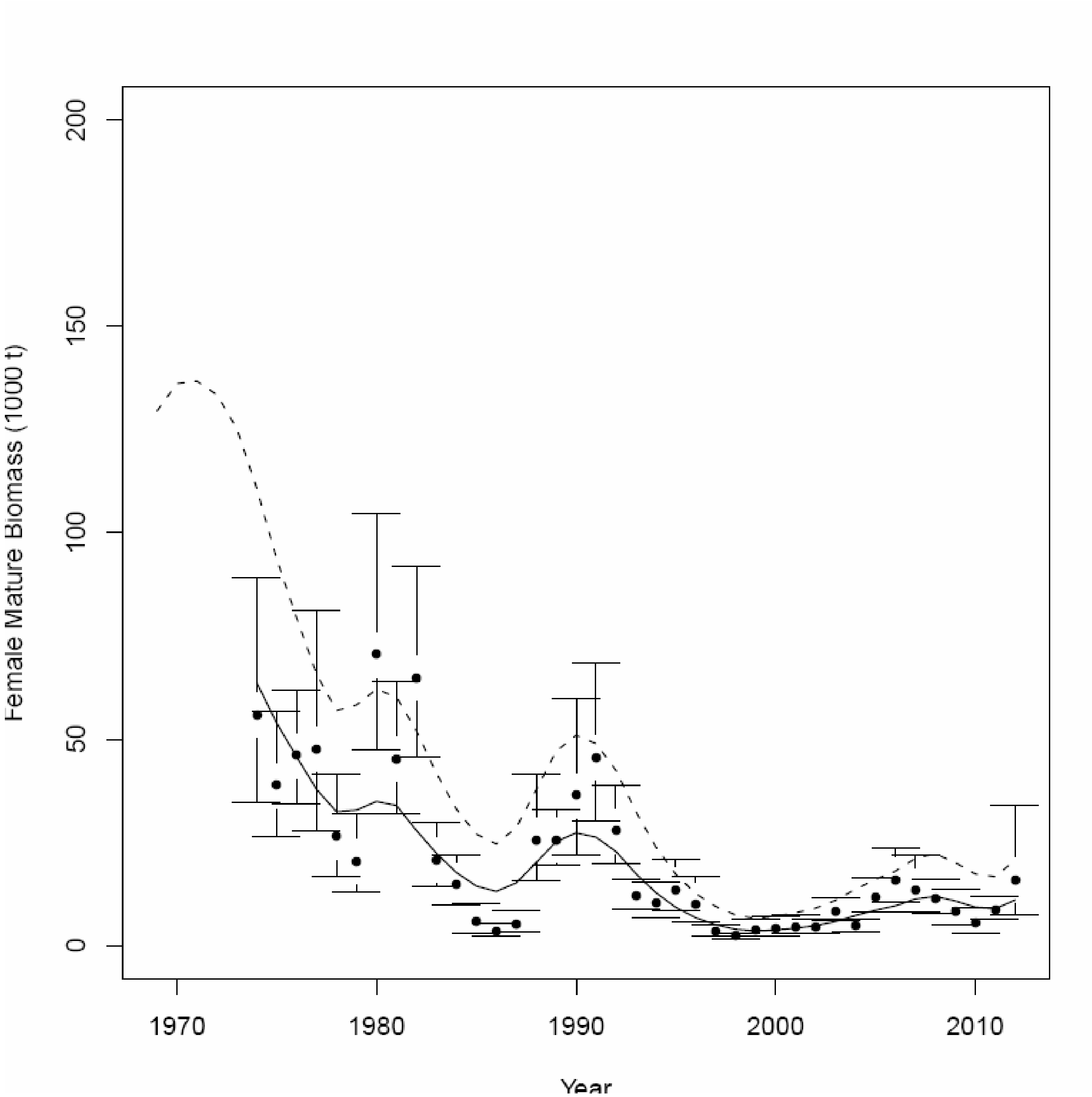


Figure 61. *Model (1)* population female mature biomass (1000 t, dotted line), model estimate of survey female mature biomass (solid line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

