Length-Based Stock Assessment Model of eastern Bering Sea Tanner Crab

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Background

We report on the current status and performance of the Tanner crab stock assessment model (TCSAM). The 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. Review findings and recommendations for model development from the Workshop, SSC and CPT are found in their respective meeting reports. The model was extensively revised after May 2011 and the report to the CPT in September 2011 (Rugolo and Turnock 2011a) described the developments in the model in accordance with recommendations of the CPT, SSC and Crab Modeling Workshop through September 2011. In January 2012, the TCSAM was presented for review to a second Crab Modeling Workshop and modifications were made to the model 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 for model improvements by the January 2011 Workshop and SSC formed a work plan for revisions to the model which were made in February and March 2012. A final model that includes all revisions recommended by the CPT, SSC and both Crab Modeling Workshops was presented to the SSC in March 2012.

Here we report on the current status and performance of the TCSAM developed through March 2012. This report focuses only on model revisions implemented between September 2011 and March 2012 in accordance with recommendations from the CPT (September 2011), the SSC (September 2011, January and March 2012), and the Crab Modeling Workshop (January 2012). We do not provide a complete description of the model (e.g., data inputs, formulation and equations), and refer the reader to Rugolo and Turnock (2011a) available through the NPFMC link (TCSAM Report_12_Sep_2011.pdf) for details on those aspects of the model developed September 2011.

We present the model to the CPT in consideration of its suitability for stock assessment and the rebuilding analysis. We formulated a *Base Model* that attends to virtually all of the review findings and recommendations of the Council process and Workshops to date. Four additional model configurations are presented to show the effects of fixing growth, natural mortality and survey selectivity on model performance. The TCSAM is significantly improved over the version that concluded the Crab Modeling Workshop in January 2012. The current Base Model represents a level of performance in modeling stock and fishery dynamics that may be acceptable to stock assessment, OFL-setting and projection analysis. If the model is approved by the CPT in May 2012 and by the SSC in June 2012, it will apply to OFL-setting and stock status determination in the 2012/13 assessment cycle.

In Appendix A, we report on results of a rebuilding analysis using output from the *Base Model* to a projection model of stock simulations in order to evaluate the consequences of alternative harvest strategies on stock rebuilding and fishery performance.

Model Summary

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 1974-2011. 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 1965-2010. Retained male length-frequency by shell condition (1981-2011) and discard length frequency (1991-2011) 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 (1989-2011), and from groundfish fisheries (1973-2011) were used to characterize non-directed stock losses and fishery performance.

Male and female survey selectivity were estimated for two time periods (1974-1981, 1982-2011) 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 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 the reference period 1974-1980 representing the proxy B_{MSY}, or as the product of mean recruitment in 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 experienced a substantial decline 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 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.

A. MODEL DEVELOPMENT

In this section, we present developments in the TCSAM implemented since the September 2011 CPT meeting, including those recommended by the CPT in September 2011, the SSC through March 2012 and by the Crab Modeling Workshop in January 2012. An annotated outline of changes to the model over this period is presented. The document (Rugolo and Turnock 2011a) provides a complete description of the model and presentation of model developments between May 2011 and September 2011.

1. Model Development Outline Implemented Since September 2011

We implemented extensive revisions to the model reviewed by the CPT in September 2011. Model development addressed the author's identified research needs as well as recommendations of the aforementioned groups as described in their respective meeting reports. The scope of current work performed on the model ranges from development of new effort time series data input to the model to revisions and extensions to the model code. Those developments are:

i. Sample Sizes:

Re-estimated sample sizes for directed retained fishery such that mean=200. All fleet Ns were scaled using the same scaling factor as the directed retained fishery giving means < 200. Sample sizes in individual years were capped at maximum=200 and minimum=4. Ns for survey LFs=200 for male and female crab.

ii. Stock Accounting in Over Biological Year:

Modified code in the accounting from start of the biological year (01 July) to nominal mating (15 February). Since fishery spans mating, natural mortality occurs continuously through mid-February, then mating, then the catch is extracted instantaneously.

iii. Multinomial Likelihood:

Generalized code to use same constant in all likelihood components and offsets to ensure no calculation of log(0).

iv. Mortality Episode:

Generalized code for allow estimation of an additional mortality episode over a user-specified range of years.

v. Code Refinement:

Modified code to allow switches in control file to facilitate scenario evaluation.

vi. Parameterization Selectivity Function:

Re-parameterized the selectivity function used in model to estimate 50%, Q and difference (95%-50%) parameters. Added Q-Prior switch in control file.

vii. Time-Series Effort:

Developed time-series effort data for the snow (1978-2011) and Bristol Bay red king crab (1966-2011) fisheries. Modified code to estimate Tanner discards per unit of pot lift effort pre-1992 based on the relationship between F and effort for years with discard data (1992-P).

viii. Directed Tanner Effort:

Developed time-series domestic (1968-2011) and foreign (1953-1972) effort for directed fishery. Investigated use of effort to estimate historical Fs proved unsuccessful due to limited fishery data 1992-P to estimate var(q) used in q-devs penalty, and issues of standardizing Japanese and Russian tangle net and pot effort data to domestic effort data.

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

x. Penalty on F:
Investigated removal of penalty on F in the directed fishery proved unsuccessful. Resulted in the estimation of historical Fs greater than >100, and directed mortality (65-70,000 t) and discard catch (130,000-140,000 t) in directed fishery at unrealistic levels.

B. MODEL CONFIGURATION – The Current Analysis

In this analysis, we formulated a *Base Model* that incorporates all revisions *i-x* previously outlined. Four additional model configurations are presented to show the effects of fixing growth, natural mortality and survey selectivity on model performance.

The specification of the *Base Model* 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 2005-2010/11) 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 2005-2010/11. 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 2005-2010/11. 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 1997-2007. 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.

vii. Recruitment Periods:
Estimates recruitment in 2 periods, 1950-1973 and 1974-2011 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:**
Re-estimated sample sizes for directed retained fishery such that mean=200. All fleet Ns were scaled using the same scaling factor as the directed retained fishery giving means < 200. Sample sizes in individual years were capped at maximum=200 and minimum=4. Ns for survey LFs=200 for male and female crab.

xi. **Additional Mortality Episode:**
Mortality episode estimated as M over 1980-1984.

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.

Specifications for the additional four model configurations presented in this analysis are:

Model 0: *Base Model*
Model 1: *Base Model* modified such that male growth fixed at GOA [a,b] parameters; female growth estimated.
Model 2: *Base Model* modified such that natural morality is fixed at 0.23 for immature and mature male and female crab; estimate 1980-84 mortality episode.
Model 3: *Base Model* modified such that 1982-2011 survey Q is fixed = 0.88 for male and female crab.
Model 4: *Base Model* modified such that no 1980-84 mortality episode estimated.

Model:	**Specification**
0	Base Model
1	Base Model *but* fix male growth=GOA, estimate female growth
2	Base Model *but* fix M at 0.23 for male and female; estimate 1980-84 episode
3	Base Model *but* fix survey Q=0.88 for 1982-2011 for male and female
4	Base Model *but* no 1980-84 episode estimated

C. RESULTS

All results tabled in this document and all figures are outcomes of the *Base Model* unless otherwise noted. Table 1 presents the change in male and female biomass of Tanner crab observed in the bottom trawl survey over 1980-1985 for customary survey size groups. These data show that abundance over all sexes and sizes declined over this period. Estimates of predicted retained and discard catch of Tanner crab by sex and total male catch in the directed fishery from 1974/75 through 2009/10 is shown in Table 2. Table 3 presents the predicted discard catch of male and female crab in the non-directed pot and groundfish fisheries estimated from 1974/75 through 2010/11. The predicted total (retained plus discard) Tanner crab catch biomass in the directed and non-directed fisheries combined for years 1974/75 through 2010/11 is shown in Table 4. Predicted discard catch biomass is estimated using post-release discard mortality rates of 0.50 for pot fisheries and 0.80 for groundfish fisheries. 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 5. Table 6 provides the parameter values and whether the parameters were estimated in the model, excluding recruitments and fishing mortality parameters. Table 9 shows the likelihood values by component and the total likelihood for the *Base Model* and the alternative models 1 through 4, and Table 8 presents the weighting factors for the likelihood equations used for all models.

Figure 1 presents the sample sizes used in the fitting of the fishery length compositions for all model runs. The model estimates of natural morality for male and female Tanner crab, and the estimated rate of additional mortality over 1980-84 are shown in Figure 2. The estimated rate of additional morality on male Tanner crab over 1980-84 is approximately four times the baseline natural mortality. 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 3. 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.

Figure 4 presents predicted retained male catch and predicted retained plus discard catch of male Tanner crab in the directed fishery, and total male catch in all fisheries combined for 1968-2011. The model estimate of the probability of maturing by size for male and female crab, and the probability of maturing by size used in the Amendment #24 OFL analysis (NPFMC 2007) is shown in Figure 5. Estimated total selectivity for combined shell condition male crab in the directed fishery was estimated in three periods (1981-1990, 1991-1996 and 2005-2010) (Figure 6). 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) is presented in Figure 7.

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 15). The model does not fit the increasing survey biomass trend in 2005-2008, but better fits the 2009-2011 observed biomass. The increasing trend in 2005-2008 was driven principally by hot-spot tows which inflated total biomass estimates (Rugolo and Turnock 2011b). 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 13). All three parameters (50%, Q and difference (95%-50%) of the logistic function for male (Figure 8) and female (Figure 9) survey selectivity was estimated in two periods (1974-1981 and 1982-2011); we inform Q using the prior of 0.88 in the recent period based on Somerton and

Otto (2000). Male and female Tanner crab fishery selectivity in the Bristol Bay red king crab fishery (Figure 10) and in the snow crab fishery (Figure 11) was 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 12).

The model fit to the retained catch of Tanner crab from 1968-2011 is shown in Figure 13. Model fits to discard catch biomass of male crab in the snow crab fishery, the Bristol Bay red king crab fishery, and the groundfish fishery are shown in Figures 14, 15 and 16 respectively. Figure 17 shows results of the model fit to observed MMB, and the estimated population mature male biomass from 1968-2011. The model fits the observed MMB well over the time-series with the exception of 2005-2008. The relative lack of fit to observed survey MMB in this period is not unexpected due to uncertainty in the accuracy of the estimates due to the large influence of one or two high density tows on the total area-swept calculations. Observed female mature biomass is relatively more variable than MMB and the model does not fit these female data as well over the time series (Figure 18).

Model fits to the survey length frequencies for males and females including observed survey biomass are shown in Figure 19 and Figure 21 respectively. Residuals of model fits to the male survey length frequencies are shown in Figure 20, and those for mature females in Figure 22. A summary plot of the model fit to the survey length frequencies for males and females over all years is shown in Figure 23. Figure 24 is a summary plot of the fit to the survey mature male and mature female length frequencies over all years, and Figure 25 is the equivalent summary plot for the fit to immature male and female crab.

The relationships of pre-molt length to post-molt length for male and female crab estimated in the model are shown in Figure 26. Figure 27 illustrates the estimated recruitment to model of crab 25 mm to 50 mm by fertilization year. The distribution of recruits by carapace width to the model is shown in Figure 28. Model fits to the retained male size frequency data in the 1981-2009 directed fishery, and the summary fit to the retained male size frequencies over all years are shown in Figure 29 and Figure 30 respectively. The model fits to the total male size frequency data for 1981-2009 in all fisheries combined, and the summary fit to the total male size frequencies over all years are shown in Figure 31 and Figure 32 respectively. Figure 33 presents the summary fit to the discard female size frequency data in the directed fishery over all years. Figures 34 through 36 present the summary model fits to the size frequencies of male and female Tanner crab discard catch in the snow crab fishery, the Bristol Bay red king crab fishery and n the EBS groundfish fisheries.

Full-selection total fishing mortality rates estimated in the model from 1969-2011 are shown in Figure 37 and Table 5. The pattern of full-selection fishing mortality rates concur with a history of exploitation, peaking in the late 1970s and in the early 1990s and coincident with peak extraction of catch and decline in stock biomass. Figure 38 shows realized instantaneous fishing morality rate vs. male mature biomass at mating by fishing year and the OFL control rule where $F_{35\%}$=0.616 and $B_{35\%}$=157.43 thousand t. The pattern of recruitment to the model vs. male mature biomass is illustrated in Figure 39. Figure 40 presents the trajectory of estimated male mature biomass at the time of mating from 1974-2011. From the high biomass in 1974, MMB at mating has sharply declined in 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 (Table 5), but this peak did not persist due to the high exploitation rates observed in this period

(Figure 37). The male size frequencies from 1974-2011 (Figure 19) 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 metrics of stock and fishery performance of Tanner crab over the history from 1974-2011 indicate a severe stock decline.

Alternative Model Scenarios:

For the additional four models (1-4), we present only the comparative results in the likelihood components (Table 7) relative to the *Base Model (0)*. We developed these model scenarios to address 'what if' questions of the SSC (March 2012), and neither are considered viable alternatives to the *Base Model*.

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Table 1. 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

Table 2. *Base Model* predicted retained and discard catch (1000 t) by sex in the directed Tanner crab pot fishery, 1974/75-2010/11.

Directed Fishery Predicted Retained and Discard Catch Biomass (1000 t)				
Year	Retained	Discard Catch		Total
	Male Catch	Male	Female	Male Catch
1974/75	15.25	9.01	0.94	24.27
1975/76	17.66	9.34	0.97	27.00
1976/77	29.99	16.07	1.69	46.05
1977/78	35.48	20.39	2.30	55.87
1978/79	21.04	13.36	1.70	34.40
1979/80	18.91	15.17	2.16	34.07
1980/81	13.36	11.54	1.60	24.91
1981/82	5.06	3.07	0.58	8.13
1982/83	2.70	1.37	0.31	4.07
1983/84	1.39	0.57	0.17	1.96
1984/85	1.68	0.63	0.28	2.31
1985/86	0	0	0	0
1986/87	0	0	0	0
1987/88	1.38	0.89	0.18	2.27
1988/89	3.15	2.00	0.32	5.14
1989/90	10.92	7.27	1.03	18.19
1990/91	18.00	10.78	1.62	28.78
1991/92	14.23	9.12	1.36	23.35
1992/93	15.29	6.40	1.66	21.69
1993/94	7.34	3.92	0.76	11.26
1994/95	3.40	1.86	0.33	5.26
1995/96	1.97	1.48	0.17	3.45
1996/97	0.99	0.30	0.09	1.29
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	0.78	0.61	0.04	1.39
2006/07	1.19	0.85	0.06	2.05
2007/08	1.25	1.12	0.07	2.37
2008/09	1.19	0.35	0.09	1.53
2009/10	0.75	0.06	0.17	0.81
2010/11	0	0	0	0

Table 3. *Base Model* predicted discard catch (1000 t) by sex in the non-directed domestic pot and groundfish fisheries by sex, 1974/75-2010/11.

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	2.50	0.22	2.76	1.9E-01	19.56
1975/76	2.19	0.19	2.64	1.8E-01	7.53
1976/77	1.83	0.16	3.38	2.3E-01	3.76
1977/78	1.39	0.13	3.44	2.6E-01	2.23
1978/79	3.34	0.35	2.07	1.8E-01	1.52
1979/80	4.25	0.45	1.17	1.2E-01	2.71
1980/81	7.34	0.75	2.15	2.1E-01	1.71
1981/82	5.35	0.77	1.71	2.1E-01	1.22
1982/83	2.26	0.41	0.56	8.0E-02	0.49
1983/84	0.78	0.21	0.41	7.0E-02	0.59
1984/85	0.95	0.36	0	0	0.55
1985/86	1.15	0.46	0	0	0.40
1986/87	2.35	0.54	0.19	4.0E-02	0.54
1987/88	4.93	0.78	0.34	4.0E-02	0.55
1988/89	6.88	0.87	0.50	5.0E-02	0.48
1989/90	12.11	1.37	0.71	7.0E-02	0.61
1990/91	17.67	2.12	0.93	9.0E-02	0.80
1991/92	13.85	1.76	0.70	7.0E-02	2.03
1992/93	12.70	1.73	0.27	3.0E-02	2.23
1993/94	7.18	1.07	0.20	2.0E-02	1.46
1994/95	3.51	0.56	0	0	1.76
1995/96	2.42	0.40	0	0	1.35
1996/97	0.43	0.07	0.08	9.0E-03	1.46
1997/98	0.72	0.33	0.05	1.2E-05	1.03
1998/99	0.65	0.26	0.05	9.1E-06	0.71
1999/00	0.21	0.08	0.05	7.9E-06	0.47
2000/01	0.17	0.05	0.05	8.2E-06	0.59
2001/02	0.22	0.06	0.06	9.6E-06	0.95
2002/03	0.27	0.08	0.07	1.1E-05	0.59
2003/04	0.24	0.07	0.09	1.3E-05	0.42
2004/05	0.23	0.06	0.11	1.6E-05	0.59
2005/06	0.42	0.12	0.06	3.2E-07	0.56
2006/07	0.63	0.19	0.07	3.6E-07	0.64
2007/08	0.84	0.25	0.07	4.0E-07	0.63
2008/09	0.56	0.15	0.08	4.8E-07	0.52
2009/10	0.61	0.16	0.09	4.8E-07	0.38
2010/11	0.59	0.16	0.09	4.1E-07	0.32

Table 4. *Base Model* 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	39.30	11.12
1974/75	35.59	5.10
1975/76	53.14	3.96
1976/77	61.82	3.81
1977/78	40.57	2.99
1978/79	40.86	4.08
1979/80	35.25	3.42
1980/81	15.80	2.17
1981/82	7.14	1.05
1982/83	3.44	0.73
1983/84	3.53	0.91
1984/85	1.35	0.66
1985/86	2.81	0.85
1986/87	7.81	1.28
1987/88	12.76	1.47
1988/89	31.32	2.77
1989/90	47.77	4.22
1990/91	38.92	4.21
1991/92	35.77	4.53
1992/93	19.37	2.59
1993/94	9.64	1.77
1994/95	6.55	1.25
1995/96	2.53	0.90
1996/97	1.29	0.85
1997/98	1.05	0.62
1998/99	0.49	0.31
1999/00	0.51	0.35
2000/01	0.75	0.54
2001/02	0.64	0.37
2002/03	0.54	0.28
2003/04	0.63	0.36
2004/05	2.15	0.44
2005/06	3.07	0.57
2006/07	3.60	0.63
2007/08	2.44	0.50
2008/09	1.70	0.52
2009/10	0.83	0.31

Table 5. *Base Model* 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	664.74	2687.16	128.13	416.42	544.55	158.01	163.23	314.51	0.17
1975/76	594.09	2266.34	113.10	401.56	514.66	162.11	408.10	306.36	0.17
1976/77	514.72	2474.86	96.03	353.55	449.58	143.01	263.96	248.55	0.31
1977/78	420.42	2345.66	78.23	278.24	356.47	108.39	243.02	175.92	0.53
1978/79	338.32	2201.73	65.50	194.86	260.36	67.01	82.13	126.40	0.50
1979/80	305.69	1793.91	63.16	156.46	219.62	45.81	24.33	94.54	0.72
1980/81	284.62	1348.68	63.27	149.81	213.07	41.81	56.73	59.09	0.54
1981/82	212.92	983.05	60.91	104.37	165.28	38.05	19.16	46.55	0.21
1982/83	160.26	688.63	53.84	80.10	133.94	34.23	191.05	38.34	0.11
1983/84	118.23	842.07	43.90	55.31	99.21	27.11	165.83	27.23	0.08
1984/85	90.50	938.07	34.91	31.57	66.48	15.76	419.65	14.70	0.14
1985/86	91.62	1535.18	29.05	19.97	49.02	8.82	298.20	16.18	0.01
1986/87	122.91	1775.35	28.36	28.97	57.33	11.05	275.46	23.04	0.02
1987/88	169.24	1911.83	33.50	49.88	83.38	17.13	195.28	36.94	0.12
1988/89	218.29	1844.82	43.06	79.62	122.69	27.64	99.48	58.15	0.16
1989/90	258.12	1589.00	52.56	118.80	171.35	42.41	42.84	74.79	0.40
1990/91	256.53	1241.46	55.49	135.01	190.50	51.29	21.80	73.15	0.58
1991/92	213.83	898.30	51.71	117.86	169.57	44.19	17.07	65.73	0.52
1992/93	166.79	636.11	43.73	98.11	141.84	37.68	13.95	50.66	0.75
1993/94	113.84	435.56	32.93	68.41	101.34	25.56	13.32	40.09	0.46
1994/95	78.71	313.49	24.01	47.71	71.72	18.22	18.65	31.32	0.28
1995/96	56.71	249.62	17.28	34.25	51.53	13.34	20.81	22.82	0.22
1996/97	41.66	213.10	12.50	24.31	36.81	9.68	52.38	18.13	0.19
1997/98	35.07	257.26	9.34	19.63	28.98	7.67	21.90	15.37	0.05
1998/99	31.94	234.92	7.27	17.01	24.28	6.75	65.98	13.43	0.04
1999/00	32.98	307.71	6.42	15.99	22.41	6.31	36.63	13.13	0.03
2000/01	37.12	308.54	6.79	17.62	24.41	6.70	115.66	14.50	0.03
2001/02	44.85	466.86	7.47	21.52	28.99	8.28	46.93	17.54	0.04
2002/03	51.92	451.62	8.35	25.02	33.37	9.98	79.70	20.69	0.02
2003/04	61.46	505.78	9.84	29.81	39.64	11.68	168.94	24.90	0.02
2004/05	75.21	726.56	12.04	36.50	48.54	14.34	49.62	30.50	0.02
2005/06	87.70	659.09	14.03	45.67	59.70	18.02	39.39	36.87	0.07
2006/07	96.60	582.91	15.76	51.58	67.34	21.28	30.55	41.02	0.09
2007/08	103.38	502.99	18.51	57.05	75.56	22.22	36.11	45.30	0.08
2008/09	106.53	449.23	19.63	67.38	87.02	26.85	140.61	55.06	0.09
2009/10	104.31	618.79	17.76	70.71	88.47	30.74	166.67	58.59	0.16
2010/11	100.30	805.35	15.18	64.24	79.42	28.42	119.61	53.93	0.01
2011/12	102.52	859.62	14.33	58.01	72.34	25.58	-	-	-

Table 6. *Base Model* 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	0.246	0.01	Y
Natural Mortality - mature male	0.254	0.01	Y
Natural Mortality - mature female	0.341	0.01	Y
Additional 1980-84 Mortality - mature male	1.020	0.16	Y
Additional 1980-84 Mortality - mature female	0.312	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	1.55	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	0.16	0.01	Y
Fishery selectivity total male slope - 2005-2010	0.11	0.01	Y
Fishery selectivity total male length at 50%, 1991	126.45	0.02	Y
Fishery selectivity total male length at 50%, 1992	132.72	0.01	Y
Fishery selectivity total male length at 50%, 1993	128.55	0.02	Y
Fishery selectivity total male length at 50%, 1994	126.57	0.02	Y
Fishery selectivity total male length at 50%, 1995	118.61	0.03	Y
Fishery selectivity total male length at 50%, 1996	133.80	0.05	Y
Fishery selectivity total male length at 50%, 2005	123.52	0.02	Y
Fishery selectivity total male length at 50%, 2006	122.83	0.02	Y
Fishery selectivity total male length at 50%, 2007	119.60	0.02	Y
Fishery selectivity total male length at 50%, 2008	142.75	0.02	Y
Fishery selectivity total male length at 50%, 2009	168.82	0.03	Y
Fishery retention curve males slope, 1991-1996	0.79	0.15	Y
Fishery retention curve males length at 50%, 1991-1996	137.58	0.33	Y
Fishery retention curve males slope, 2005-2010	1.02	0.27	Y
Fishery retention curve males length at 50%, 2005-2010	137.60	0.23	Y
Directed Fishery discard selectivity female slope	0.13	0.01	Y
Directed Fishery discard selectivity female length at 50%	110.80	2.40	Y
Snow crab male selectivity slope ascending, 1989-1996	0.05	0.00	Y
Snow crab male selectivity length at 50% ascending, 1989-1996	115.85	4.10	Y
Snow crab male selectivity slope descending, 1989-1996	0.22	0.07	Y
Snow crab male selectivity length at 50% descending, 1989-1996	79.87	3.76	Y
Snow crab male selectivity slope ascending, 1997-2004	0.15	0.06	Y
Snow crab male selectivity length at 50% ascending, 1997-2004	84.27	6.43	Y
Snow crab male selectivity slope descending, 1997-2004	0.35	0.11	Y
Snow crab male selectivity length at 50% descending, 1997-2004	87.36	1.60	Y
Snow crab male selectivity slope ascending, 2005-2010	0.21	0.10	Y
Snow crab male selectivity length at 50% ascending, 2005-2010	138.49	3.35	Y
Snow crab male selectivity slope descending, 2005-2010	0.26	0.09	Y
Snow crab male selectivity length at 50% descending, 2005-2010	91.88	2.88	Y

Table 6. (continued)

Parameter	Value	S.Deviation	Estimated?
Snow crab fishery female selectivity slope, 1989-1996	0.18	0.11	Y
Snow crab fishery female selectivity length at 50%, 1989-1996	142.05	5.00	Y
Snow crab fishery female selectivity slope, 1997-2004	0.17	0.03	Y
Snow crab fishery female selectivity length at 50%, 1997-2004	101.05	2.23	Y
Snow crab fishery female selectivity slope, 2005-2010	0.27	0.07	Y
Snow crab fishery female selectivity length at 50%, 2005-2010	137.41	1.54	Y
Red king crab fishery male selectivity slope, 1989-1996	0.26	0.13	Y
Red king crab fishery male selectivity length at 50%, 1989-1996	97.40	8.16	Y
Red king crab fishery male selectivity slope, 1997-2004	0.14	0.02	Y
Red king crab fishery male selectivity length at 50%, 1997-2004	150.00	0.12	Y
Red king crab fishery male selectivity slope, 2005-2010	0.16	0.02	Y
Red king crab fishery male selectivity length at 50%, 2005-2010	170.00	4.65	Y
Red king crab fishery female selectivity slope, 1989-1996	0.21	0.08	Y
Red king crab fishery female selectivity length at 50%, 1989-1996	114.49	4.14	Y
Red king crab fishery female selectivity slope, 1997-2004	0.11	0.04	Y
Red king crab fishery female selectivity length at 50%, 1997-2004	123.47	10.13	Y
Red king crab fishery female selectivity slope, 2005-2010	0.07	0.01	Y
Red king crab fishery female selectivity length at 50%, 2005-2010	150.00	0.00	Y
Groundfish Fishery male selectivity slope, 1973-1986	0.15	0.03	Y
Groundfish Fishery male selectivity length at 50%, 1973-1986	42.11	1.88	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, 1997-2010	0.10	0.01	Y
Groundfish Fishery male selectivity length at 50%, 1997-2010	68.65	3.06	Y
Groundfish Fishery female selectivity slope, 1973-1986	0.16	0.03	Y
Groundfish Fishery female selectivity length at 50%, 1973-1986	46.90	1.90	Y
Groundfish Fishery female selectivity slope, 1987-1996	0.17	0.13	Y
Groundfish Fishery female selectivity length at 50%, 1987-1996	40.72	4.89	Y
Groundfish Fishery female selectivity slope, 1997-2010	0.08	0.01	Y
Groundfish Fishery female selectivity length at 50%, 1997-2010	81.60	4.50	Y
Survey Q 1974-1981 – male	0.50	0.00	Y
Survey 1974-1981 difference in length (95%-50%) of Q – male	21.02	3.55	Y
Survey 1974-1981 length at 50% of Q – male	44.55	1.94	Y
Survey Q 1982-2011 – male	0.79	0.03	Y
Survey 1982-2011 difference in length (95%-50%) of Q – male	60.73	9.50	Y
Survey 1982-2011 length at 50% of Q – male	27.94	3.66	Y
Survey Q 1974-1981 – female	0.58	0.12	Y
Survey 1974-1981 difference in length (95%-50%) of Q – female	47.17	19.57	Y
Survey 1974-1981 length at 50% of Q – female	53.20	10.30	Y
Survey Q 1982-2011 – female	0.58	0.04	Y
Survey 1982-2011 difference in length (95%-50%) of Q – female	100.00	0.00	Y
Survey 1982-2011 length at 50% of Q – female	-7.46	17.73	Y
Fishery cpue q	0.00055		N

Table 7. Likelihood values by component for the Tanner crab assessment model shown for *Base Model*, and four alternative models 1-4.

