Bering Sea Snow Crab

May 2015 Crab Plan Team Model Runs

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A number of changes were made to the 2014 Bering Sea snow crab assessment model most notably in the estimation of the growth function and removal of fishing mortality penalties.

Models presented here are:

Model 1 – includes all changes (see below). Plots in Appendix A.

Model 2 – Model 1 with fishery selectivity estimated separately in 2013/14. Plots in Appendix B.

Model 3 – Model 2 with standard deviation in the growth function fixed at 0.01. Plots in Appendix C.

2014 Model assessment – accepted assessment from September 2014. Plots in Appendix D.

1. Growth curve estimation

   Recall that the growth function is:

$$?_?(?) \quad ?_? \quad ?_? ? \quad ? \quad \text{È É}$$

$$?_? \quad ?_? \quad (?_? - ?_?)?$$

$$?(?) \quad ?_?(?)\,?\text{È} - ?\ ?\frac{? - ?}{?}?? \quad ?_?(?)\,??\ ?\frac{? - ?}{?}??$$

   Where ? is the cumulative distribution function for a standard normal random variable. ? constrains the breakpoint, and *s* is a scale parameter determining how smooth the transition is between equation segments. The cumd_norm function was used in ADMB for the cumulative normal distribution. Separate parameters were estimated for male and female crab, except one *s* parameter was estimated for both sexes. This results in 4 estimated parameters per sex plus the *s* parameter, for a total of 9 estimated parameters.

The fit to growth data and shape of the growth curves was improved by removing a constraint on the estimation of the probability of maturing and increasing the weight on the growth likelihoods to 3 (from 2). The female growth curve is estimated similar to the male curve at sizes less than about 55 mm for Model 1 (Appendix A and Figures 1 and 2).

A constraint on the difference between the maturity curves estimated outside the model for new shell males and females and the model estimated probability of maturing was still included in the 2014 assessment to help with smoothing the function. The removal of this constraint resulted in a small change in the probability of maturing for both males and females (Figure 11). This resulted in a change in the estimated growth curves mainly for the female growth curve which was estimated higher (more similar to the male growth curve) for models 1, 2 and 3 relative to the 2014 model. The weight on the second difference likelihood for the probability of maturing for females was increased from 2.0 to 10.0 to make the curve smoothly ascending at larger sizes (declined slightly in 2014 model).

In Model 1 the standard deviation of the growth function was estimated in the model at 4.7. When the standard deviation of the cumulative normal distribution in the growth function is reduced to a small value (e.g. 0.01), there is no overlap between lower and upper curves (model 3 vs model 2 Appendix B and C and Figures 1 and 2). With a very small standard deviation the growth function is essentially a hockey stick type curve where either growth is all one curve or the other with no combining of functions. A power function was also formulated for the growth function however the fits were similar to the current growth function with a large standard deviation. A large standard deviation tends to give one smooth curve, however, does not fit the data as well as a small standard deviation.

2. Fishing mortality penalties

Fishing mortality penalties have been removed for 1992 to present where discard and retained catch are available. The constraint on fishing mortality from 1978 to 1991 was changed to be a sum of squares likelihood between the model estimated F and the F estimated from effort data (potlifts) and the relationship between effort data and F for 1992 to present. A weight of 0.2 was used on the sum of squares likelihood. Potlifts from 1978 to 1991 were multiplied by the mean mean (potlifts/F) for years 1992 to 2014 to estimate F for 1978 to 1991 (Figures 3 and 4). The changes in F in Model 1 from the 2014 assessment are due to a combination of changes in growth and removing the F penalties which resulted in a higher survey q. Fishing mortalities are higher in the last few years for model 1 due to removing F penalties.

Fishing mortality for female discard catch previous to 1992 were estimated using potlifts and the same method as male fishing mortalities. This reduced the number of parameters from the

2014 model due to fewer model estimated Fishing mortality parameters. Penalties on female F deviations and trawl F were removed in the last phase for Models 1, 2 and 3.

3. Differences between 2013 assessment and 2014 assessment in ending biomass values. Why did ending biomass values change between assessments?

   Many model runs were done to investigate the sensitivity to ending biomass values with lowering weights on likelihoods for survey biomass (male and female), survey length frequencies (male and female) and fishery length frequencies. These resulted in small changes in ending biomass, however did not explain the differences between the 2014 and 2013 assessments.

   The difference in the 2013 and 2014 assessment results was due to the higher level of discards in the 2013/14 fishery. Model 2 estimates a separate fishery selectivity curve for the 2013/14 fishery, removing any influence on recruitment from the catch in that year (Figures 5 and 6). The higher level of fishery discard without any change in the fishery or distribution of crab indicates a shift in recruitment in the stock that is different than indicated by the survey data (Figures 7 and 8). Model 2 estimates a higher recruitment in 2009 as well as 2010 that results in higher ending biomass as the recruitment moves into the mature biomass (Figures 9 and 10). In model 1 and the 2014 model the 2009 recruitment is low compared to 2010. When the fishery selecitivity curve is estimated separately in the 2014 fishery from previous years, results for the 2014 model are similar to 2013 assessment where model estimated biomass did not decline to fit the lower 2013 observed survey biomass. The levels of recruitment and biomass values are higher for models 2 and 3 on average due to a lower estimate of survey q (about 0.61 Vs 0.7 for model 1).

Changes 4 through 8 resulted in very little change in results of the model –

4. The calculation of the Francis multiplier on the multinomial sample size to estimate effective N was added to the model. The multipliers are very small, which would result in very small effective N values (Table 2). Input N values for length frequency data are 200. No runs were made with the Francis effective Ns.

5. Logistic survey selectivity curves were estimated with 3 parameters: 1) size at 95%, 2) size at 50%, and 3) q. The parameter that estimates the size where selectivity is 95% was changed to an offset parameter (size at 95%-size at 50%) because sometimes the 95% parameter was being estimated lower than 50%.

6. The survey period 1 q (1978 to 1987) and the 2010 industry survey q were changed to a probit scale because the estimates were hitting the bound of 1.0. This does not change the value of the qs (still 1.0), however, allows the estimation of the variances.

7. Increased the weight on last 4 trawl catches with addition likelihood multiplier of 4.0. These catches are very small and sometimes estimated as zero by the model. Increased weight results in nonzero estimates.

Table 1. Likelihood values for Model runs.

Likelihood Component	Model 1	Model 2	Model 3	2014 Model
Recruitment	34.9	33.0	34.4	33.9
Initial numbers old shell males small length bins	2.3	2.3	2.2	2.2
ret fishery length	338.1	338.3	347.7	355.1
total fish length	766.6	762.2	761.0	777.8
female fish length	202.6	202.6	201.5	214.6
survey length	3810.8	3783.0	3806.1	3778.4
trawl length	272.1	264.0	280.5	272.8
2009 BSFRF length	-83.7	-81.1	-81.8	-83.2
2009 NMFS study area length	-71.7	-71.1	-70.5	-70.6
M prior	10.0	8.3	10.9	10.6
maturity smooth	15.1	14.5	13.2	56.0
growth males	48.6	43.7	42.1	43.3
growth females	39.0	40.2	50.6	47.8
2009 BSFRF biomass	0.3	0.2	0.2	0.2
2009 NMFS study area biomass	0.2	0.1	0.1	0.1
retained catch	3.7	2.4	2.2	3.7
discard catch	132.2	126.0	101.7	135.9
trawl catch	7.0	7.6	6.2	9.8
female discard catch	0.2	0.2	0.2	5.8
survey biomass	180.5	177.0	173.1	181.5
F constraint 1978-1991	2.9	7.3	8.8	80.2*
2010 BSFRF Biomass	3.1	0.9	0.9	2.2
2010 NMFS Biomass	2.1	2.0	1.8	1.3
initial numbers fit	508.1	508.0	506.0	508.0
2010 BSFRF length	-55.4	-61.0	-58.4	-55.5
2010 NMFS length	-64.3	-71.2	-70.1	-65.9
male survey selectivity smooth constraint	3.8	3.5	3.7	3.7
init nos smooth constraint	40.8	40.1	38.4	39.4
Total				
	6150.1	6083.0	6112.8	6208.9
No. Parameters	307	308	307	320
Q 1989-present	0.697	0.616	0.617	0.614
M mature males	0.269	0.265	0.270	0.270

* Fishing mortality penalties 1978-2014			

Table 2. Effective N for Survey length frequency, retained and total male fishery length frequencies. Model 1.

Survey length frequencies		Francis multiplier	Francis effective N	Input N	average effective N
Female	immature	0.0275	5.5	200	145.5
	mature	0.0773	15.5	200	220.0
Male	immature	0.0831	16.6	200	164.6
	mature	0.0901	18.0	200	895.6
Fishery directed male length					
	retained	0.1012	20.2	200	299.8
	total	0.1271	25.4	200	318.3

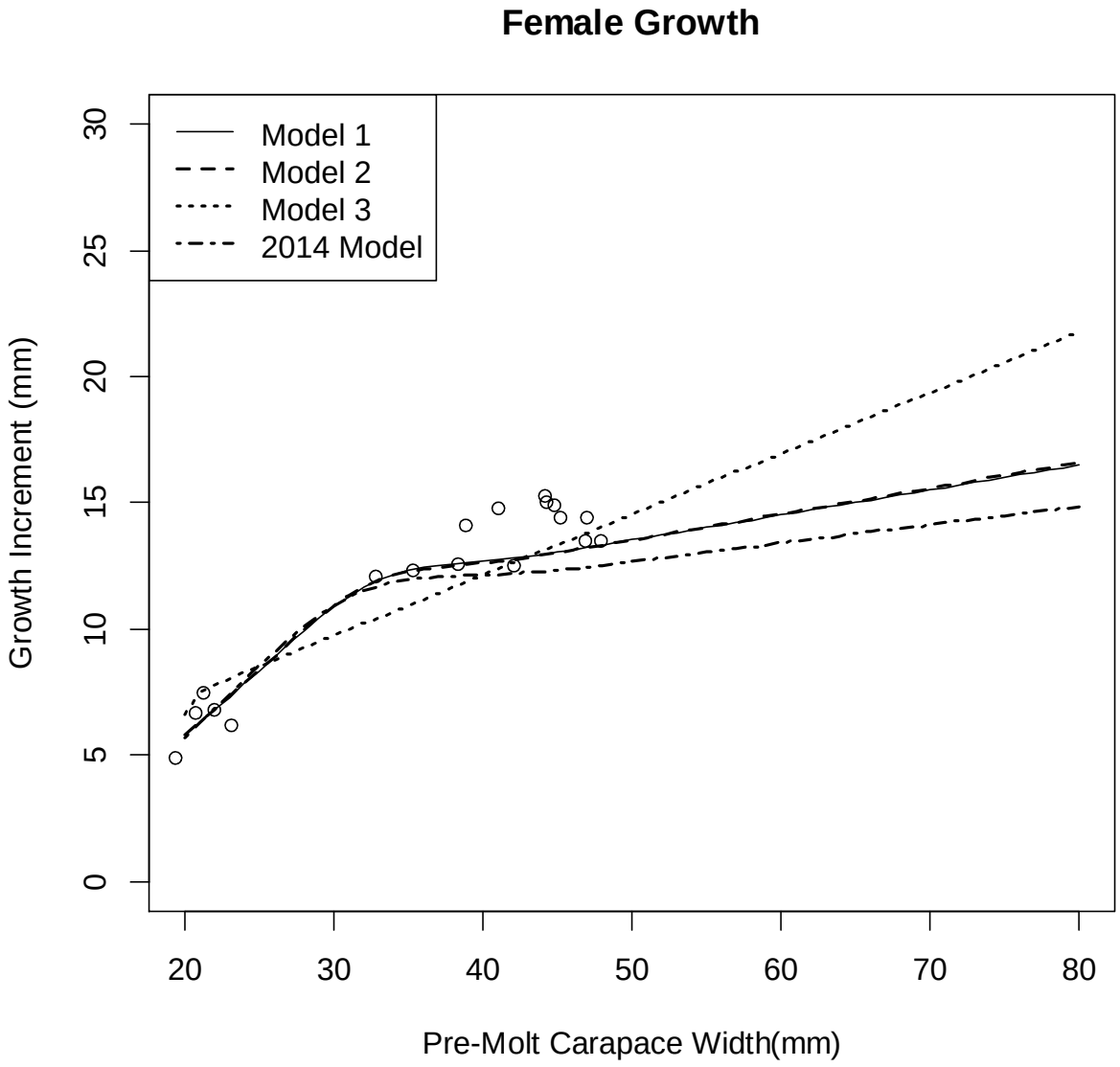

Figure 1. Estimated growth increment for female snow crab for 4 model runs.

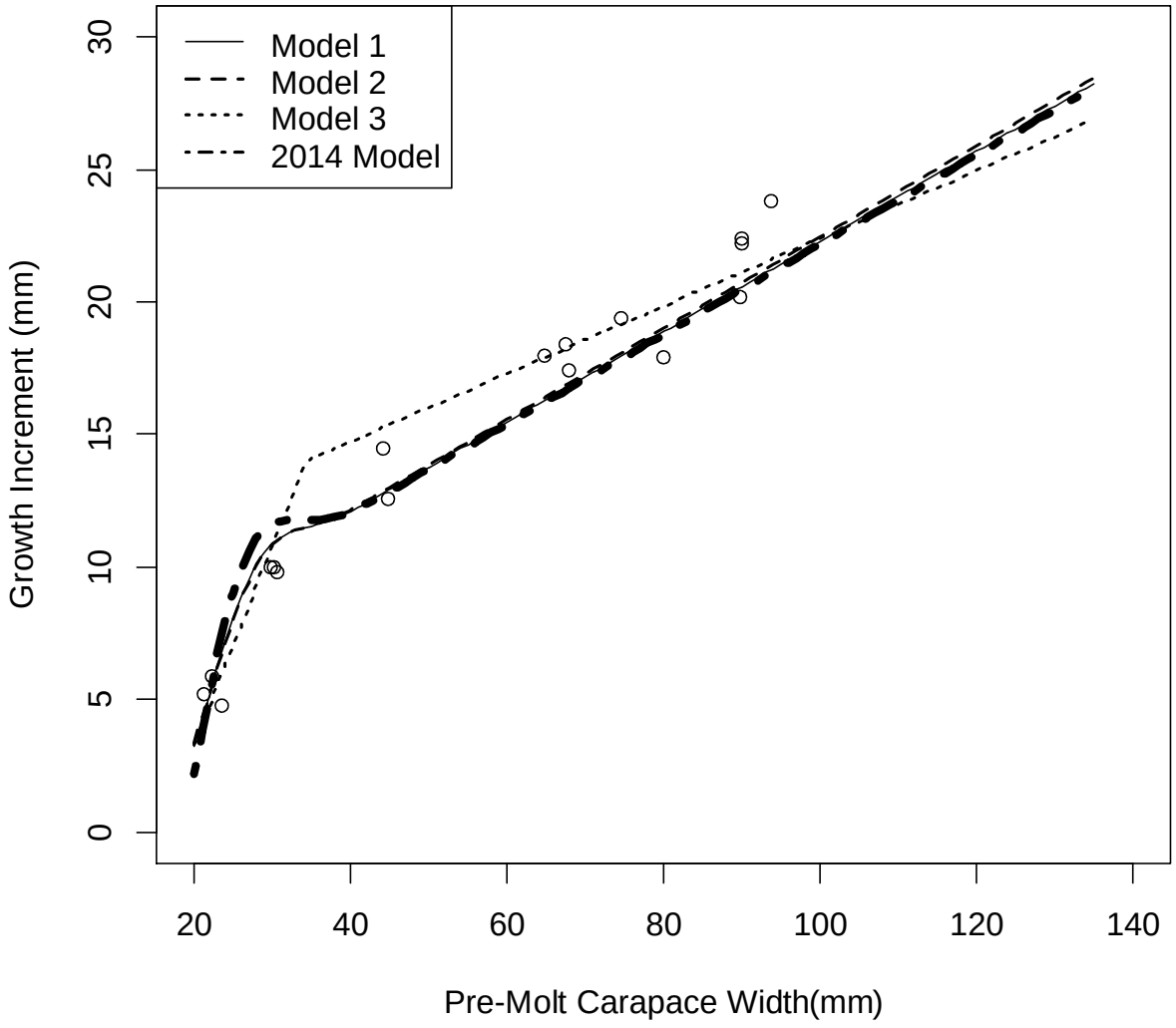

Figure 2. Estimated growth increment for male snow crab for 4 model runs.

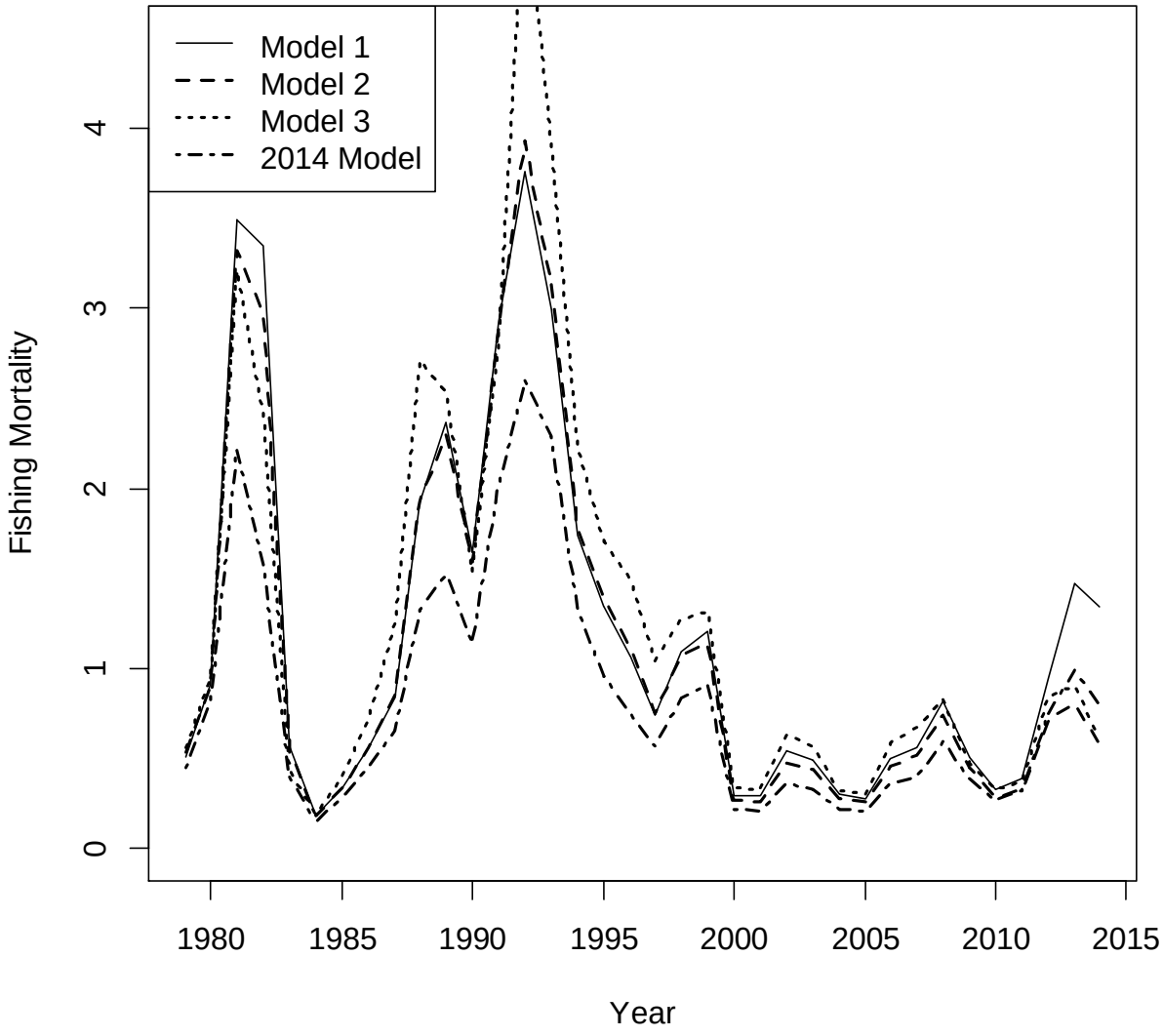

Figure 3. Estimated fishing mortality by year (1978/79 to 2013/14) for 4 model runs.

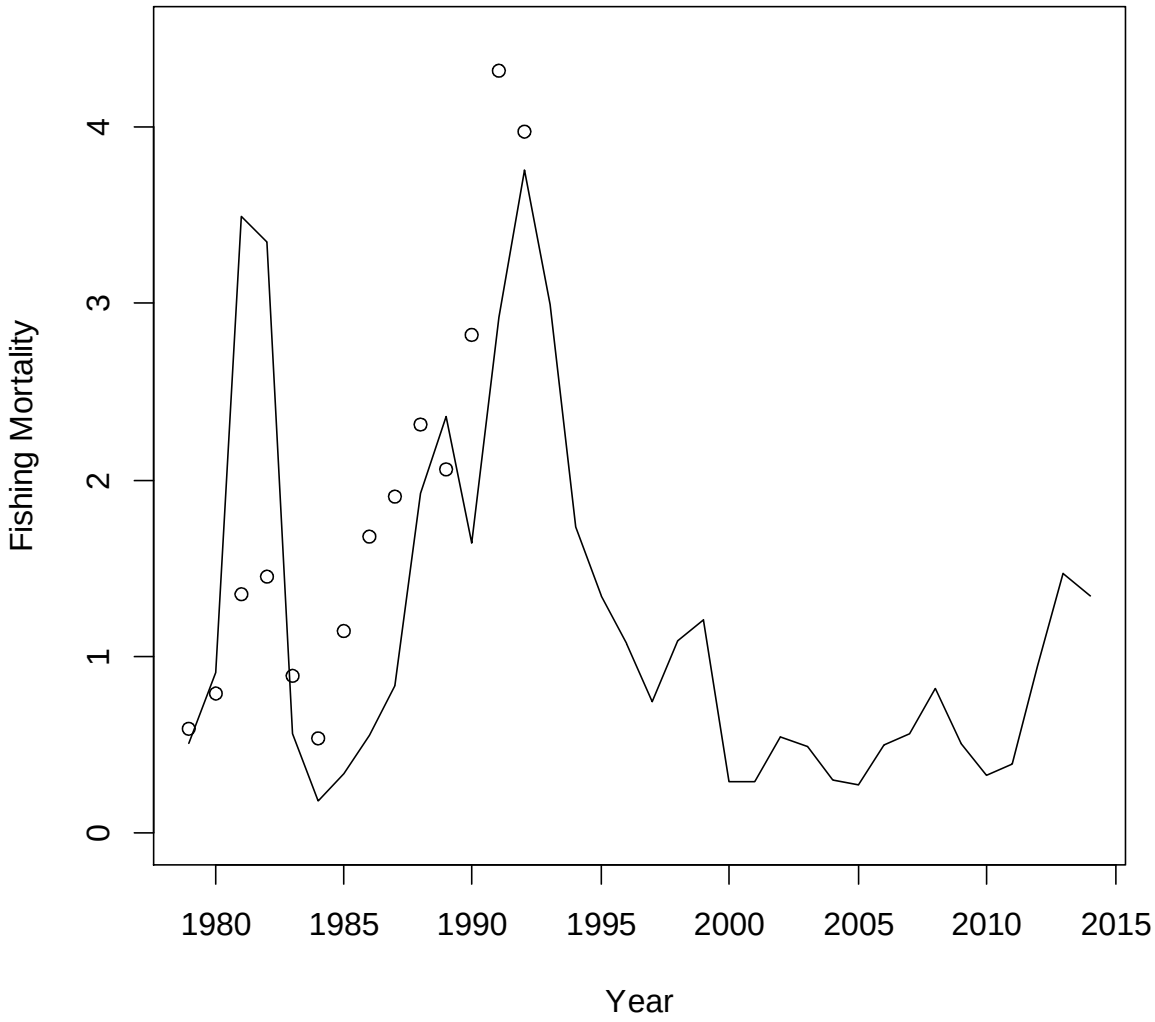

Figure 4. Estimated fishing mortality from Model 1 (line) compared to estimated F using potlifts for 1978/79 to 1991/1992 fishery and the relationship between potlifts and F for 1992/93-2013/14. Sum of squared difference was used to constrain the model estimated F in 1979 to 1992.

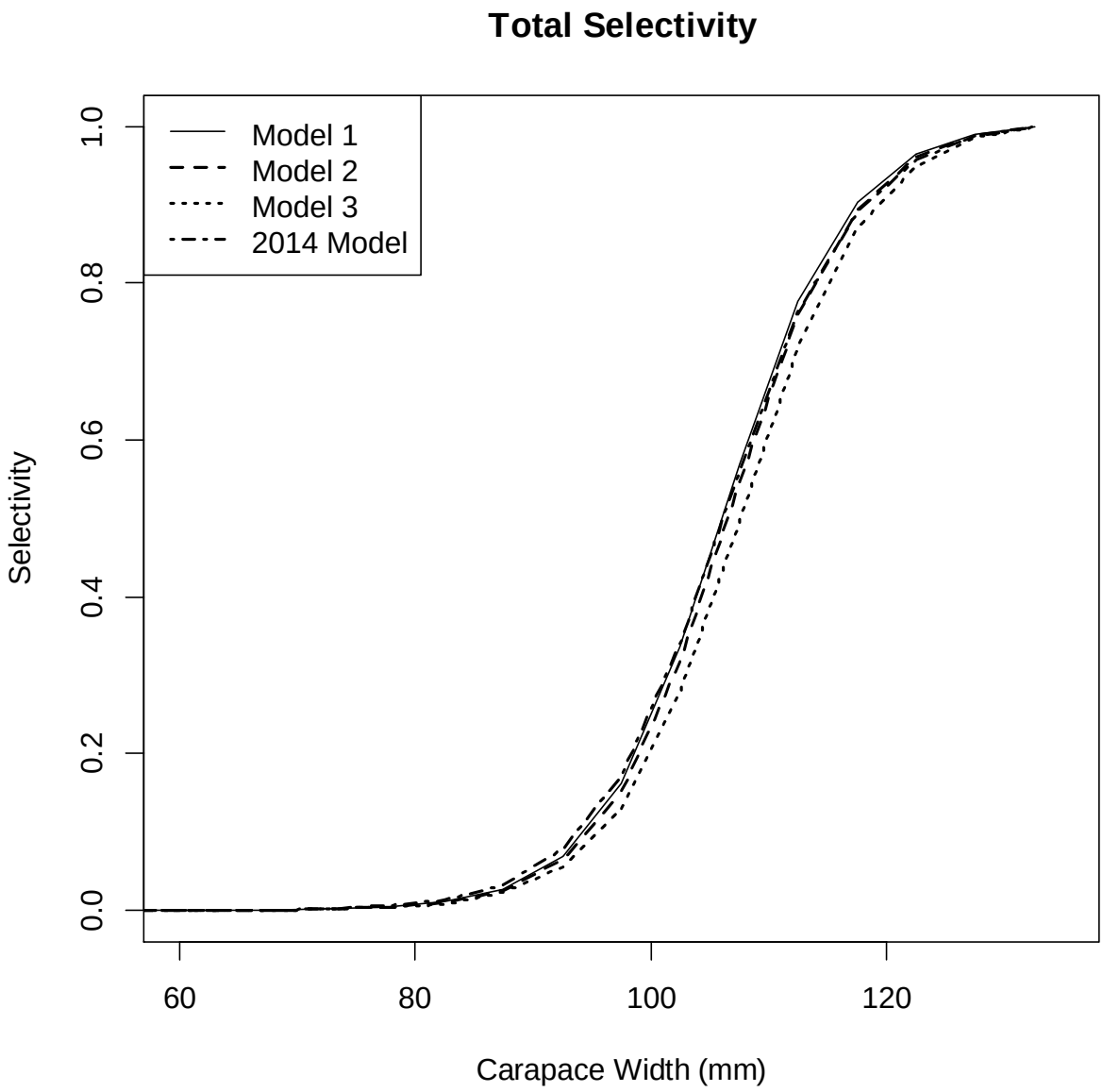

Figure 5. Estimated 2013/14 total fishery selectivity curves for the directed snow crab fishery for 4 model runs.

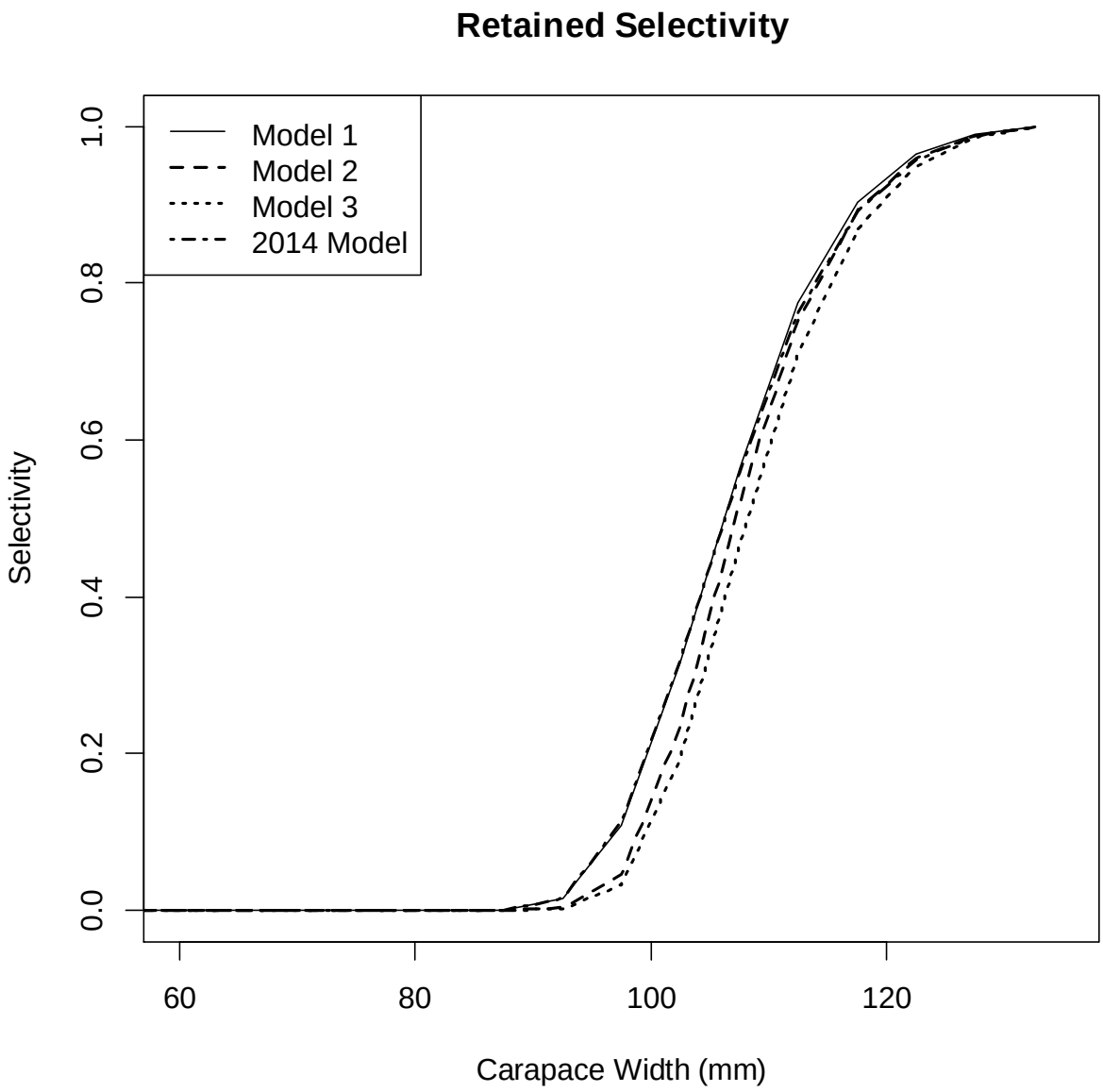

Figure 6. Estimated 2013/14 retained fishery selectivity curves for the directed snow crab fishery for 4 model runs.

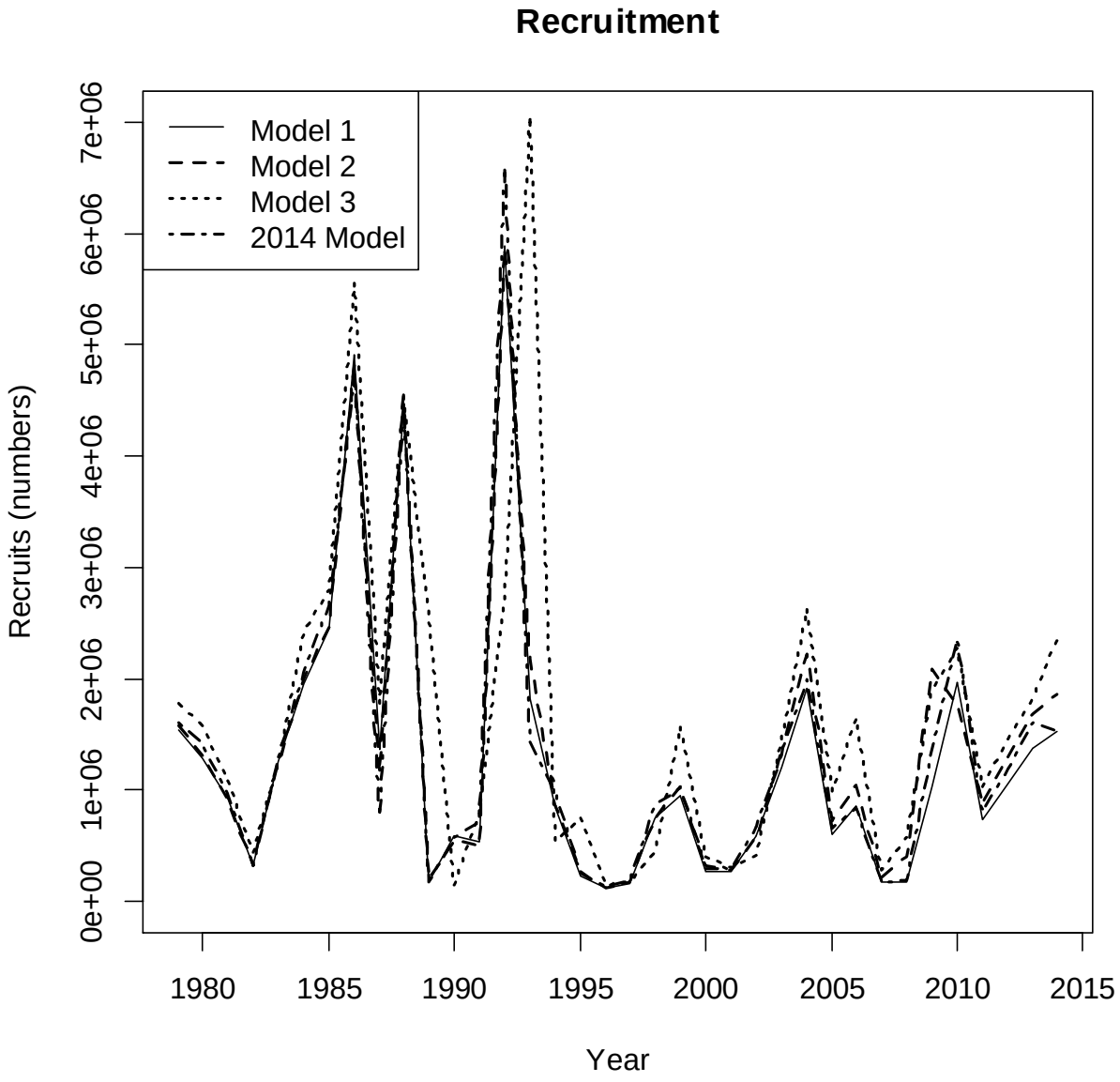

Figure 7. Estimated recruitment for 4 model runs.

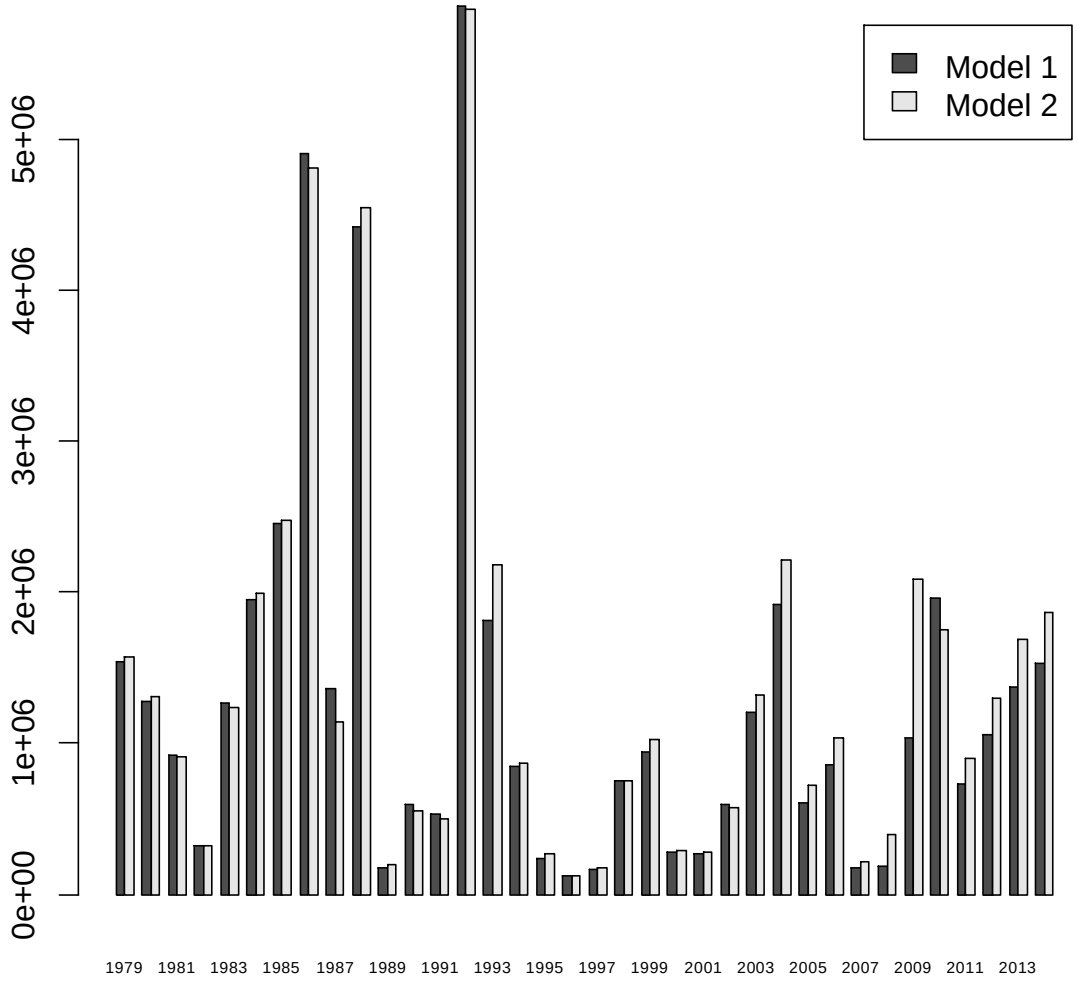

Figure 8. Estimated recruitment for model 1 and model 2 (separate estimated fishery selectivity 2013/14 fishery).

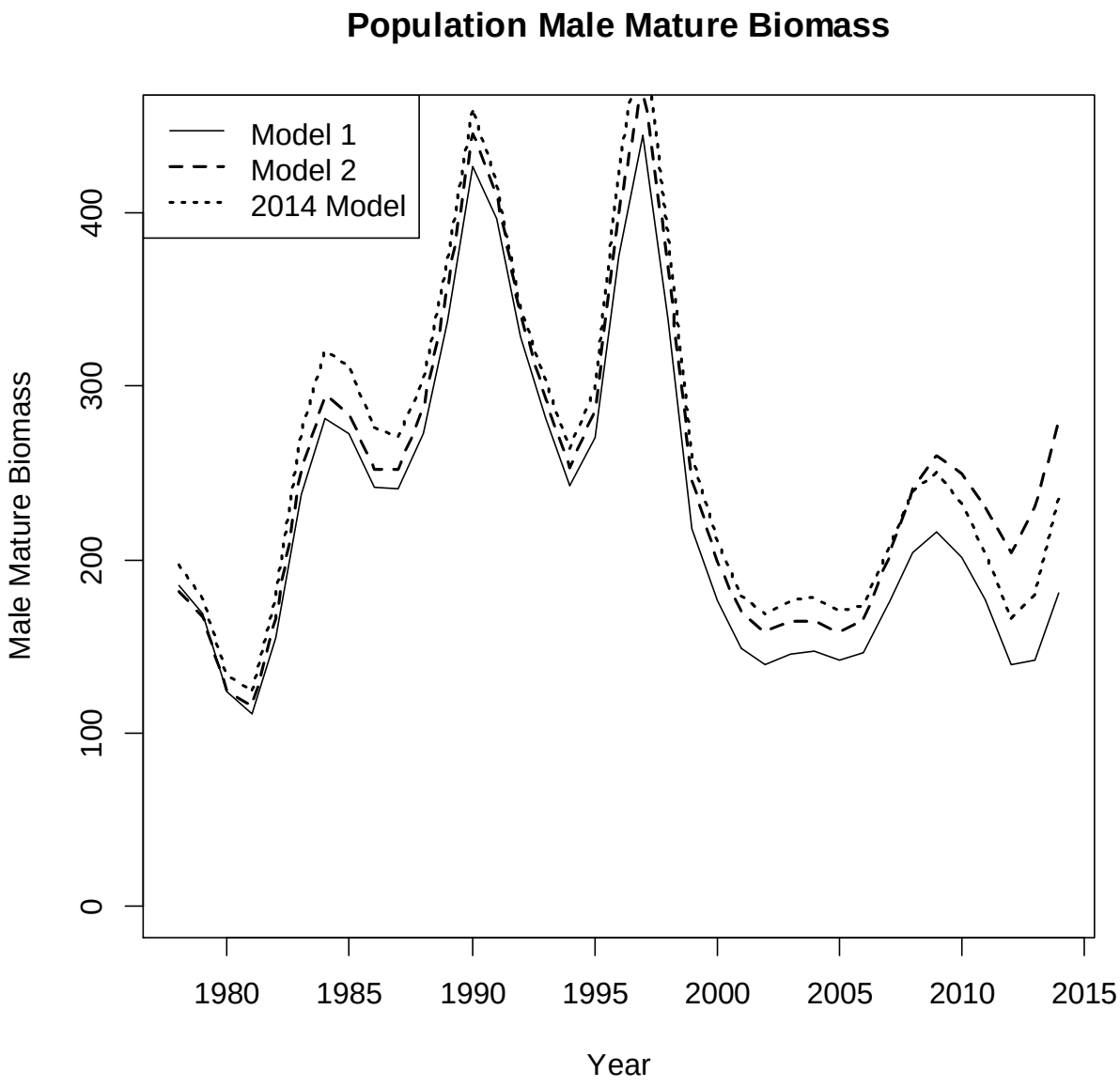

Figure 9. Estimated population male mature biomass for Model 1, 2 and 2014 assessment.

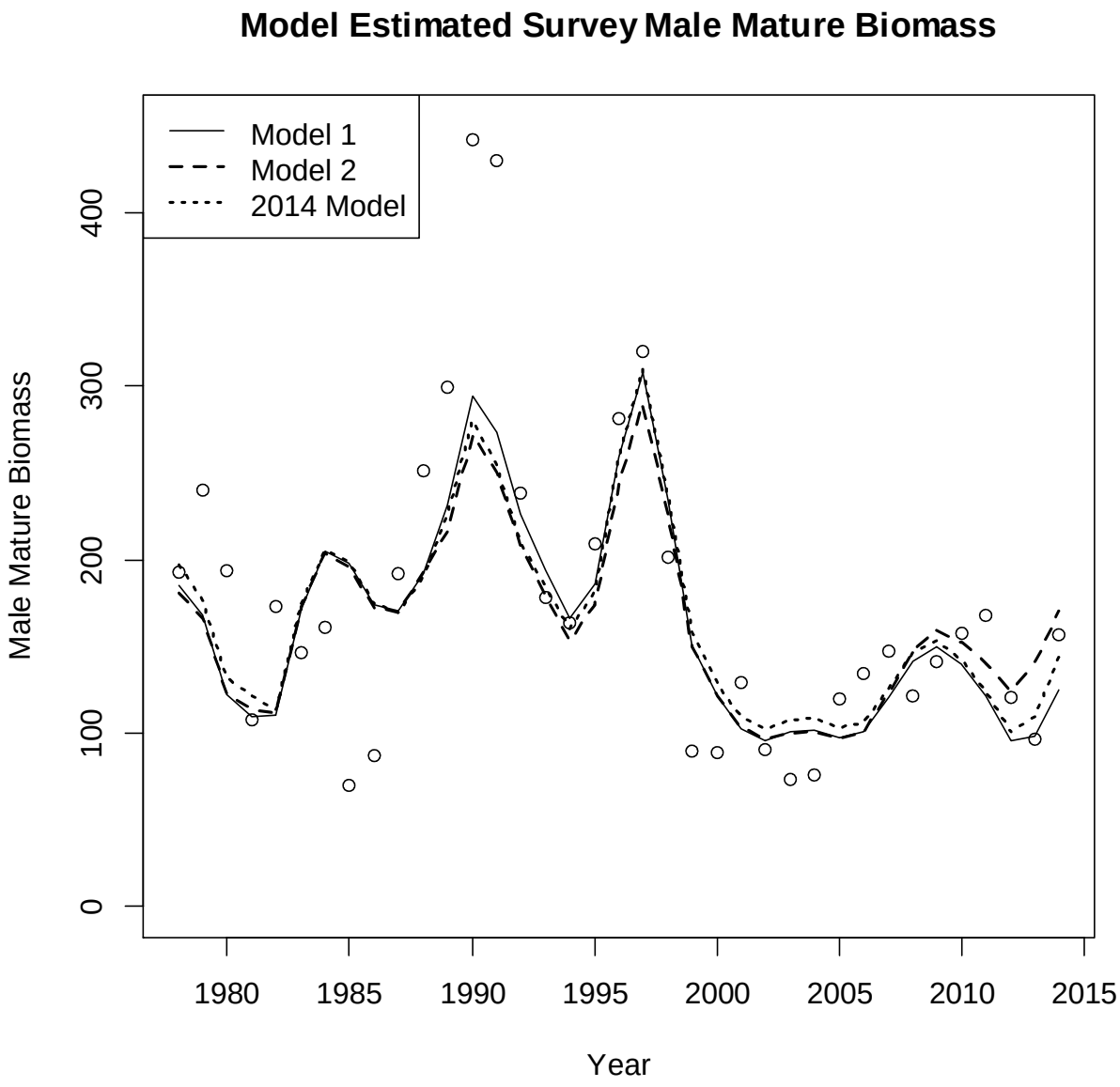

Figure 10. Model estimated survey male mature biomass (1000s tons) for Model 1, 2 and 2014 assessment compared to observed survey male mature biomass (points).

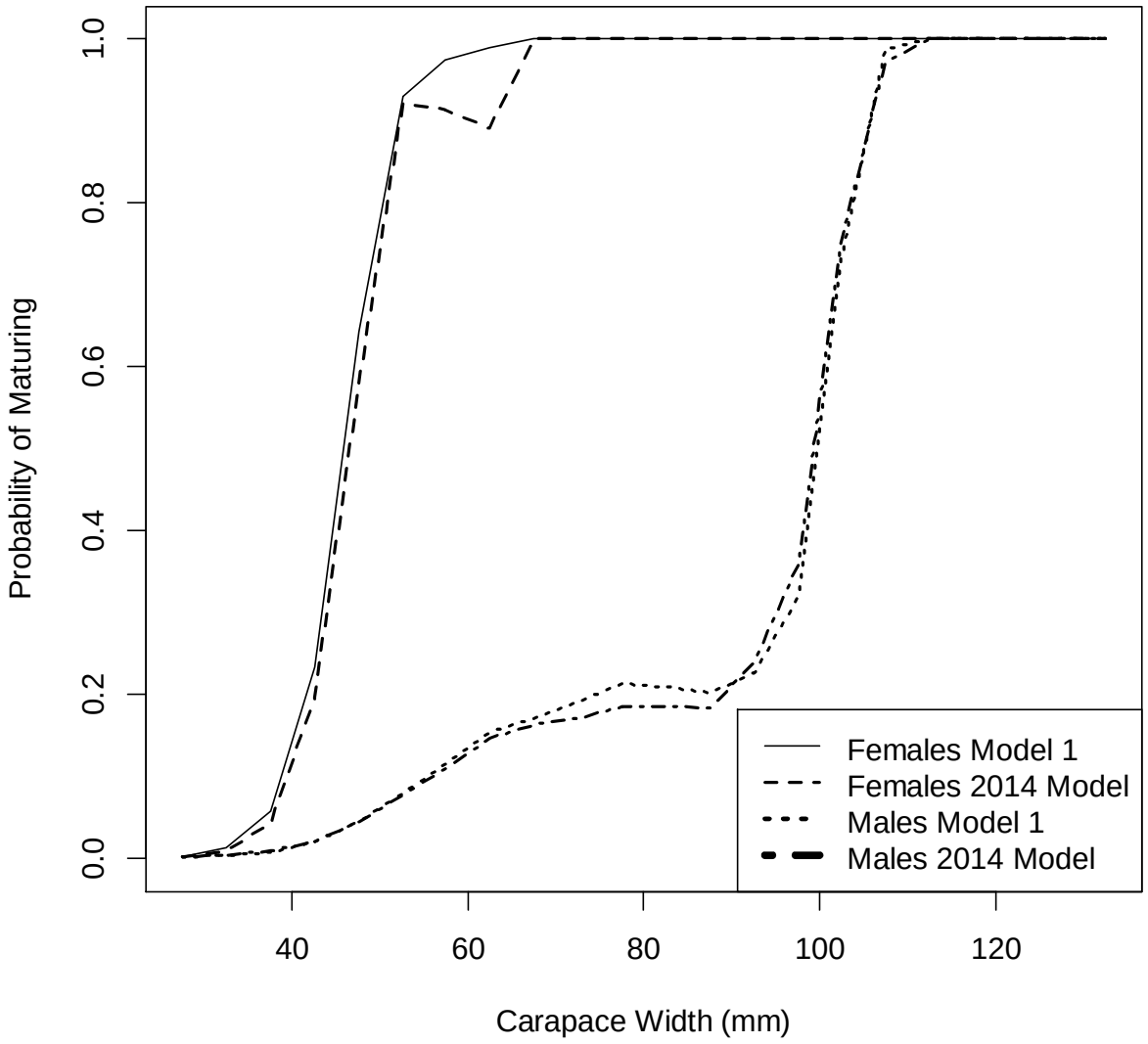

Figure 11`. Probability of maturing for female and male snow crab for Model 1 and the 2014 assessment model.

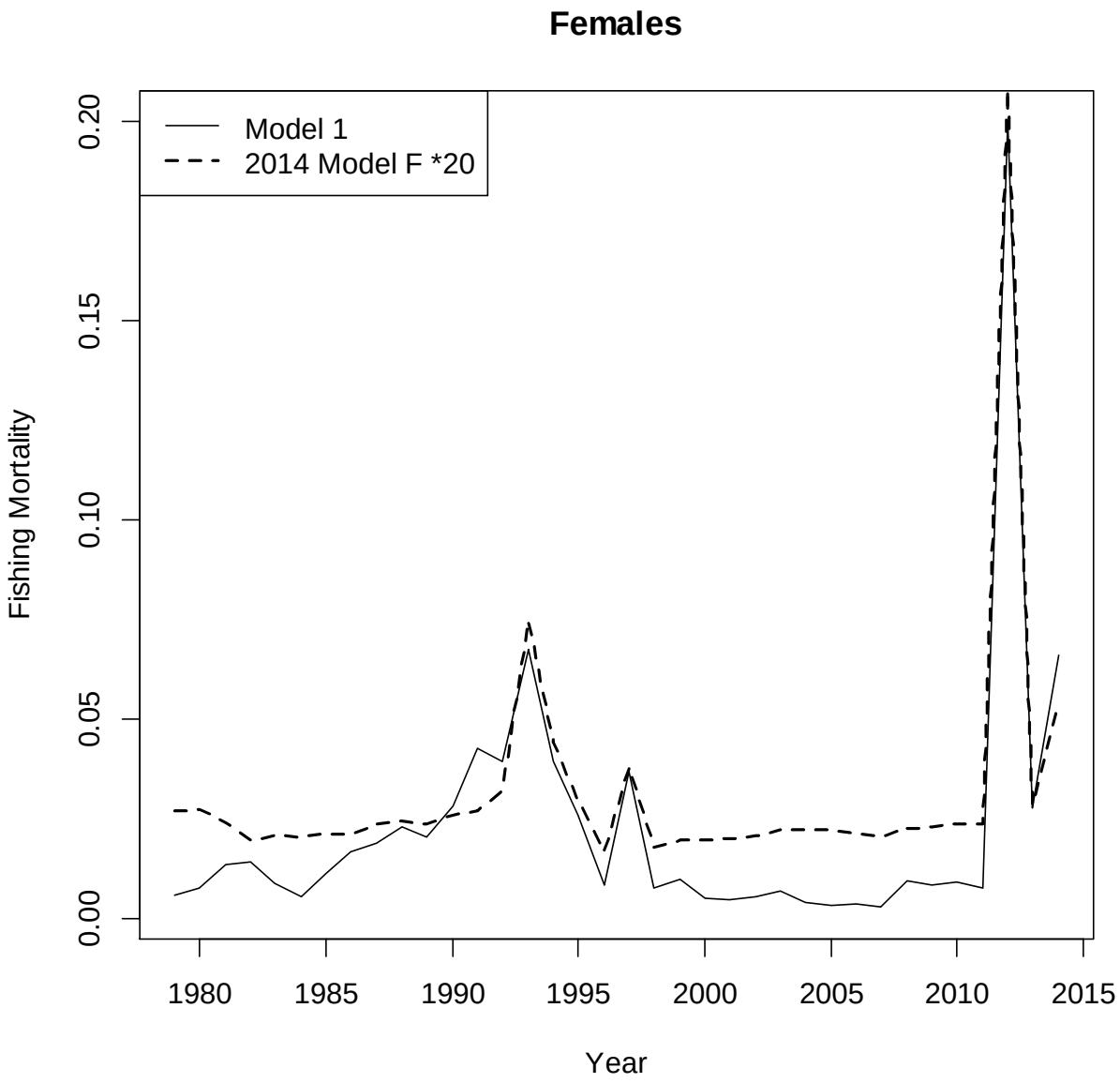

Figure 12. Female discard fishing mortality estimates for Model 1 and the 2014 model multiplied by 20 to account for differences in estimated selectivity.

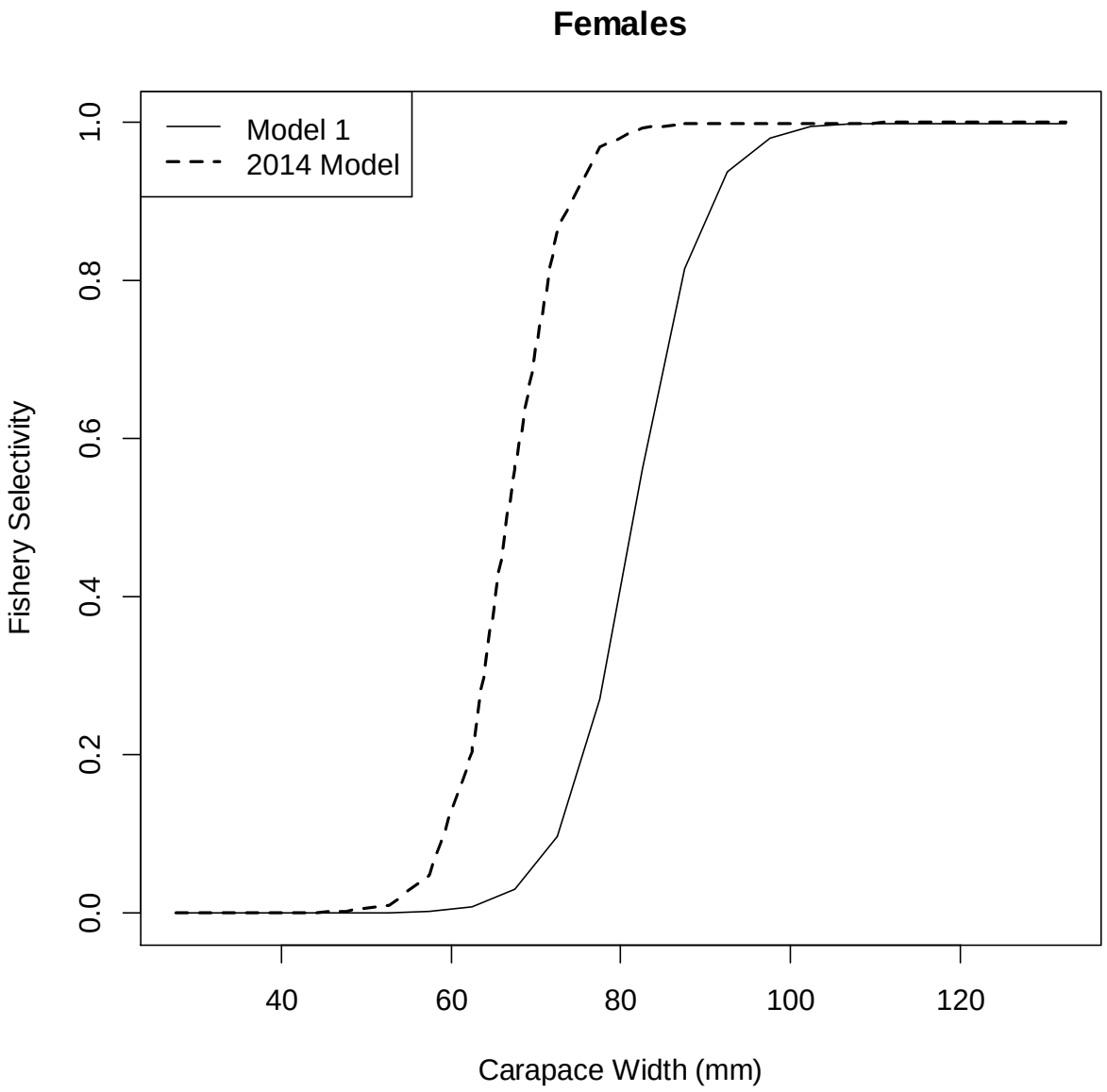

Figure 13. Female discard fishery selectivity for Model 1 and the 2014 Model. The size at 50% is fixed in both models. The size at 50% was fixed at a higher value for Models 1, 2 and 3 to give a better fit to length data. The parameter is fixed because the model is not able to estimate a plausible value for the size at 50%.

Appendix A. Plots for Model 1.

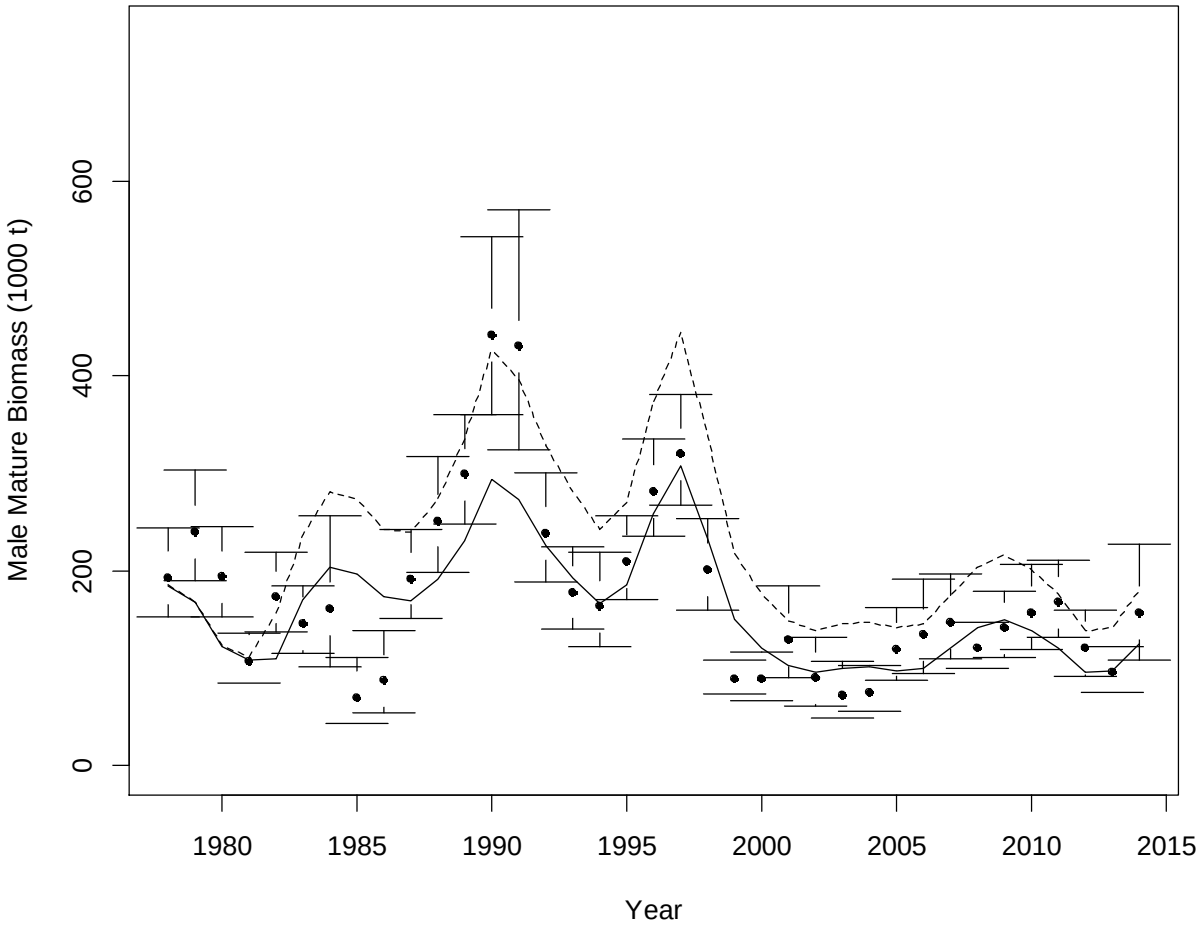

Figure A-1.

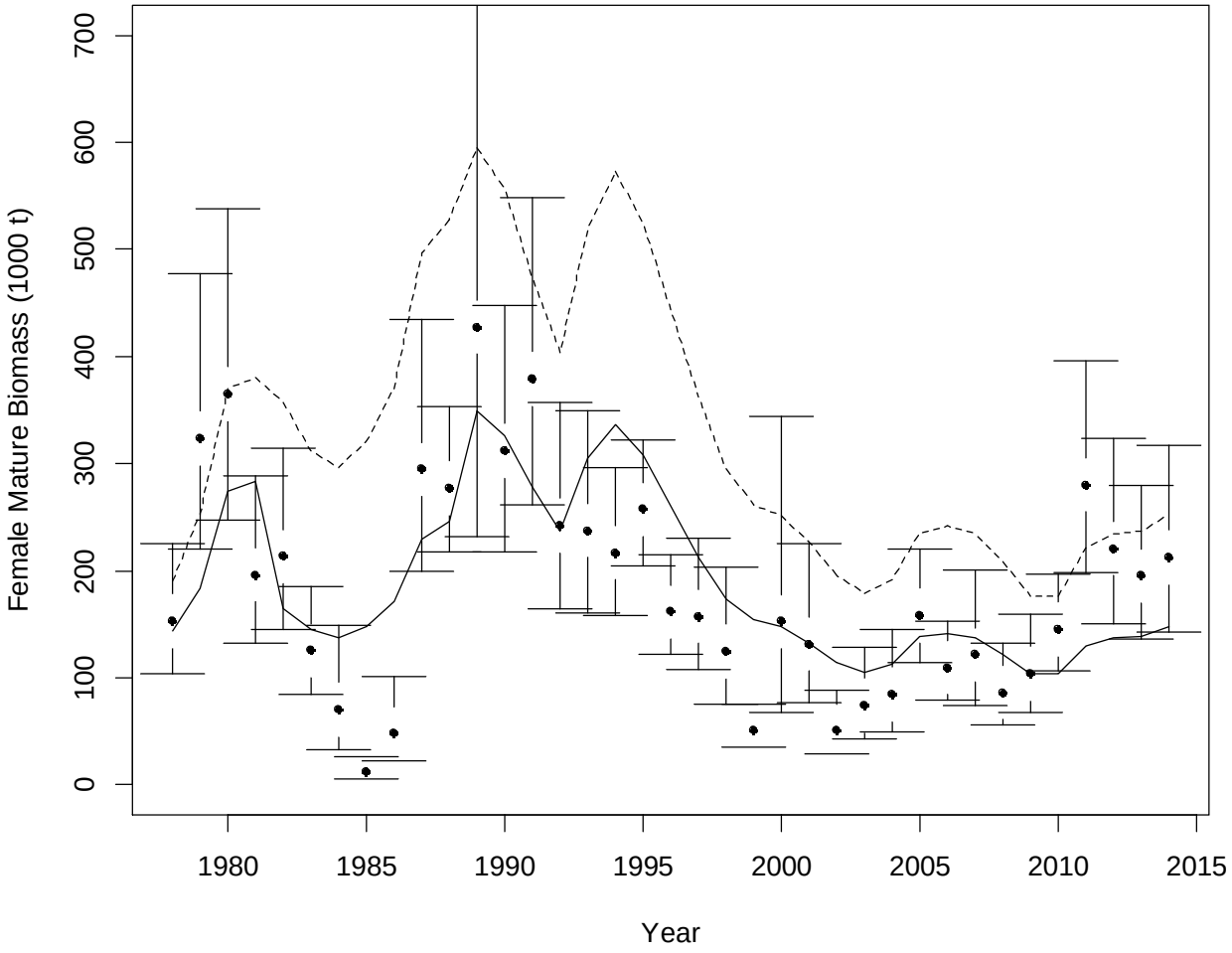
Female Mature Biomass (1000 t)
0
100
200
300
400
500
600
700
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure A-2.

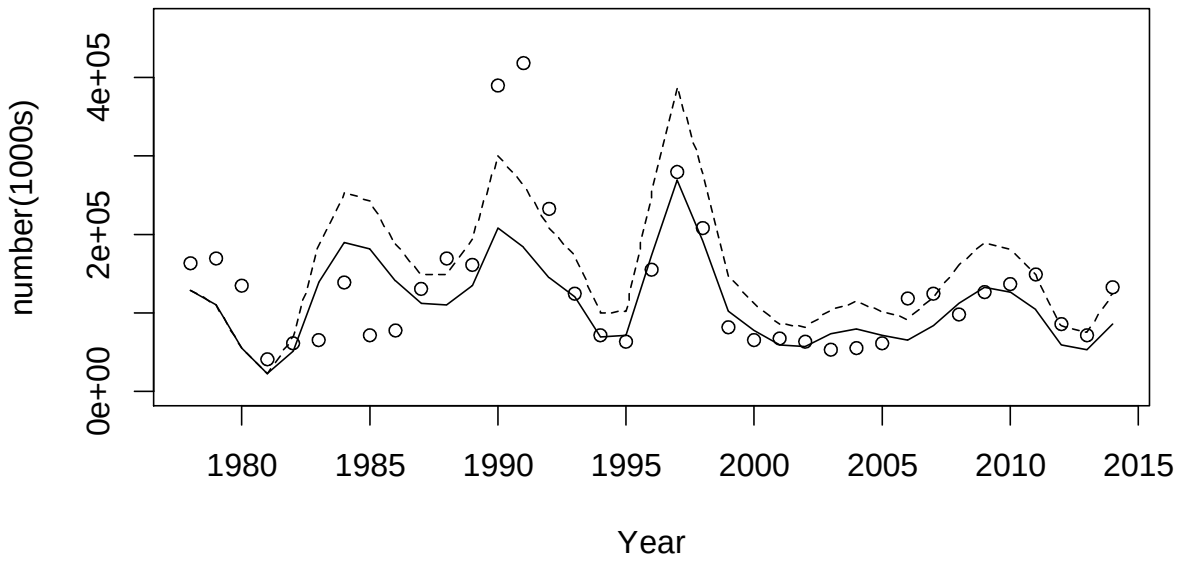

Figure A-3.

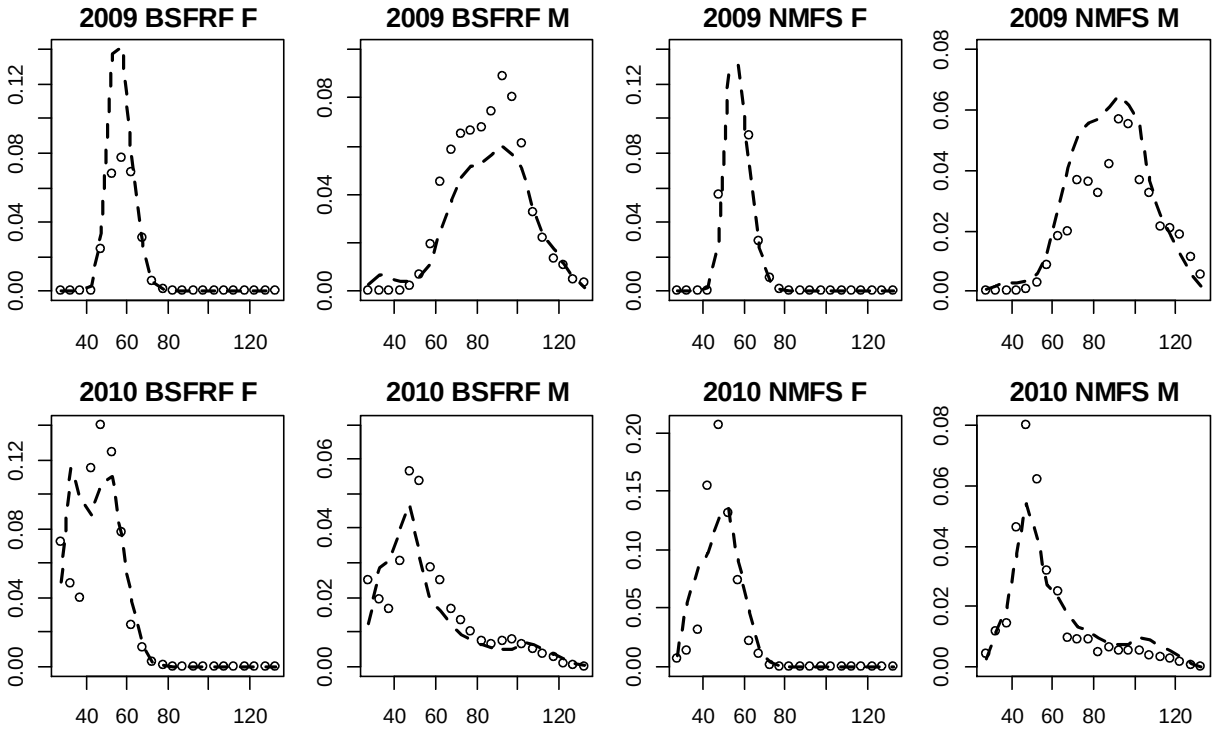

Figure A-4.