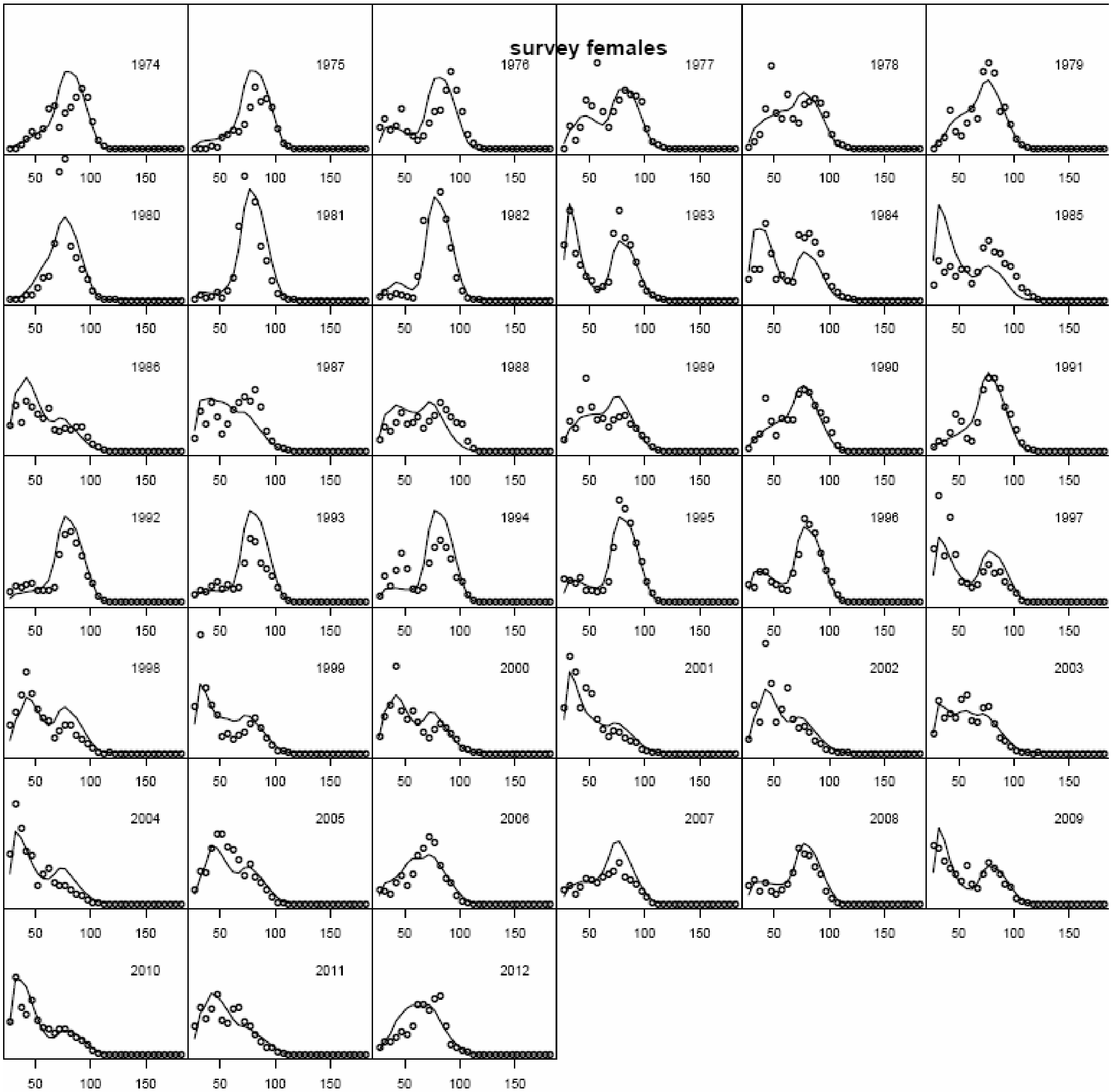


Figure 62. *Model (1)* fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

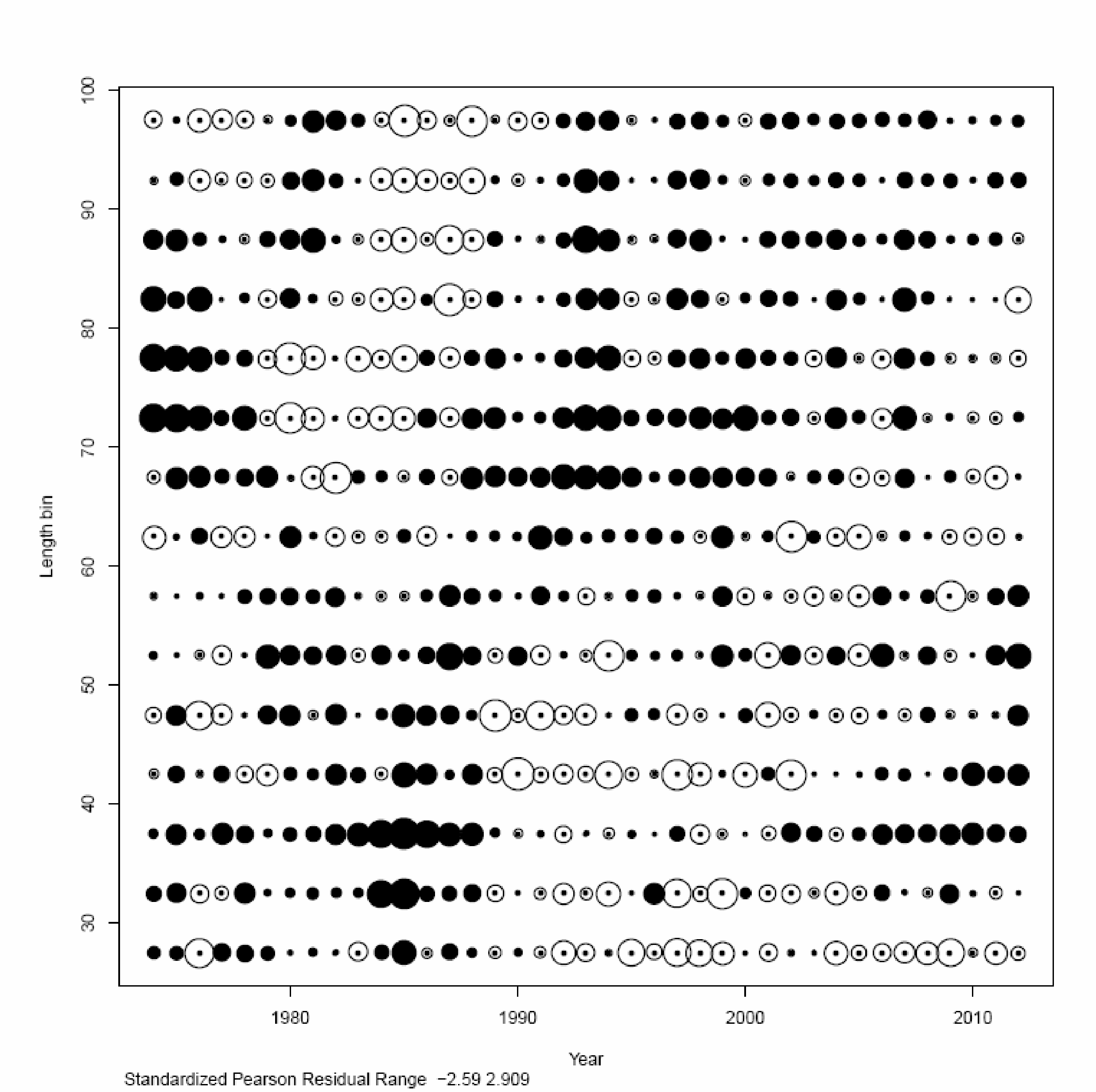


Figure 63. *Model (1)*standardized Pearson residuals of the model fit to the survey female size frequency data. Solid circles= overestimate and open circles=underestimate. Diameter of circle proportional to extent of lack of fit. Residual range shown at bottom.

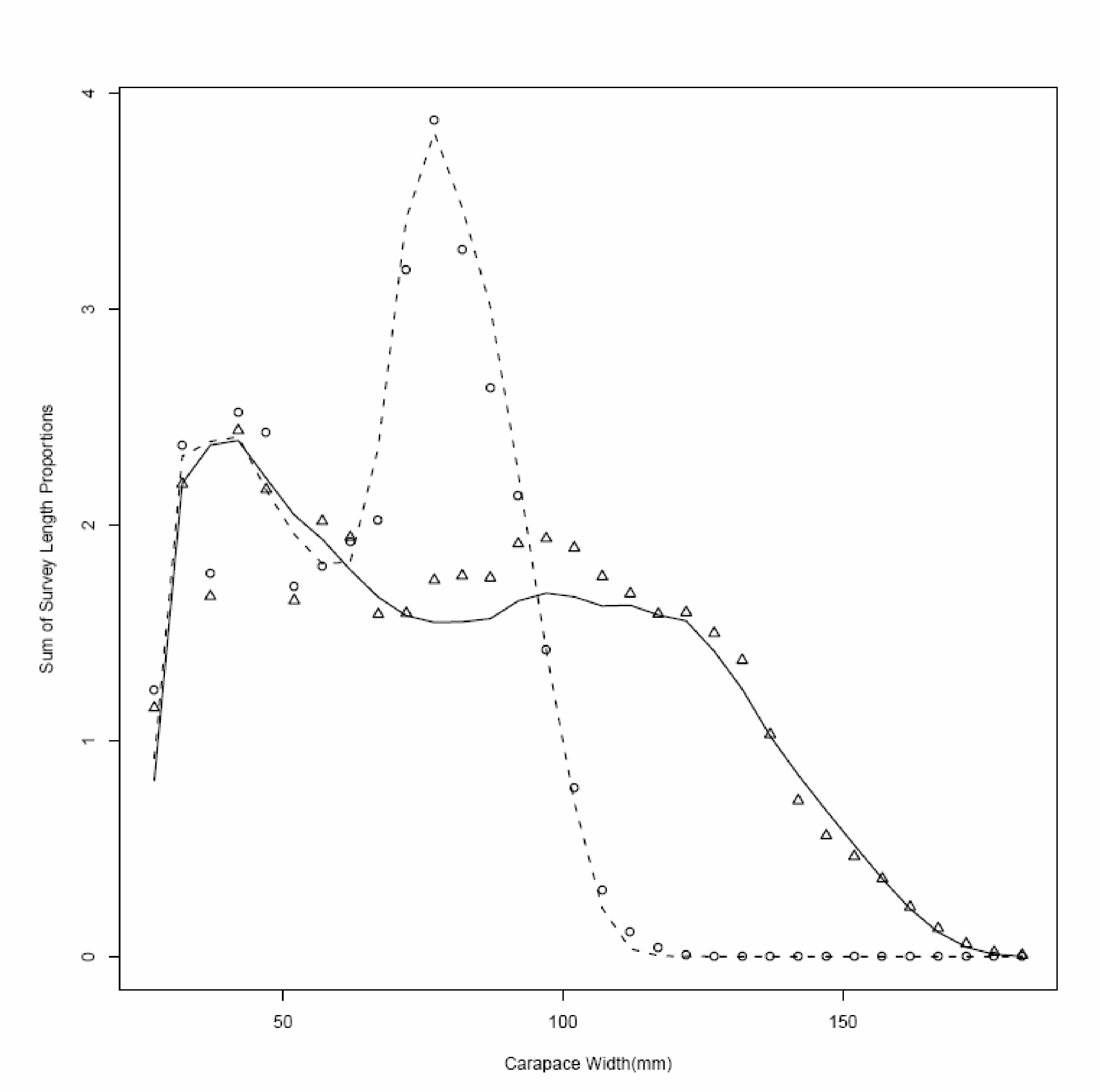


Figure 64. *Model (1)* summary fit to the survey male (solid line) and female (dotted line) size frequency data, all shell conditions combined. Symbols are observed data.