Likelihood Component	Likelihood Value				
	Base (0)	*1*	*2*	*3*	*4*
recruitment deviations	5.4	5.4	5.2	5.2	5.5
probability of maturity smooth constraint	1.7	1.6	1.6	1.6	1.6
Survey q penalty	19.5	56.5	52.8	0.0	21.1
F penalty	197.4	209.3	204.4	194.6	229.5
retained length	37.9	36.7	37.7	37.6	38.3
total directed length	68.9	64.2	69.5	69.8	69.8
female directed length	9.4	8.6	8.5	8.6	9.4
survey length	861.2	895.2	933.9	892.3	868.7
groundfish fishery length	39.5	34.0	55.1	36.5	38.0
snow fishery length	44.7	39.8	46.3	44.9	46.3
red king fishery length	49.8	48.3	50.3	49.7	49.0
survey biomass	179.7	254.3	209.2	178.3	210.6
fishery cpue	-	-	-	-	-
directed fishery male discard catch	15.2	14.0	14.8	14.7	20.3
directed fishery male retained catch	23.0	26.0	24.2	23.1	26.7
directed fishery female discard catch	12.4	10.9	13.6	13.8	12.1
groundfish fishery male + female catch	1.9	1.5	2.5	2.4	2.1
snow fishery male + female catch	14.8	10.4	21.0	18.8	16.4
red king fishery male + female catch	18.0	16.1	18.0	18.6	17.8
natural mortality penalty	49.3	32.4	0.0	61.6	44.3
Total Likelihood	1650.8	1765.7	1769.5	1672.2	1728.3

Table 8. Weighting factors for likelihood equations for *Base Model*.

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	0.5
survey length composition	1.0
groundfish fishery length composition	0.5
snow and red king fishery length composition	1.0
survey biomass	1.0
recruitment deviations	1.0
directed fishing mortality deviations	0.1
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
survey Q standard deviation penalty	0.05

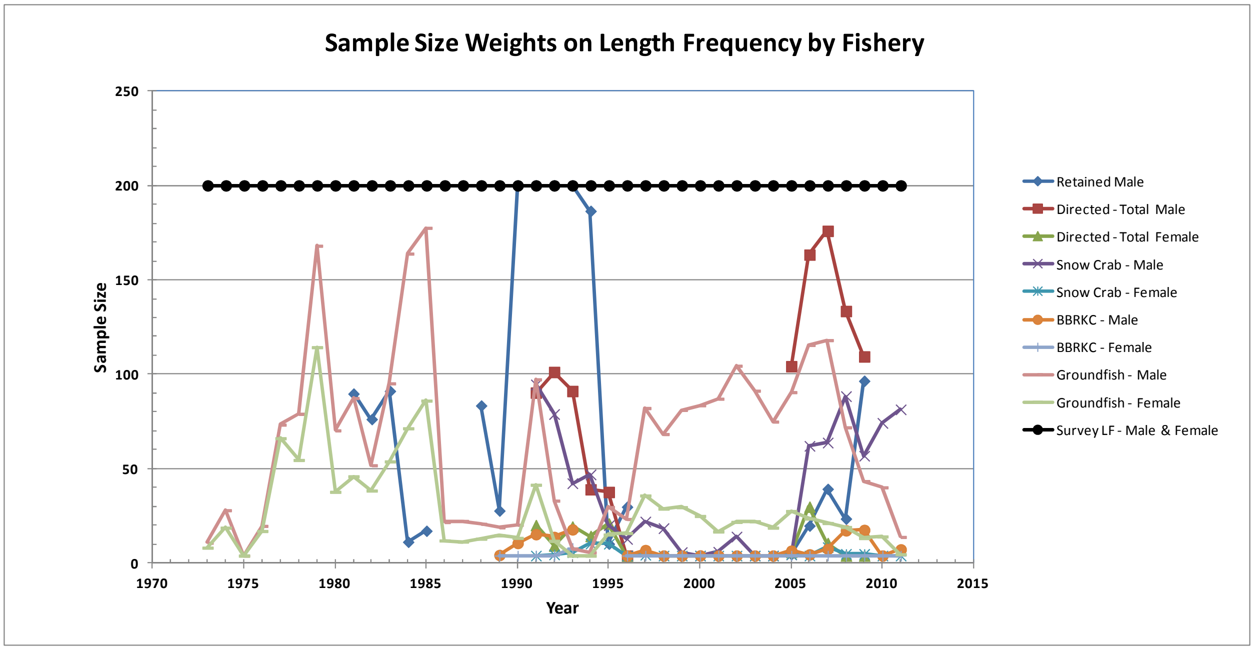

Figure 1. Sample sizes used in the fitting of the fishery length compositions for all fleets.

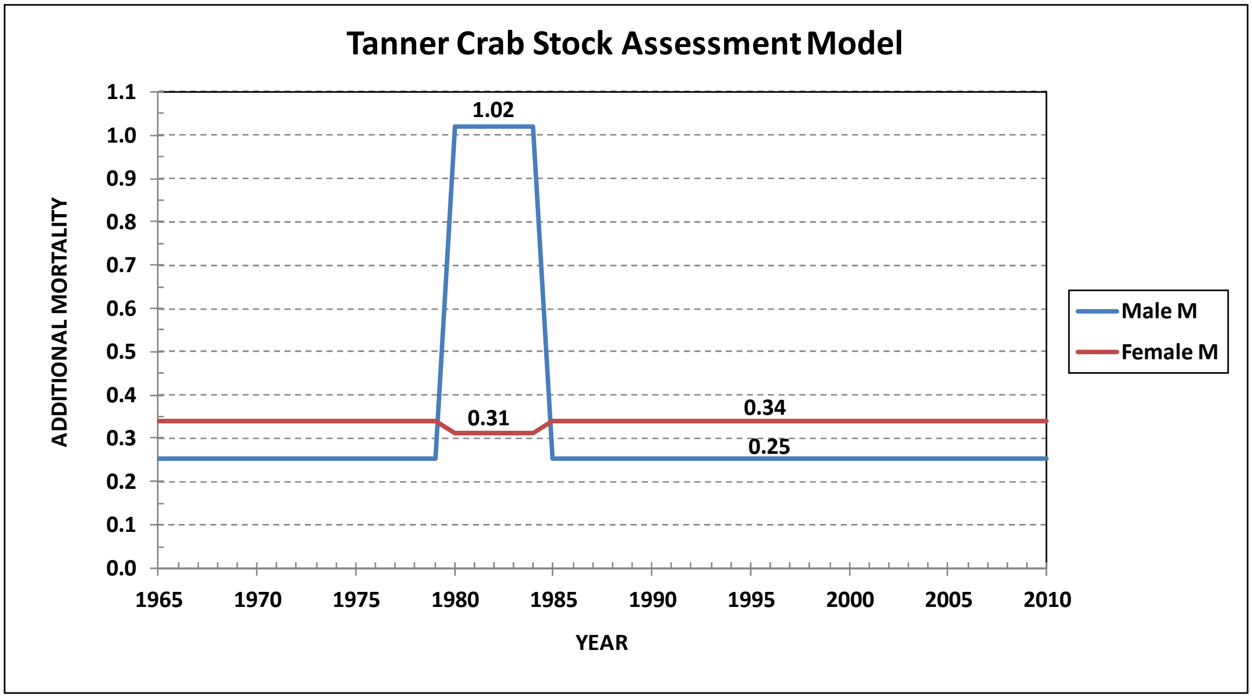

Figure 2. *Base Model* estimates of the natural mortality rate for male and female Tanner crab, 1965-2011.

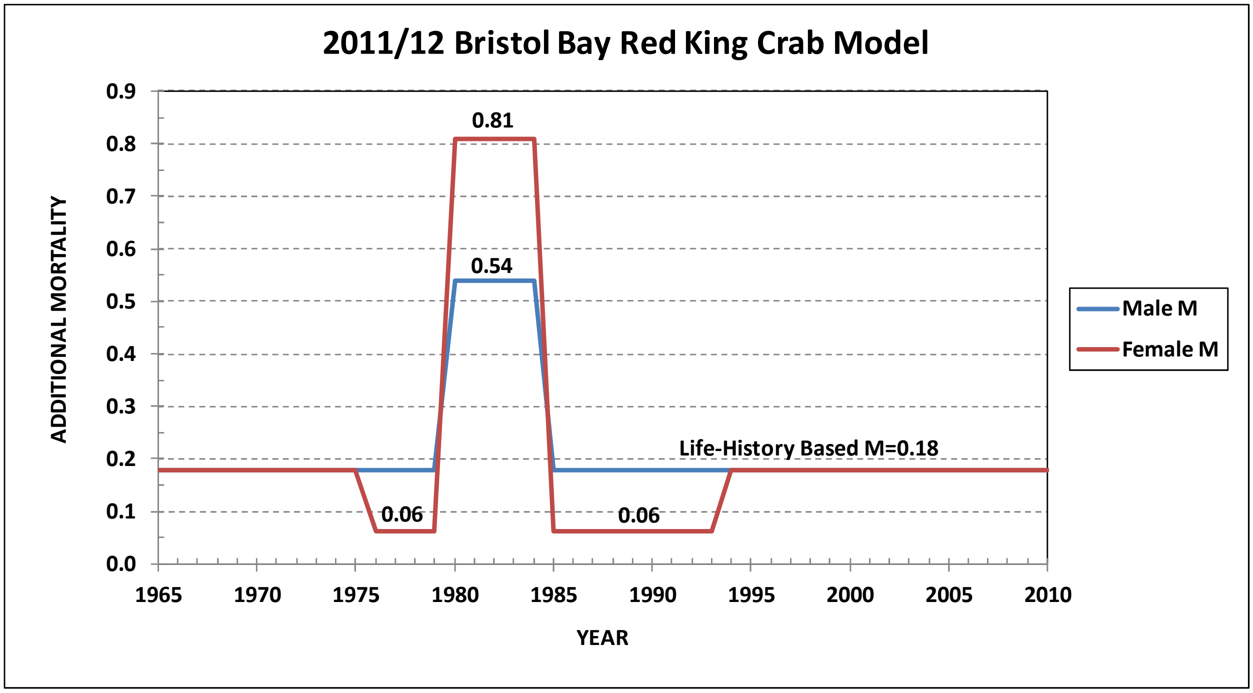

Figure 3. Model estimates of natural mortality rate for male (1980-1984) and female (1976-1993) Bristol Bay red king crab, and fixed M for remaining years in the 2011/12 stock assessment model (Zheng 2011).

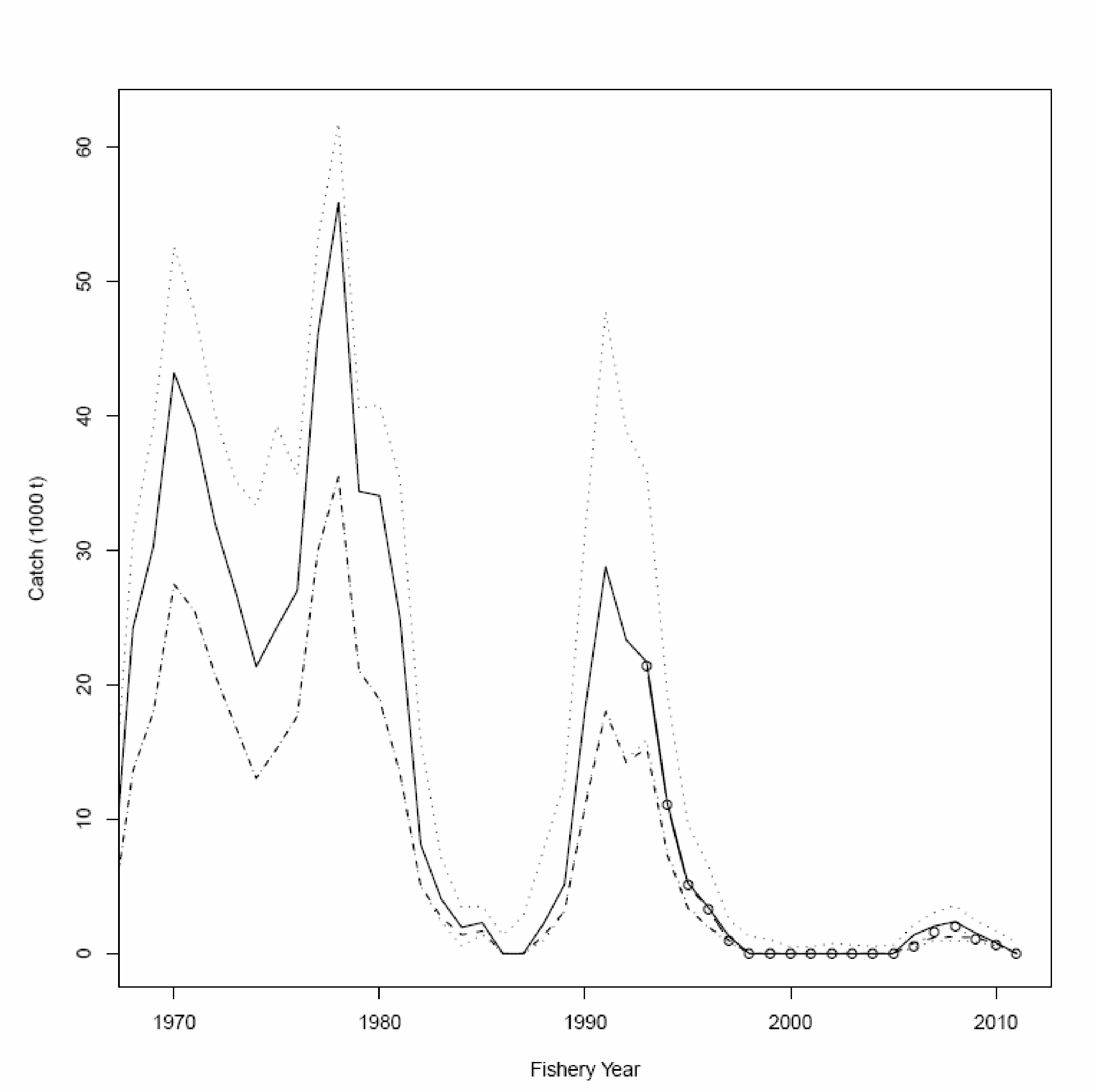

Figure 4. *Base Model* predicted catch history of male Tanner crab catch by survey year. [solid line=predicted retained plus discard catch in the directed fishery; dashed line=predicted retained catch in the directed fishery; dotted line=predicted total male catch from all sources].

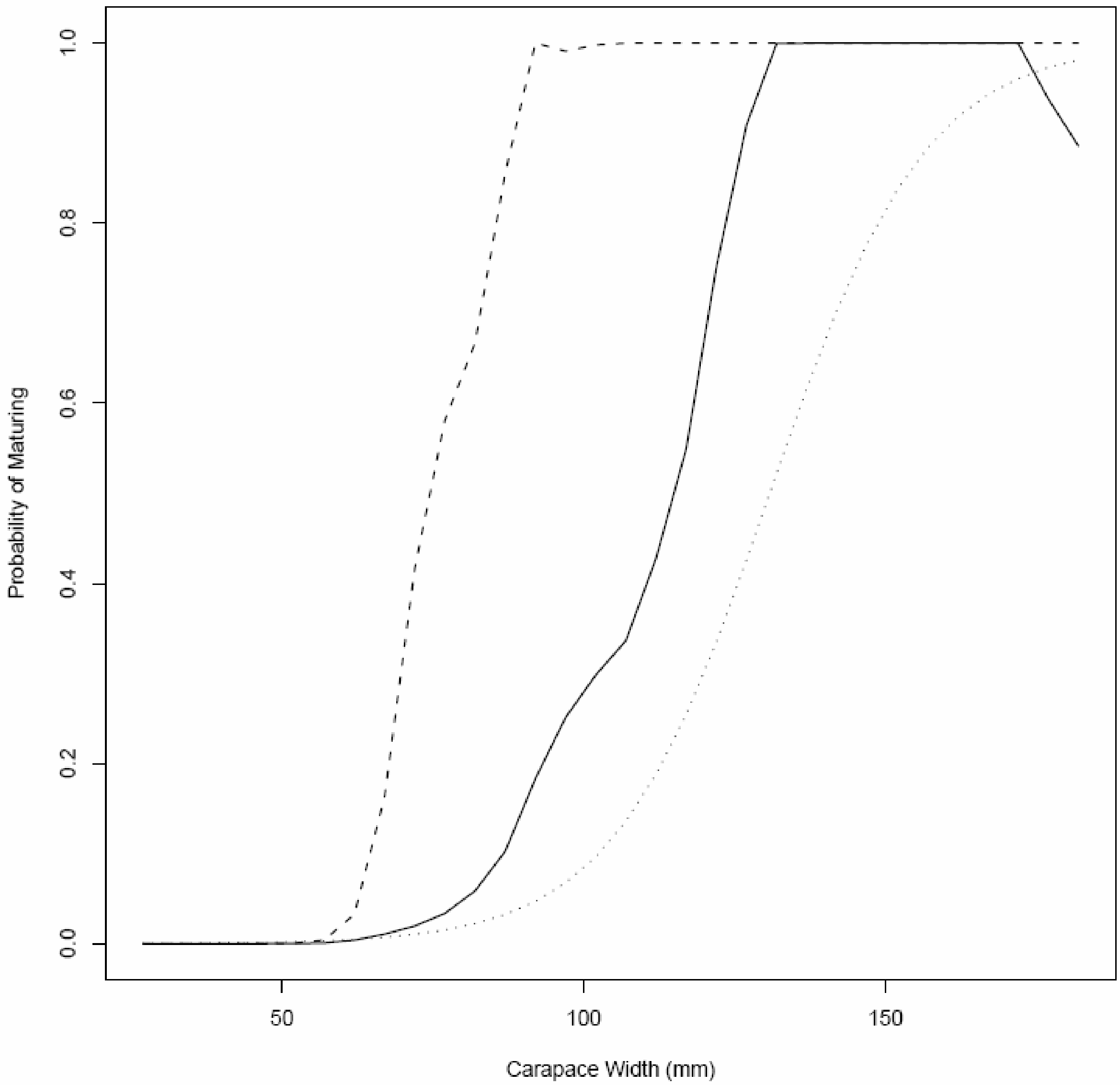

Figure 5. *Base Model* estimate of probability of maturing by size for male (solid) and female (dashed) Tanner crab (not average fraction mature), and male probability of maturing by size used in Amendment #24 OFL analysis (dotted) (NPFMC 2007).

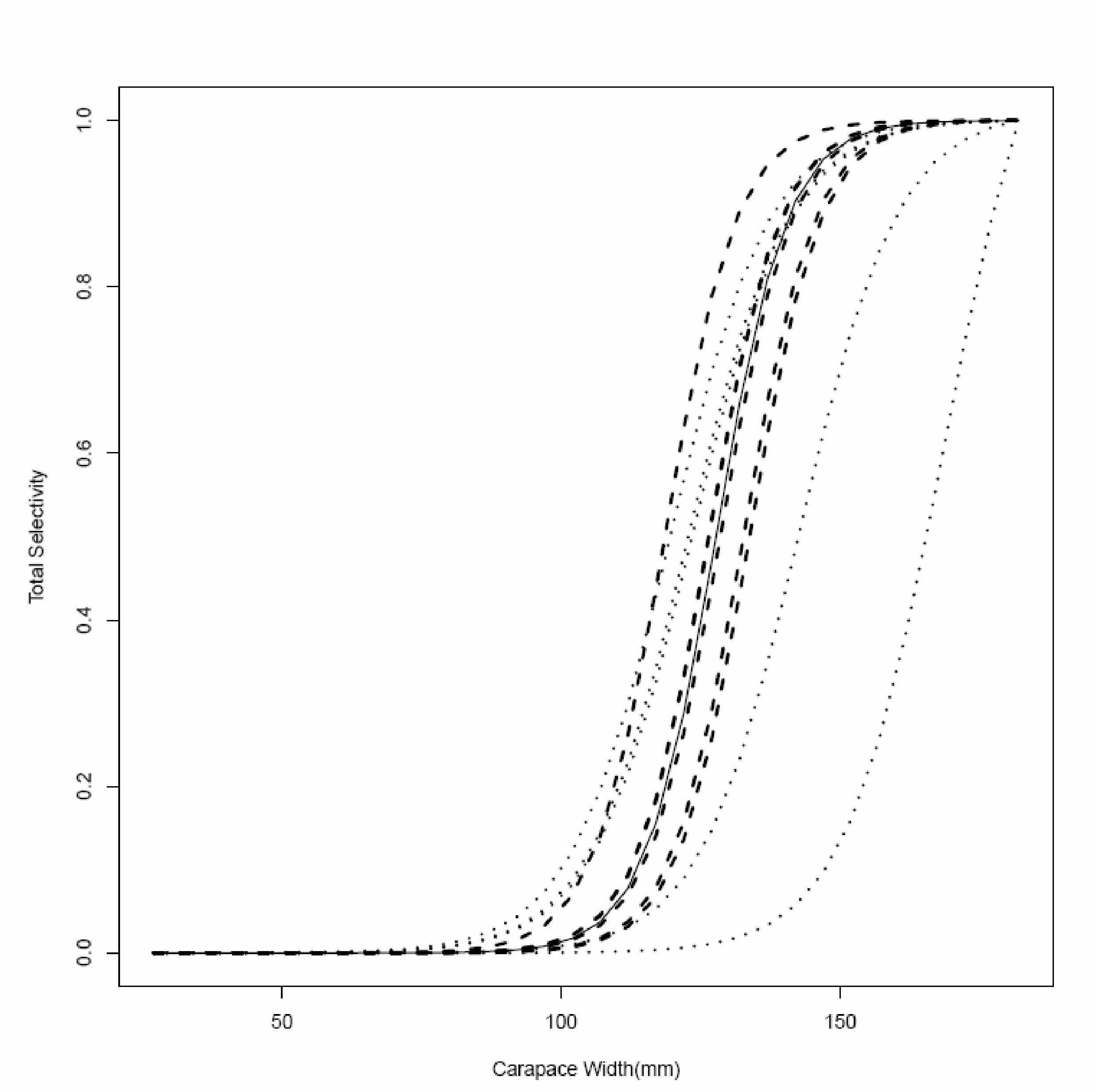

Figure 6. *Base Model* estimated total selectivity for combined shell condition male Tanner crab in the directed fishery for 3 periods: period-1 (1981-1990) fixed selectivity (solid line), period-2 (1991-1996) annual selectivity (series of dashed lines), and period-3 (2005-2010) annual selectivity (series of dotted lines). Lines from left to right: 2007, 2005, 1996, 2006, 1995, 2010, 2008, 1991, 1981-1990 (solid), 1994, 1993, 1992 and 2009.