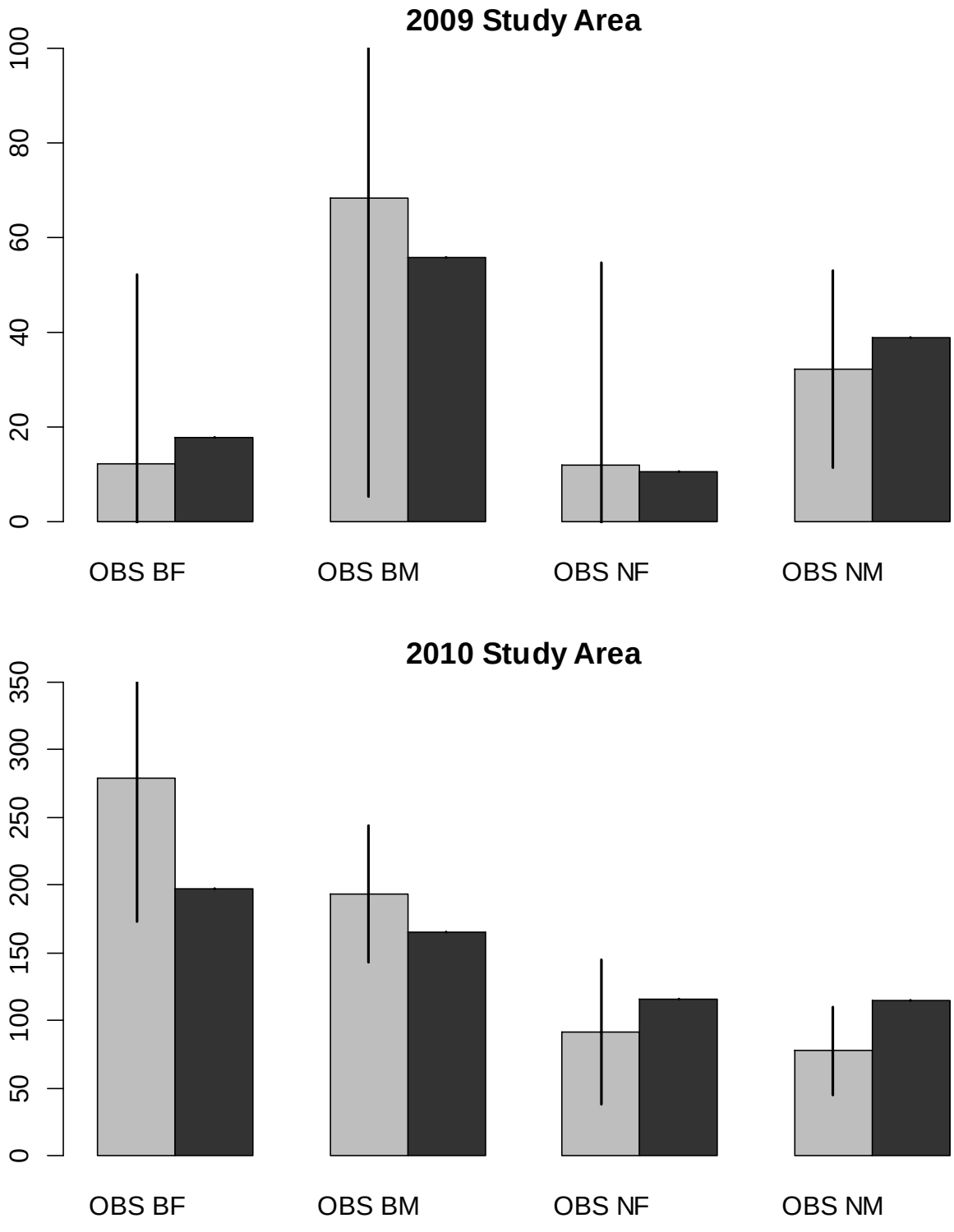
2009 Study Area
0
20
40
60
80
100
OBS BF
OBS BM
OBS NF
OBS NM
2010 Study Area
0
50
100
150
200
250
300
350
OBS BF
OBS BM
OBS NF
OBS NM

Figure A-5.

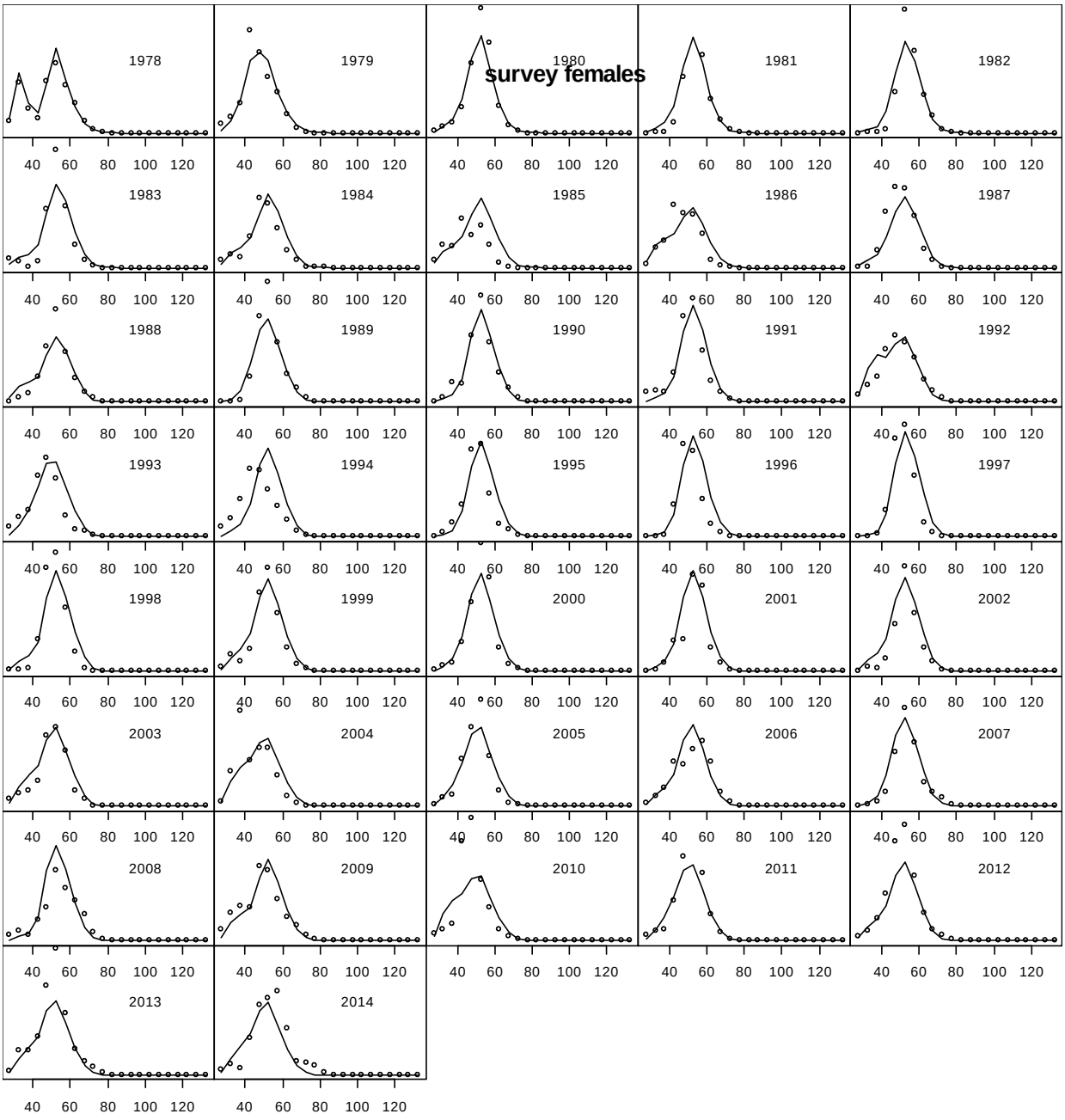
survey females
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
40 60 80 100 120

Figure A-6.

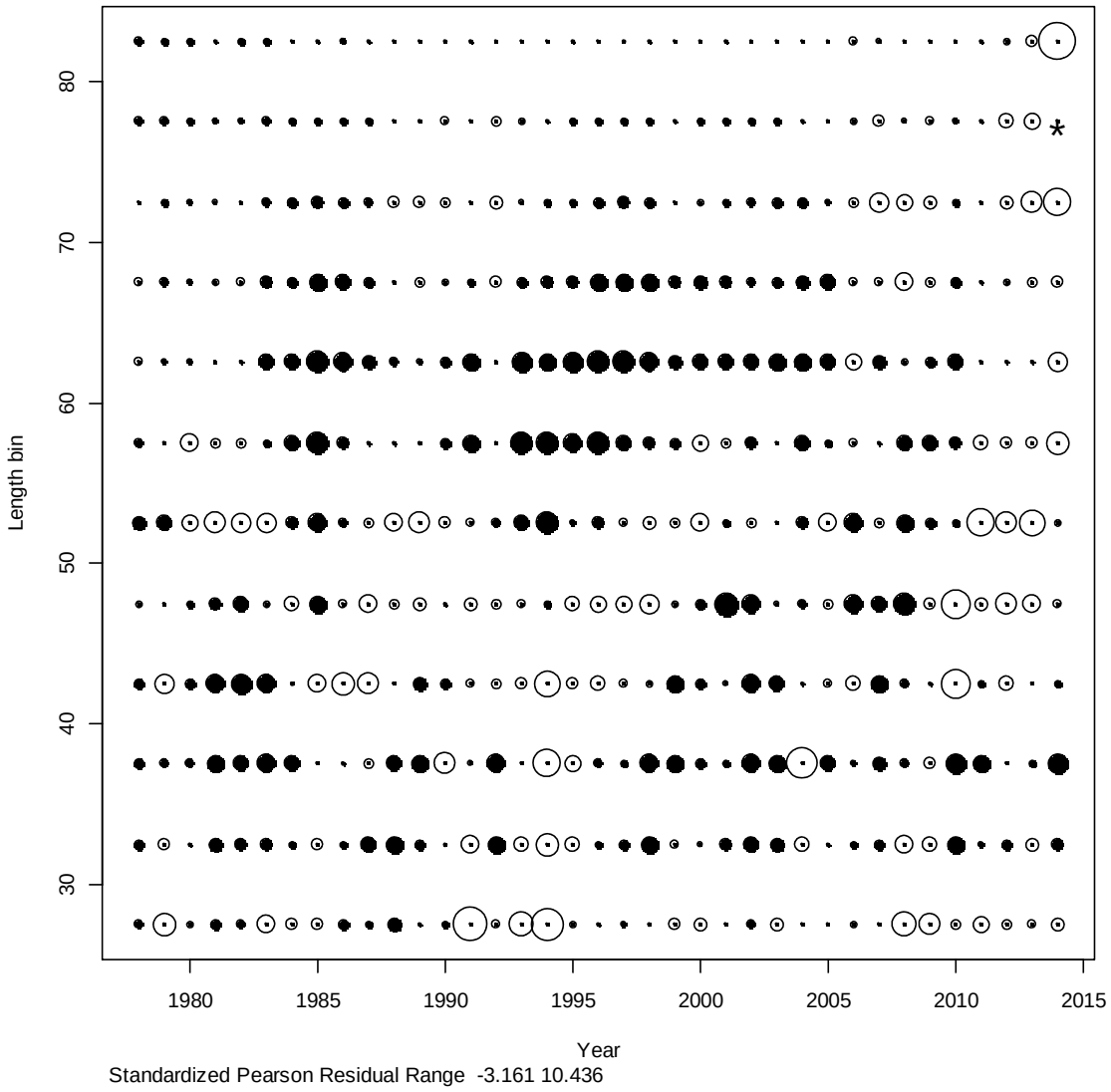
Length bin
30
40
50
60
70
80
1980
1985
1990
1995
2000
2005
2010
2015
Year
Standardized Pearson Residual Range -3.161 10.436

Figure A-7.

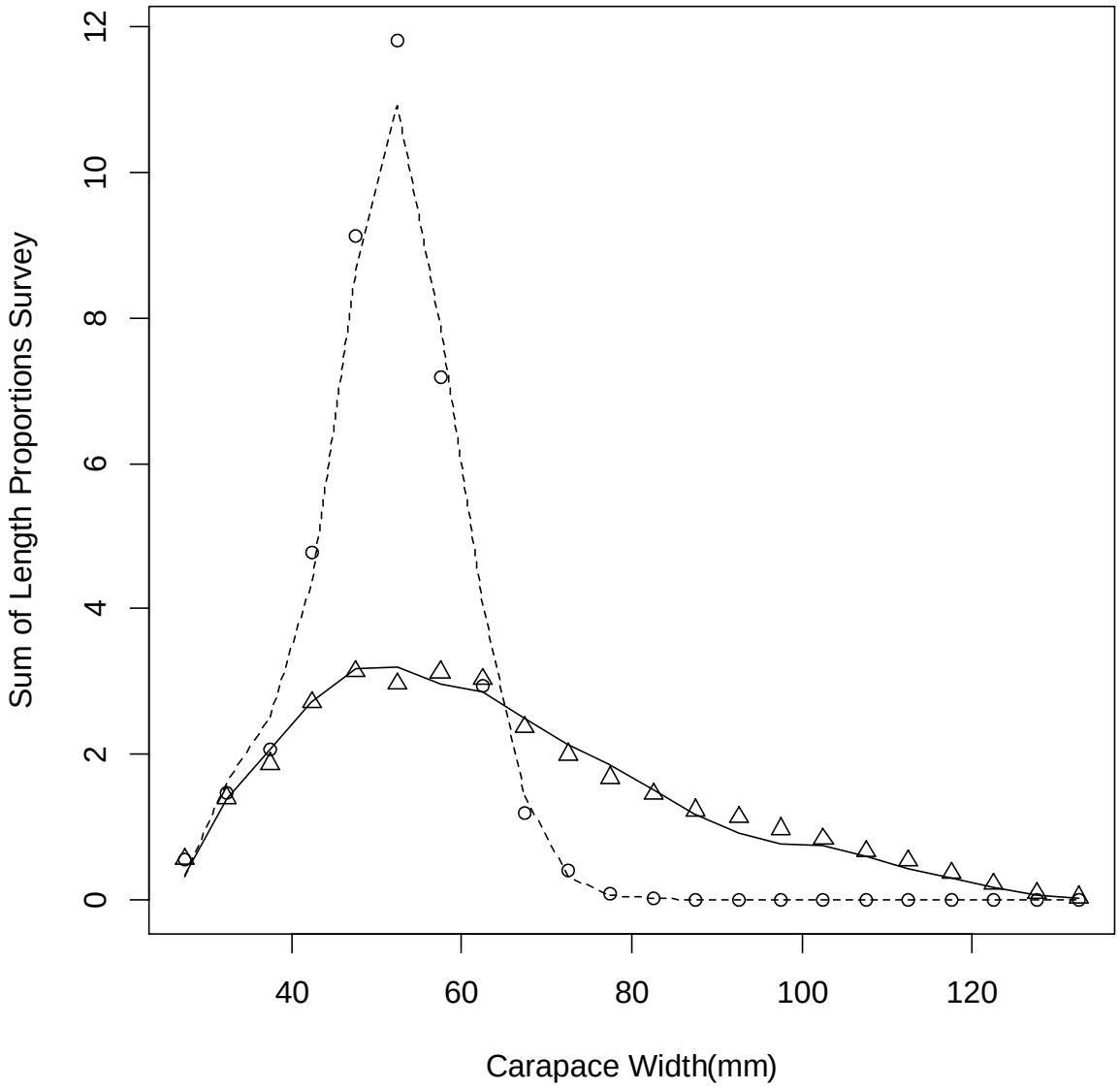
Sum of Length Proportions Survey
0
2
4
6
8
10
12
40
60
80
100
120
Carapace Width(mm)

Figure A-8.

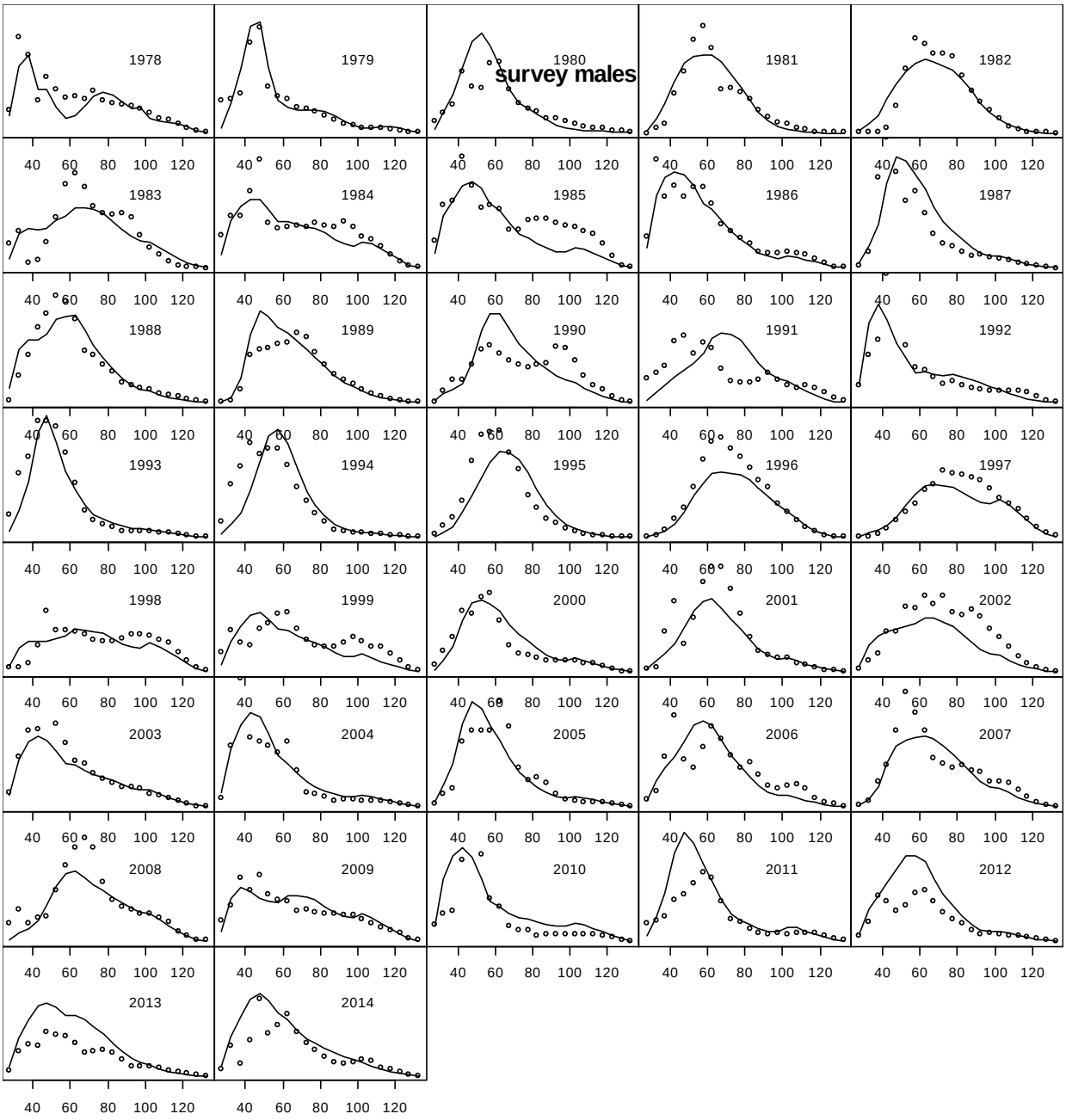
survey males
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
40 60 80 100 120

Figure A-9.

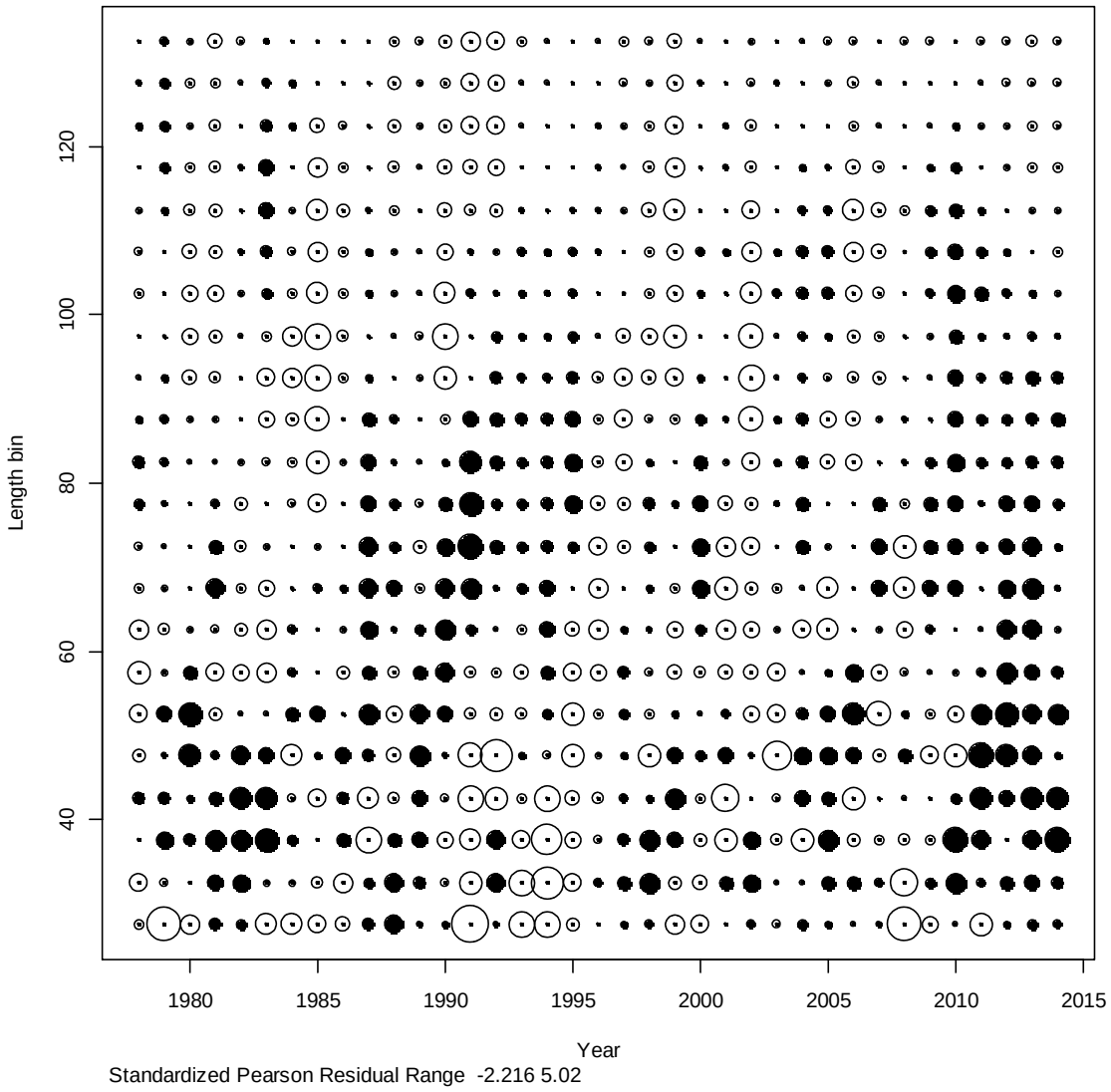
Length bin
40
60
80
100
120
1980
1985
1990
1995
2000
2005
2010
2015
Year
Standardized Pearson Residual Range -2.216 5.02

Figure A-10.

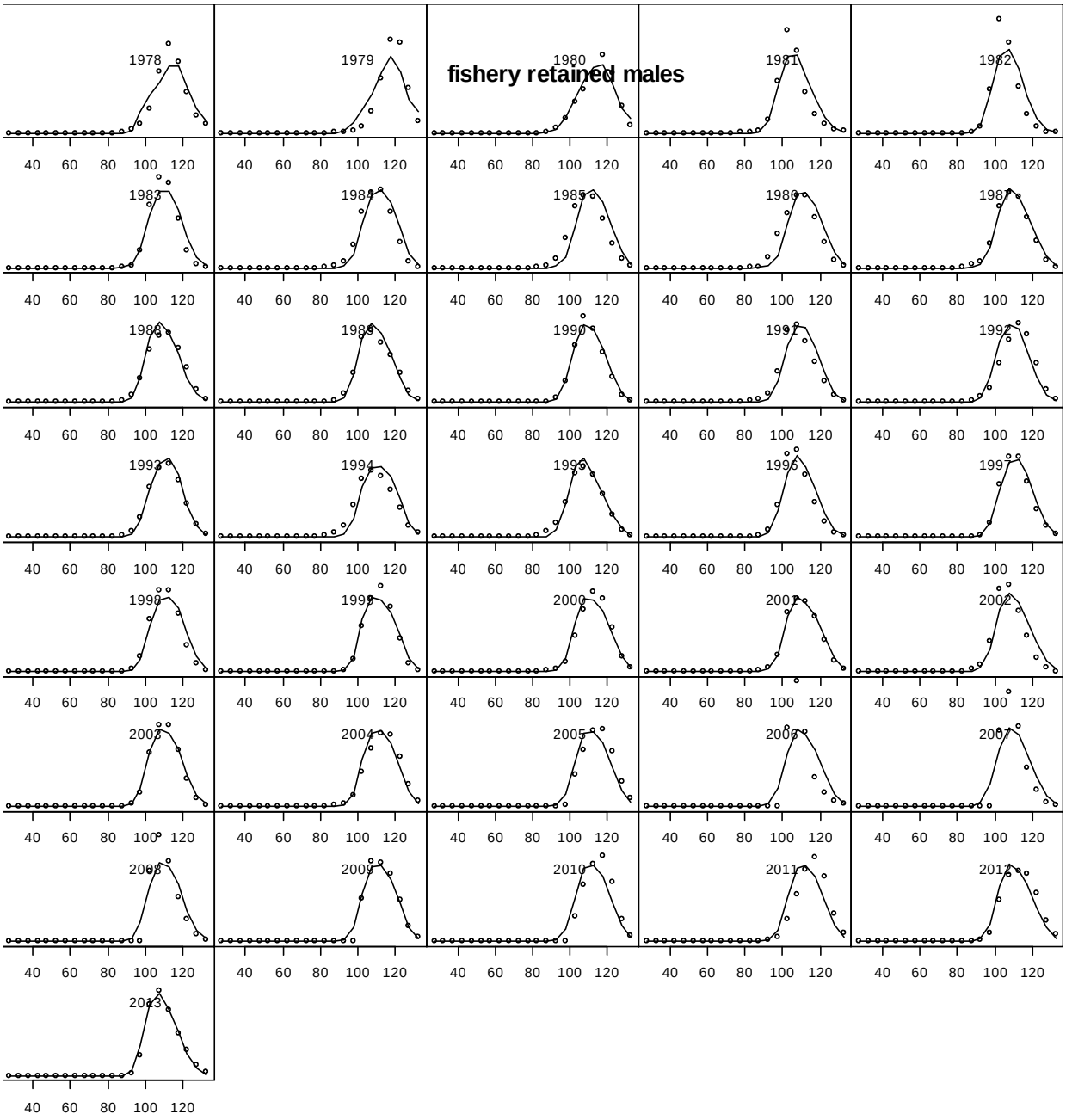
fishery retained males
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40 60 80 100 120

Figure A-11.

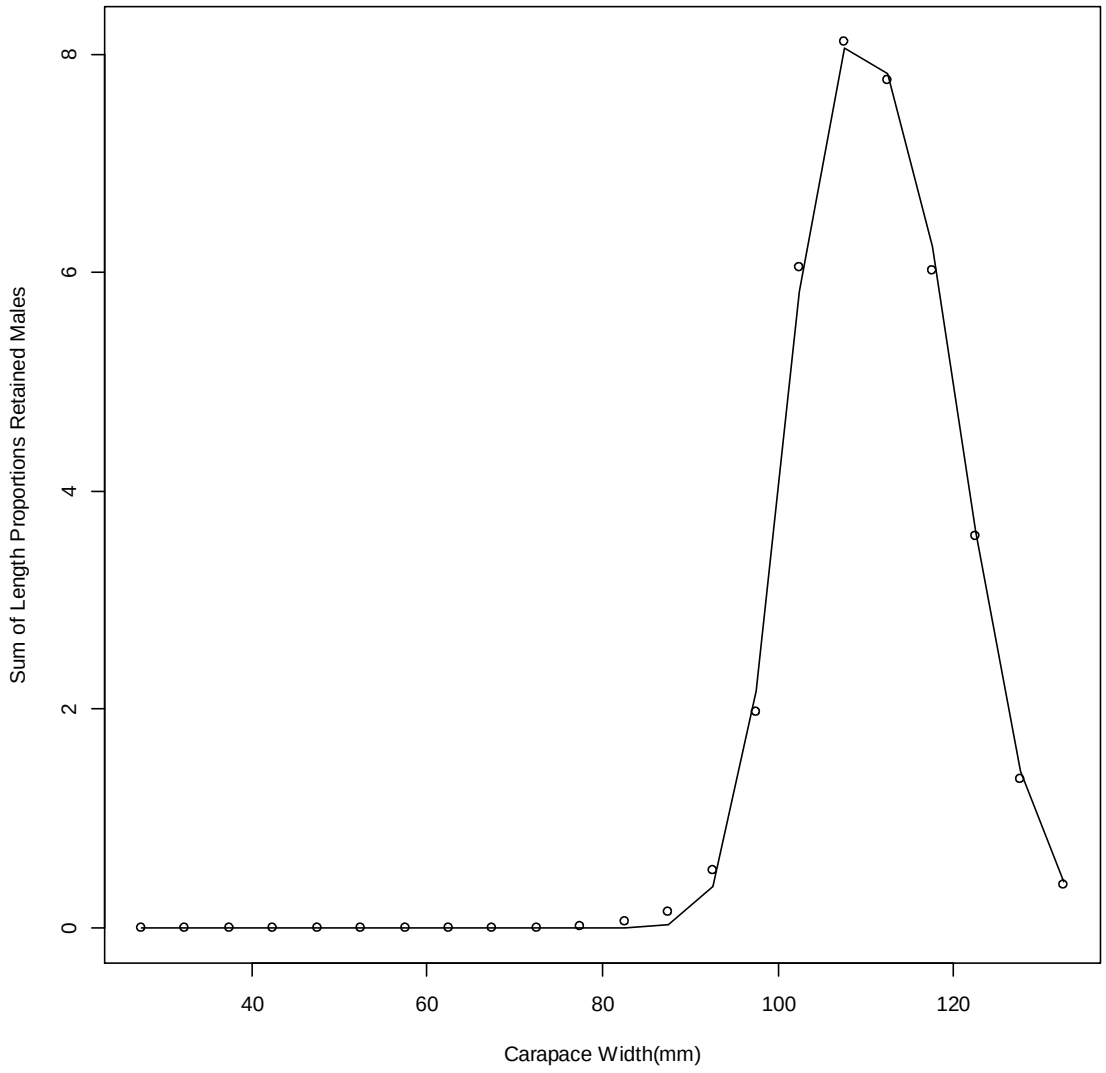
Sum of Length Proportions Retained Males
0
2
4
6
8
40
60
80
100
120
Carapace Width(mm)

Figure A-12.

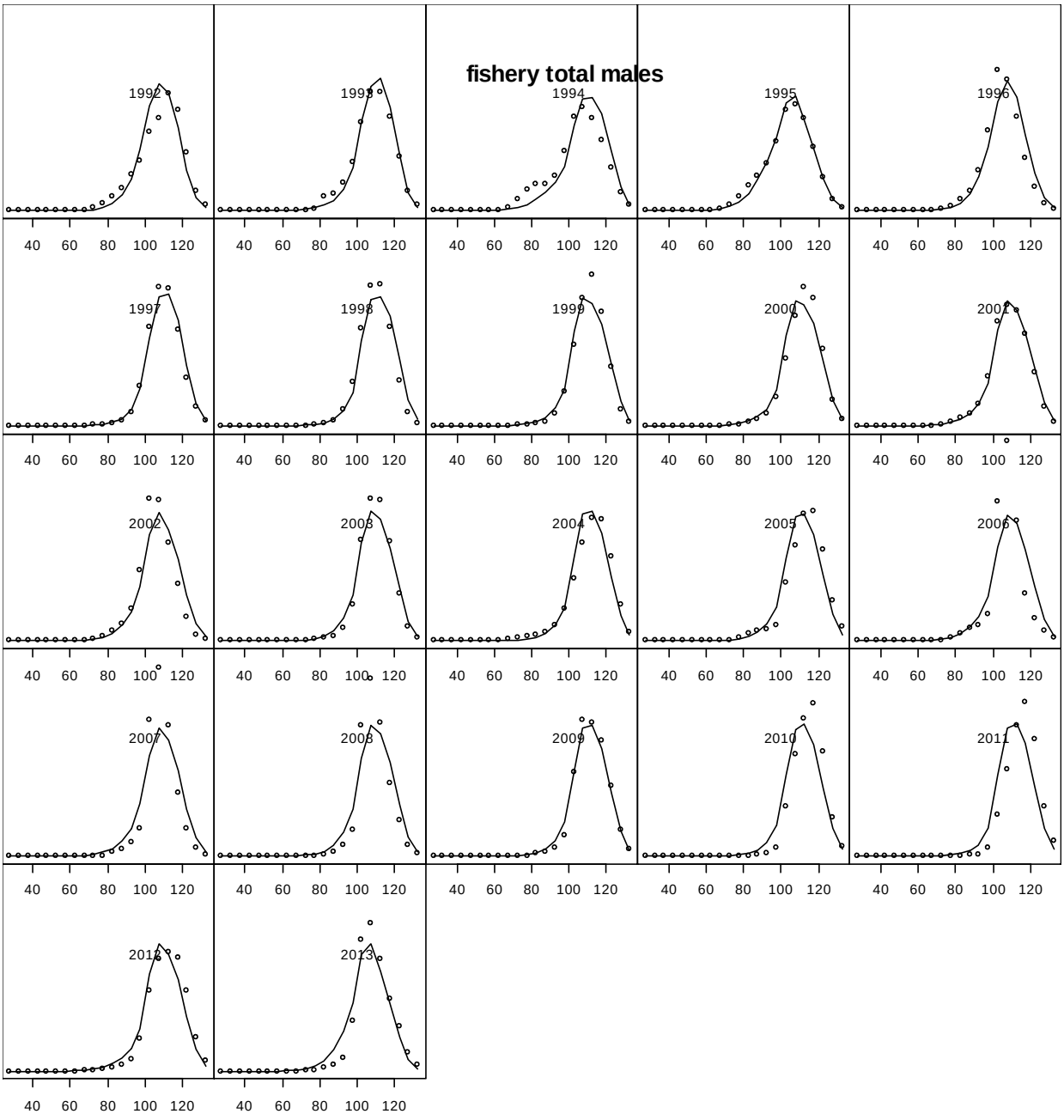
fishery total males
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40 60 80 100 120

Figure A-13.

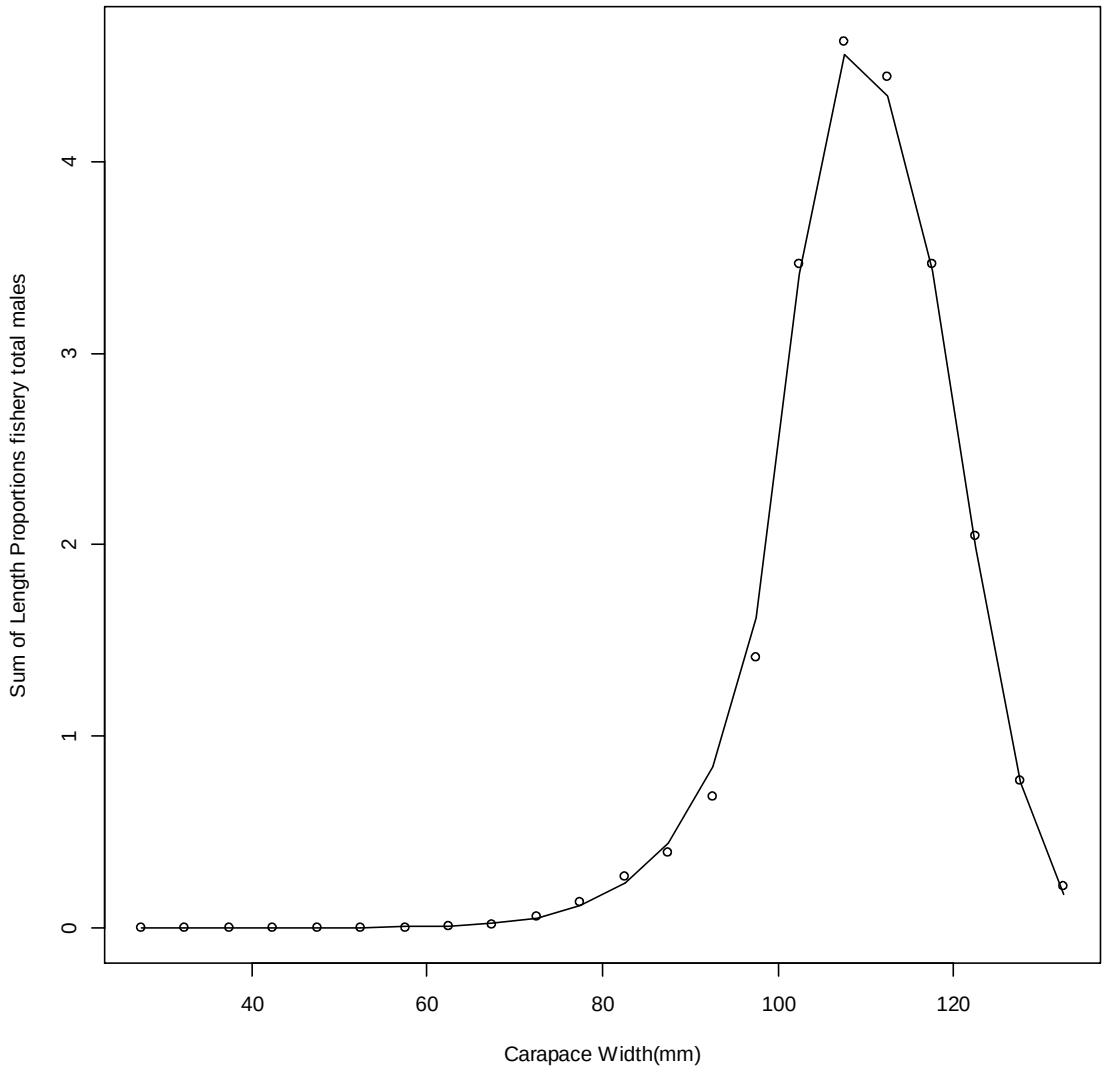
Sum of Length Proportions fishery total males
0
1
2
3
4
40
60
80
100
120
Carapace Width(mm)

Figure A-14.

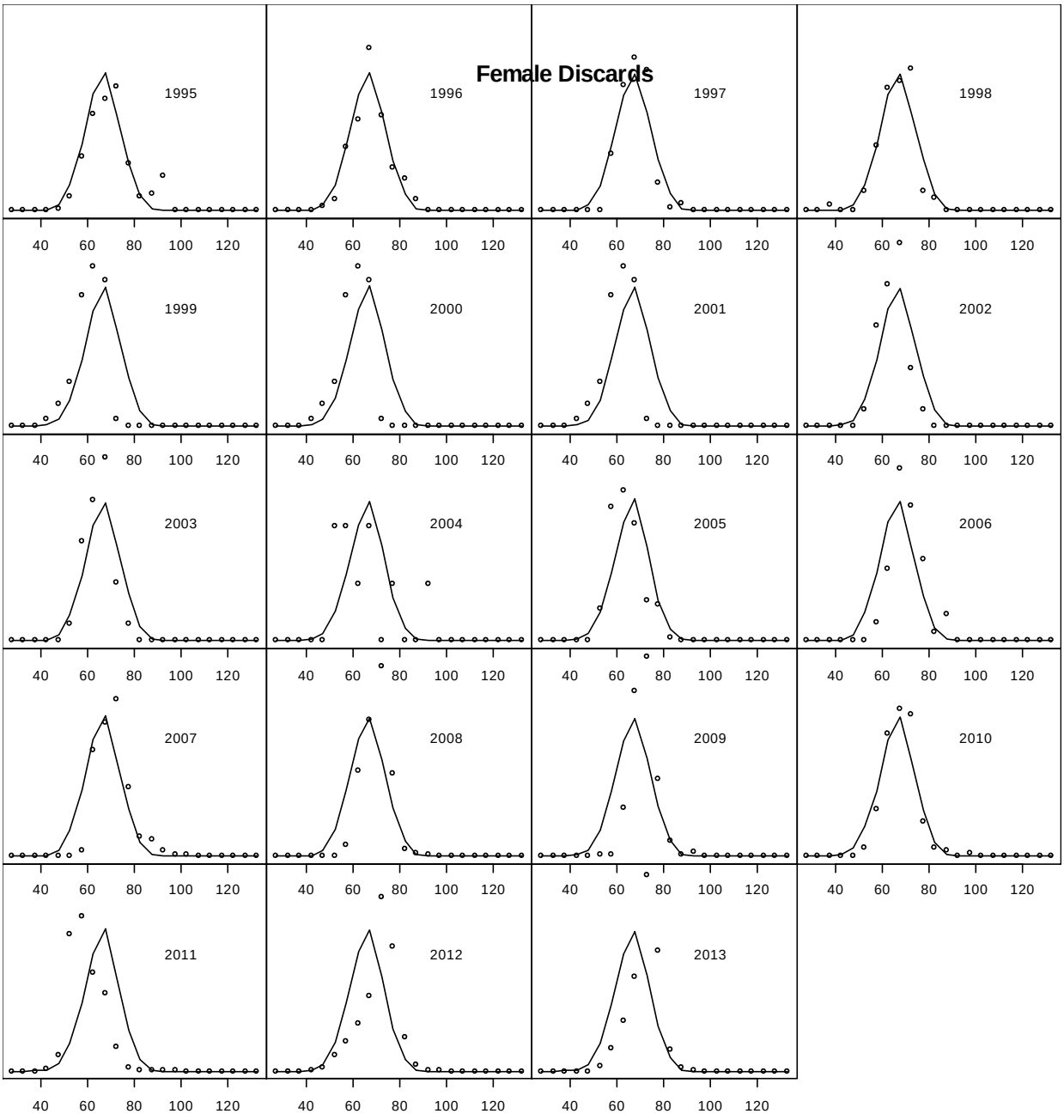
Female Discards
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40
60
80
100
120

Figure A-15.

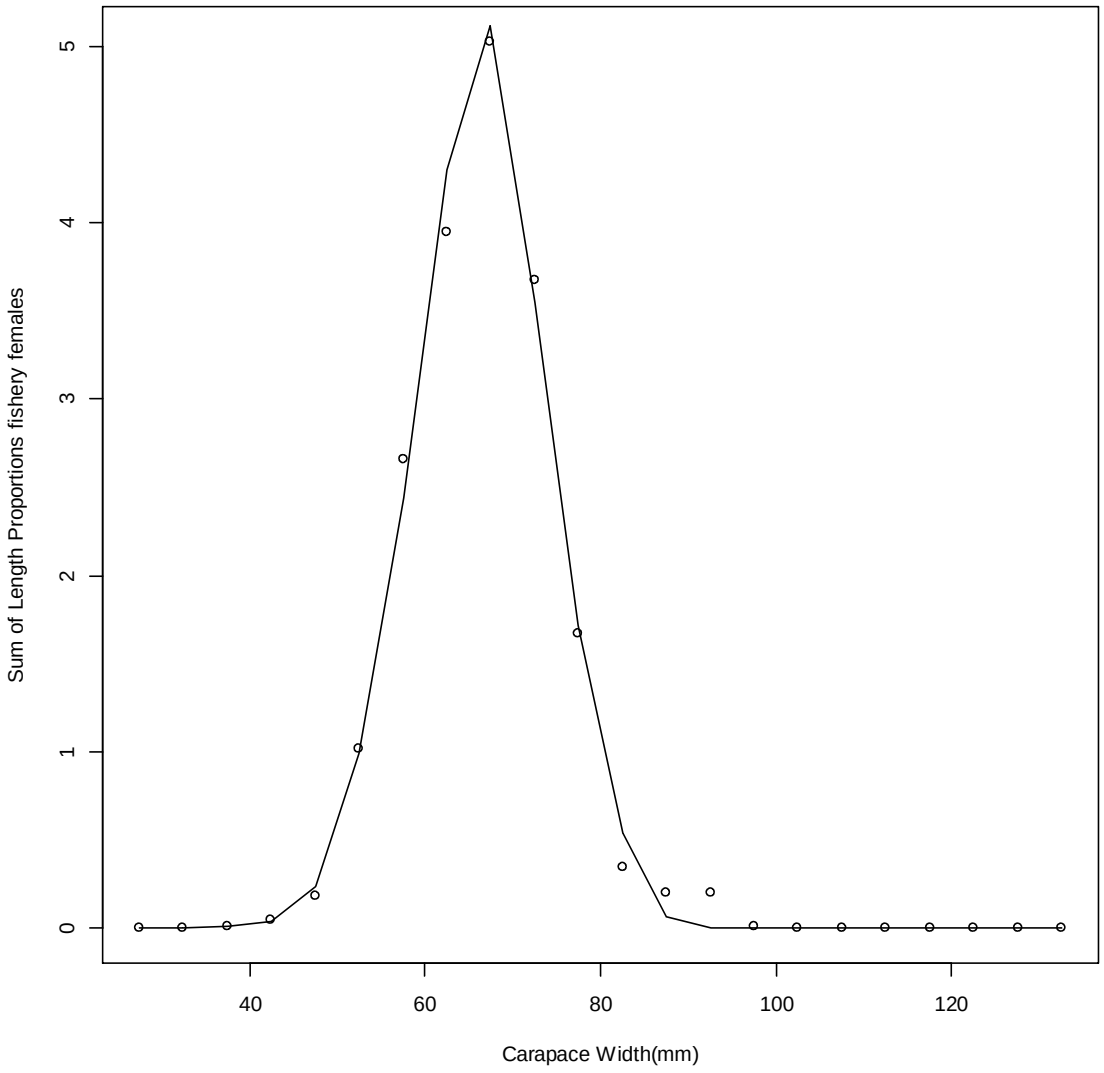
Sum of Length Proportions fishery females
0
1
2
3
4
5
40
60
80
100
120
Carapace Width(mm)

Figure A-16.

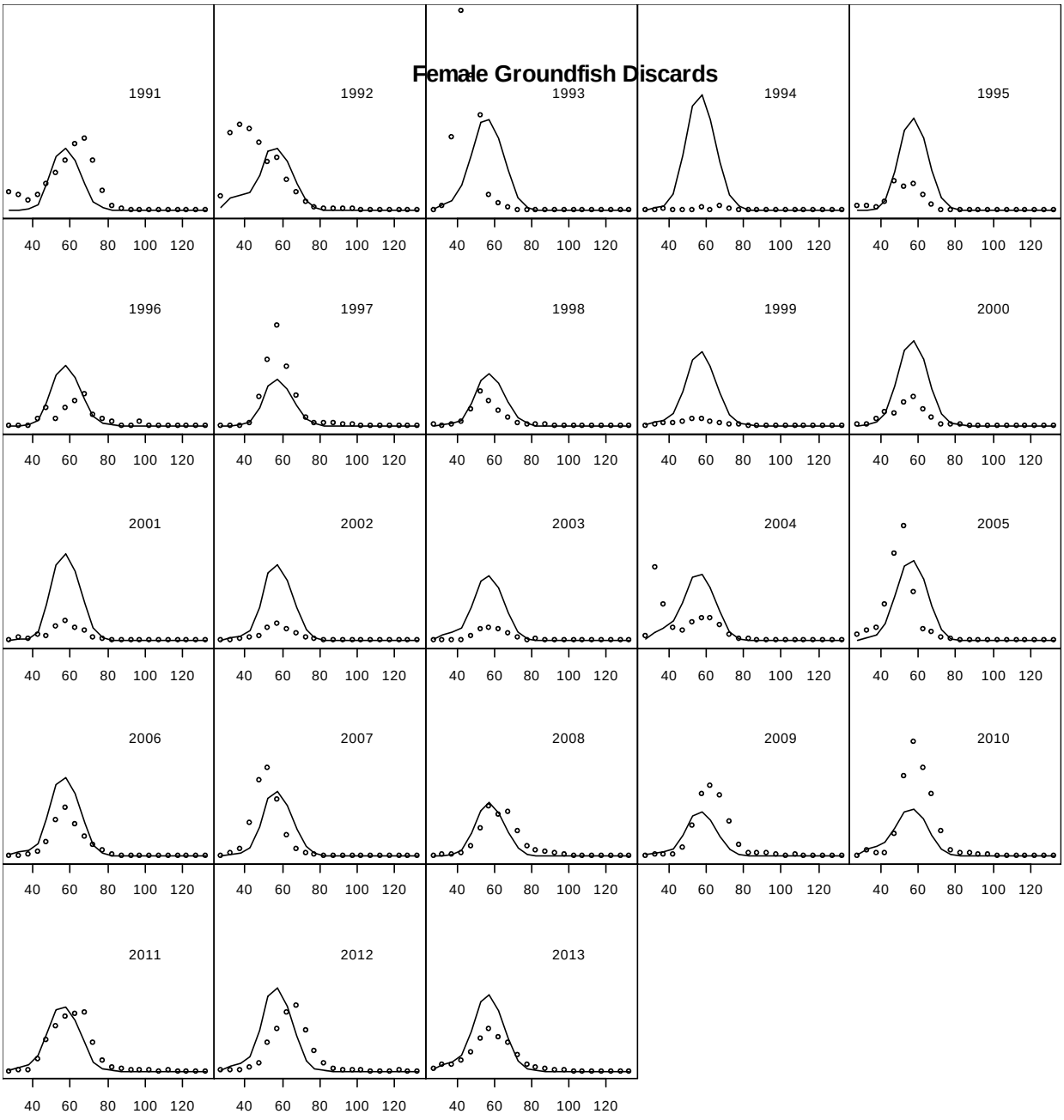
Female Groundfish Discards
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40 60 80 100 120

Figure A-17.

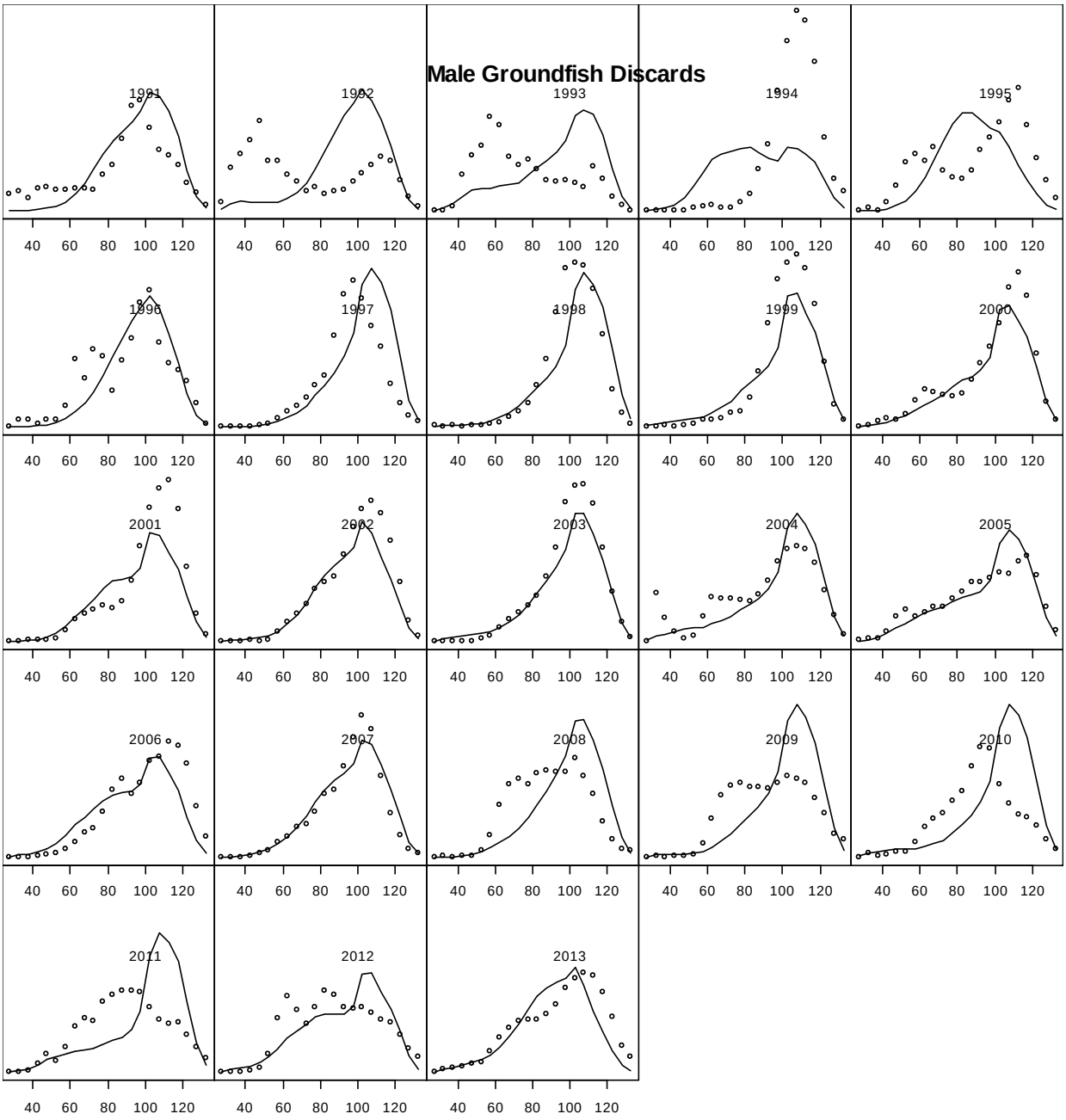
Male Groundfish Discards
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40 60 80 100 120

Figure A-18.

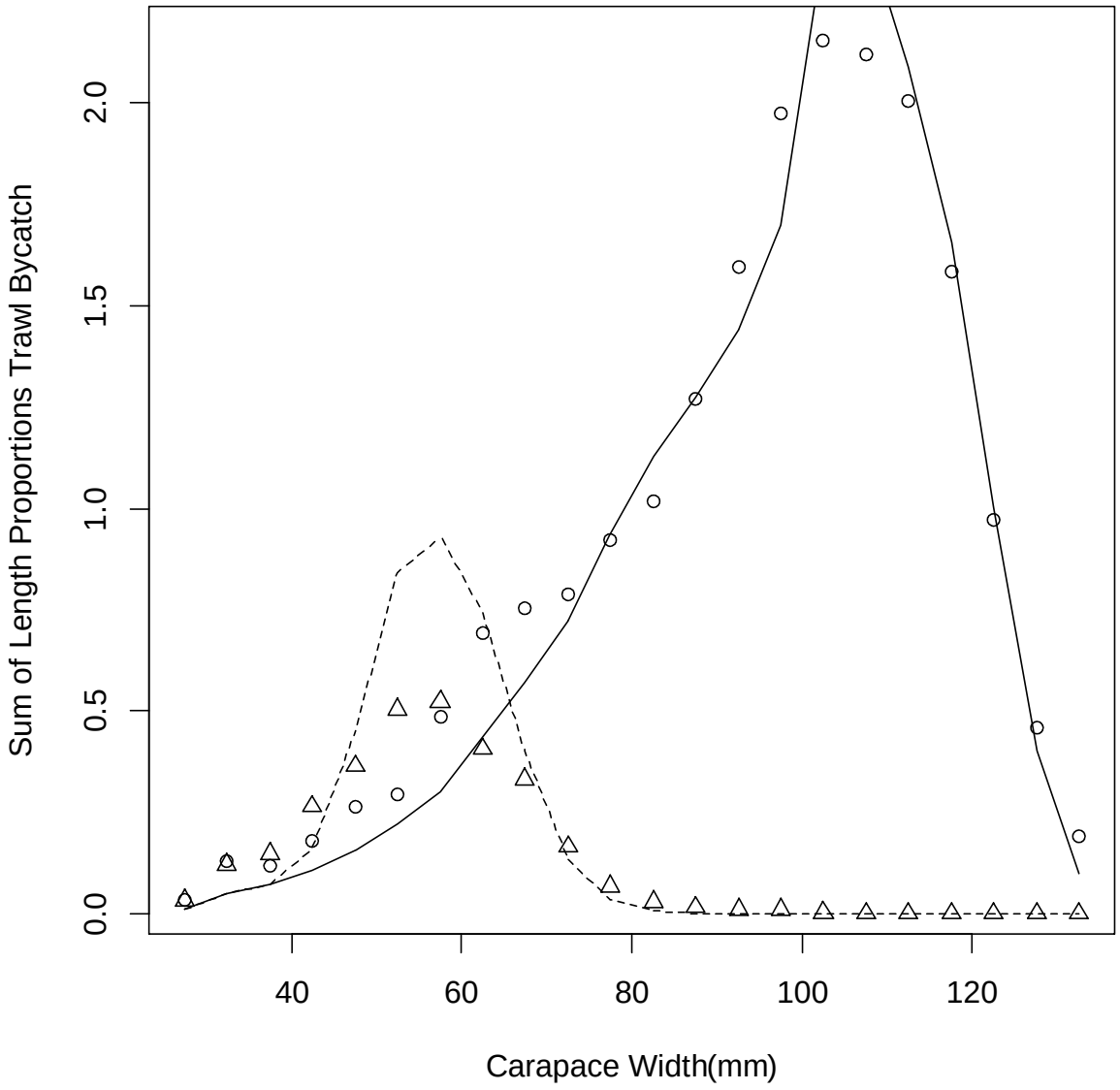
Sum of Length Proportions Trawl Bycatch
0.0
0.5
1.0
1.5
2.0
40
60
80
100
120
Carapace Width(mm)

Figure A-19.

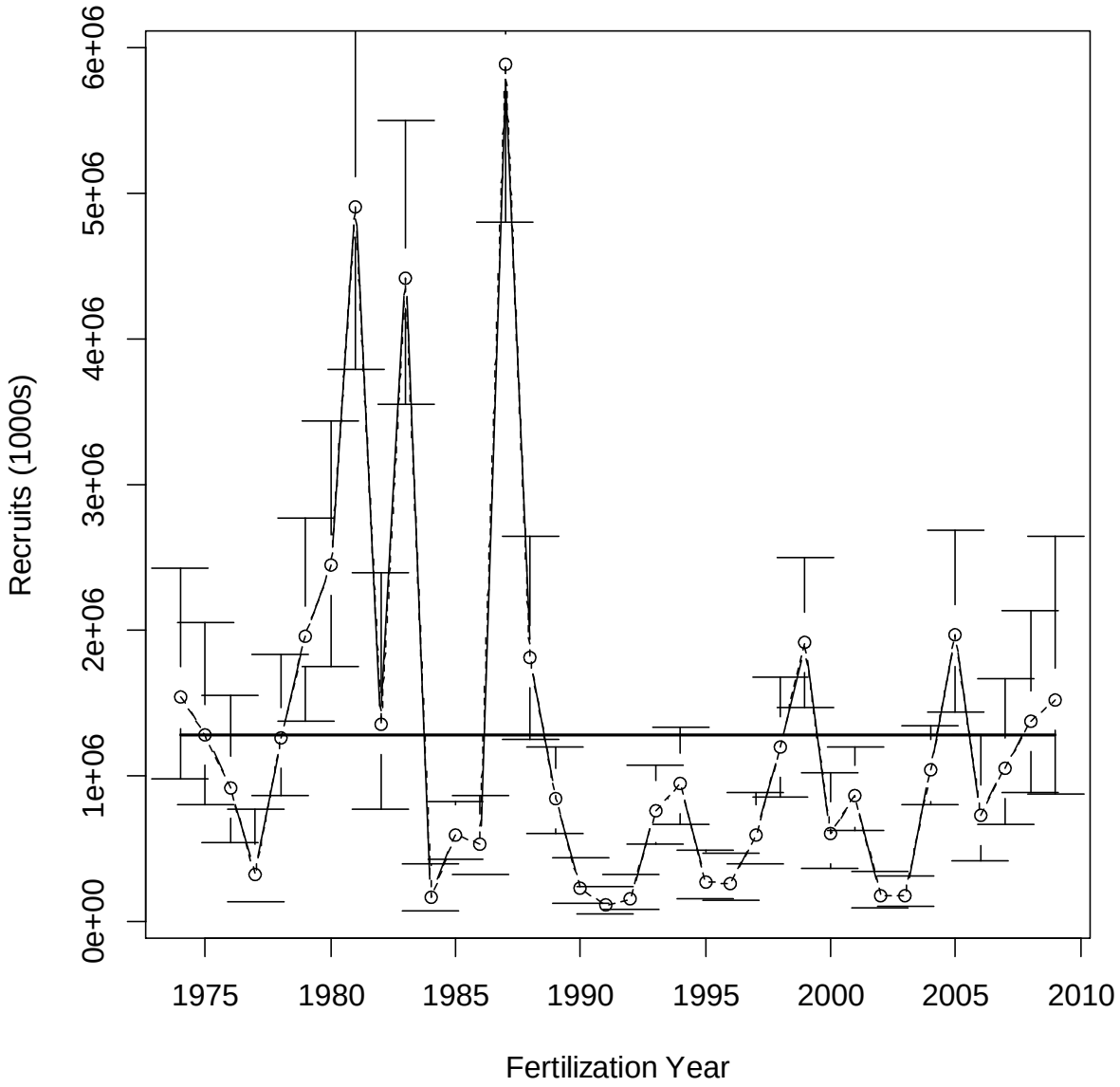
Recruits (1000s)
0e+00
1e+06
2e+06
3e+06
4e+06
5e+06
6e+06
1975
1980
1985
1990
1995
2000
2005
2010
Fertilization Year

Figure A-20.

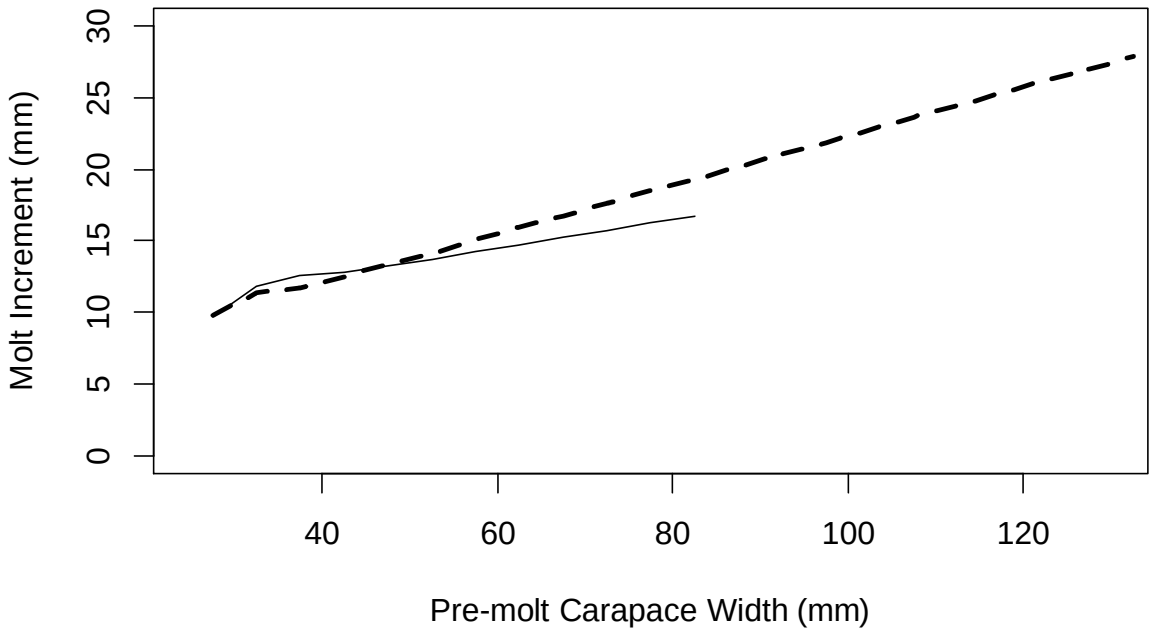
Molt Increment (mm)
0
5
10
15
20
25
30
40
60
80
100
120
Pre-molt Carapace Width (mm)

Figure A-21.

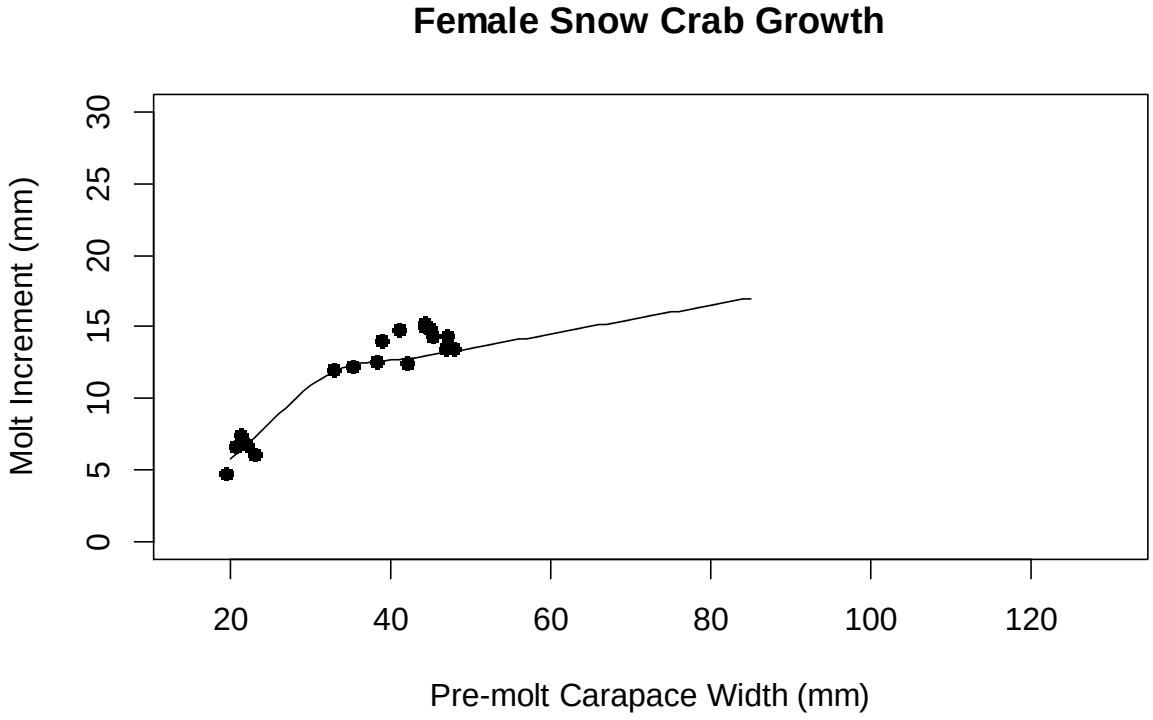
Female Snow Crab Growth
Molt Increment (mm)
0
5
10
15
20
25
30
20
40
60
80
100
120
Pre-molt Carapace Width (mm)

Figure A-22.

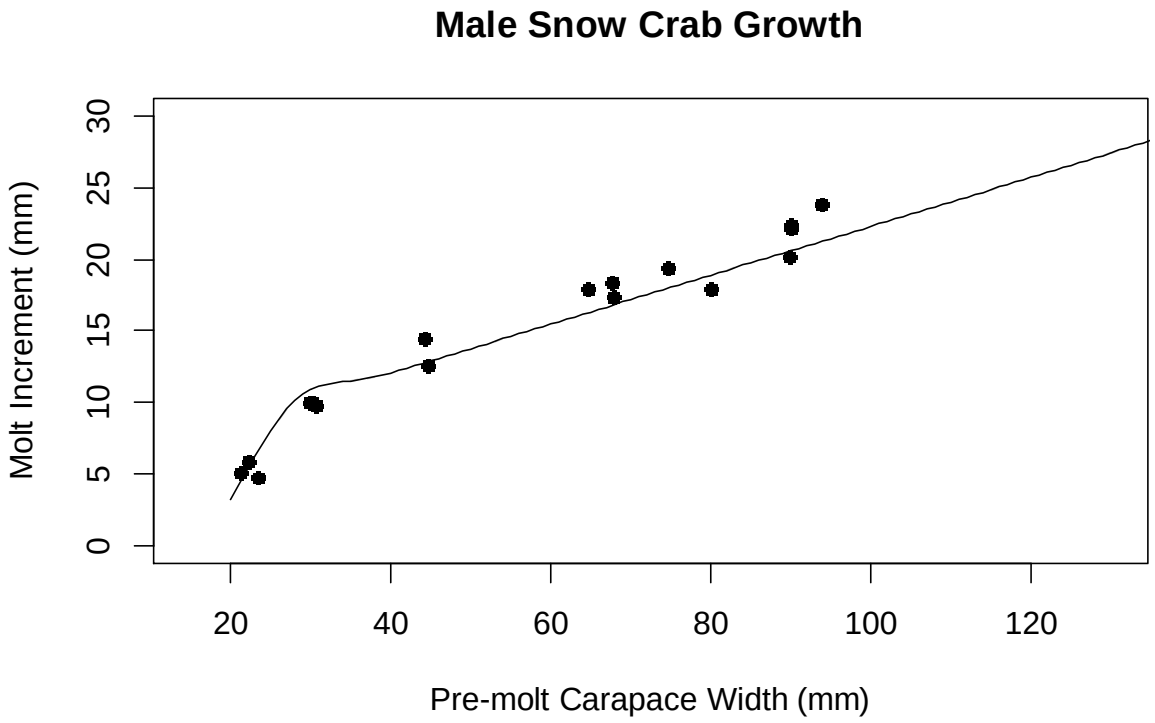

Figure A-23.