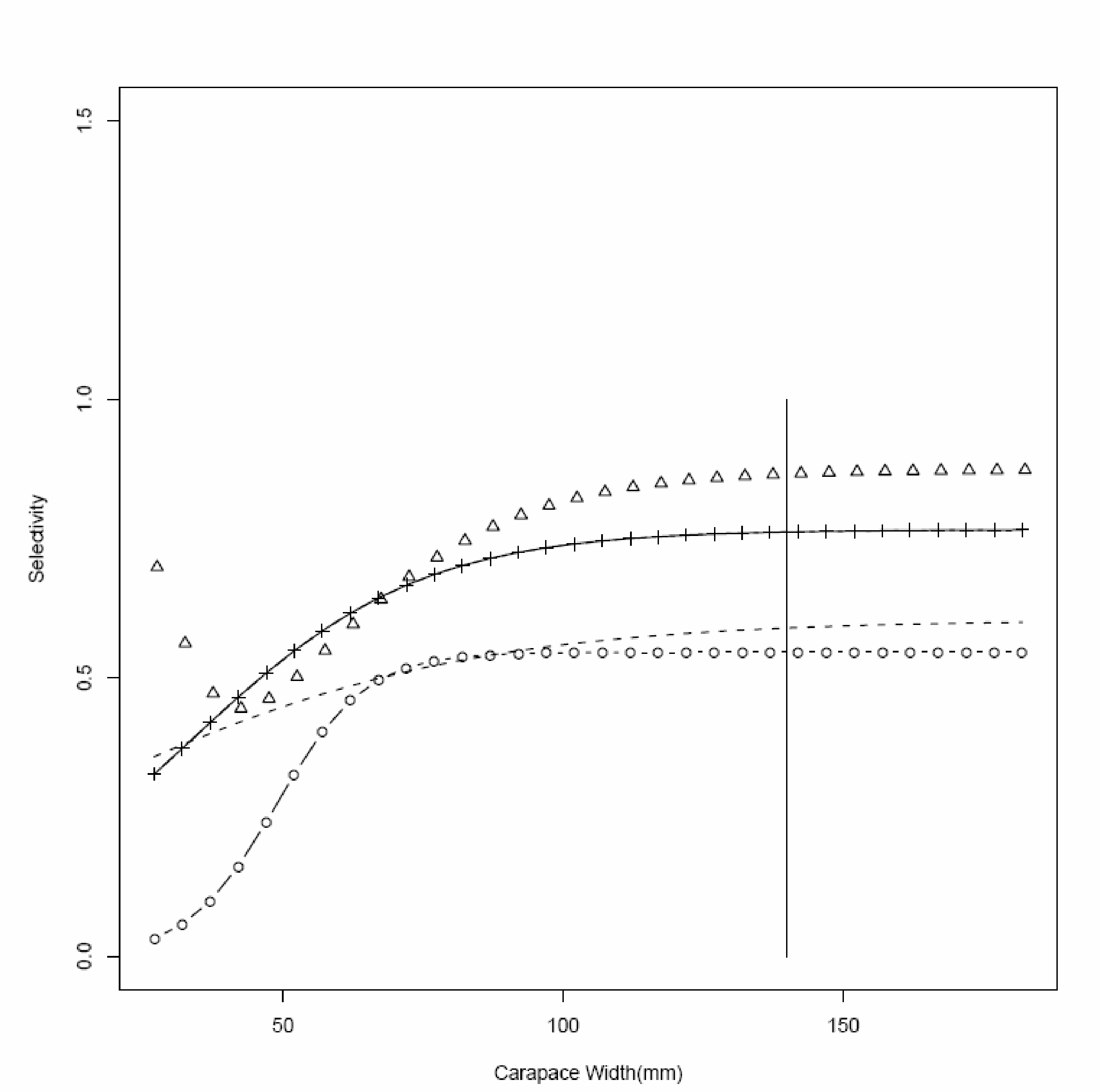


Figure 65. *Model (1)* survey selectivity curves for male Tanner crab estimated for 1974-1981 (dashed line with circles), 1982-2012 (solid line with pluses) with vertical reference line at 140 mm. Survey selectivity estimated by Somerton and Otto (1999) are triangle symbols, and female selectivity for 1982-2012 is dashed line for reference.

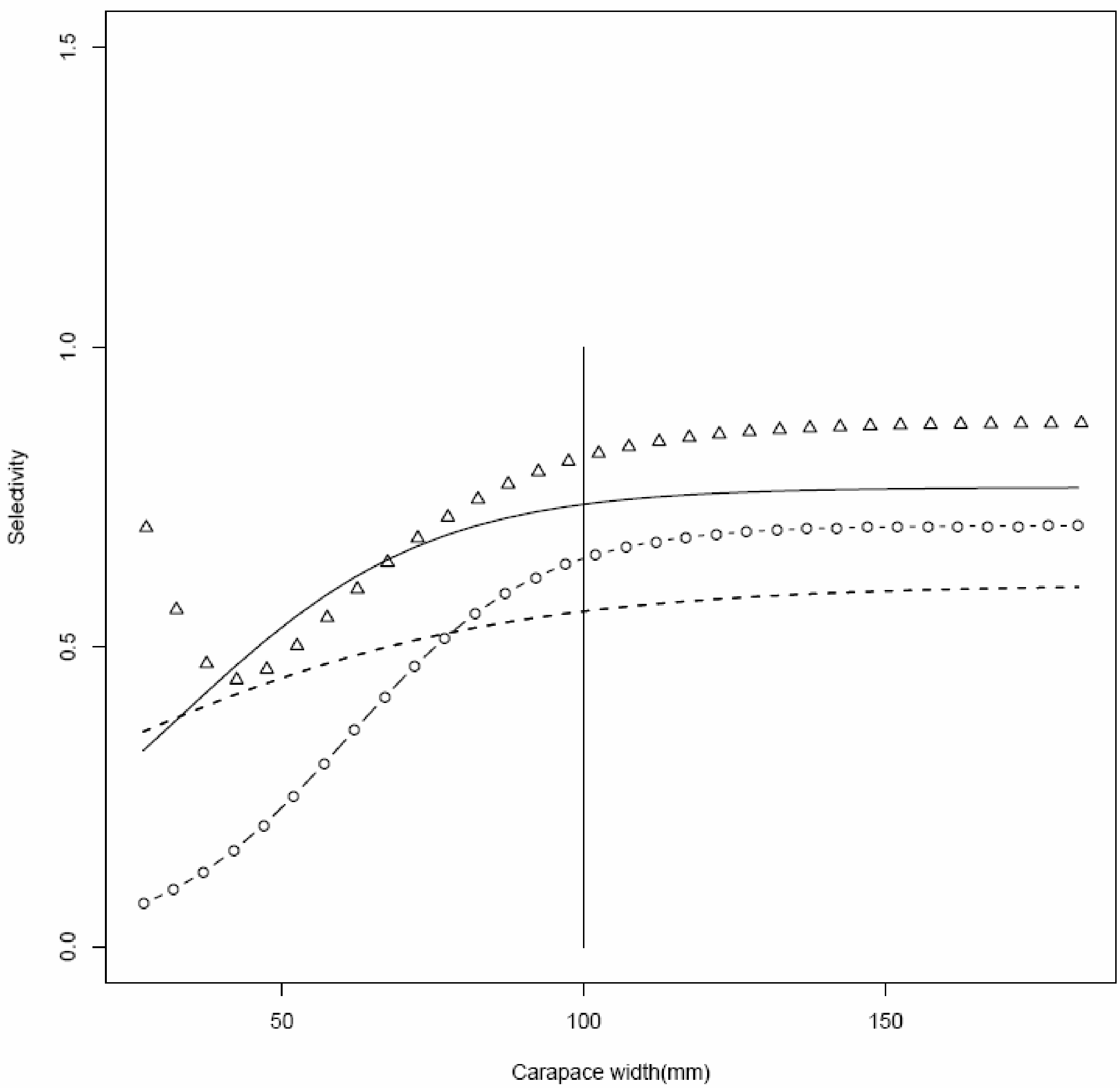


Figure 66. *Model (1)* survey selectivity curves for female Tanner crab estimated for 1974-1981 (dashed line with circles), 1982-2012 (dashed line) with vertical reference line at 100 mm. Survey selectivity estimated by Somerton and Otto (1999) are triangle symbols, and male selectivity for 1982-2012 is upper solid line for reference.

Appendix A. Projections and Rebuilding Analysis

Introduction

In this appendix, we report on results of a rebuilding analysis using output of the *Base Model (0)* and *Model (1)* in a projection modeling framework to perform stock simulations to evaluate the consequences of harvest strategies on stock rebuilding and fishery performance. The specification of the projection model is presented in section in I.11 (Projection Model Structure). The OFL in this analysis is based on the Tier-3 control rule where the proxy F_{MSY} is taken to be $F_{35\%}$ and the proxy B_{MSY} to be $B_{35\%}$ (NPFMC, 2008). The OFL is a total-catch OFL computed as the sum of catches from five sources: (i) retained legal males in directed fishery, (ii) discards in the directed fishery, (iii) bycatch in the snow crab fishery, (iv) bycatch in the Bristol Bay red king crab fishery, and (v) bycatch in the groundfish fisheries.

The following table presents the eight model-mean recruitment combinations potentially eligible for rebuilding analysis and the respective values of $B_{35\%}$, $F_{35\%,}$ 2011/12 MMB at the time of mating, and the percent the 2011/12 MMB at mating is of $B_{35\%}$. Recall, mean period recruitments are: R1=1966-1972; R2=1966-1988; R3=1982-2012; and R4=1966-2012.

Summary Table: Model vs Mean Recruitment Period ($B_{35\%}$ and MMB in 1000 t)					
Mean Recruitment	Model	$B_{35\%}$	$F_{35\%}$	$MMB_{11/12}$	$\%MMB_{11/12}$ / B35%
R1	Model (0)	161.37	0.61	58.59	36.31
	Model (1)	157.48	0.59		37.20
R2	Model (0)	90.14	0.61		65.01
	Model (1)	97.57	0.59		60.05
R3	Model (0)	33.45	0.61		175.18
	Model (1)	35.60	0.59		164.59
R4	Model (0)	56.00	0.61		104.62
	Model (1)	59.55	0.59		98.38

For both *Model (0)* and *Model (1)*, simulations begin with the terminal year biomass form the respective assessment model. Simulations are performed under up to four scenarios: (1) fishing at the full F_{OFL}; (2) fishing at F_{OFL}=0 with only groundfish fishery discard mortality included; (3) fishing at F_{OFL}=0 with all non-directed fishery discard mortality included; and, if required, (4) fishing at a percentage full F_{OFL} that achieves rebuilding within 10 years. The fourth scenario was not run if the stock was shown to rebuild within 10 years under either scenario (1), (2) or (3). Rebuilding simulations were not run for either *Model (0)* or *Model (1)* for cases where R3 and R4 mean recruitment since the stock began the first year of simulation at or in excess of 100% of $B_{35\%}$.