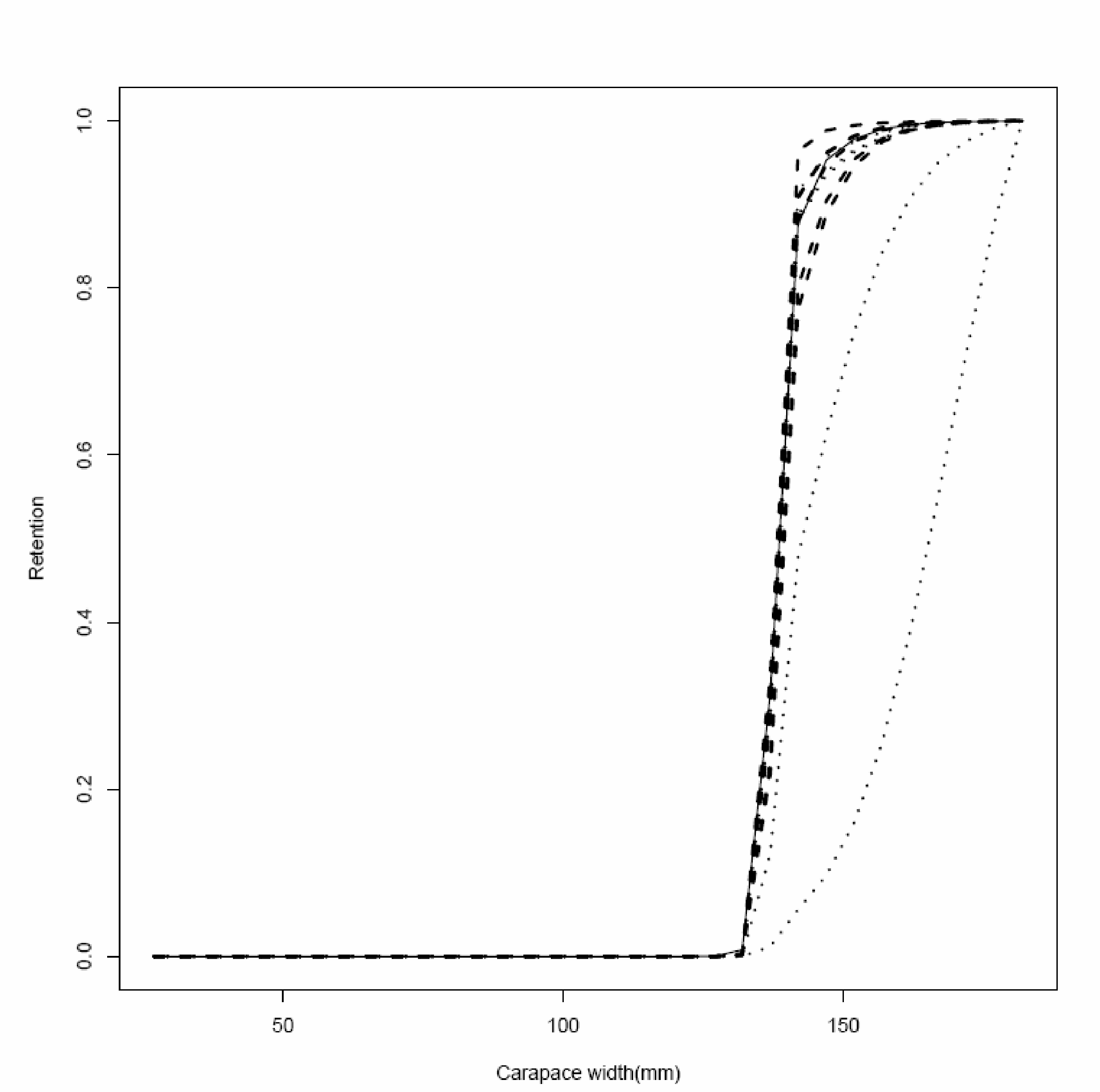

Figure 7. *Base Model* estimated fraction of total catch retained by size for male crab in the directed fishery, all shell conditions combined for 3 periods: period-1 (1981-1990) fixed selectivity (solid line), period-2 (1991-1996) annual selectivity (series of dashed lines), and period-3 (2005-2010) annual selectivity (series of dotted lines). Lines from left to right: 2007, 2005, 1996, 2006, 1995, 2010, 2008, 1991, 1981-1990 (solid), 1994, 1993, 1992 and 2009. The retention function is multiplied by the total directed male selectivity to estimate the directed fishery retained selectivity.

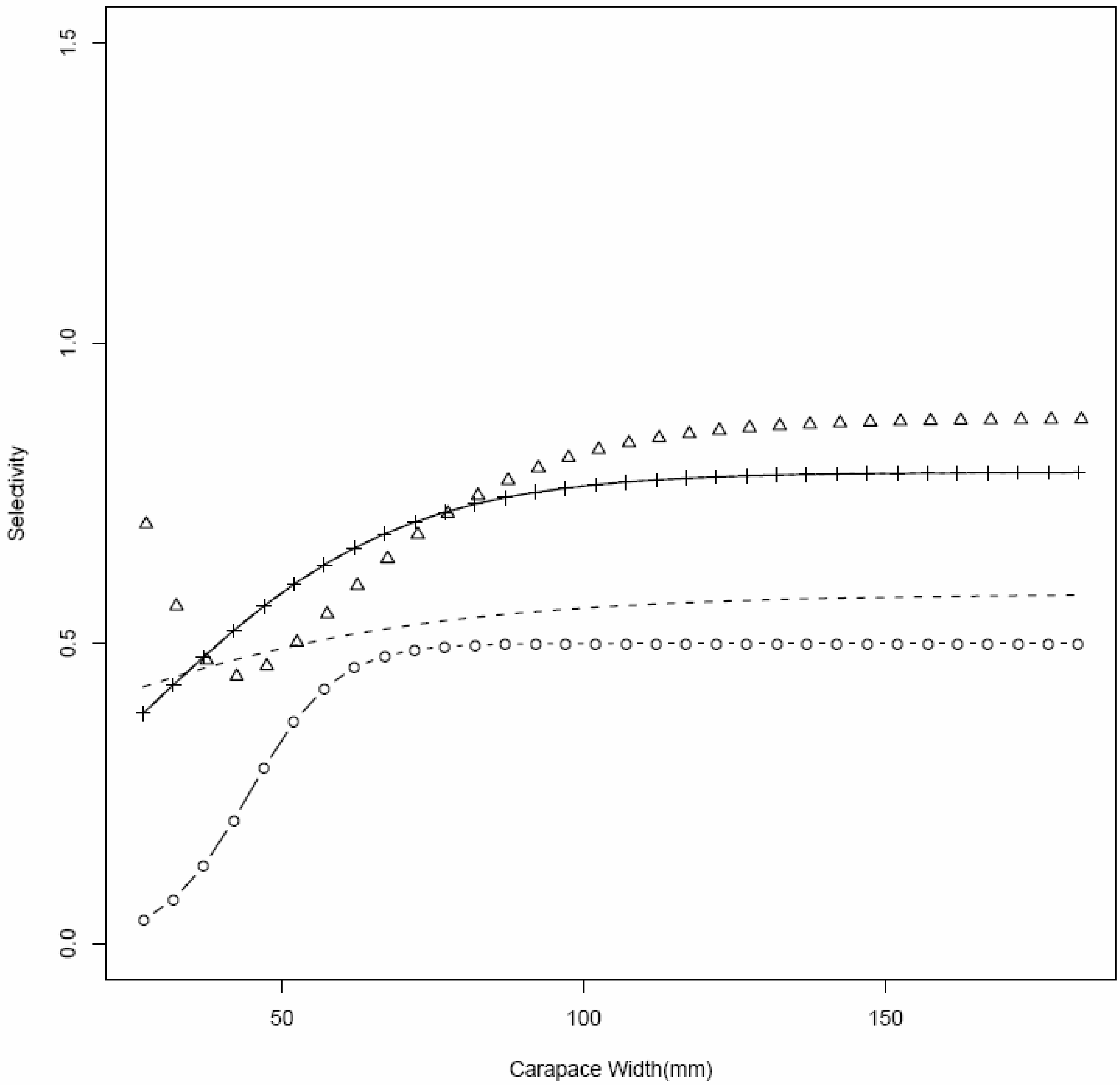

Figure 8. *Base Model* survey selectivity curves for male Tanner crab estimated for 1974-1981 (dashed line with circles), 1982-2011 (solid line with pluses). Survey selectivity estimated by Somerton and Otto (1998) are triangle symbols, and female selectivity for 1988-2011 is dashed line for reference.

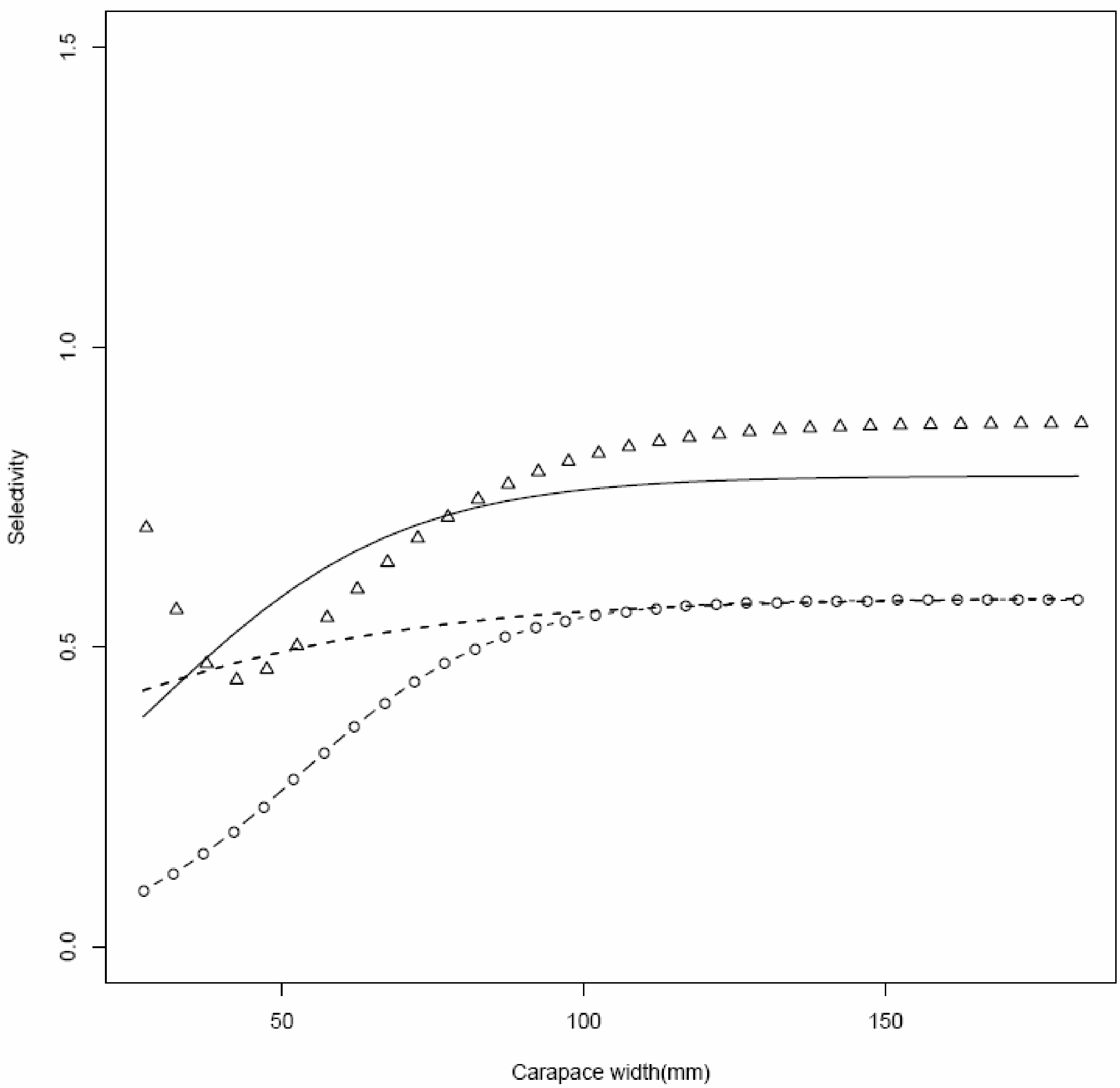

Figure 9. *Base Model* survey selectivity curves for female Tanner crab estimated for 1974-1981 (dashed line with circles), 1982-2011 (dashed line). Survey selectivity estimated by Somerton and Otto (1998) are triangle symbols, and male selectivity for 1988-2011 is upper solid line for reference.

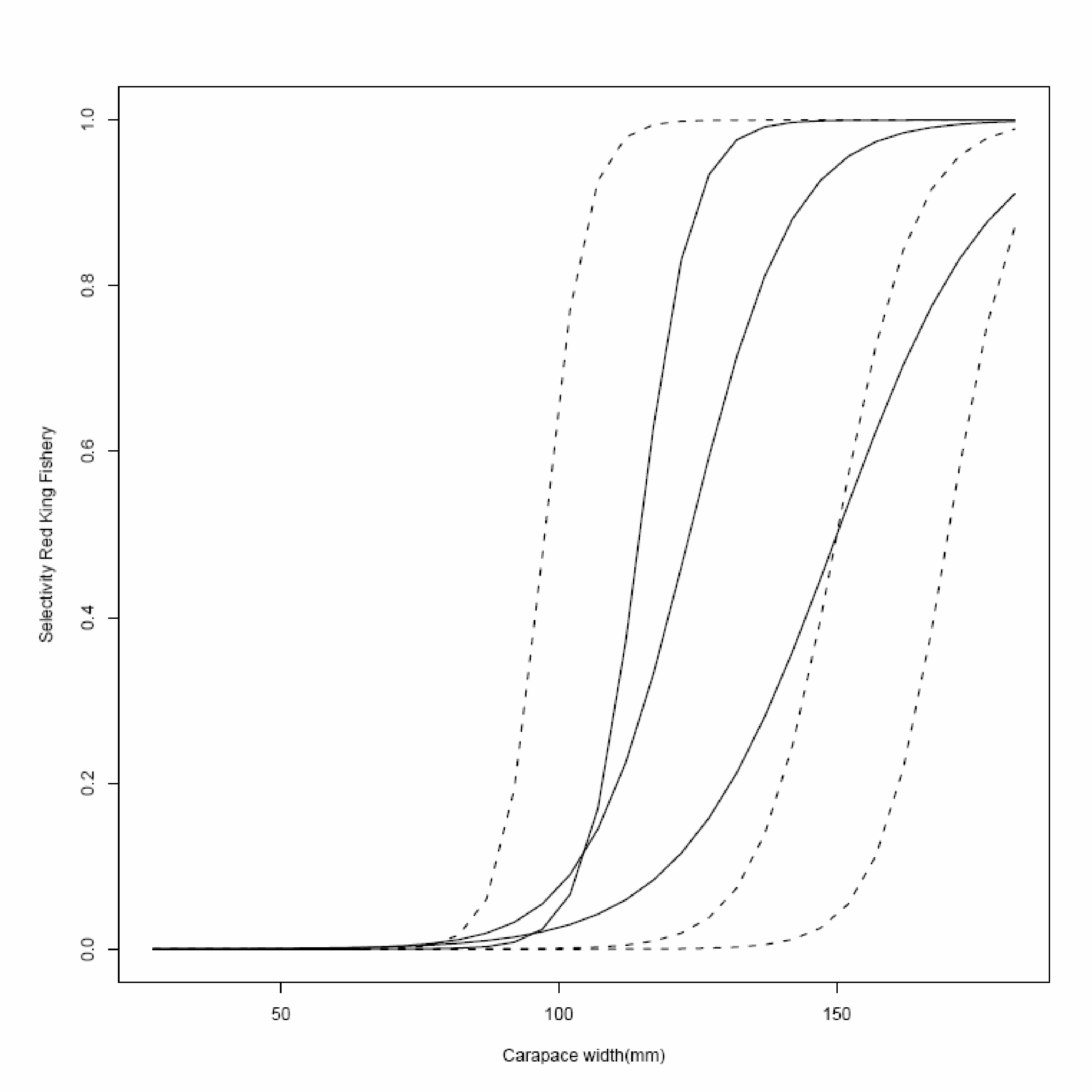

Figure 10. *Base Model* selectivity curve estimated by the model for bycatch in the Bristol Bay red king crab fishery for females (dashed) and males (solid) for three periods: period-1 (1989-1996), period-2 (1997-2004) and period-3 (2005-P). The male and female curves for the three time periods are in chronological order from left to right – i.e., earliest to left, intermediate in center, and most recent to right.

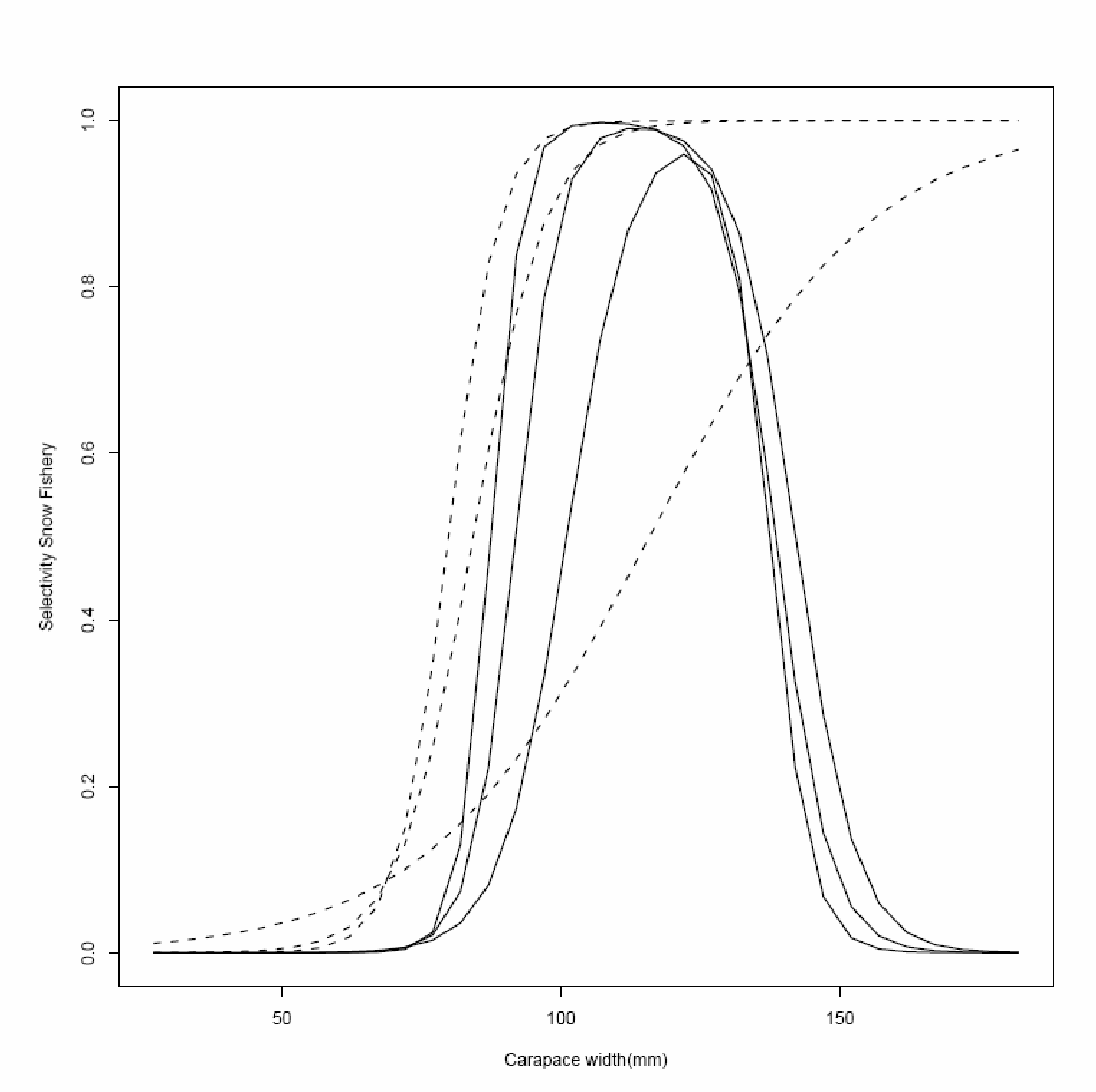

Figure 11. *Base Model* selectivity curve estimated by the model for bycatch in the snow crab fishery for females (dashed) and males (solid) for three periods: period-1 (1989-1996), period-2 (1997-2004) and period-3 (2005-P). The curves for males: period-1 (left), period-2 (center) and period-3 (right). Curves for females: period-1 (right), period-2 (left) and period-3 (center).

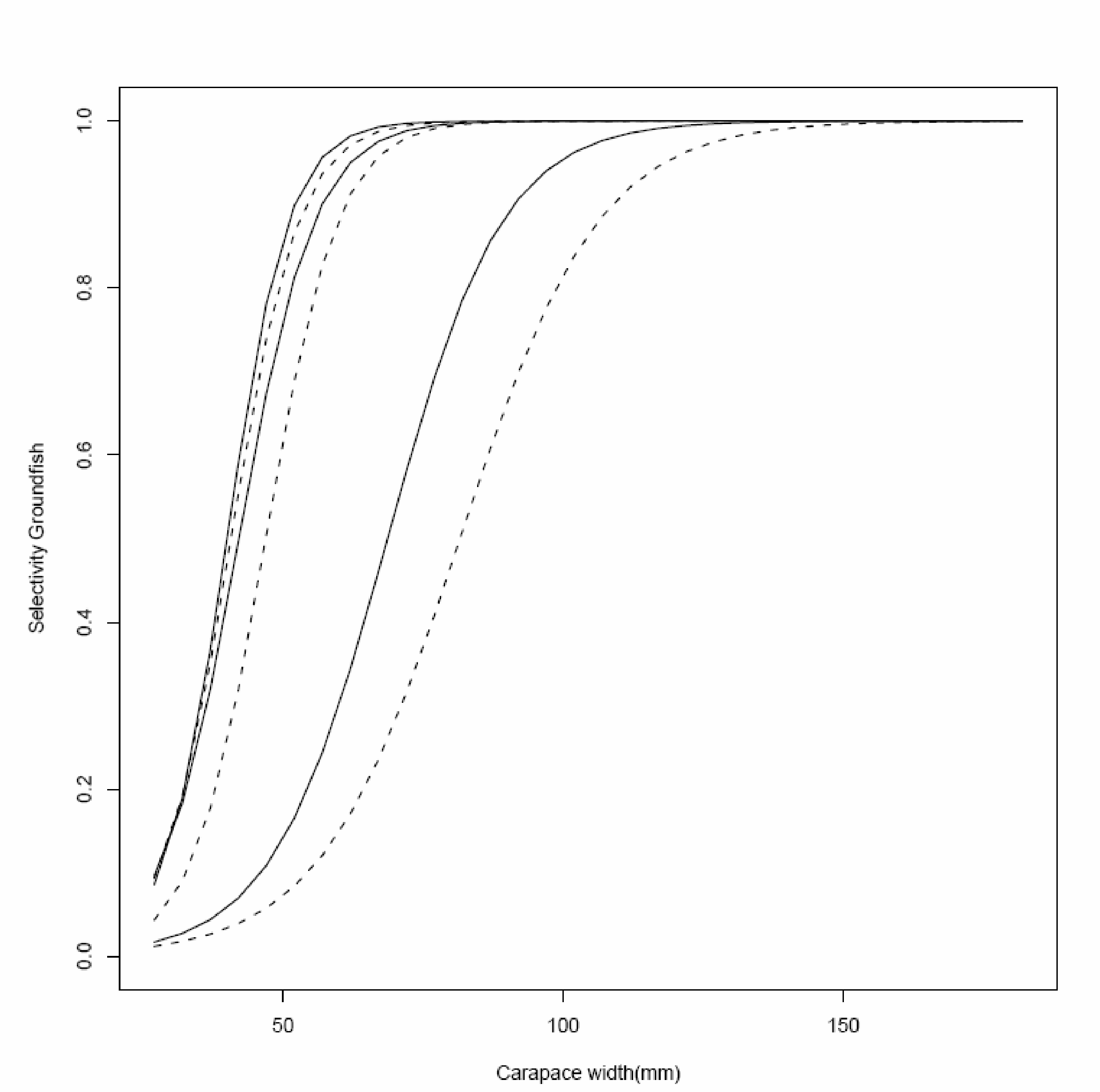

Figure 12. *Base Model (0)* selectivity curve estimated by the model for bycatch of males (dashed) and females (solid) in the groundfish fishery for three periods: period-1 (1973-1986), period-2 (1987-1996) and period-3 (1997-P). The curves for males: period-1 (left), period-2 (center) and period-3 (right). Curves for females: period-1 (left), period-2 (right) and period-3 (center).

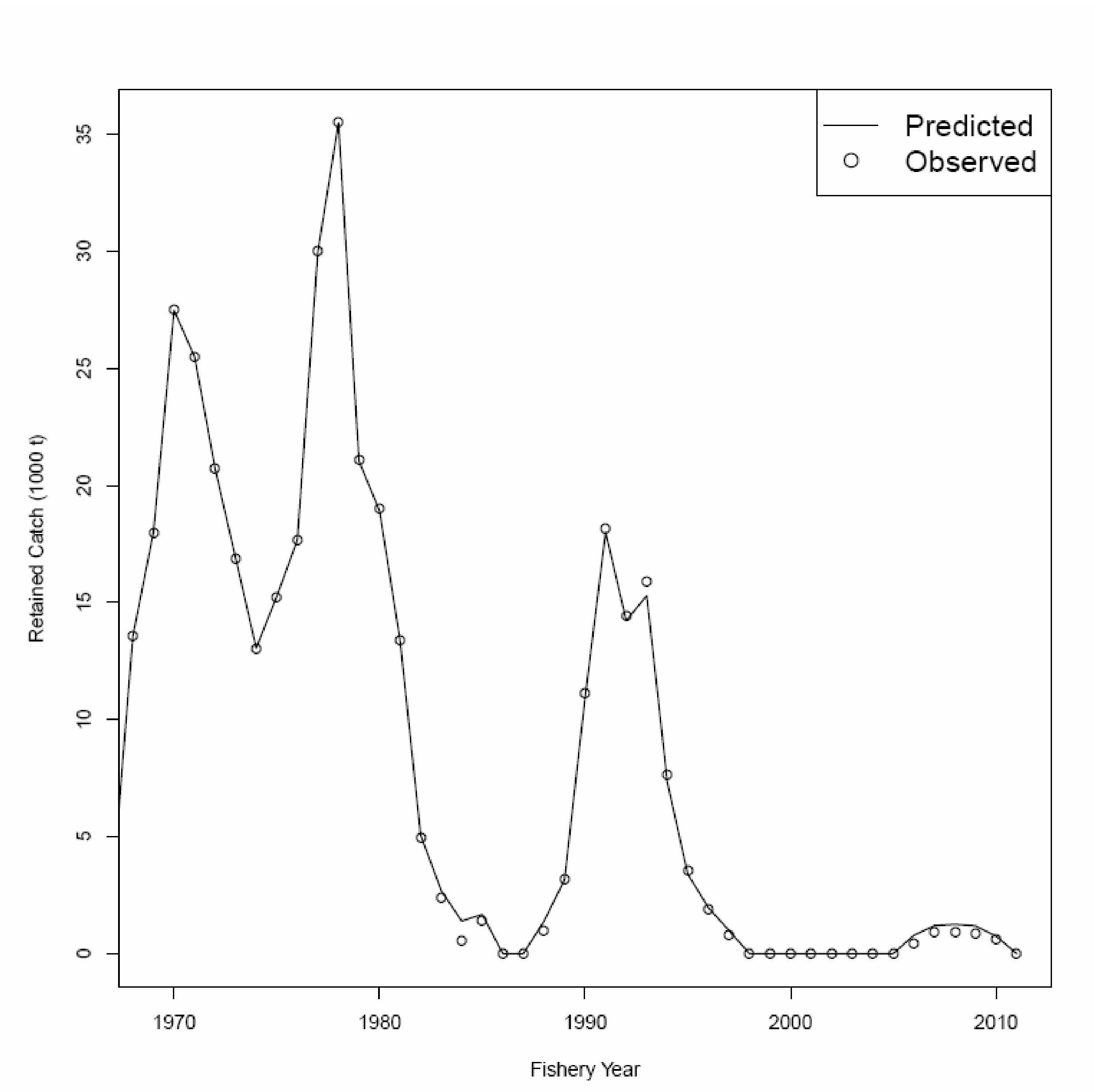

Figure 13. *Base Model* fit to the retained catch, 1968-2011.