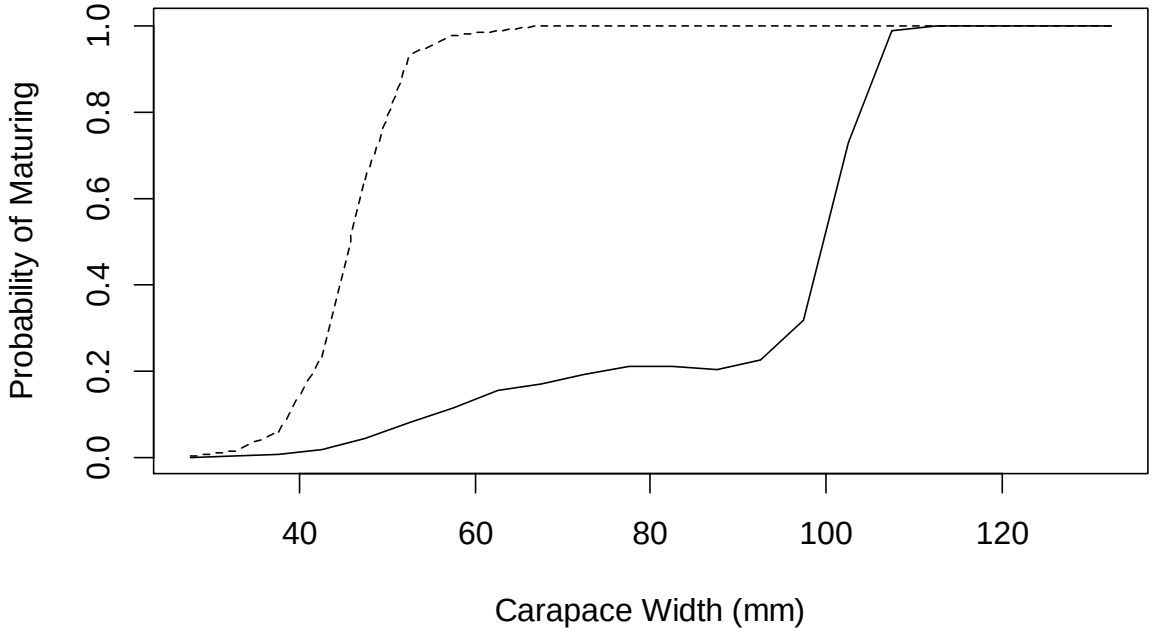
Probability of Maturing
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
Carapace Width (mm)

Figure A-24.

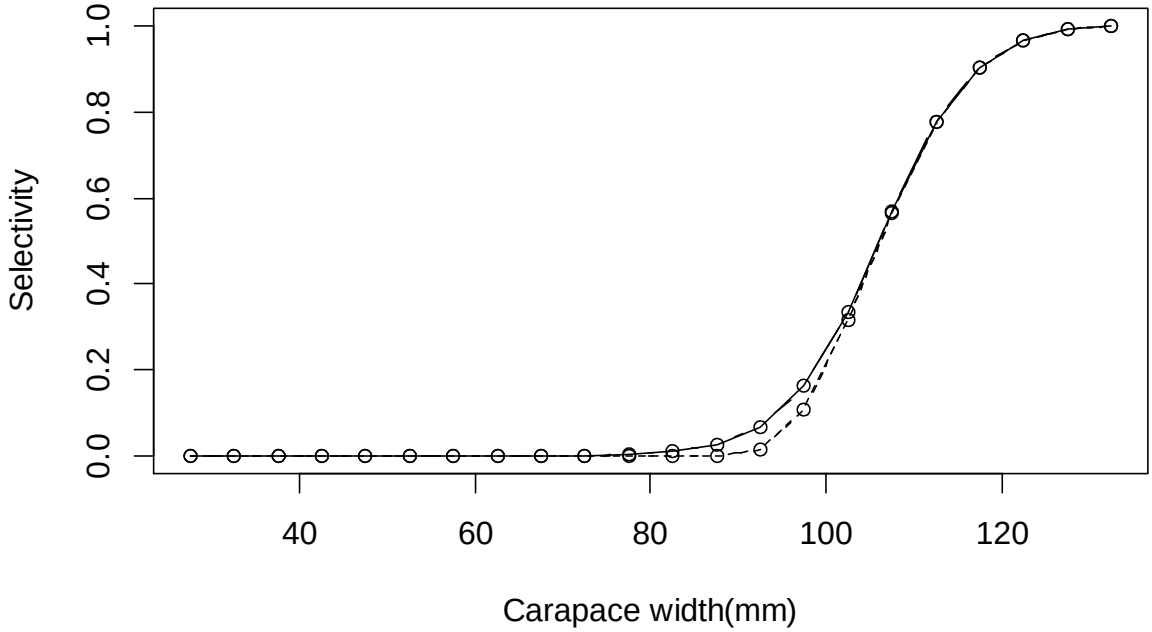
Selectivity
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
Carapace width(mm)

Figure A-25.

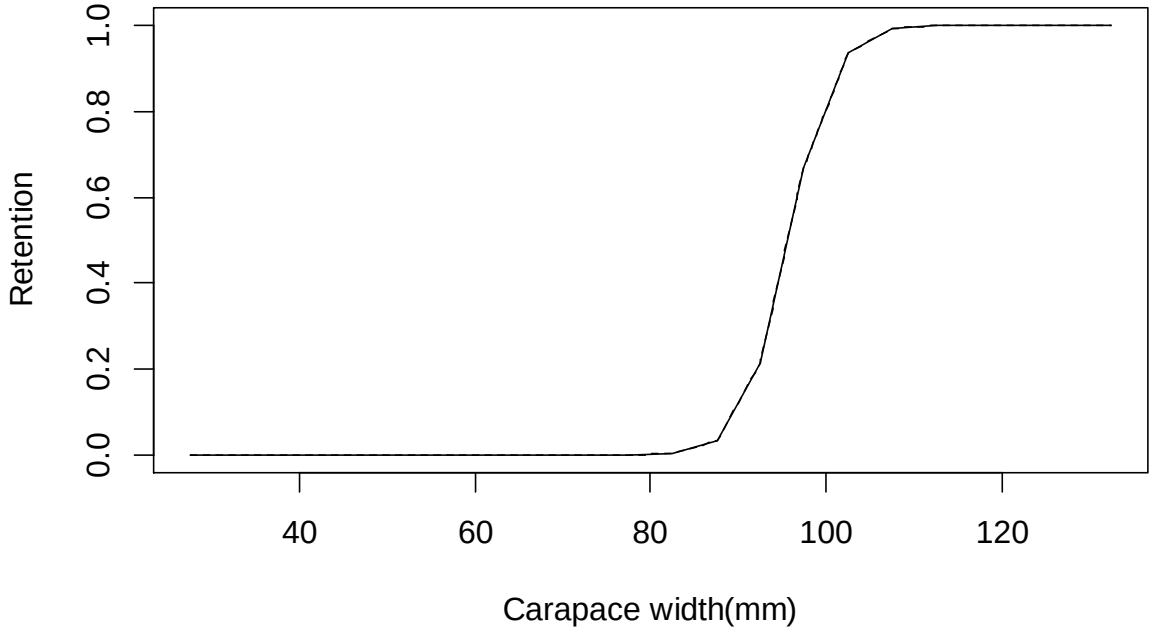

Figure A-26.

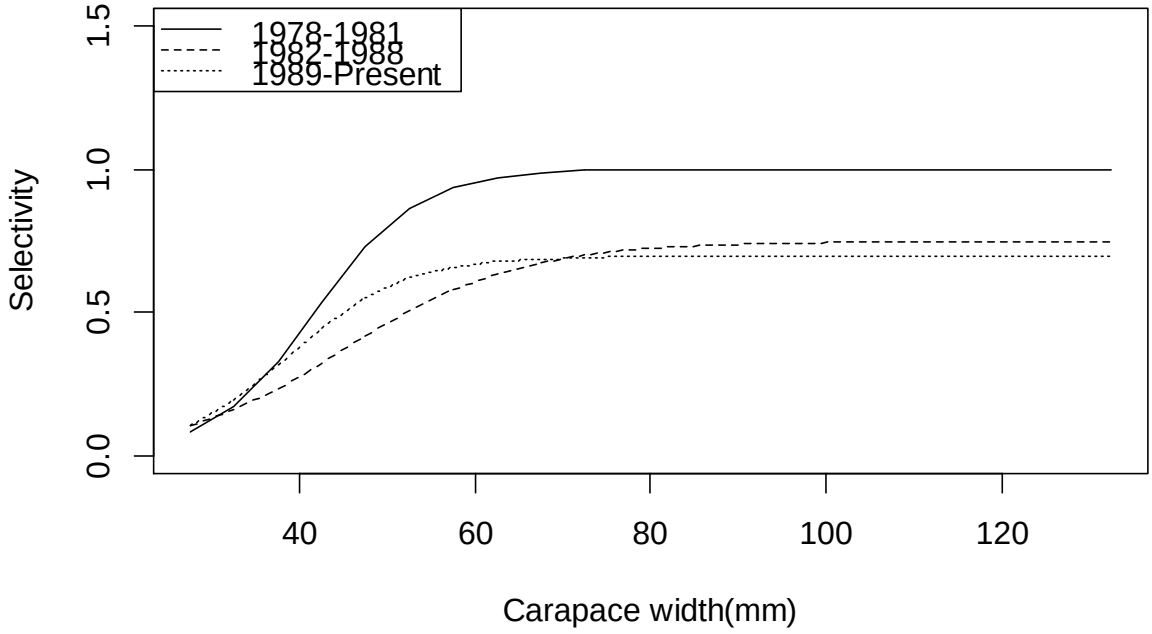
1978-1981
1982-1988
1989-Present
Selectivity
0.0
0.5
1.0
1.5
40
60
80
100
120
Carapace width(mm)

Figure A-27.

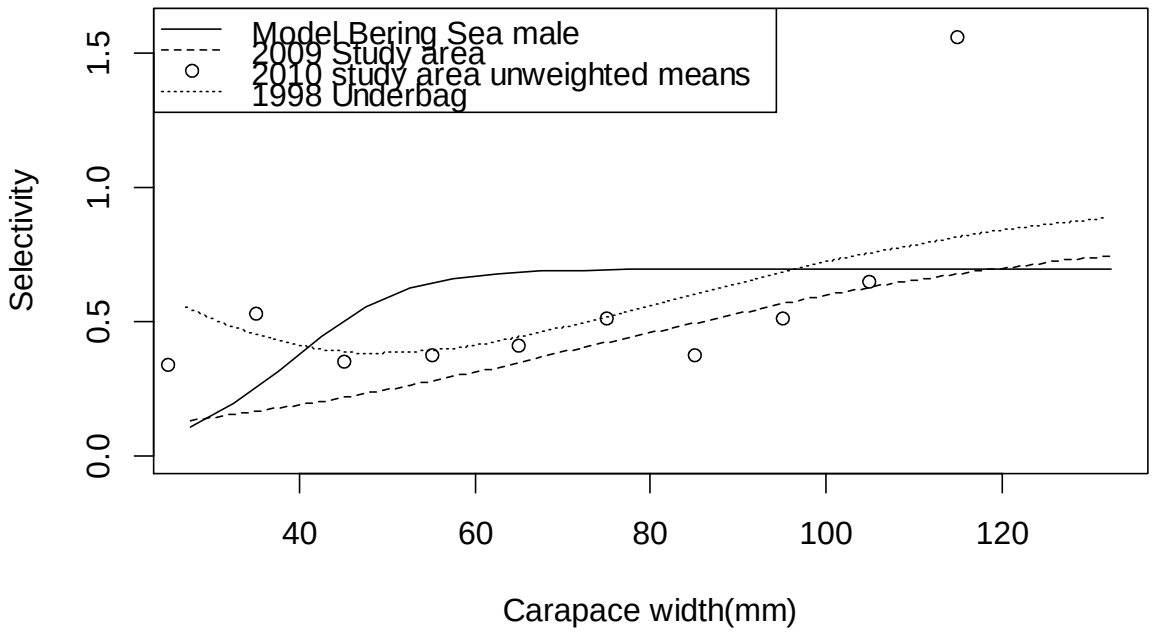
Model Bering Sea male
2009 Study area
2010 study area unweighted means
1998 Underbag
Selectivity
0.0
0.5
1.0
1.5
40
60
80
100
120
Carapace width(mm)

Figure A-28.

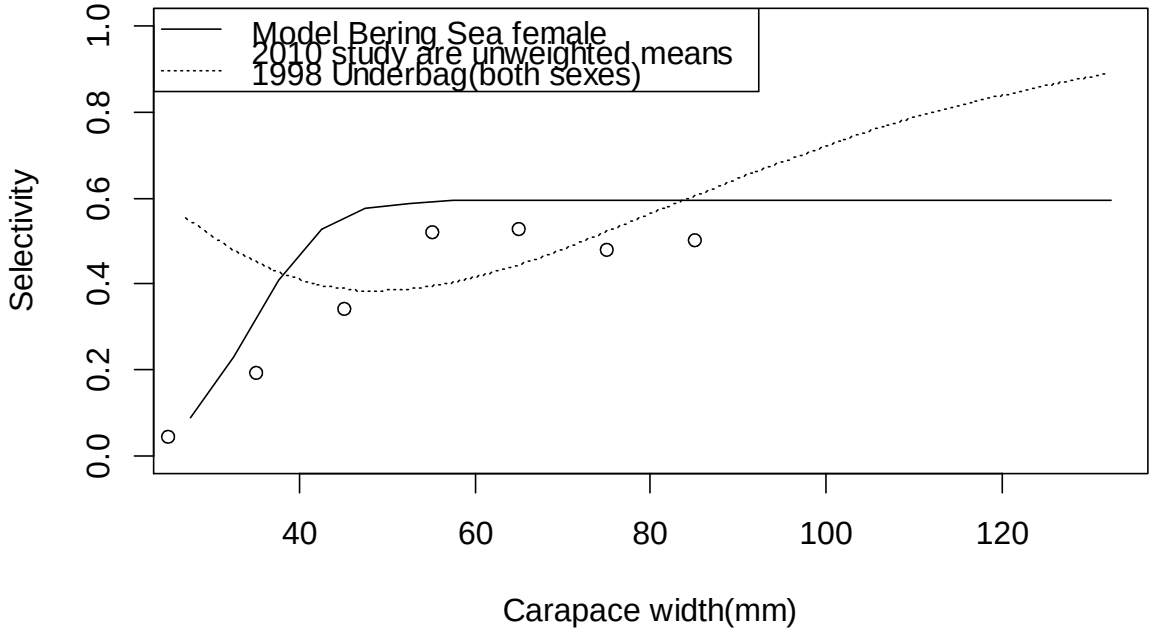
Model Bering Sea female
2010 study are unweighted means
1998 Underbag(both sexes)
Selectivity
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
Carapace width(mm)

Figure A-29.

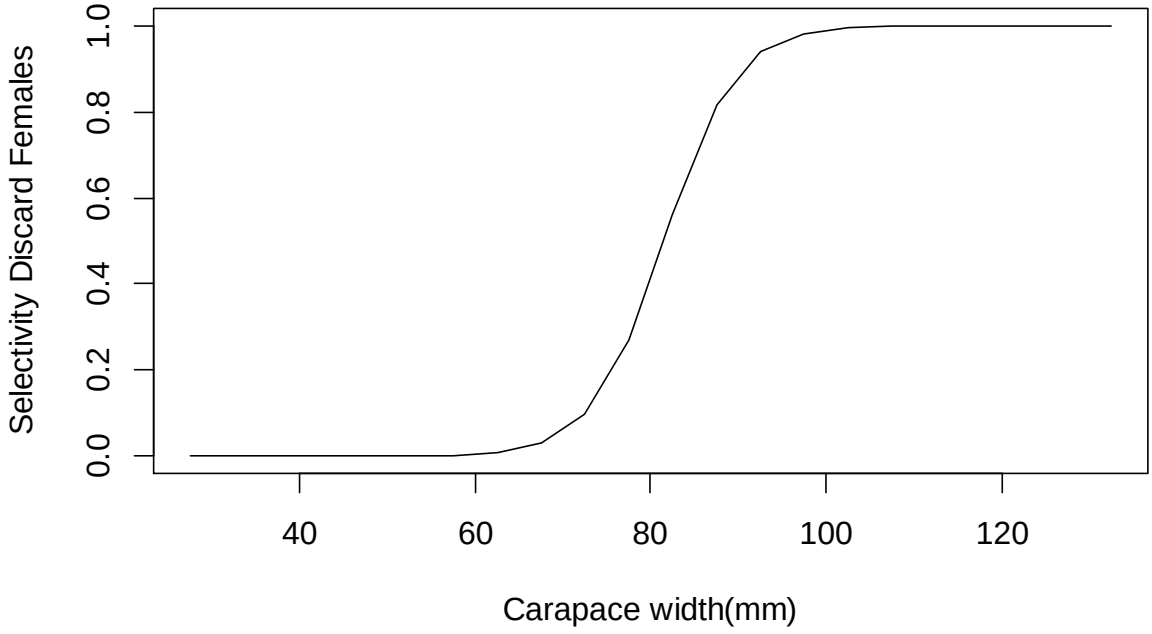
Selectivity Discard Females
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
Carapace width(mm)

Figure A-30.

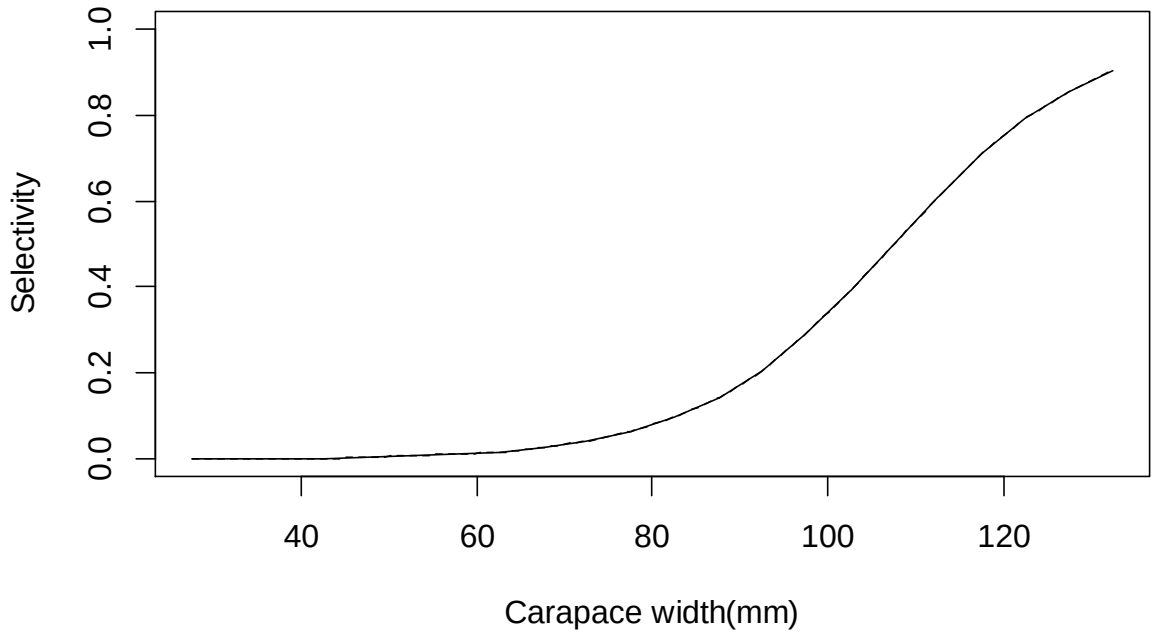

Figure A-31.

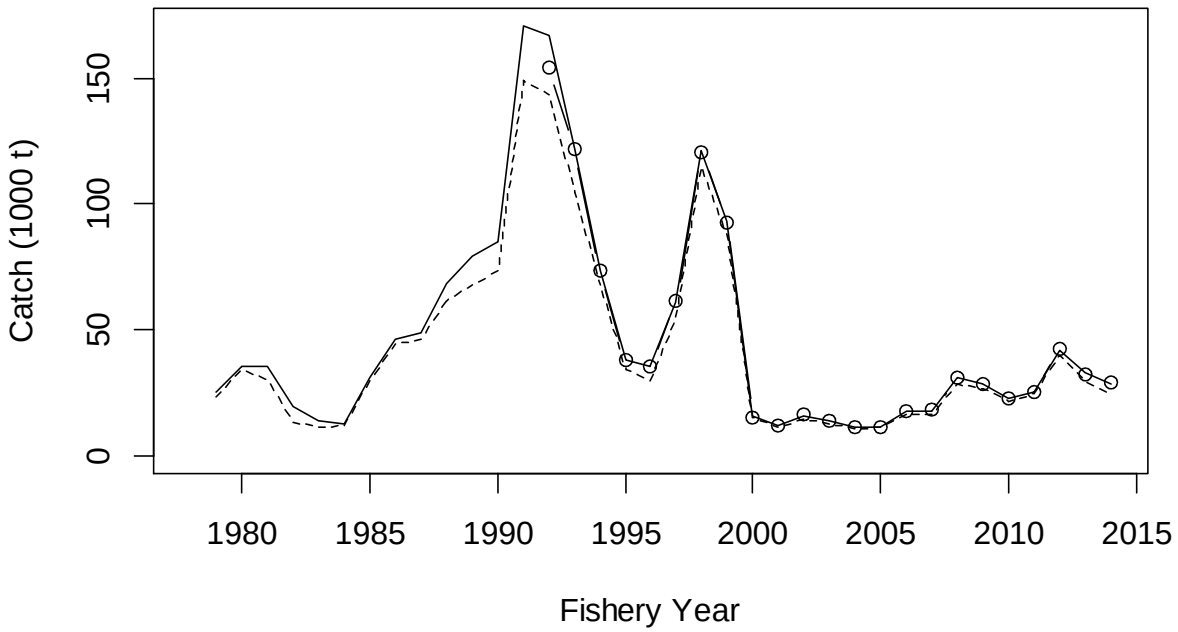
Catch (1000 t)
0
50
100
150
1980
1985
1990
1995
2000
2005
2010
2015
Fishery Year

Figure A-32.

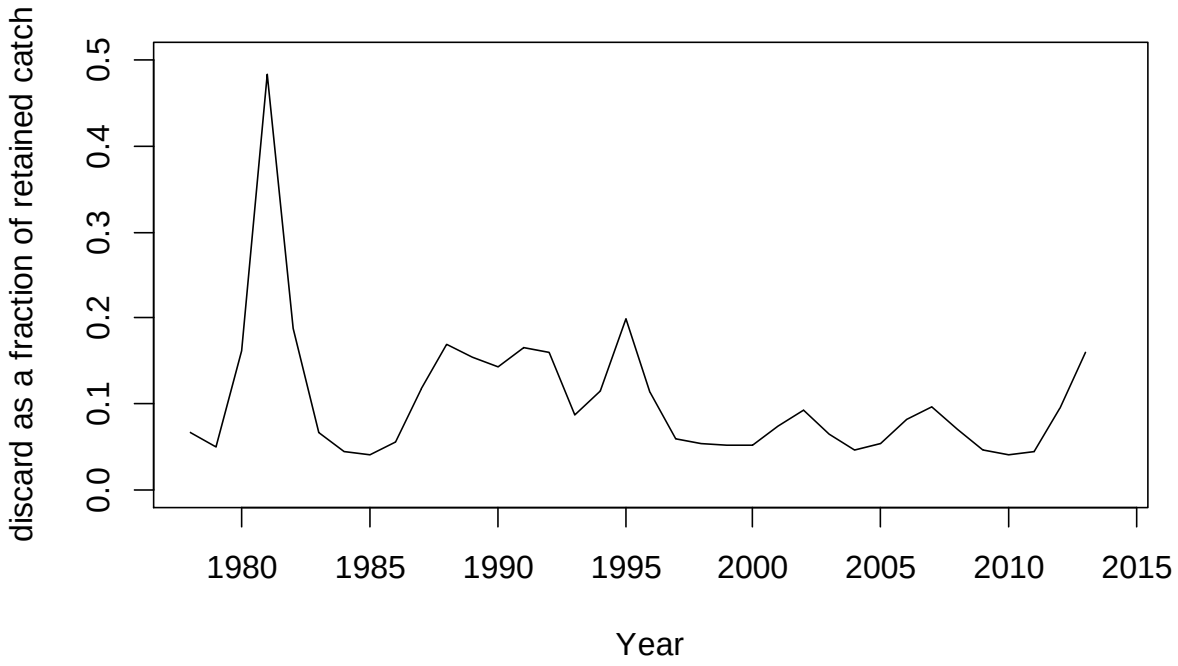
discard as a fraction of retained catch
0.0
0.1
0.2
0.3
0.4
0.5
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure A-33.

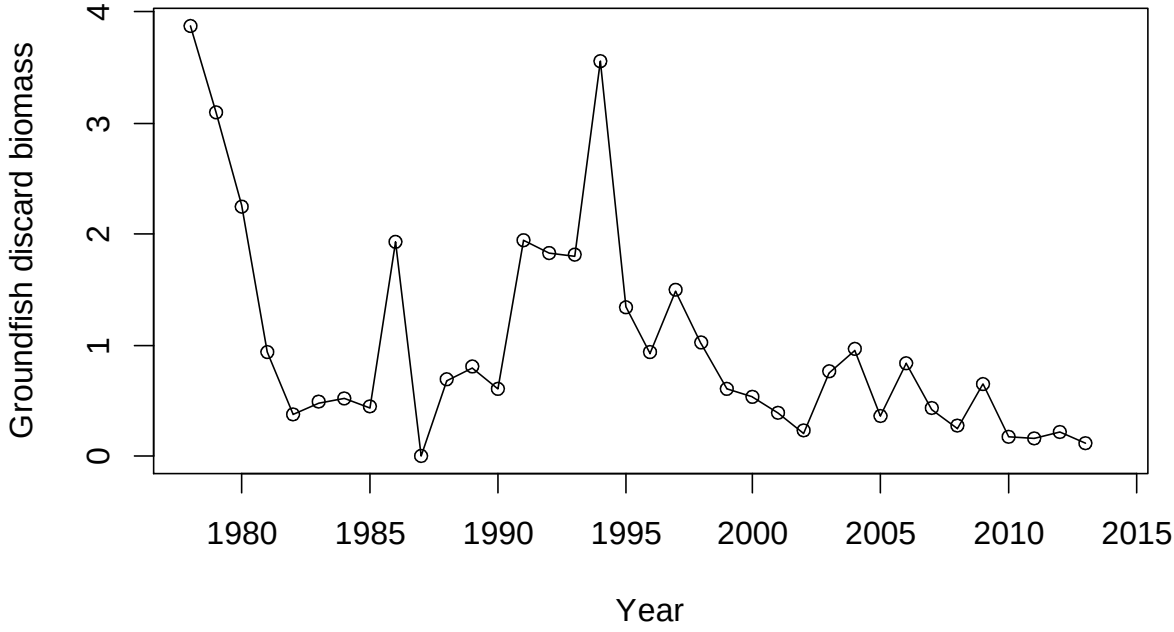
Groundfish discard biomass
0
1
2
3
4
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure A-34.

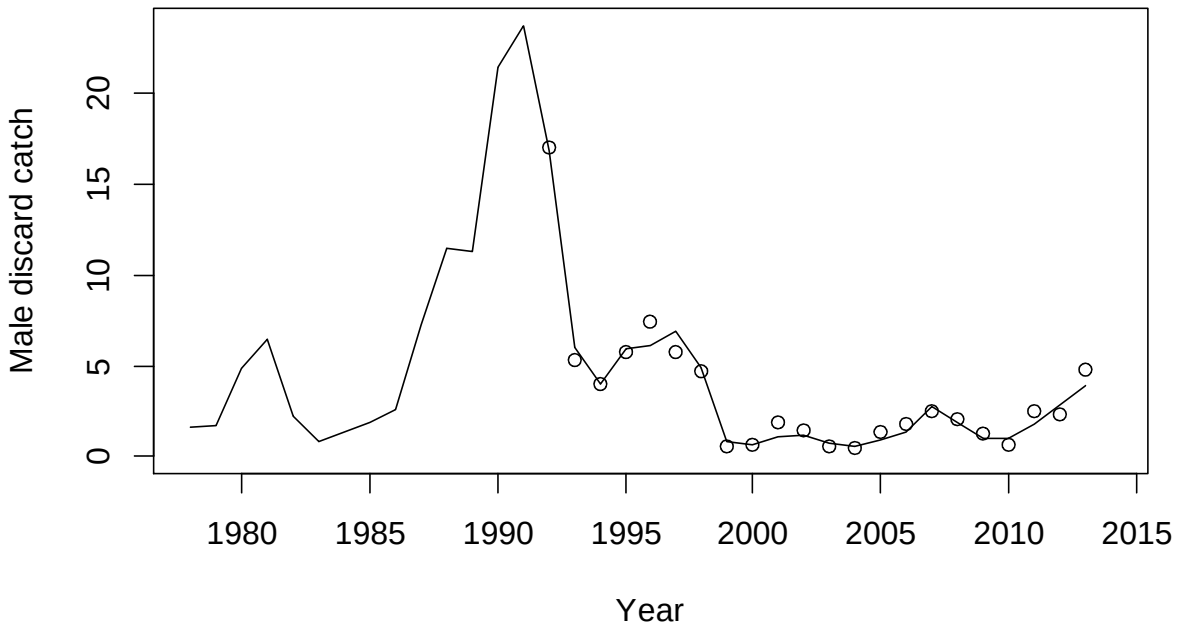
Male discard catch
0
5
10
15
20
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure A-35.

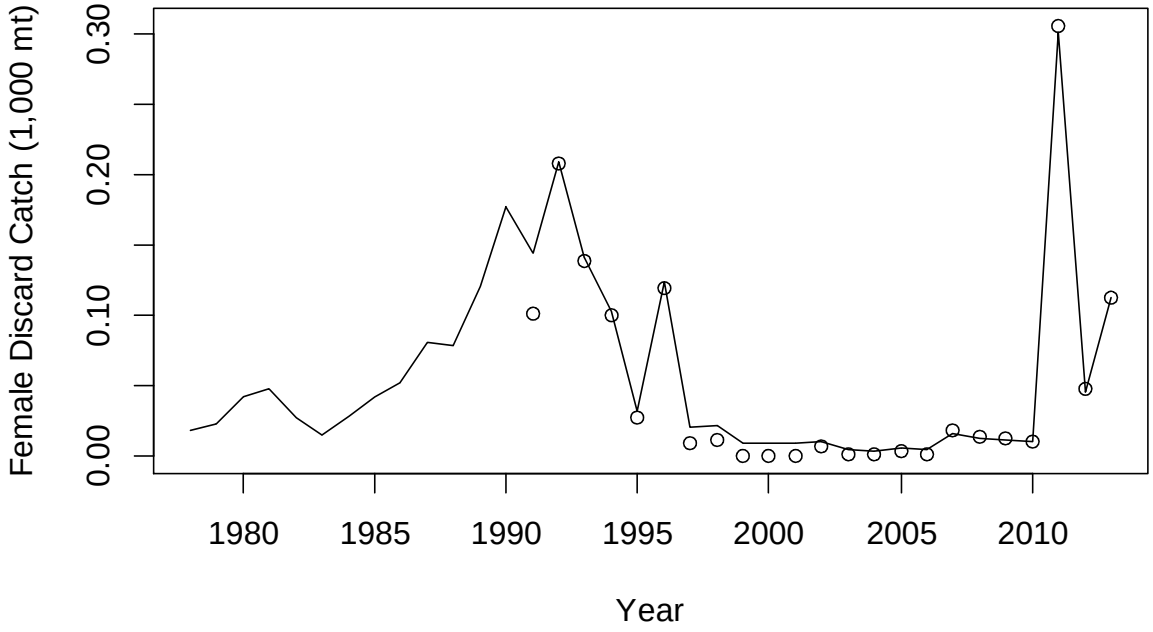
Female Discard Catch (1,000 mt)
0.00
0.10
0.20
0.30
1980
1985
1990
1995
2000
2005
2010
Year

Figure A-36.

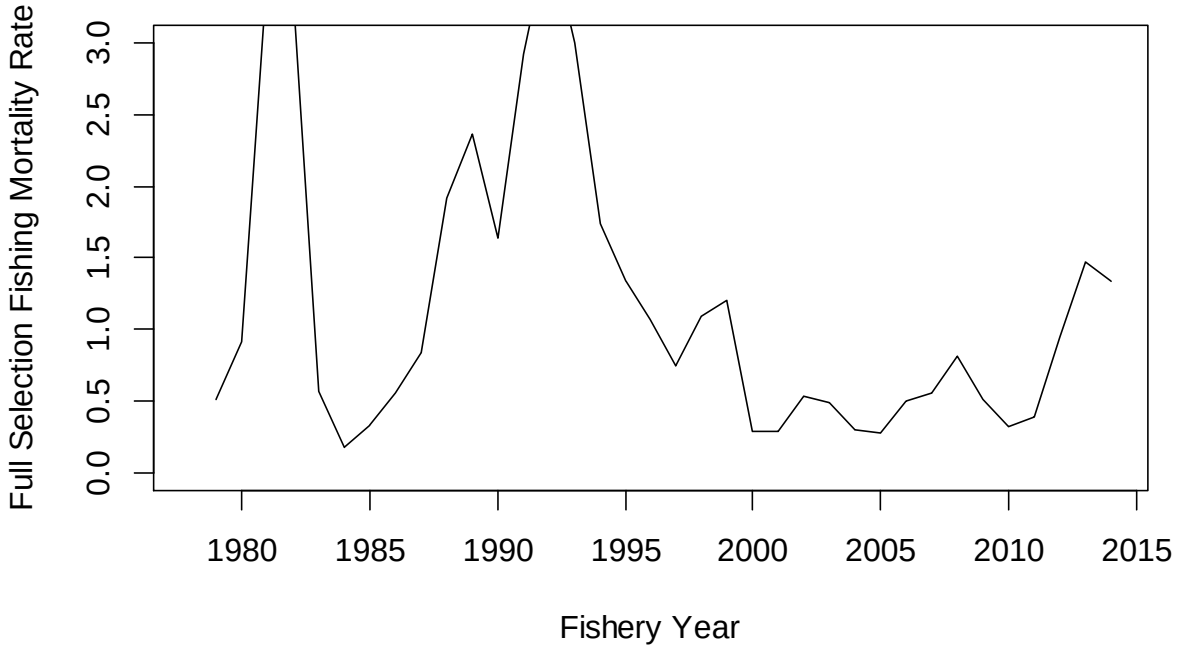
Full Selection Fishing Mortality Rate
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1980
1985
1990
1995
2000
2005
2010
2015
Fishery Year

Figure A-37.

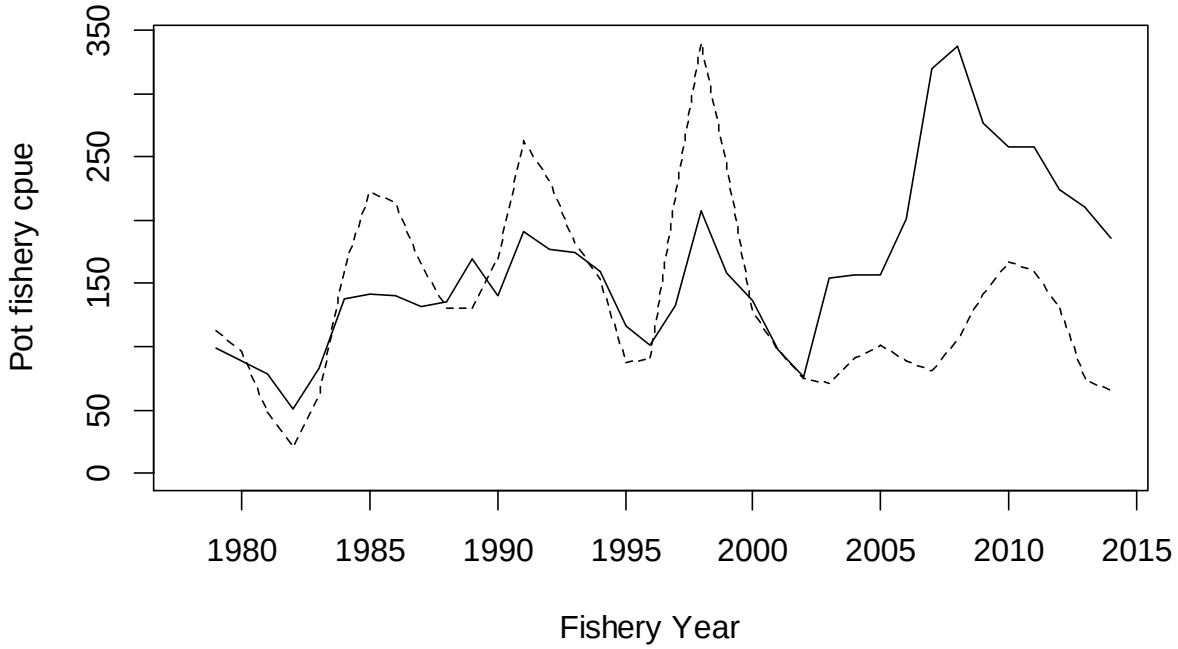
Pot fishery cpue
0
50
150
250
350
1980
1985
1990
1995
2000
2005
2010
2015
Fishery Year

Figure A-38.

Appendix B. Plots for Model 2.

.

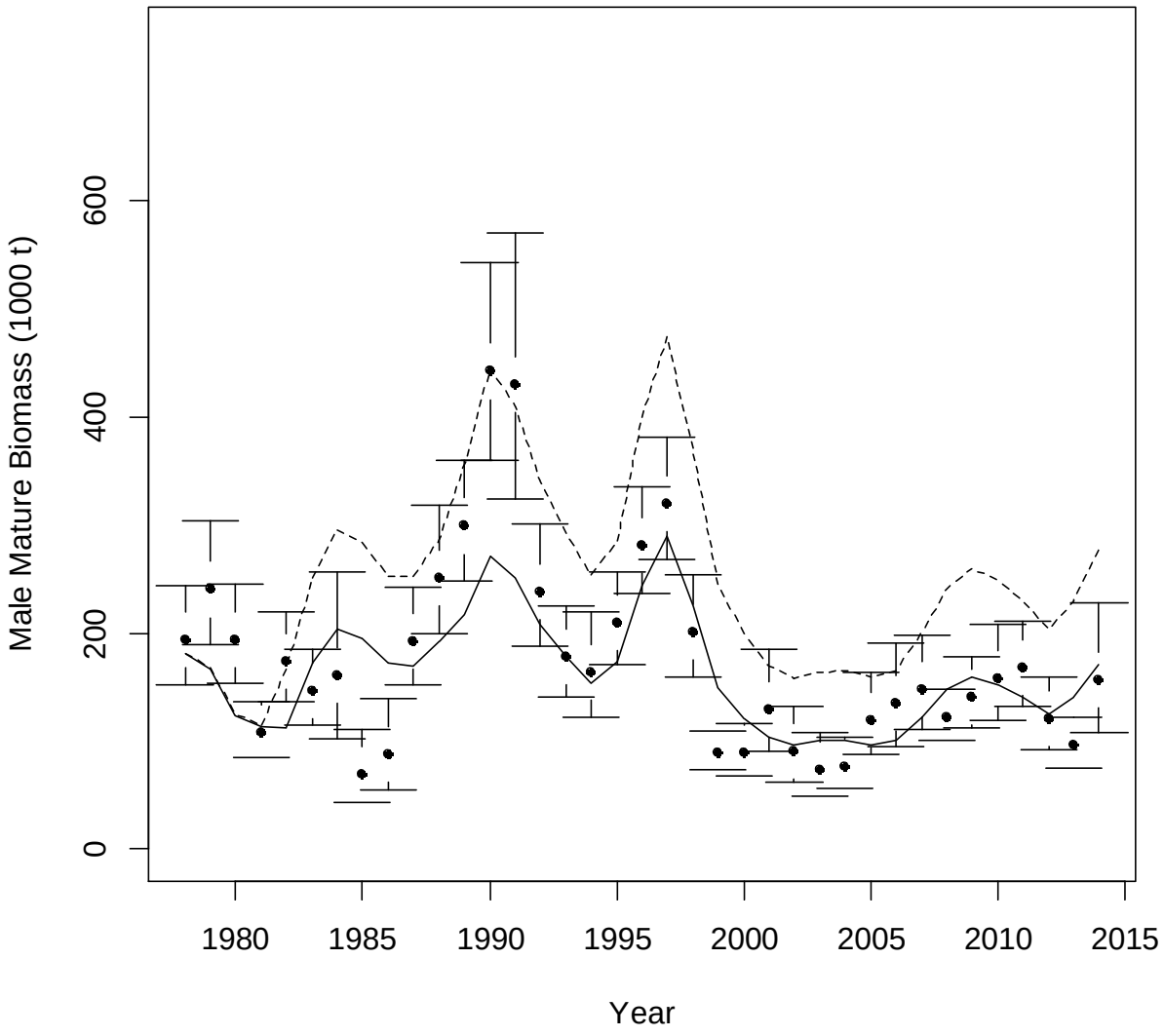

Figure B-1.

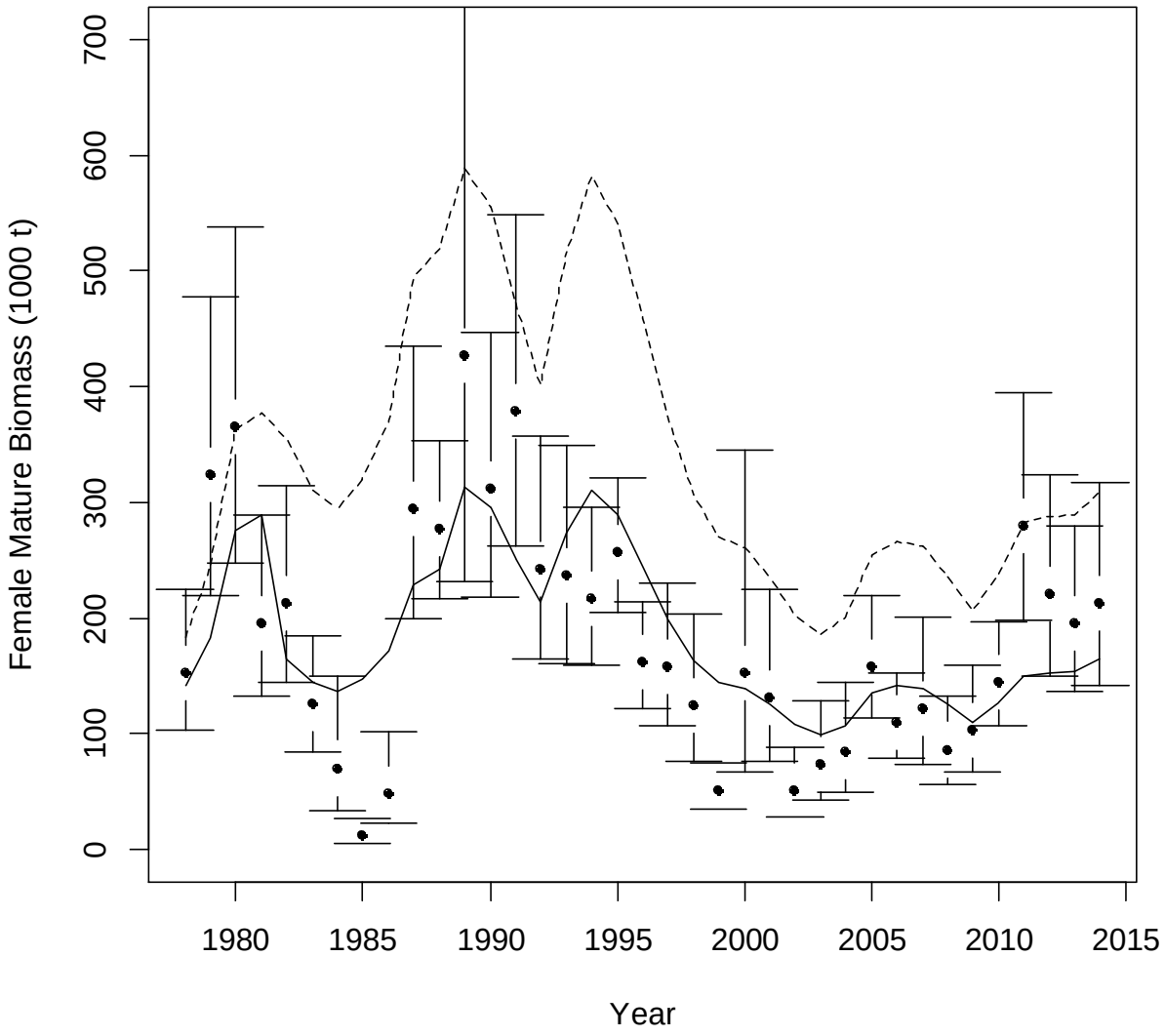
Female Mature Biomass (1000 t)
0
100
200
300
400
500
600
700
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure B-2.

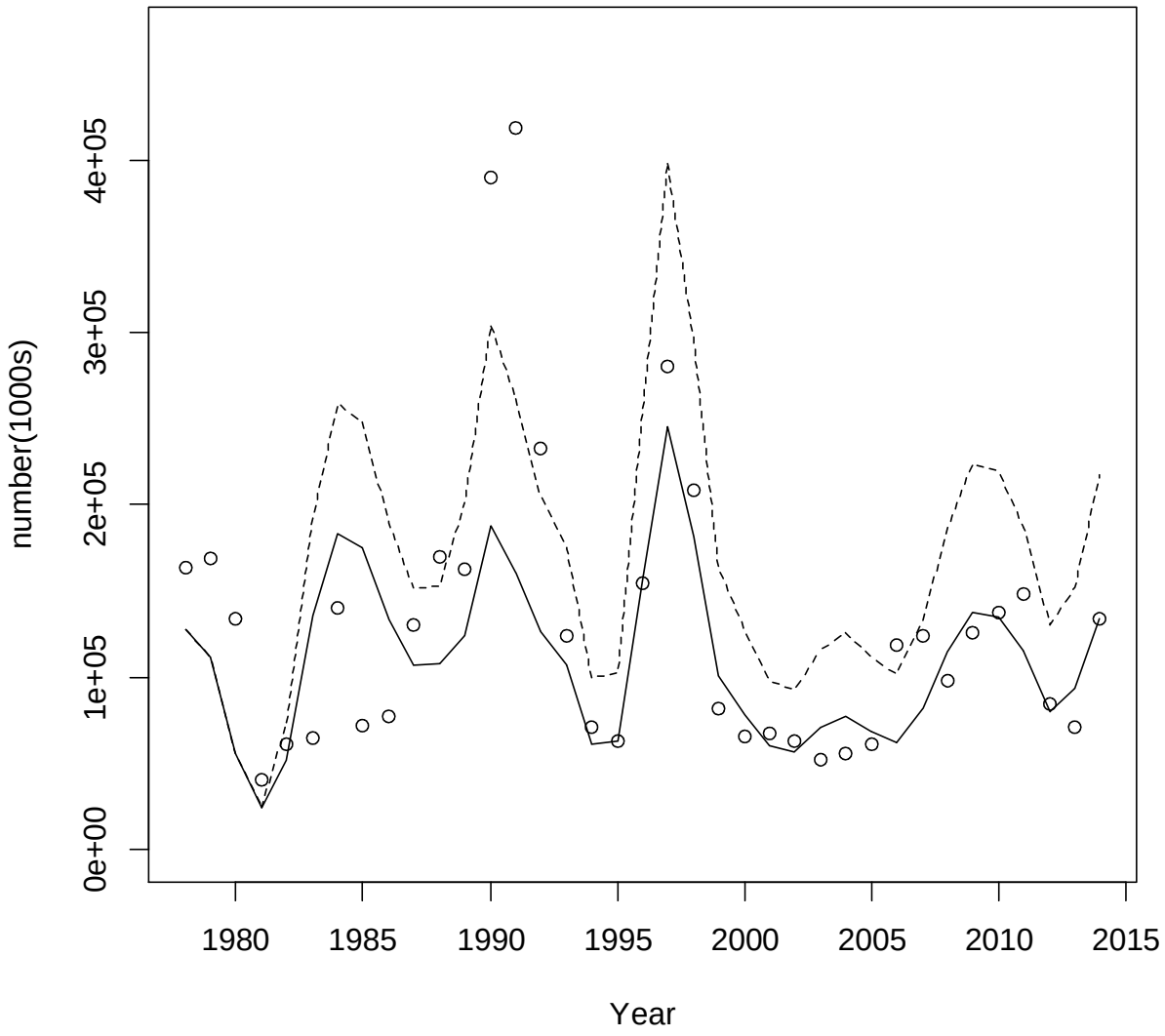
number(1000s)
0e+00
1e+05
2e+05
3e+05
4e+05
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure B-3.

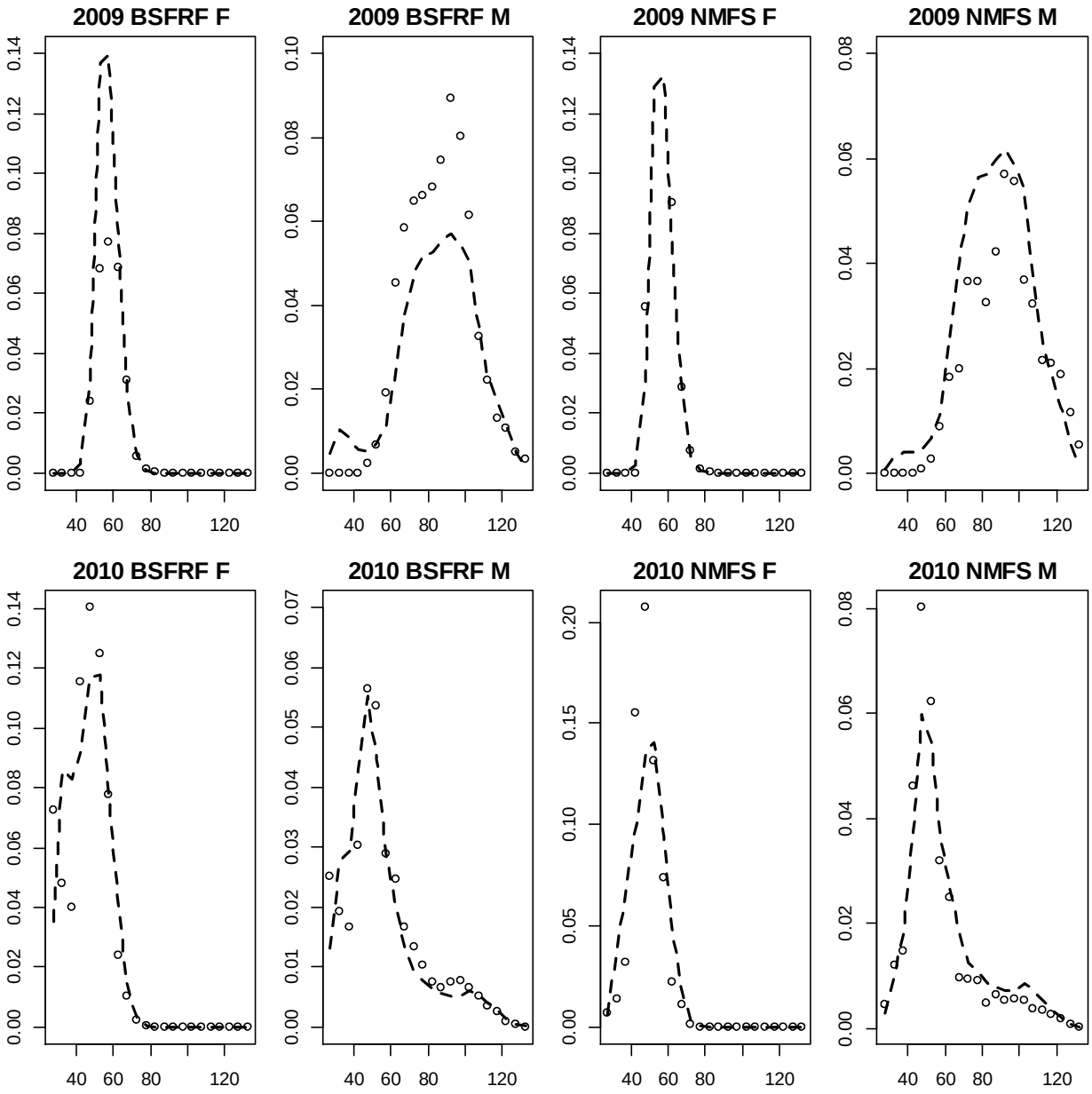
2009 BSFRF F
2009 BSFRF M
2009 NMFS F
2009 NMFS M
2010 BSFRF F
2010 BSFRF M
2010 NMFS F
2010 NMFS M
40 60 80 120

Figure B-4.

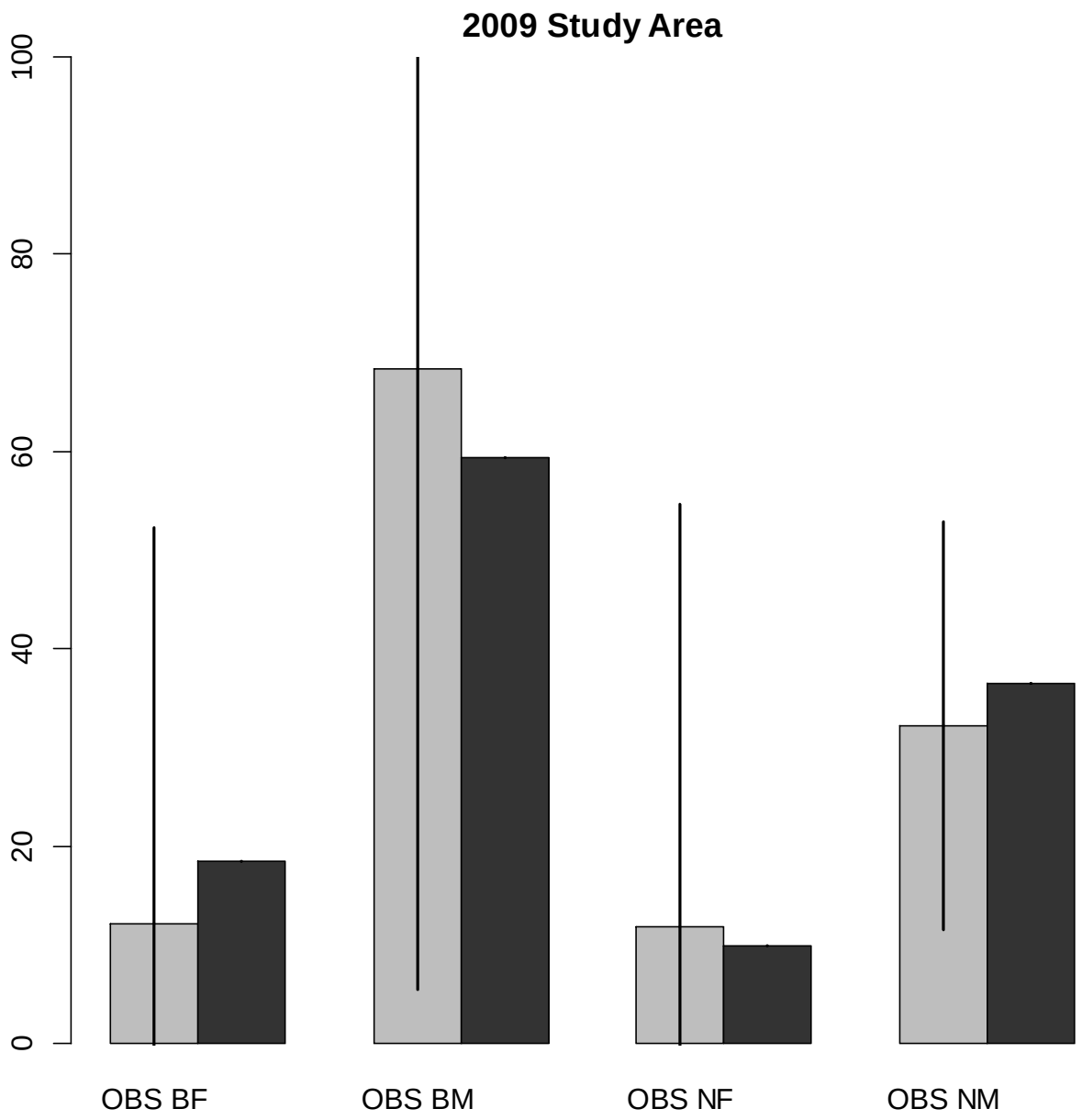

Figure B-5.

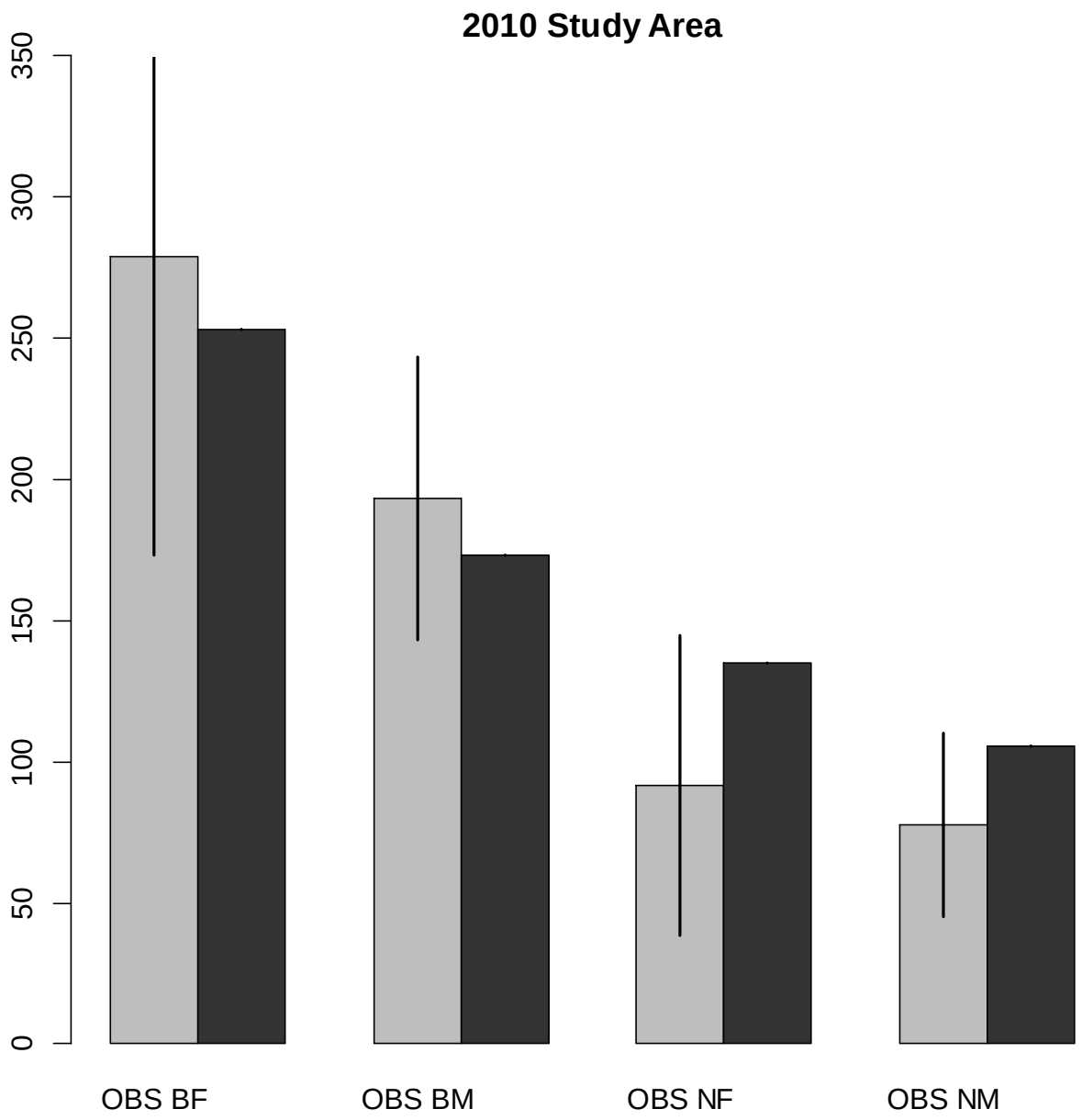
2010 Study Area
0
50
100
150
200
250
300
350
OBS BF
OBS BM
OBS NF
OBS NM

Figure B-6.

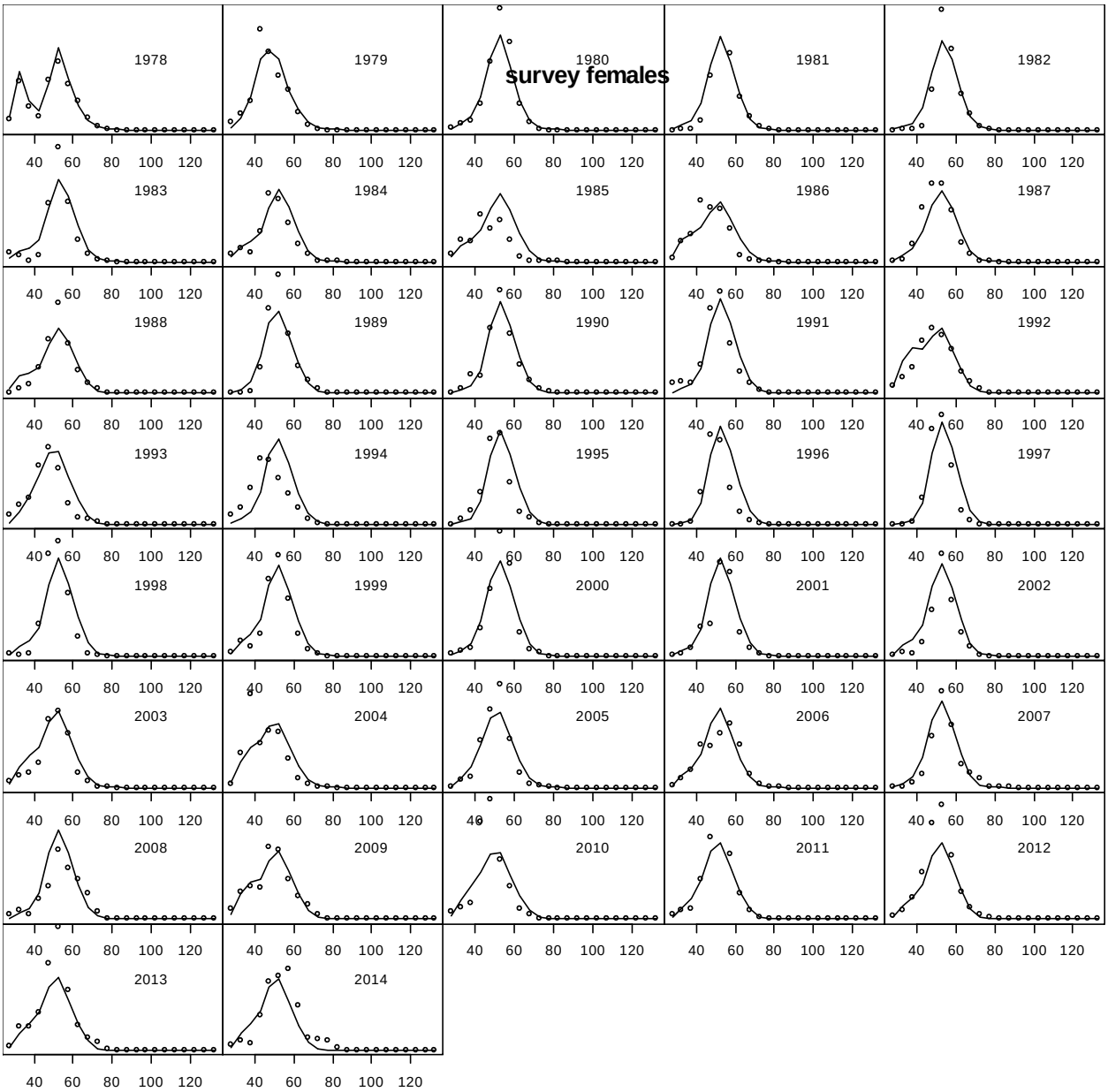
survey females
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
40 60 80 100 120

Figure B-7.

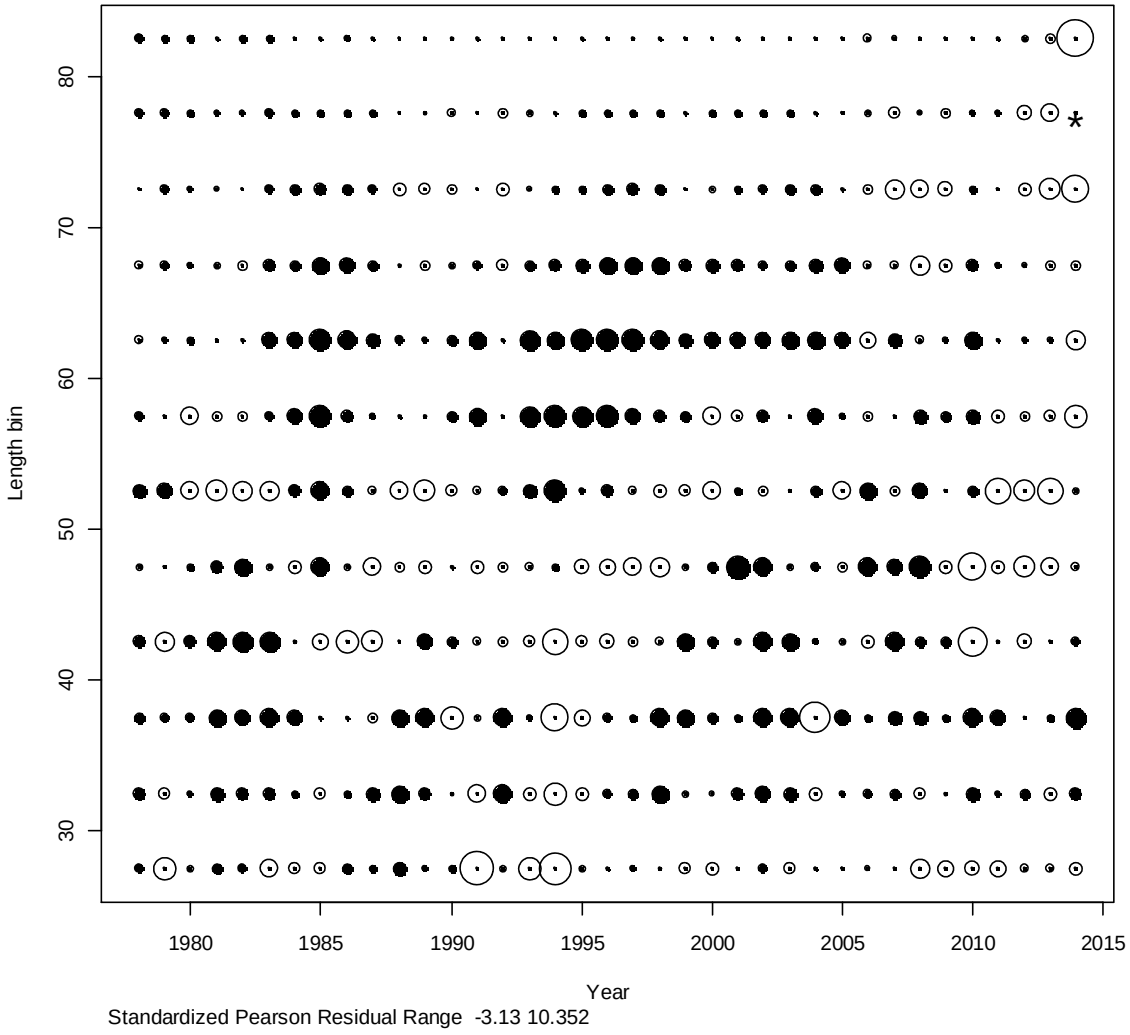
Length bin
80
70
60
50
40
30
1980
1985
1990
1995
2000
2005
2010
2015
Year
Standardized Pearson Residual Range -3.13 10.352

Figure B-8.

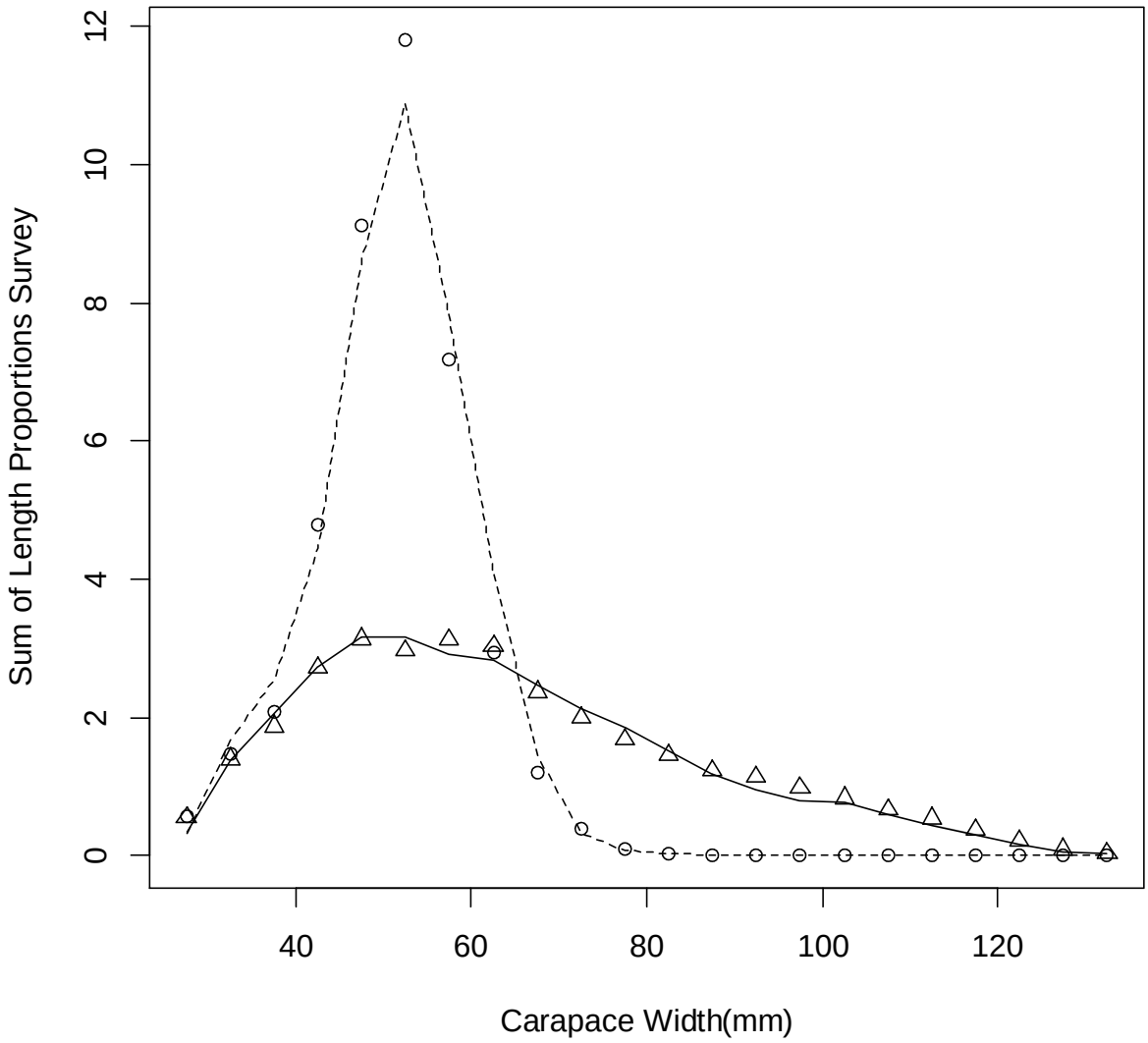
Sum of Length Proportions Survey
0
2
4
6
8
10
12
40
60
80
100
120
Carapace Width(mm)

Figure B-9.