The calculation of the total catch OFL is based on the assumption that F_{OFL} is the fishing mortality rate from the directed fishery for total males, plus the full-selection F for males in the snow crab, Bristol Bay red king crab and groundfish fisheries. The future full-selection retained fishing mortality rate for males in the directed fishery is given by the directed fishery component of the F_{OFL} multiplied by the fishery selectivity for retained males estimated in the assessment model. The future fishing mortality rate on Tanner crab in the snow crab, Bristol Bay red king crab and groundfish trawl fisheries equals the average value over the last five years with their applied fishery selectivity curves estimated in the model. Thus, changes to F_{OFL} directly impact the predicted catches of retained males in the directed fishery as well as the predicted discard of males and females in the directed fishery, while the fishing mortality rates leading to bycatch in the snow, red king crab and groundfish fisheries are constant and independent of $F_{OFL.}$

The new legal minimum size limit in effect for the 2012/13 fisheries is 122 mm to the east of 166^0 W longitude and 112 mm for fisheries to the west. The previously minimum legal size limit was 5.5" (138 mm cw) throughout the Eastern Subdistrict. However, the industry may self-impose retention of crab above 5.5" (138 mm cw) and 5" (127 mm cw) east and west of 166° West longitude, respectively.

Since fishery performance has not been observed under the new size limit regime, we approximated east-west retained fishery selectivity and the catch splits in the modeling framework. Total selectivity is assumed to remain unchanged for both areas since no gear change accompanied the size limit change. Retained selectivity for the eastern and western districts was formulated based on the industry imposed size limits of 138 mm (east) and >127 mm (west). For the eastern fishery, retained selectivity is unchanged. For the western fishery, the retained selectivity curve formulated based on a minimum legal size limit of 138 mm was shifted 10 mm to the proposed 128 mm minimum size limit (Figure A-1). The split in the catch east-west was approximated by the 3-year average proportion of the abundance of crab observed in the 2010 to 2012 surveys east and west of 166^0 W longitude. Figure A-2 presents the mean proportion of male abundance observed in the 2010-2012 NMFS bottom trawl survey east and west of 166^0 W longitude.

Results

Projections using output from the *Model (0)* and *Model (1)* were run under a maximum of four harvest strategy scenarios: (1) fishing at the full F_{OFL}; (2) fishing at F_{OFL}=0 for the directed fishery but with only groundfish fishery discard mortality included; (3) fishing at F_{OFL}=0 for the directed fishery but with all non-directed fishery discard mortality included; (4) fishing at a percentage of the full F_{OFL} that achieves rebuilding within 10 years. The starting year of estimated MMB at mating is 2012/13 (nominal 15 February) which, by procedure, is assessed in September 2013. Years to rebuilding, therefore, are gauged against the starting 2012/13 MMB at mating, and MMB at mating in any tabled year (t) is similarly assessed in the year t+1 September assessment cycle.

Projections using output from *Model (0)* and *Model (1)* were run at up to four harvest strategies against two benchmark $B_{35\%}$ reference points formulated using R1 and R2 mean recruitments. As noted, when either R3 or R4 mean recruitment was used to estimate $B_{35\%}$, the terminal year MMB for either *Model (0)* or *Model (1)* was at or in excess of 100% $B_{35\%}$. Thus, stock rebuilding simulations were not run for *Model (0)* and *Model (1)* under R3 and R4 mean recruitment. The various $B_{35\%}$ values estimated using mean recruitments to the model R1 through R4 are tabled above, as are the percentage of the 2011/12 MMB at mating relative to the respective $B_{35\%}$.

Tables A-1 through A-4 present results of *Model (0)* for mean recruitment R1 fishing at four harvest strategies. Rebuilding is not achieved in 10 years fishing at the full F_{OFL}, $1.0F_{35\%}$ (Table A-1). Fishing at F=0 with only groundfish bycatch mortality (Table A-2), rebuilding is achieved in 2018/19 (6 y). Fishing at F=0 with bycatch mortality from all fisheries (Table A-3), rebuilding is achieved in 2021/22 (9 y). Fishing at a constant 33% of the F_{OFL}, $0.33F_{35\%}$ (Table A-4), rebuilding is achieved in 2022/23 (10 y).

For *Model (0)* using $B_{35\%}$ based on R2 mean recruitments, rebuilding is achieved in 2021/22 (9 y) fishing at the full F_{OFL}, $1.0F_{35\%}$ (Table A-5). Rebuilding is achieved in 2014/15 (2 y) fishing at F=0 with only groundfish bycatch mortality (Table A-6), and in 2017/18 (5 y) fishing at F=0 with bycatch mortality from all fisheries (Table A-7). Since rebuilding is achieved within 10 years fishing at the full F_{OFL}, $1.0F_{35\%}$, no $\%F_{OFL}$ projections are required.

Tables A-8 through A-11 present results of *Model (1)* for mean recruitment R1 fishing at four harvest strategies. Rebuilding is not achieved in 10 years fishing at the full F_{OFL}, $1.0F_{35\%}$ (Table A-8). Fishing at F=0 with only groundfish bycatch mortality (Table A-9), rebuilding is achieved in 2018/19 (6 y). Fishing at F=0 with bycatch mortality from all fisheries (Table A-10), rebuilding is achieved in 2022/23 (9 y). Fishing at a constant 27% of the F_{OFL}, $0.27F_{35\%}$ (Table A-11), rebuilding is achieved in 2022/23 (10 y).

For *Model (1)* using $B_{35\%}$ based on R2 mean recruitments, rebuilding is achieved in 2022/23 (10 y) fishing at the full F_{OFL}, $1.0F_{35\%}$ (Table A-12). Rebuilding is achieved in 2015/16 (3 y) fishing at F=0 with only groundfish bycatch mortality (Table A-13), and in 2018/19 (6 y) fishing at F=0 with bycatch mortality from all fisheries (Table A-14). Since rebuilding is achieved within 10 years fishing at the full F_{OFL}, $1.0F_{35\%}$, no $\%F_{OFL}$ projections are required.

For projections presented here, if actual total or retained fishery selectivity under the new SOA size limit strategy east or west of 166^0 W longitude are different than those approximated in this analysis, $F_{35\%}$ and $B_{35\%}$ will be different and rebuilding trajectories will change. Estimated recruitment to the model have show an increasing trend, however, if recruitment is lower than expected, longer rebuilding times will result.

Table A-1. *Model (0)* fishing at $1.0F_{35\%}$ control rule. R1 $B_{35\%}$ = 161.37, $F_{35\%}$=0.61. Median total catch (ABC_{TOT} 1000 t), median retained catch (C_{DIR} 1000 t), percent mature male biomass at mating relative to $B_{35\%}$, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is the full selection fishing mortality. East-West total catch splits include bycatch from the snow crab, the red king crab or the groundfish fisheries.

Year	ABC_{TOT}	C_{DIR}	%MMB/$B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch (1000 t)			
						East		West	
	(1000 t)					Total	Retain	Total	Retain
2012/13	9.3(8.2,10.4)	2.7(2.2,3.2)	32.2(29.7,34.5)	0	0.14	1.9	1.4	1.6	1.3
2013/14	11.7(9.4,15.4)	3.1(1.7,5.5)	36.1(33,39)	0	0.16	2.3	1.5	2.1	1.5
2014/15	15.4(11.8,20.9)	5(2.5,8.8)	42.9(38.4,46.9)	0	0.21	3.7	2.5	3.3	2.5
2015/16	15.1(11.3,21.1)	5.4(2.7,9.8)	43.6(38.1,48.6)	0	0.21	3.8	2.8	3.3	2.7
2016/17	13.7(9.4,22.2)	4.5(2.2,8.7)	40.7(33.8,51.7)	0	0.19	3.3	2.3	2.8	2.2
2017/18	16.1(8.5,48.7)	4.8(1.9,17.4)	44(31.4,78.2)	0.02	0.22	3.6	2.4	3.3	2.4
2018/19	23(8.9,79.9)	8(2,33.8)	53.8(31,116.5)	0.08	0.28	6.0	4.0	5.6	4.1
2019/20	28.8(8.9,98.2)	10.6(2.1,41.8)	61.7(31.6,141.1)	0.16	0.33	7.8	5.3	7.2	5.4
2020/21	31.1(8.7,100.8)	12.6(2.1,46.4)	65.1(31.4,147.4)	0.22	0.35	9.3	6.3	8.4	6.4
2021/22	32(8.5,104.8)	12.5(2.2,47.2)	66.9(30.4,147.2)	0.25	0.35	9.2	6.2	8.4	6.3
2022/23	34(8.7,106)	13.3(2.2,44.1)	67.6(30.5,154.5)	0.29	0.36	9.8	6.6	8.9	6.8
2023/24	33.5(8.8,112.8)	12.8(2,50.1)	67.5(32,162.2)	0.34	0.36	9.6	6.3	8.9	6.6

Table A-2. *Model (0)* fishing at F=0. R1 $B_{35\%}$ = 161.37, $F_{35\%}$=0.61. Median total catch (ABC_{TOT} 1000 t), median retained catch (C_{DIR} 1000 t), percent mature male biomass at mating relative to $B_{35\%}$, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is the full selection fishing mortality. East-West total catch splits include groundfish bycatch only.