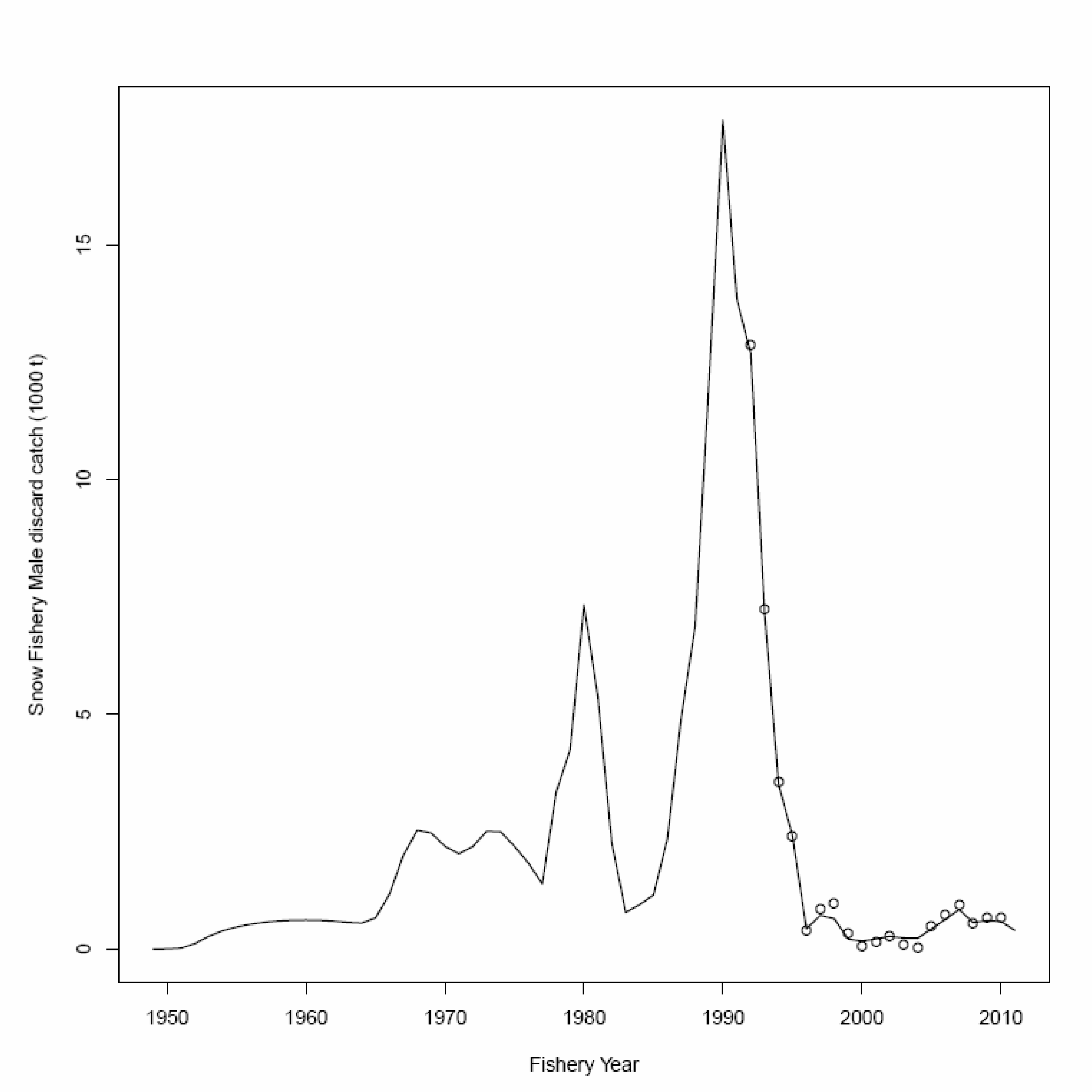

Figure 14. *Base Model* fit to the discard catch of Tanner crab in the snow crab fishery.

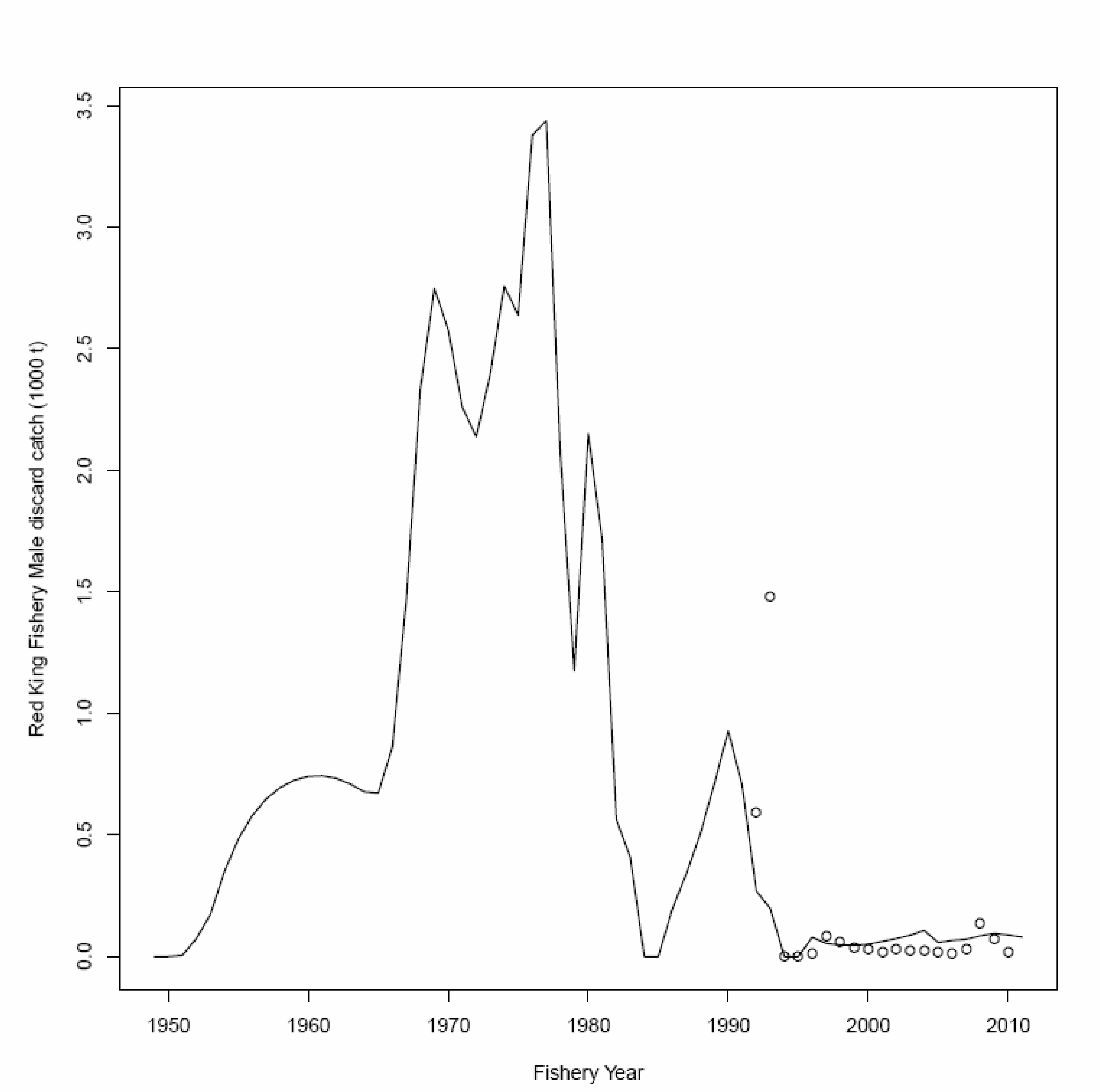

Figure 15. *Base Model* fit to the discard catch of Tanner crab in the Bristol Bay red king crab fishery.

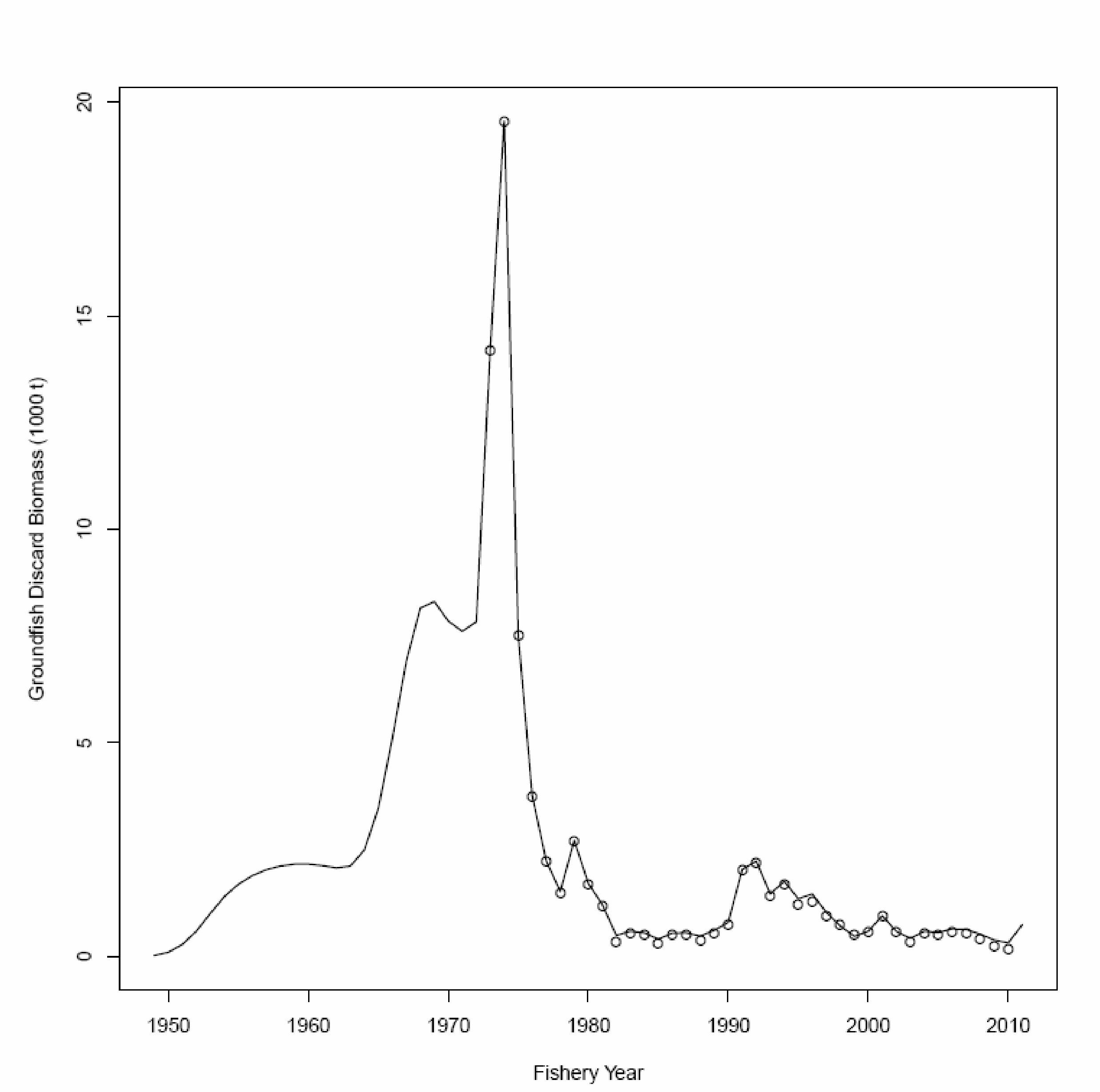

Figure 16. *Base Model* fit to the discard catch of Tanner crab in the groundfish fisheries.

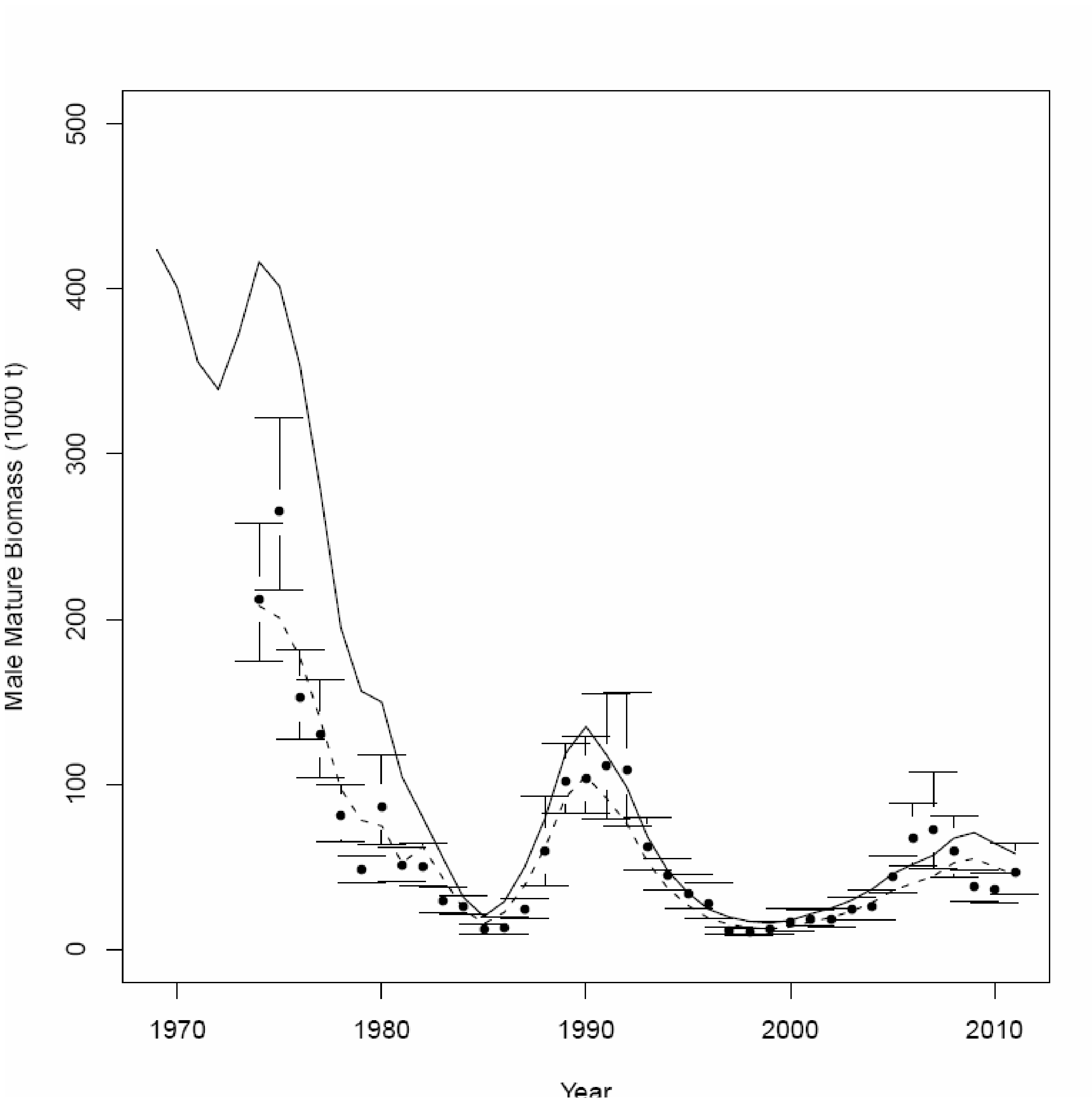

Figure 17. *Base Model* population mature male biomass (1000 t, solid line) at the time of the survey, model estimate of survey mature biomass (dotted line) and observed survey mature male biomass with approximate lognormal 95% confidence intervals.

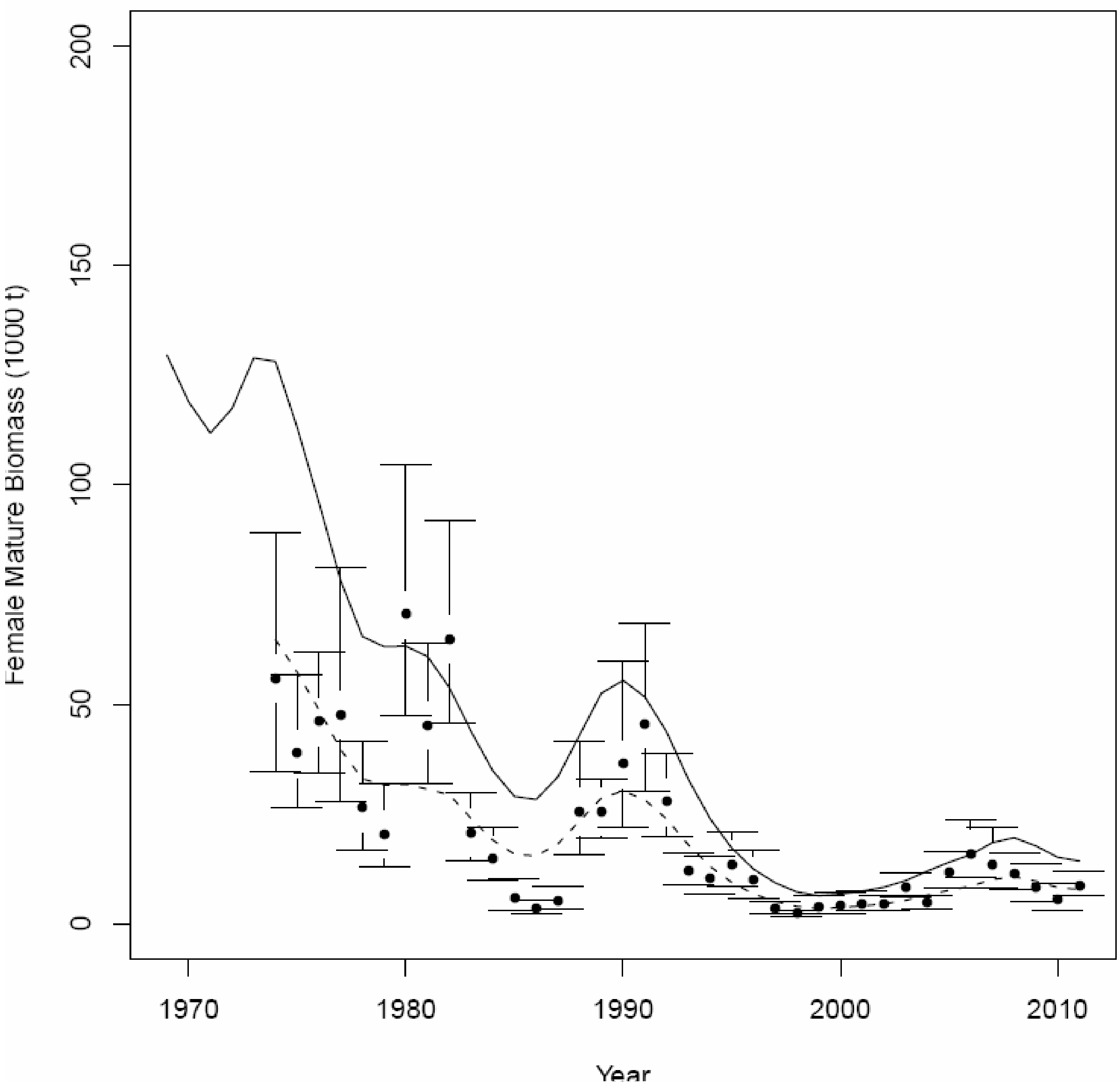

Figure 18. *Base Model* population female mature biomass (1000 t, solid line), model estimate of survey female mature biomass (dotted line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

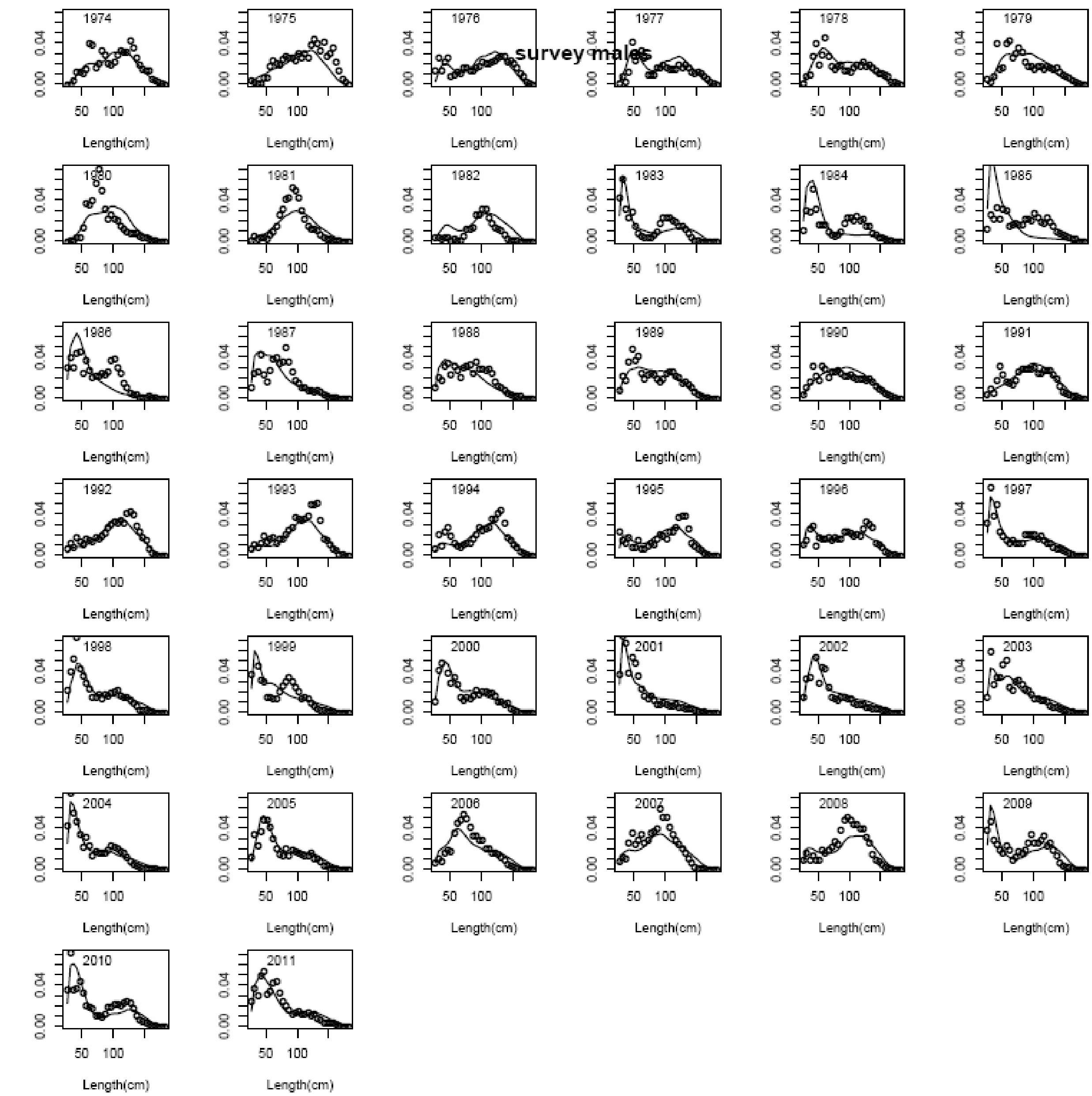

Figure 19. *Base Model* fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

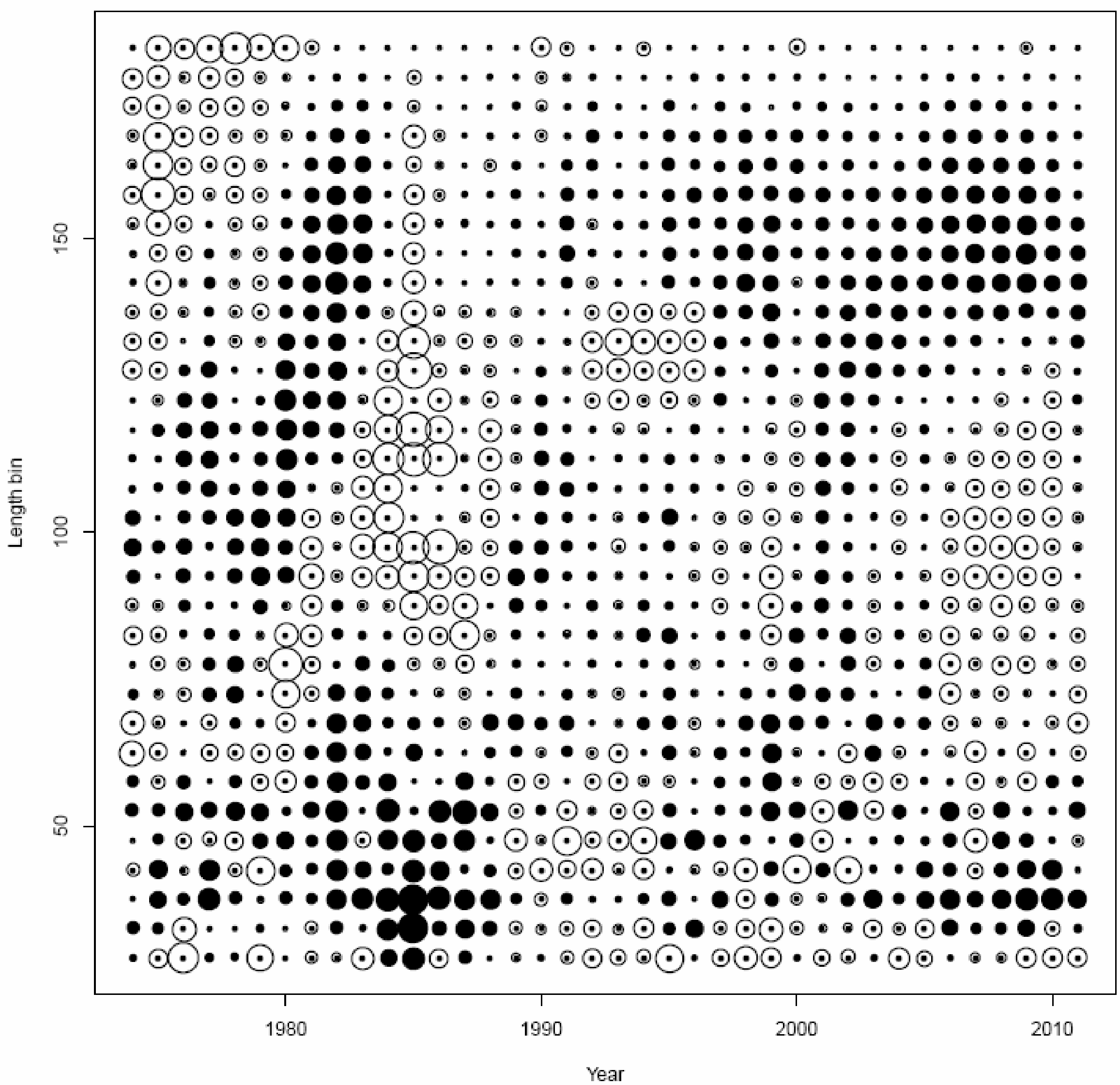

Figure 20. *Base Model* residuals of the model fit to the survey male size frequency data. Solid circles= overestimate and open circles=underestimate. Diameter of circle proportional to extent of lack of fit.