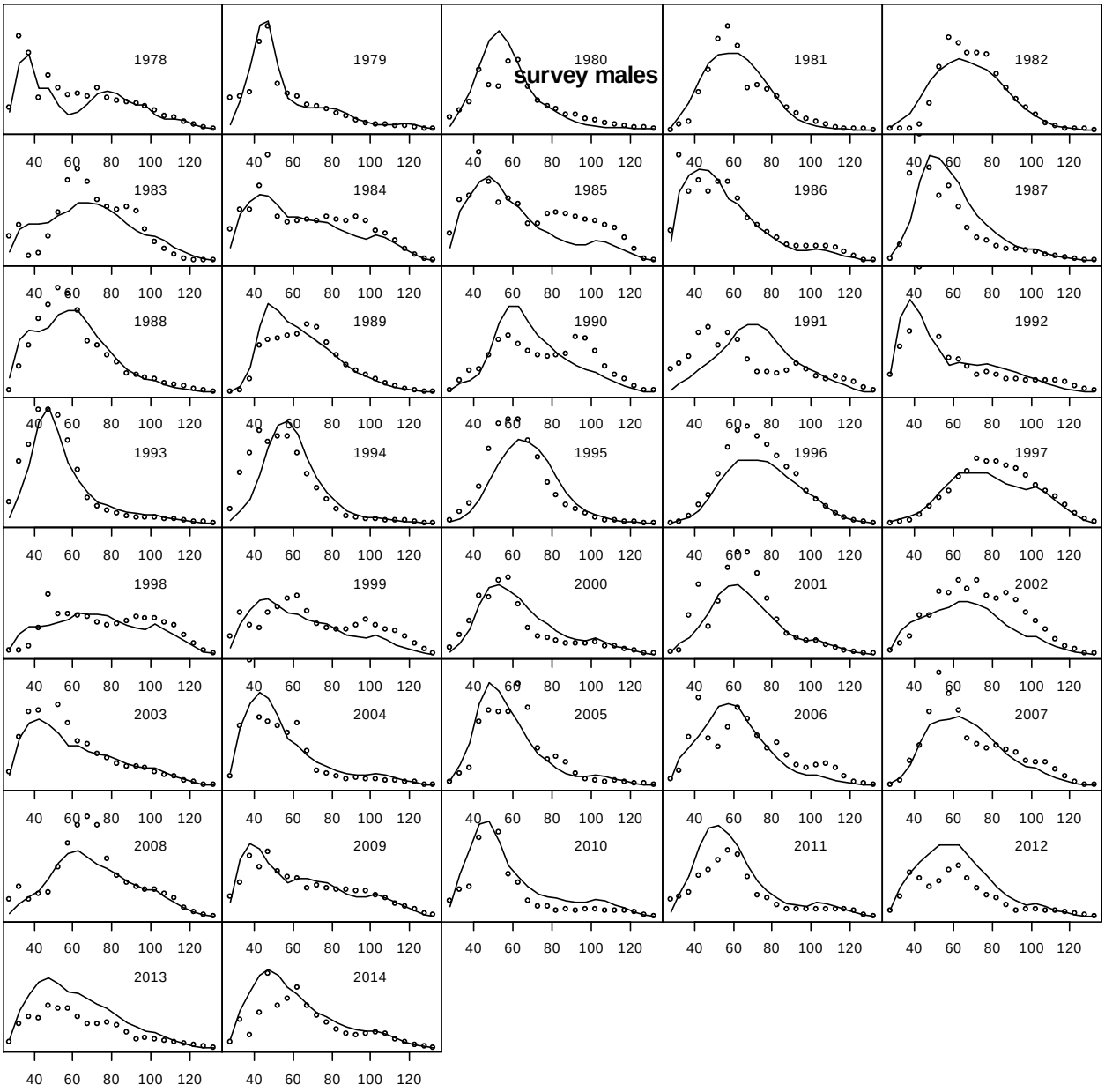
survey males
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
40 60 80 100 120

Figure B-10.

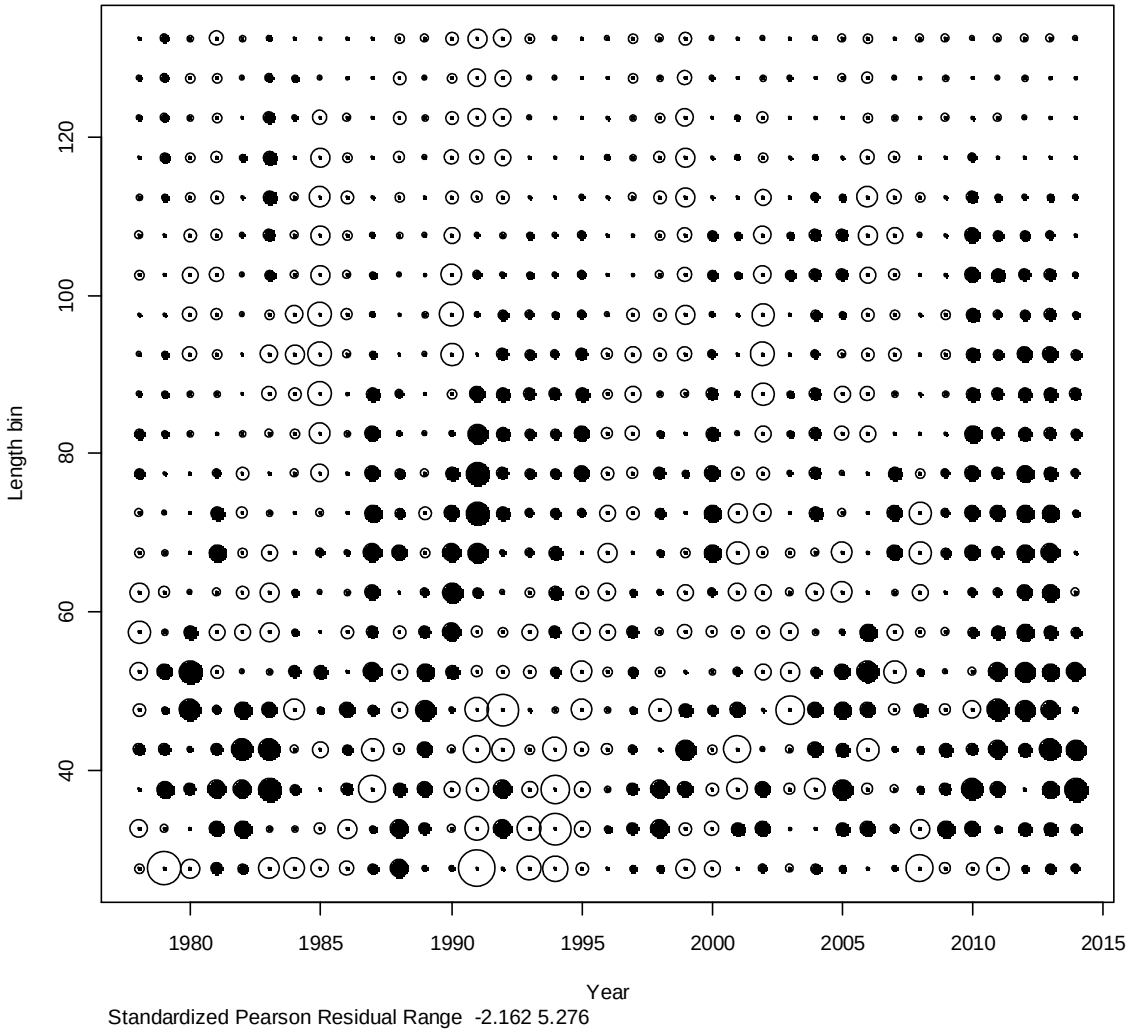
Length bin
40
60
80
100
120
1980
1985
1990
1995
2000
2005
2010
2015
Year
Standardized Pearson Residual Range -2.162 5.276

Figure B-11.

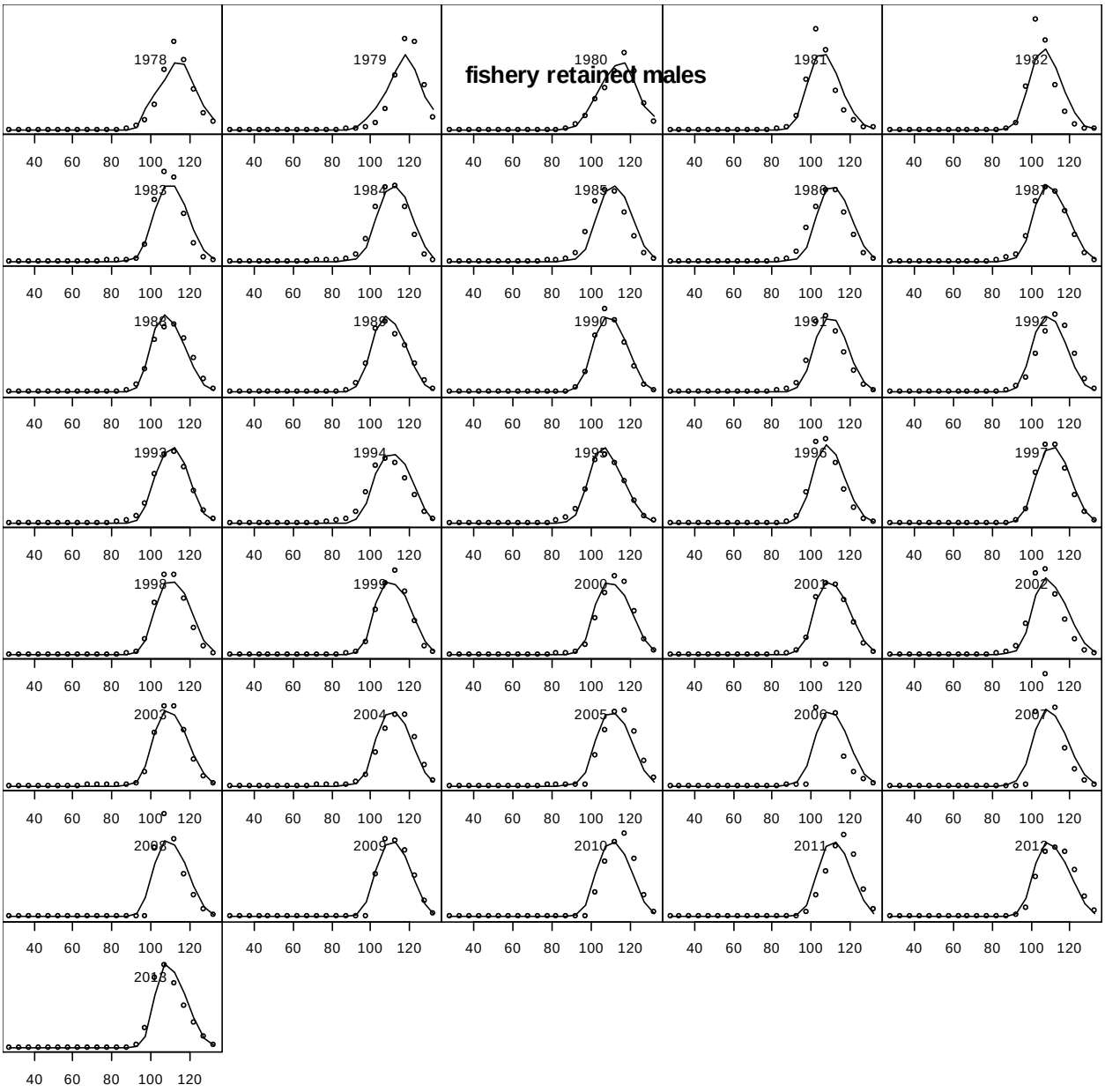
fishery retained males
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40 60 80 100 120

Figure B-12.

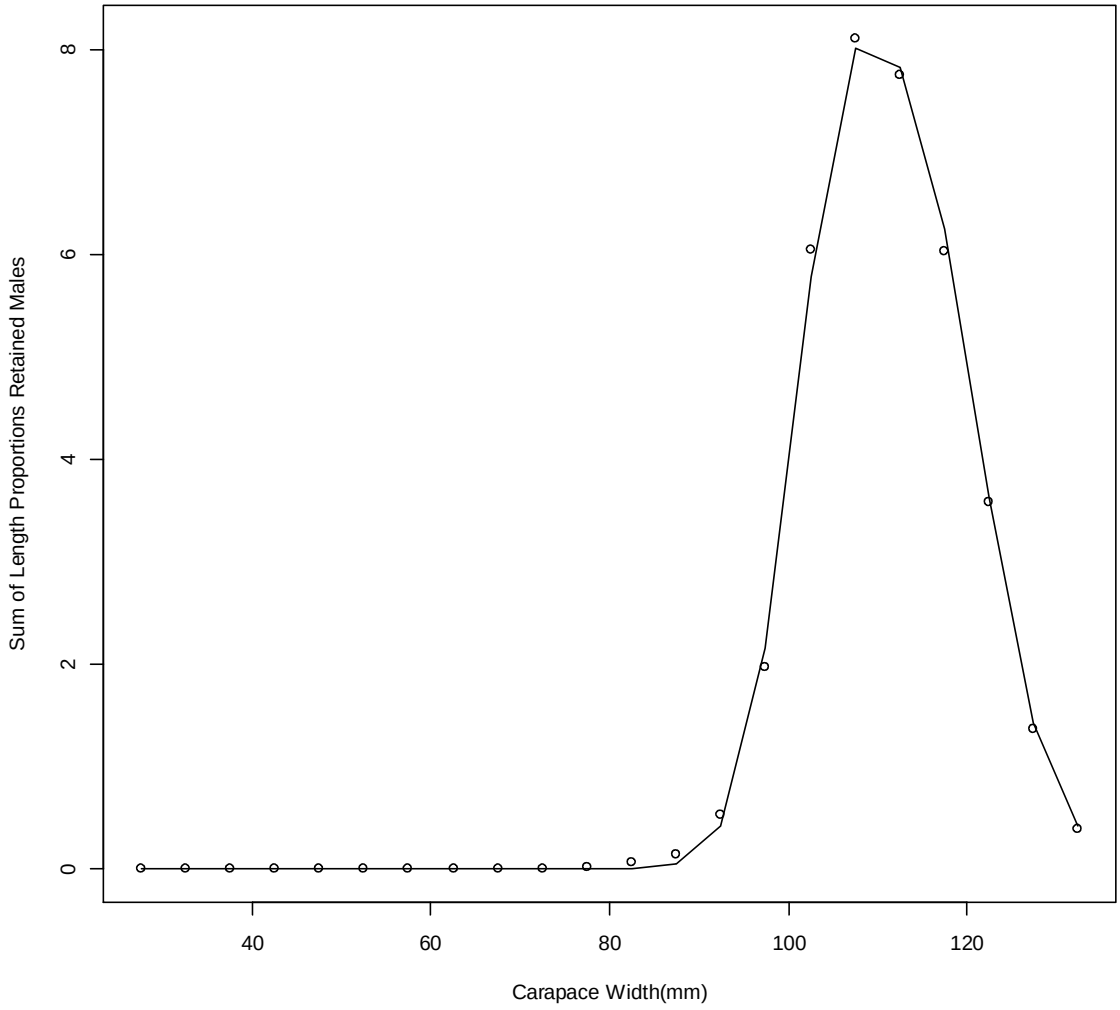
Sum of Length Proportions Retained Males
0
2
4
6
8
40
60
80
100
120
Carapace Width(mm)

Figure B-13.

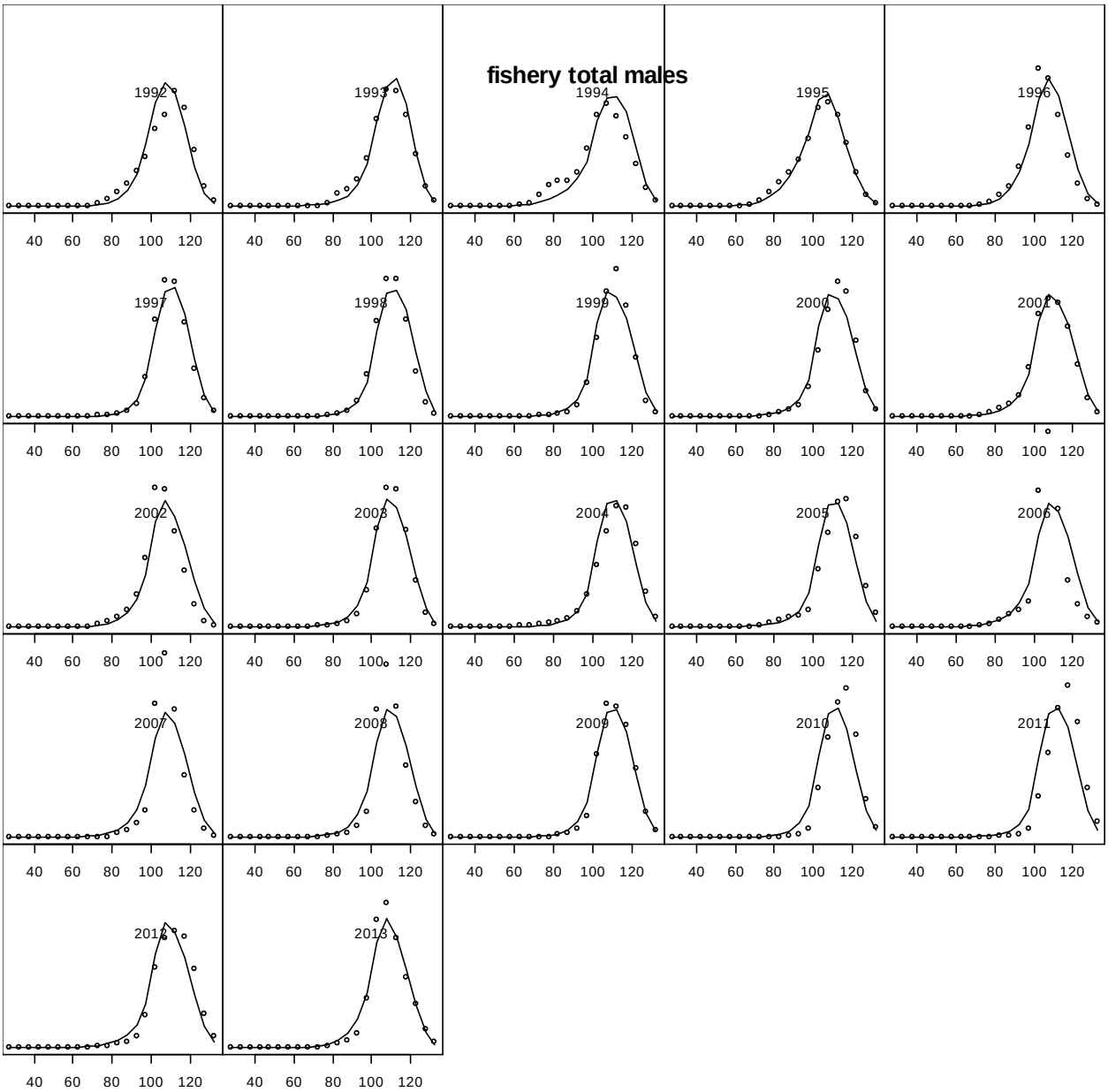
fishery total males
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40 60 80 100 120

Figure B-14.

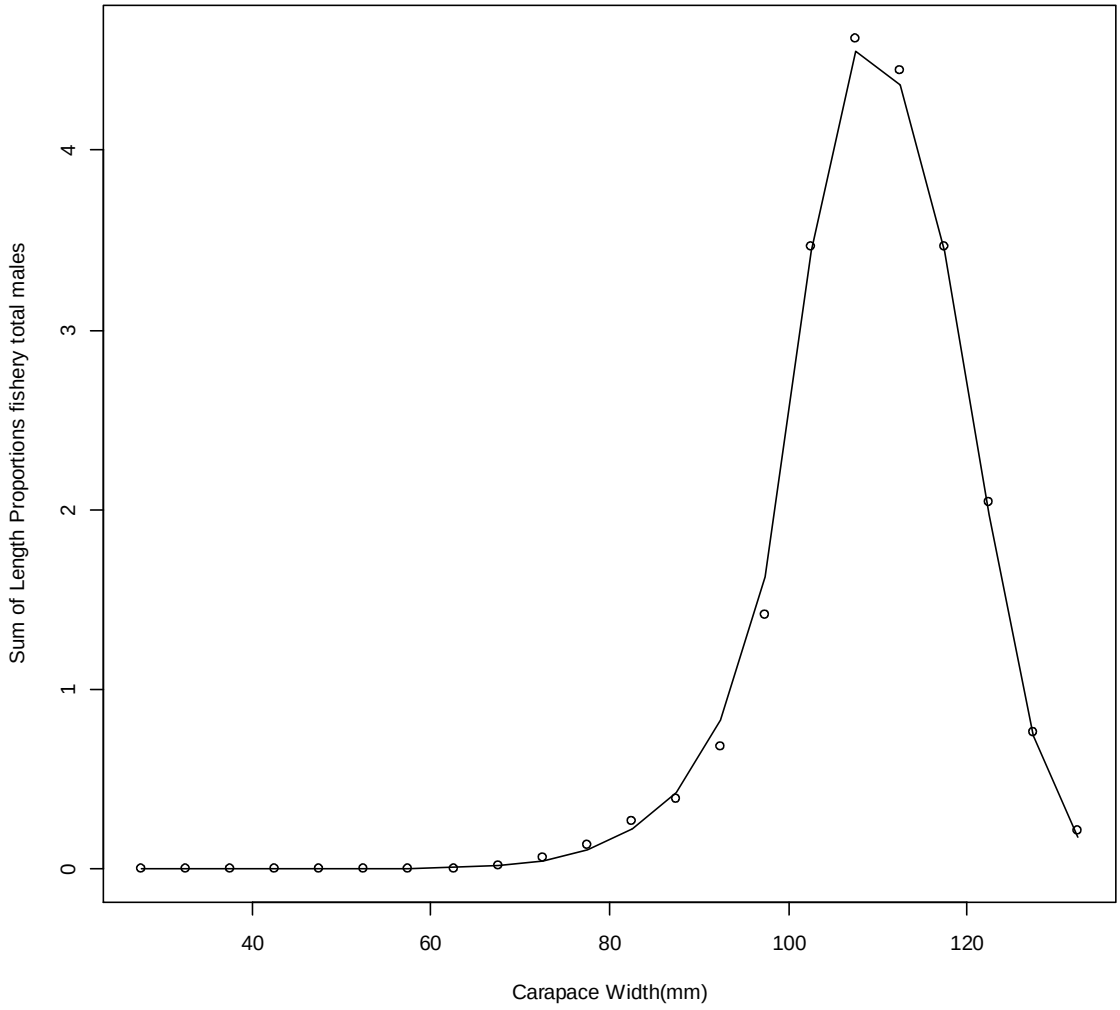
Sum of Length Proportions fishery total males
0
1
2
3
4
40
60
80
100
120
Carapace Width(mm)

Figure B-15.

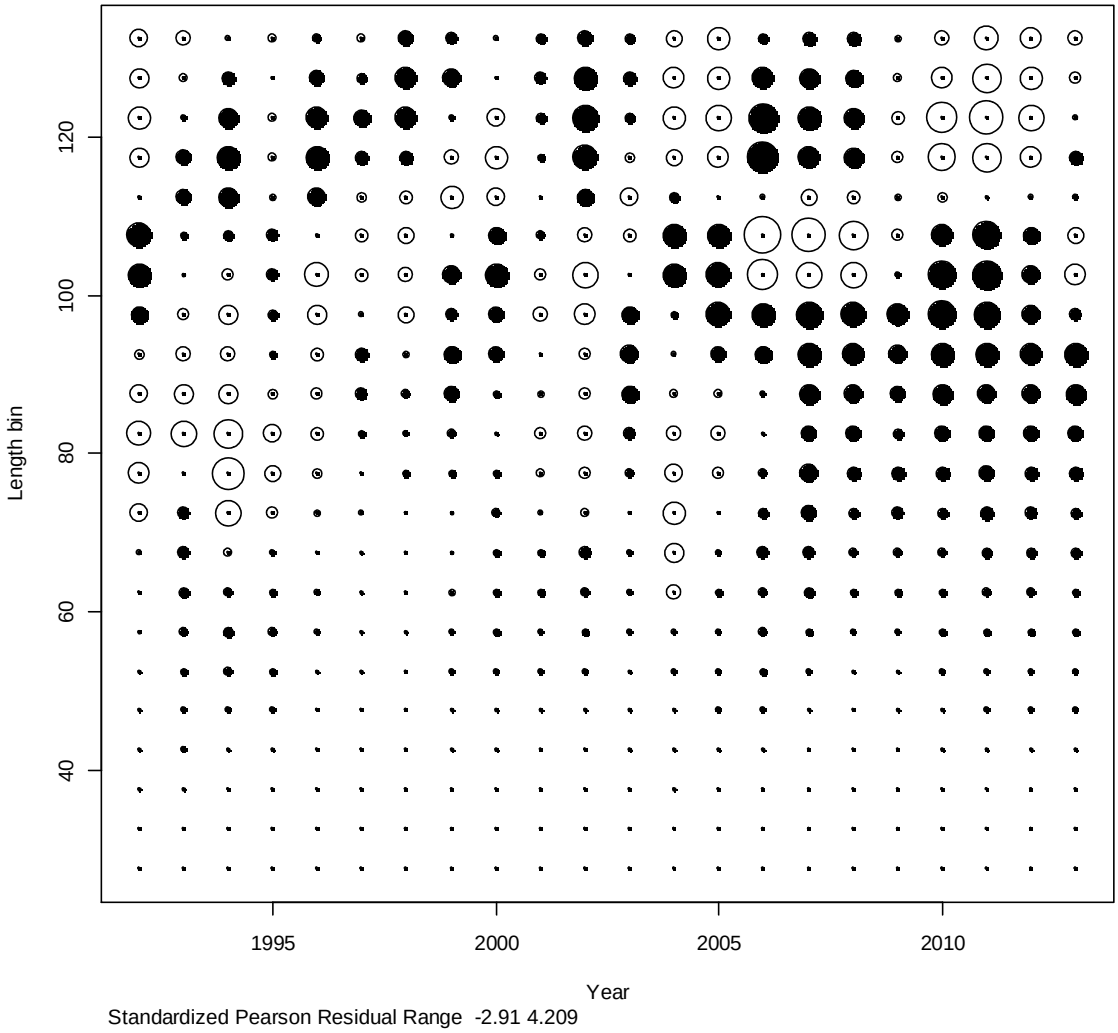
Length bin
120
100
80
60
40
1995
2000
2005
2010
Year
Standardized Pearson Residual Range -2.91 4.209

Figure B-16.

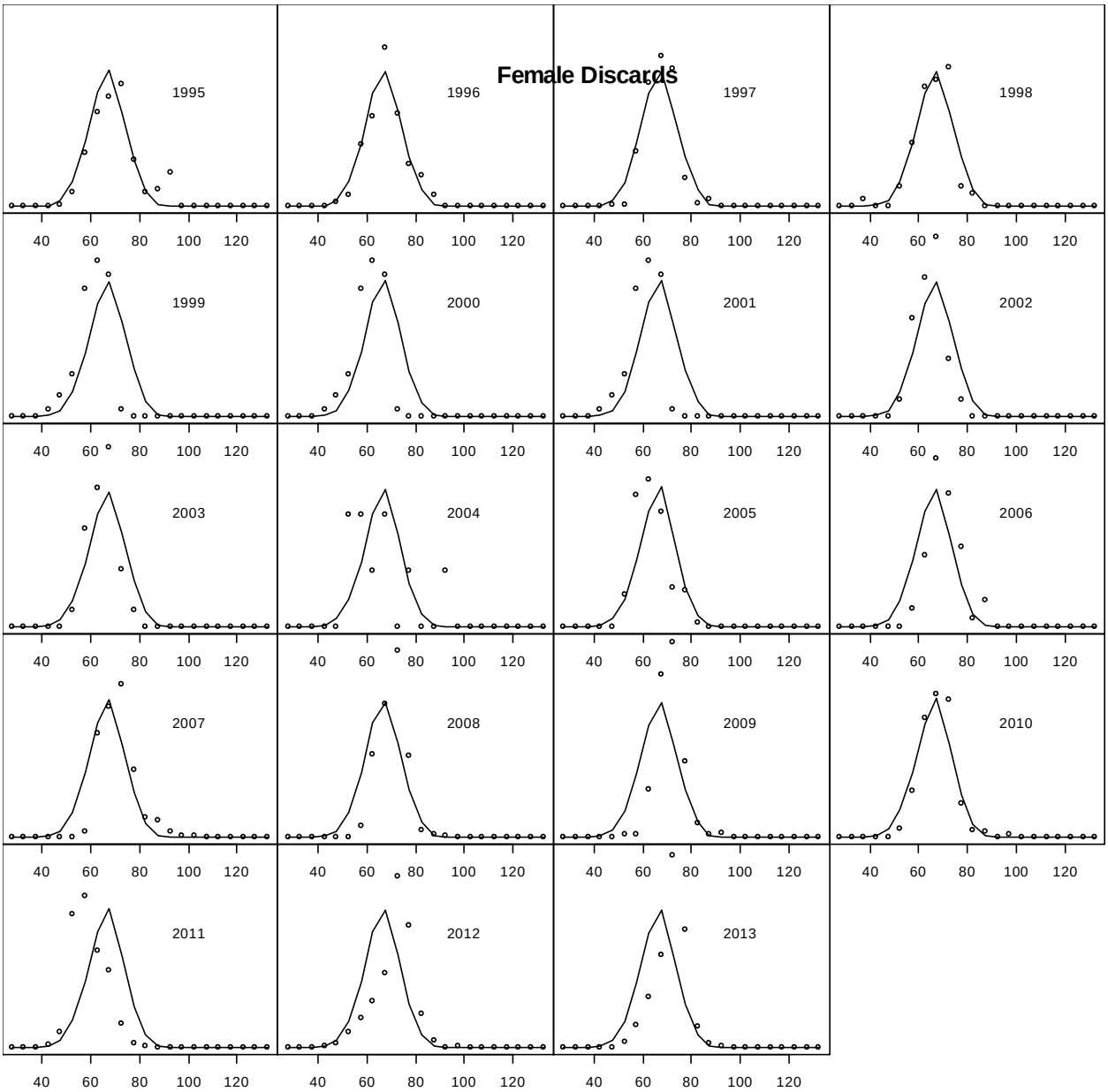
Female Discards
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40
60
80
100
120

Figure B-17.

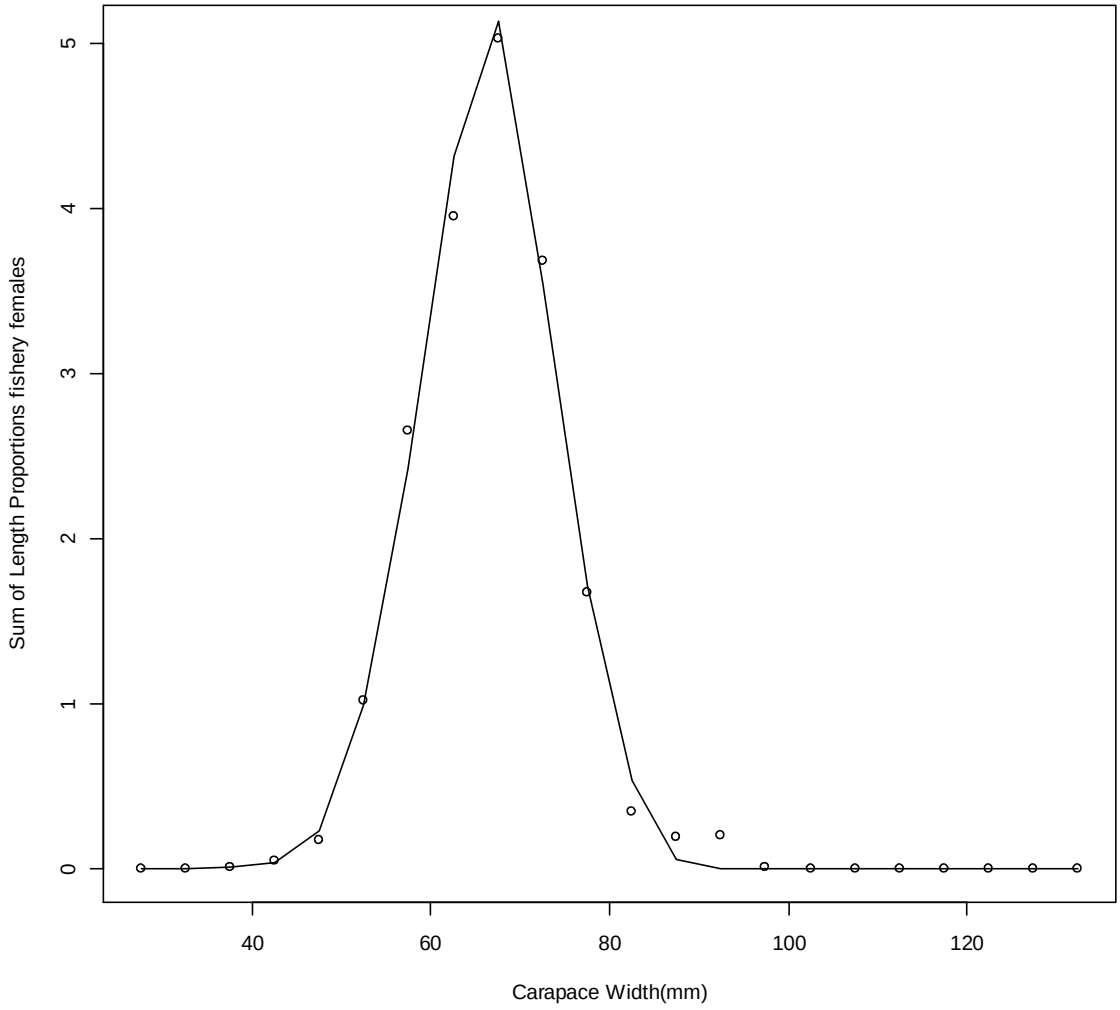
Sum of Length Proportions fishery females
0
1
2
3
4
5
40
60
80
100
120
Carapace Width(mm)

Figure B-18.

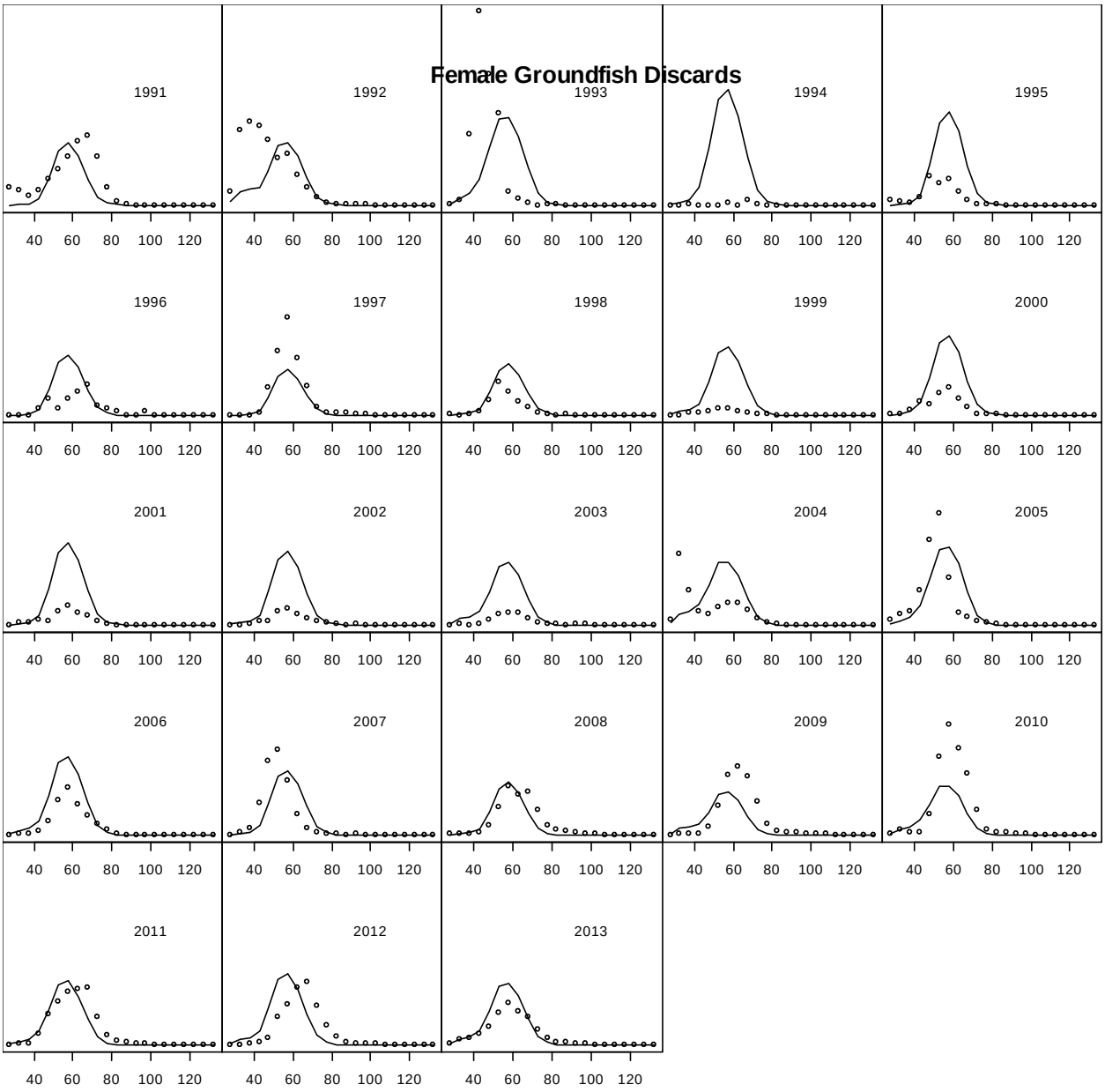
Female Groundfish Discards
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40 60 80 100 120

Figure B-19.

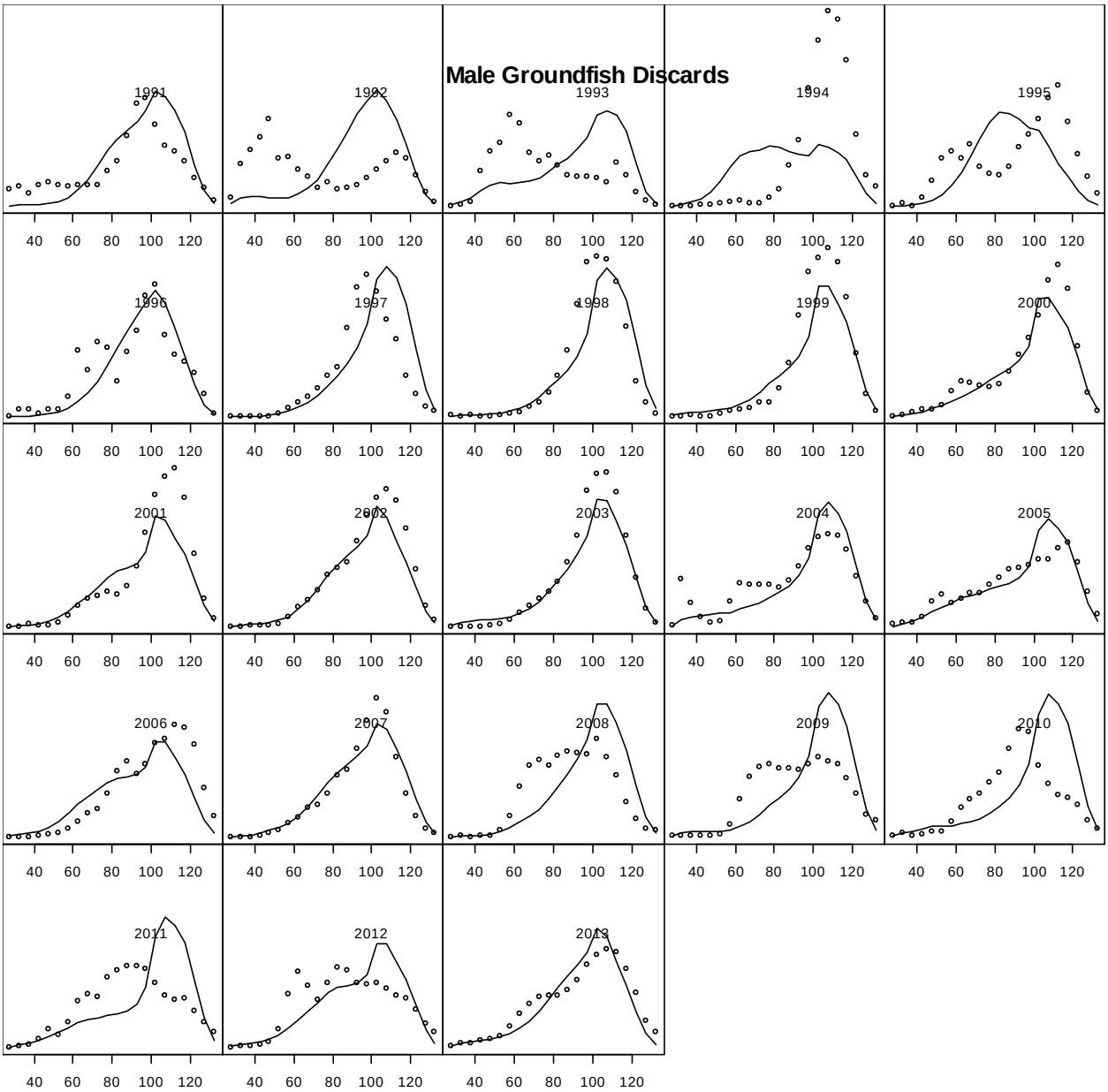
Male Groundfish Discards
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40 60 80 100 120

Figure B-20.

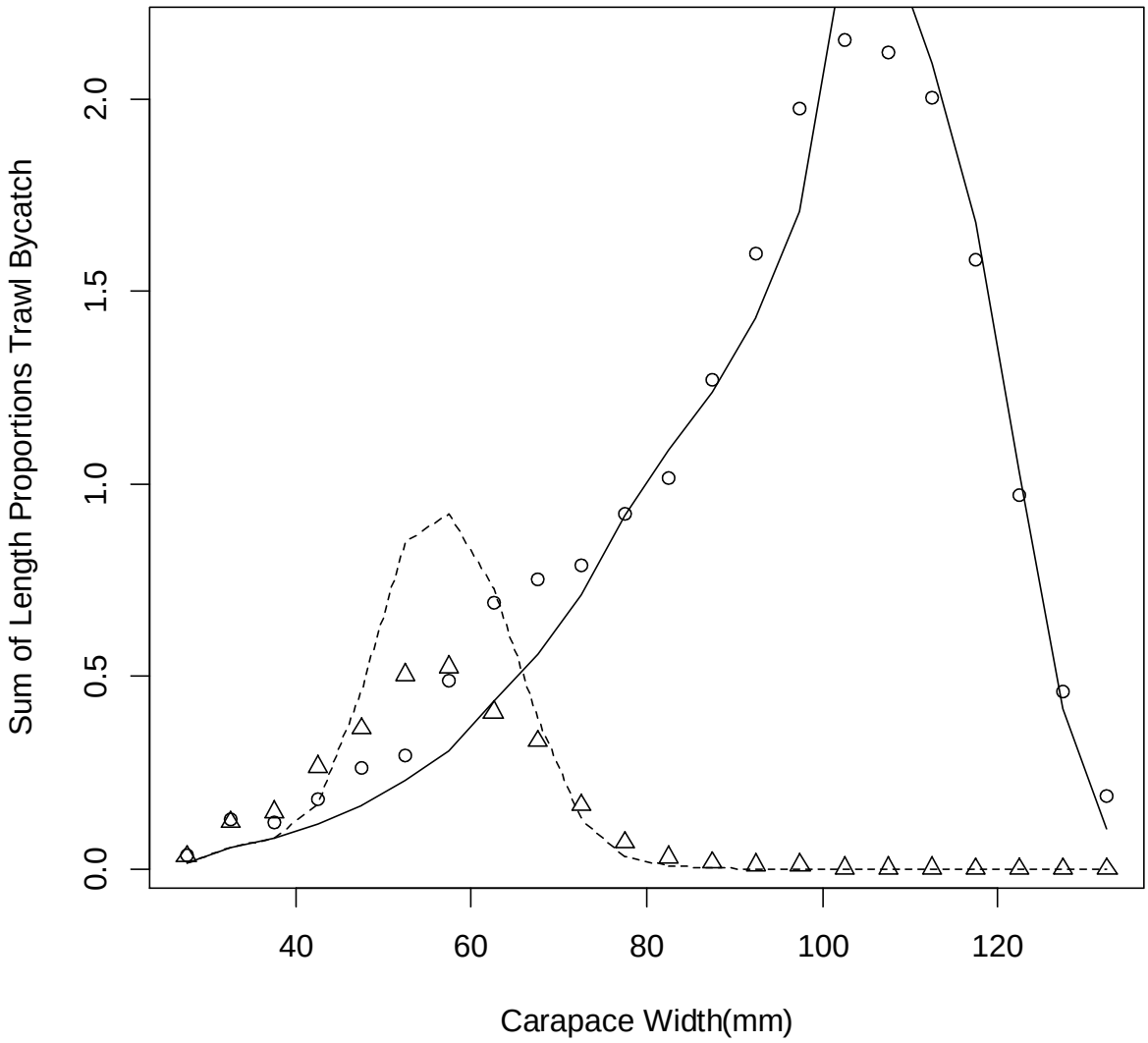
Sum of Length Proportions Trawl Bycatch
0.0
0.5
1.0
1.5
2.0
40
60
80
100
120
Carapace Width(mm)

Figure B-21.

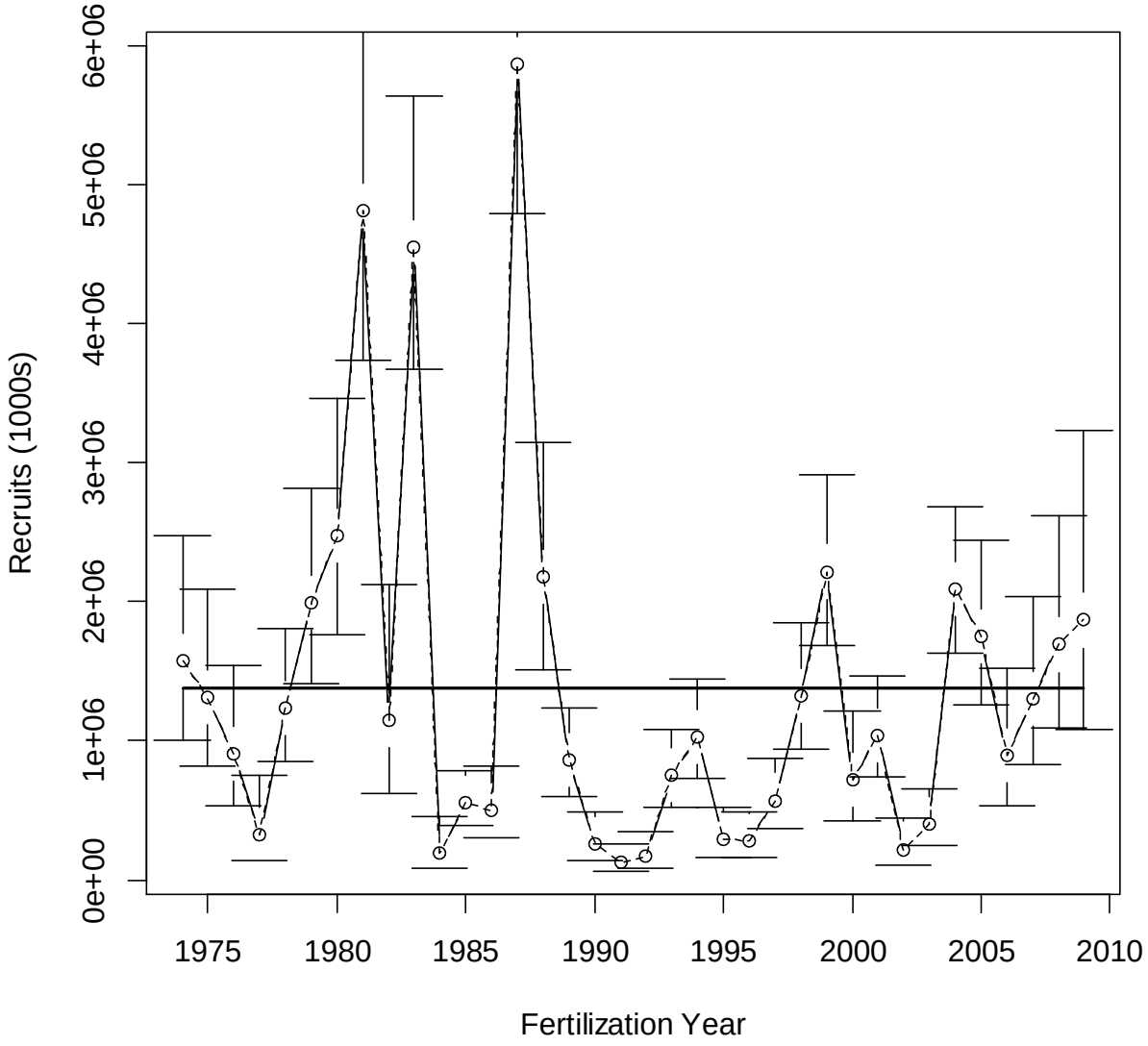
Recruits (1000s)
0e+00
1e+06
2e+06
3e+06
4e+06
5e+06
6e+06
1975
1980
1985
1990
1995
2000
2005
2010
Fertilization Year

Figure B-22.

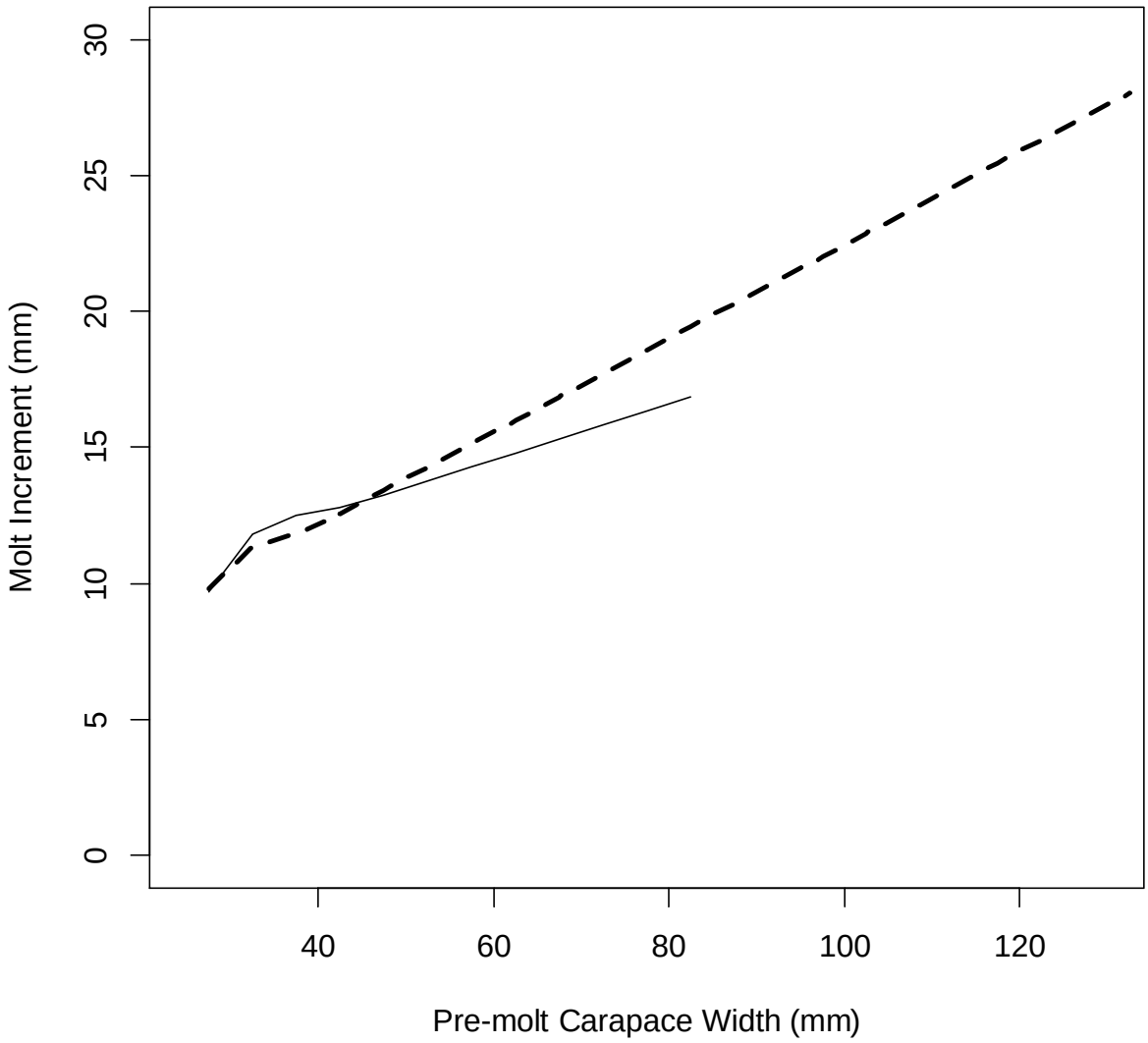
Molt Increment (mm)
0
5
10
15
20
25
30
40
60
80
100
120
Pre-molt Carapace Width (mm)

Figure B-23.

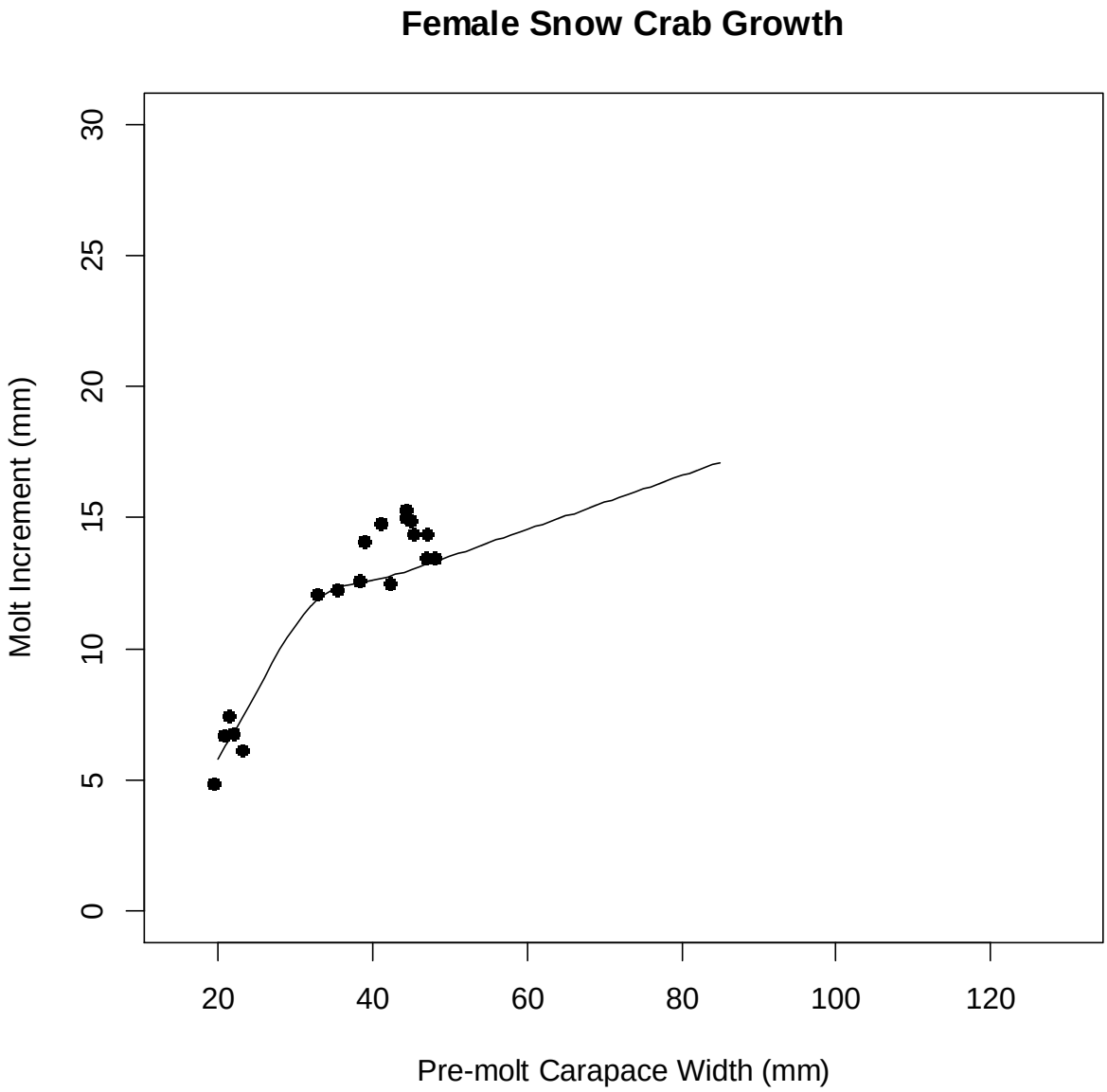
Female Snow Crab Growth
Molt Increment (mm)
0
5
10
15
20
25
30
20
40
60
80
100
120
Pre-molt Carapace Width (mm)

Figure B-24.

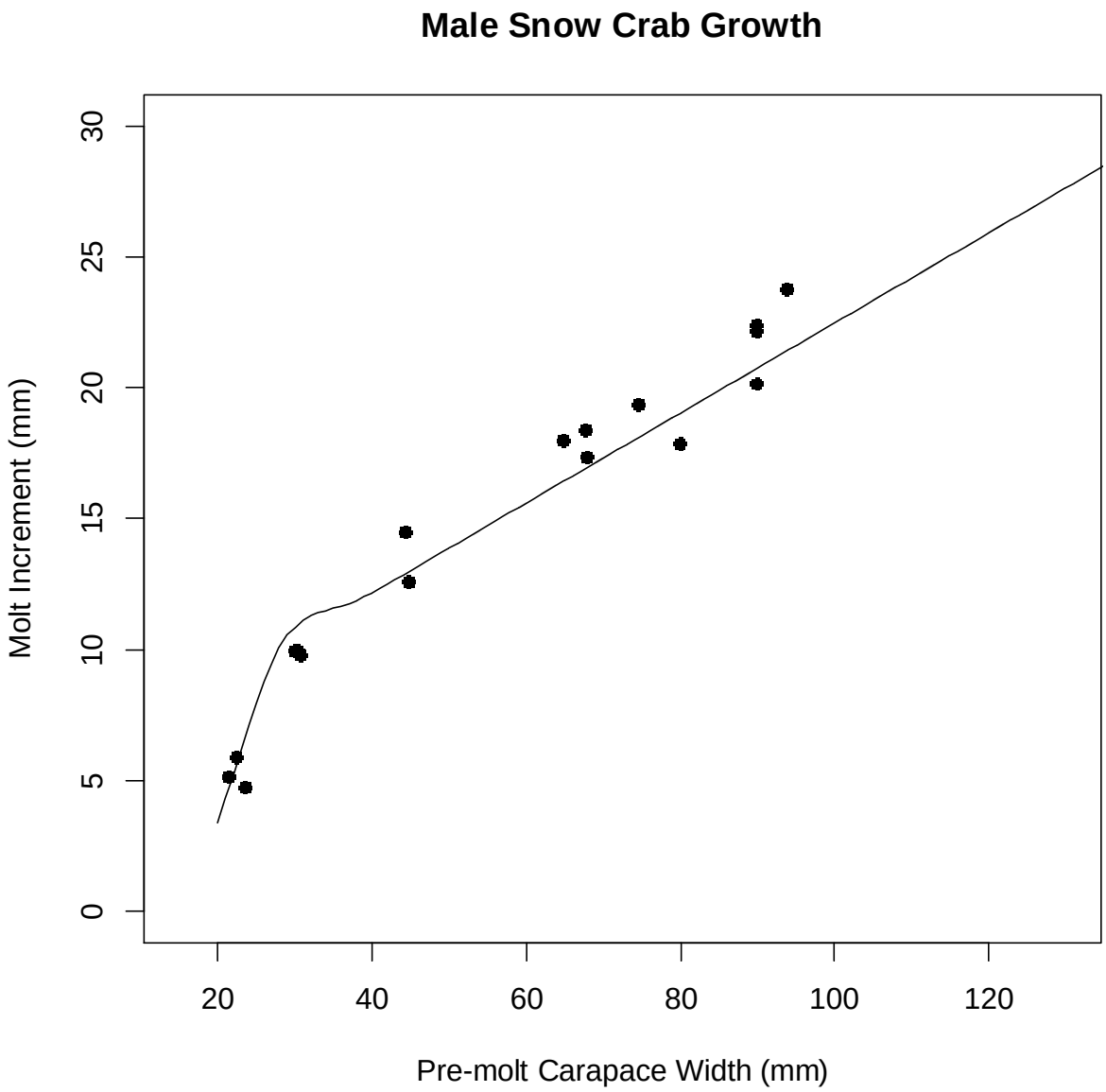
Male Snow Crab Growth
Molt Increment (mm)
0
5
10
15
20
25
30
20
40
60
80
100
120
Pre-molt Carapace Width (mm)

Figure B-25.

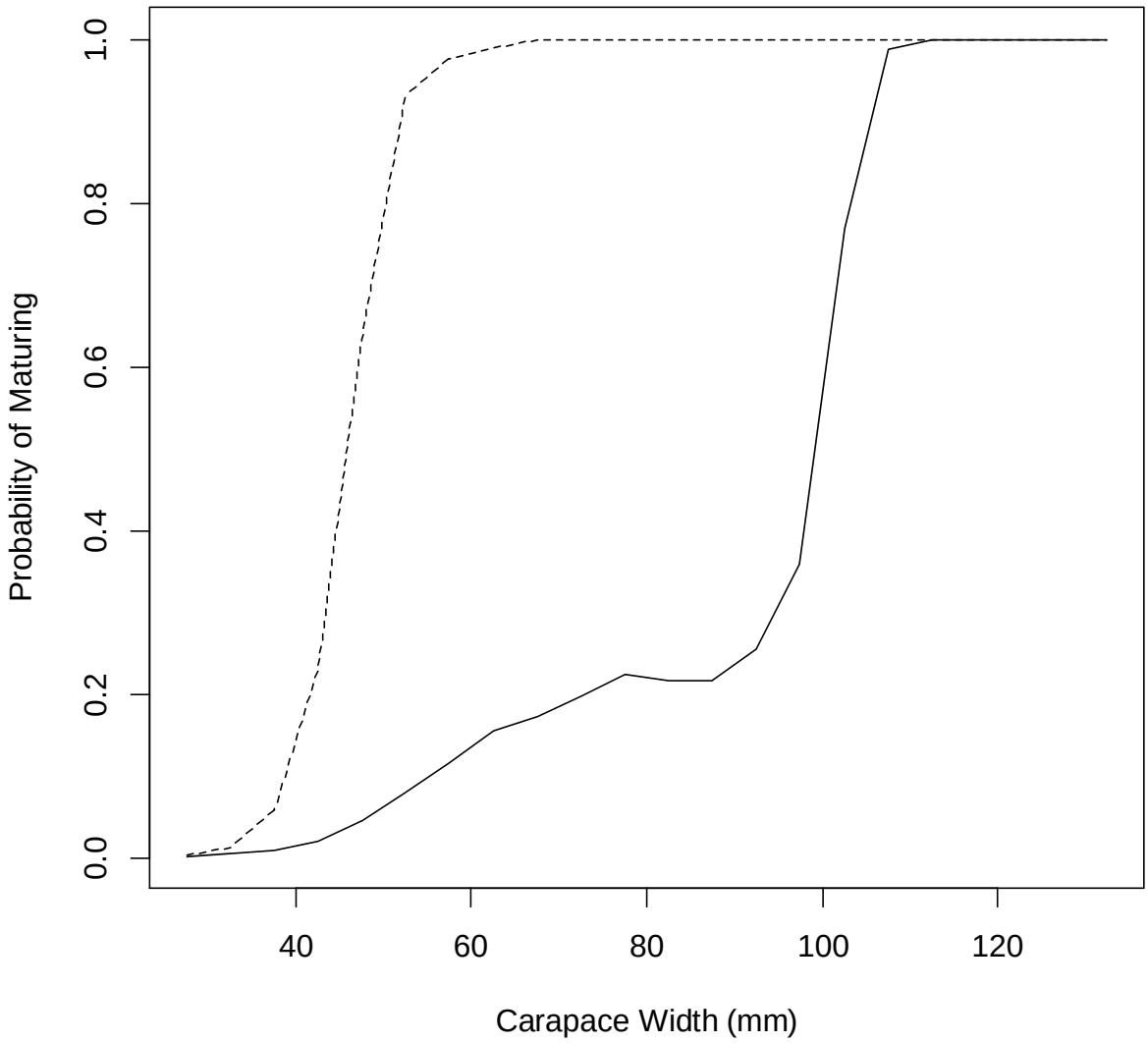
Probability of Maturing
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
Carapace Width (mm)

Figure B-26.

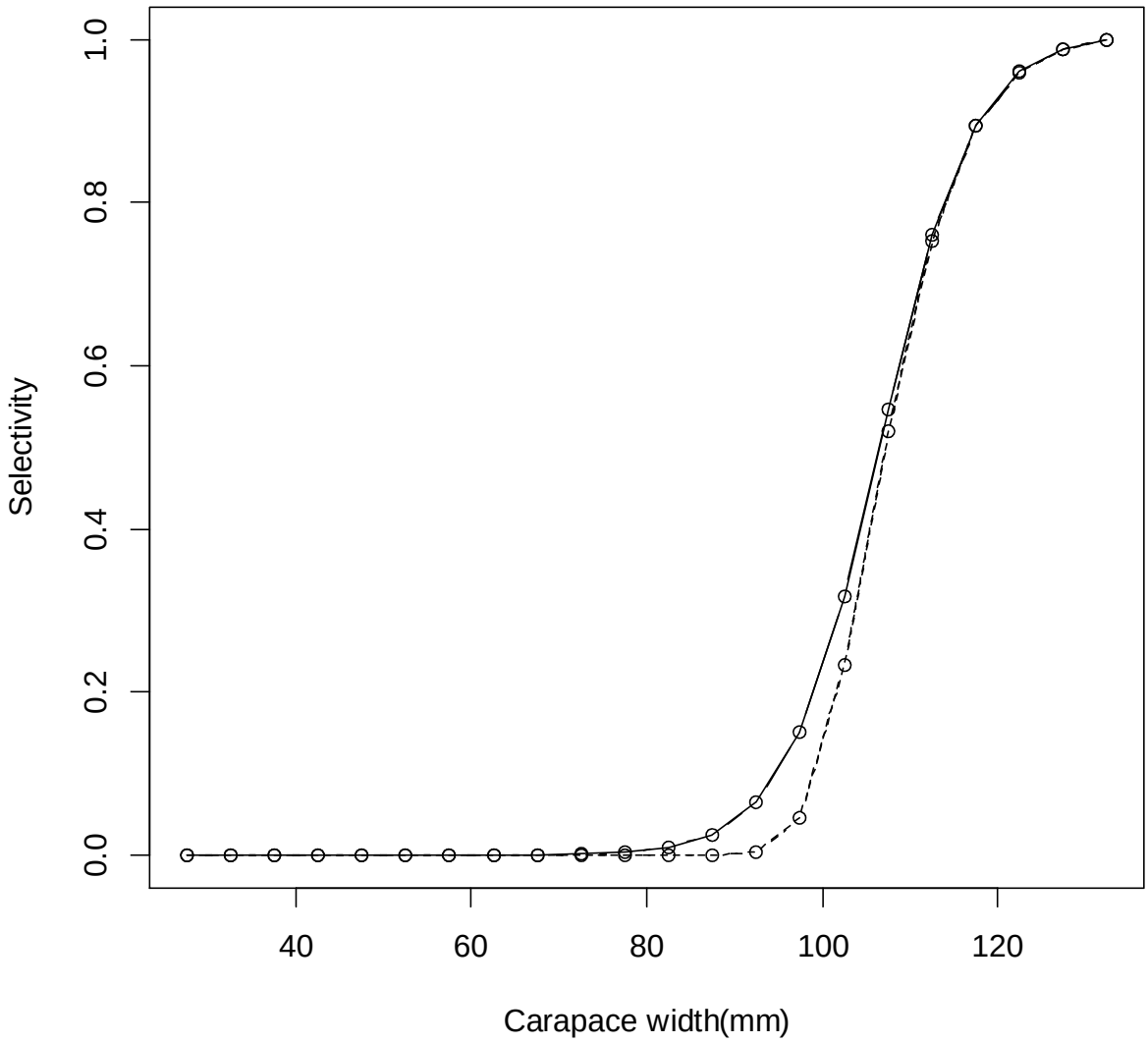
Selectivity
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
Carapace width(mm)

Figure B-27.