Year	ABC_{TOT}	C_{DIR}	$\%MMB/B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch (1000 t)			
						East		East	
	(1000 t)					Total	Retain	Total	Retain
2012/13	0.1(0.1,0.1)	0(0,0)	36.6(33.5,39.5)	0	0	0	0	0	0
2013/14	0.2(0.2,0.3)	0(0,0)	45.7(42,49.4)	0	0	0	0	0	0
2014/15	0.3(0.3,0.3)	0(0,0)	59.6(54.7,64.4)	0	0	0	0	0	0
2015/16	0.2(0.2,0.4)	0(0,0)	66.8(61.4,72.9)	0	0	0	0	0	0
2016/17	0.3(0.1,0.8)	0(0,0)	70.6(61.1,97)	0.04	0	0	0	0	0
2017/18	0.5(0.2,1.6)	0(0,0)	91.1(61.6,190)	0.39	0	0	0	0	0
2018/19	0.7(0.2,2)	0(0,0)	125.6(67,314.9)	0.69	0	0	0	0	0
2019/20	0.7(0.2,2.1)	0(0,0)	158.5(72.7,408.5)	0.81	0	0	0	0	0
2020/21	0.6(0.2,1.9)	0(0,0)	177.6(76.7,475.6)	0.86	0	0	0	0	0
2021/22	0.6(0.2,2)	0(0,0)	195.1(78.1,495.1)	0.89	0	0	0	0	0
2022/23	0.6(0.2,2)	0(0,0)	215.5(82.7,543.8)	0.92	0	0	0	0	0
2023/24	0.6(0.2,2.4)	0(0,0)	227.6(87,606.6)	0.94	0	0	0	0	0

Table A-3. *Model (0)* fishing at F=0. R1 $B_{35\%}$ = 161.37, $F_{35\%}$=0.61. Median total catch (ABC_{TOT} 1000 t), median retained catch (C_{DIR} 1000 t), percent mature male biomass at mating relative to $B_{35\%}$, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is the full selection fishing mortality. East-West total catch splits include bycatch from the snow crab, the red king crab or the groundfish fisheries.

Year	ABC_{TOT}	C_{DIR}	$\%MMB/B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch (1000 t)			
						East		West	
	(1000 t)					Total	Retain	Total	Retain
2012/13	5.5(5,5.9)	0(0,0)	34.3(31.5,37.1)	0	0	0	0	0	0
2013/14	7.2(6.6,7.8)	0(0,0)	40.5(37.1,43.7)	0	0	0	0	0	0
2014/15	8.5(7.8,9.1)	0(0,0)	50.7(46.5,54.7)	0	0	0	0	0	0
2015/16	8(7.3,8.9)	0(0,0)	54.3(49.9,58.8)	0	0	0	0	0	0
2016/17	7.7(6.3,12)	0(0,0)	52.4(46.9,64.7)	0.002	0	0	0	0	0
2017/18	9.6(5.9,21.4)	0(0,0)	57.2(42.7,102.1)	0.06	0	0	0	0	0
2018/19	12.1(6,31.1)	0(0,0)	70.1(41.9,158.8)	0.23	0	0	0	0	0
2019/20	14(6.1,37.7)	0(0,0)	86.3(42.8,208.9)	0.38	0	0	0	0	0
2020/21	15.1(5.9,39)	0(0,0)	94.8(42.8,245.9)	0.48	0	0	0	0	0
2021/22	16.4(6,41)	0(0,0)	105(41.9,254.2)	0.56	0	0	0	0	0
2022/23	17.3(6.2,45.4)	0(0,0)	114.6(44.4,283.1)	0.63	0	0	0	0	0
2023/24	18(6.8,51.4)	0(0,0)	121.2(46.7,312)	0.68	0	0	0	0	0

Table A-4. *Model (0)* fishing at $0.33F_{35\%}$ control rule. R1 $B_{35\%}$ = 161.37, $F_{35\%}$=0.61. Median total catch (ABC_{TOT} 1000 t), median retained catch (C_{DIR} 1000 t), percent mature male biomass at mating relative to $B_{35\%}$, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is the full selection fishing mortality. East-West total catch splits include bycatch from the snow crab, the red king crab or the groundfish fisheries.

Year	ABC_{TOT}	C_{DIR}	%MMB/$B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch (1000 t)			
						East		West	
	(1000 t)					Total	Retain	Total	Retain
2012/13	6.9(6.2,7.6)	0.8(0.7,1)	33.6(30.9,36.1)	0	0.04	0.6	0.4	0.5	0.4
2013/14	9.1(7.9,10.7)	1.1(0.5,2.1)	38.9(35.7,41.9)	0	0.05	0.8	0.6	0.7	0.5
2014/15	11.3(9.6,14.2)	2(0.9,3.9)	47.5(43.6,51.3)	0	0.07	1.4	1.0	1.3	1.0
2015/16	11.3(9.2,14.6)	2.3(1,4.7)	49.9(45.5,54.1)	0	0.08	1.6	1.2	1.4	1.1
2016/17	10.7(8,16.9)	2.1(0.9,4.3)	47.1(41.2,58.6)	0.001	0.07	1.5	1.1	1.2	1
2017/18	12.9(7.4,34.8)	2.3(0.8,8.5)	51.4(37.6,90.9)	0.04	0.08	1.7	1.2	1.5	1.1
2018/19	17.4(7.6,50.5)	3.8(0.9,14.2)	63(36.5,140.5)	0.16	0.11	2.8	1.9	2.5	1.9
2019/20	21.5(7.7,62.9)	5.3(1,19.2)	74.3(37.5,179.7)	0.29	0.13	3.9	2.7	3.4	2.6
2020/21	23.7(7.3,68.3)	6.7(1,22.2)	81(37.5,202)	0.37	0.14	4.8	3.4	4.2	3.3
2021/22	25.9(7.5,70.9)	7.2(1,24.3)	85.6(36.8,207)	0.44	0.14	5.2	3.7	4.5	3.5
2022/23	28.4(7.7,77.6)	8.2(1,23.3)	90.7(37.9,224.2)	0.51	0.15	5.9	4.1	5.2	4.0
2023/24	28.9(8.1,82.5)	8.6(1.1,26)	93.1(39.2,241.8)	0.56	0.15	6.2	4.4	5.4	4.3

Table A-5. *Model (0)* fishing at $1.0F_{35\%}$ control rule. R2 $B_{35\%}$ = 90.14, $F_{35\%}$=0.61. Median total catch (ABC_{TOT} 1000 t), median retained catch (C_{DIR} 1000 t), percent mature male biomass at mating relative to $B_{35\%}$, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is the full selection fishing mortality. East-West total catch splits include bycatch from the snow crab, the red king crab or the groundfish fisheries.

Year	ABC_{TOT}	C_{DIR}	$\%MMB/B_{35\%}$	$P[MMB>B_{35\%}]$	Full-Select F	Directed Fishery Catch (1000 t)			
						East		West	
	(1000 t)					Total	Retain	Total	Retain
2012/13	12.7(11.1,14.3)	5.2(4.4,6.1)	54(50.1,57.6)	0	0.29	3.7	2.7	3.2	2.5
2013/14	14.8(11.5,20)	5.2(3.1,8.5)	58.5(52.6,63.6)	0	0.31	3.9	2.6	3.7	2.7
2014/15	19.1(14.1,26.3)	7.6(4.3,12.2)	67.8(58.6,75.7)	0	0.38	5.7	3.7	5.3	3.9
2015/16	18.1(13.4,25.5)	7.8(4.5,12.7)	67.4(56.1,77.5)	0	0.36	5.6	3.9	5	3.9
2016/17	15.9(10.8,24.8)	6.3(3.4,10.7)	61.9(49.5,80.9)	0.01	0.33	4.6	3.2	4.1	3.1
2017/18	18.5(9.5,47.9)	6.5(2.8,17.1)	67.6(47.2,120.3)	0.12	0.37	5	3.2	4.7	3.4
2018/19	25.8(10.1,69.7)	10.4(3.1,28.7)	80.6(46.9,175.9)	0.30	0.45	7.9	5.0	7.4	5.4
2019/20	30.2(10,82.3)	12.5(3.2,35)	89.2(47.2,211.2)	0.43	0.49	9.4	6.2	8.9	6.5
2020/21	31.4(9.1,82)	13.7(3,38.4)	92(45.7,213.9)	0.49	0.49	10.4	6.7	9.7	7.2
2021/22	30.8(8.7,82.8)	12.9(2.8,37.8)	92.3(43.6,209.5)	0.54	0.48	9.7	6.3	9.1	6.7
2022/23	31.8(8.5,80.2)	13.1(2.7,33.6)	90.7(43.5,214)	0.59	0.48	9.9	6.4	9.4	6.8
2023/24	29.4(8.2,82.9)	12.3(2.4,37)	88.9(43.8,215)	0.62	0.47	9.3	6.0	8.7	6.4

Table A-6. *Model (0)* fishing at F=0. R2 $B_{35\%}$ = 90.14, $F_{35\%}$=0.61. Median total catch (ABC_{TOT} 1000 t), median retained catch (C_{DIR} 1000 t), percent mature male biomass at mating relative to $B_{35\%}$, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is the full selection fishing mortality. East-West total catch splits include groundfish bycatch only.