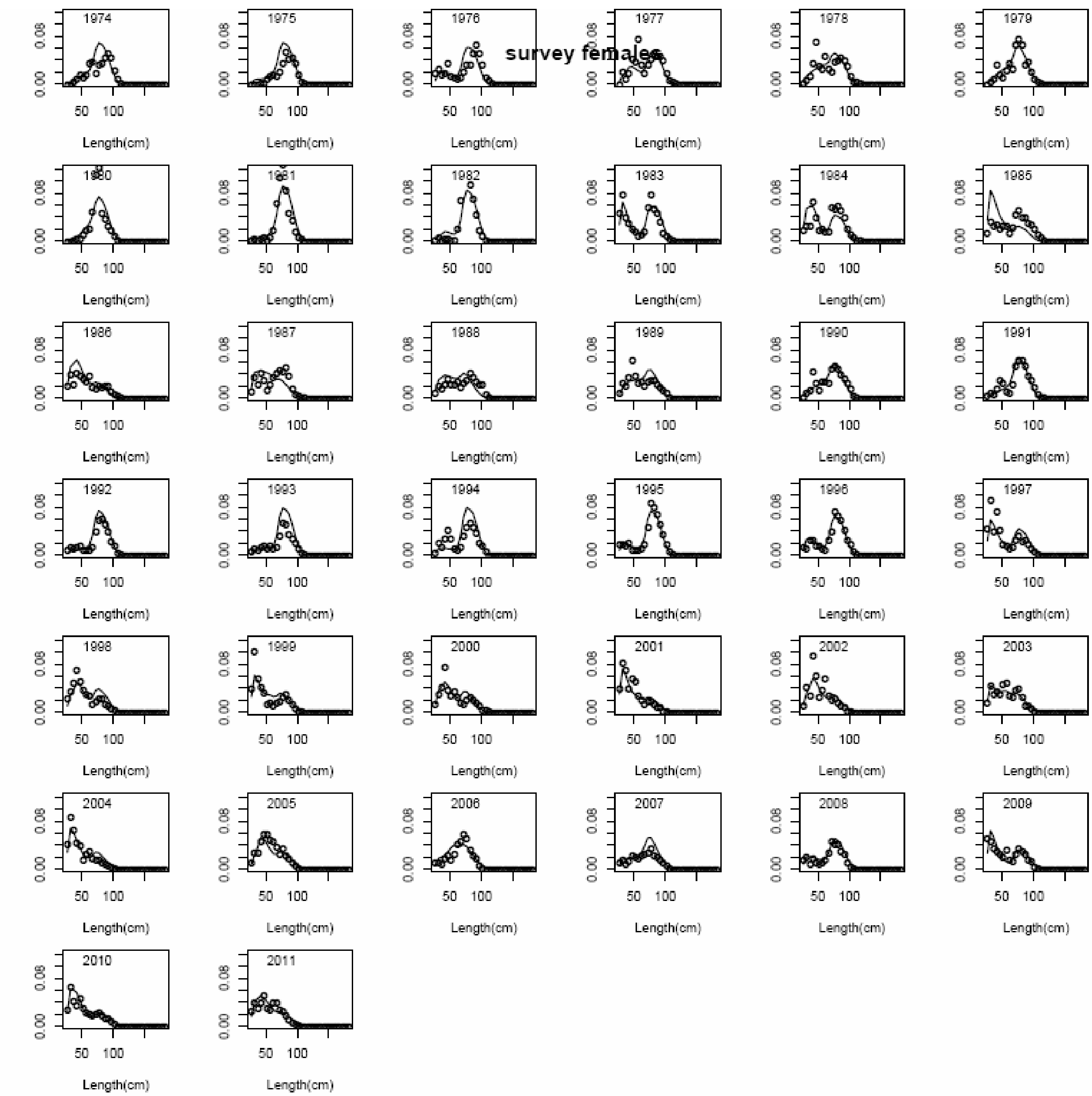

Figure 21. *Base Model* fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

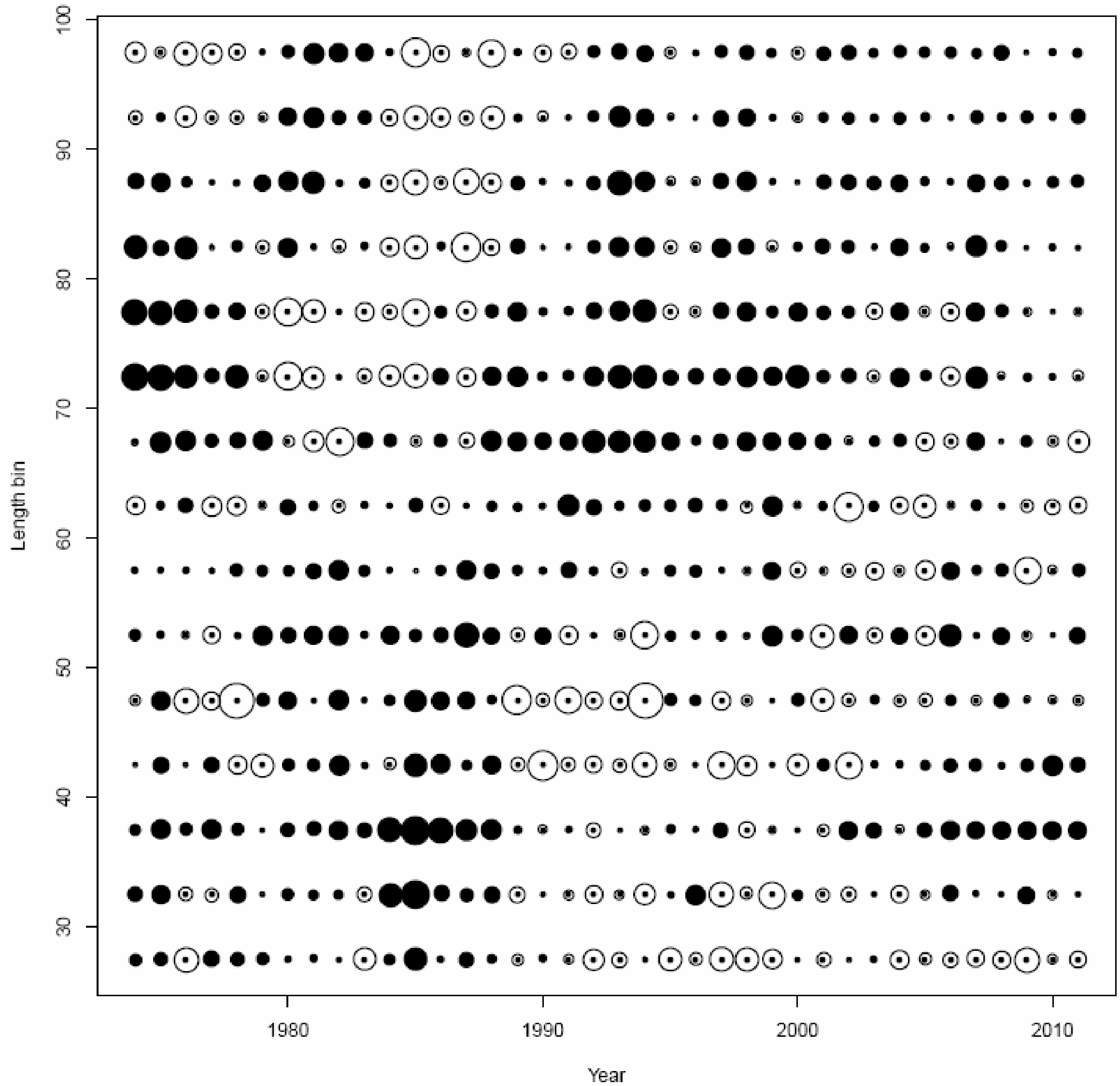

Figure 22. *Base Model* residuals of the model fit to the survey female size frequency data. Solid circles= overestimate and open circles=underestimate. Diameter of circle proportional to extent of lack of fit.

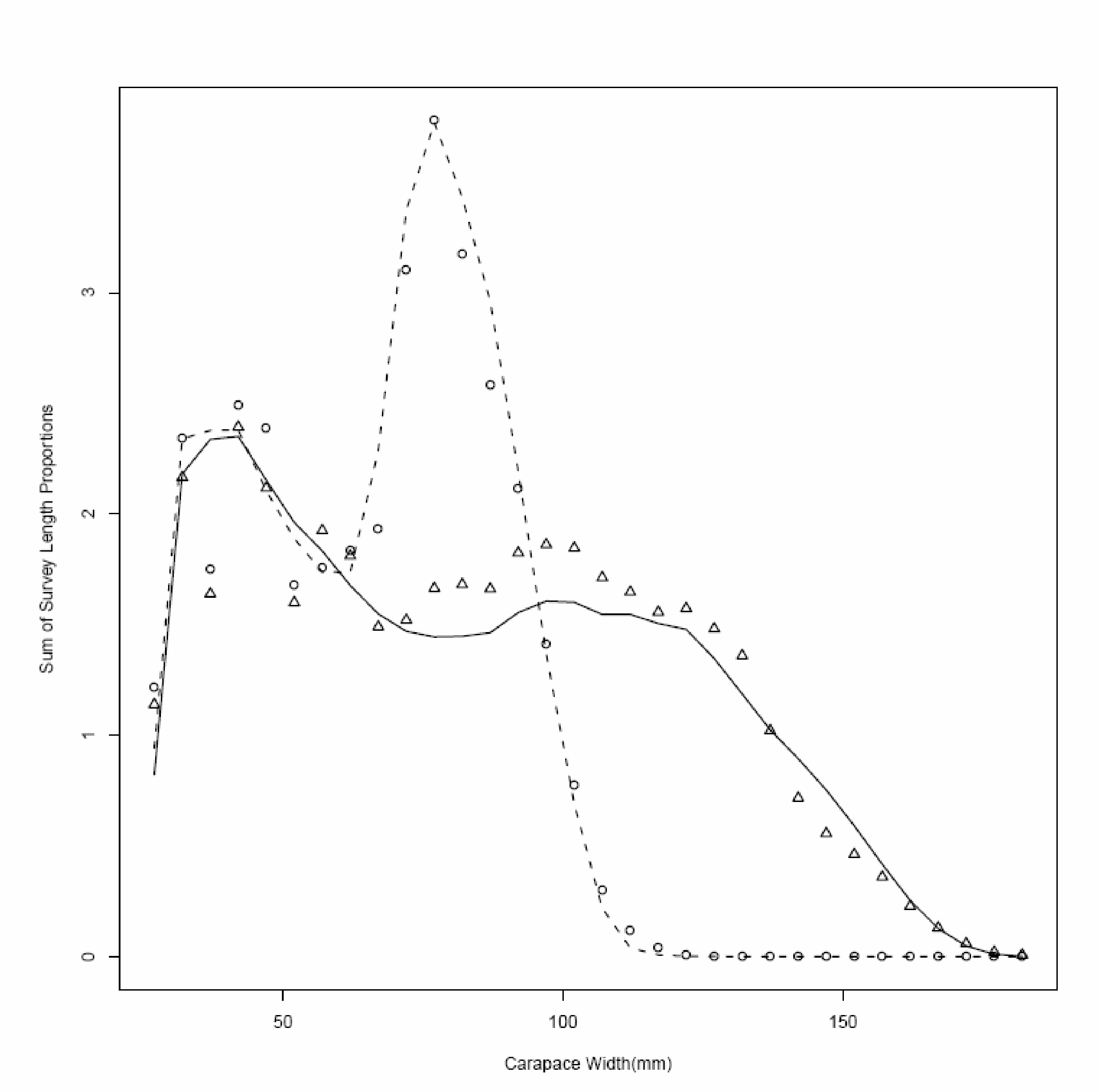

Figure 23. *Base Model* summary fit over all years to the survey male (solid line) and female (dotted line) size frequency data, all shell conditions combined. Symbols are observed data.

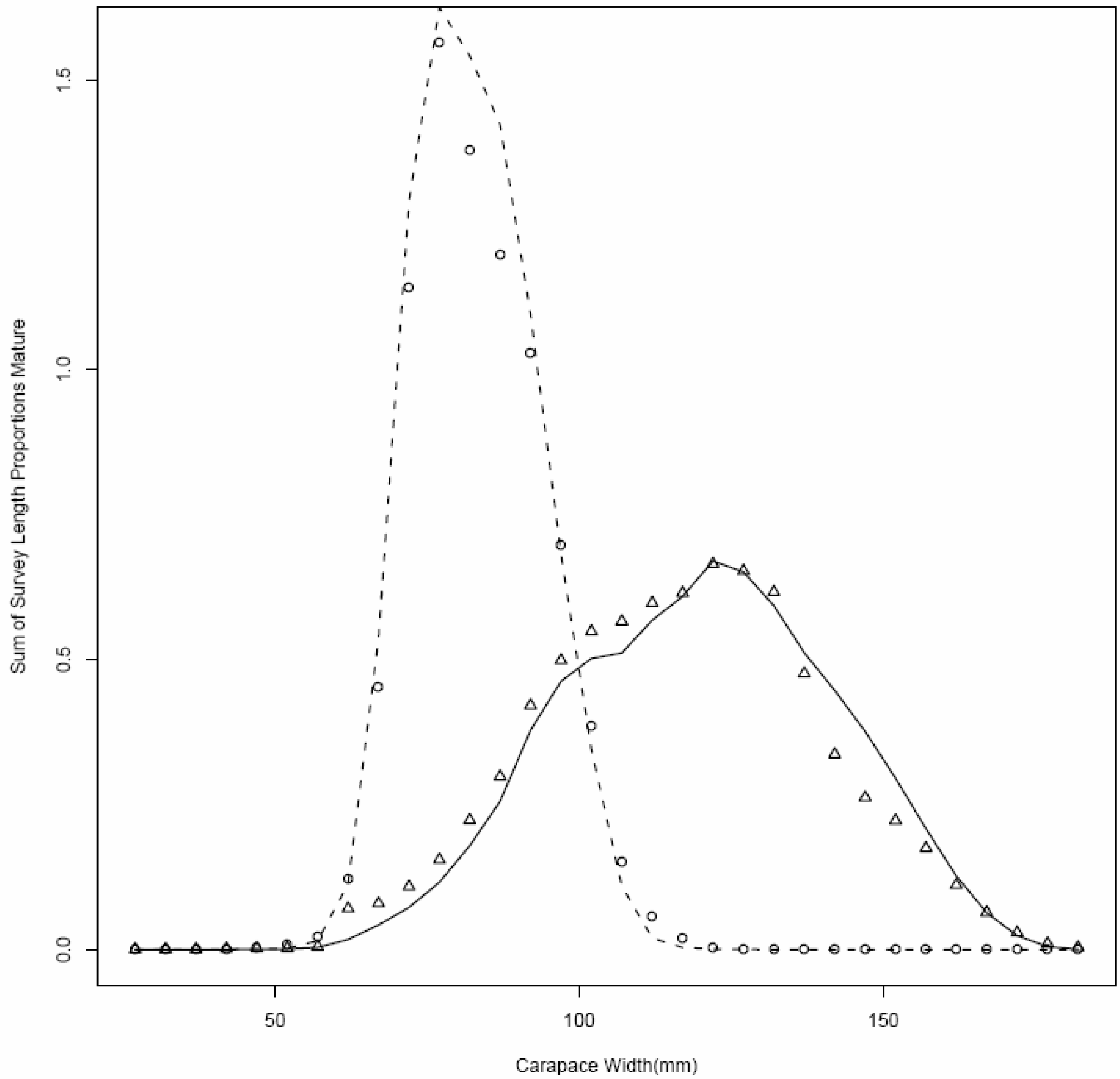

Figure 24. *Base Model* summary fit over all years to the survey mature male (solid line) and mature female (dotted line) size frequency data, all shell conditions combined. Symbols are observed data.

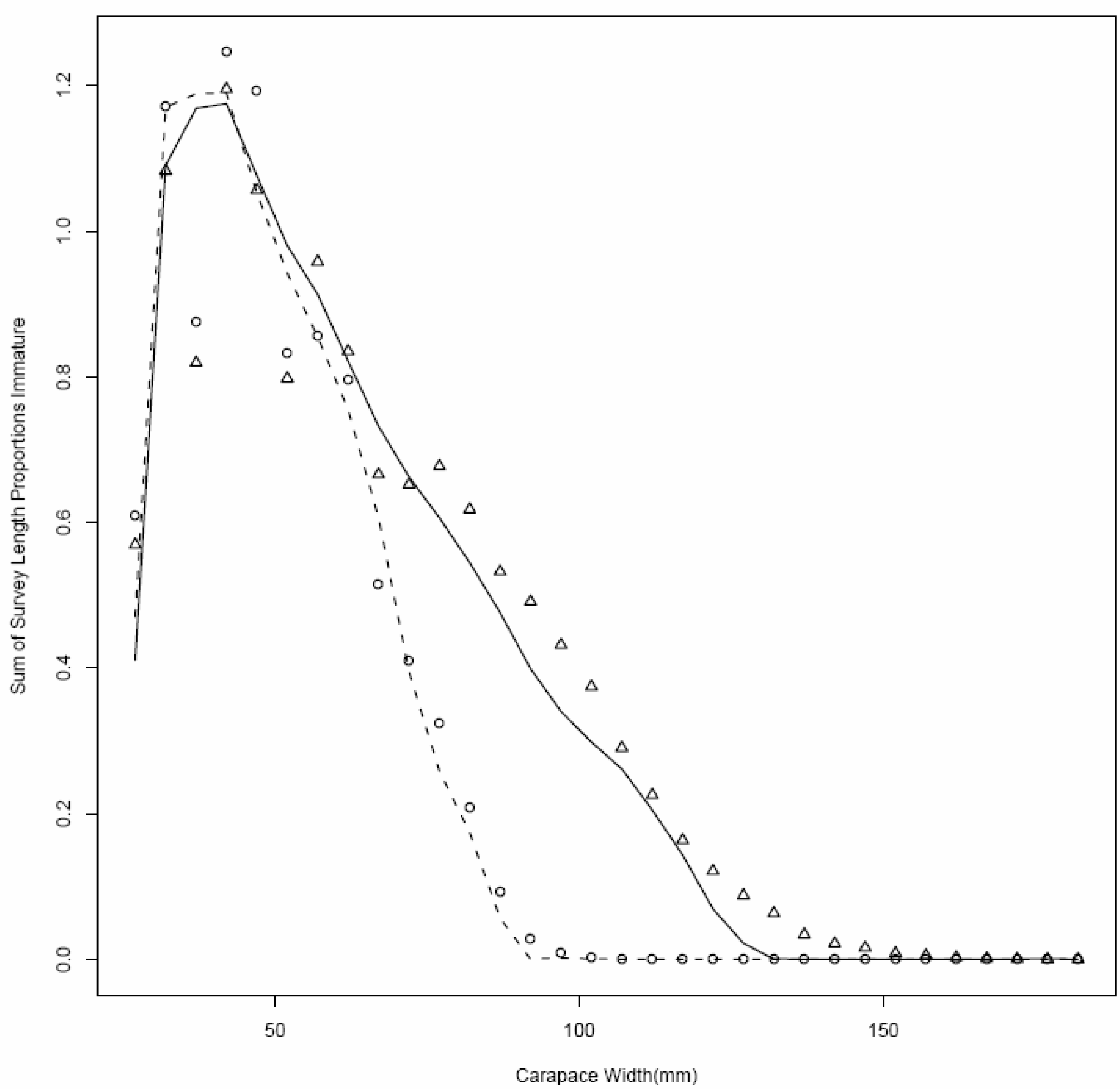

Figure 25. *Base Model* summary fit over all years to the survey immature male (solid line) and immature female (dotted line) size frequency data, all shell conditions combined. Symbols are observed data.

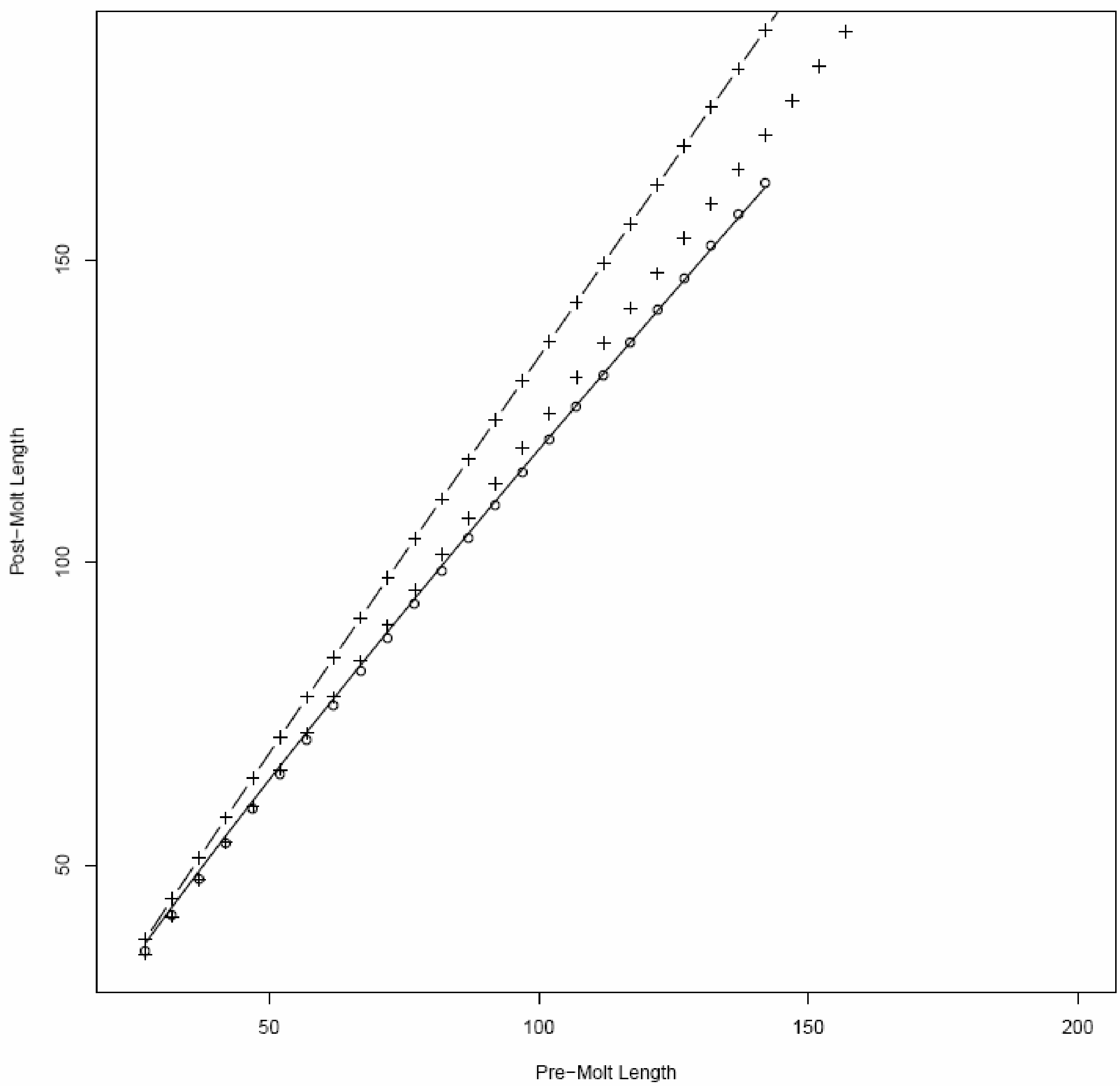

Figure 26. *Base Model* estimated relationships of pre-molt length to post-molt length (mm cw) for male (dashed with pluses) and female (dashed with circles) eastern Bering Sea Tanner crab. The empirically-derived growth relationships for male (pluses) and female (circles) based on data collected near Kodiak Island in the Gulf of Alaska are shown for reference.