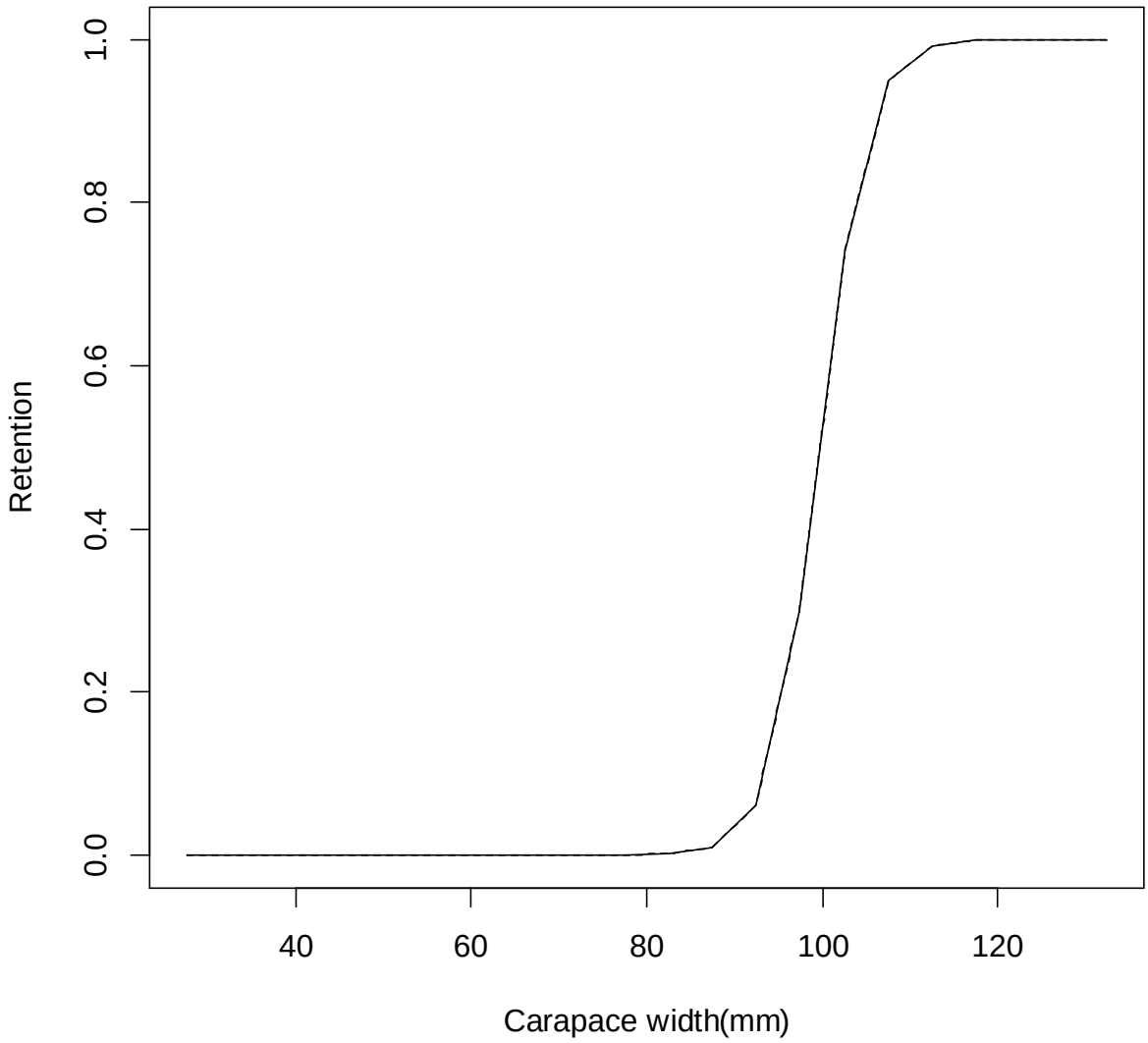

Figure B-28.

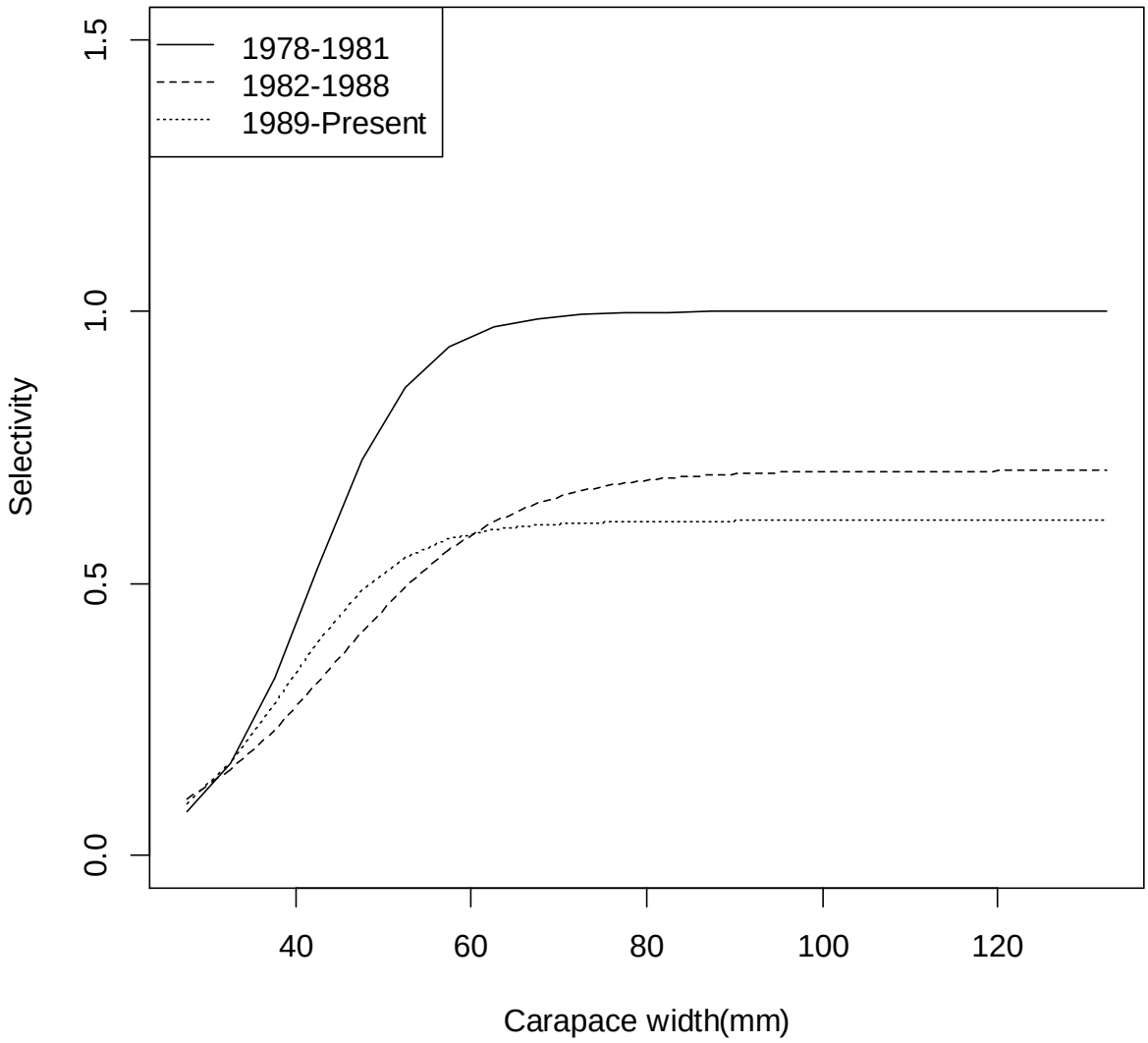
1978-1981
1982-1988
1989-Present
Selectivity
0.0
0.5
1.0
1.5
40
60
80
100
120
Carapace width(mm)

Figure B-29.

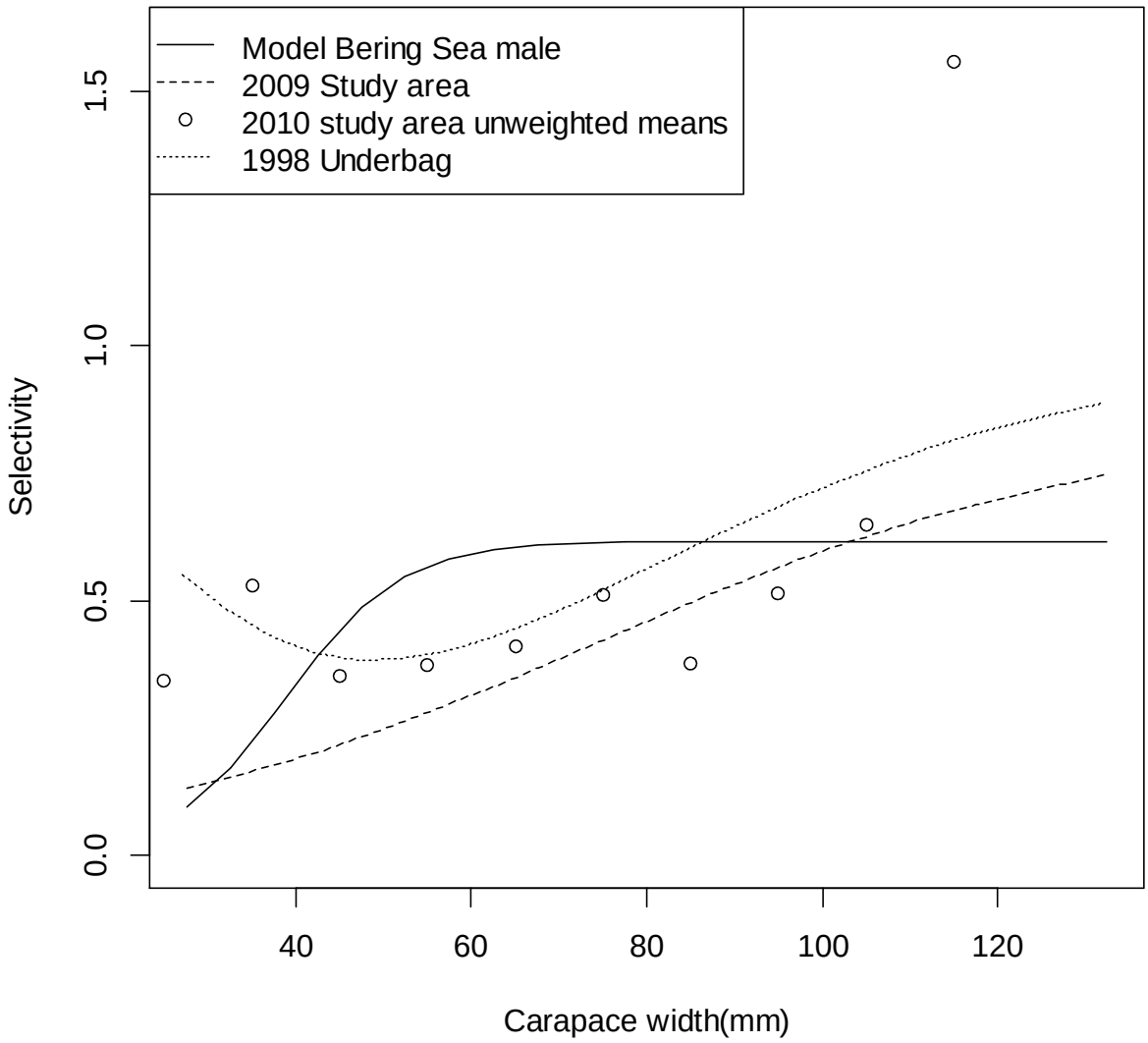
Model Bering Sea male
2009 Study area
2010 study area unweighted means
1998 Underbag
Selectivity
0.0
0.5
1.0
1.5
40
60
80
100
120
Carapace width(mm)

Figure B-30.

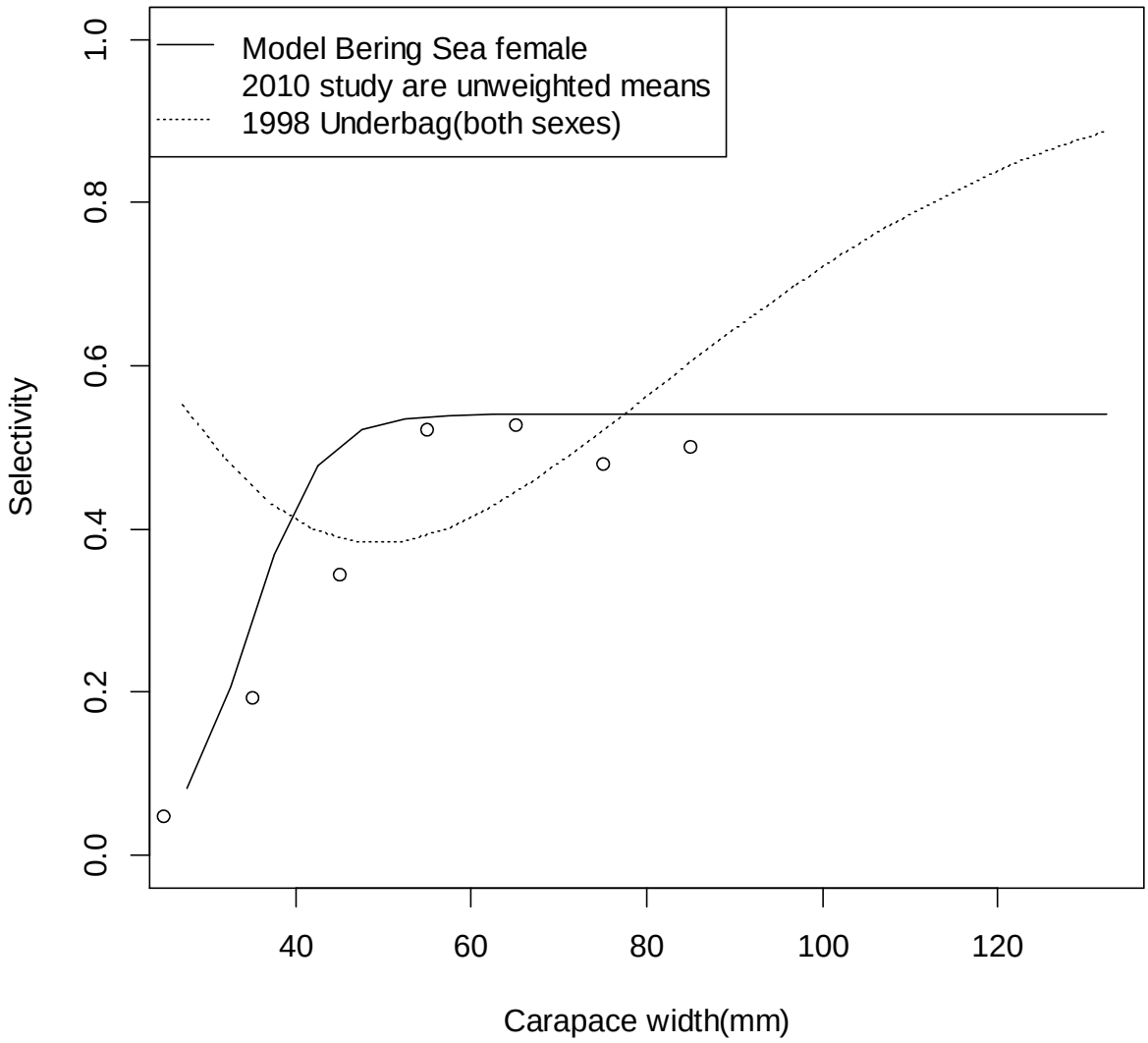
Model Bering Sea female
2010 study are unweighted means
1998 Underbag(both sexes)
Selectivity
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
Carapace width(mm)

Figure B-31.

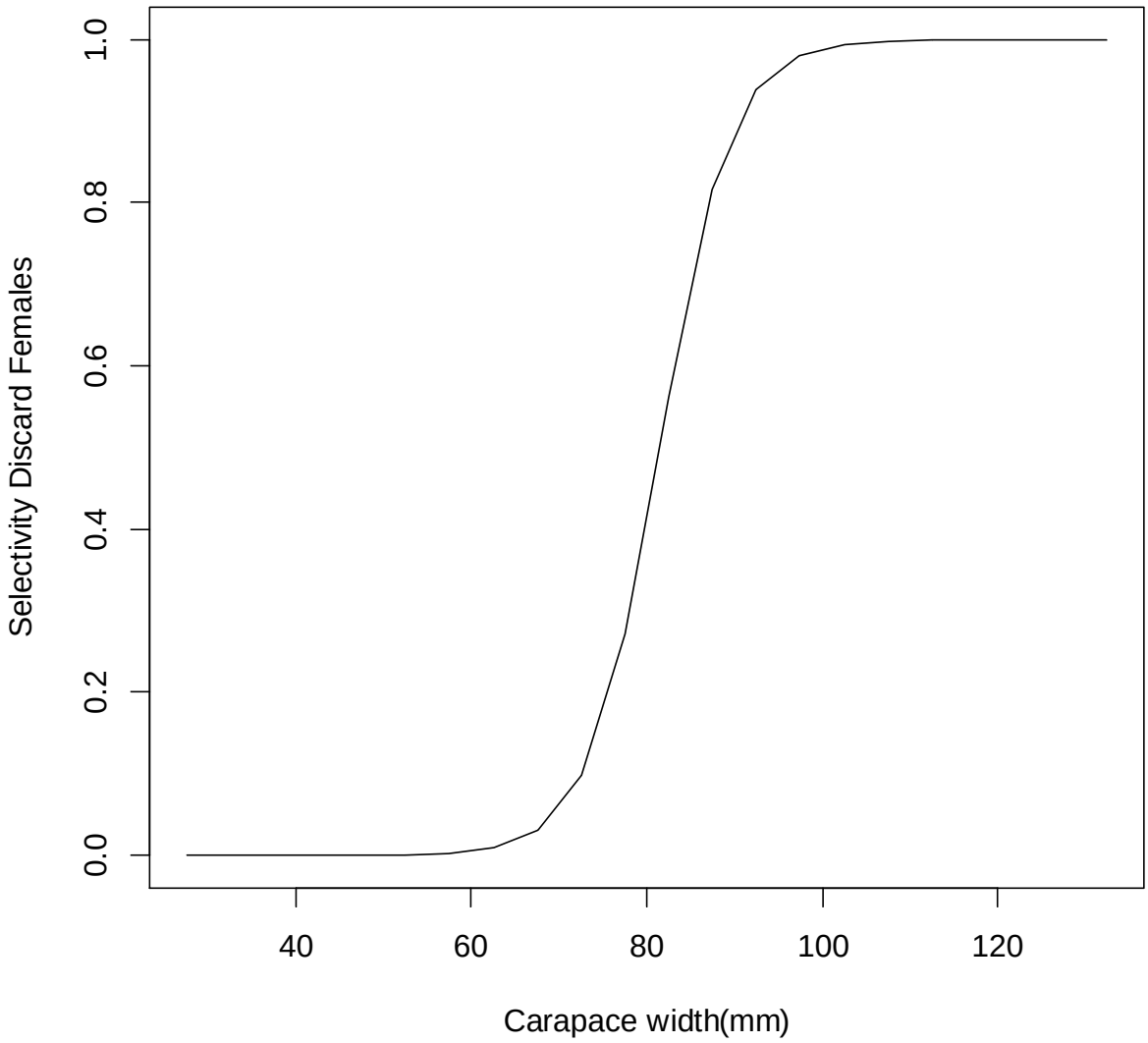
Selectivity Discard Females
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
Carapace width(mm)

Figure B-32.

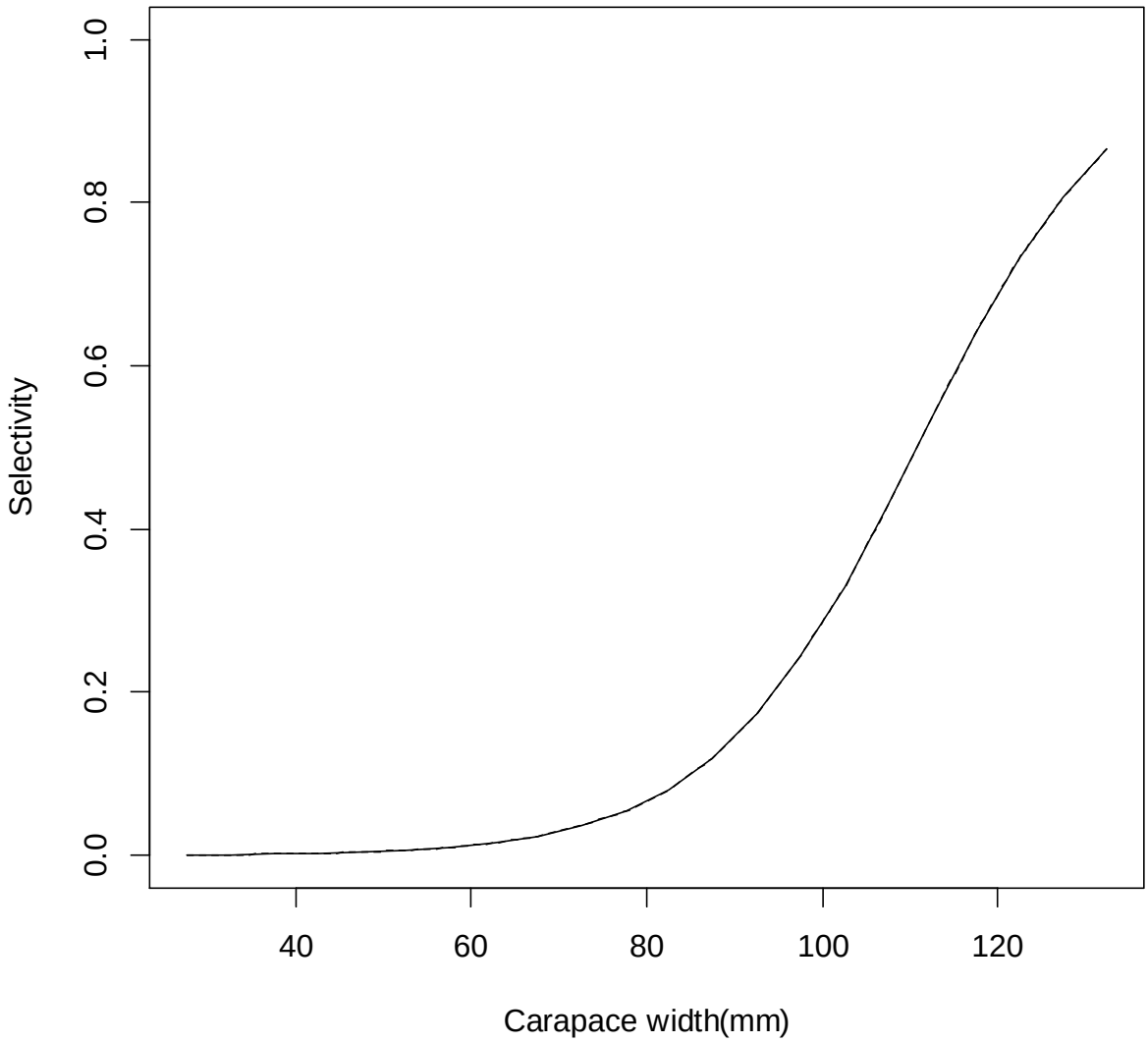
Selectivity
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
Carapace width(mm)

Figure B-33.

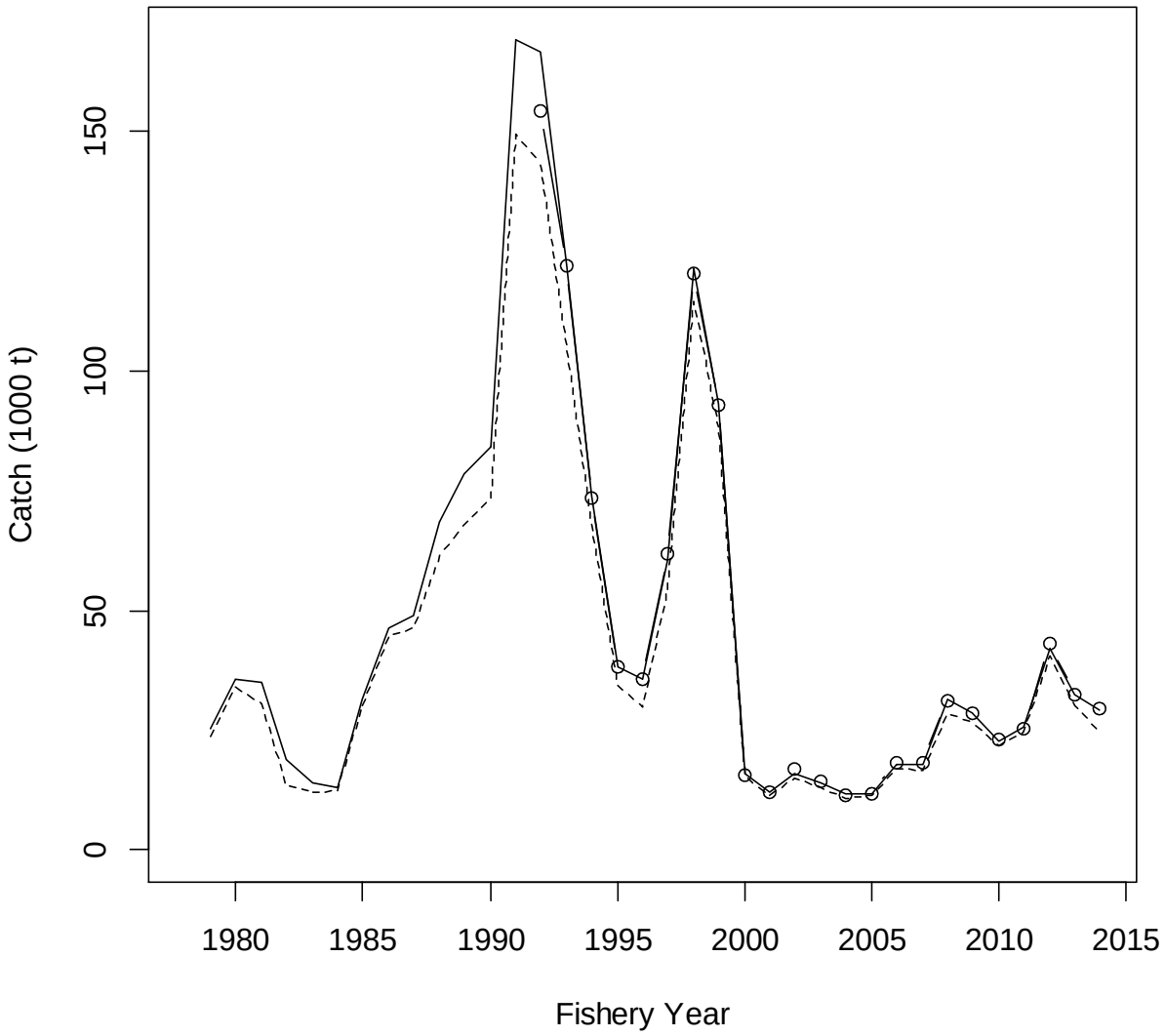
Catch (1000 t)
0
50
100
150
1980
1985
1990
1995
2000
2005
2010
2015
Fishery Year

Figure B-34.

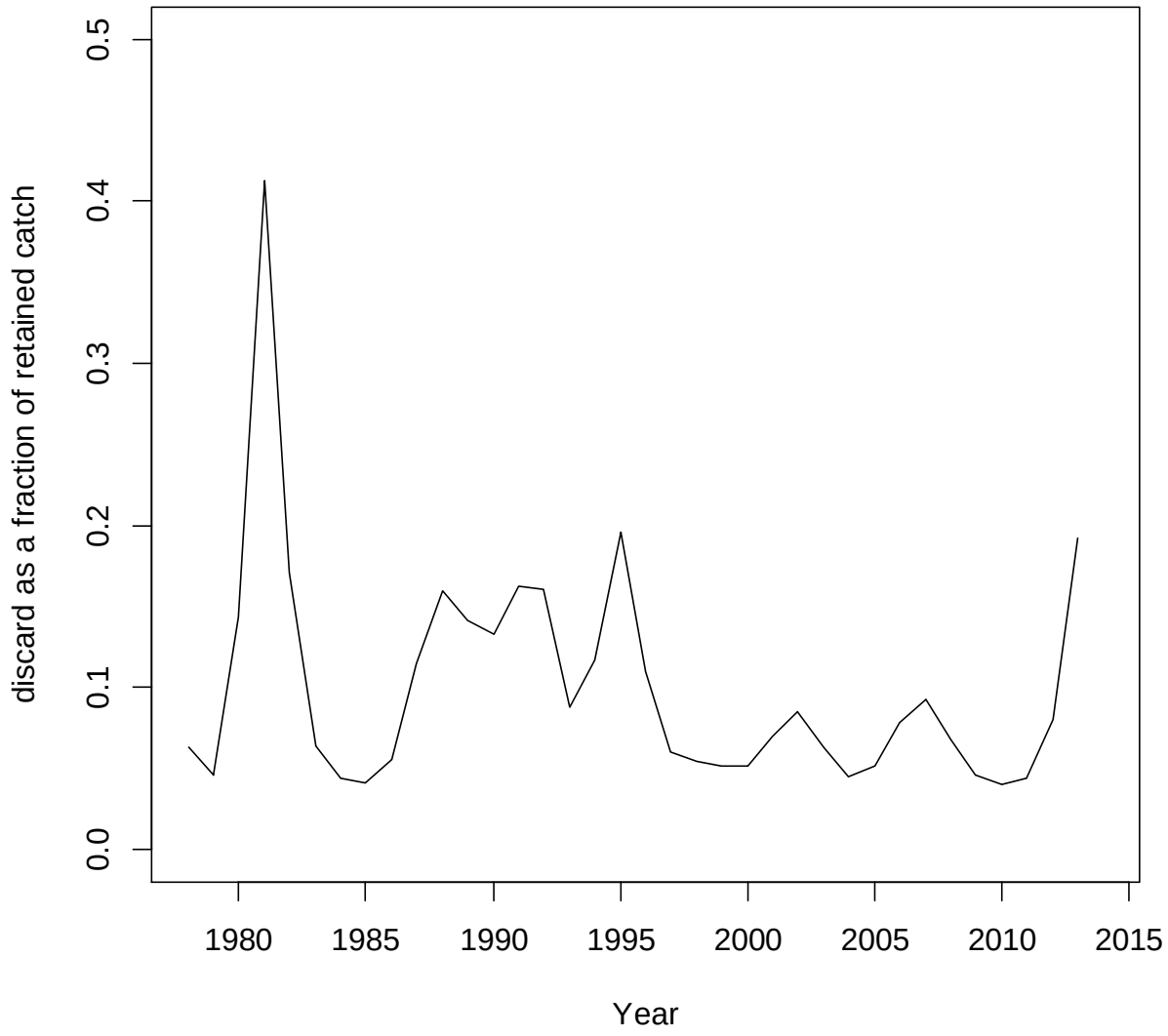
discard as a fraction of retained catch
0.0
0.1
0.2
0.3
0.4
0.5
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure B-35.

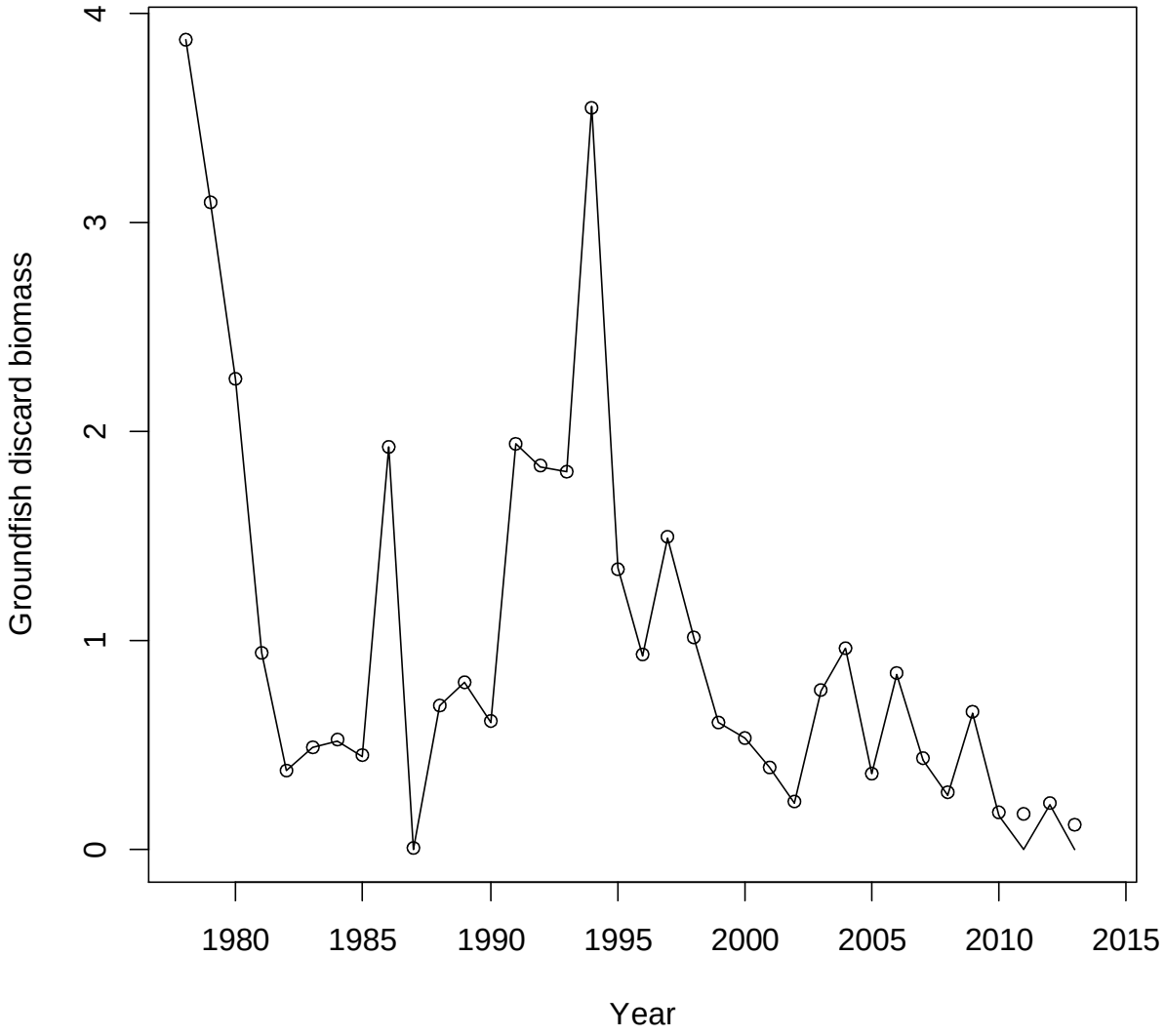
Groundfish discard biomass
0
1
2
3
4
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure B-36.

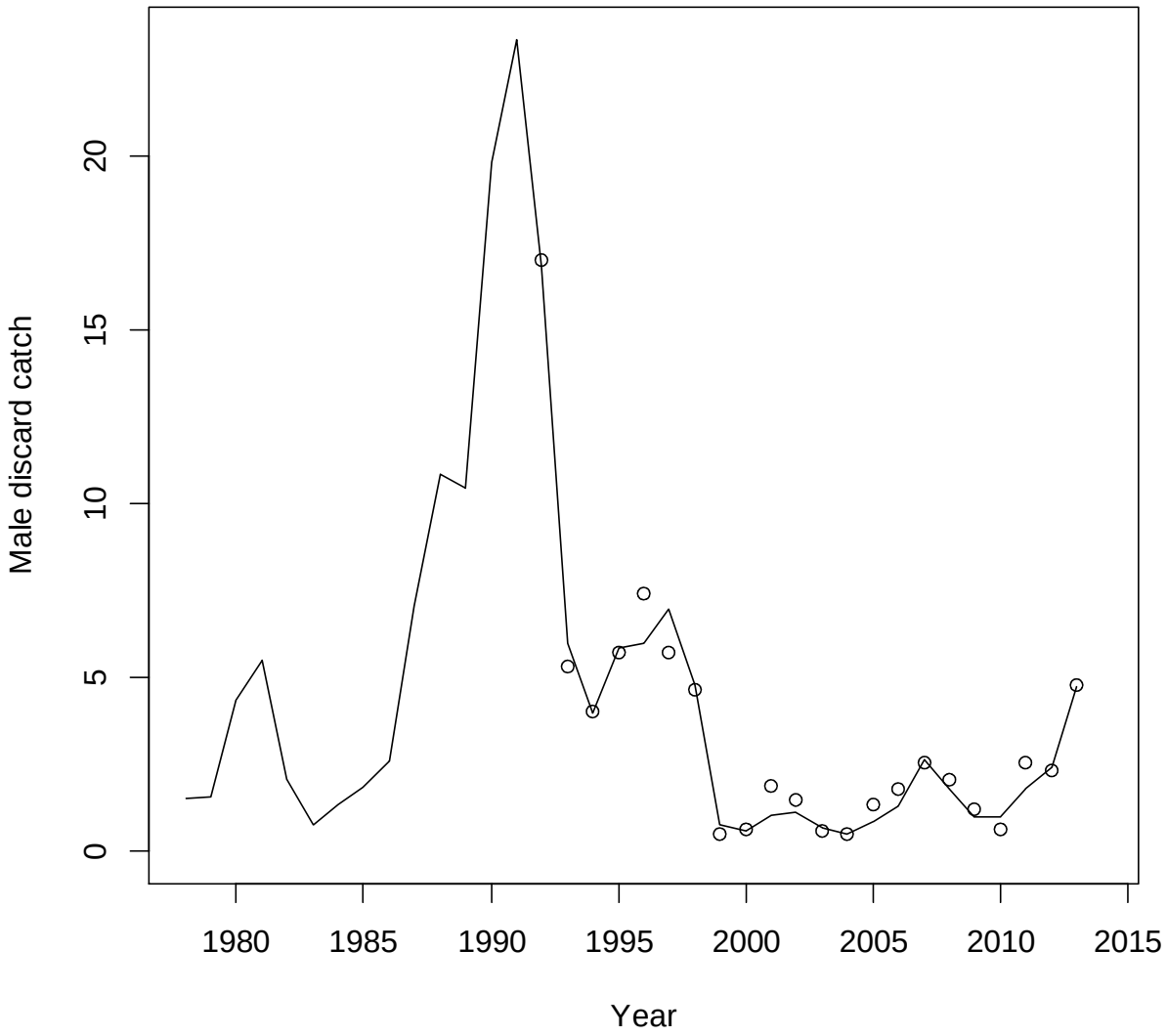
Male discard catch
0
5
10
15
20
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure B-37.

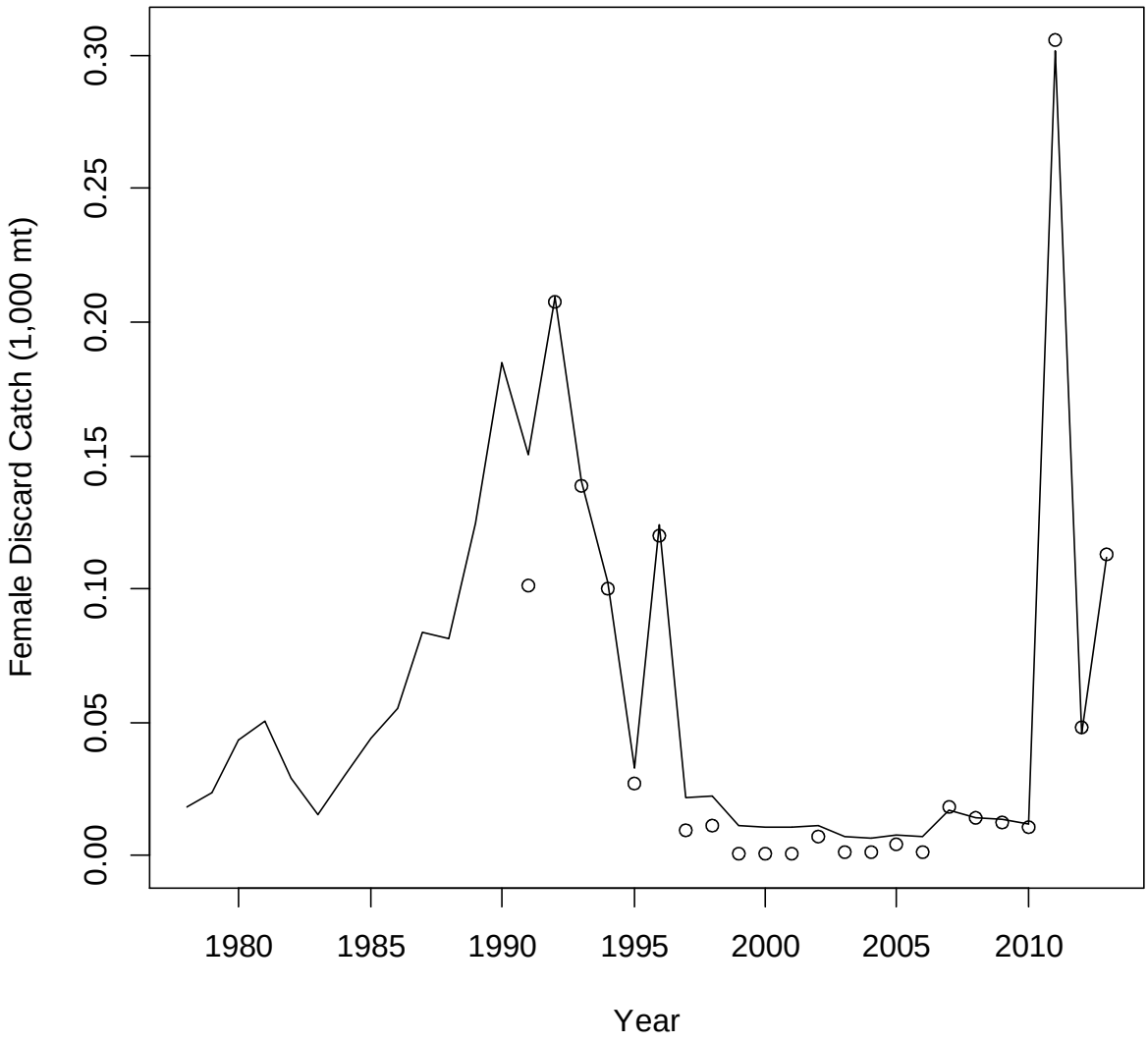
Female Discard Catch (1,000 mt)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
1980
1985
1990
1995
2000
2005
2010
Year

Figure B-38.

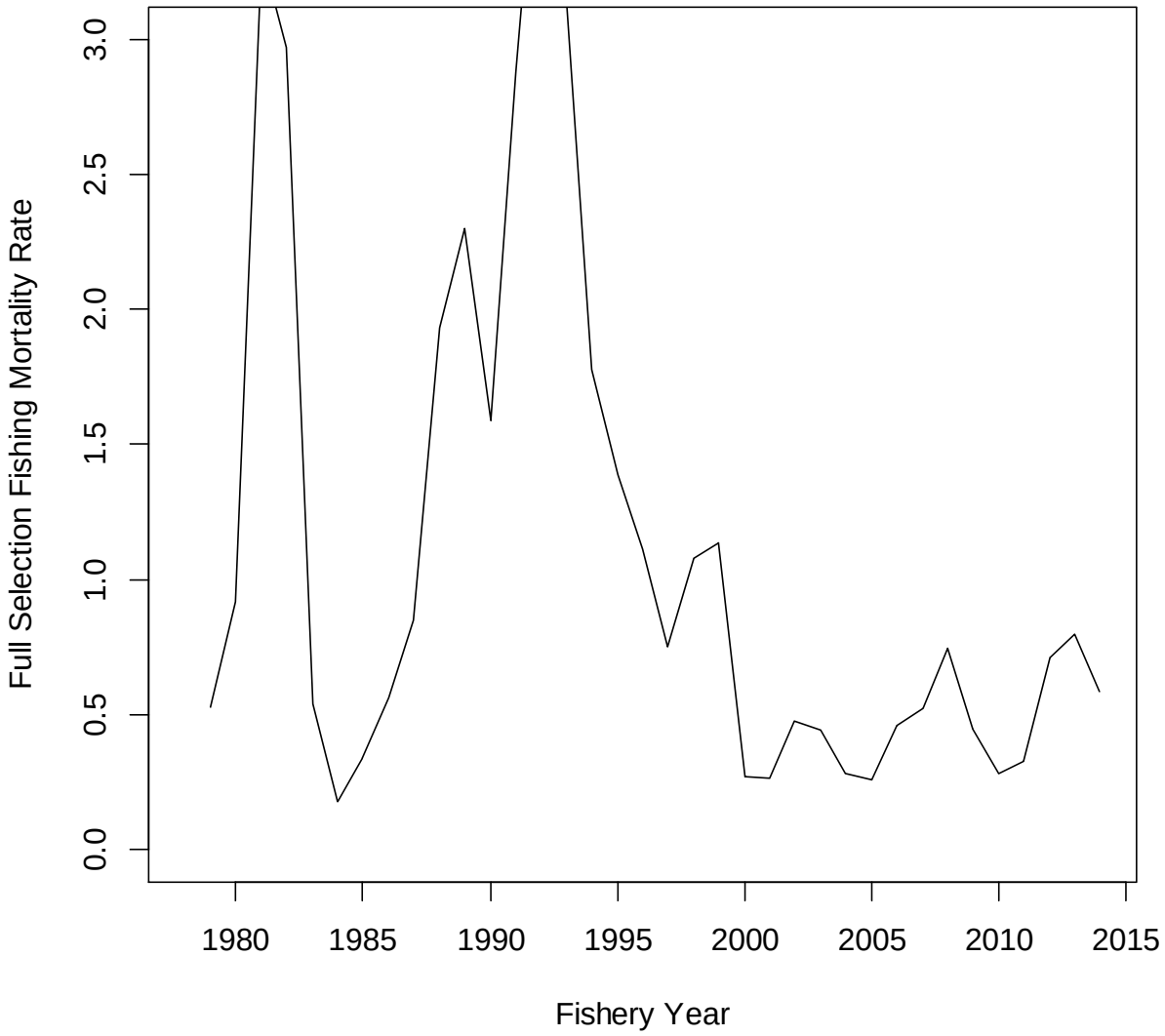
Full Selection Fishing Mortality Rate
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1980
1985
1990
1995
2000
2005
2010
2015
Fishery Year

Figure B-39.

Appendix C. Plots for Model 3.

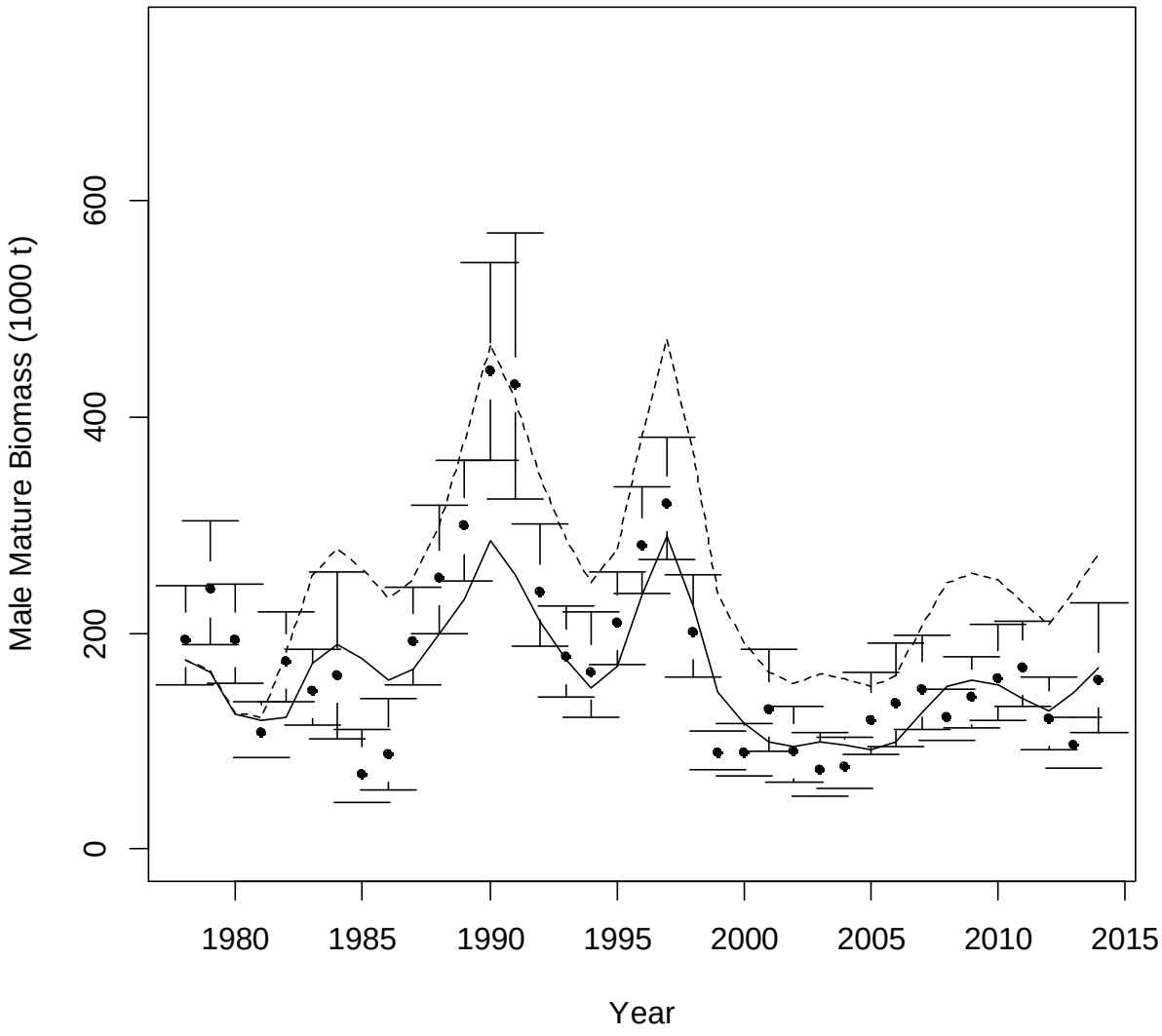

Figure C-1.

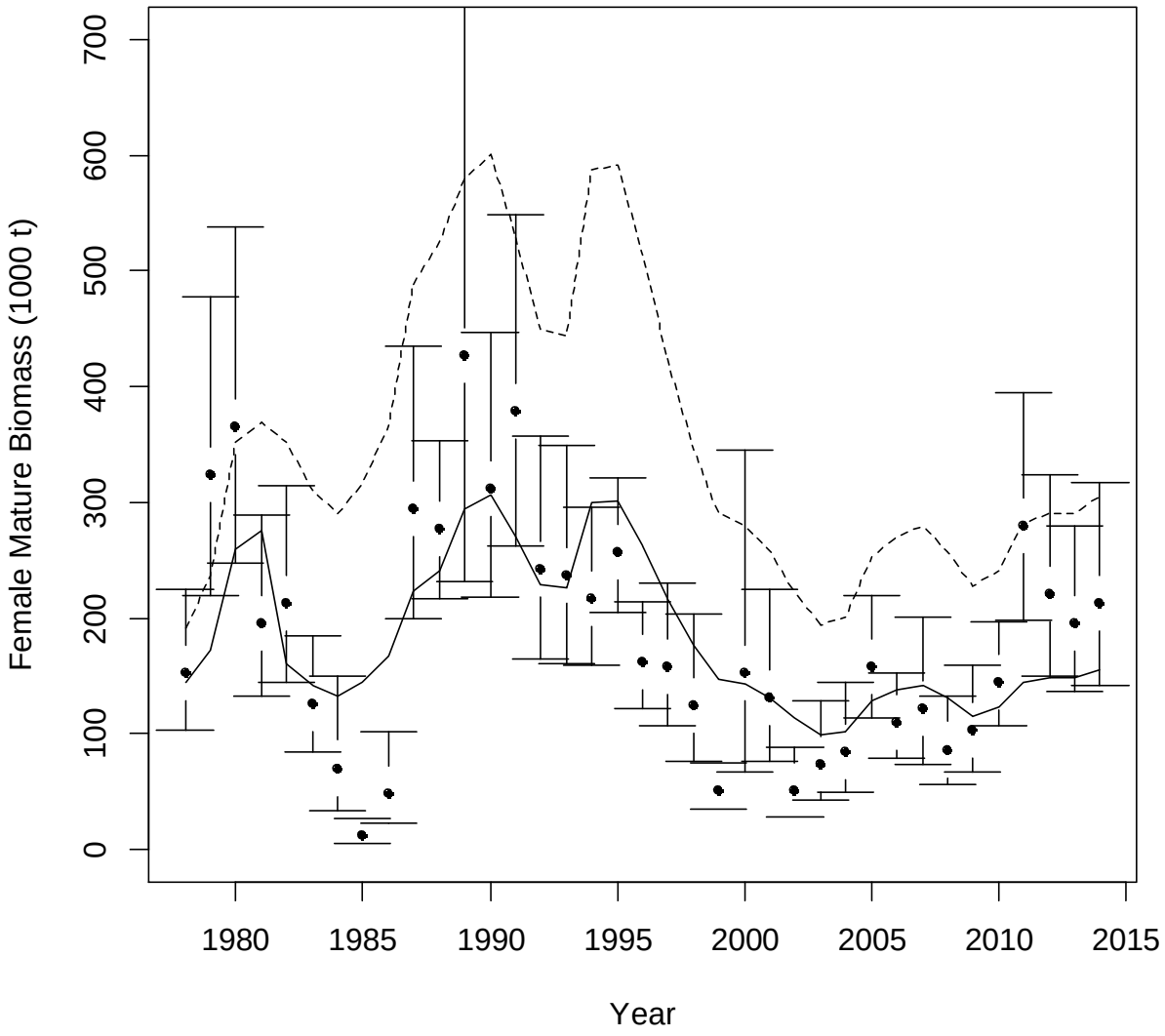
Female Mature Biomass (1000 t)
0
100
200
300
400
500
600
700
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure C-2.

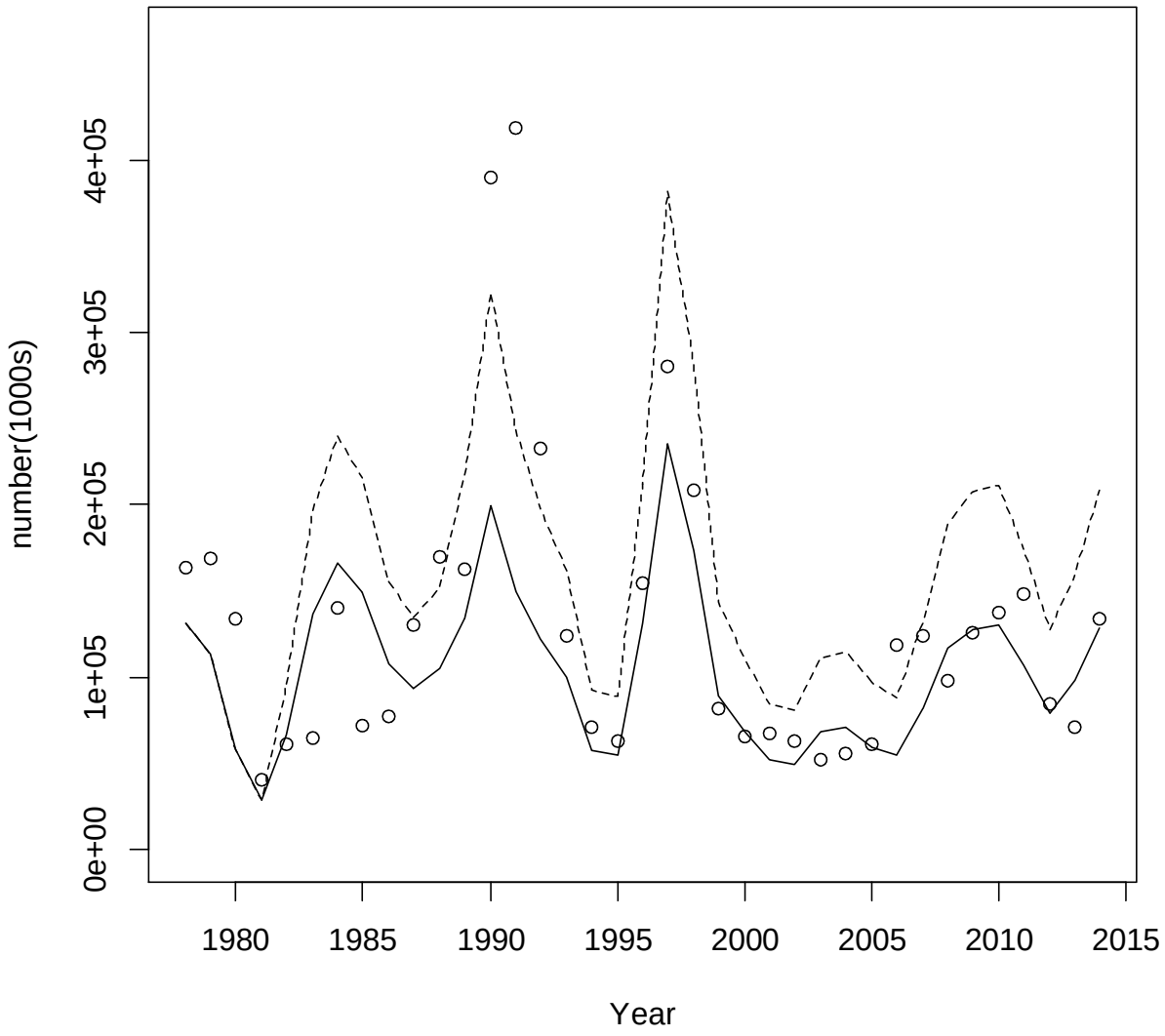
number(1000s)
0e+00
1e+05
2e+05
3e+05
4e+05
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure C-3.

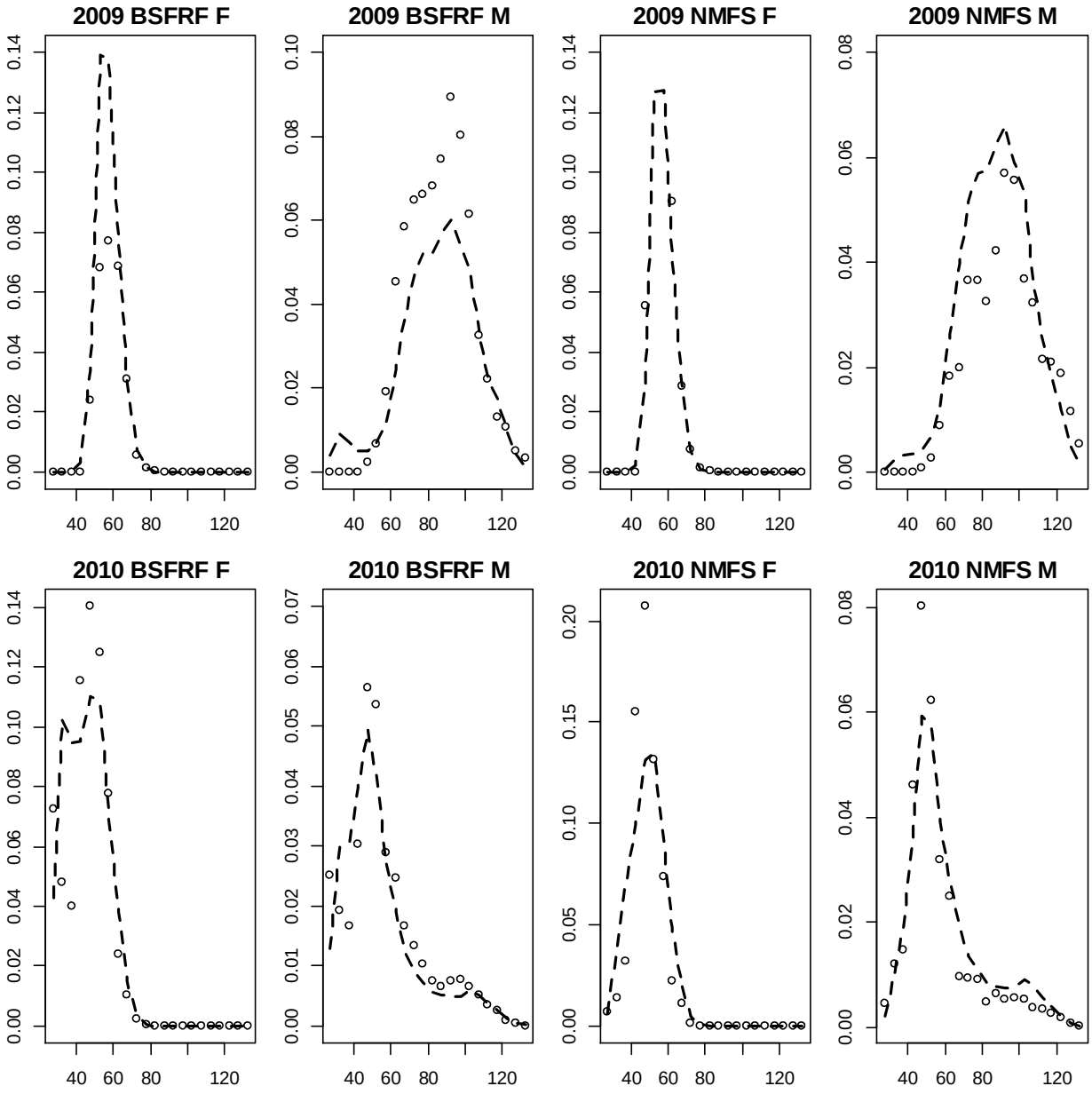
2009 BSFRF F
2009 BSFRF M
2009 NMFS F
2009 NMFS M
2010 BSFRF F
2010 BSFRF M
2010 NMFS F
2010 NMFS M
40 60 80 120

Figure C-4.

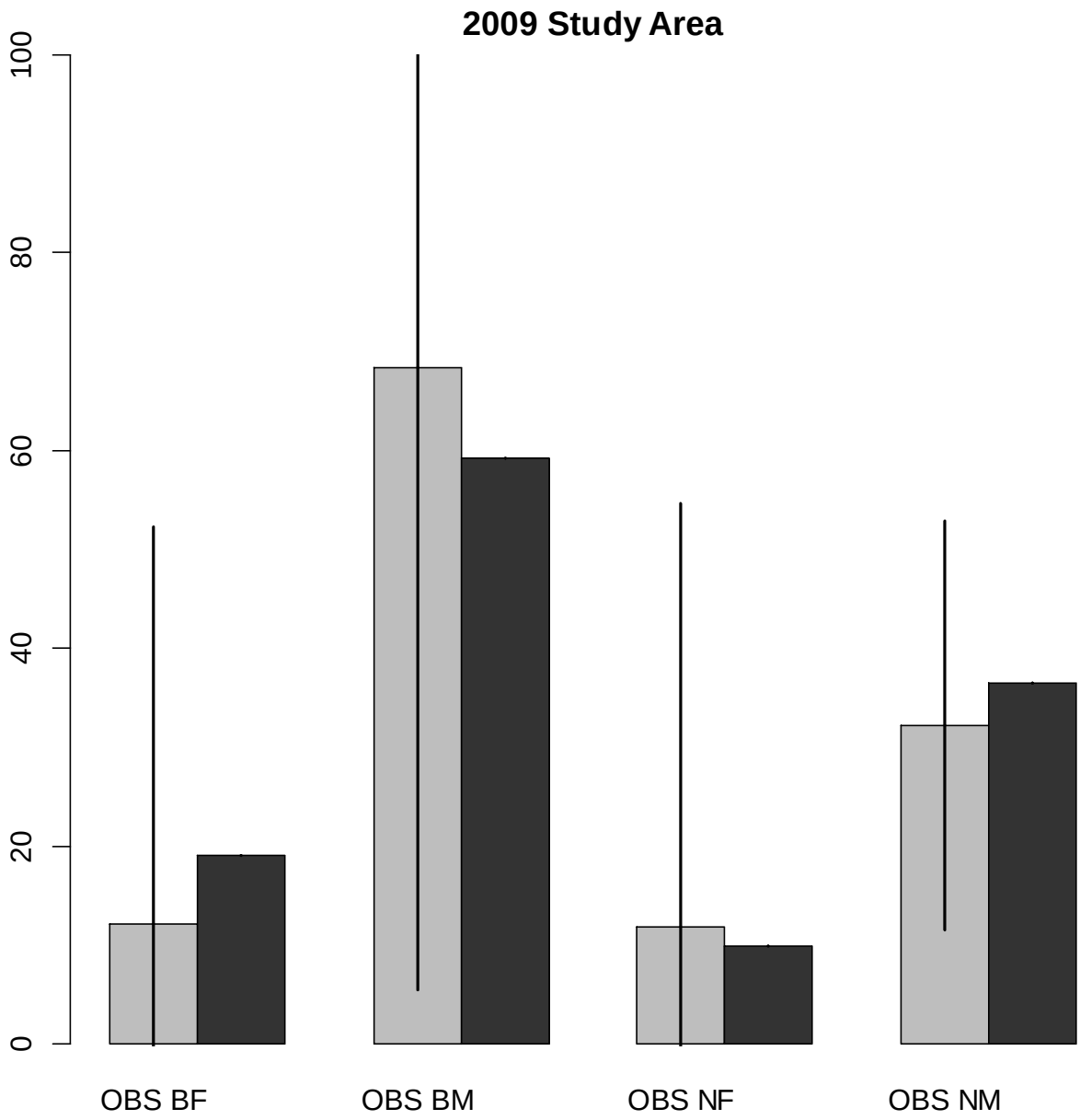

Figure C-5.

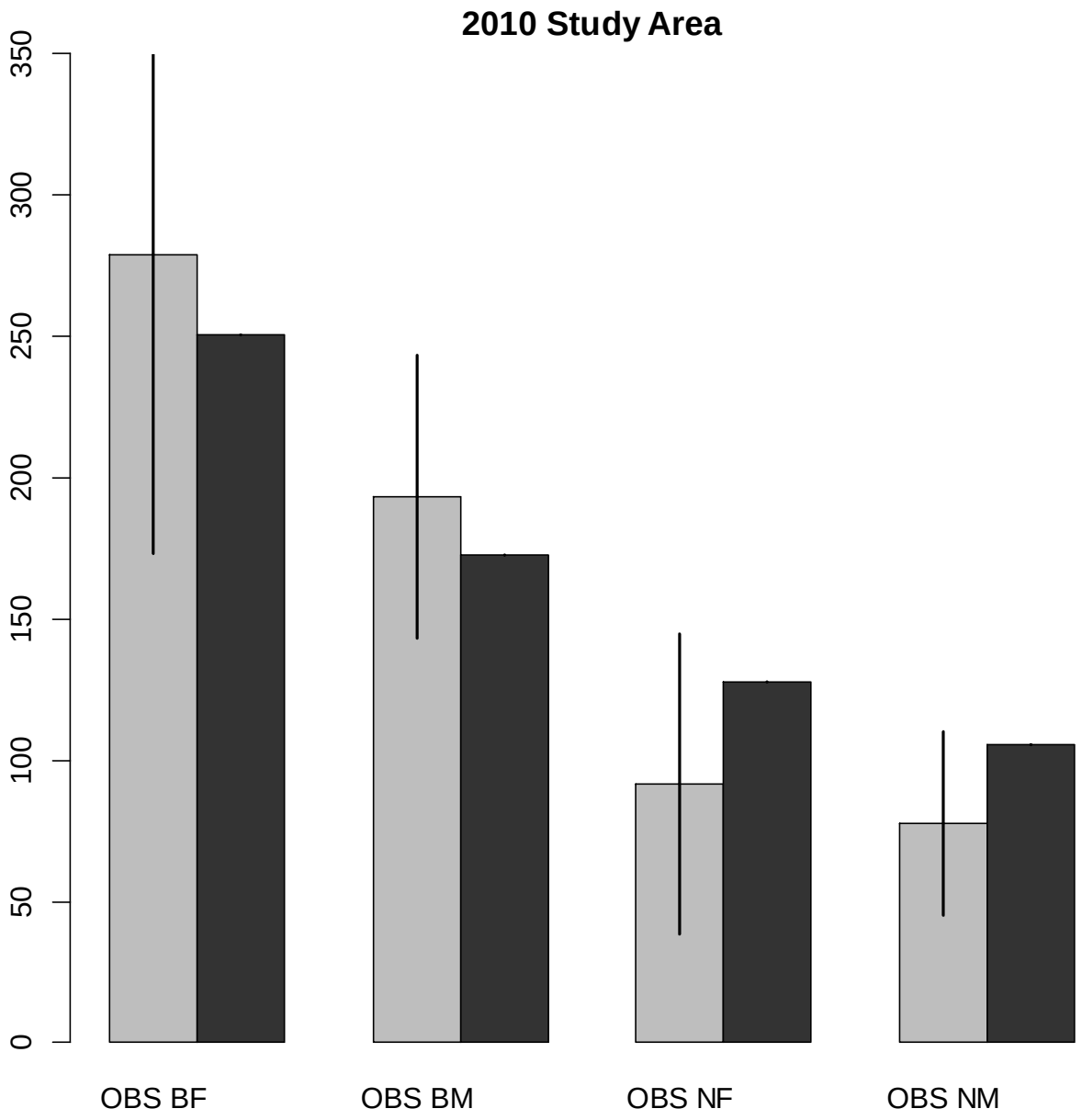
2010 Study Area
0
50
100
150
200
250
300
350
OBS BF
OBS BM
OBS NF
OBS NM

Figure C-6.