Year	ABC_{TOT}	C_{DIR}	%MMB/$B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch (1000 t)			
						East		East	
	(1000 t)					Total	Retain	Total	Retain
2012/13	0.1(0.1,0.1)	0(0,0)	65.5(60.1,70.7)	0	0	0	0	0	0
2013/14	0.2(0.2,0.3)	0(0,0)	81.9(75.1,88.4)	0	0	0	0	0	0
2014/15	0.3(0.3,0.3)	0(0,0)	106.7(97.8,115.2)	0.91	0	0	0	0	0
2015/16	0.2(0.2,0.3)	0(0,0)	119(109.4,129.2)	1.0	0	0	0	0	0
2016/17	0.3(0.1,0.6)	0(0,0)	122.2(108.4,154.6)	1.0	0	0	0	0	0
2017/18	0.4(0.2,1.1)	0(0,0)	146.6(107,263.9)	1.0	0	0	0	0	0
2018/19	0.5(0.2,1.4)	0(0,0)	188.5(111.8,409.1)	1.0	0	0	0	0	0
2019/20	0.5(0.2,1.4)	0(0,0)	224.8(117.1,517.7)	1.0	0	0	0	0	0
2020/21	0.5(0.1,1.3)	0(0,0)	245.7(119.8,576.5)	1.0	0	0	0	0	0
2021/22	0.5(0.1,1.3)	0(0,0)	264.6(119.3,604.3)	1.0	0	0	0	0	0
2022/23	0.4(0.1,1.3)	0(0,0)	286.3(123,637.7)	1.0	0	0	0	0	0
2023/24	0.4(0.2,1.4)	0(0,0)	294(125.7,690)	1.0	0	0	0	0	0

Table A-7. *Model (0)* fishing at F=0. R2 $B_{35\%}$ = 90.14, $F_{35\%}$=0.61. Median total catch (ABC_{TOT} 1000 t), median retained catch (C_{DIR} 1000 t), percent mature male biomass at mating relative to $B_{35\%}$, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is the full selection fishing mortality. East-West total catch splits include bycatch from the snow crab, the red king crab or the groundfish fisheries.

Year	ABC_{TOT}	C_{DIR}	%MMB/$B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch (1000 t)			
						East		West	
	(1000 t)					Total	Retain	Total	Retain
2012/13	5.5(5,5.9)	0(0,0)	61.5(56.4,66.4)	0	0	0	0	0	0
2013/14	7.2(6.6,7.8)	0(0,0)	72.5(66.5,78.3)	0	0	0	0	0	0
2014/15	8.5(7.8,9.1)	0(0,0)	90.7(83.2,97.9)	0.02	0	0	0	0	0
2015/16	8(7.3,8.8)	0(0,0)	97.2(89.3,105)	0.29	0	0	0	0	0
2016/17	7.7(6.3,11.5)	0(0,0)	93.7(84.2,113.9)	0.39	0	0	0	0	0
2017/18	9.5(6,19.8)	0(0,0)	102(77,174.5)	0.63	0	0	0	0	0
2018/19	11.4(6.1,27.5)	0(0,0)	122.9(75.6,258.2)	0.78	0	0	0	0	0
2019/20	12.8(5.9,31.7)	0(0,0)	144.7(75.9,328.1)	0.84	0	0	0	0	0
2020/21	13.5(5.7,32.2)	0(0,0)	155.2(74.8,369.6)	0.89	0	0	0	0	0
2021/22	14.4(5.7,33.6)	0(0,0)	166.9(73,381.3)	0.91	0	0	0	0	0
2022/23	14.8(5.7,36.3)	0(0,0)	179.5(75.1,412.2)	0.93	0	0	0	0	0
2023/24	15.2(6.2,39.8)	0(0,0)	185.8(77.3,445.4)	0.94	0	0	0	0	0

Table A-8. *Model (1)* fishing at 1.0$F_{35\%}$ control rule. R1 $B_{35\%}$ = 157.48, $F_{35\%}$=0.59. Median total catch (ABC_{TOT} 1000 t), median retained catch (C_{DIR} 1000 t), percent mature male biomass at mating relative to $B_{35\%}$, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is the full selection fishing mortality. East-West total catch splits include bycatch from the snow crab, the red king crab or the groundfish fisheries.

Year	ABC_{TOT}	C_{DIR}	%MMB/$B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch (1000 t)			
						East		West	
	(1000 t)					Total	Retain	Total	Retain
2012/13	9.1(8,10.2)	2.5(2,3)	32(29.6,34.3)	0.00	0.13	1.8	1.3	1.5	1.2
2013/14	12(9.6,15.6)	3.1(1.7,5.5)	36.7(33.5,39.7)	0.00	0.16	2.3	1.5	2.1	1.5
2014/15	16(12.2,21.6)	5.2(2.6,9.1)	44.3(39.7,48.5)	0.00	0.21	3.8	2.6	3.4	2.6
2015/16	15.7(11.8,21.9)	5.7(2.9,10.2)	45.3(39.5,50.6)	0.00	0.21	4.0	2.9	3.5	2.8
2016/17	14(9.8,21.6)	4.7(2.3,8.7)	41.9(34.9,51.9)	0.00	0.19	3.3	2.4	2.9	2.3
2017/18	15.9(8.7,43.8)	4.9(1.9,15.7)	44.3(32.3,75)	0.01	0.21	3.6	2.4	3.2	2.4
2018/19	21.8(8.9,72.5)	7.6(2,30.5)	53(31.8,108.7)	0.07	0.26	5.6	3.8	5.1	3.8
2019/20	26.8(9.1,89)	9.9(2.1,38)	60(32.3,130.2)	0.13	0.31	7.2	5.0	6.5	5.0
2020/21	29(8.7,89.8)	11.5(2.2,41.9)	63.8(31.9,134.6)	0.19	0.33	8.5	5.8	7.6	5.8
2021/22	30.2(8.5,94.9)	11.7(2.2,43.4)	65.9(30.9,137.9)	0.22	0.33	8.5	5.9	7.7	5.9
2022/23	32.7(8.9,97.7)	12.7(2.3,40.6)	67.1(31.5,144)	0.26	0.34	9.3	6.3	8.3	6.3
2023/24	32.4(9.2,105.8)	12.6(2.1,45.9)	67.8(33.2,154.8)	0.32	0.35	9.3	6.2	8.4	6.4

Table A-9. *Model (1)* fishing at F=0. R1 $B_{35\%}$ = 157.48, $F_{35\%}$=0.59. Median total catch (ABC_{TOT} 1000 t), median retained catch (C_{DIR} 1000 t), percent mature male biomass at mating relative to $B_{35\%}$, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is the full selection fishing mortality. East-West total catch splits include groundfish bycatch only.

Year	ABC_{TOT} (1000 t)	C_{DIR}	$\%MMB/B_{35\%}$	$P[MMB>B_{35\%}]$	Full-Select F	Directed Fishery Catch (1000 t) East Total	East Retain	East Total	East Retain
2012/13	0.1(0.1,0.2)	0(0,0)	36.4(31.7,41.1)	0.00	0	0	0	0	0
2013/14	0.3(0.2,0.3)	0(0,0)	46.5(40.5,52.6)	0.00	0	0	0	0	0
2014/15	0.3(0.3,0.3)	0(0,0)	61.8(53.7,69.7)	0.00	0	0	0	0	0
2015/16	0.3(0.2,0.4)	0(0,0)	69.7(60.8,78.8)	0.00	0	0	0	0	0
2016/17	0.3(0.2,0.8)	0(0,0)	73.1(62.1,96.6)	0.04	0	0	0	0	0
2017/18	0.5(0.2,1.5)	0(0,0)	91.4(62.9,177.8)	0.38	0	0	0	0	0
2018/19	0.7(0.2,1.9)	0(0,0)	122.1(67.6,284.6)	0.68	0	0	0	0	0
2019/20	0.7(0.2,1.9)	0(0,0)	152(73.2,368.6)	0.79	0	0	0	0	0
2020/21	0.6(0.2,1.8)	0(0,0)	170.4(76.4,429.6)	0.86	0	0	0	0	0
2021/22	0.6(0.2,1.9)	0(0,0)	187.1(77.9,449.1)	0.90	0	0	0	0	0
2022/23	0.7(0.2,2)	0(0,0)	208.3(82.4,499.3)	0.92	0	0	0	0	0
2023/24	0.7(0.2,2.3)	0(0,0)	222.4(87.9,561.6)	0.95	0	0	0	0	0

Table A-10. *Model (1)* fishing at F=0. R1 $B_{35\%}$ = 157.48, $F_{35\%}$=0.59. Median total catch (ABC_{TOT} 1000 t), median retained catch (C_{DIR} 1000 t), percent mature male biomass at mating relative to $B_{35\%}$, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is the full selection fishing mortality. East-West total catch splits include bycatch from the snow crab, the red king crab or the groundfish fisheries.