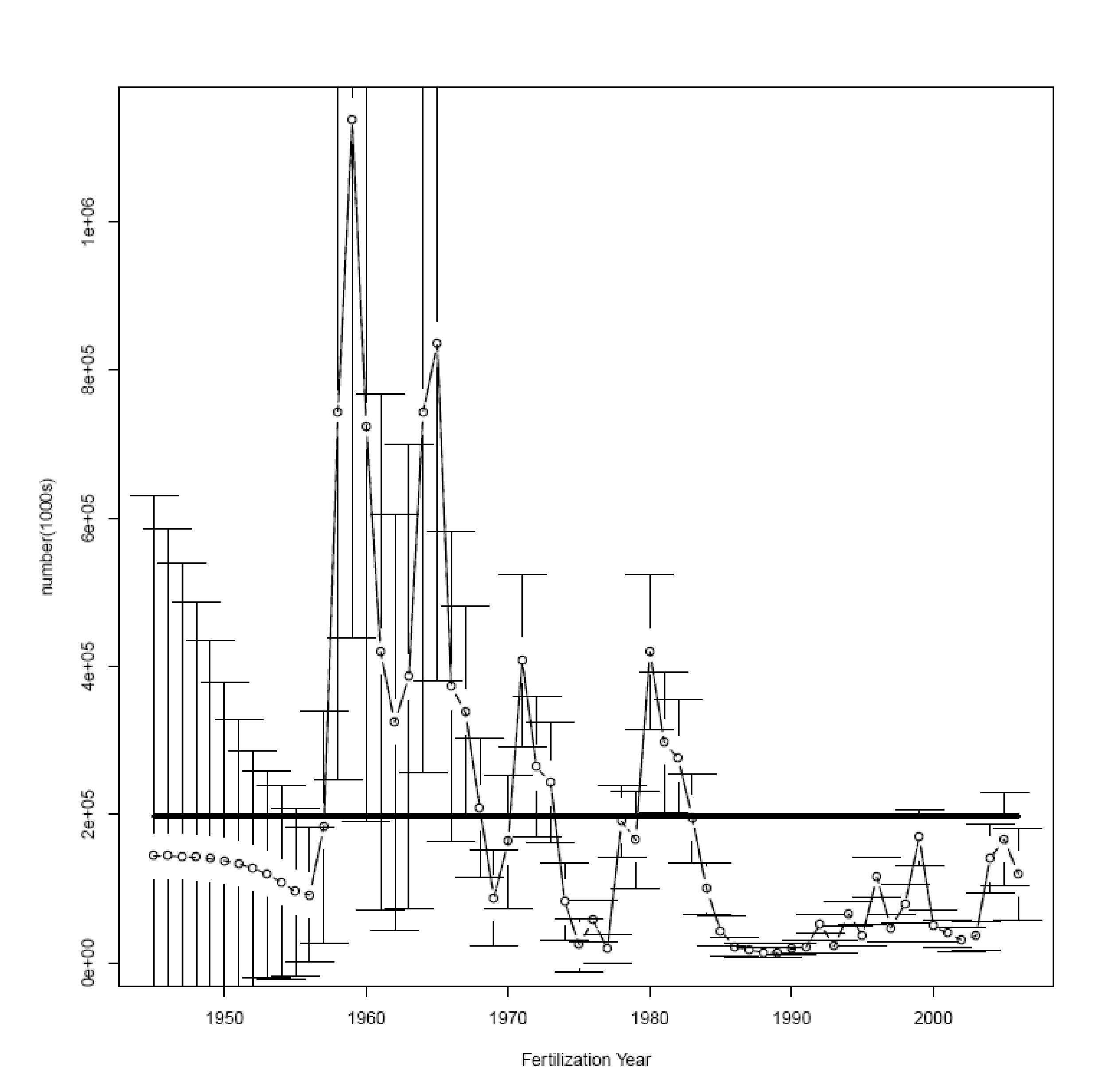

Figure 27. *Base Model* recruitment to model of crab 25 mm to 50 mm by fertilization year. Total recruitment is 2 times recruitment in the plot given that male and female recruitment is set to be equal. Solid horizontal line is average recruitment over all years.

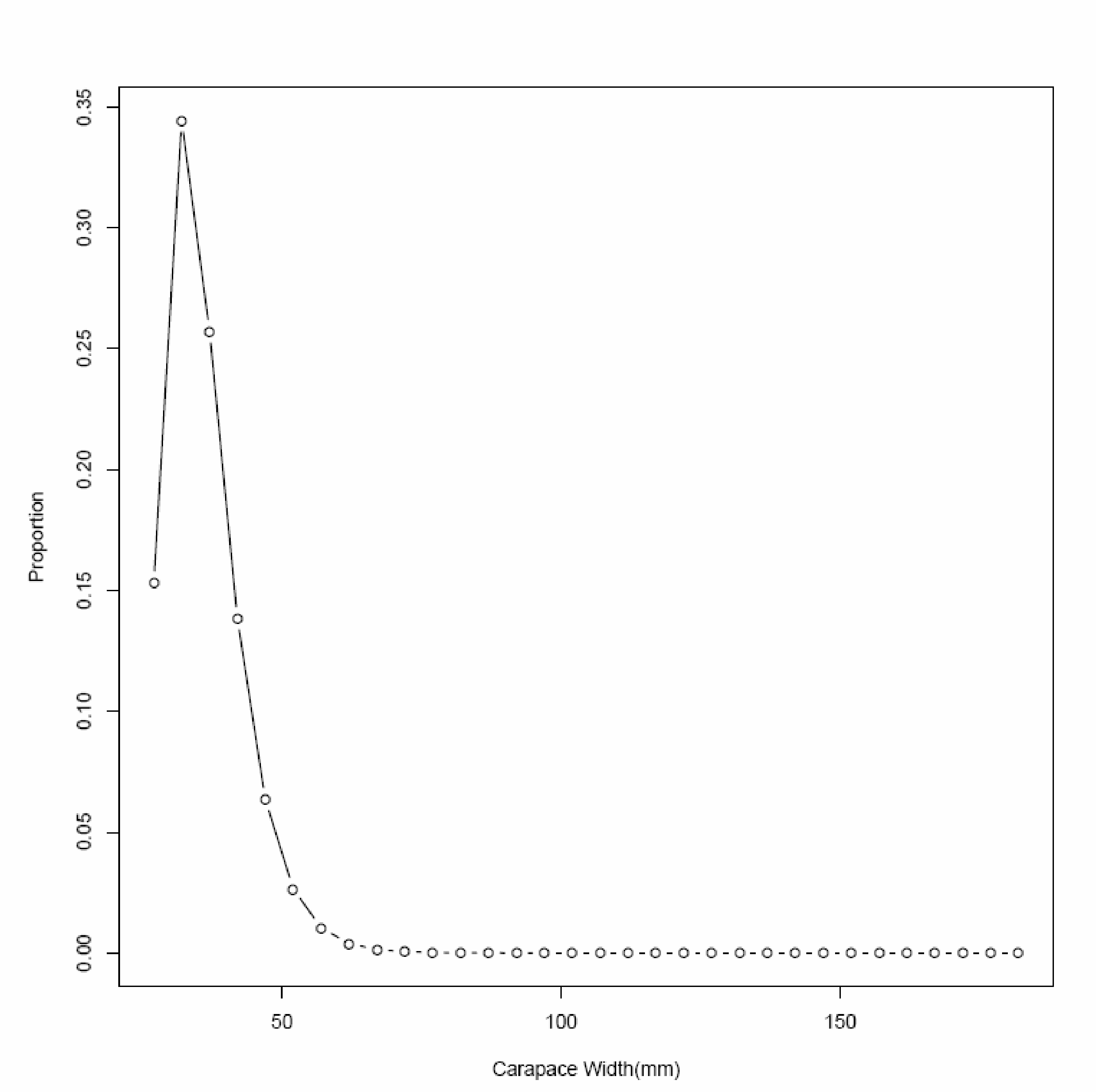

Figure 28. *Base Model* distribution of recruits to length bins estimated by the model.

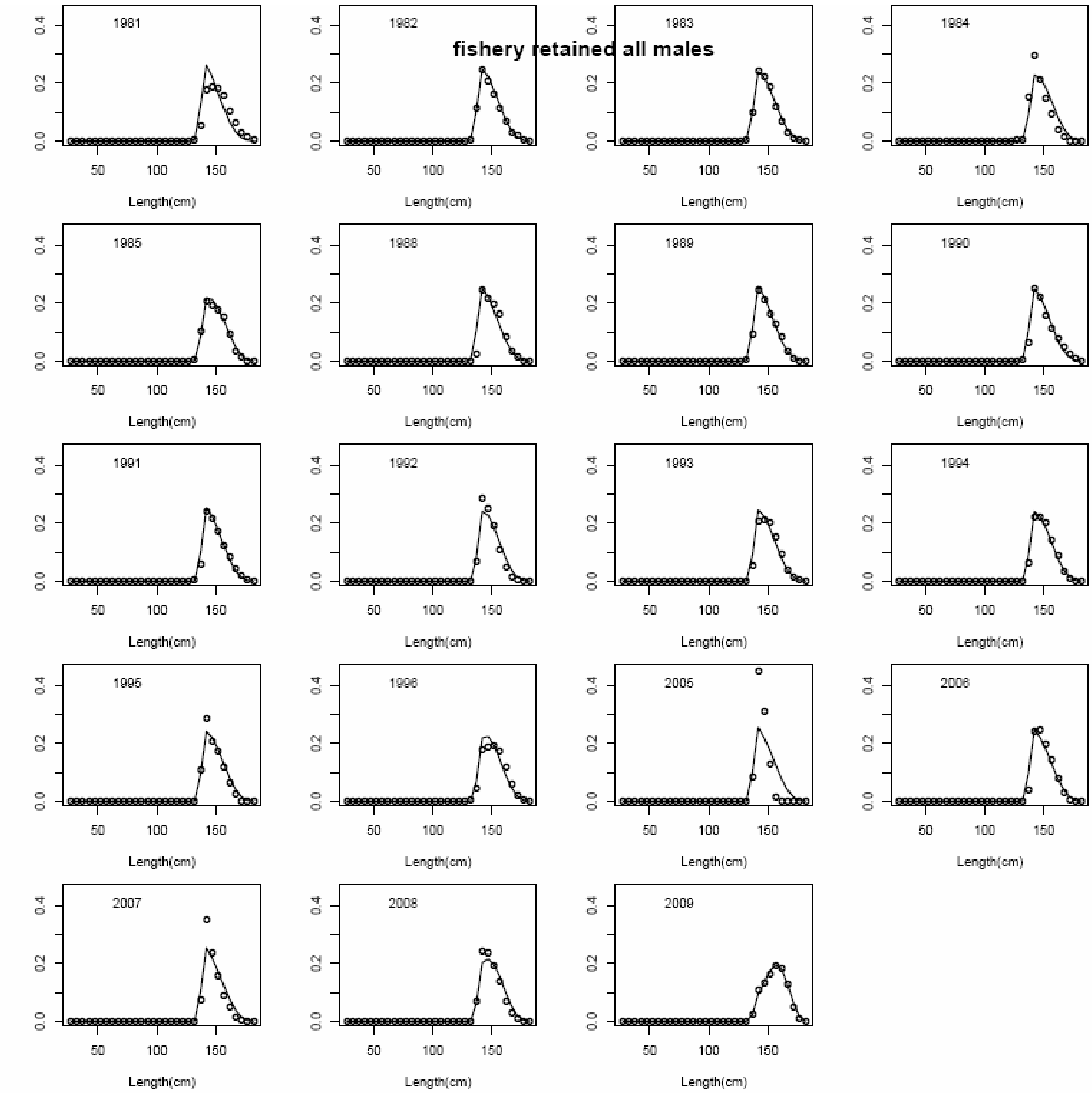

Figure 29. *Base Model* fit to the retained male size frequency data in the directed fishery, shell condition combined. Circles are observed data.

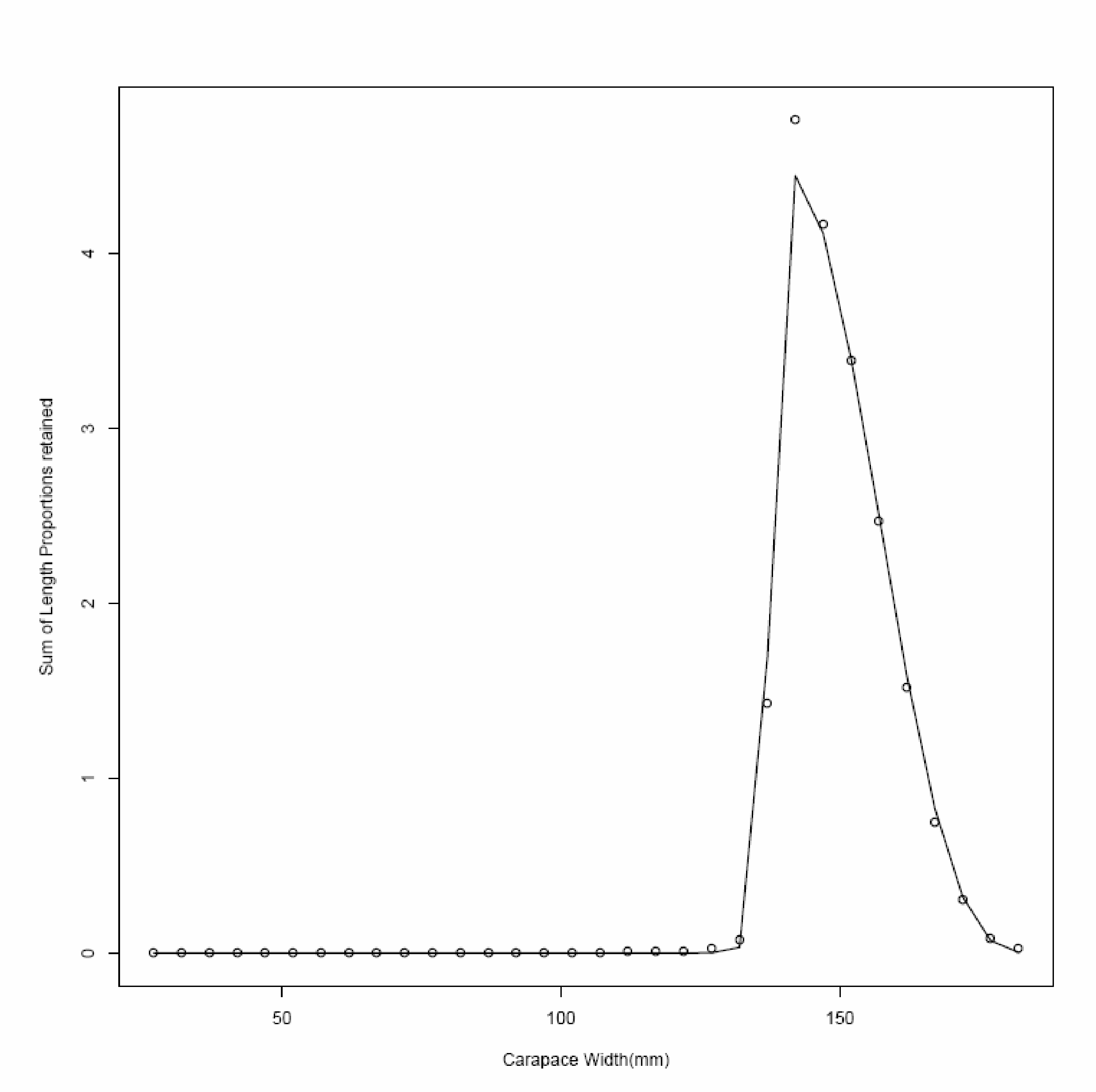

Figure 30. *Base Model* summary fit over all years to the retained male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data.

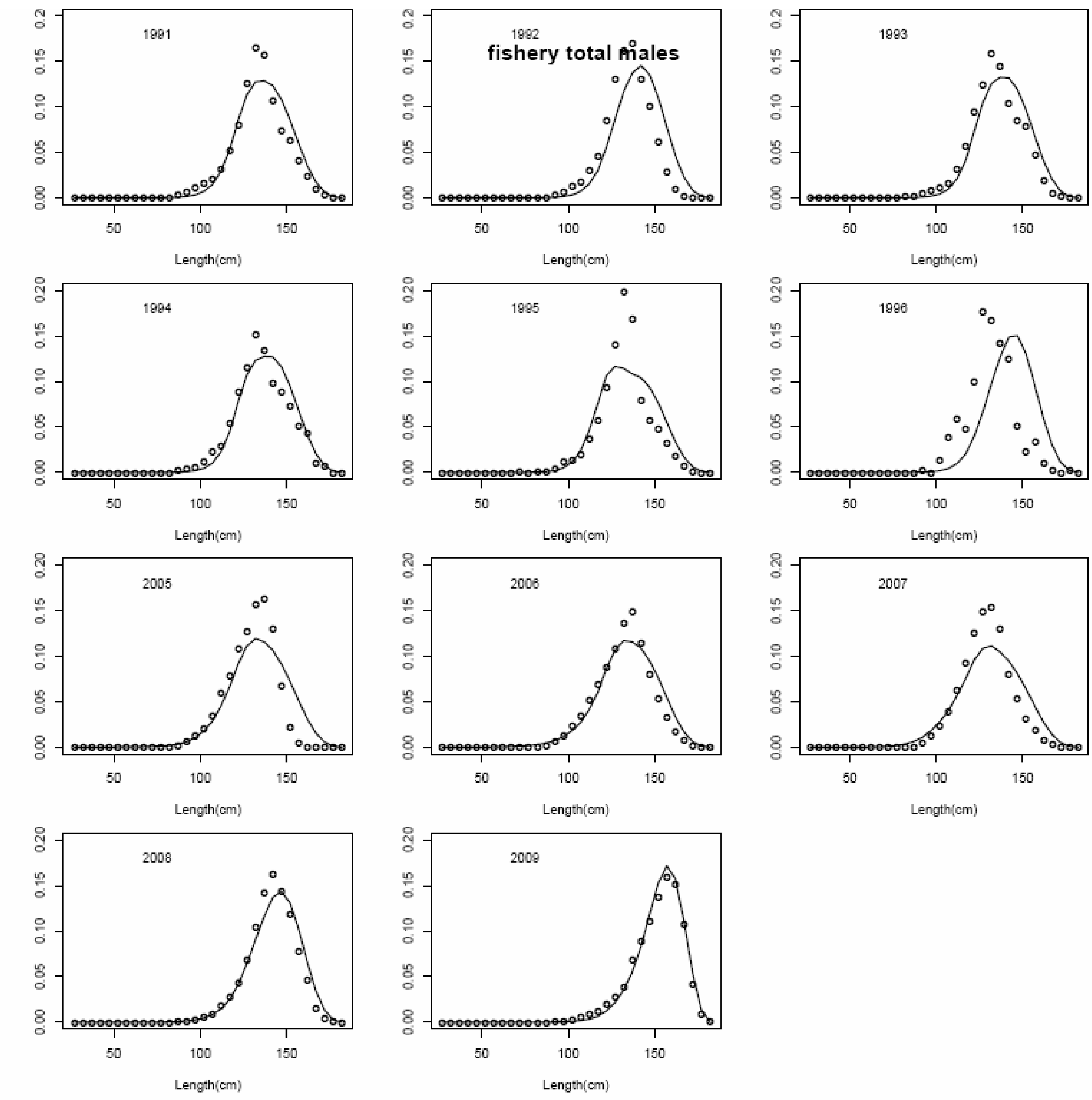

Figure 31. *Base Model* fit to the total (discard plus retained) male size frequency data in all fisheries combined, shell condition combined. Circles are observed data.

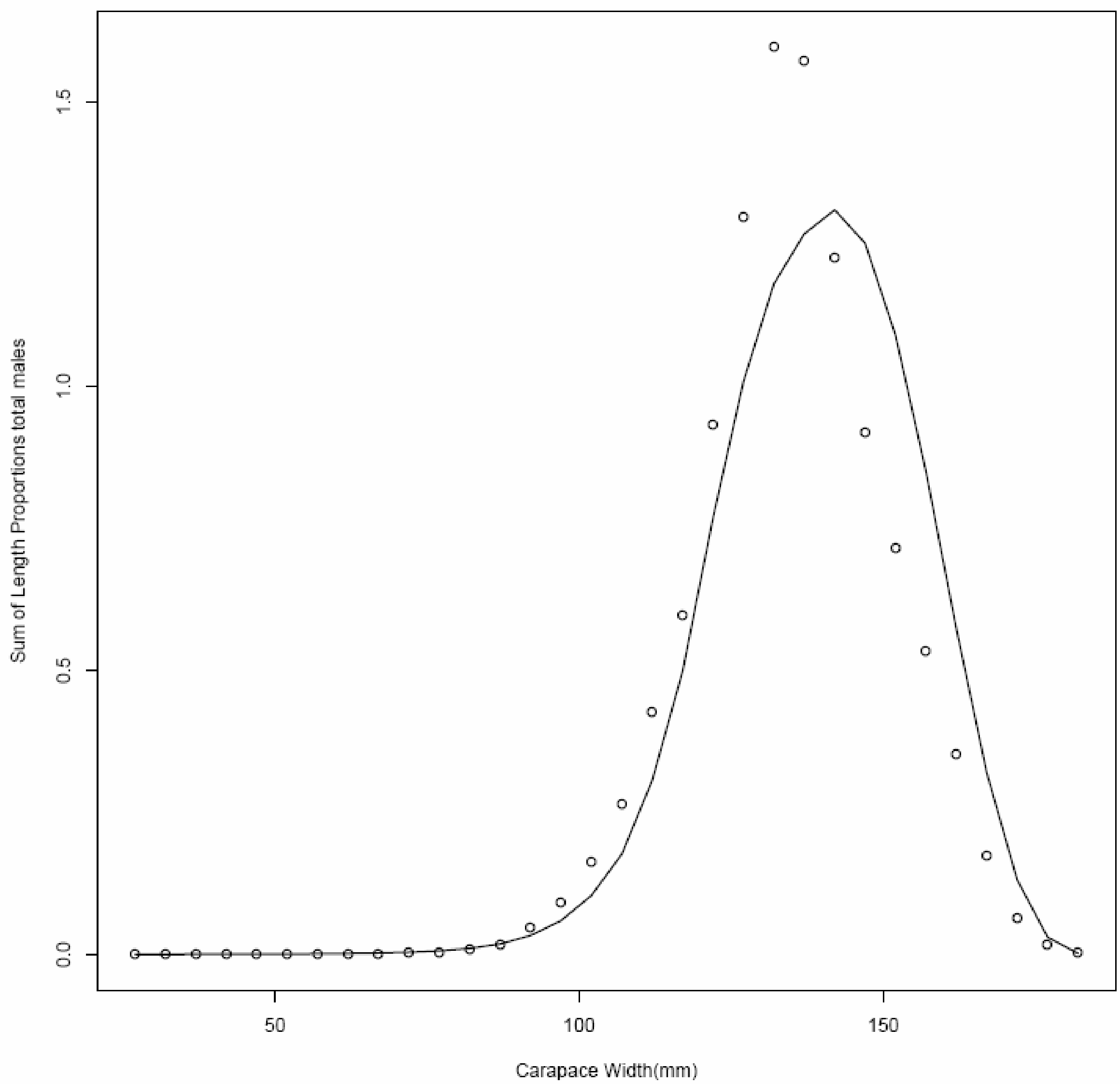

Figure 32. *Base Model* summary fit over all years to the total (discard plus retained) male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data.

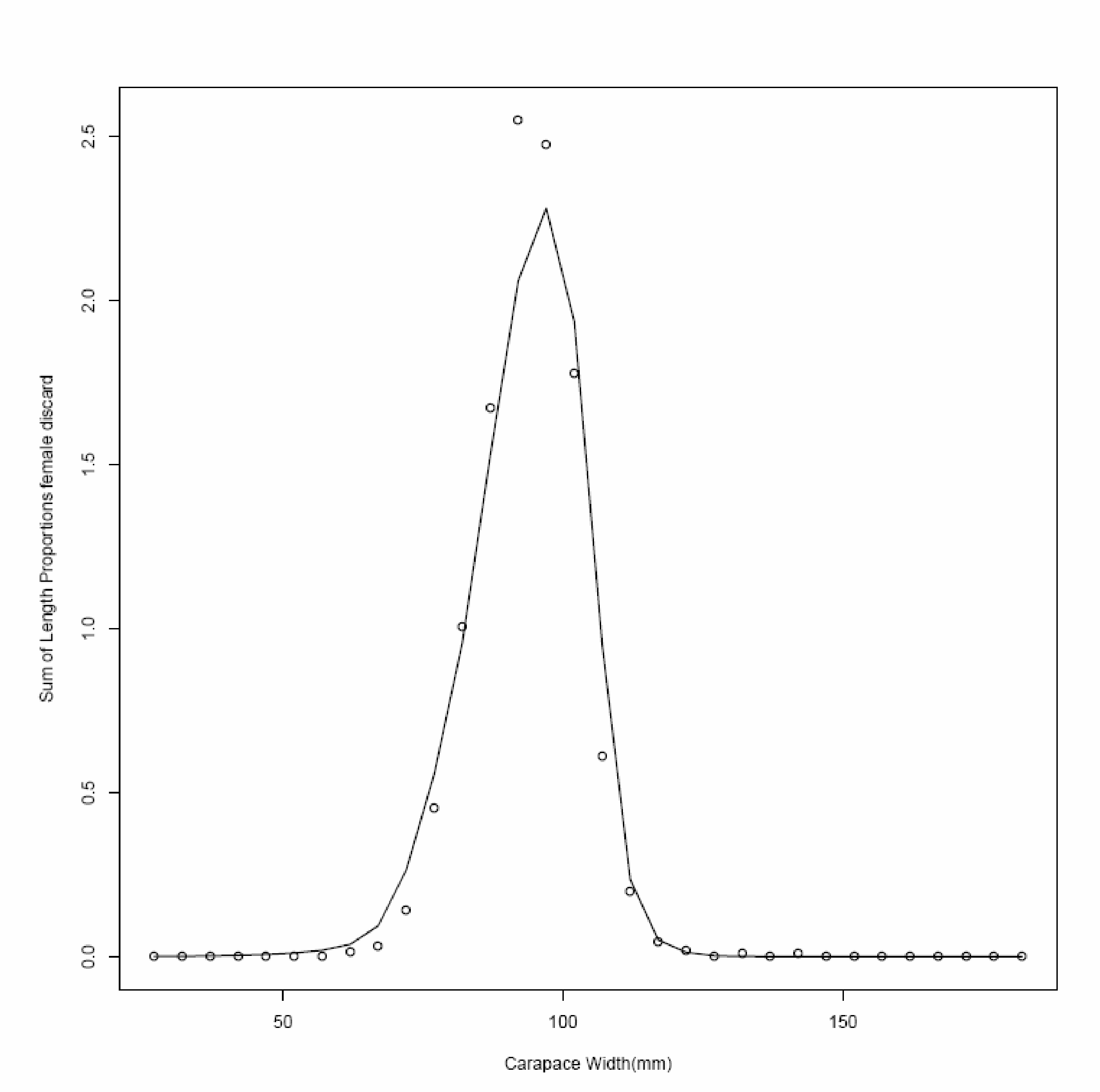

Figure 33. *Base Model* summary fit over all years to the discard female size frequency data in the directed fishery. Solid line is the model fit. Circles are observed data.