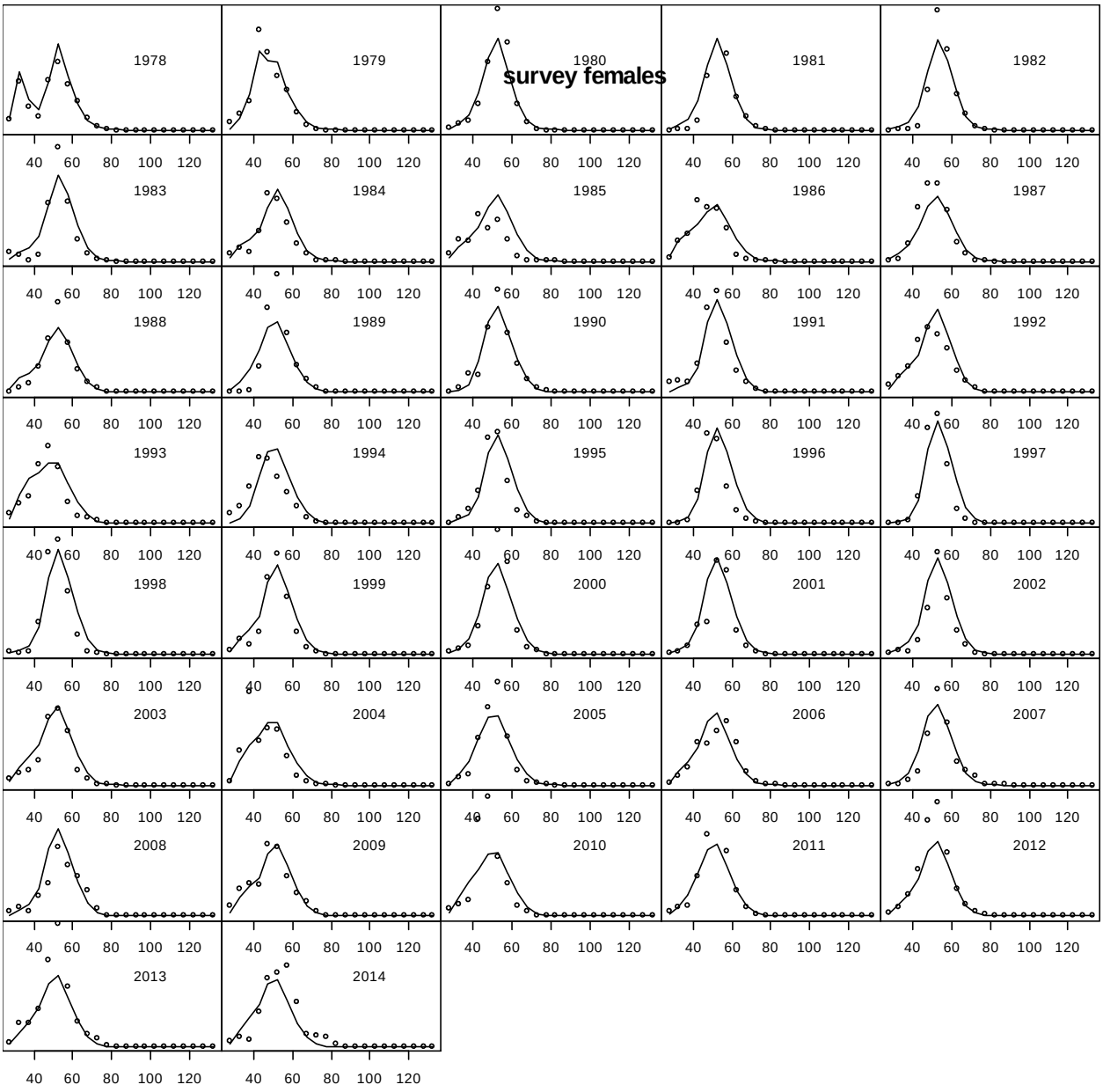
survey females
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
40 60 80 100 120

Figure C-7.

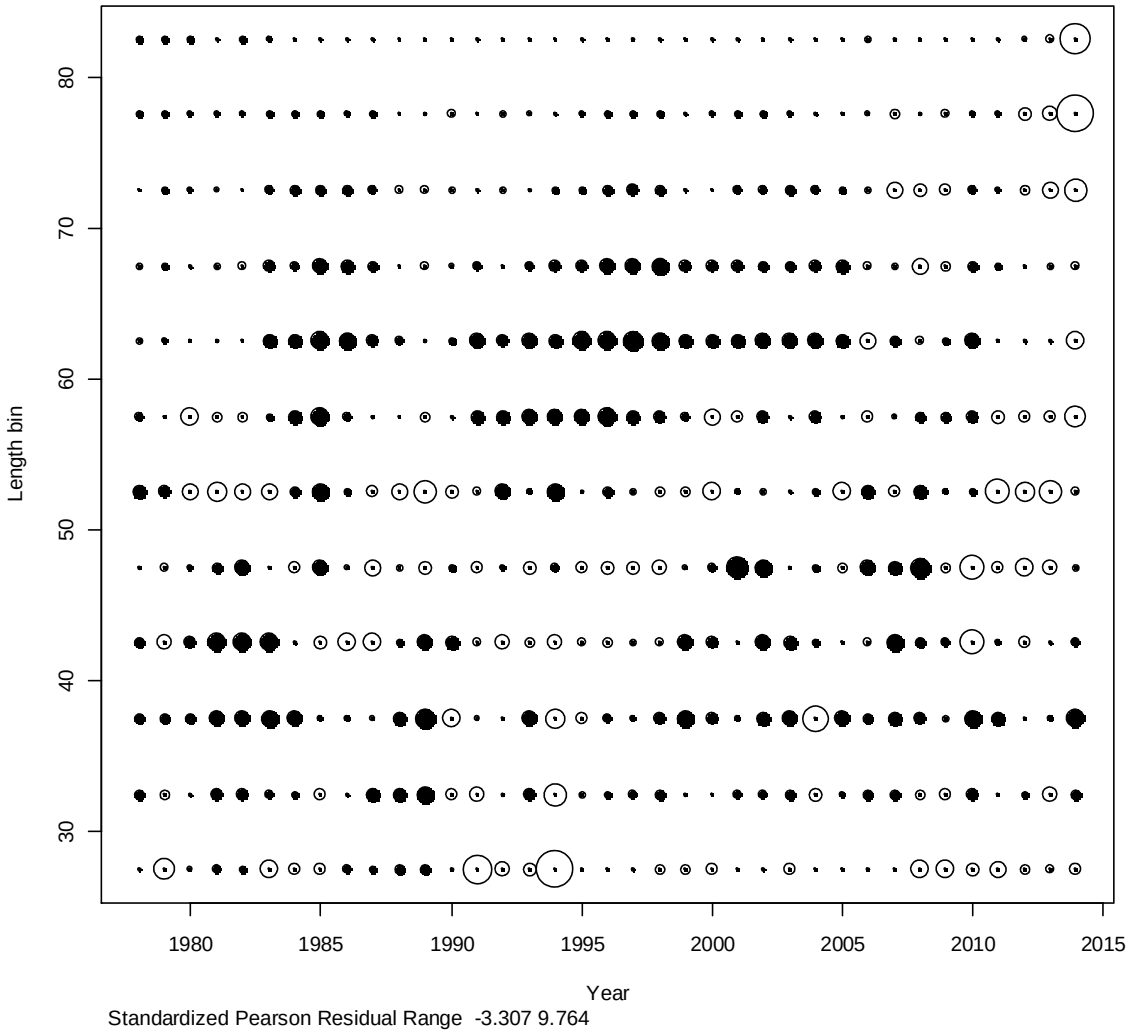
Length bin
30
40
50
60
70
80
1980
1985
1990
1995
2000
2005
2010
2015
Year
Standardized Pearson Residual Range -3.307 9.764

Figure C-8.

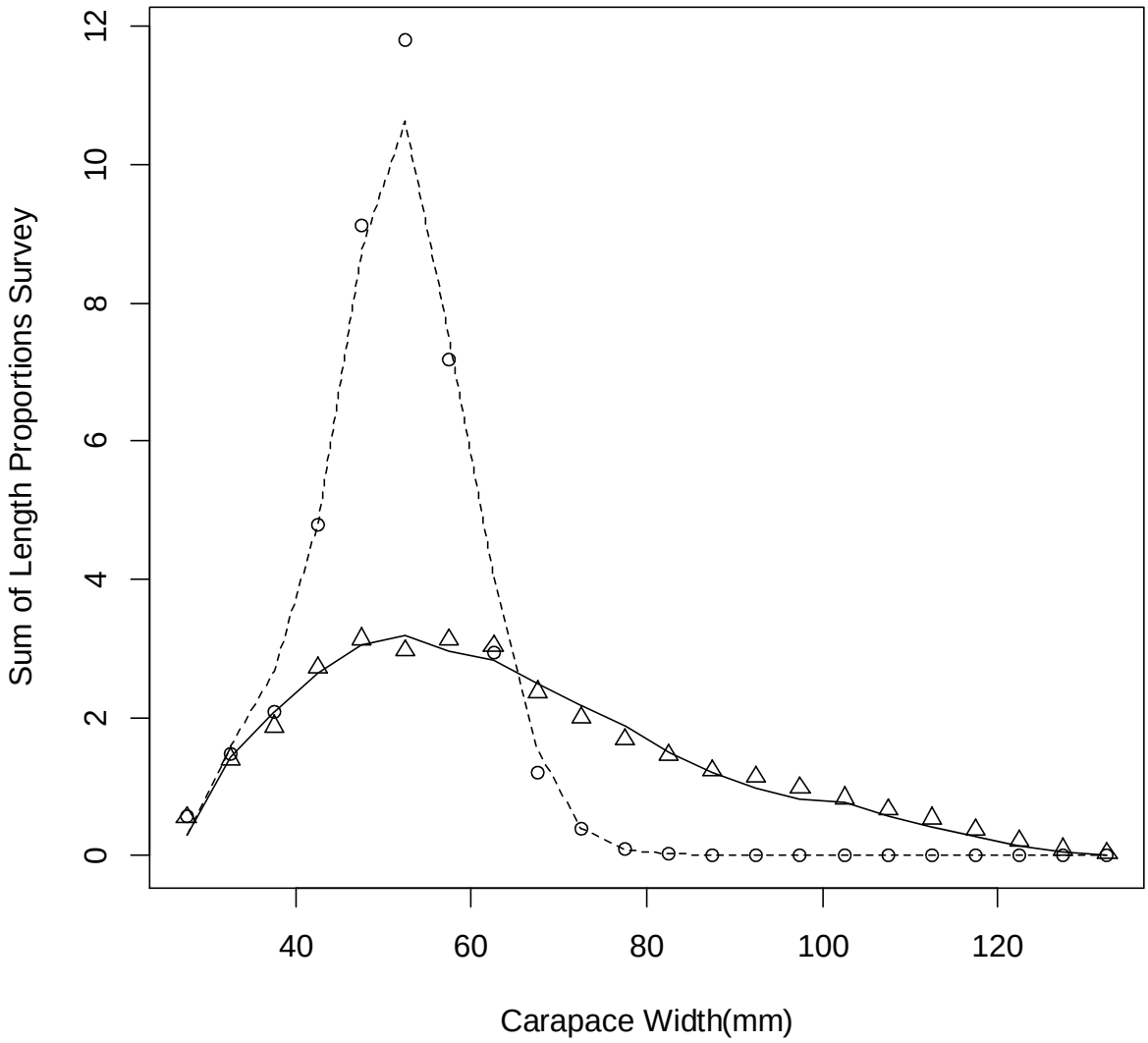
Sum of Length Proportions Survey
0
2
4
6
8
10
12
40
60
80
100
120
Carapace Width(mm)

Figure C-9.

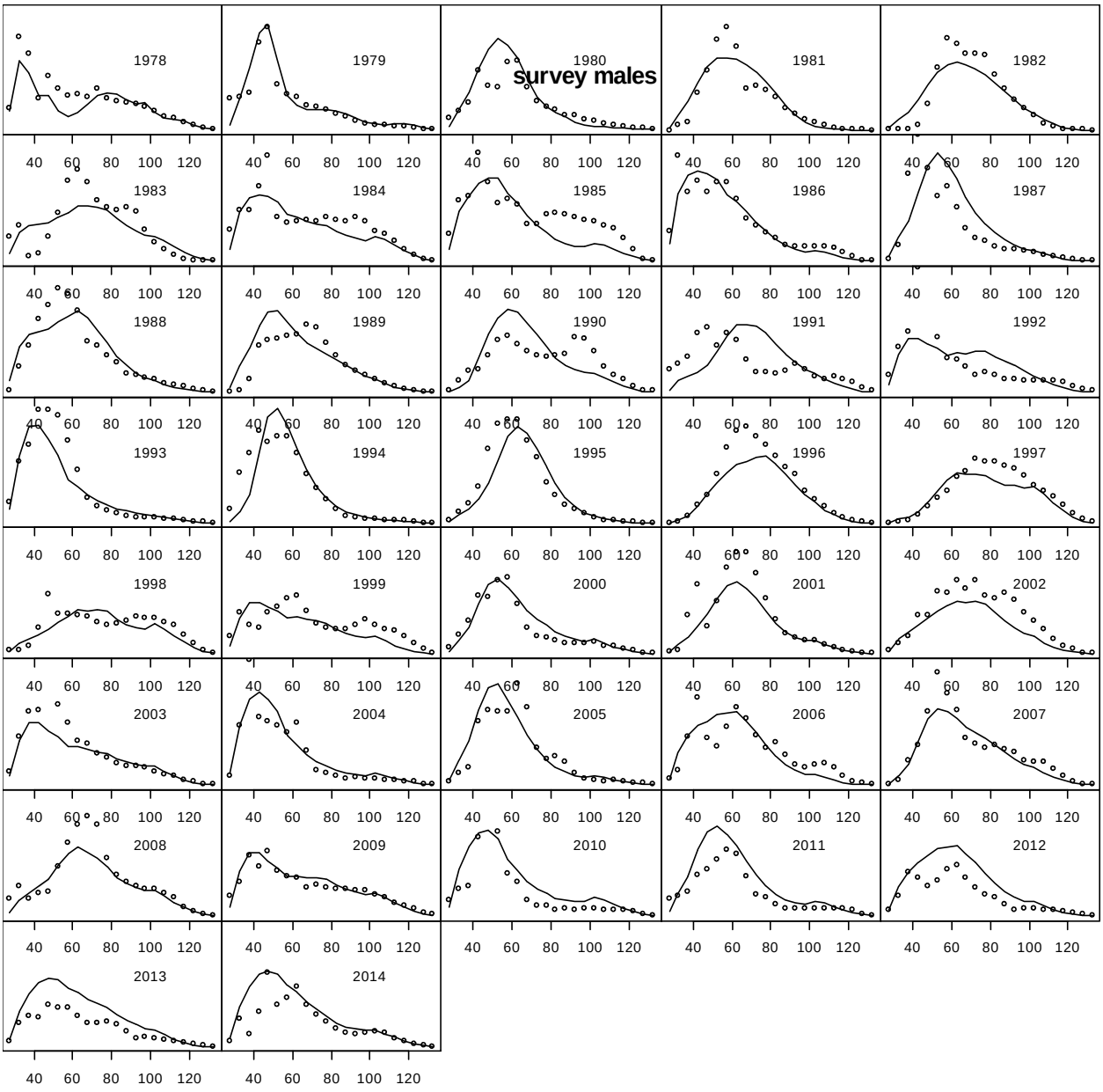
survey males
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
40 60 80 100 120

Figure C-10.

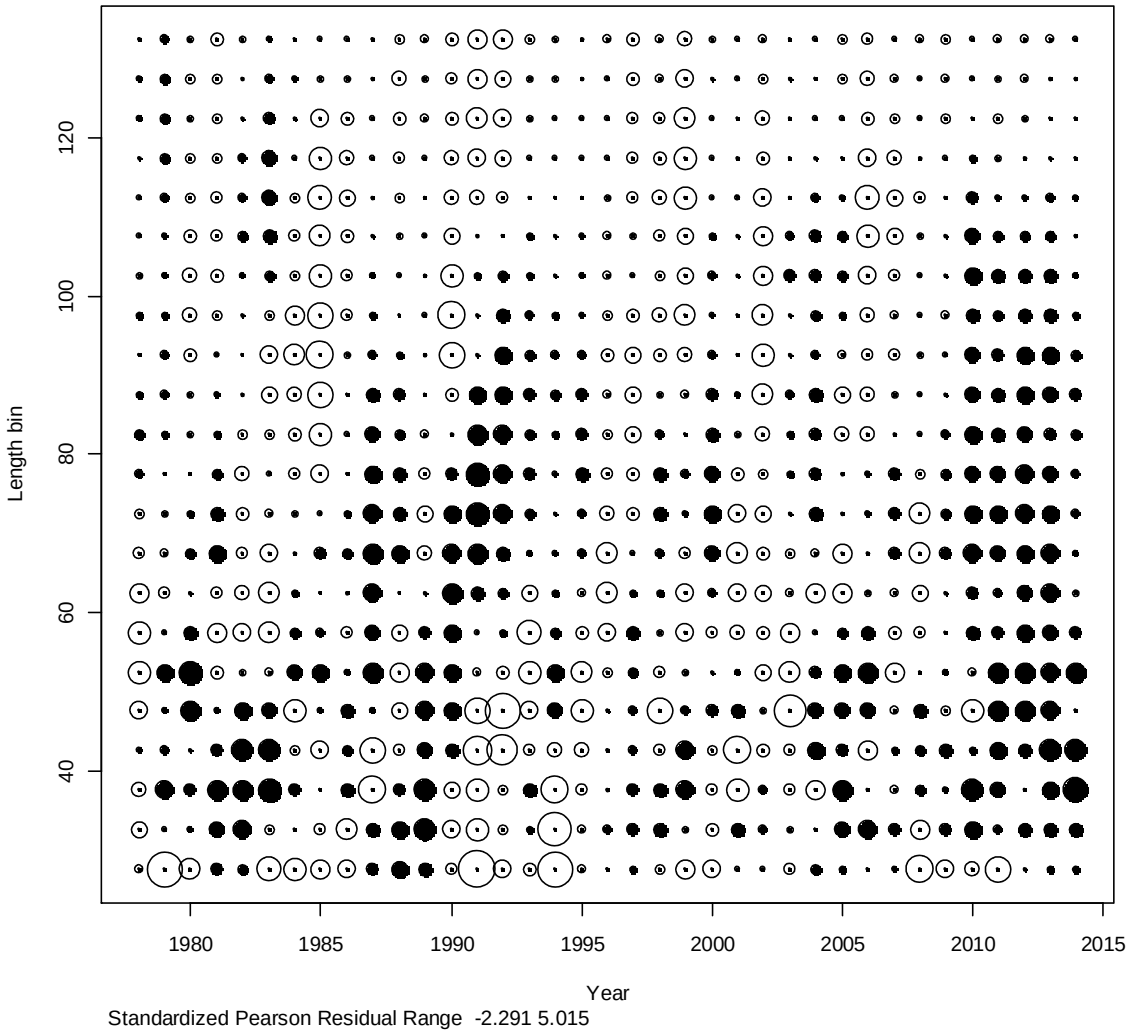
Length bin
40
60
80
100
120
1980
1985
1990
1995
2000
2005
2010
2015
Year
Standardized Pearson Residual Range -2.291 5.015

Figure C-11.

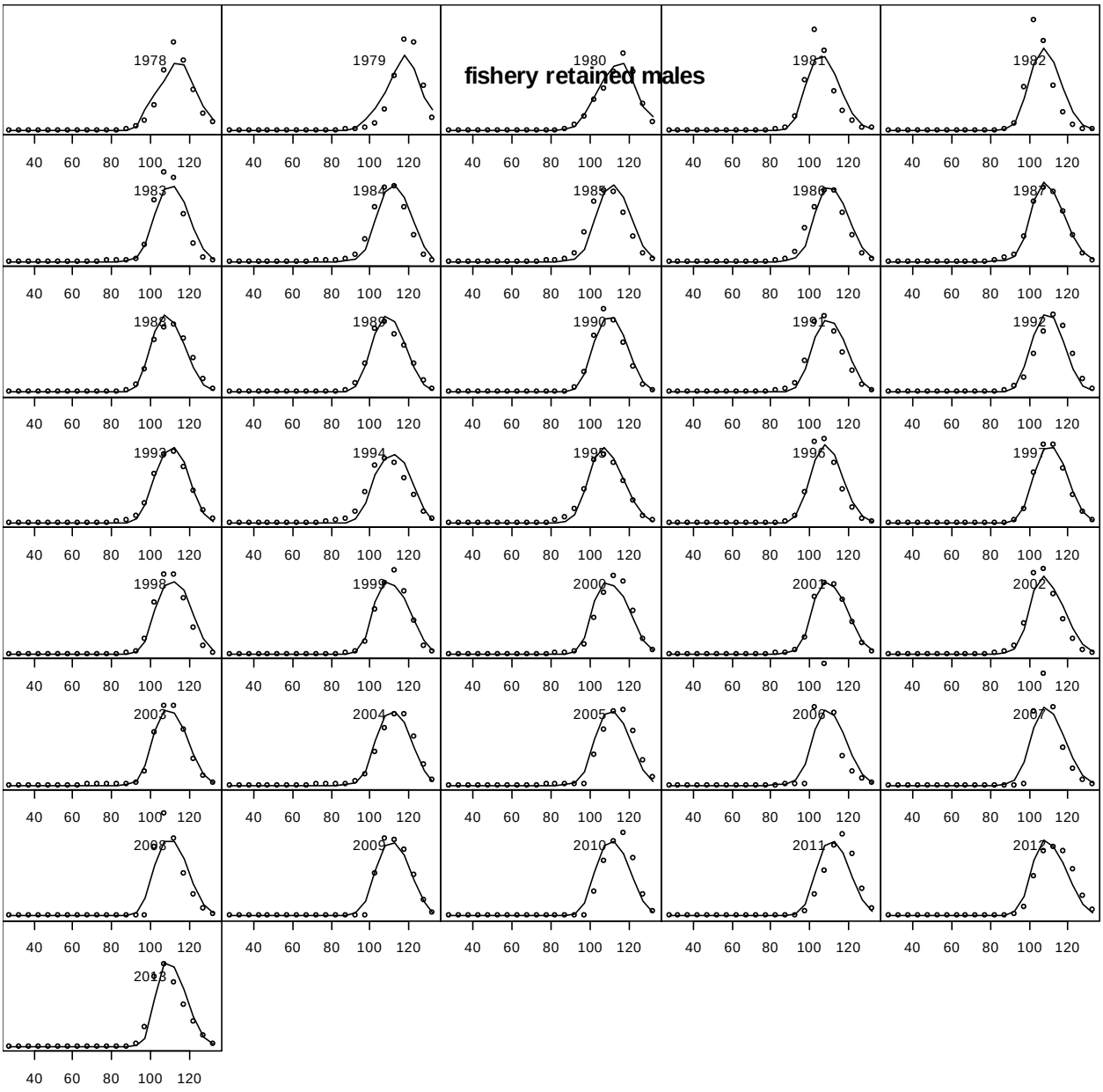
fishery retained males
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40 60 80 100 120

Figure C-12.

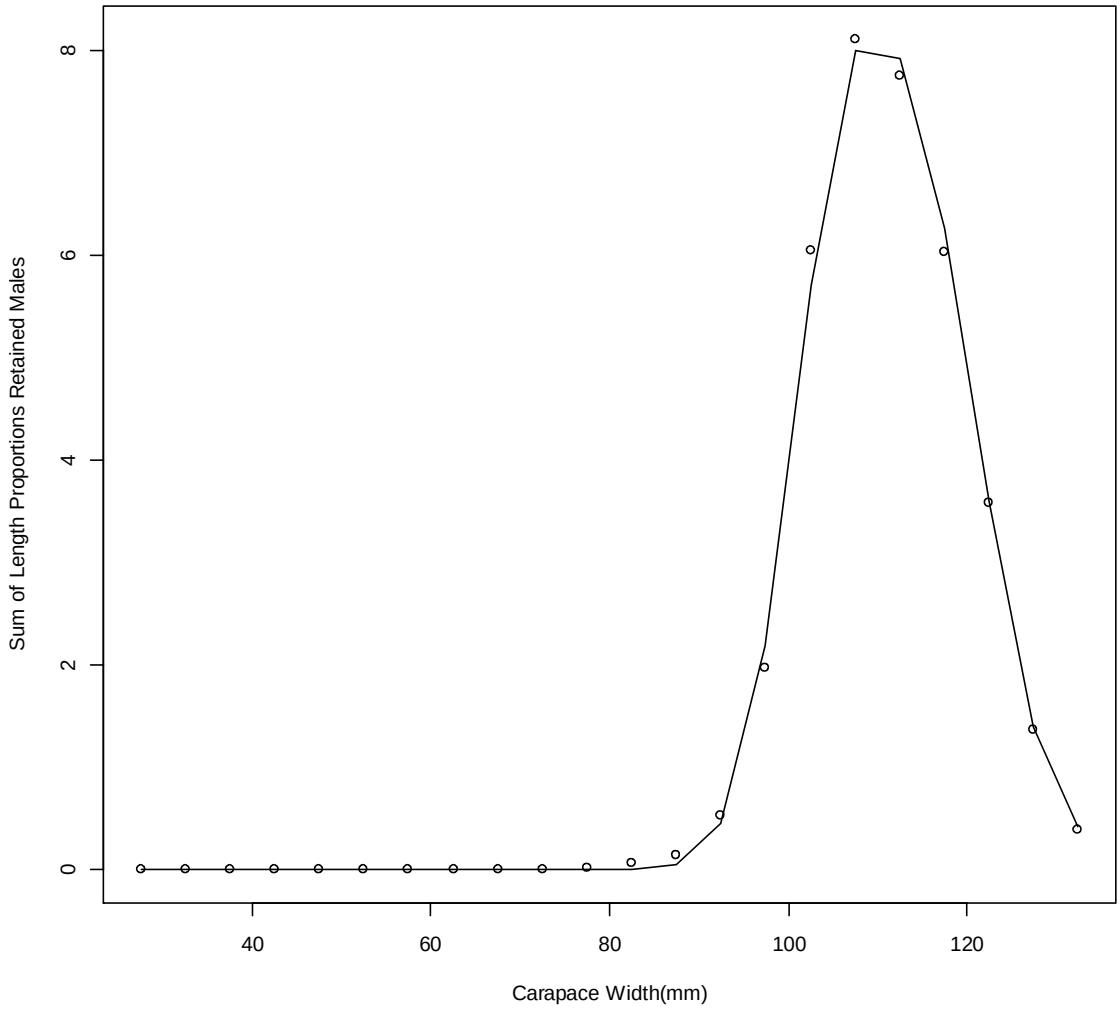
Sum of Length Proportions Retained Males
0
2
4
6
8
40
60
80
100
120
Carapace Width(mm)

Figure C-13.

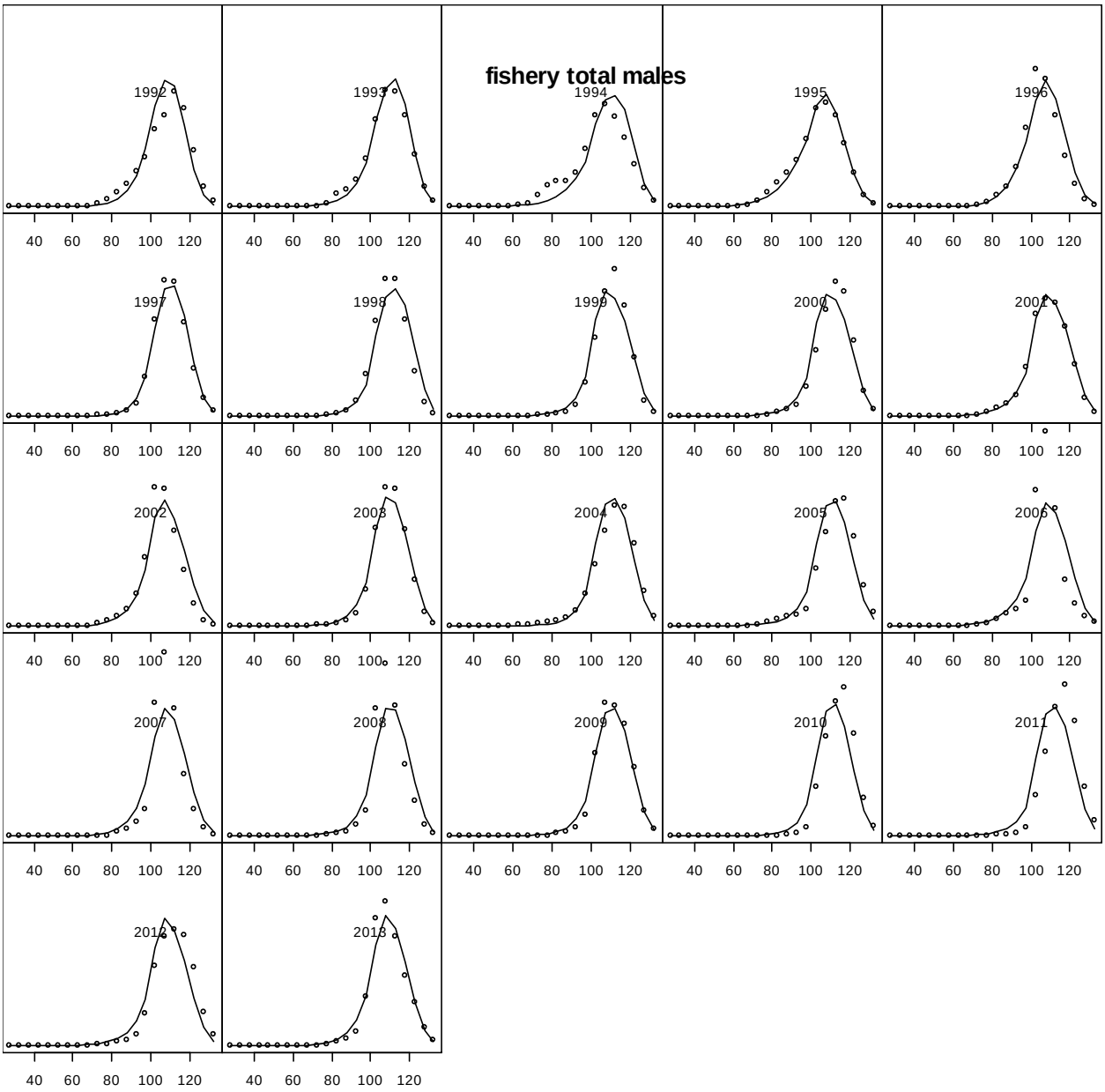
fishery total males
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40 60 80 100 120

Figure C-14.

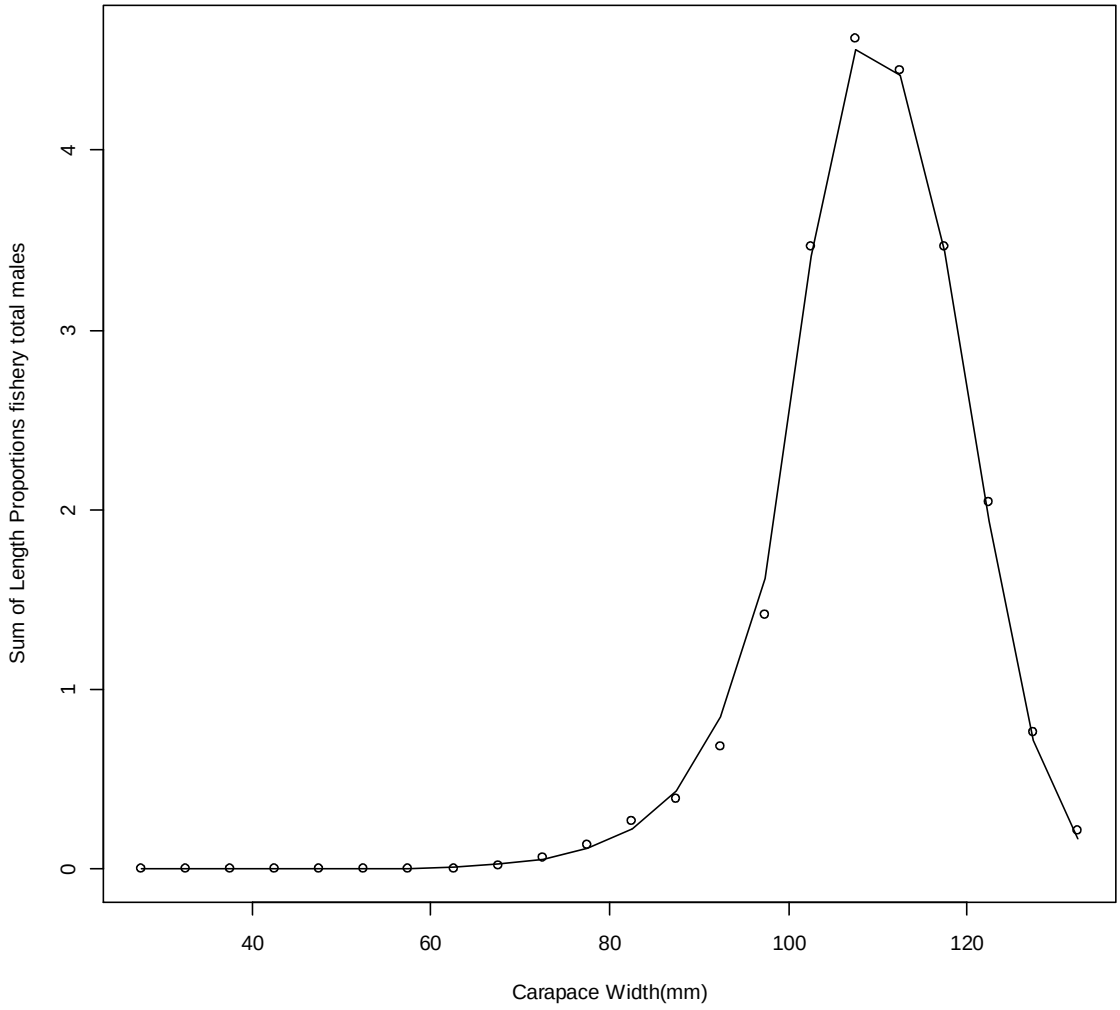
Sum of Length Proportions fishery total males
0
1
2
3
4
40
60
80
100
120
Carapace Width(mm)

Figure C-15.

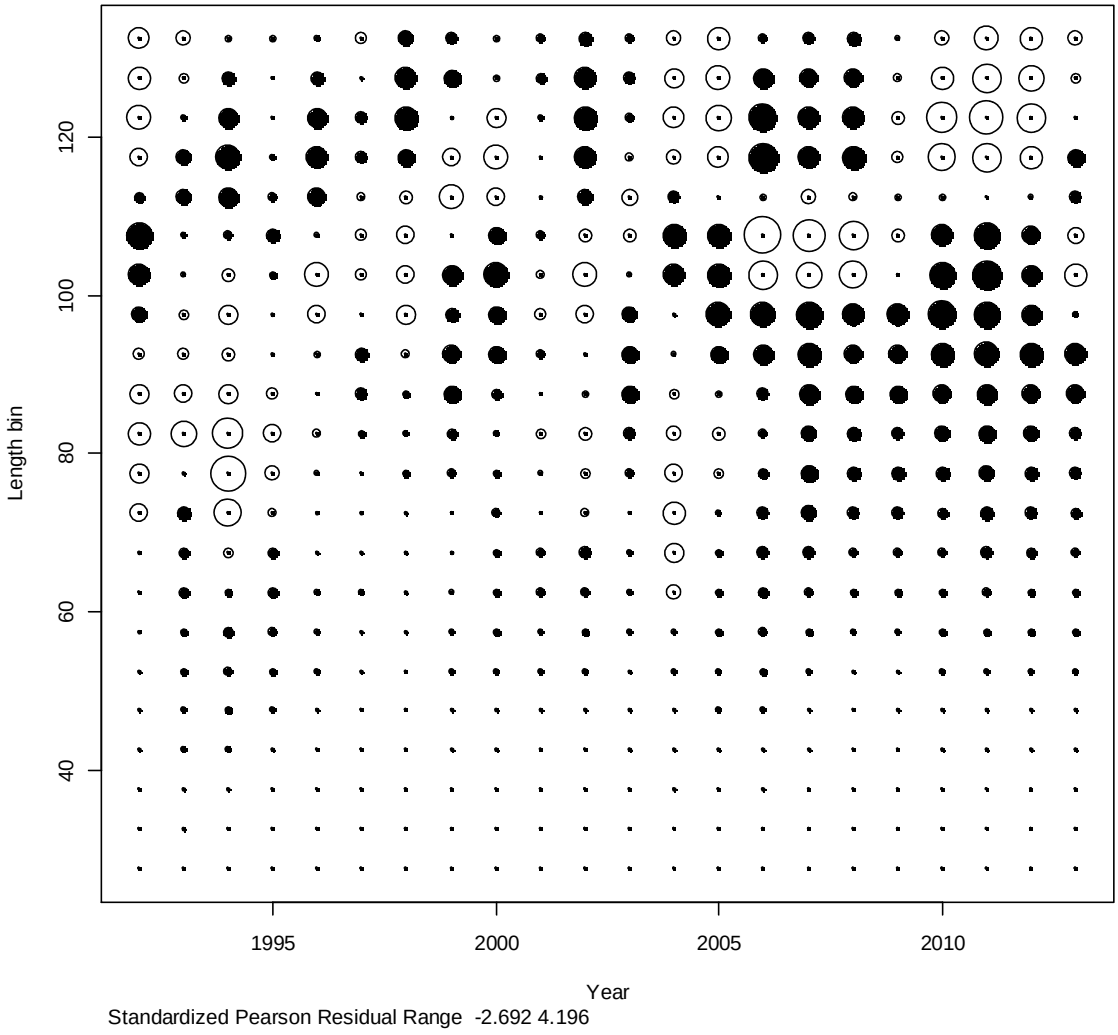
Length bin
120
100
80
60
40
1995
2000
2005
2010
Year
Standardized Pearson Residual Range -2.692 4.196

Figure C-16.

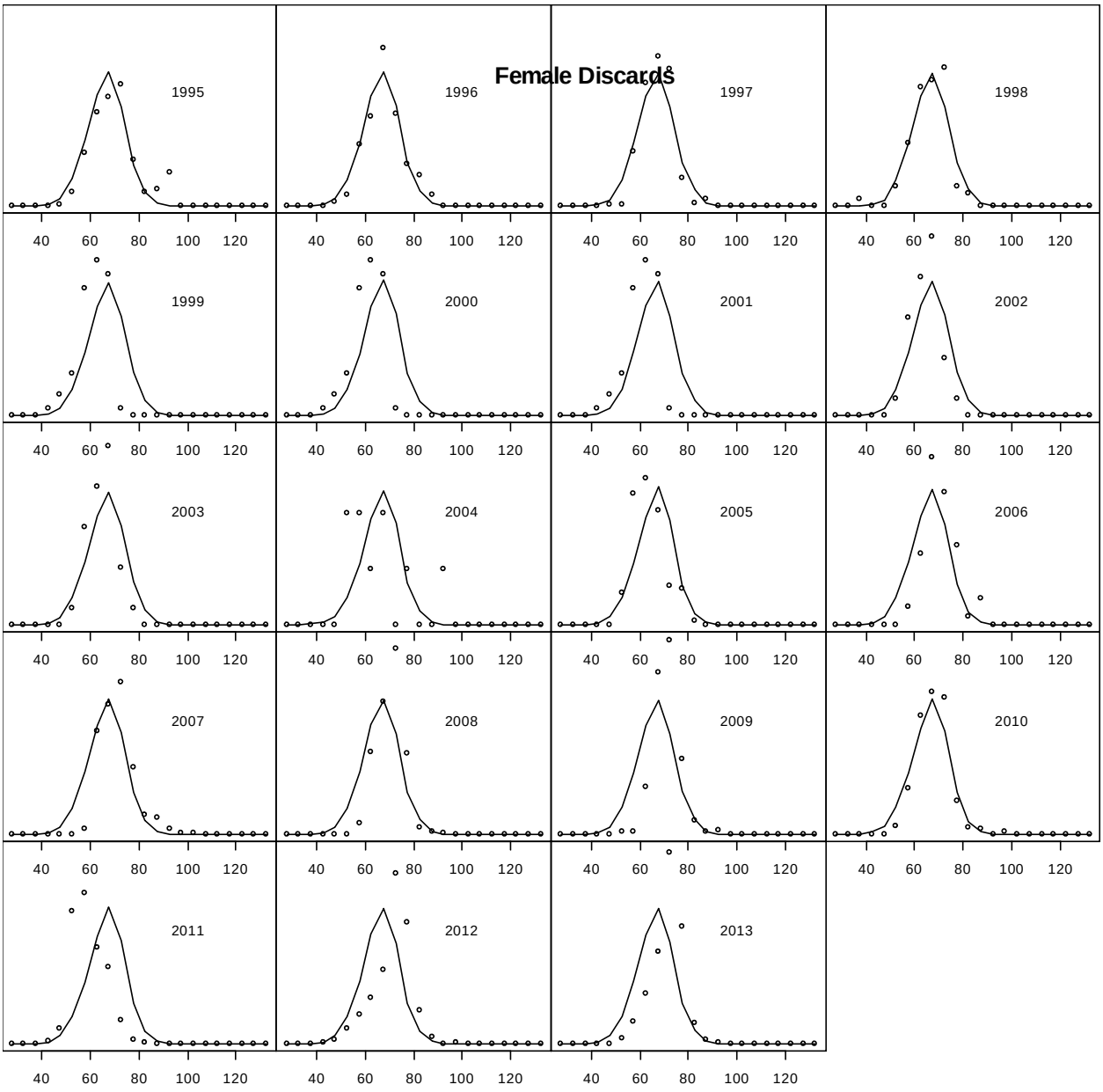
Female Discards
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40
60
80
100
120

Figure C-17.

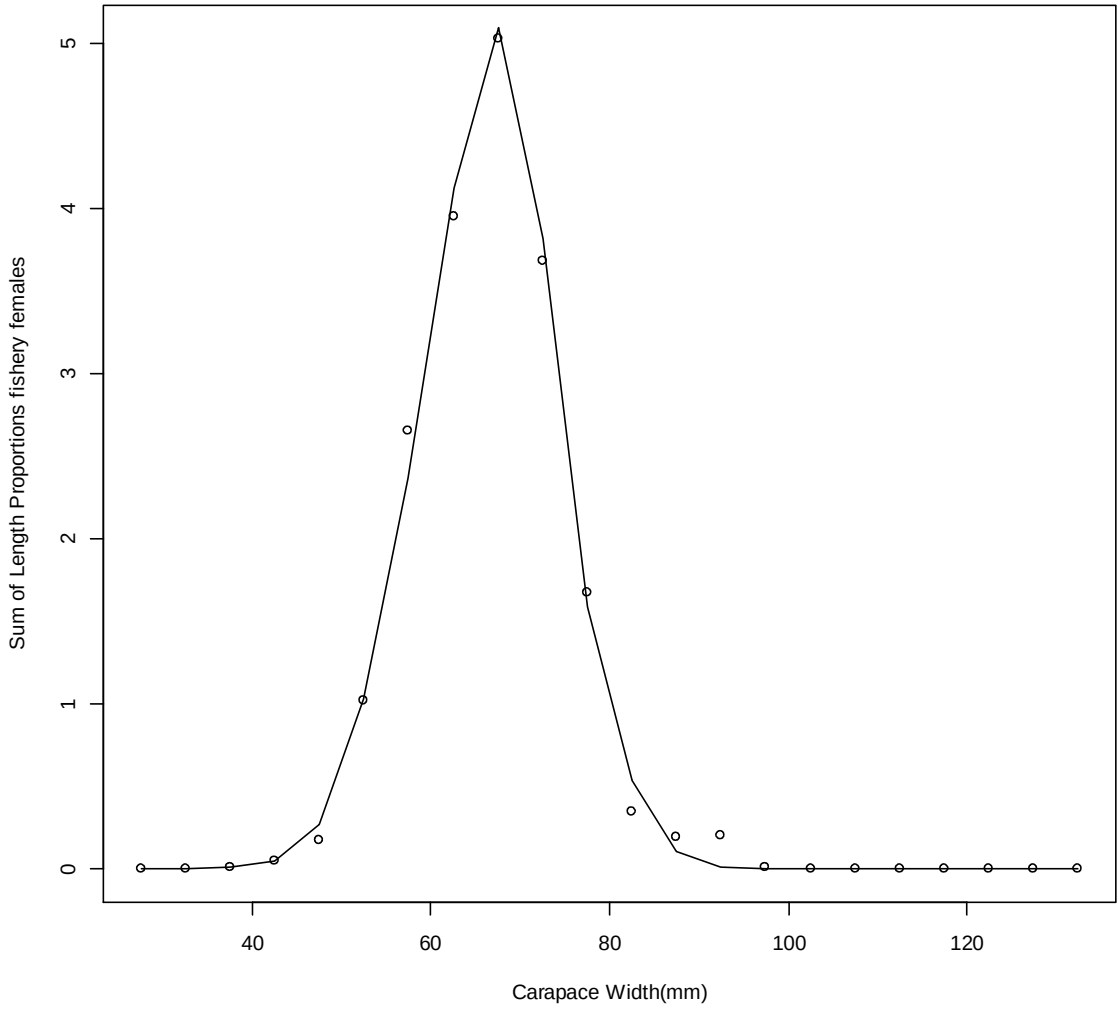
Sum of Length Proportions fishery females
0
1
2
3
4
5
40
60
80
100
120
Carapace Width(mm)

Figure C-18.

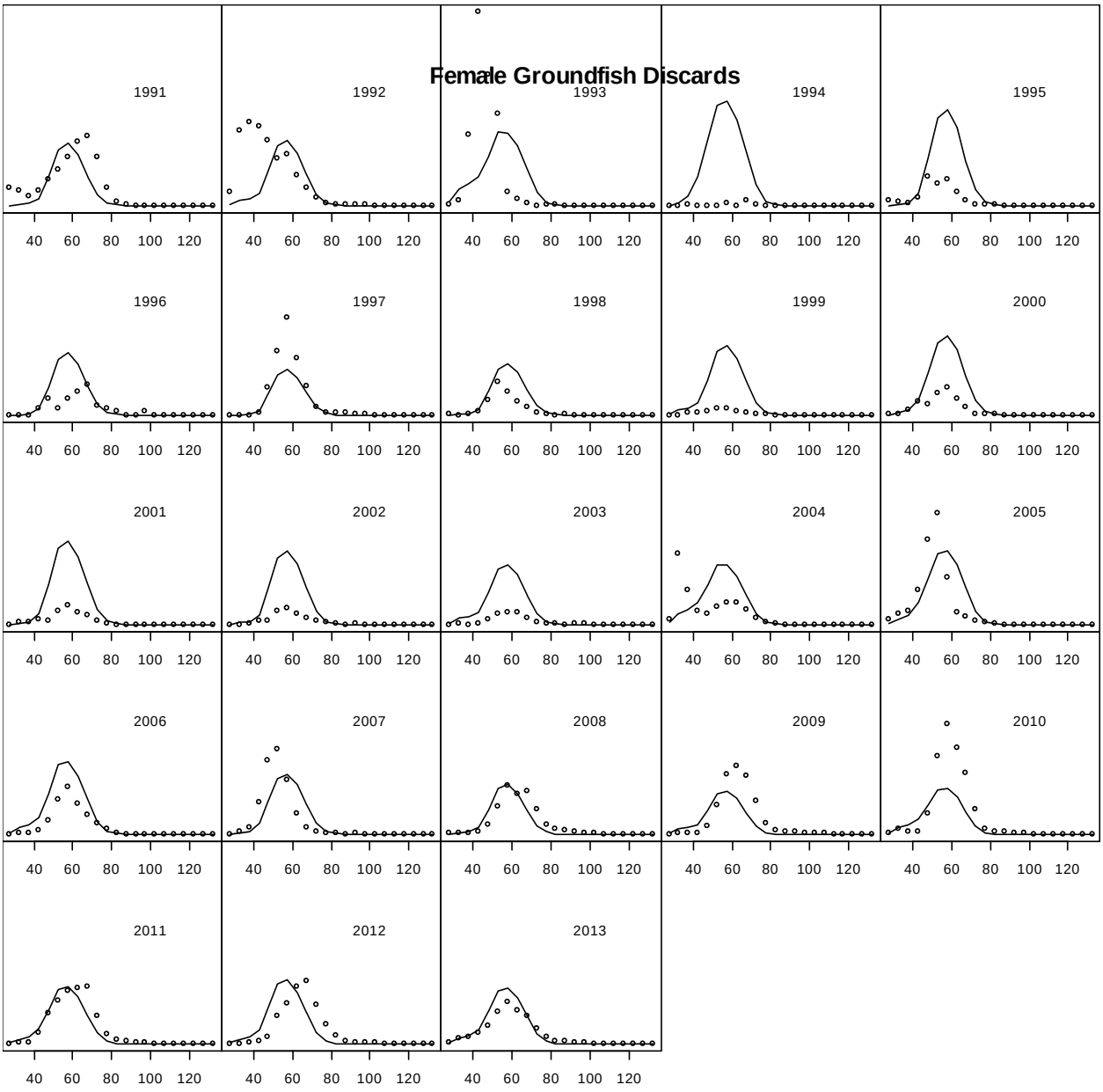
Female Groundfish Discards
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40 60 80 100 120

Figure C-19.

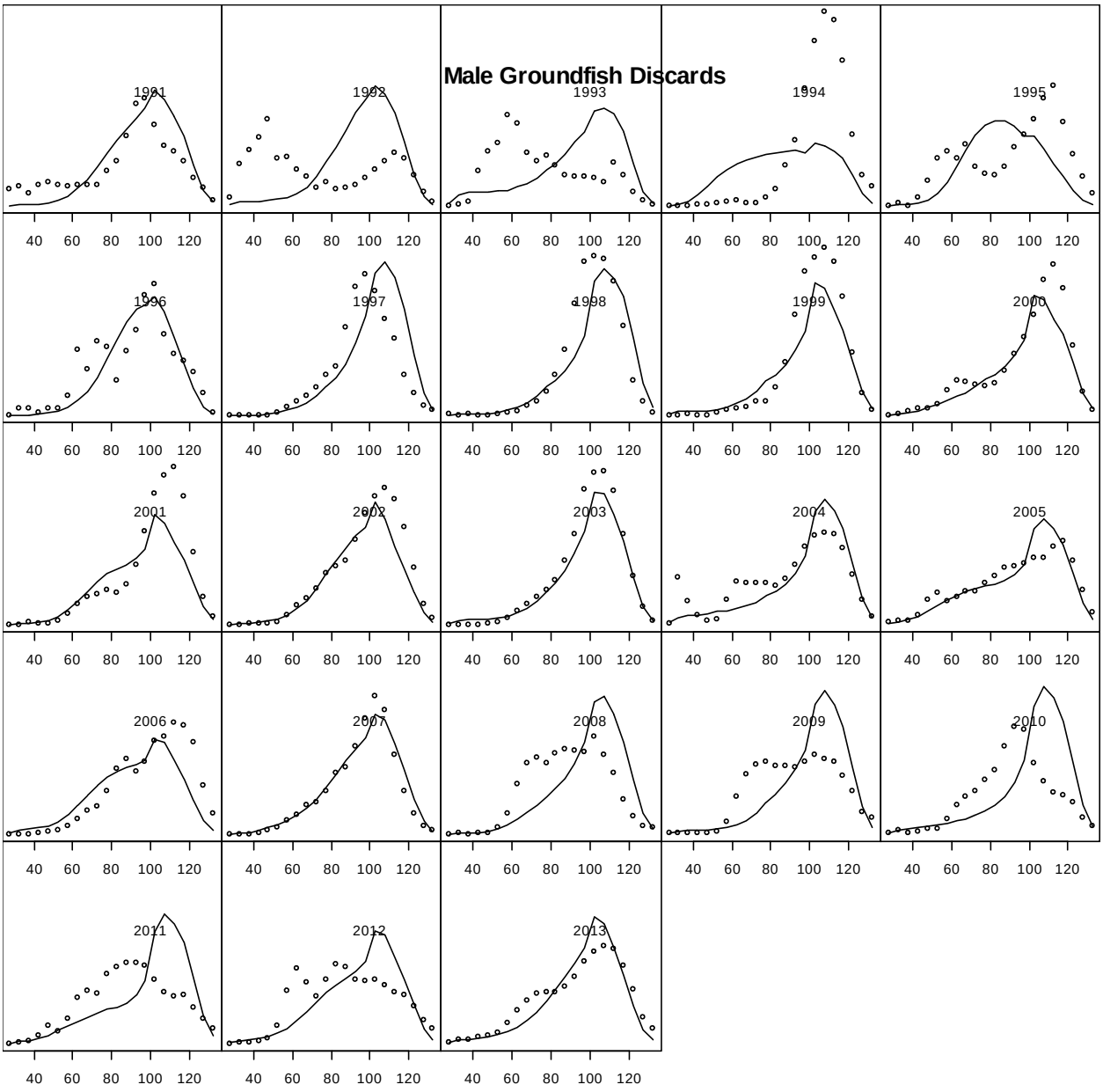
Male Groundfish Discards
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40 60 80 100 120

Figure C-20.

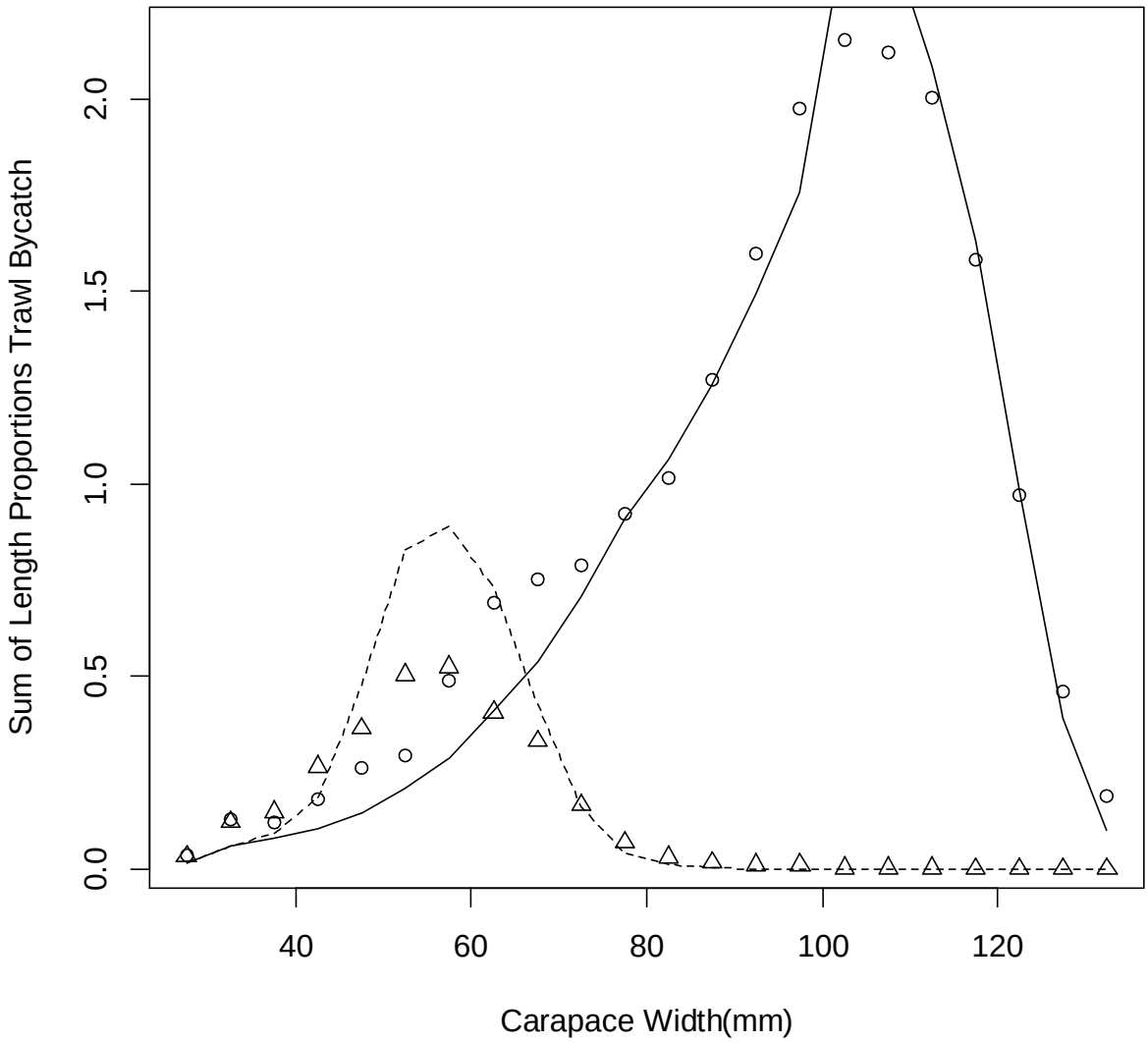
Sum of Length Proportions Trawl Bycatch
0.0
0.5
1.0
1.5
2.0
40
60
80
100
120
Carapace Width(mm)

Figure C-21.

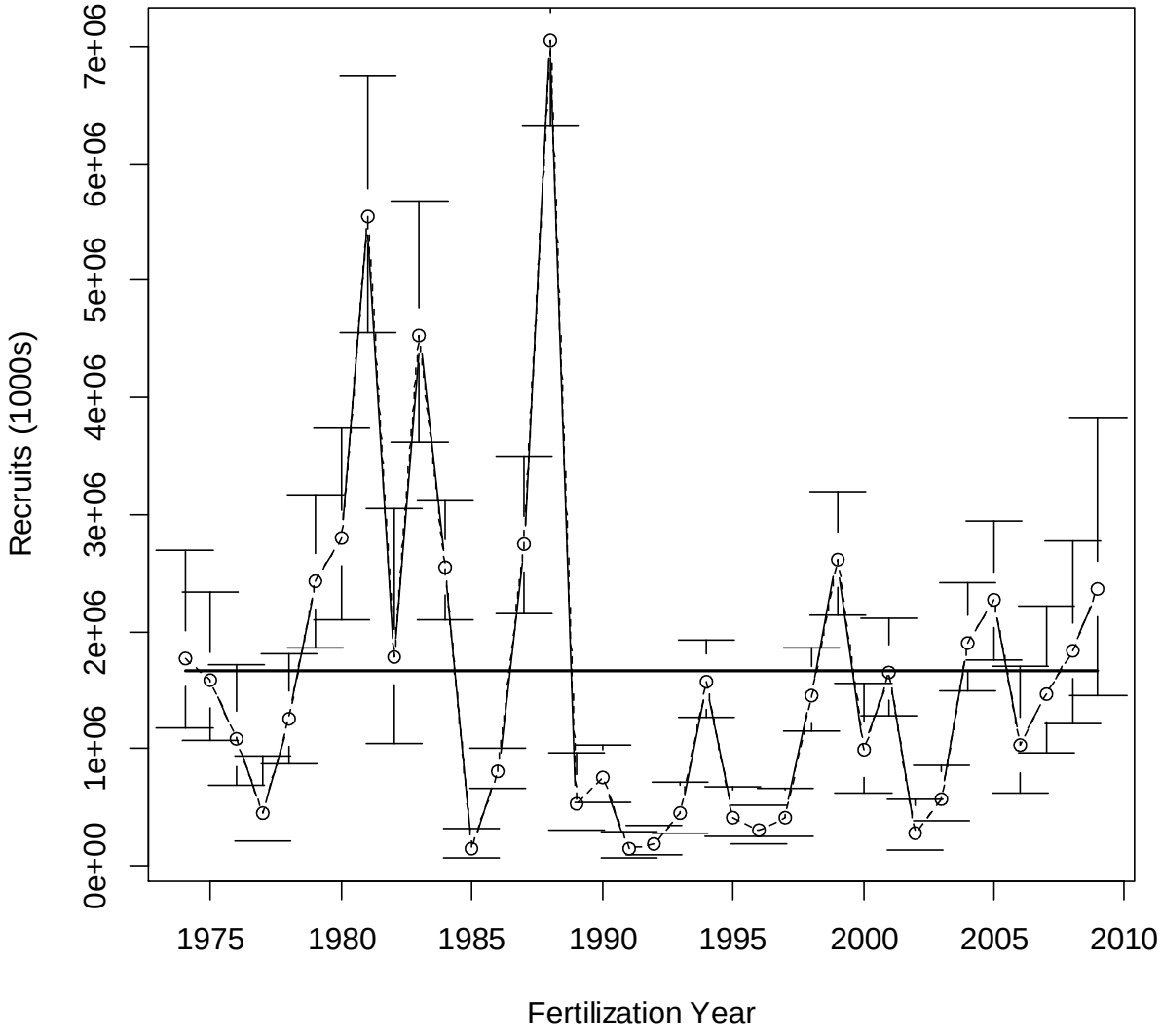
Recruits (1000s)
0e+00
1e+06
2e+06
3e+06
4e+06
5e+06
6e+06
7e+06
1975
1980
1985
1990
1995
2000
2005
2010
Fertilization Year

Figure C-22.

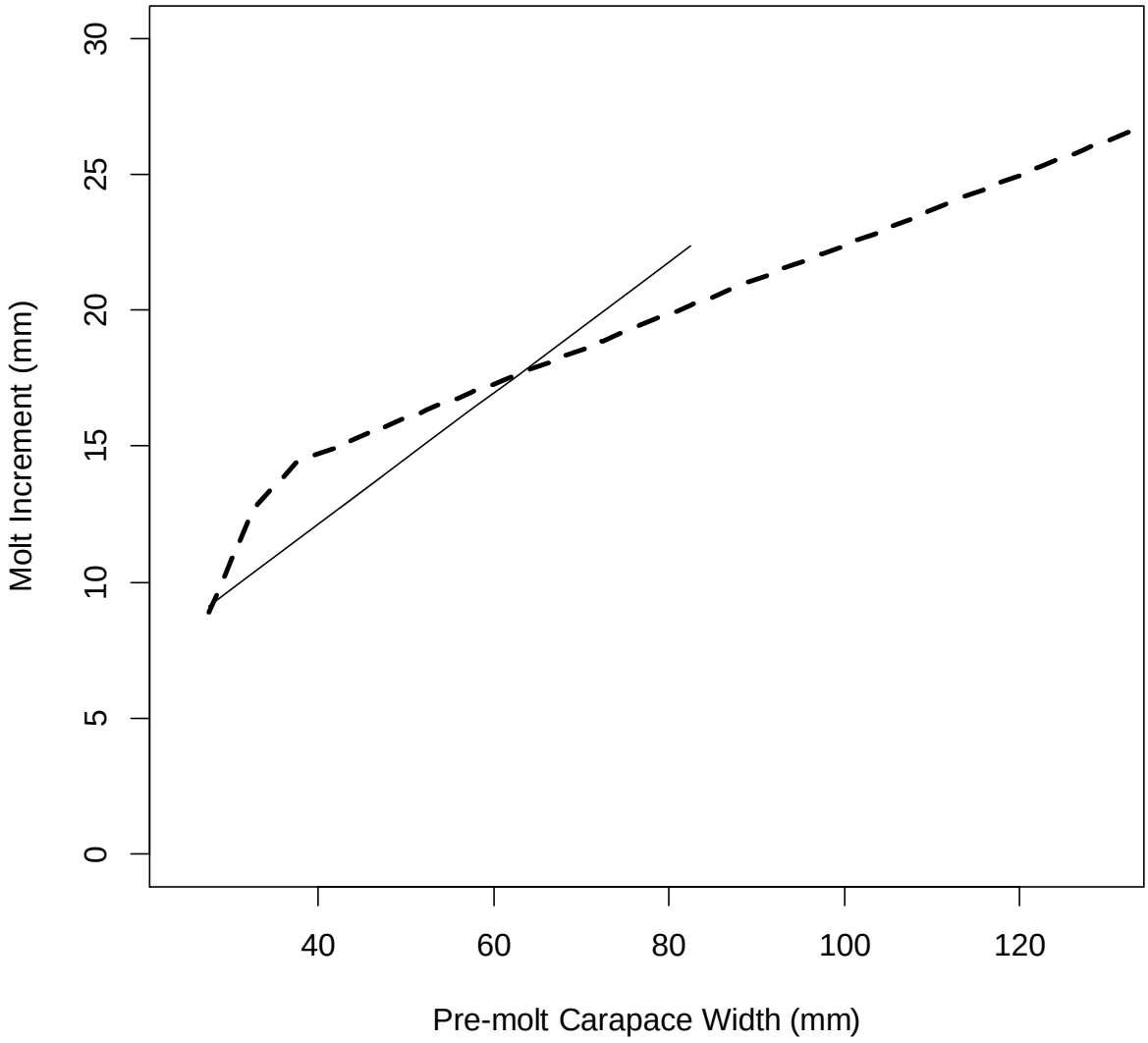
Molt Increment (mm)
0
5
10
15
20
25
30
40
60
80
100
120
Pre-molt Carapace Width (mm)

Figure C-23.

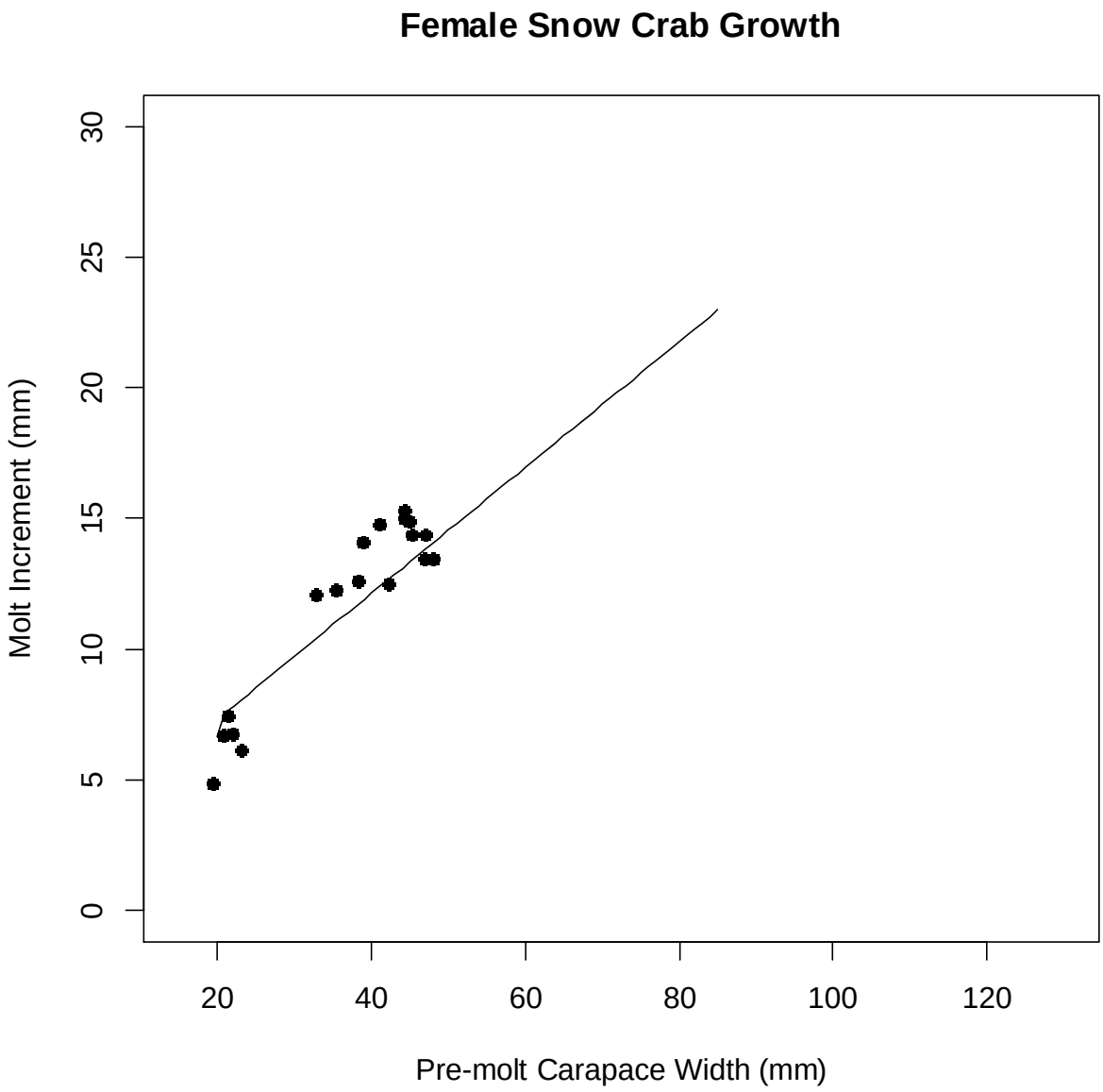
Female Snow Crab Growth
Molt Increment (mm)
0
5
10
15
20
25
30
20
40
60
80
100
120
Pre-molt Carapace Width (mm)

Figure C-24.

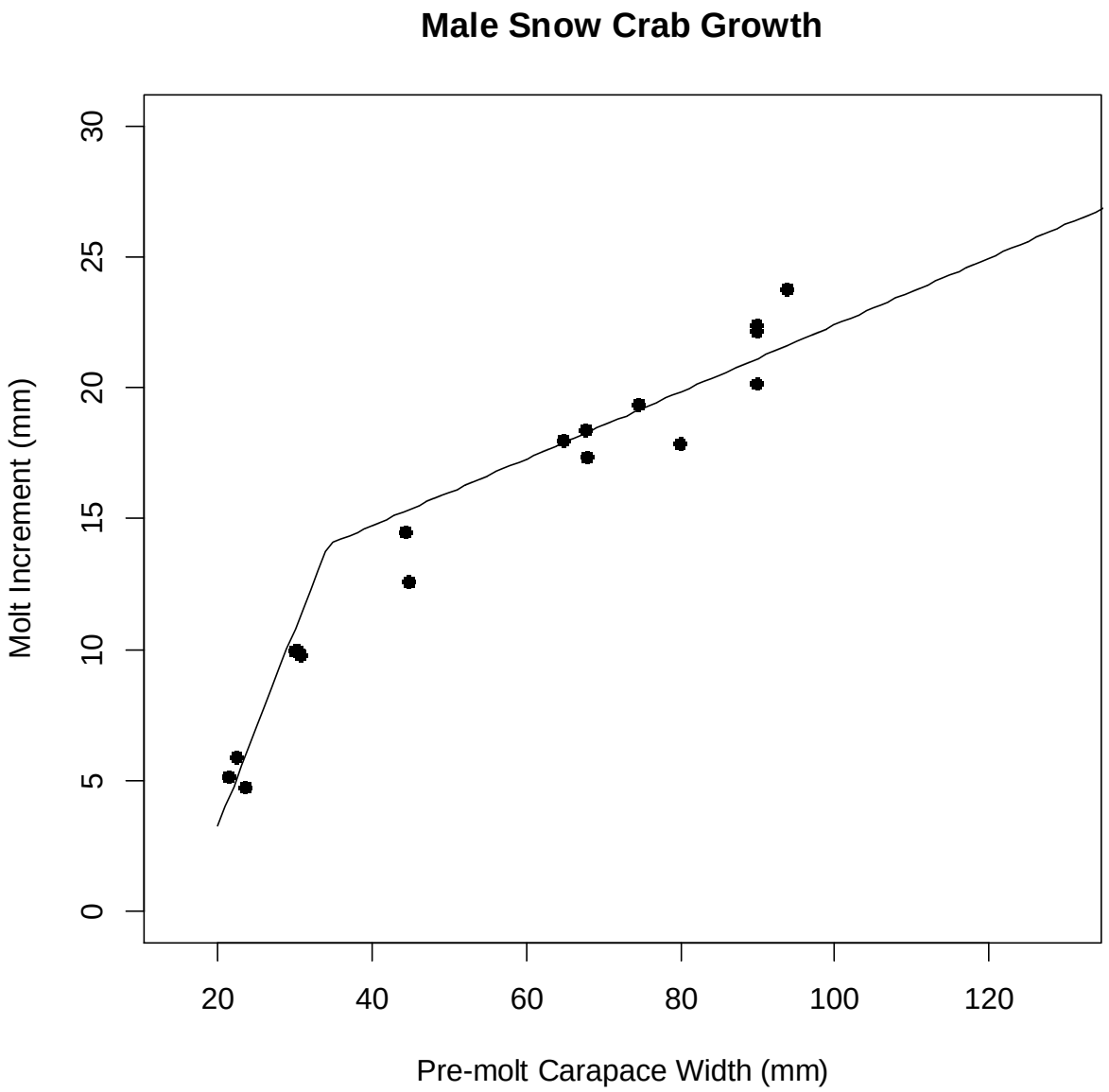
Male Snow Crab Growth
Molt Increment (mm)
0
5
10
15
20
25
30
20
40
60
80
100
120
Pre-molt Carapace Width (mm)

Figure C-25.