Year	ABC_{TOT}	C_{DIR}	$\%MMB/B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch (1000 t)			
						East		West	
	(1000 t)					Total	Retain	Total	Retain
2012/13	5.5(4.8,6.2)	0(0,0)	34.2(29.7,38.6)	0.00	0	0	0	0	0
2013/14	7.5(6.5,8.4)	0(0,0)	41.1(35.8,46.5)	0.00	0	0	0	0	0
2014/15	8.8(7.7,9.9)	0(0,0)	52.4(45.6,59.2)	0.00	0	0	0	0	0
2015/16	8.3(7.3,9.5)	0(0,0)	56.5(49.3,63.8)	0.00	0	0	0	0	0
2016/17	7.9(6.4,11.8)	0(0,0)	54.6(46.9,66.1)	0.00	0	0	0	0	0
2017/18	9.6(6,20)	0(0,0)	58.1(43.9,97.5)	0.04	0	0	0	0	0
2018/19	11.8(6.2,28.2)	0(0,0)	69.7(42.8,145.8)	0.21	0	0	0	0	0
2019/20	13.4(6.1,34.6)	0(0,0)	83.9(43.7,190.4)	0.36	0	0	0	0	0
2020/21	14.6(6,35.3)	0(0,0)	92.4(43.6,226.8)	0.45	0	0	0	0	0
2021/22	15.9(6.1,38.1)	0(0,0)	102(43.2,235.2)	0.54	0	0	0	0	0
2022/23	17(6.4,42)	0(0,0)	112(45.3,263.4)	0.61	0	0	0	0	0
2023/24	17.9(7.1,48.9)	0(0,0)	119.8(47.9,290.3)	0.67	0	0	0	0	0

Table A-11. *Model (1)* fishing at $0.27F_{35\%}$ control rule. R1 $B_{35\%}$ = 157.48, $F_{35\%}$=0.59. Median total catch (ABC_{TOT} 1000 t), median retained catch (C_{DIR} 1000 t), percent mature male biomass at mating relative to $B_{35\%}$, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is the full selection fishing mortality. East-West total catch splits include bycatch from the snow crab, the red king crab or the groundfish fisheries.

Year	ABC_{TOT}	C_{DIR}	$\%MMB/B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch (1000 t)			
						East		West	
	(1000 t)					Total	Retain	Total	Retain
2012/13	6.6(6,7.3)	0.6(0.5,0.8)	33.5(30.8,36.1)	0.00	0.03	0.4	0.3	0.4	0.3
2013/14	9(7.9,10.4)	0.9(0.4,1.7)	39.8(36.6,42.9)	0.00	0.04	0.6	0.4	0.6	0.4
2014/15	11.3(9.7,13.7)	1.7(0.7,3.3)	49.7(45.6,53.5)	0.00	0.06	1.2	0.8	1.1	0.8
2015/16	11.2(9.3,14.2)	2(0.9,4.1)	52.6(48.3,57)	0.00	0.06	1.4	1.1	1.2	1.0
2016/17	10.6(8,15.8)	1.8(0.8,3.8)	49.6(43.8,59.8)	0.00	0.06	1.2	0.9	1.0	0.8
2017/18	12.2(7.4,30.1)	1.9(0.7,6.6)	52.7(39.8,88.2)	0.03	0.06	1.4	1.0	1.2	0.9
2018/19	15.9(7.5,43)	3(0.7,10.7)	63.2(38.5,132.7)	0.15	0.08	2.2	1.5	1.9	1.5
2019/20	19.4(7.5,53.1)	4.2(0.8,14.5)	74.2(39,168.3)	0.28	0.10	3.0	2.1	2.6	2.0
2020/21	21.4(7.2,57.4)	5.3(0.8,16.7)	81.1(39.2,189.2)	0.36	0.11	3.7	2.7	3.2	2.5
2021/22	23.6(7.4,60)	5.8(0.8,18.3)	86.3(38.5,199.7)	0.43	0.11	4.1	3.0	3.5	2.8
2022/23	26.1(7.7,67.1)	6.7(0.9,18)	92.1(40,215.9)	0.51	0.12	4.8	3.4	4.1	3.2
2023/24	26.9(8.3,73.6)	7.2(0.9,20.3)	96.3(41.6,237.4)	0.57	0.12	5.2	3.7	4.5	3.5

Table A-12. *Model (1)* fishing at $1.0F_{35\%}$ control rule. R2 $B_{35\%}$ = 97.57, $F_{35\%}$=0.59. Median total catch (ABC_{TOT} 1000 t), median retained catch (C_{DIR} 1000 t), percent mature male biomass at mating relative to $B_{35\%}$, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is the full selection fishing mortality. East-West total catch splits include bycatch from the snow crab, the red king crab or the groundfish fisheries.

Year	ABC_{TOT}	C_{DIR}	%MMB/$B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch (1000 t)			
						East		West	
	(1000 t)					Total	Retain	Total	Retain
2012/13	11.7(10.2,13.2)	4.4(3.7,5.2)	49.2(45.6,52.6)	0.00	0.25	3.2	2.3	2.7	2.1
2013/14	14.4(11.3,19.3)	4.8(2.9,8)	54.8(49.5,59.5)	0.00	0.27	3.6	2.4	3.3	2.4
2014/15	19.1(14.2,26.2)	7.4(4.1,12.1)	64.8(56.4,72.1)	0.00	0.34	5.5	3.7	5.1	3.8
2015/16	18.3(13.6,25.5)	7.8(4.5,12.8)	65(54.6,74.4)	0.00	0.33	5.6	3.9	4.9	3.9
2016/17	15.9(10.9,24.6)	6.2(3.3,10.6)	59.4(47.9,75.2)	0.00	0.30	4.5	3.2	3.9	3.0
2017/18	18(9.5,46.4)	6.3(2.8,16.9)	63.4(45.1,107.4)	0.07	0.33	4.7	3.1	4.4	3.2
2018/19	24.5(9.8,65.4)	9.6(2.9,27.4)	74.4(44.6,156)	0.23	0.40	7.3	4.7	6.7	4.9
2019/20	28.5(9.9,77.4)	11.6(3,33)	81.9(44.7,181.4)	0.36	0.44	8.7	5.7	8.0	5.9
2020/21	29.6(9.1,78.9)	12.8(2.9,36.1)	85.1(43.3,188.5)	0.43	0.45	9.4	6.3	8.7	6.5
2021/22	29.6(8.7,80.1)	12.3(2.7,36.4)	86.2(41.4,187.5)	0.47	0.44	9.2	6.1	8.4	6.3
2022/23	30.9(8.6,78.6)	12.7(2.7,33.5)	85.8(41.8,192.5)	0.53	0.44	9.5	6.3	8.7	6.5
2023/24	29.6(8.5,82.5)	12.3(2.4,37.7)	85(42.4,198)	0.58	0.44	9.1	6.0	8.5	6.3

Table A-13. *Model (1)* fishing at F=0. R2 $B_{35\%}$ = 97.57, $F_{35\%}$=0.59. Median total catch (ABC_{TOT} 1000 t), median retained catch (C_{DIR} 1000 t), percent mature male biomass at mating relative to $B_{35\%}$, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is the full selection fishing mortality. East-West total catch splits include groundfish bycatch only.

Year	ABC_{TOT}	C_{DIR}	%MMB/$B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch (1000 t)			
						East		East	
	(1000 t)					Total	Retain	Total	Retain
2012/13	0.1(0.1,0.2)	0(0,0)	58.7(53.9,63.4)	0.00	0	0	0	0	0
2013/14	0.3(0.2,0.3)	0(0,0)	75.1(68.9,81)	0.00	0	0	0	0	0
2014/15	0.3(0.3,0.3)	0(0,0)	99.6(91.3,107.5)	0.47	0	0	0	0	0
2015/16	0.3(0.2,0.4)	0(0,0)	111.9(102.9,121.2)	0.98	0	0	0	0	0
2016/17	0.3(0.2,0.6)	0(0,0)	115(102.2,144.1)	0.99	0	0	0	0	0
2017/18	0.4(0.2,1.1)	0(0,0)	137.1(100.8,243.2)	1.00	0	0	0	0	0
2018/19	0.5(0.2,1.4)	0(0,0)	174.8(105.1,373.6)	1.00	0	0	0	0	0
2019/20	0.5(0.2,1.4)	0(0,0)	208.4(109.6,465)	1.00	0	0	0	0	0
2020/21	0.5(0.2,1.3)	0(0,0)	228.2(112.6,522.6)	1.00	0	0	0	0	0
2021/22	0.5(0.2,1.4)	0(0,0)	246.4(111.9,549.9)	1.00	0	0	0	0	0
2022/23	0.5(0.2,1.4)	0(0,0)	267.8(116.2,592.7)	1.00	0	0	0	0	0
2023/24	0.5(0.2,1.6)	0(0,0)	278.4(120,656.3)	1.00	0	0	0	0	0

Table A-14. *Model (1)* fishing at F=0. R2 $B_{35\%}$ = 97.57, $F_{35\%}$=0.59. Median total catch (ABC_{TOT} 1000 t), median retained catch (C_{DIR} 1000 t), percent mature male biomass at mating relative to $B_{35\%}$, probability of rebuilding in 1 year. Values in parentheses are 90% CI. F is the full selection fishing mortality. East-West total catch splits include bycatch from the snow crab, the red king crab or the groundfish fisheries.