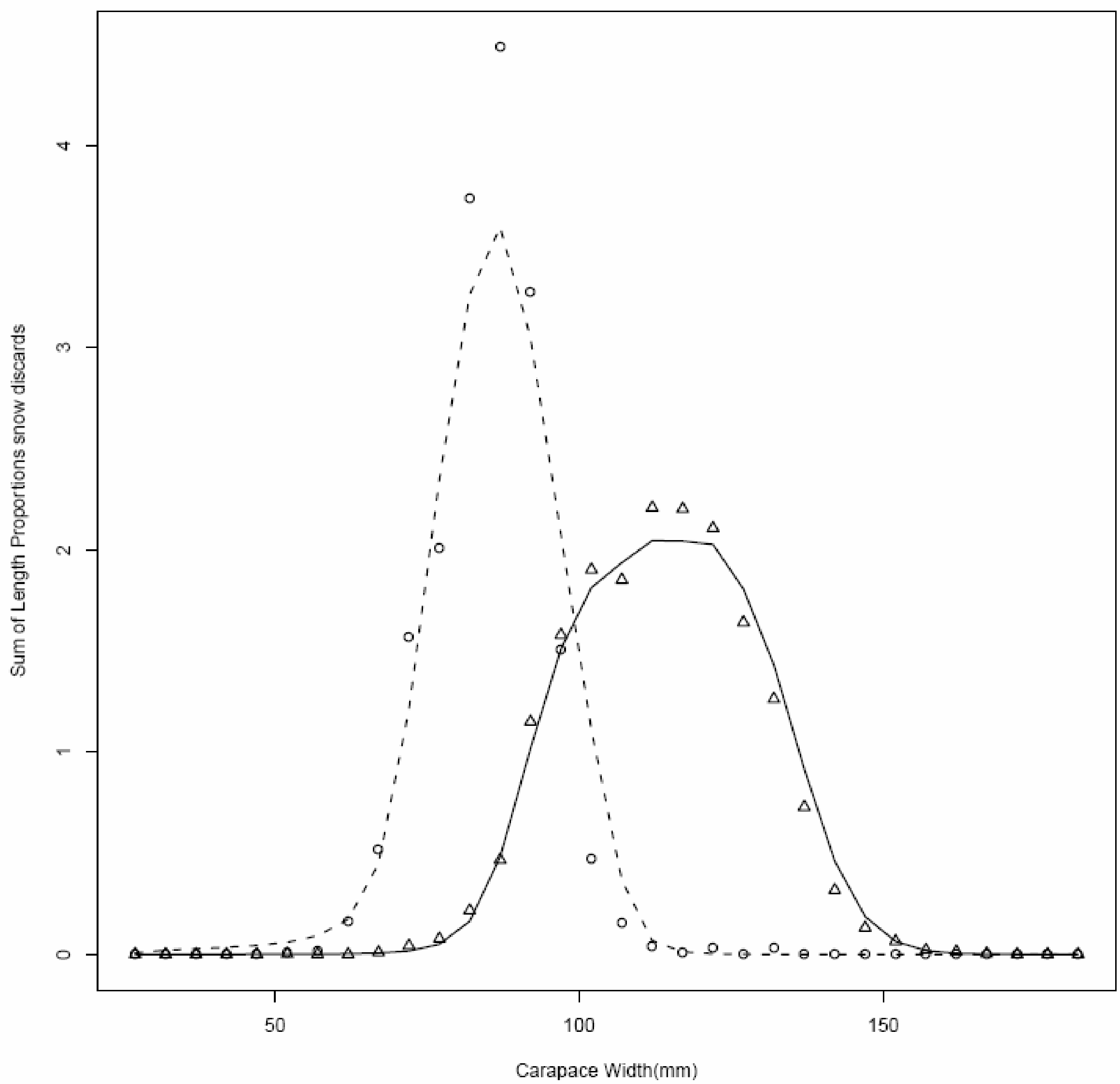

Figure 34. *Base Model* summary fit over all years to the discards in the snow crab fishery for males (solid line) and females (dotted line) size frequency data. Symbols are observed data.

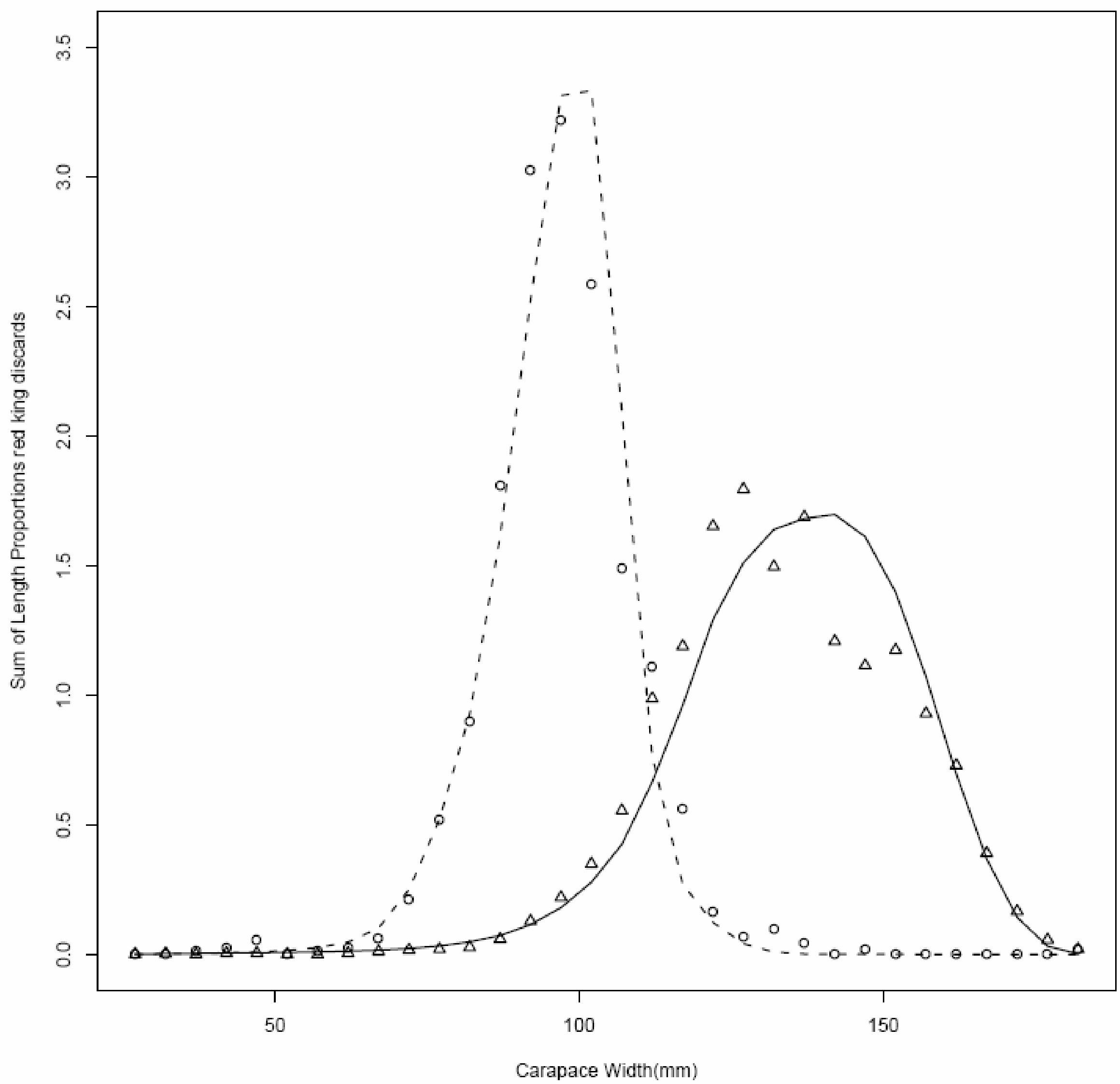

Figure 35. *Base Model* summary fit over all years to the discards in the Bristol Bay red king crab fishery for males (solid line) and females (dotted line) size frequency data. Symbols are observed data.

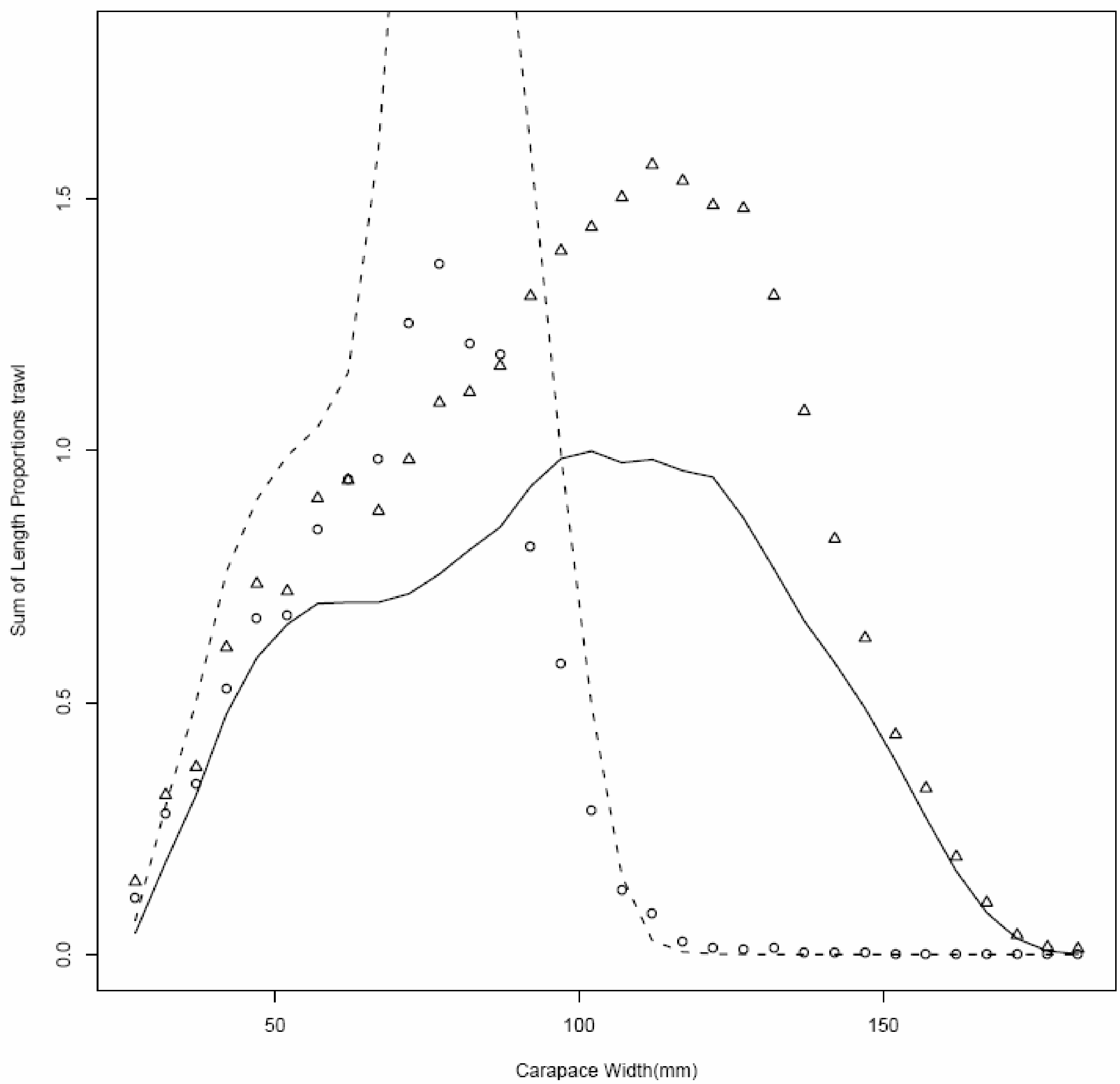

Figure 36. *Base Model* summary fit over all years to the discards in the eastern Bering Sea groundfish fisheries for males (solid line) and females (dotted line) size frequency data. Symbols are observed data.

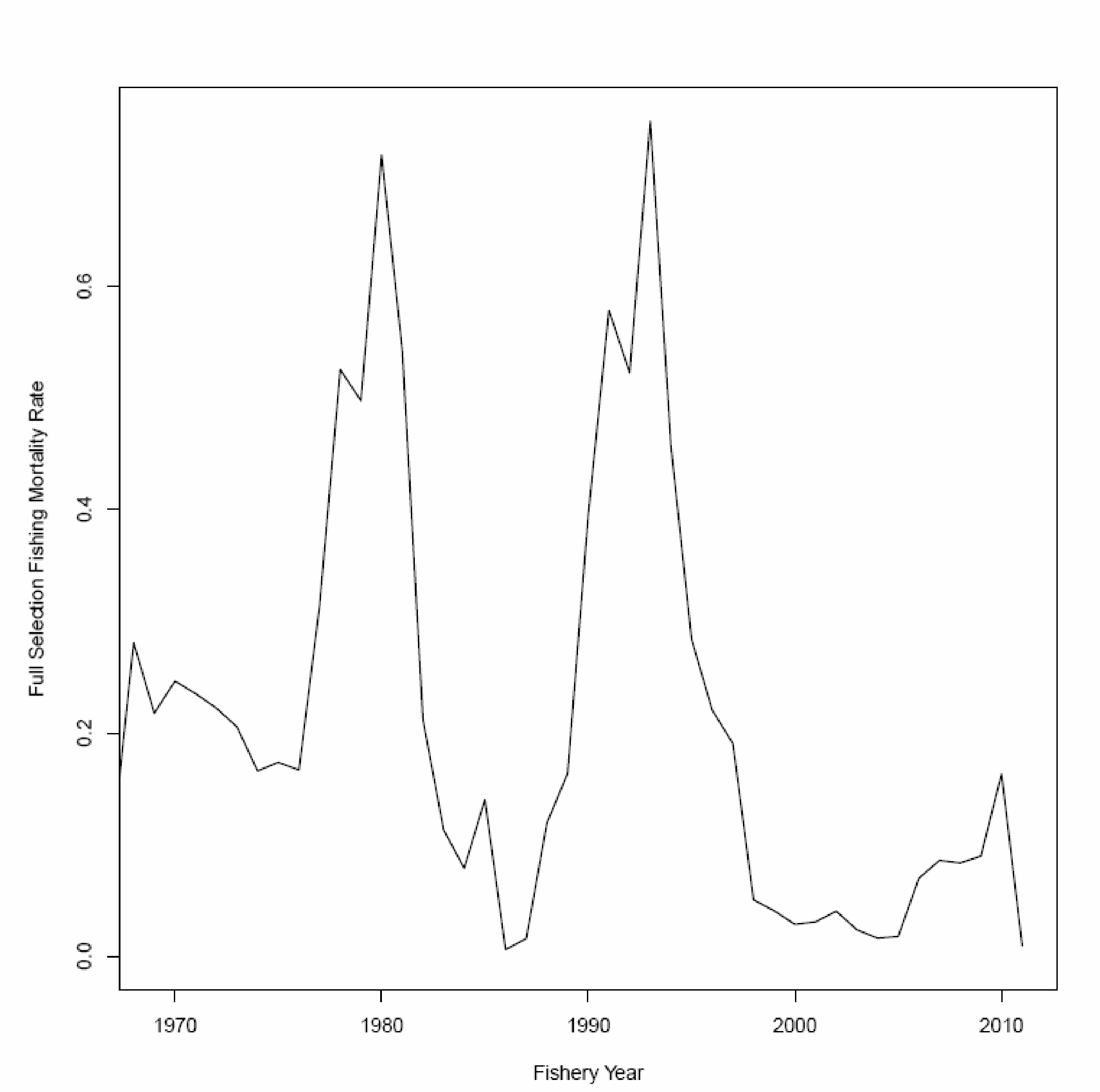

Figure 37. *Base Model* full-selection total fishing mortality rates estimated in the model from 1970 to 2011 fishery seasons (1969 to 2010 survey years).

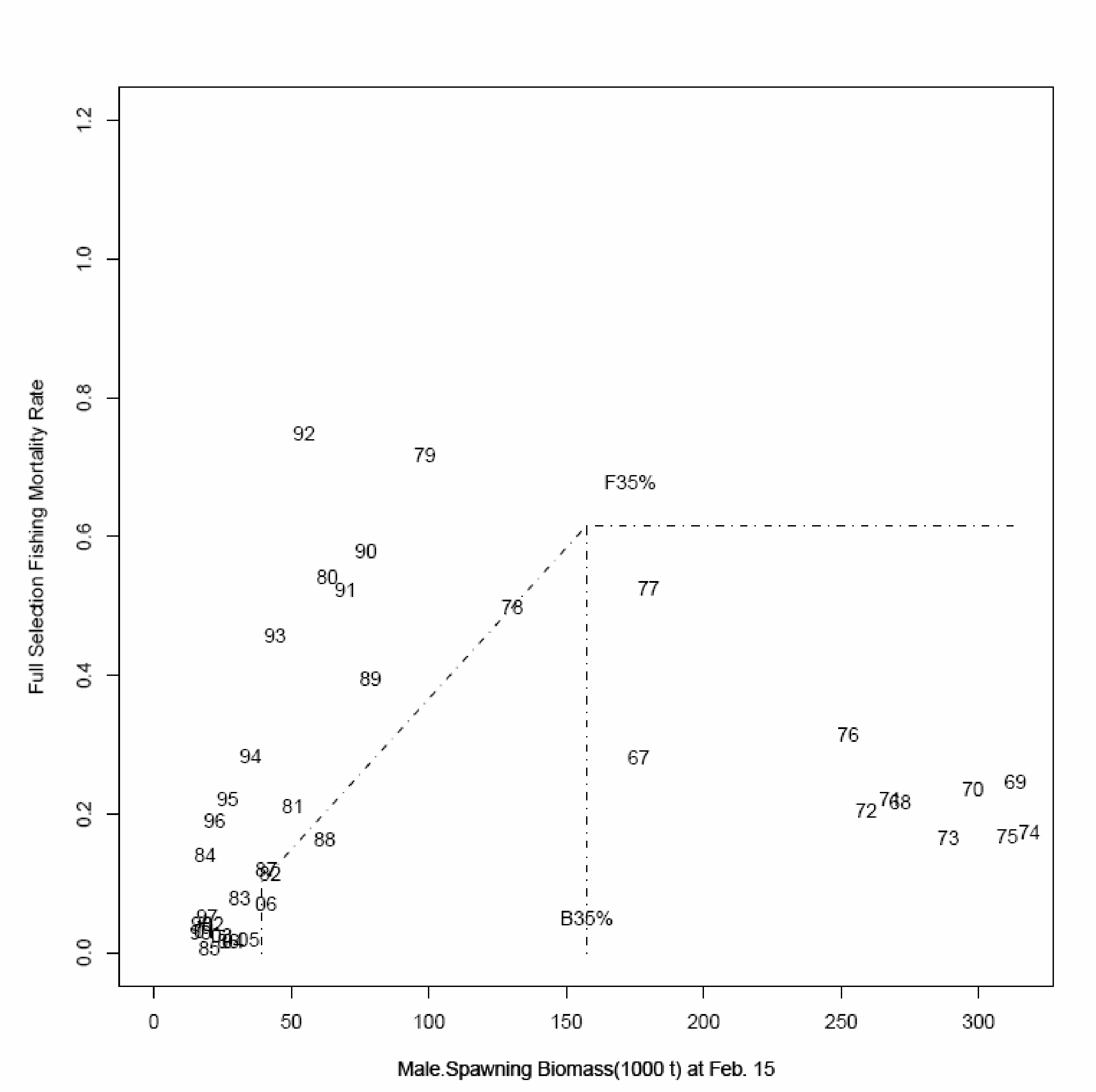

Figure 38. Full-selection fishing mortality versus male mature biomass at mating in fishing years 1967-2010/11. The *Base Model* OFL control rule where $F_{35\%}$=0.616 and $B_{35\%}$=157.43 thousand t.

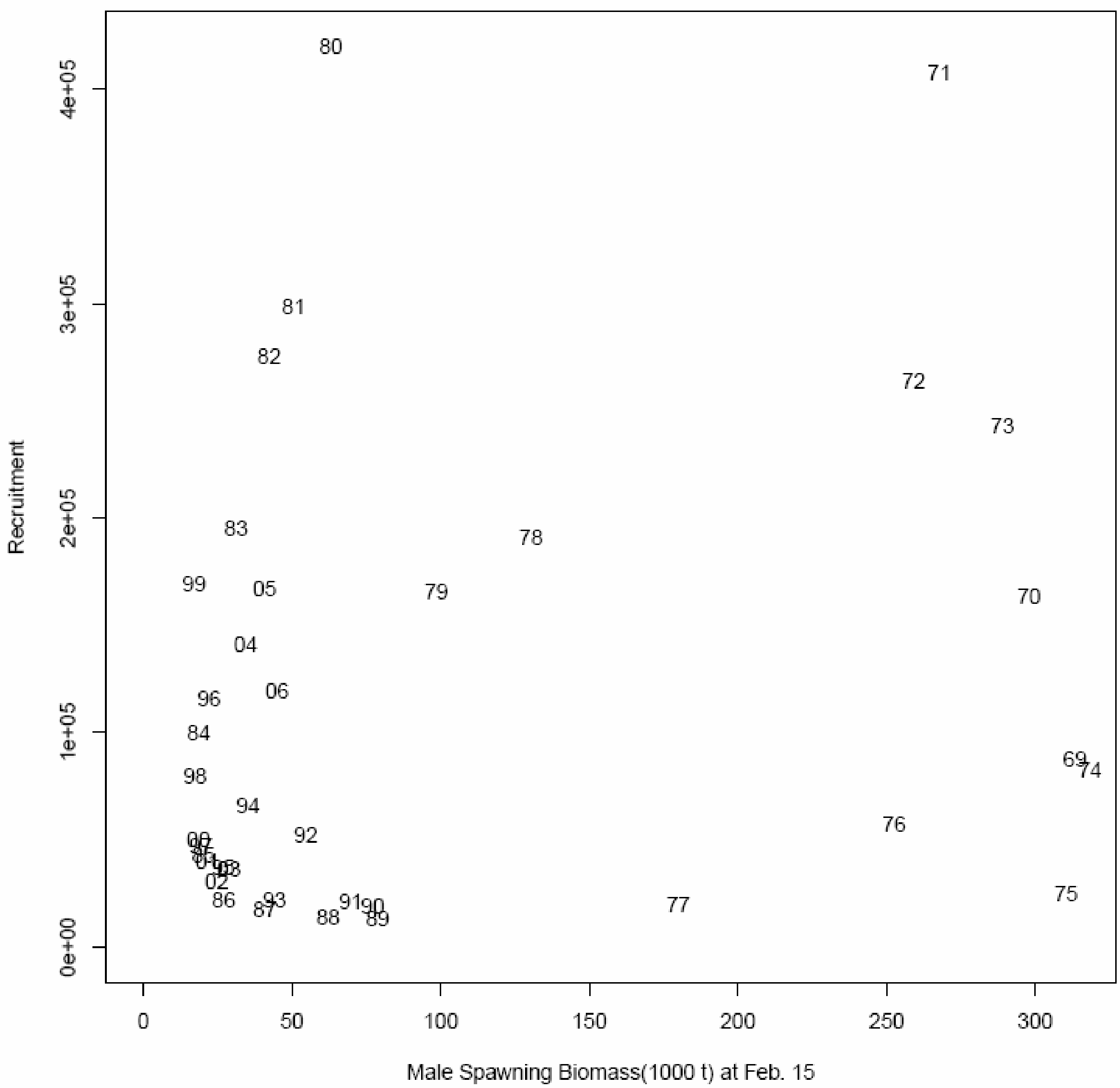

Figure 39. *Base Model* recruitment (1000 crab) vs. male mature biomass at time of mating (1000 t). Two digit year numbers are fertilization year which is lagged 5 years from recruitment to the model. Recruitment is one-half of total recruits.