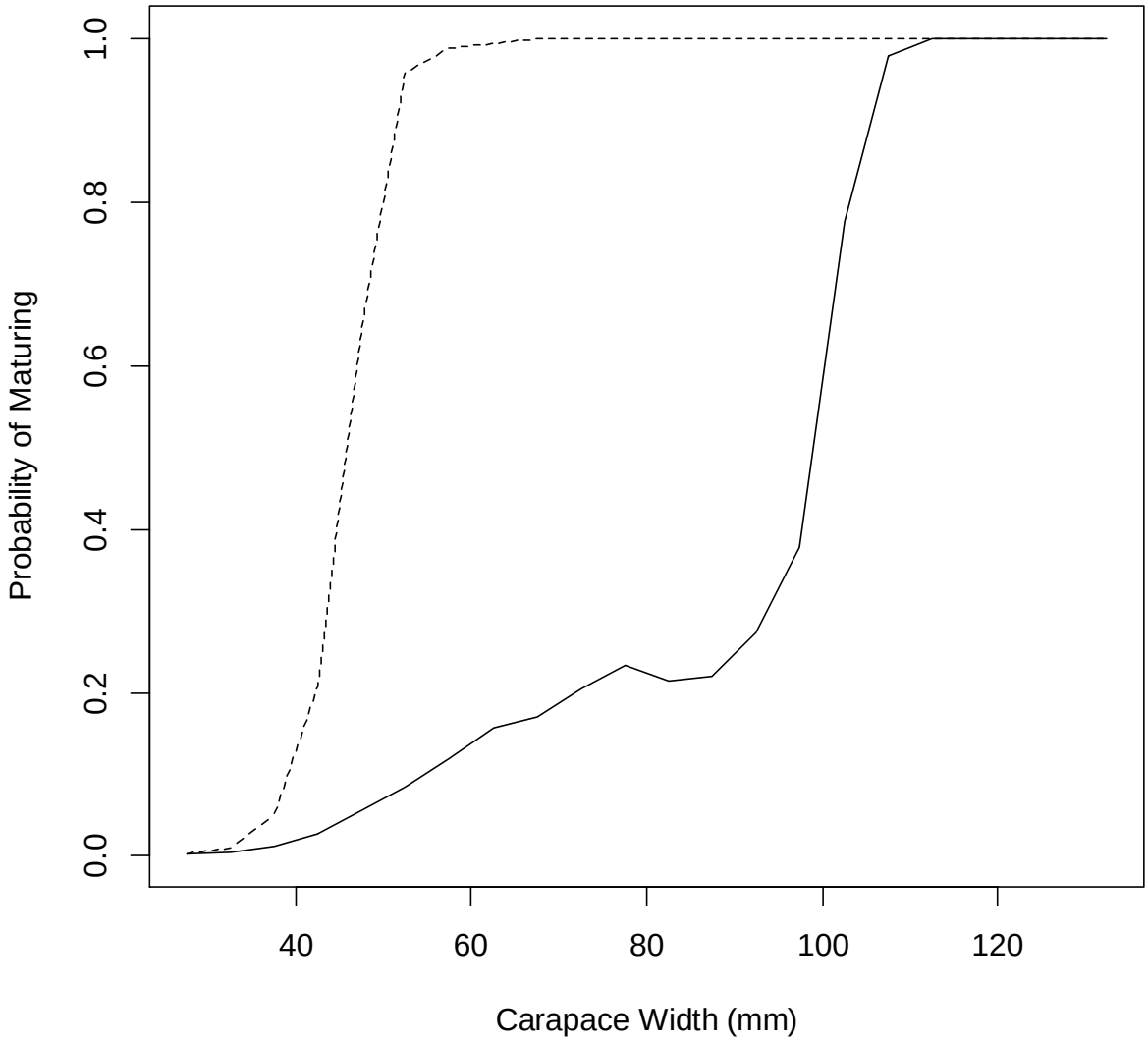
Probability of Maturing
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
Carapace Width (mm)

Figure C-26.

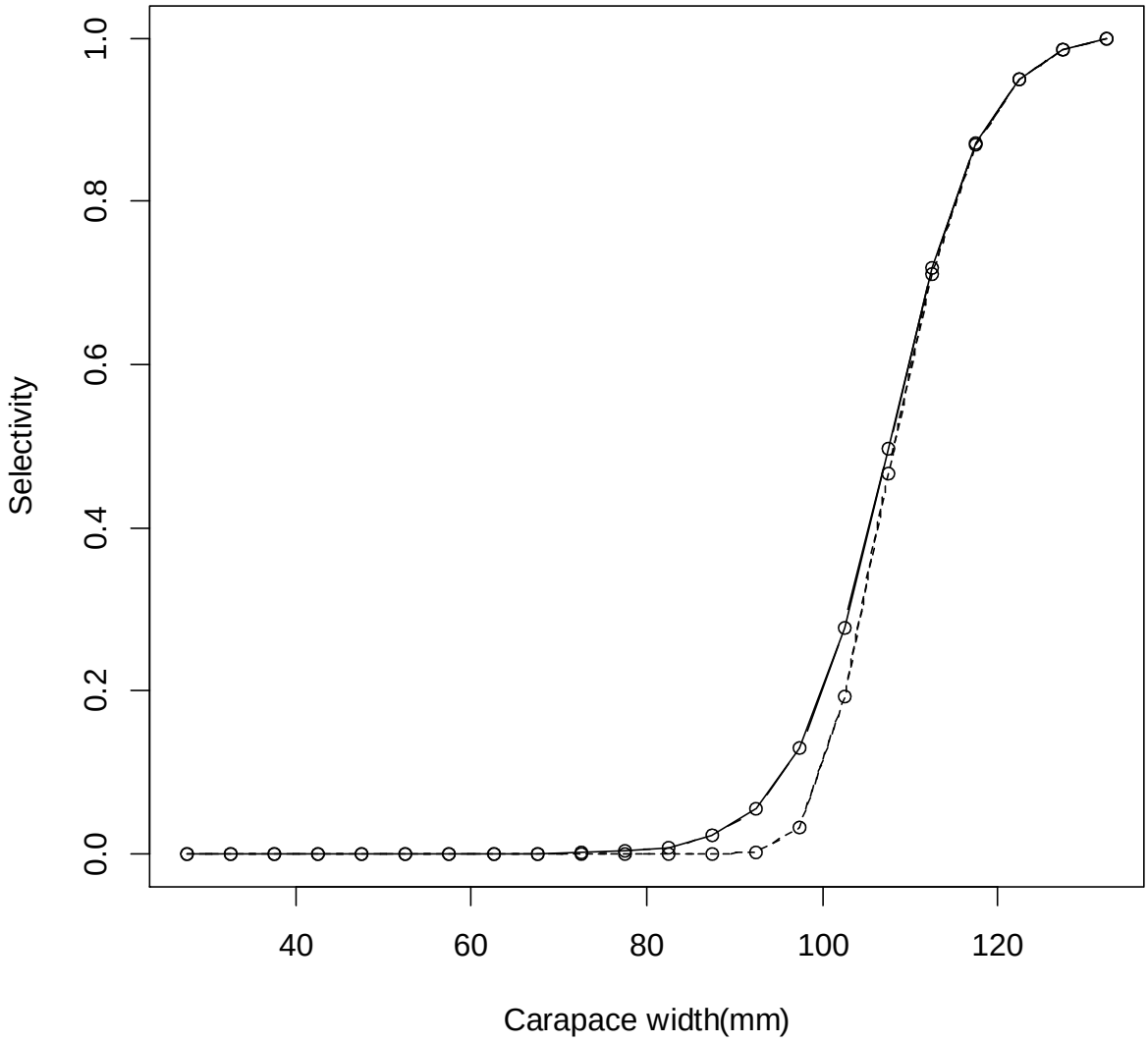
Selectivity
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
Carapace width(mm)

Figure C-27.

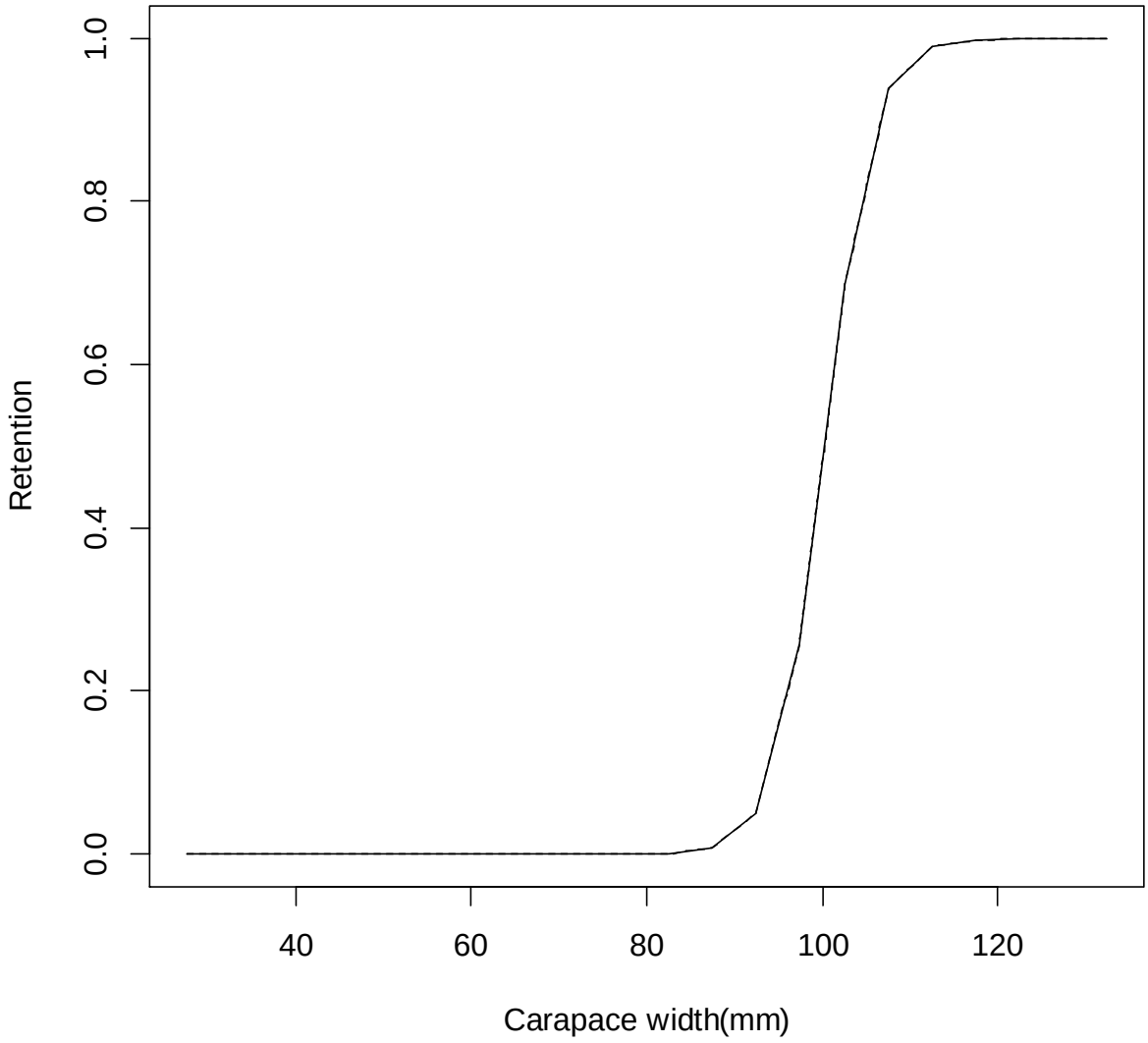

Figure C-28.

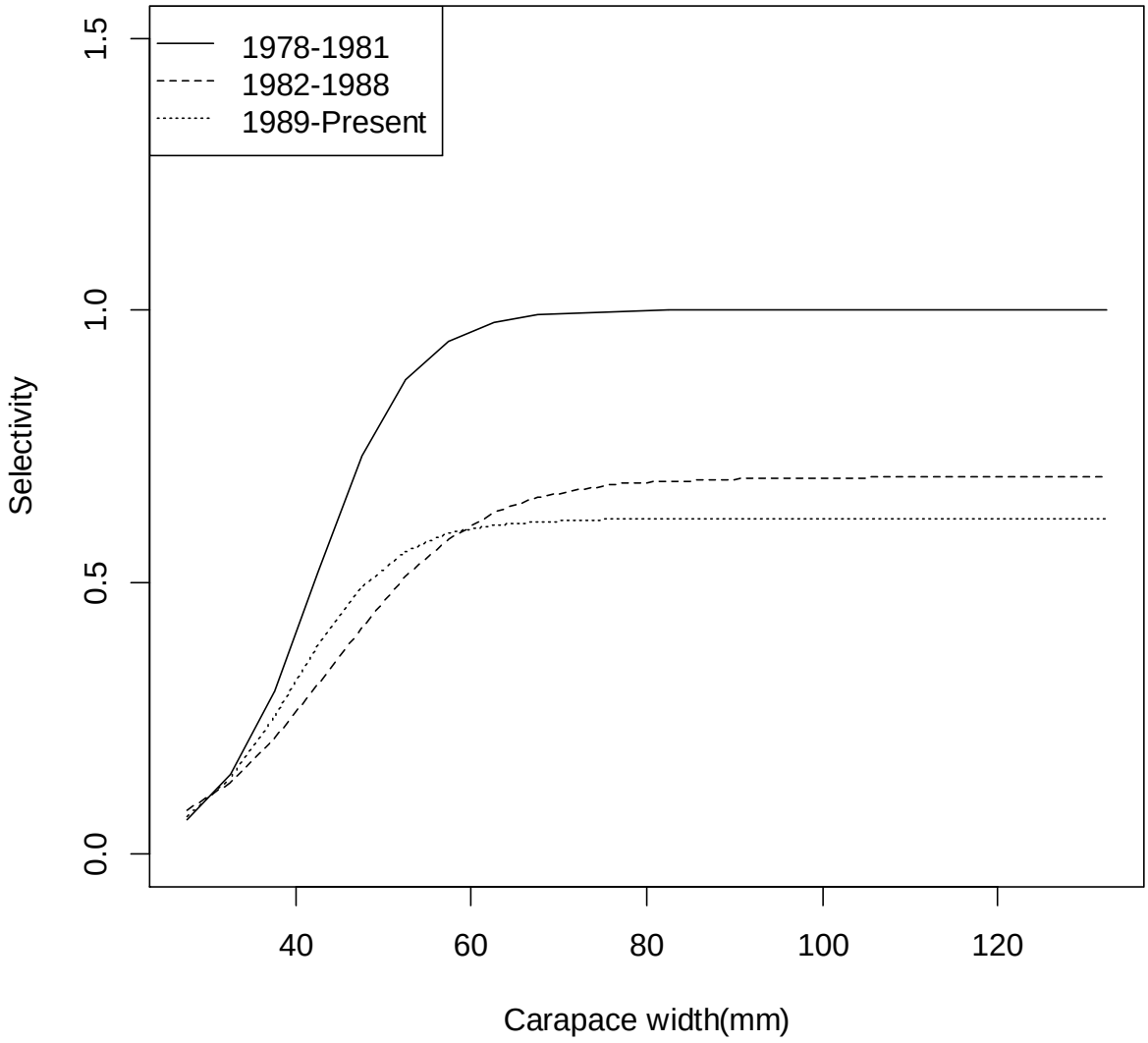
1978-1981
1982-1988
1989-Present
Selectivity
0.0
0.5
1.0
1.5
40
60
80
100
120
Carapace width(mm)

Figure C-29.

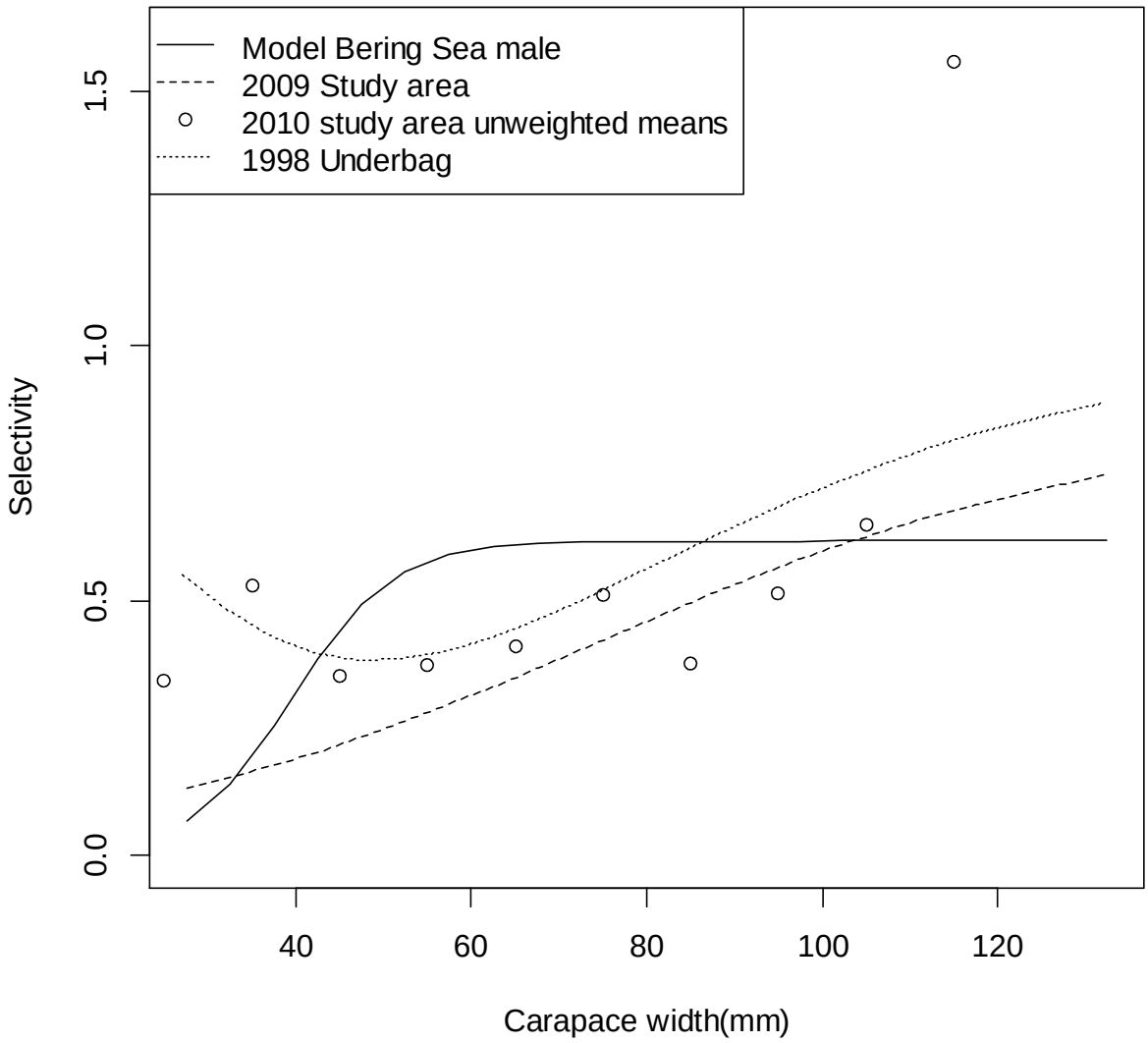
Model Bering Sea male
2009 Study area
2010 study area unweighted means
1998 Underbag
Selectivity
0.0
0.5
1.0
1.5
40
60
80
100
120
Carapace width(mm)

Figure C-30.

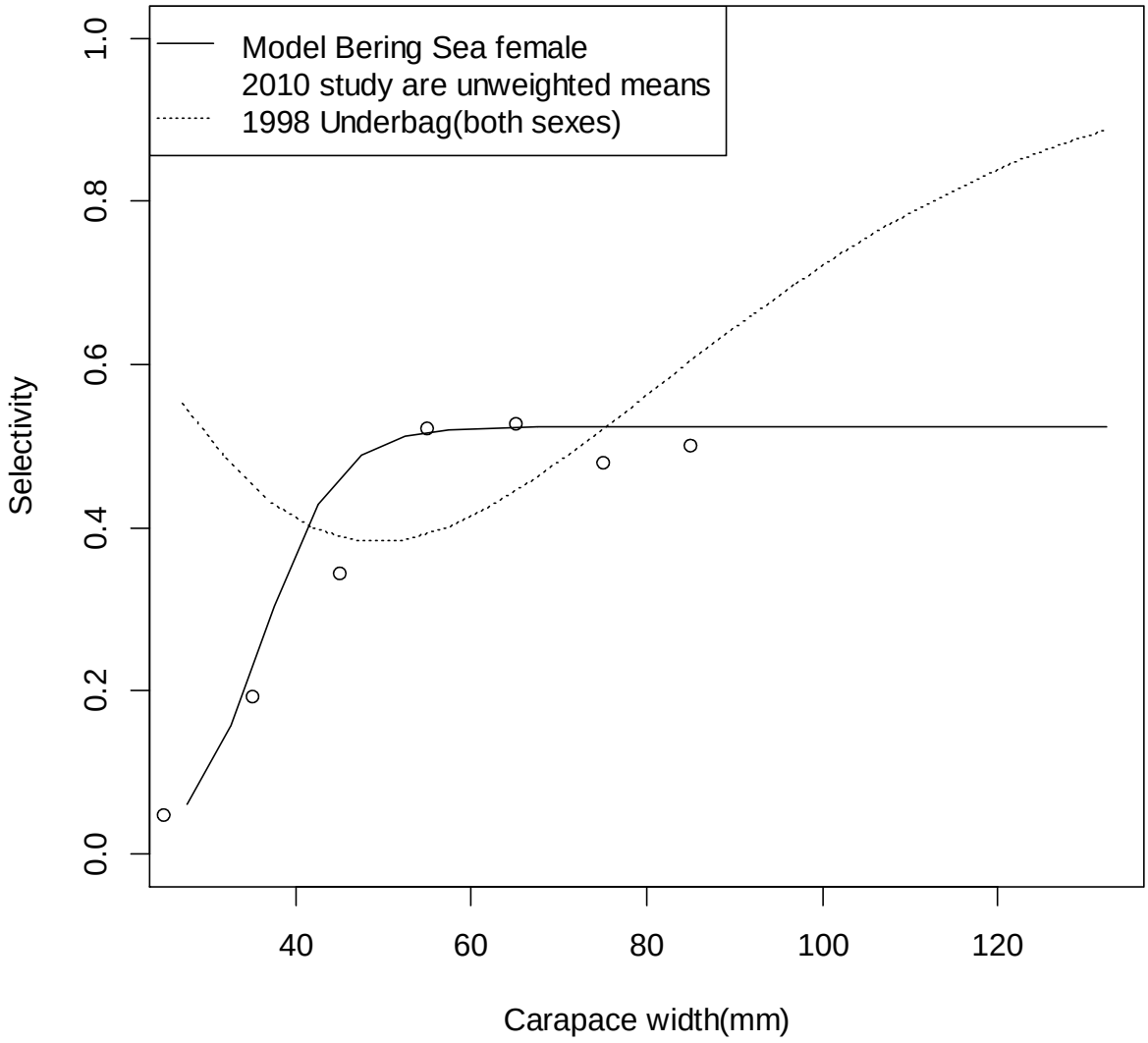
Model Bering Sea female
2010 study are unweighted means
1998 Underbag(both sexes)
Selectivity
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
Carapace width(mm)

Figure C-31.

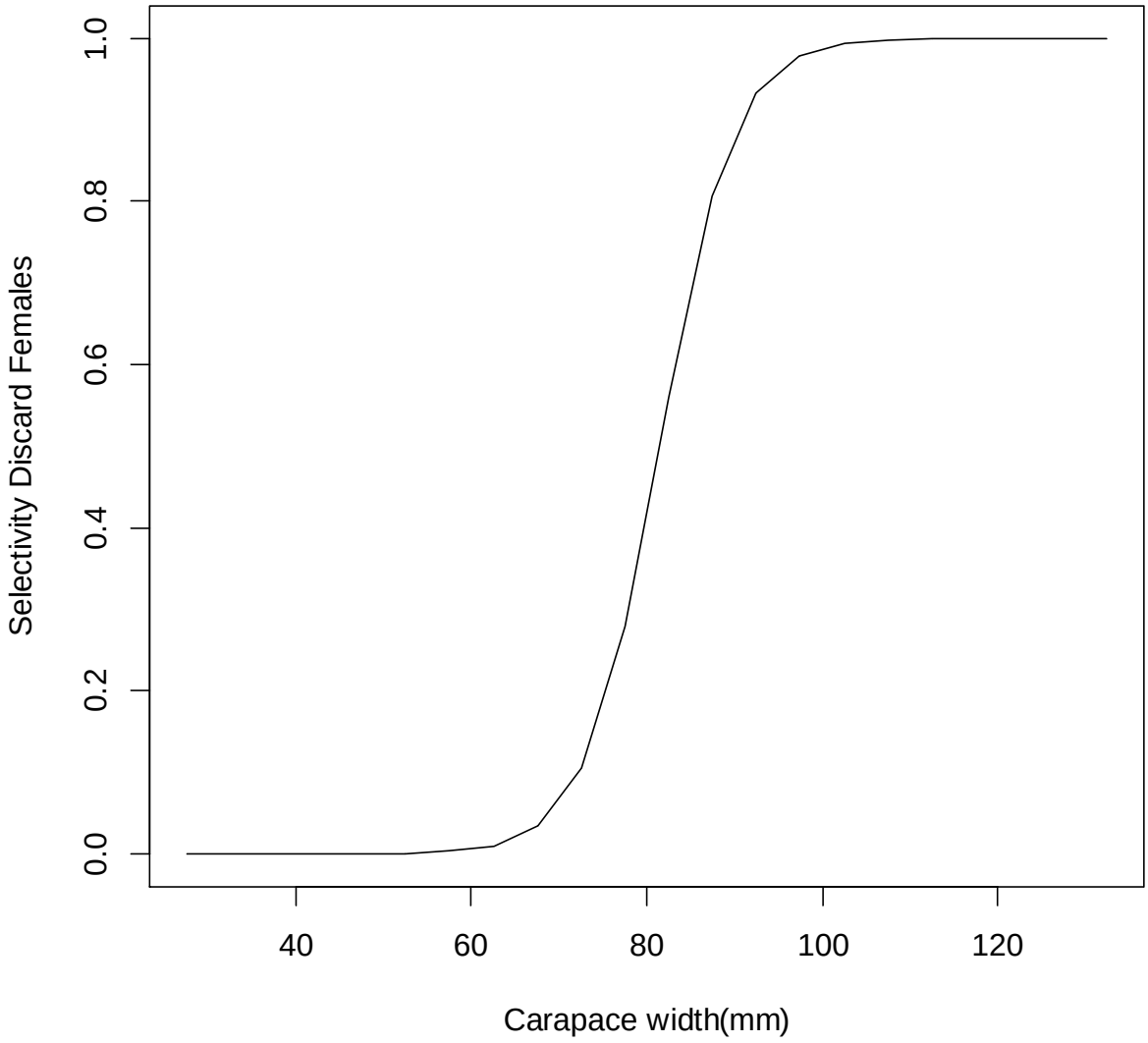
Selectivity Discard Females
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
Carapace width(mm)

Figure C-32.

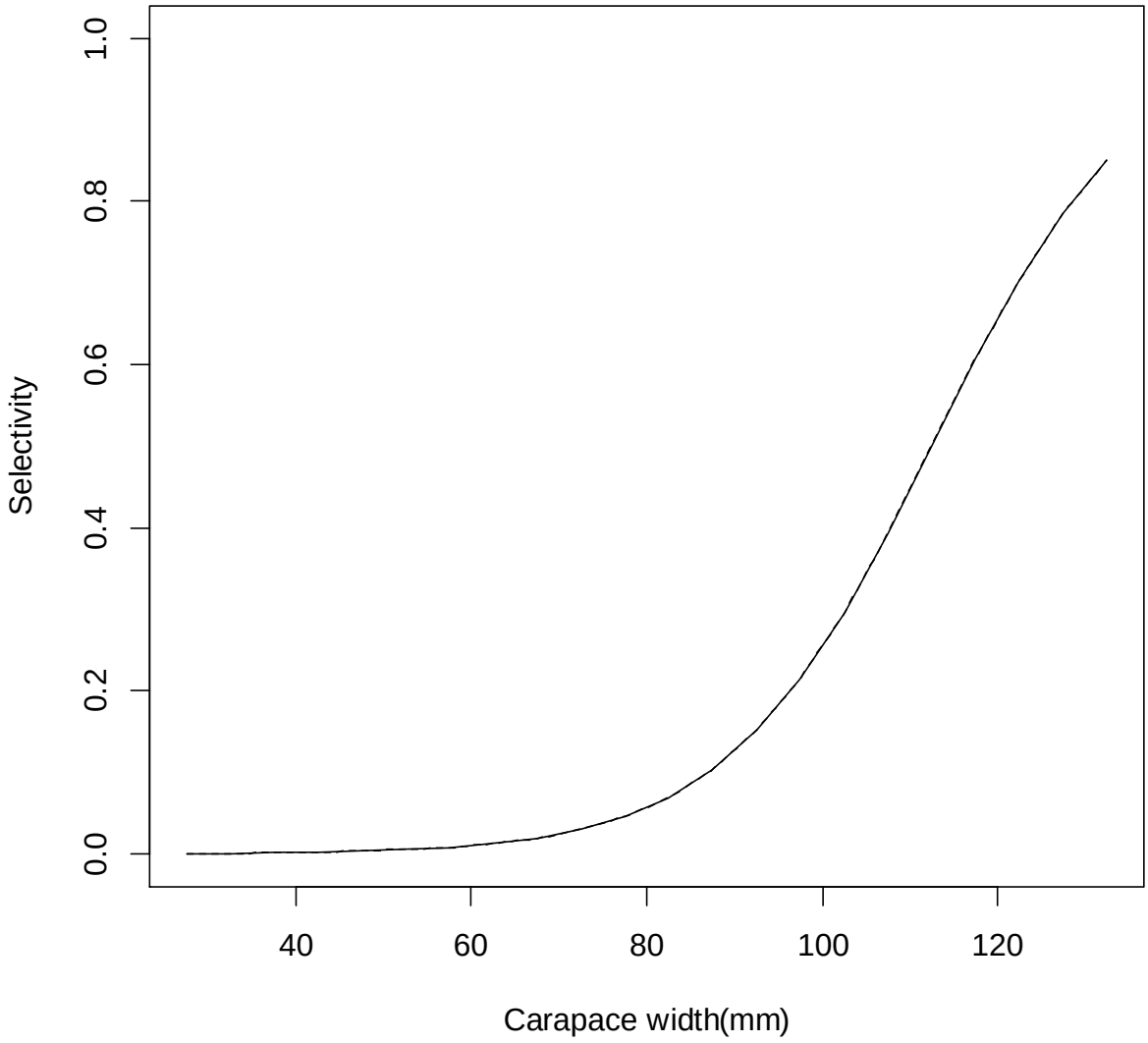
Selectivity
0.0
0.2
0.4
0.6
0.8
1.0
40
60
80
100
120
Carapace width(mm)

Figure C-33.

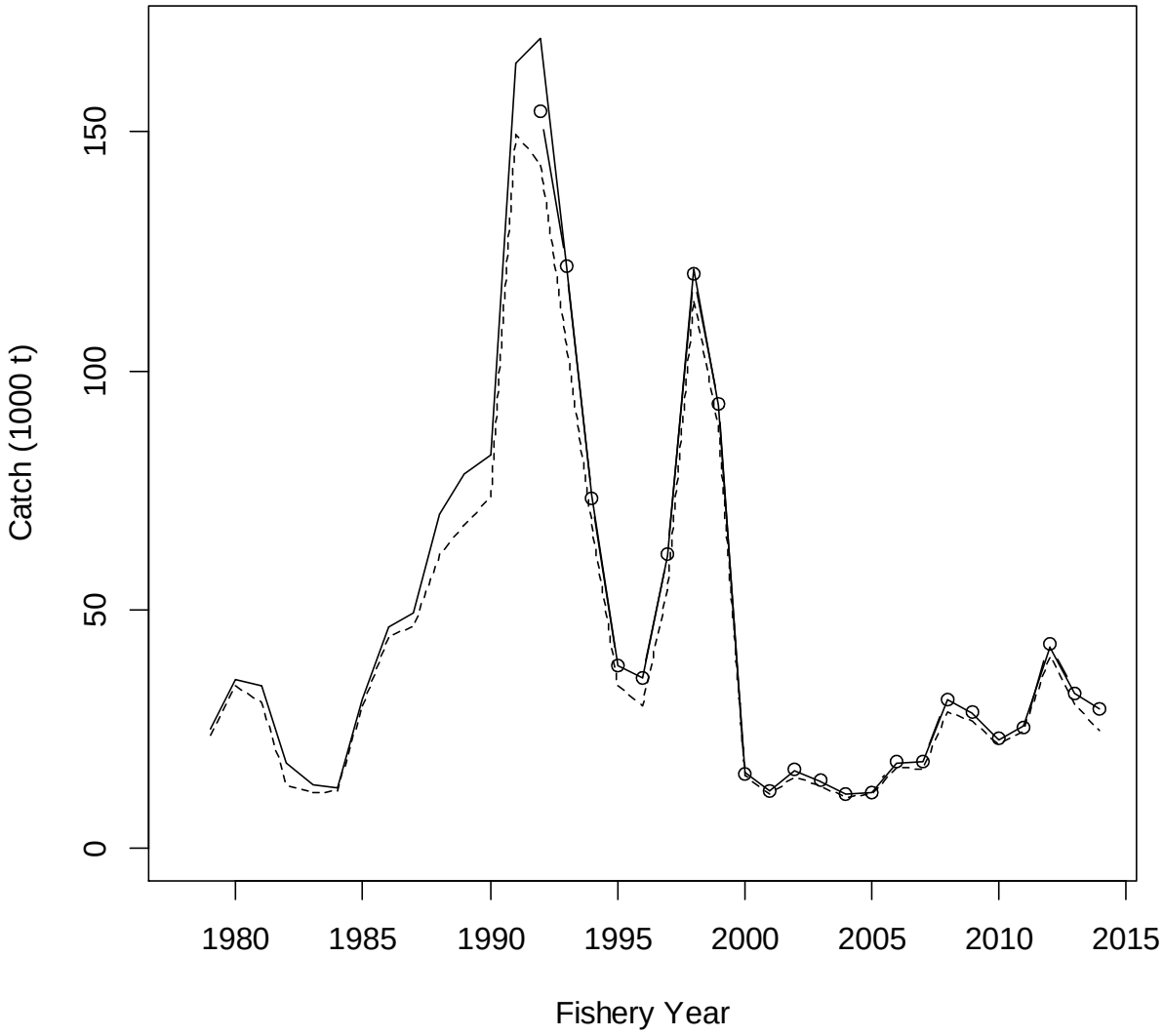
Catch (1000 t)
0
50
100
150
1980
1985
1990
1995
2000
2005
2010
2015
Fishery Year

Figure C-34.

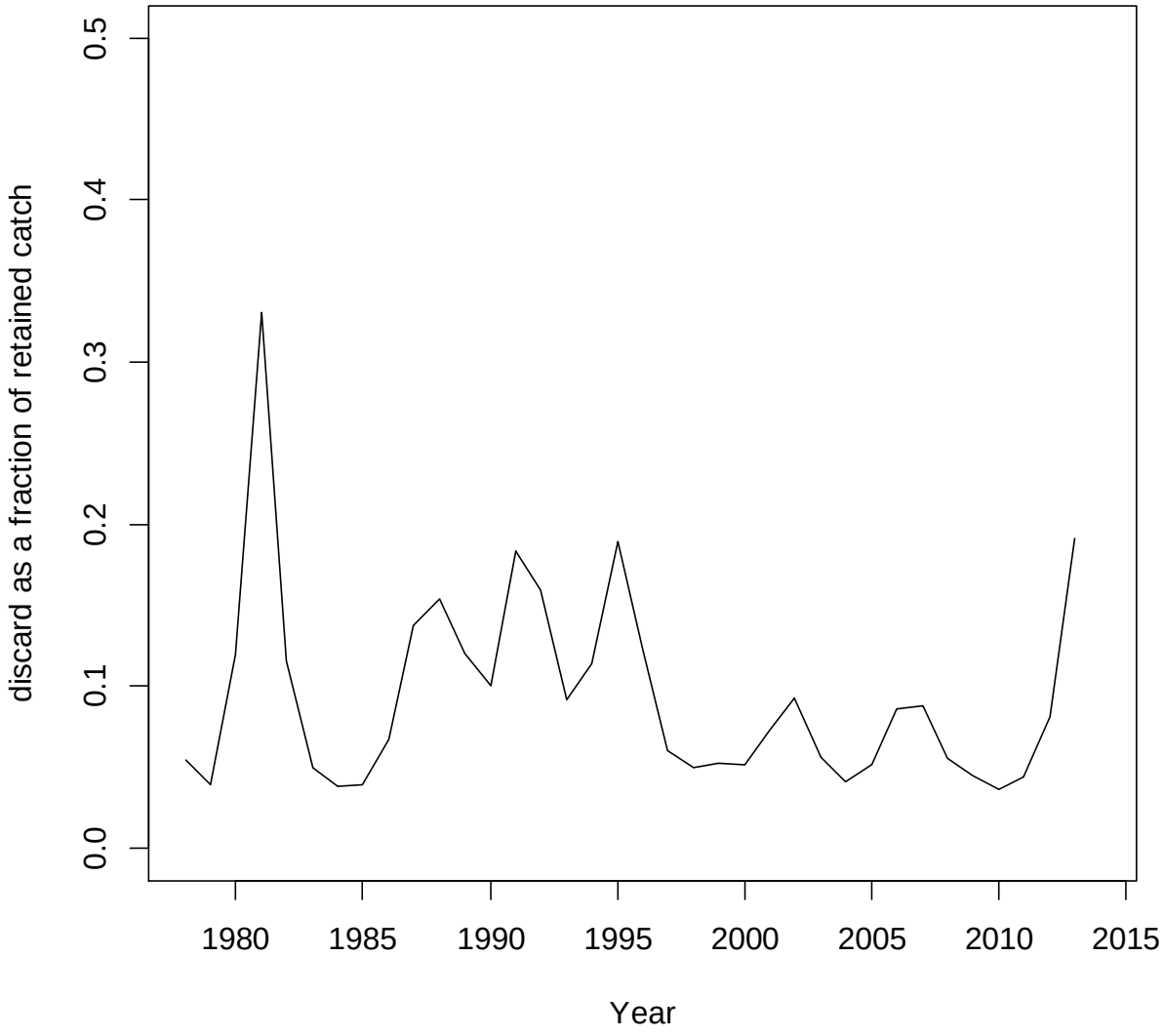
discard as a fraction of retained catch
0.0
0.1
0.2
0.3
0.4
0.5
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure C-35.

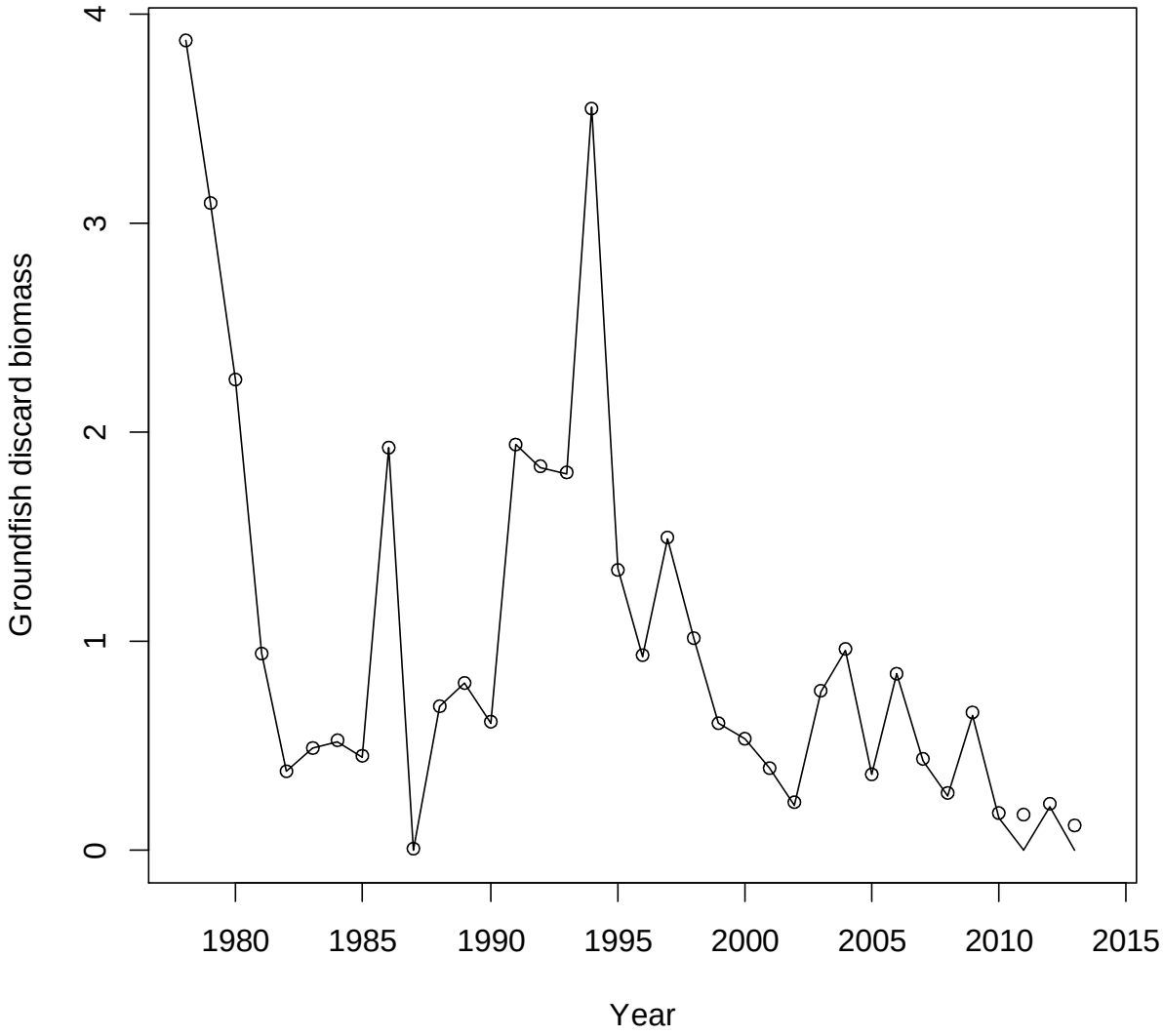
Groundfish discard biomass
0
1
2
3
4
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure C-36.

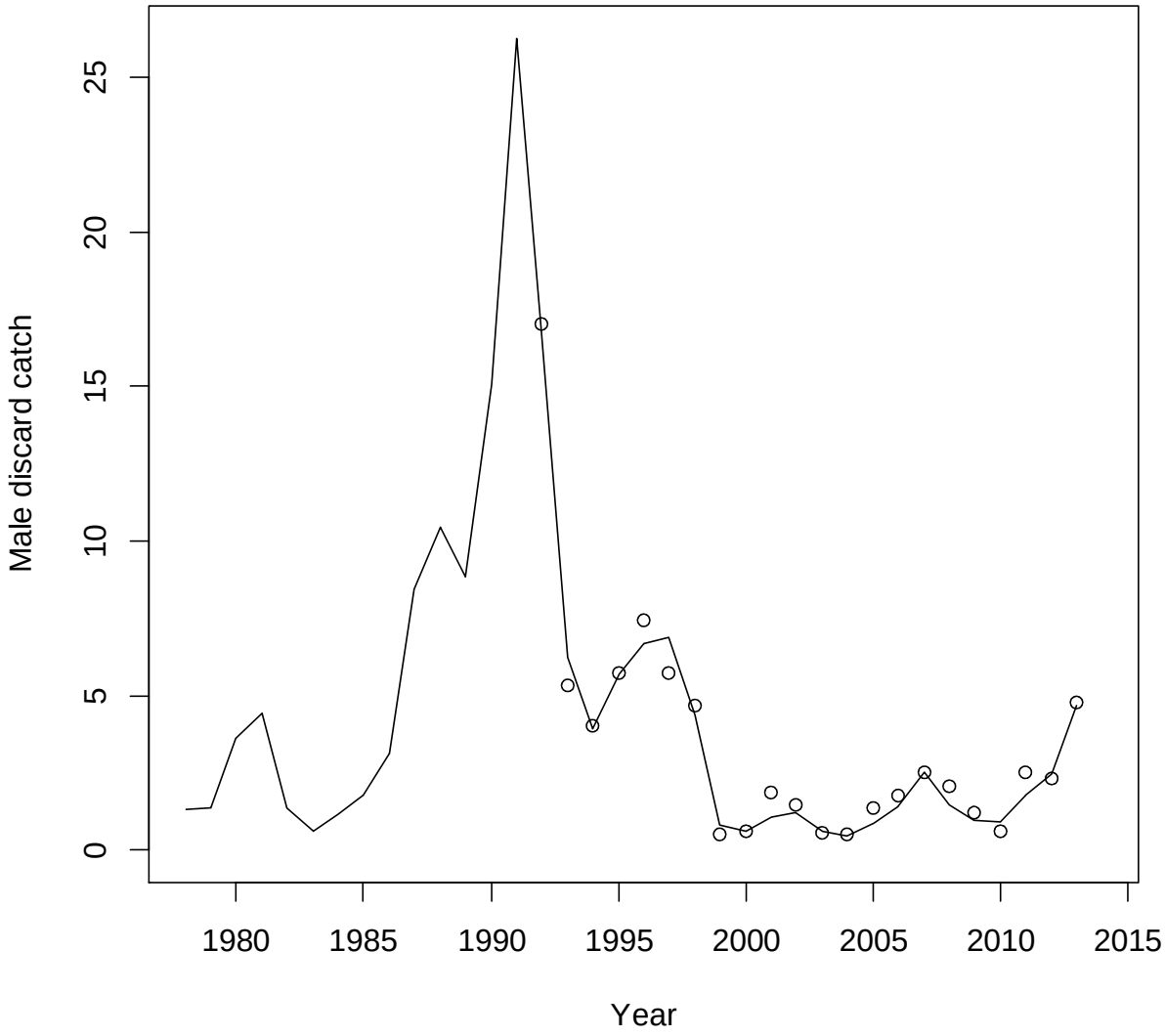
Male discard catch
0
5
10
15
20
25
1980
1985
1990
1995
2000
2005
2010
2015
Year

Figure C-37.

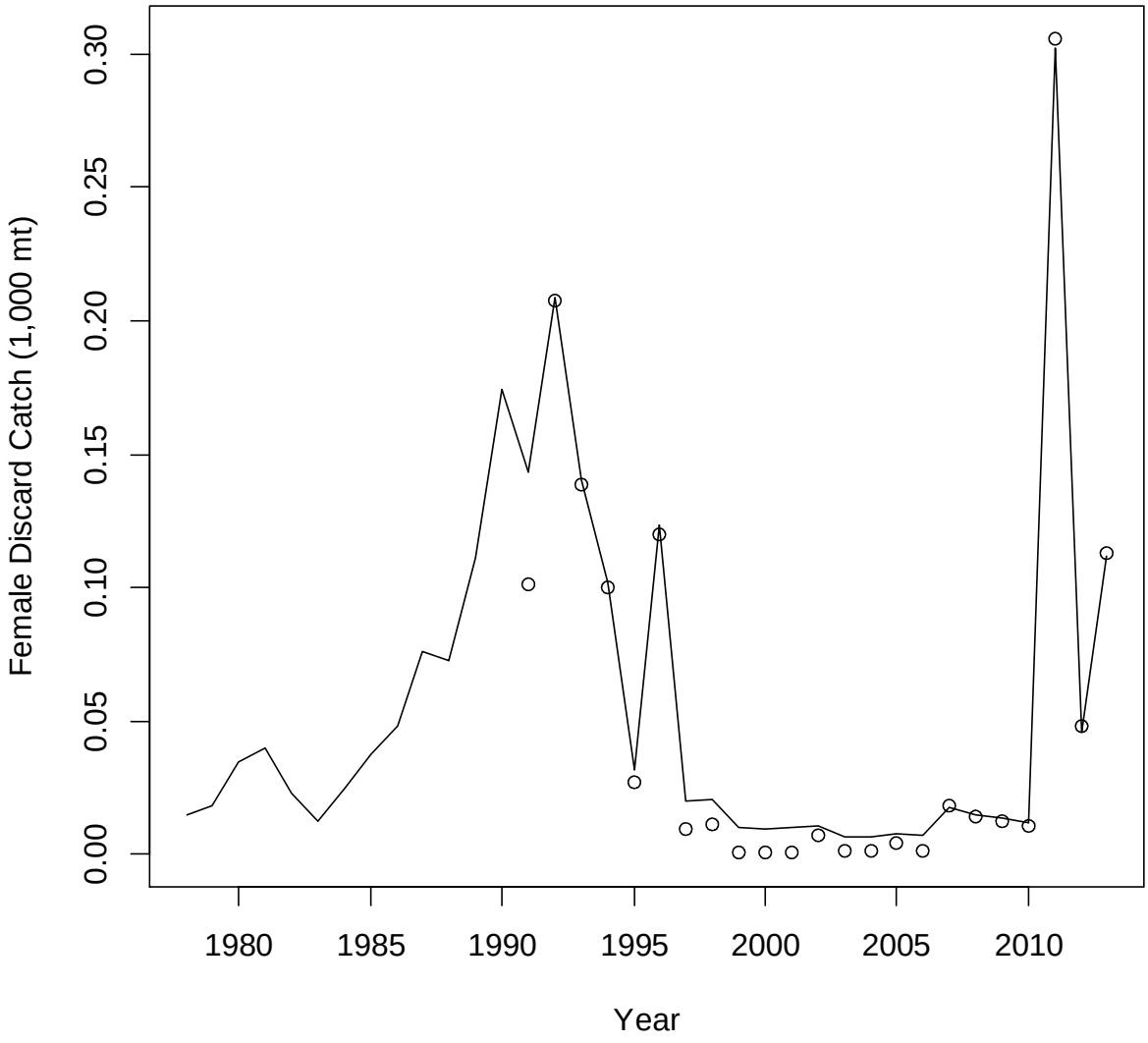
Female Discard Catch (1,000 mt)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
1980
1985
1990
1995
2000
2005
2010
Year

Figure C-38.

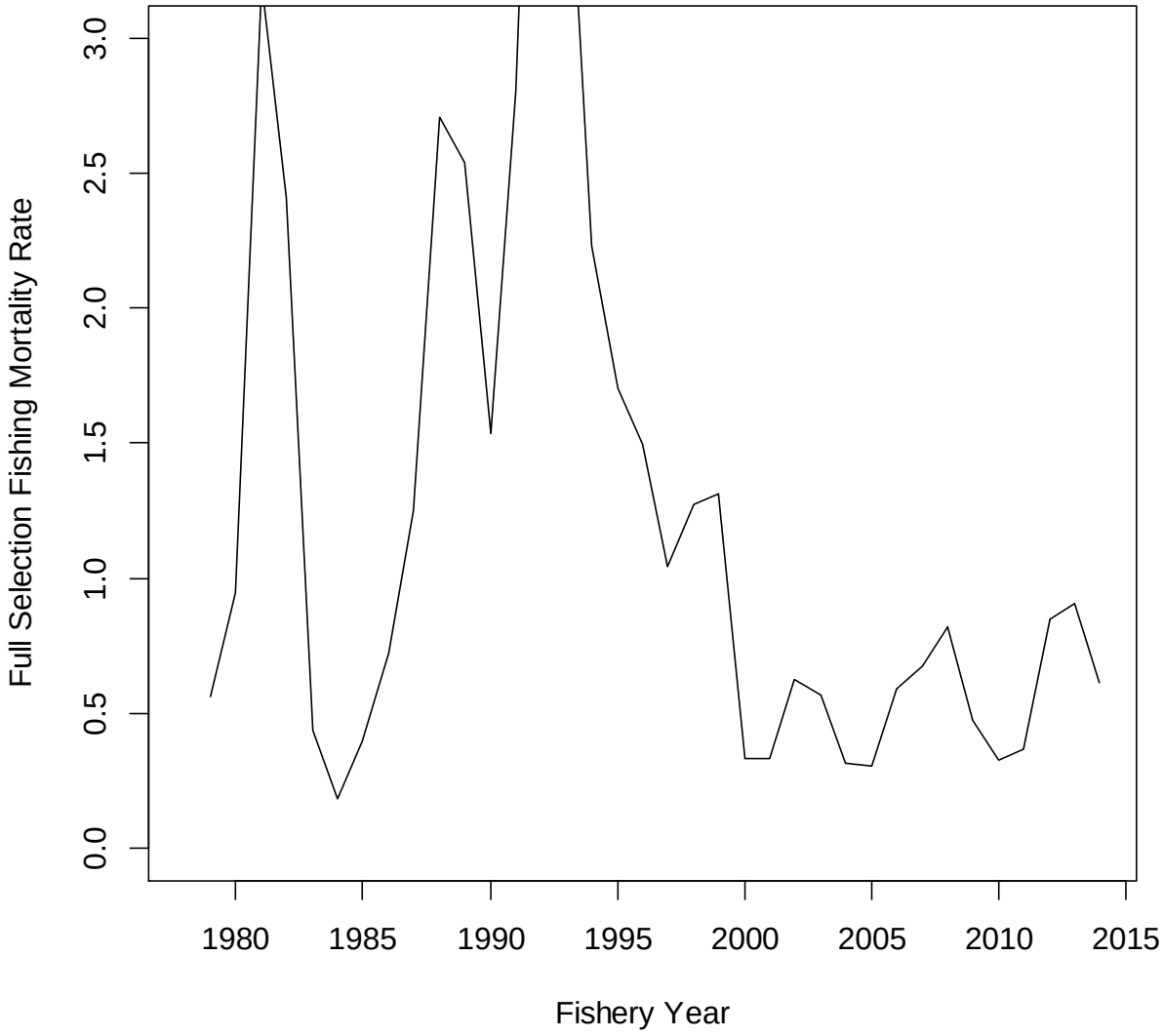
Full Selection Fishing Mortality Rate
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1980
1985
1990
1995
2000
2005
2010
2015
Fishery Year

Figure C-39.

Appendix D. Plots for 2014 Assessment model.

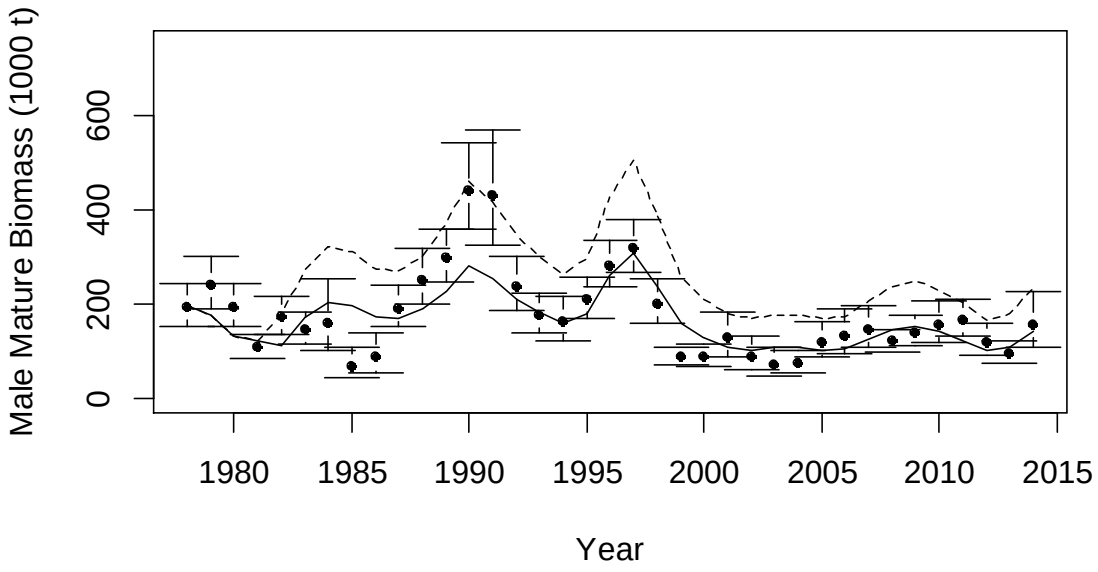

Figure D-1. 2014 Model. Population male mature biomass (1000 t, dotted line), model estimate of survey male mature biomass (solid line) and observed survey male mature biomass with approximate lognormal 95% confidence intervals.

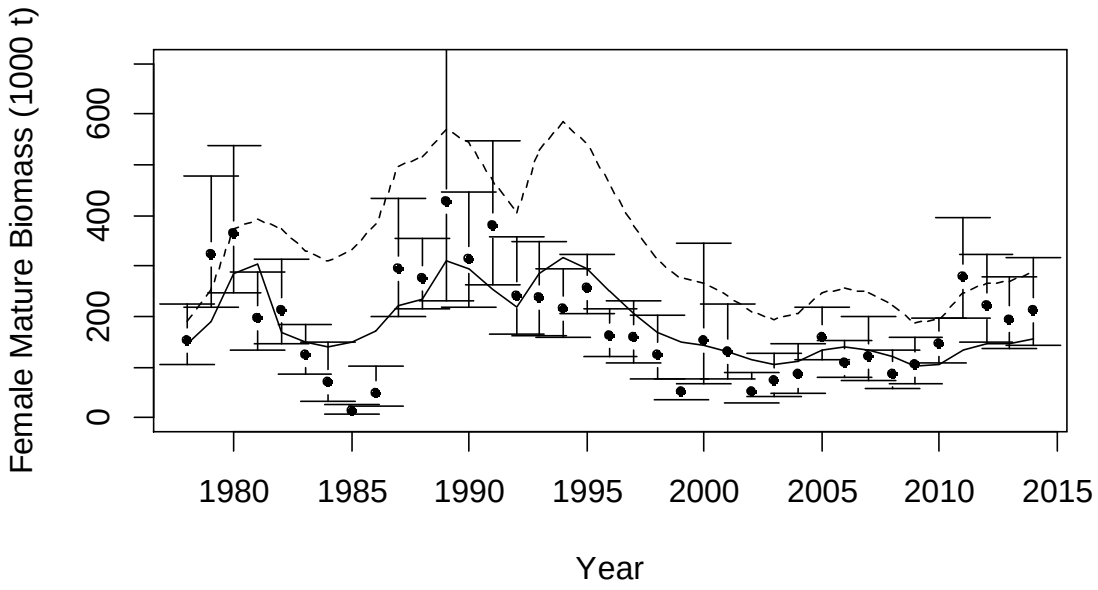

Figure D-2.2014 Model. Population female mature biomass (1000 t, dotted line), model estimate of survey female mature biomass (solid line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

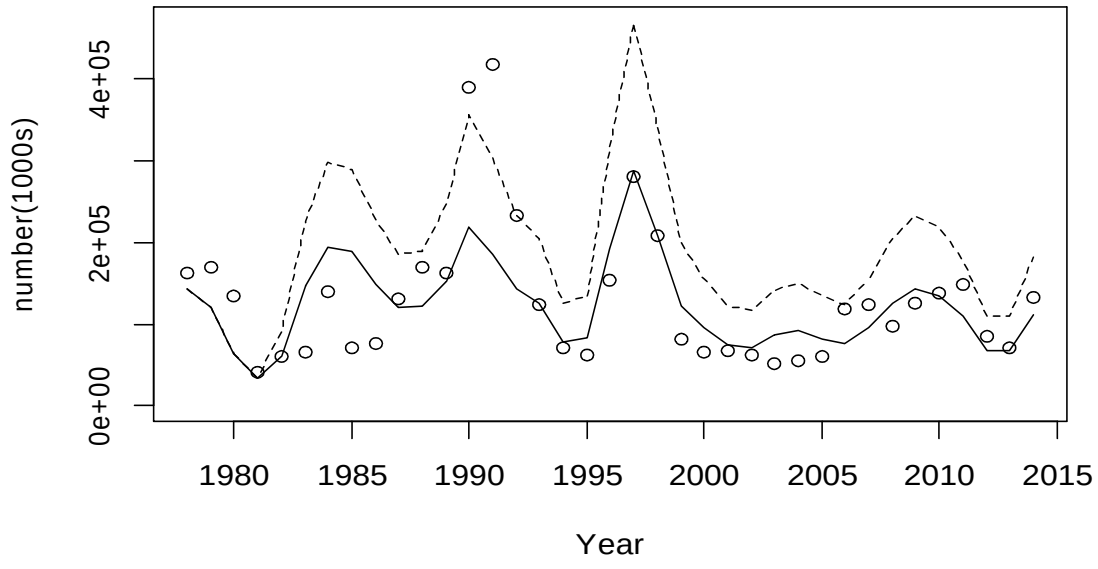

Figure D-3. 2014 Model. Observed survey numbers of males >101mm (circles), model estimates of the population number of males >101mm(solid line) and model estimates of survey numbers of males >101 mm (dotted line).

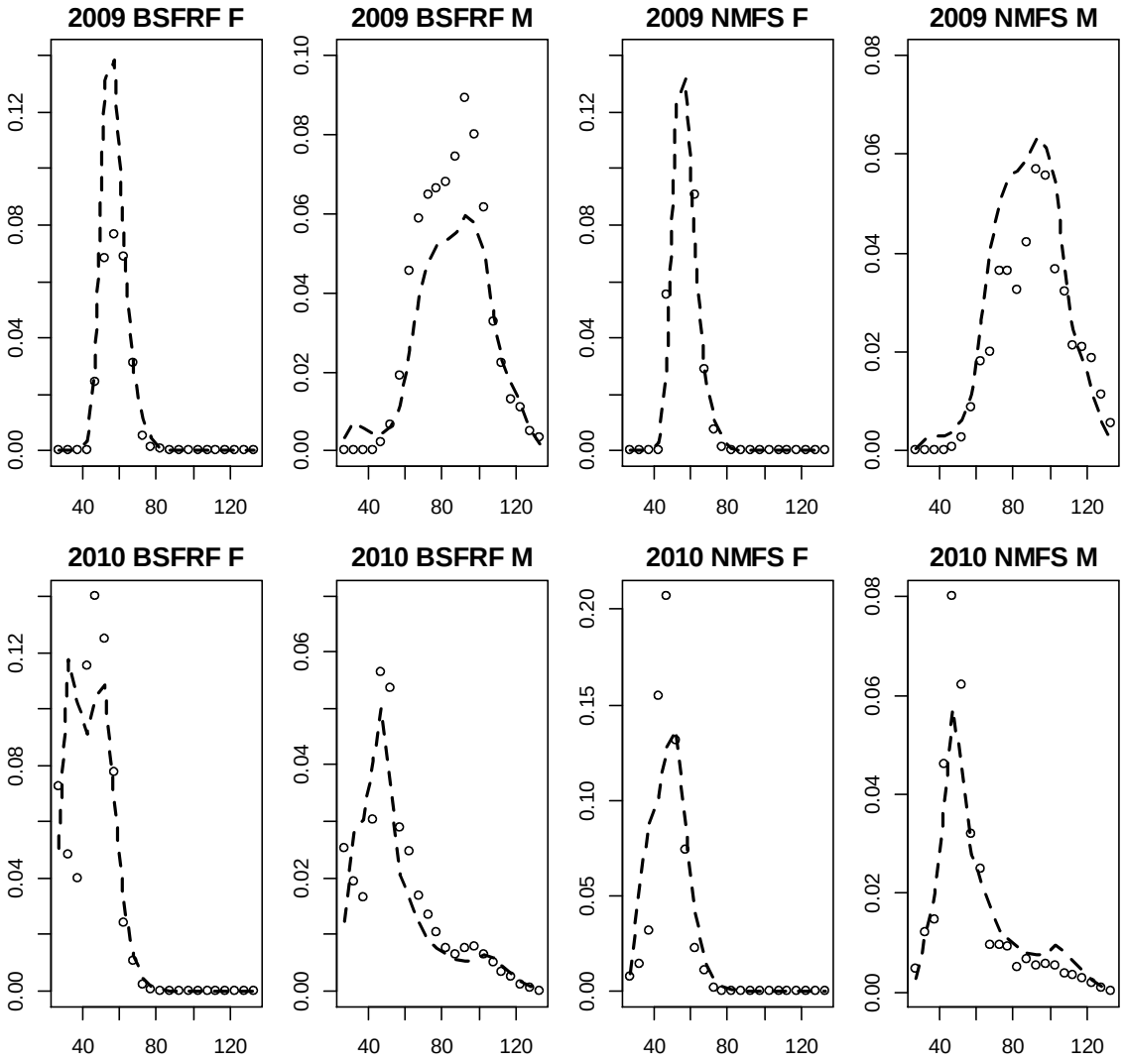

Figure D-4. 2014 Model. Model fit to length frequency for BSFRF and NMFS females and males in the study area.

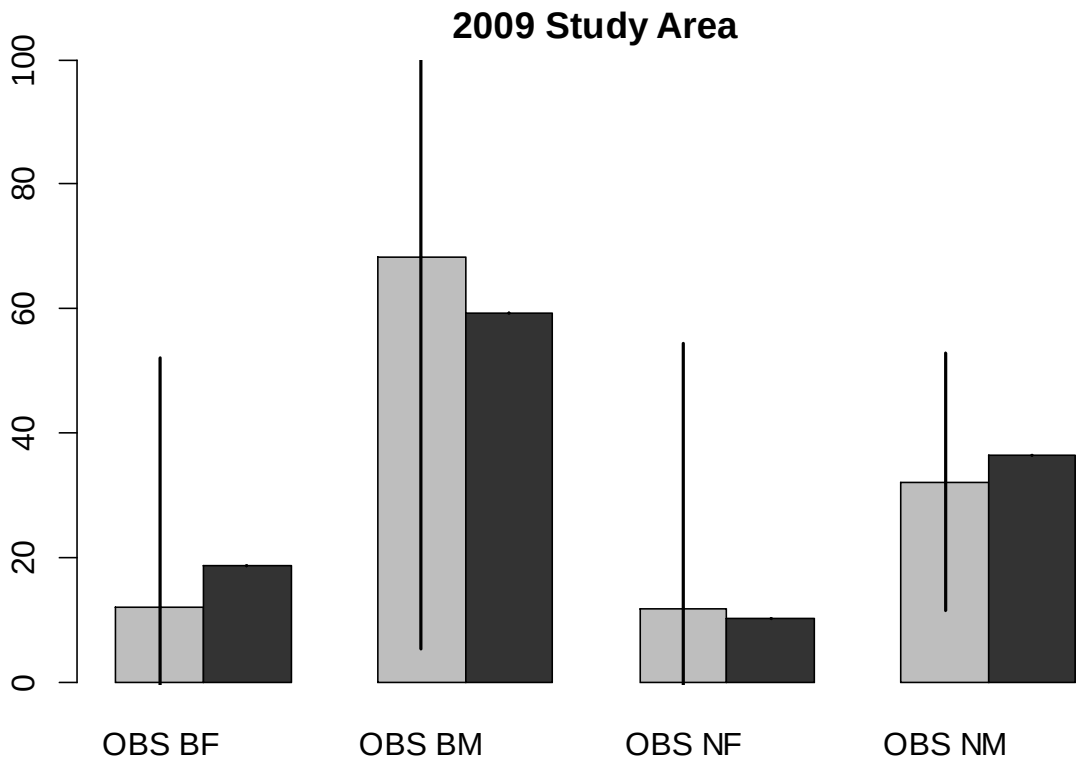

Figure D-5.2014 Model. Fits to 2009 study area mature biomass by sex for BSFRF and NMFS data.

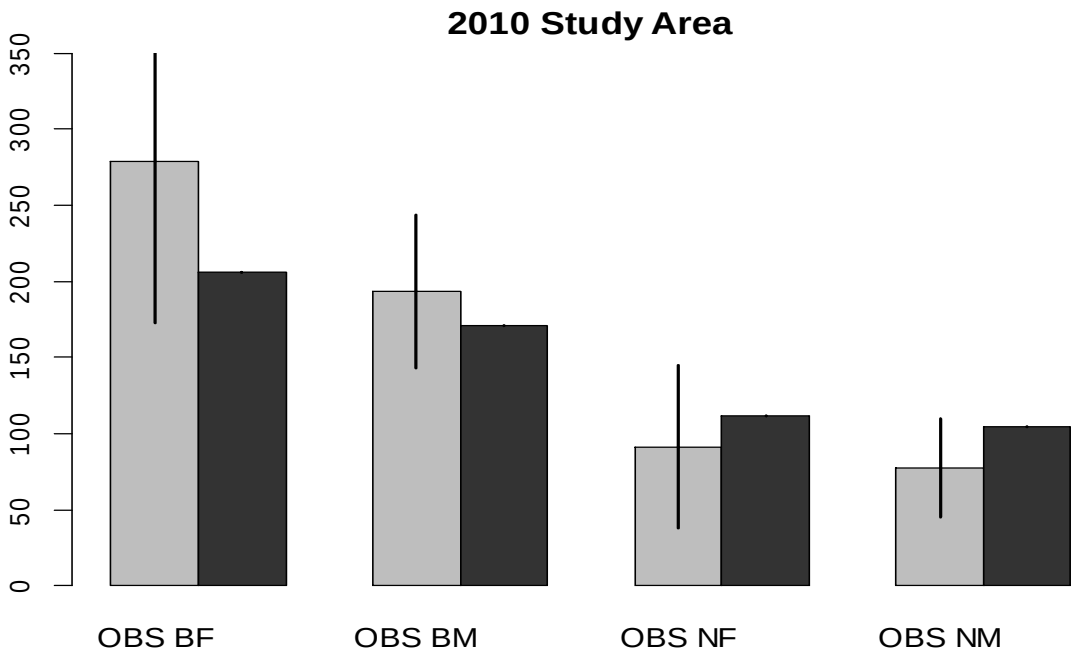

Figure D-6. 2014 Model. Fits to 2010 study area mature biomass by sex for BSFRF and NMFS data.