Year	ABC_{TOT}	C_{DIR}	%MMB/$B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch (1000 t)			
						East		West	
	(1000 t)					Total	Retain	Total	Retain
2012/13	5.5(5.1,6)	0(0,0)	55.1(50.5,59.5)	0.00	0	0	0	0	0
2013/14	7.5(6.8,8.1)	0(0,0)	66.4(60.9,71.6)	0.00	0	0	0	0	0
2014/15	8.8(8.1,9.5)	0(0,0)	84.5(77.5,91.2)	0.00	0	0	0	0	0
2015/16	8.3(7.6,9.1)	0(0,0)	91.3(83.8,98.5)	0.03	0	0	0	0	0
2016/17	7.9(6.5,11.6)	0(0,0)	87.8(78.9,104.8)	0.11	0	0	0	0	0
2017/18	9.6(6.1,19.3)	0(0,0)	93.9(71.9,154.5)	0.40	0	0	0	0	0
2018/19	11.4(6.2,26.4)	0(0,0)	110.7(70.1,225.3)	0.62	0	0	0	0	0
2019/20	12.7(6,30.7)	0(0,0)	130.8(70.4,285.3)	0.74	0	0	0	0	0
2020/21	13.5(5.8,31)	0(0,0)	140.5(69.2,325.9)	0.79	0	0	0	0	0
2021/22	14.4(5.8,33.1)	0(0,0)	152(67.3,336.5)	0.84	0	0	0	0	0
2022/23	14.9(6,35.4)	0(0,0)	162.9(69.6,367.4)	0.87	0	0	0	0	0
2023/24	15.5(6.5,40.4)	0(0,0)	170.4(72.3,395.3)	0.90	0	0	0	0	0

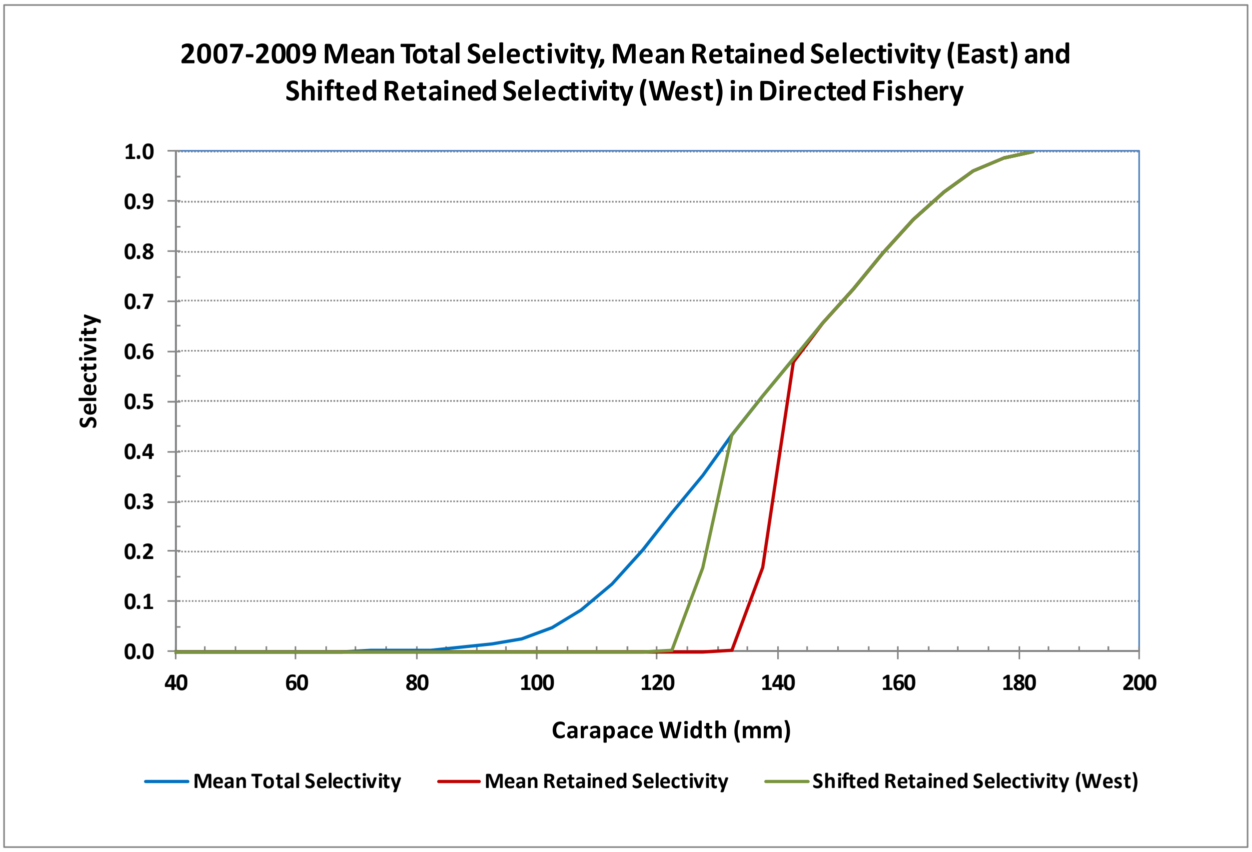


Figure A-1. Mean total and retained directed fishery selectivity curves, and the shifted (10 mm) retained selectivity curve for the area west of 166^0 W longitude for 2007 to 2009. Mean total selectivity used for both areas east and west of 1660 W longitude. The mean retained selectivity is used for the area east of 166^0 W longitude. East area industry imposed minimum size limit ≥138mm, west area industry imposed minimum size limit ≥128 mm.

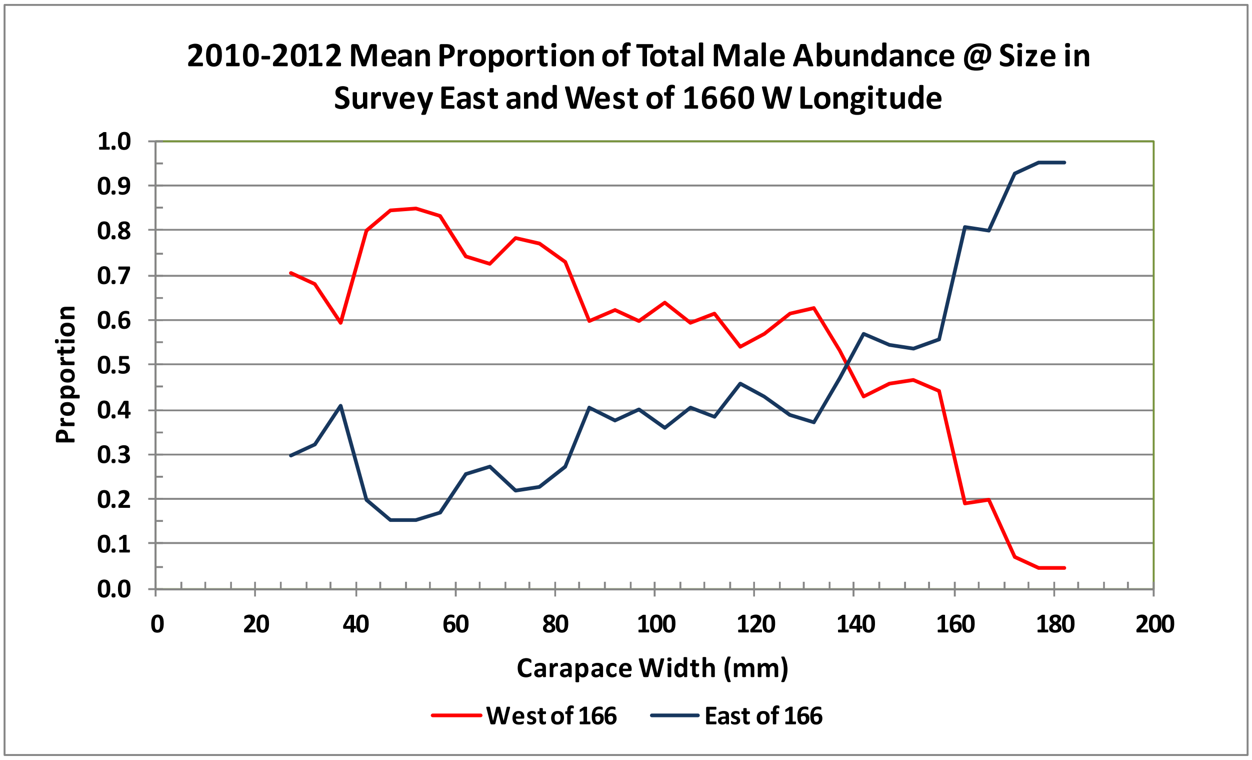


Figure A-2. Mean proportion of male abundance observed in the 2010 -2012 NMFS bottom trawl survey east and west of 166^0 W longitude by carapace width (mm).