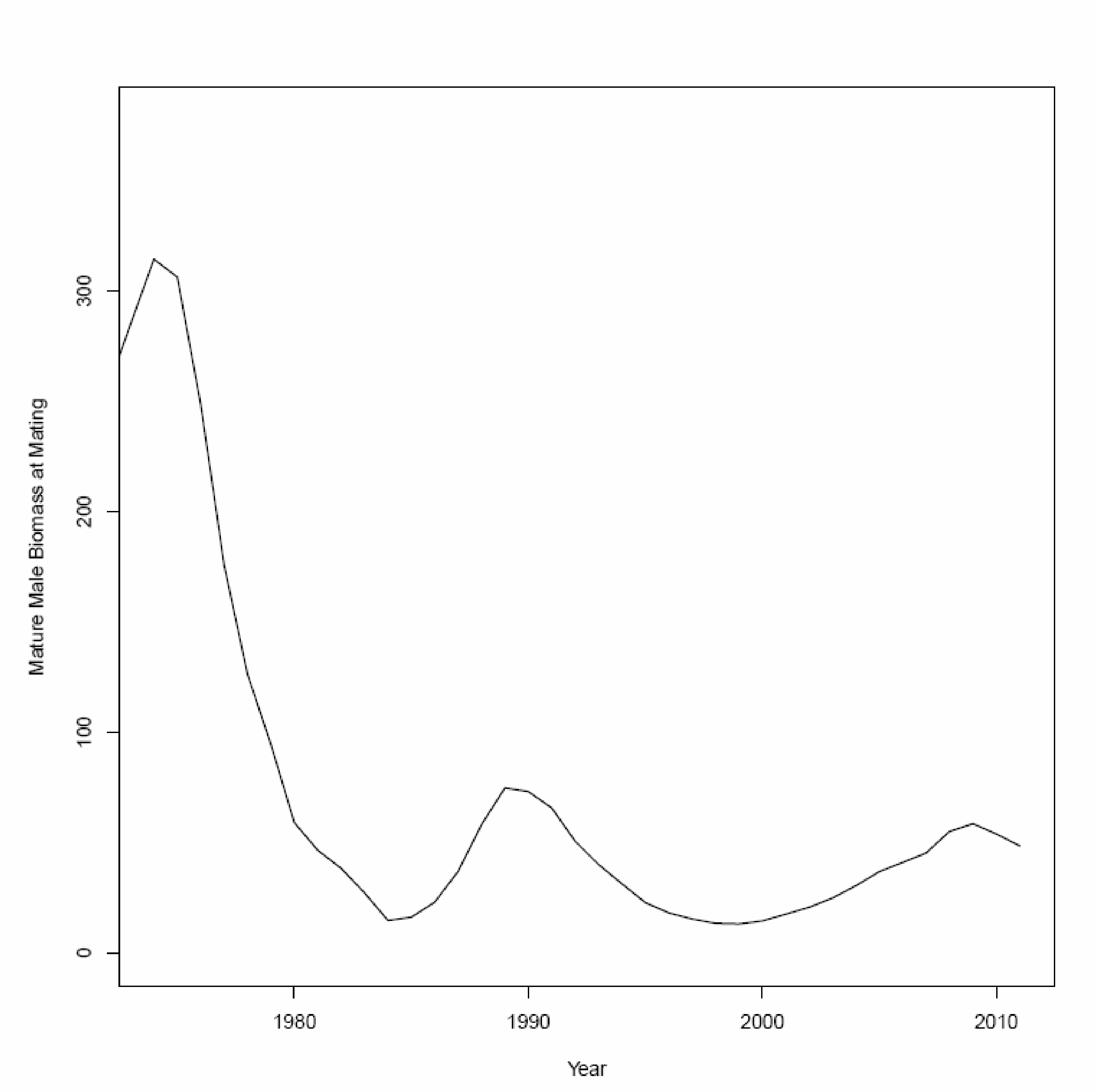

Figure 40. *Base Model* time-trajectory of mature male biomass at the time of mating for EBS Tanner crab (1000 t) for years 1974-2011.

Appendix A. Projections and Rebuilding Analysis

Introduction

In this appendix, we report on results of a rebuilding analysis using results of *Base Model* in a projection model to perform stock simulations in order to evaluate the consequences of harvest strategies on stock rebuilding and fishery performance. The specification of the projection model is presented in section in G.9 (Rugolo and Turnock 2011a). 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.

For the *Base Model*, we estimated $B_{35\%}$=157.43 thousand t and $F_{35\%}$=0.616. The model estimate of 2010/11 MMB at mating (53.93 thousand t) represents $0.34B_{35\%}$. Thus, simulations begin with the stock in an overfished condition. Simulations are performed under six scenarios: (1) fishing at the full F_{OFL}; (2) fishing at $0.75F_{OFL}$; (3) fishing at F_{OFL}=0 with only groundfish fishery discard mortality included; (4) fishing at F_{OFL}=0 with all non-directed fishery discard mortality included; (5) fishing at F_{OFL}=0 with all non-directed fishery discard mortality included, but with snow crab fishery discards at 2x the *Base Model* level; and (6) fishing at F_{OFL}=0 with all non-directed fishery discard mortality included, but with snow crab fishery discards at 4x the *Base Model* level.

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 $F_{OFL.}$

Directed fishery selectivity used for projections was based on a minimum legal size limit >=138 mm for the area east of 166^0 W longitude (Figure A-1). The new legal minimum size limit in effect for the 2011/12 fisheries to the east of 166^0 W longitude is 122 mm, however, retention will be uncertain until several fishery seasons have been prosecuted under this new size limit. The average of the previous three years for both total selectivity and retained selectivity was used for projections in the eastern area. The new size limit in effect for the area west of 166^0 W longitude was changed to 112 mm, however, an preferred minimum size limit of 128 mm may be imposed by the industry. For this analysis, the selectivity curve for the eastern area was shifted by 10 mm to approximate a possible industry-imposed limit of 128 mm for the western area.

Review of Stock Status

For the *Base Model*, $B_{35\%}$=157.43 thousand t and $F_{35\%}$=0.616, and the model estimate of 2010/11 MMB at mating (53.93 thousand t) represents $0.34B_{35\%}$. The proxy B_{MSY} used in the 2011 Tanner crab SAFE for OFL-setting under Tier-4 is estimated as the average observed MMB at the time of mating from survey data over the reference period 1974-1980 at 83,330 t (Rugolo and Turnock 2011b). The bias-corrected proxy B_{MSY} based on adjusted MMB at mating following the method of Rugolo and Turnock (2011c) is 93,240 t. The bias-corrected proxy B_{MSY} is calculated after extraction of the F_{MSY} catch rather than the observed catch which is a more consistent benchmark regardless of whether observed catches were larger or smaller than the F_{MSY} catch. In the 2011 Tier-4 SAFE, Rugolo and Turnock (2011b) estimated that after extraction of the total catch OFL, the resulting $MMB_{2010/11}/B_{MSY\ Proxy}$=0.36 using the bias-corrected proxy B_{MSY}, and 0.32 using the non-bias corrected proxy B_{MSY}.

By comparison, the average of the *Base Model* estimated MMB at mating over 1974-1980 is 189,339 t. After extraction of the 2010/11 total catch OFL, the resulting MMB at mating in 2010/11 = 53,930 t which represents a ratio $MMB_{2010/11}/B_{MSY\ Proxy}$=0.34. This is comparable to the bias-corrected Tier-4 assessment results using the same reference period.

The Tanner crab stock sharply declined 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 stock 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 pattern of male mature biomass (Figure 17) reflects that of the attendant directed fisheries (Figure 4) with peaks in the early- and late-1970s and early-1990s, and declines subsequent to these peaks. Full-selection fishing mortality rates estimated in the model concur with a history of excessive exploitation (Figure 37), peaking in 1992/93 coincident with peak extraction of catch and decline in stock biomass. If the $F_{35\%}$ OFL control rule established by Amendment 24 had been in effect from 1974/75-2010/11, in approximately one-half of the 44 years, the realized F would have exceeded the overfishing limit (Figure 38). 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 of crab 25 mm to 50 mm cw fluctuated widely from 1950-2006 displaying a prominent period of moderately high recruitment in the early-to-mid-1960s (Figure 27). 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 recovery.

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. Under the former BSAI King and Tanner Crab fishery management plan (NPFMC 1998) and overfishing definitions, the Tanner crab stock was above the B_{MSY} level indicative of a restored stock for the second consecutive year in 2007 and declared rebuilt. The increases in survey biomass in 2005-2008 were driven principally by a few large tows that inflated total biomass estimates (Rugolo et al. 2008) raising concerns whether there was an actual increase in MMB in this period. The stock was again declared overfished in 2010 and deemed in need of a new rebuilding plan (Rugolo and Turnock 2010).

Results

Projections using output from the *Base Model* were run under six harvest strategy scenarios: (1) fishing at the full F_{OFL}; (2) fishing at $0.75F_{OFL}$; (3) fishing at F_{OFL}=0 for the directed fishery but with only groundfish fishery discard mortality included; (4) fishing at F_{OFL}=0 for the directed fishery but with all non-directed fishery discard mortality included; (5) fishing at F_{OFL}=0 for the directed fishery but with all non-directed fishery discard mortality included, and with snow crab fishery discards at 2x the *Base Model* level; and (6) fishing at F_{OFL}=0 for the directed fishery but with all non-directed fishery discard mortality included, and with snow crab fishery discards at 4x the *Base Model* level (Tables A-1 through A-6).

$B_{35\%}$ (157,430 t) was estimated using average recruitment to the model for the period 1966-1972, or 1961-1967 fertilization year, which resulted in MMB estimated in 1974-1980 (Table 5, Figures 27 and 40). The directed fishery was closed by regulation in the 2011/12 fishing season. Because the fishery was closed, the directed catch was zero in 2011/12 for all projections.

Tables A-1 and A-2 contain the splits of directed fishery total male catch and retained catch in the eastern and western areas based on the observed 2011/12 survey abundance by length in each area. Fishing at $1.0F_{OFL}$ (Table A-1), a probability of MMB at mating exceeding $B_{35\%}$ of greater than 0.5 (p=0.505) is achieved in 2022/23. Fishing at $0.75F_{OFL}$ (Table A-2), a probability of MMB at mating exceeding $B_{35\%}$ of greater than 0.5 (p=0.538) is achieved in 2021/22. Fishing at F_{OFL}=0 except for the occurrence of groundfish discard catch only, a probability of MMB at mating exceeding $B_{35\%}$ of greater than 0.5 (p=0.558) is achieved in 2017/18 (Table A-3). Fishing at F_{OFL}=0 with all non-directed fishery discard mortality included, a probability of MMB at mating exceeding $B_{35\%}$ of greater than 0.5 (p=0.605) is achieved in 2018/19. Fishing at F_{OFL}=0 with all non-directed fishery discard mortality included, but with snow crab fishery discards at 2x the *Base Model* level, a probability of MMB at mating exceeding $B_{35\%}$ of greater than 0.5 (p=0.524) is achieved in 2018/19. Fishing at F_{OFL}=0 with all non-directed fishery discard mortality included, but with snow crab fishery discards at 4x the *Base Model* level, a probability of MMB at mating exceeding $B_{35\%}$ of greater than 0.5 (p=0.539) is achieved in 2020/21.

For projection under all harvest strategy scenarios presented here, the stock was shown to rebuild within the 10-year time frame. If actual fishery selectivity under the new SOA size limit strategy is different than those used here, $F_{35\%}$ and $B_{35\%}$ will be different and rebuilding trajectories will change.

Table A-1. *Base Model* fishing at $1.0F_{35\%}$ control rule (OFL). $B_{35\%}$ = 157.43, $F_{35\%}$=0.616. East and west of 166^0 W longitude total catch splits do not 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)			
	(1000 t)					East		West	
						Total	Retain	Total	Retain
2011/12	0.9(0.8,1)	0(0,0)	31.1(28.5,33.6)	0	0	0	0	0	0
2012/13	4.5(2.9,7.3)	2.0(1,3.8)	28.7(26.1,31.1)	0	0.11	1.3	0.9	1.7	1.1
2013/14	6.1(3.7,9.9)	2.6(1.2,4.9)	32.5(29.2,35.6)	0	0.14	1.8	1.2	2.5	1.5
2014/15	9(5.3,14.9)	4.1(2,7.5)	39.3(34.3,43.9)	0	0.18	2.7	1.8	3.9	2.3
2015/16	12.5(6.8,24.3)	5.9(2.8,11)	45.3(37,60.7)	0.002	0.22	4.0	2.6	5.6	3.3
2016/17	17.9(7.4,67.6)	8.4(3.4,28.5)	54.8(38.1,99.9)	0.049	0.28	5.7	3.7	8.6	4.8
2017/18	27.3(8.2,97.6)	13.4(3.7,46.6)	65.3(37.5,145.3)	0.170	0.36	9.1	5.9	13.5	7.7
2018/19	33.3(8.2,115.8)	16.2(3.8,56.6)	73.2(37.7,174.5)	0.272	0.40	11.0	7.1	16.4	9.2
2019/20	37.1(7.8,119.9)	18.5(3.6,61.8)	76.9(37.6,181.2)	0.345	0.43	12.6	8.0	18.8	10.6
2020/21	37.8(7.7,128)	18.9(3.6,64.8)	79.5(36.7,185)	0.401	0.42	12.8	8.3	19.0	10.7
2021/22	39.1(8.1,128.6)	19.6(3.6,60.4)	78.8(37.3,193.7)	0.460	0.43	13.3	8.6	19.5	11.2
2022/23	37.1(7.5,129.2)	18.0(3.2,63.6)	76.8(37.8,193.2)	0.505	0.42	12.1	7.8	18.5	10.2
2023/24	38.1(7.9,140.7)	18.1(3.3,70.4)	78.8(39.4,205.7)	0.543	0.44	12.3	7.9	19.3	10.3
2024/25	40.3(9.2,152.2)	19.6(4.0,74.0)	81.1(41.5,236.8)	0.595	0.45	13.4	8.5	20.7	11.3

Table A-2. *Base Model* fishing at $0.75F_{35\%}$ control rule (OFL). $B_{35\%} = 157.43$, $F_{35\%}=0.616$. East and west of 166^0 W longitude total catch splits do not 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	
						Total	Retain	Total	Retain
2011/12	0.9(0.8,1)	0(0,0)	31.1(28.5,33.6)	0	0	0	0	0	0
2012/13	3.7(2.5,6)	1.5(0.7,2.9)	29.1(26.7,31.5)	0	0.08	1.0	0.7	1.3	0.8
2013/14	5.2(3.2,8.4)	2.1(0.9,3.9)	33.5(30.3,36.4)	0	0.11	1.4	0.9	1.9	1.1
2014/15	7.7(4.6,12.9)	3.4(1.6,6.3)	40.8(36.3,45.3)	0	0.14	2.2	1.5	3.1	1.9
2015/16	10.8(5.9,21.2)	4.9(2.3,9.6)	47.6(39.6,63.5)	0.003	0.18	3.3	2.2	4.6	2.7
2016/17	15.8(6.6,56.3)	7.2(2.8,24.1)	57.8(41,106.5)	0.069	0.23	4.9	3.2	7.2	4.1
2017/18	24(7.3,81.9)	11.7(3.1,39.4)	69.9(40.4,159.3)	0.214	0.29	7.9	5.1	11.6	6.7
2018/19	29.6(7.3,99.5)	14.7(3.2,48.7)	79.4(40.9,197.3)	0.339	0.32	9.9	6.6	14.3	8.3
2019/20	33.7(7.1,106.1)	17.2(3.2,55.4)	84.5(40.8,210.8)	0.426	0.35	11.7	7.5	16.8	9.7
2020/21	35.7(7.1,111.8)	17.5(3.3,56.2)	88.4(39.9,214.7)	0.478	0.35	11.8	7.8	17.4	9.9
2021/22	37.4(7.6,112.3)	18.8(3.3,54)	88(39.8,230.2)	0.538	0.35	12.7	8.2	18.4	10.6
2022/23	35.6(7.1,117.1)	17.6(2.9,59.8)	87.1(41.5,231.6)	0.581	0.35	11.9	7.7	17.4	9.9
2023/24	37.1(7.5,127.9)	18.2(3.1,64.6)	88.7(42.8,246.2)	0.626	0.36	12.4	8.1	18.2	10.4
2024/25	39.7(8.8,137.2)	19.3(3.7,67.4)	91.8(45,278.2)	0.682	0.37	13.2	8.3	19.8	11.1

Table A-3. *Base Model* fishing at F=0 with discard losses from the groundfish fisheries only. $B_{35\%}$ = 157.43, $F_{35\%}$=0.616.

Year	ABC_{TOT}	C_{DIR}	%MMB/$B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch			
						East		West	
	(1000 t)					Total	Retain	Total	Retain
2011/12	0.1(0.1,0.1)	0(0,0)	31.5(28.9,34)	0	0	0	0	0	0
2012/13	0.2(0.1,0.2)	0(0,0)	31.5(28.9,34)	0	0	0	0	0	0
2013/14	0.3(0.2,0.3)	0(0,0)	38.2(35,41.3)	0	0	0	0	0	0
2014/15	0.3(0.3,0.5)	0(0,0)	49.2(45.2,53.9)	0	0	0	0	0	0
2015/16	0.4(0.3,1)	0(0,0)	61.0(53,82.4)	0.019	0	0	0	0	0
2016/17	0.6(0.3,1.8)	0(0,0)	80.5(56.7,161.5)	0.271	0	0	0	0	0
2017/18	0.8(0.3,2.3)	0(0,0)	107(59.7,257.4)	0.558	0	0	0	0	0
2018/19	0.8(0.2,2.4)	0(0,0)	133.7(62.7,343)	0.703	0	0	0	0	0
2019/20	0.8(0.2,2.4)	0(0,0)	151.9(66.4,407)	0.778	0	0	0	0	0
2020/21	0.7(0.2,2.5)	0(0,0)	169.7(66,430.5)	0.835	0	0	0	0	0
2021/22	0.7(0.2,2.4)	0(0,0)	185(70.1,466.7)	0.869	0	0	0	0	0
2022/23	0.8(0.2,2.8)	0(0,0)	192.9(73.2,521.1)	0.895	0	0	0	0	0
2023/24	0.8(0.3,3)	0(0,0)	204(78.5,547.5)	0.923	0	0	0	0	0
2024/25	0.9(0.3,3.3)	0(0,0)	217.9(85,601.8)	0.948	0	0	0	0	0

Table A-4. *Base Model* fishing at F=0 with discard losses from the groundfish, snow and red king crab fisheries. *Base Model* snow crab discards at rate F=0.023. $B_{35\%}$ = 157.43, $F_{35\%}$=0.616.

Year	ABC_{TOT}	C_{DIR}	%MMB/$B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch			
						East		West	
	(1000 t)					Total	Retain	Total	Retain
2011/12	0.9(0.8,1)	0(0,0)	31.1(28.5,33.6)	0	0	0	0	0	0
2012/13	1(0.9,1.1)	0(0,0)	30.8(28.2,33.2)	0	0	0	0	0	0
2013/14	1.4(1.3,1.5)	0(0,0)	37.1(34.0,40.0)	0	0	0	0	0	0
2014/15	1.8(1.6,2.1)	0(0,0)	47.3(43.5,51.7)	0	0	0	0	0	0
2015/16	2.2(1.7,3.8)	0(0,0)	57.6(50.6,76.3)	0.012	0	0	0	0	0
2016/17	2.9(1.6,6.9)	0(0,0)	73.5(52.9,142.9)	0.188	0	0	0	0	0
2017/18	3.6(1.7,9.5)	0(0,0)	95.4(54.3,222.8)	0.456	0	0	0	0	0
2018/19	4.1(1.8,11.6)	0(0,0)	117.9(56.3,301.6)	0.605	0	0	0	0	0
2019/20	4.6(1.7,12)	0(0,0)	133.8(59,351.6)	0.707	0	0	0	0	0
2020/21	5(1.8,12.9)	0(0,0)	149.4(58.2,373.6)	0.767	0	0	0	0	0
2021/22	5.1(1.8,13.9)	0(0,0)	162.8(61.7,412.9)	0.807	0	0	0	0	0
2022/23	5.4(2,15)	0(0,0)	170(64.3,457.4)	0.844	0	0	0	0	0
2023/24	5.7(2.2,16.3)	0(0,0)	179.4(68.9,479.7)	0.874	0	0	0	0	0
2024/25	6.2(2.4,18)	0(0,0)	192.3(74.7,524.9)	0.911	0	0	0	0	0

Table A-5. *Base Model* fishing at F=0 with bycatch from the groundfish, snow and red king crab fisheries. Snow crab discards = 2x that of *Base Model*. $B_{35\%}$ = 157.43, $F_{35\%}$=0.616.

Year	ABC_{TOT}	C_{DIR}	%MMB/$B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch			
	(1000 t)					East		West	
						Total	Retain	Total	Retain
2011/12	1.7(1.6,1.9)	0(0,0)	30.7(28.2,33.2)	0	0	0	0	0	0
2012/13	1.9(1.8,2.1)	0(0,0)	30(27.6,32.4)	0	0	0	0	0	0
2013/14	2.6(2.4,2.8)	0(0,0)	35.9(32.9,38.7)	0	0	0	0	0	0
2014/15	3.2(2.9,3.7)	0(0,0)	45.5(41.8,49.6)	0	0	0	0	0	0
2015/16	3.8(3.0,6.2)	0(0,0)	54.2(48.1,69.7)	0.006	0	0	0	0	0
2016/17	4.8(2.9,11.1)	0(0,0)	66.7(49.1,124.8)	0.124	0	0	0	0	0
2017/18	6.0(3.0,15.5)	0(0,0)	83.8(49.4,190.8)	0.352	0	0	0	0	0
2018/19	6.9(3.0,19.1)	0(0,0)	102.7(50.2,258.9)	0.524	0	0	0	0	0
2019/20	7.7(2.9,19.9)	0(0,0)	116.1(51.8,305.6)	0.621	0	0	0	0	0
2020/21	8.3(3.0,21.3)	0(0,0)	129.8(51.1,324.4)	0.69	0	0	0	0	0
2021/22	8.6(3.1,23.2)	0(0,0)	141.7(53.7,354.9)	0.738	0	0	0	0	0
2022/23	8.9(3.4,24.8)	0(0,0)	146.9(55.3,392.9)	0.779	0	0	0	0	0
2023/24	9.5(3.7,27.2)	0(0,0)	155.6(59.8,406.7)	0.827	0	0	0	0	0
2024/25	10.3(3.9,30.2)	0(0,0)	166.3(64.4,453.9)	0.864	0	0	0	0	0

Table A-6. *Base Model (0)* fishing at F=0 with bycatch from the groundfish, snow and red king crab fisheries. Snow crab discards = 4x that of *Base Model*. $B_{35\%}$ = 157.43, $F_{35\%}$=0.616.

Year	ABC_{TOT}	C_{DIR}	%MMB/$B_{35\%}$	P[MMB >$B_{35\%}$]	Full-Select F	Directed Fishery Catch			
						East		West	
	(1000 t)					Total	Retain	Total	Retain
2011/12	3.2(2.9,3.5)	0(0,0)	30.1(27.6,32.4)	0	0	0	0	0	0
2012/13	3.5(3.2,3.8)	0(0,0)	28.8(26.4,31)	0	0	0	0	0	0
2013/14	4.6(4.0.2,5)	0(0,0)	33.8(31.0,36.5)	0	0	0	0	0	0
2014/15	5.5(5.0,6.2)	0(0,0)	42.3(38.8,46)	0	0	0	0	0	0
2015/16	6.2(5.1,9.6)	0(0,0)	49.1(44.0,60.7)	0.001	0	0	0	0	0
2016/17	7.4(4.7,16.3)	0(0,0)	56.8(43.3,99.3)	0.048	0	0	0	0	0
2017/18	9.0(4.6,22.5)	0(0,0)	67.9(42.0,149.2)	0.196	0	0	0	0	0
2018/19	10.3(4.5,28.5)	0(0,0)	81.9(41.5,199.9)	0.350	0	0	0	0	0
2019/20	11.5(4.4,29.7)	0(0,0)	92.5(41.9,241.3)	0.457	0	0	0	0	0
2020/21	12.3(4.4,31.9)	0(0,0)	102.5(40.5,258.2)	0.539	0	0	0	0	0
2021/22	12.6(4.5,34.1)	0(0,0)	110.2(42.3,278.9)	0.597	0	0	0	0	0
2022/23	13.1(4.9,37.2)	0(0,0)	114.1(43.3,301.8)	0.654	0	0	0	0	0
2023/24	14.0(5.3,40.2)	0(0,0)	120.4(46.6,319.8)	0.694	0	0	0	0	0
2024/25	15.1(5.7,45.2)	0(0,0)	128.9(49.9,360.4)	0.748	0	0	0	0	0

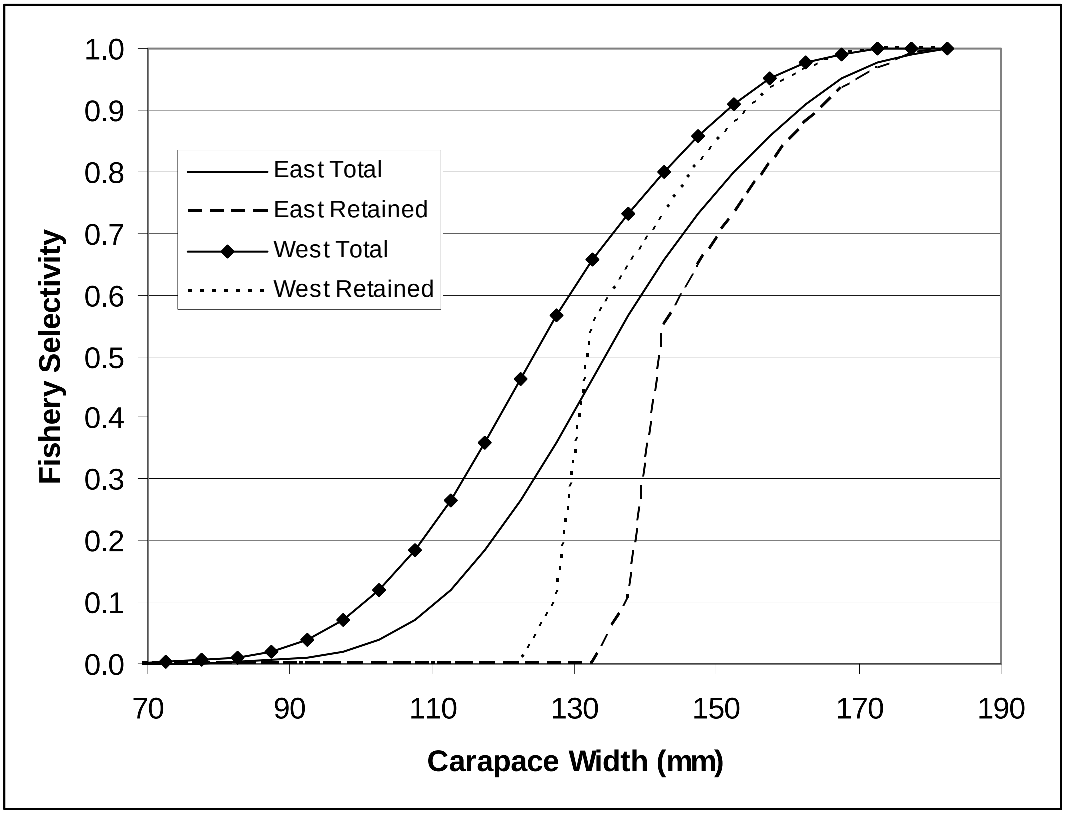

Figure A-1. Fishery selectivity curves for the areas east and west of 166^0 W longitude. The east area selectivity is estimated from the *Base Model* with a minimum legal size limit ≥138mm. The west area selectivity is shifted 10mm to approximate an industry preferred size limit ≥128 mm.