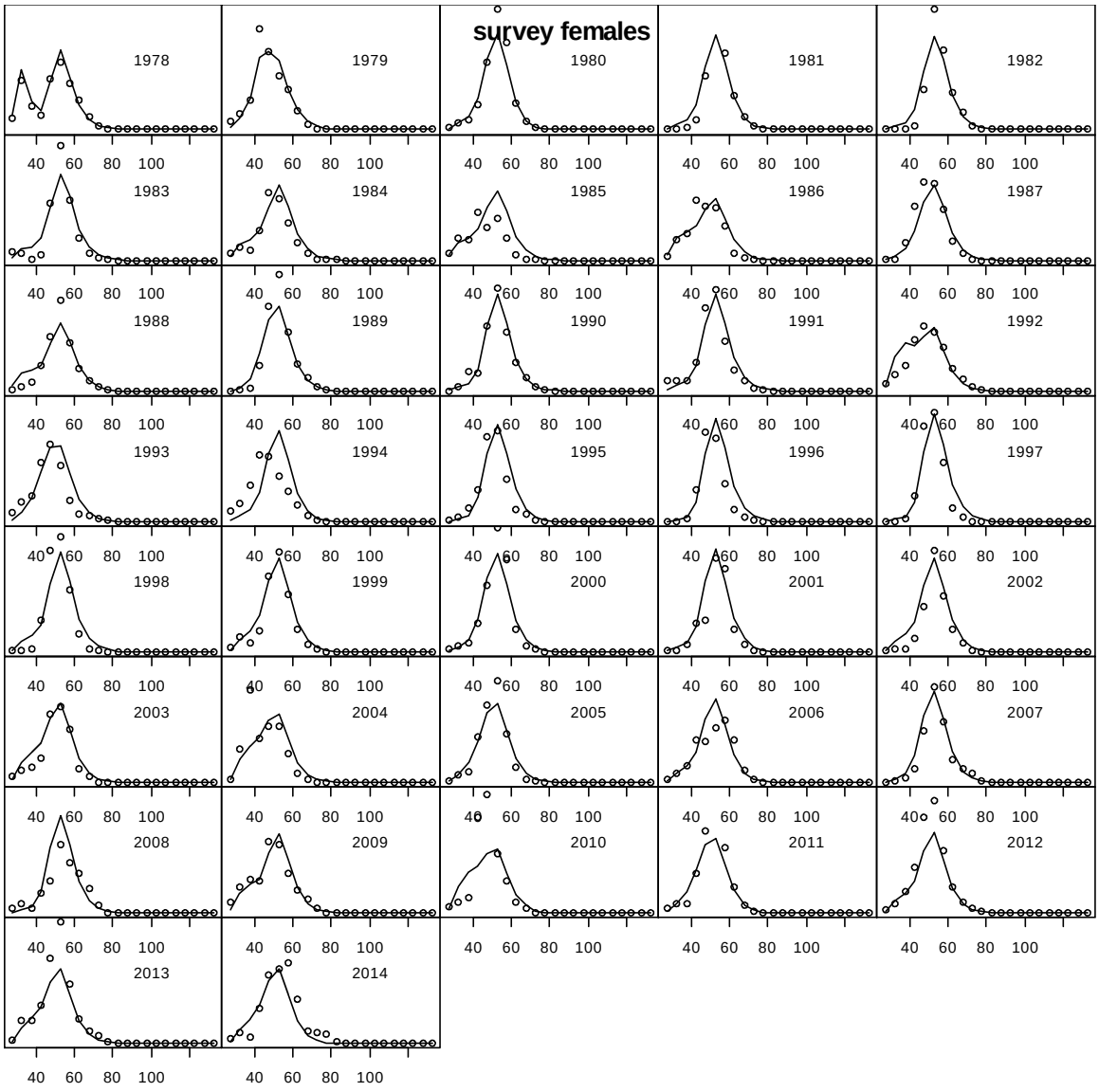

Figure D-7. 2014 Model. Model fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

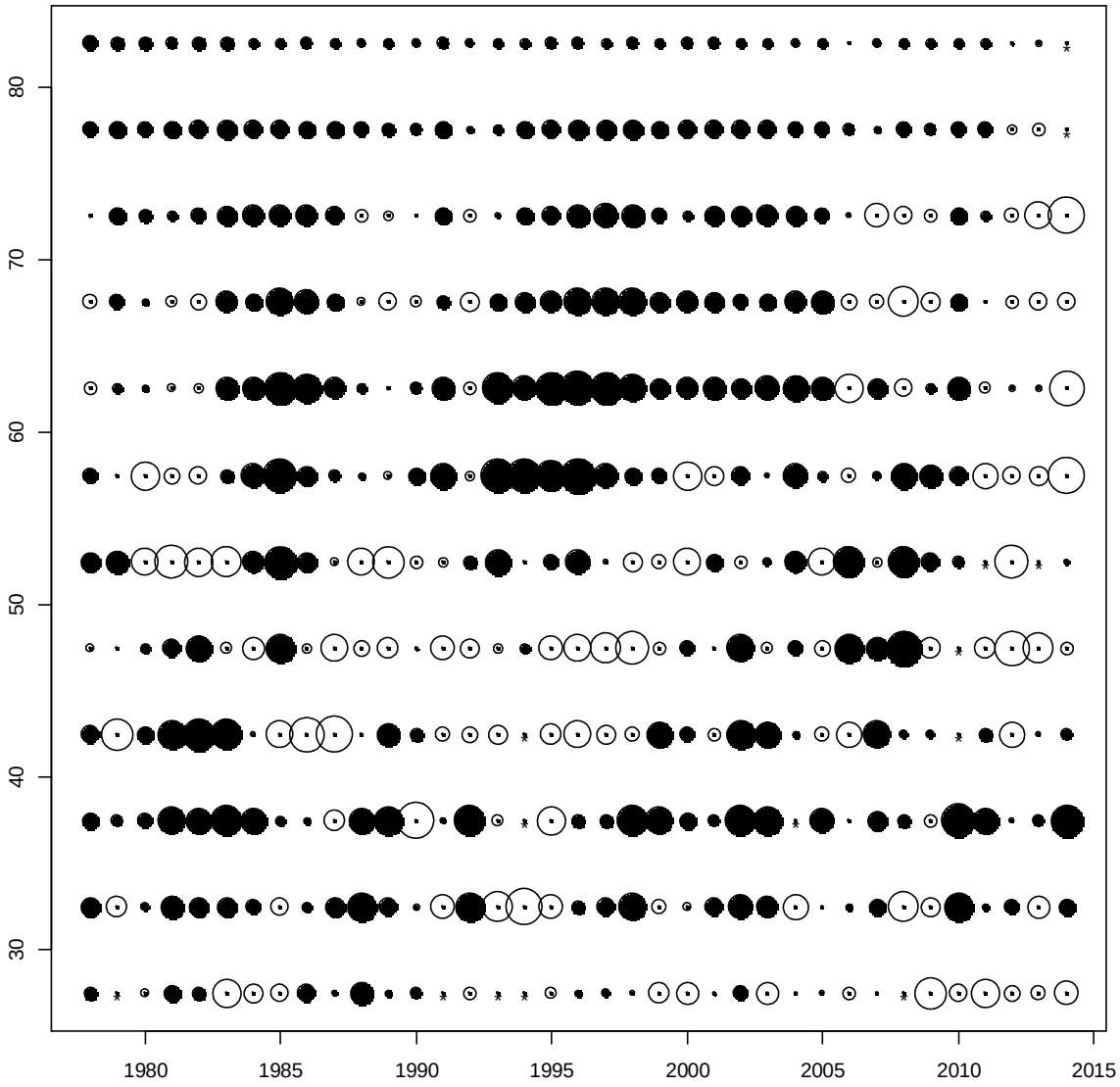

Figure D-8.2014 Model. Residuals of fit to survey female size frequency. Filled circles are negative residuals.

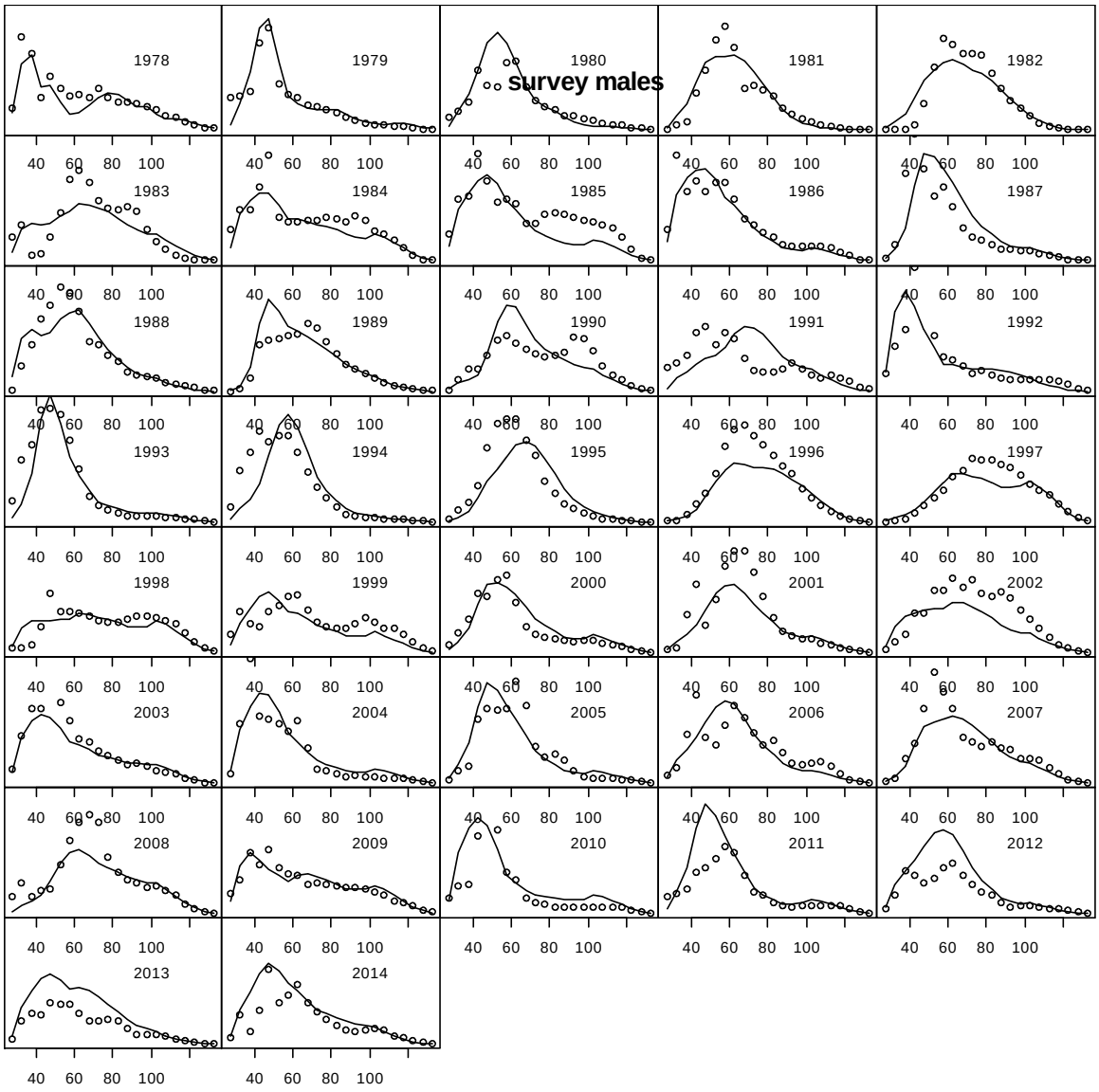

Figure D-9. 2014 Model. Model fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

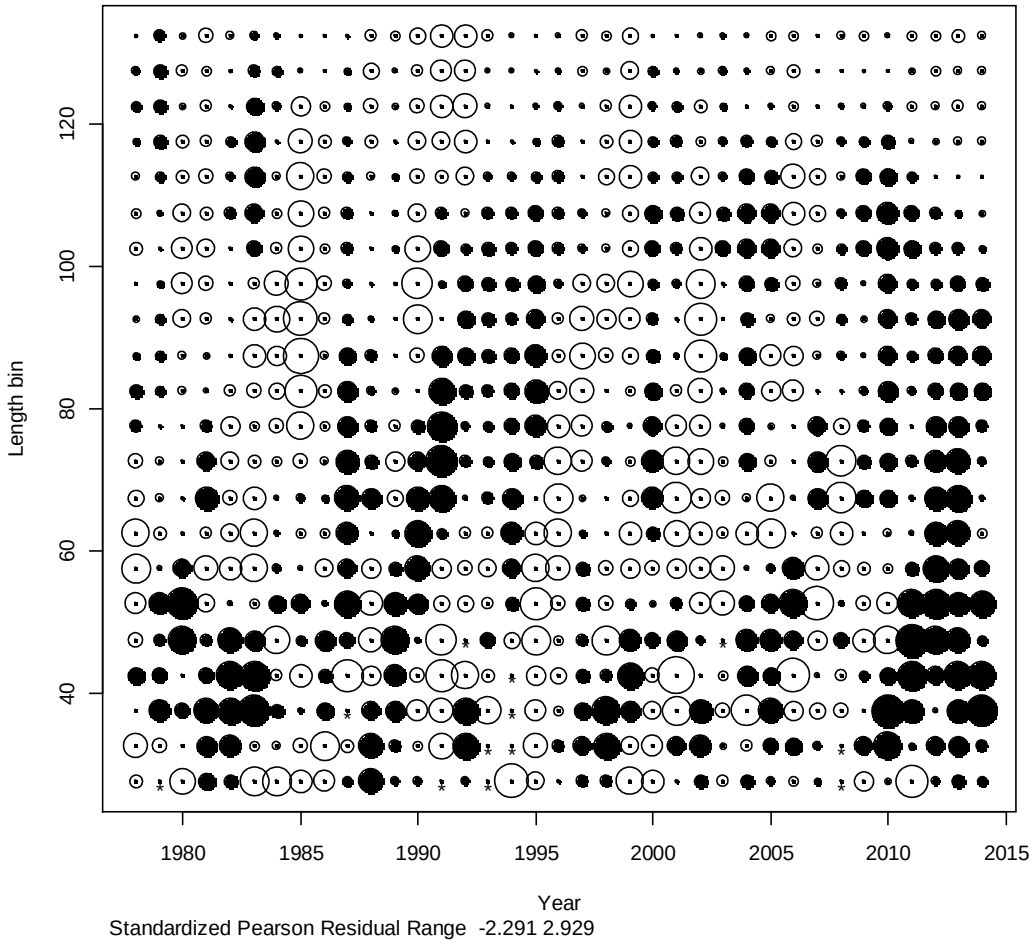

Figure D-10. 2014 Model. Residuals for fit to survey male size frequency. Filled circles are negative residuals (predicted higher than observed).

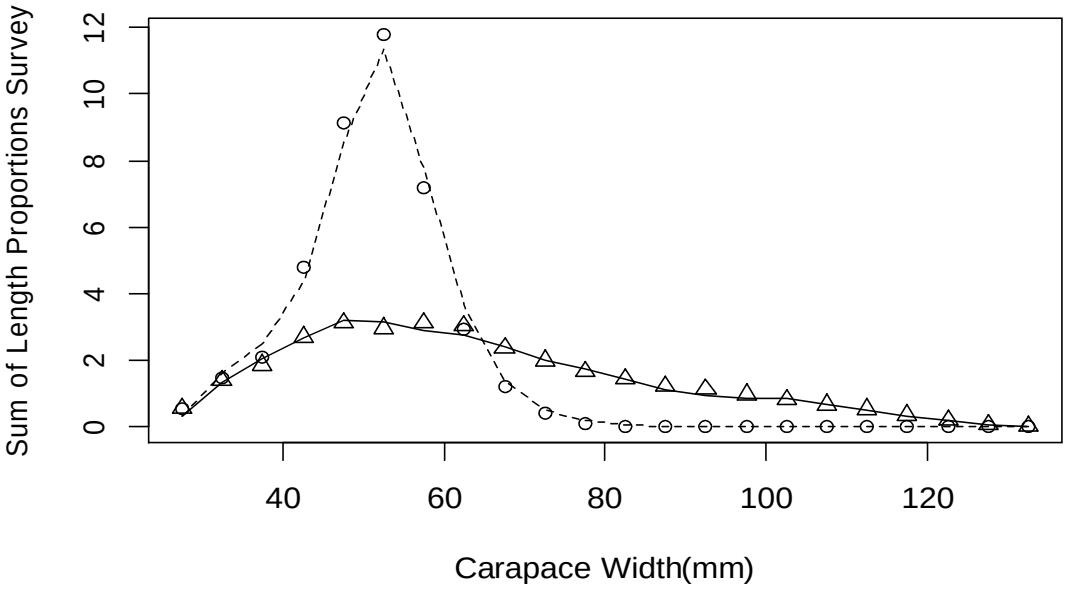

Figure D-11. 2014 Model. Summary over years of fit to survey length frequency data by sex. Dotted line is fit for females, circles are observed. Solid line is fit for males, triangles are observed.

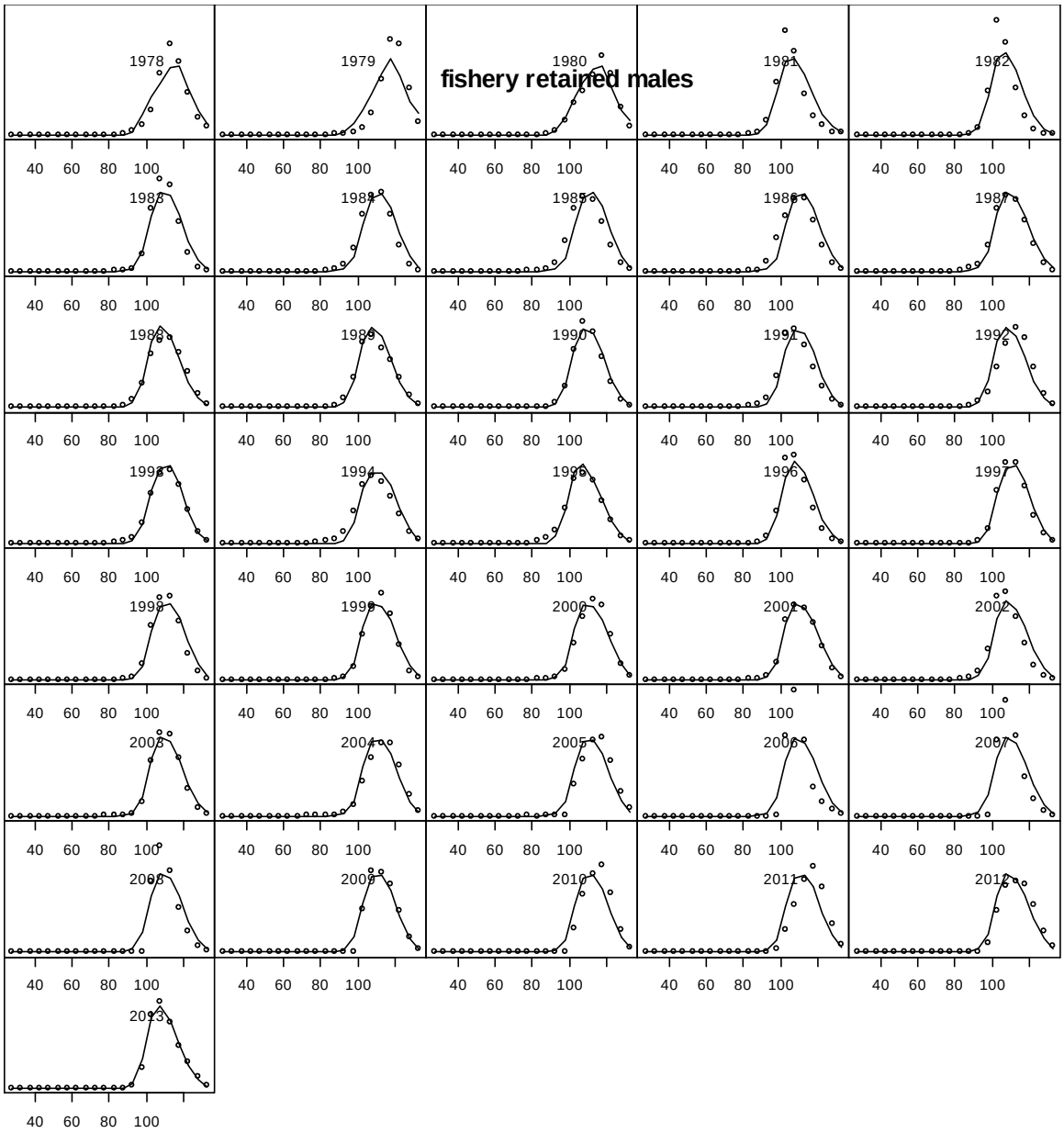

Figure D-12. 2014 Model. Model fit to the retained male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

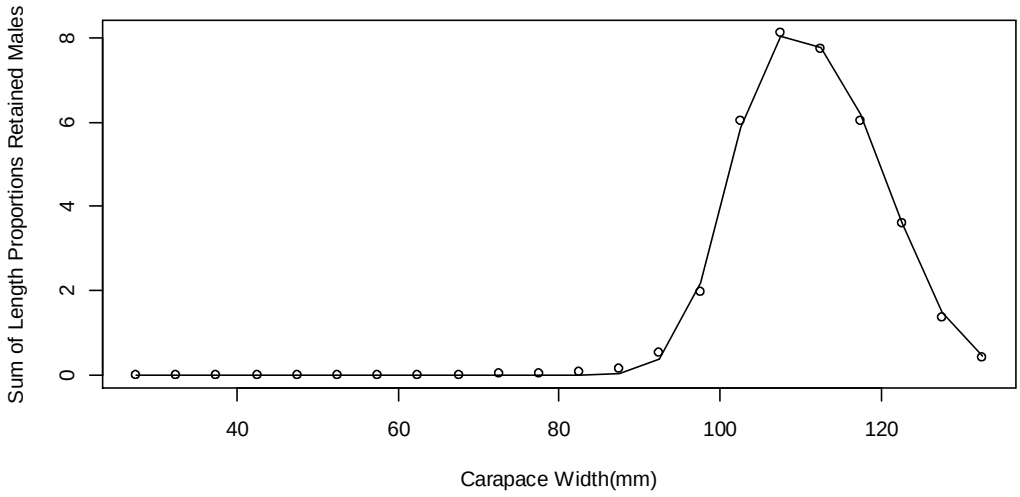

Figure D-13. 2014 Model. Summary fit to retained male length.

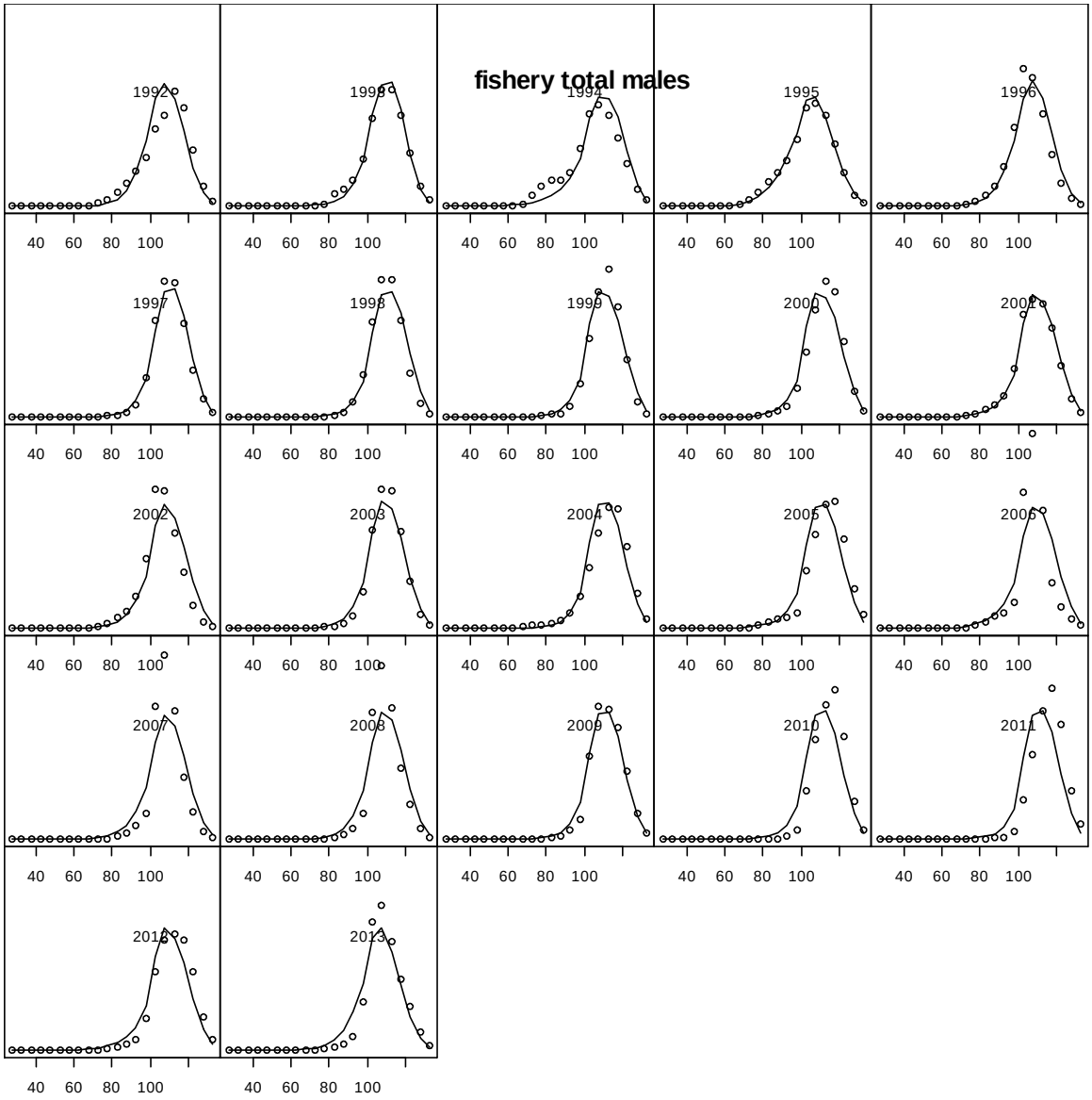
fishery total males
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
40 60 80 100

Figure D-14. 2014 Model. Model fit to the total (discard plus retained) male size frequency data, shell condition combined. Solid line is the model fit. Circles are observed data. Year is the survey year.

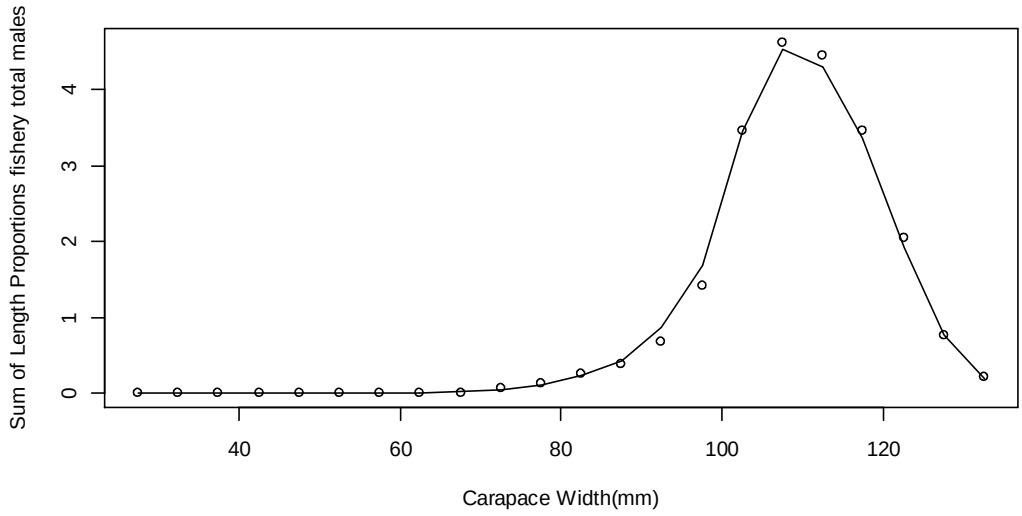

Figure D-15. 2014 Model. Summary fit to total length frequency male catch.

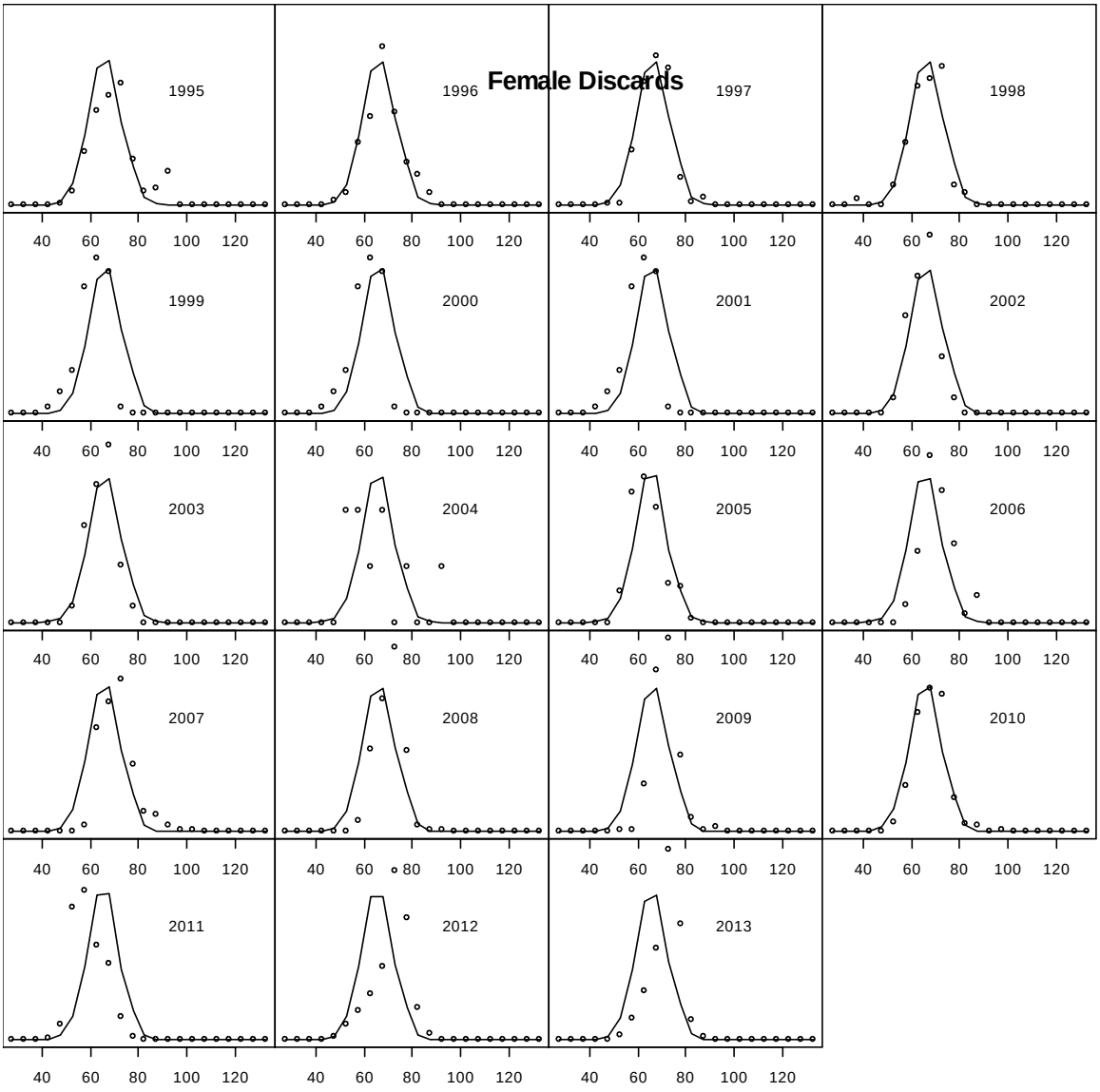

Figure D-16. 2014 Model. Model fit to the discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

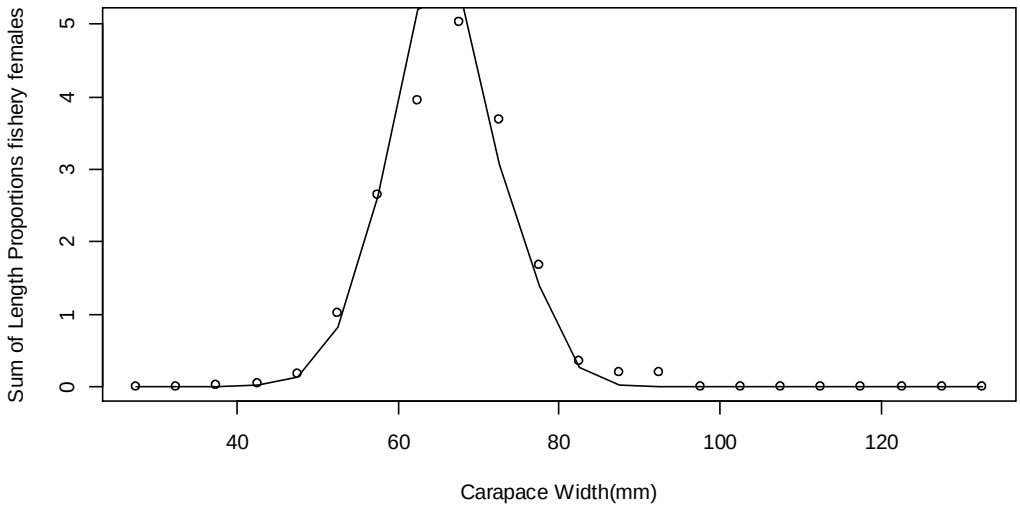

Figure D-17. 2014 Model. Summary fit to directed fishery female discards.

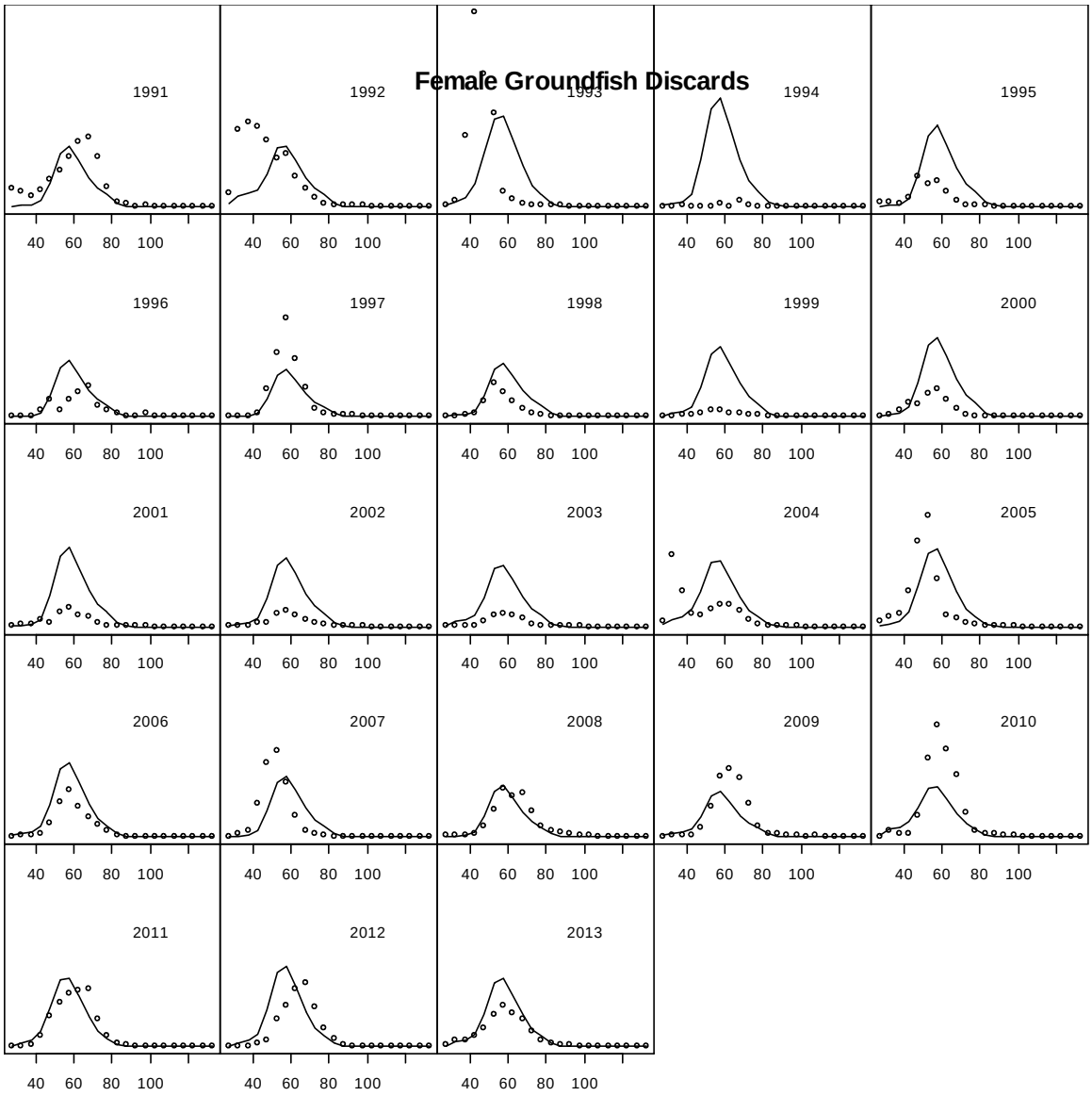

Figure D-18. 2014 Model. Model fit to the groundfish trawl discard female size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

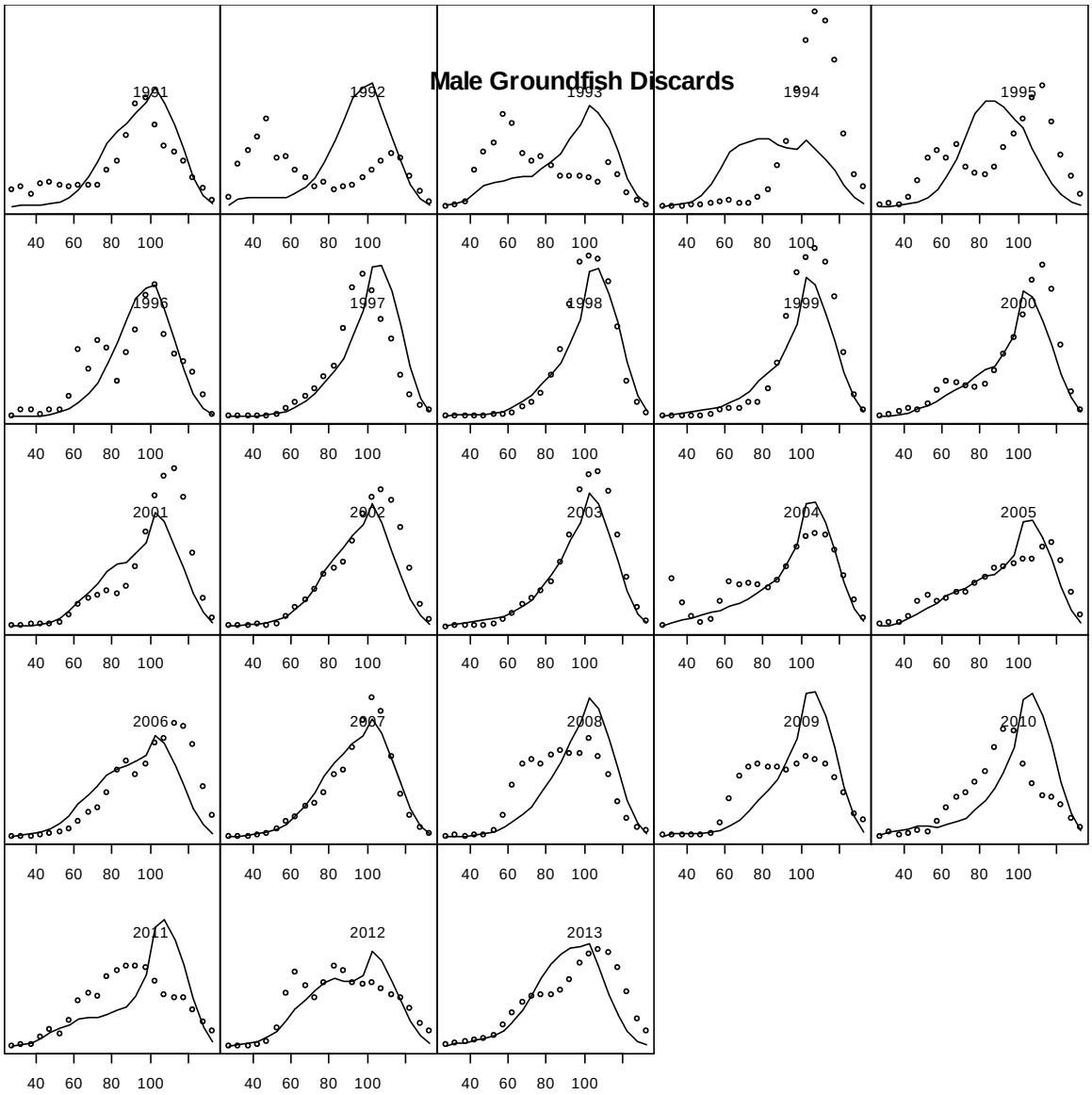

Figure D-19. 2014 Model. Model fit to the groundfish trawl discard male size frequency data. Solid line is the model fit. Circles are observed data.

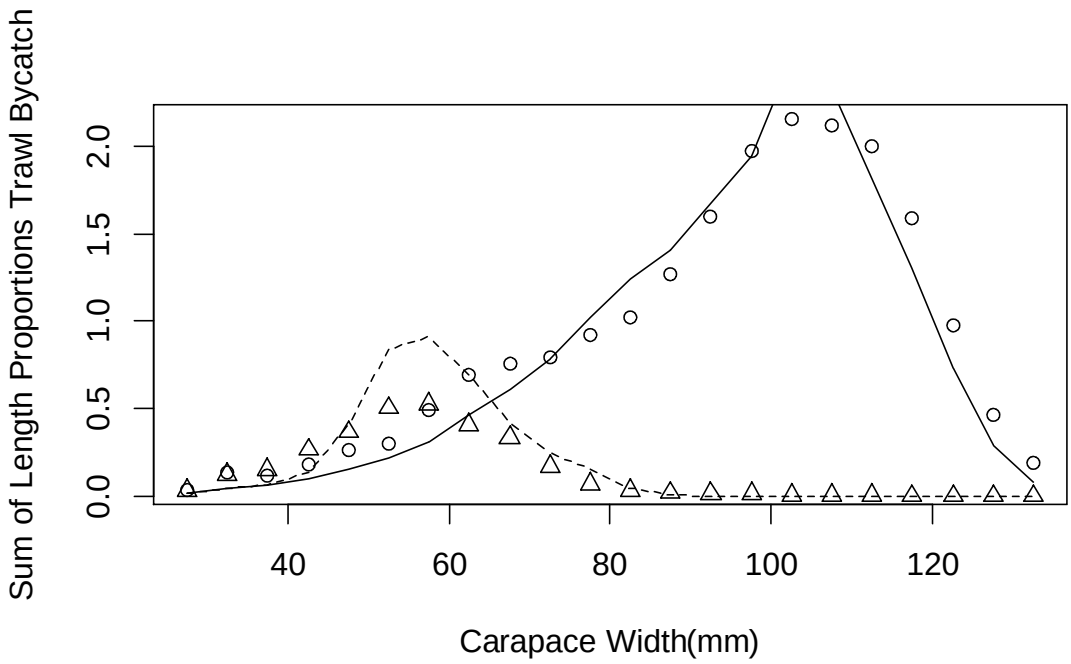

Figure D-20. 2014 Model. Summary fit to groundfish length frequency.

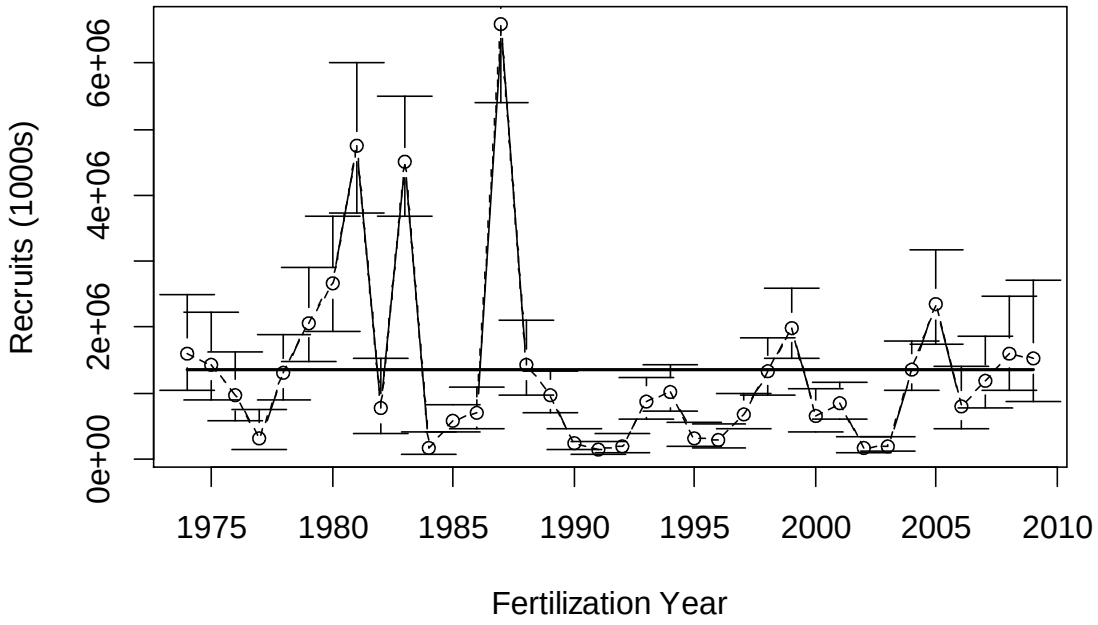

Figure D-21. 2014 Model. Recruitment to the model for crab 25 mm to 50 mm. Total recruitment is 2 times recruitment in the plot. Male and female recruitment fixed to be equal. Solid horizontal line is average recruitment. Error bars are 95% C.I.

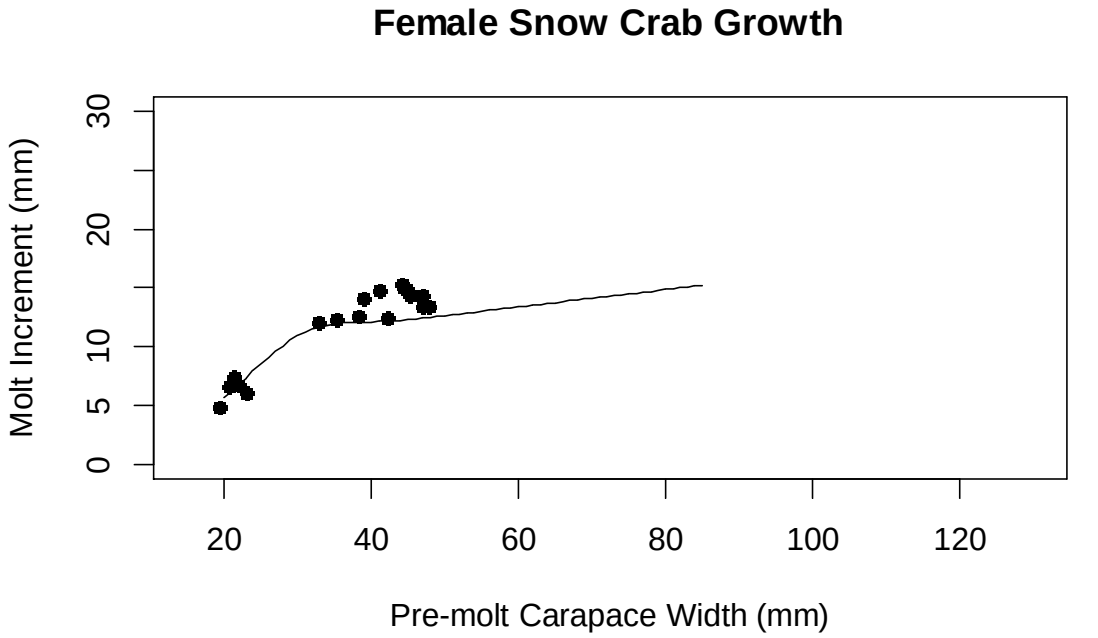

Figure D-22.

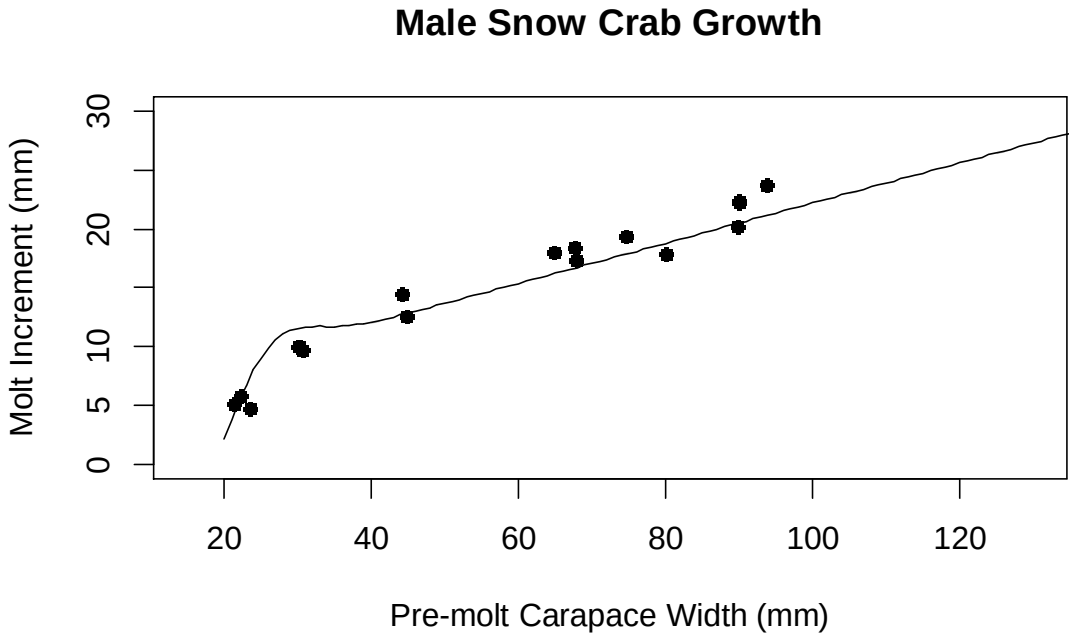

Figure D-23.

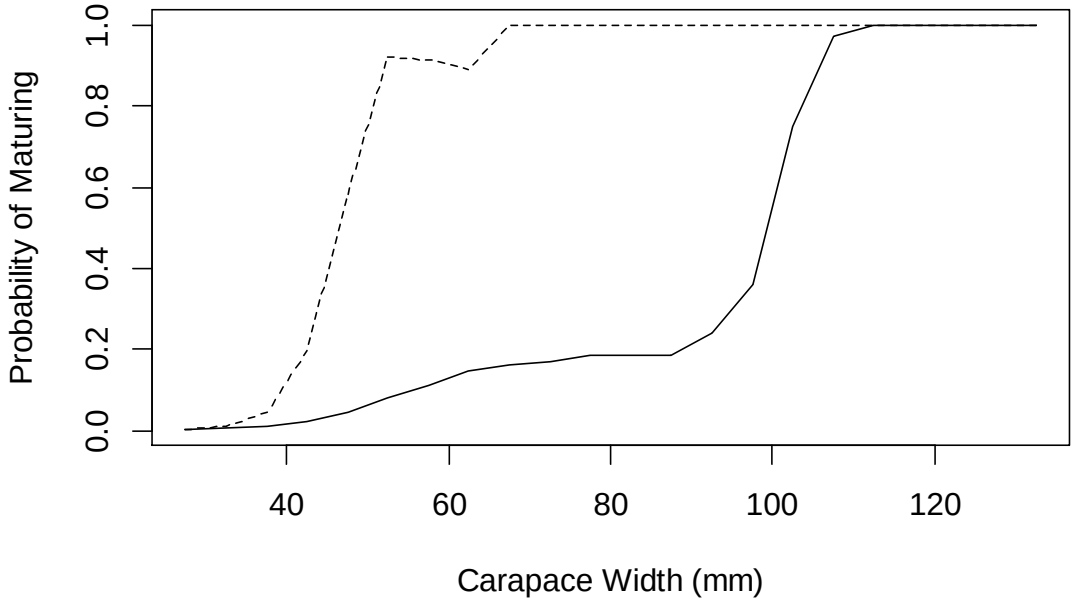

Figure D-24. Probability of maturing by size estimated in the model for male(solid line) and female (dashed line) snow crab (not the average fraction mature.

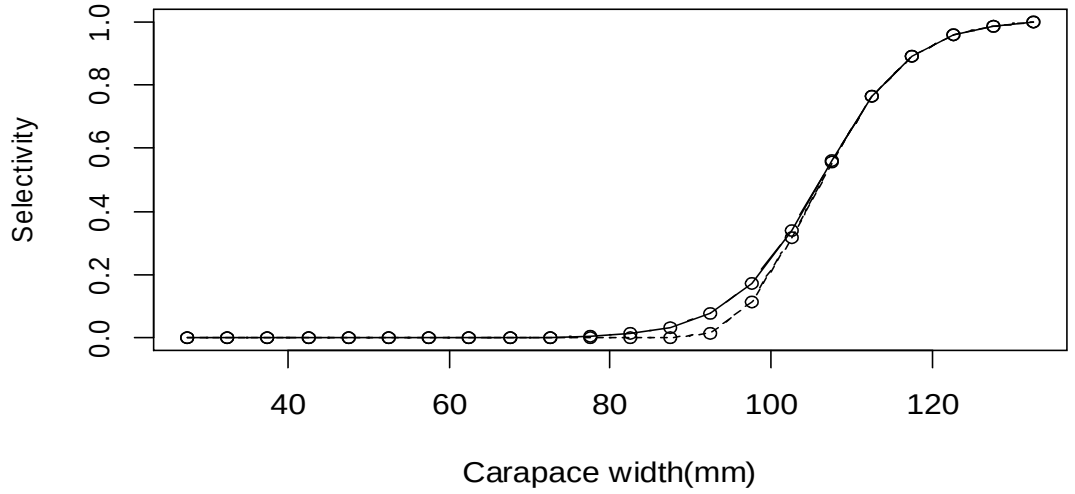

Figure D-25. 2014 Model. Selectivity curve for total catch (discard plus retained, solid line) and retained catch (dotted line) for combined shell condition male snow crab.

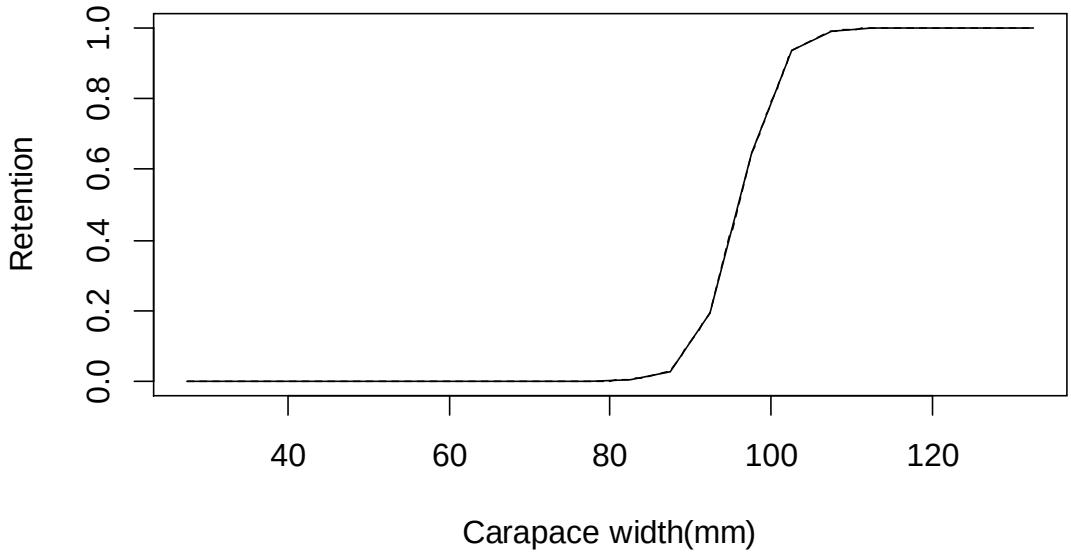

Figure D-26.2014 Model. Model estimated fraction of the total catch that is retained by size for male snow crab combined shell condition.

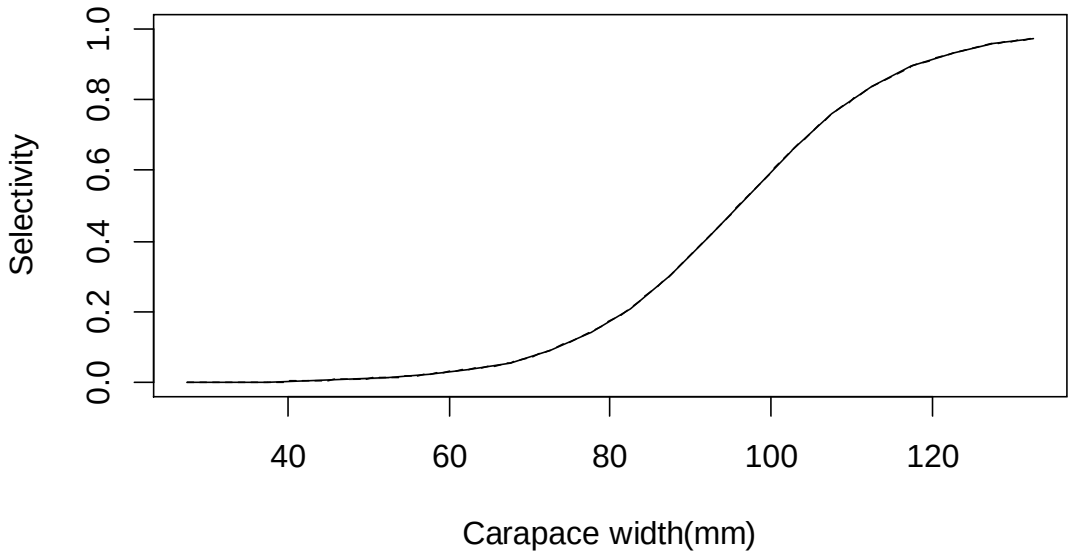

Figure D-27. 2014 Model. Selectivity curve estimated by the model for bycatch in the groundfish trawl fishery for females and males.

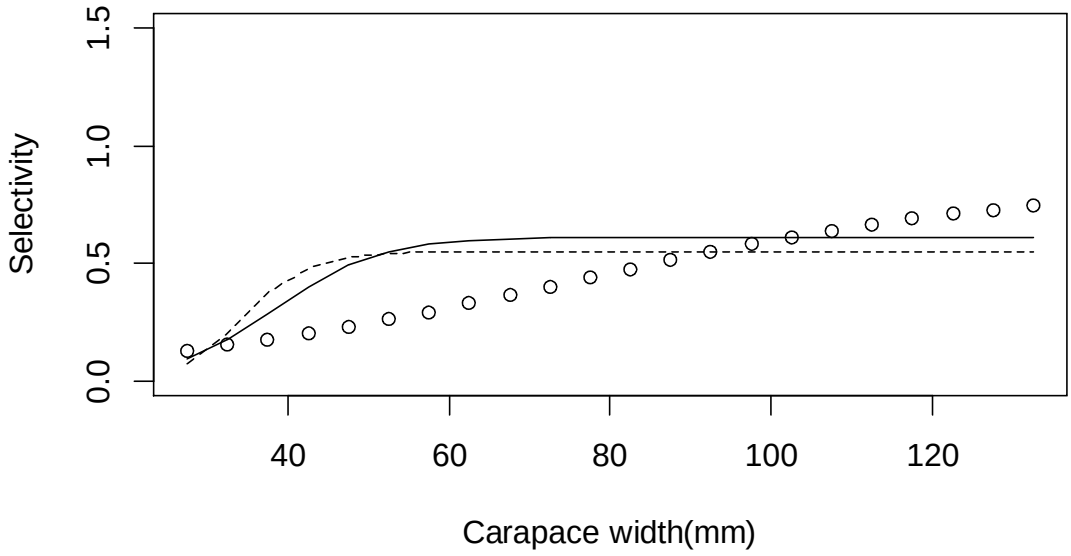

Figure D-28. 2014 Model. Survey selectivity curves for female (dotted lines) and male snow crab (solid lines) estimated by the model for 1989 to present. Survey selectivities estimated by Somerton from 2009 study area data (2010) are the circles.

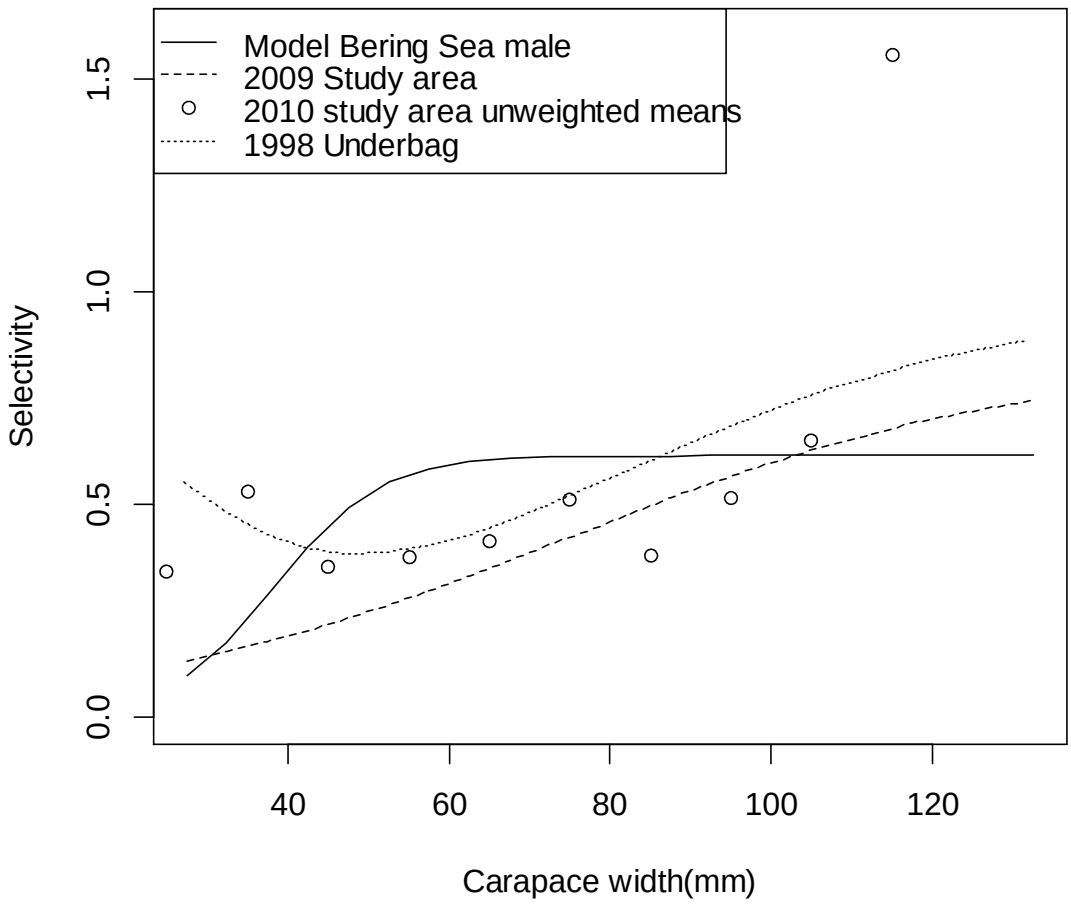

Figure D-29.2014 Model. Survey selectivity for male crab 1989- present (Model Bering Sea male), with selectivity curves estimated outside the model. 2009 study area is the curve estimated by Somerton from the 2009 study area data.

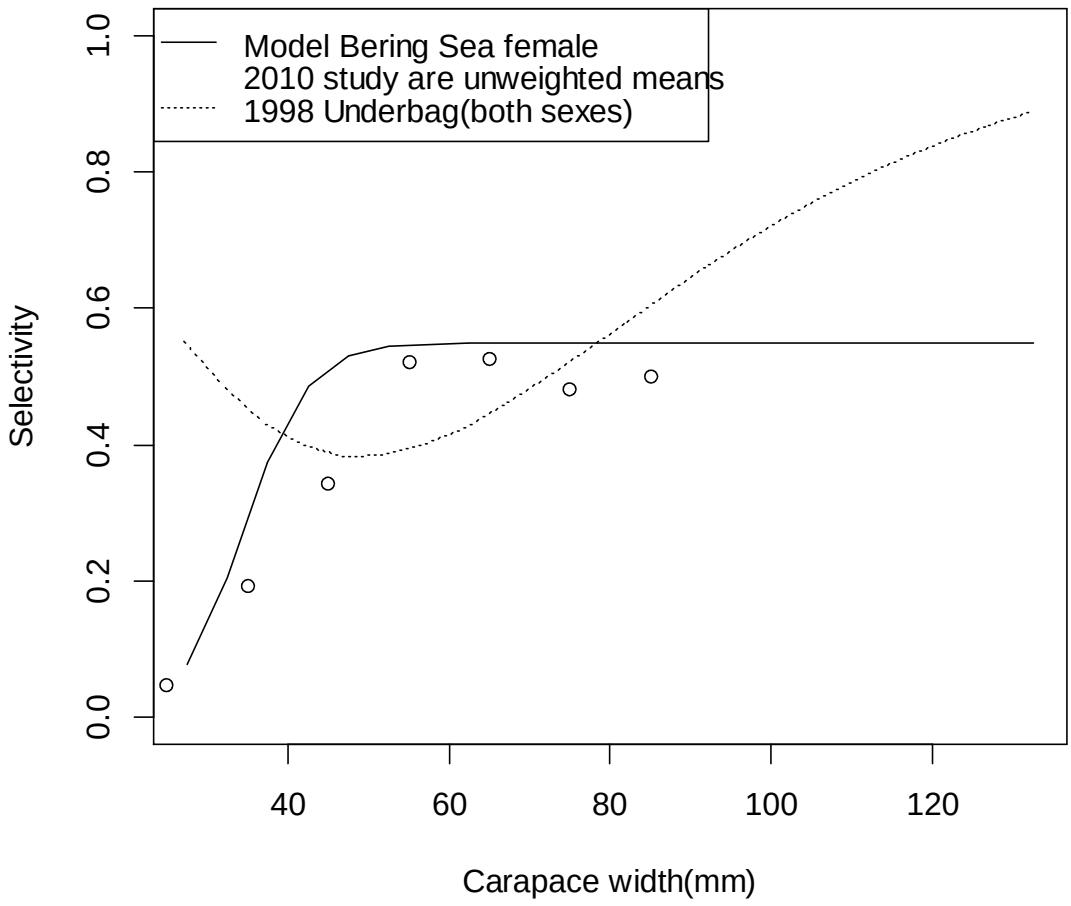

Figure D-30.2014 Model. Survey selectivity for female crab 1989- present (Model Bering Sea female).

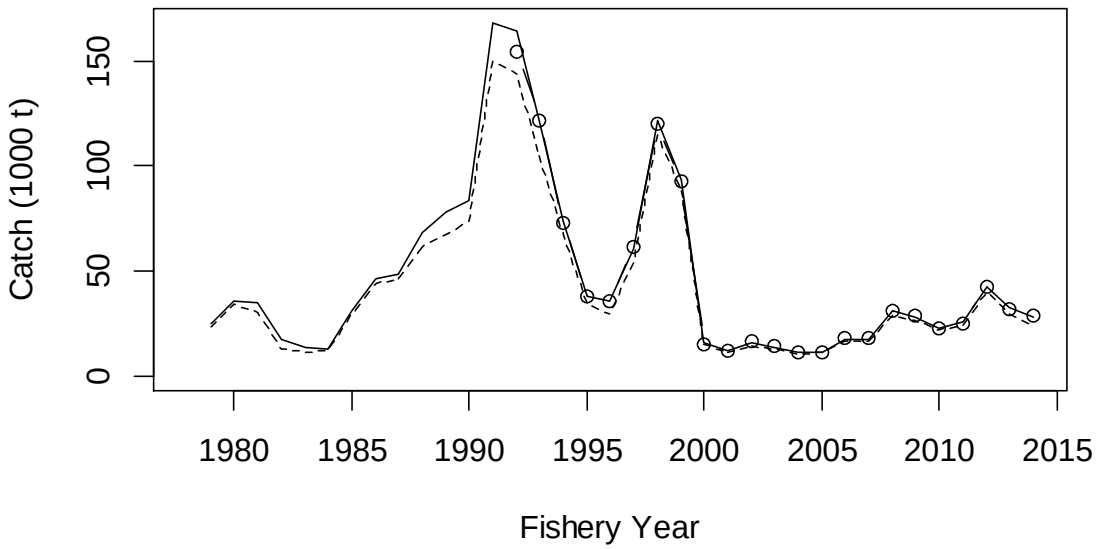

Figure D-31. 2014 Model. Estimated total catch(discard + retained) (solid line), observed total catch (solid line with circles) (assuming 30% mortality of discarded crab) and observed retained catch (dotted line).

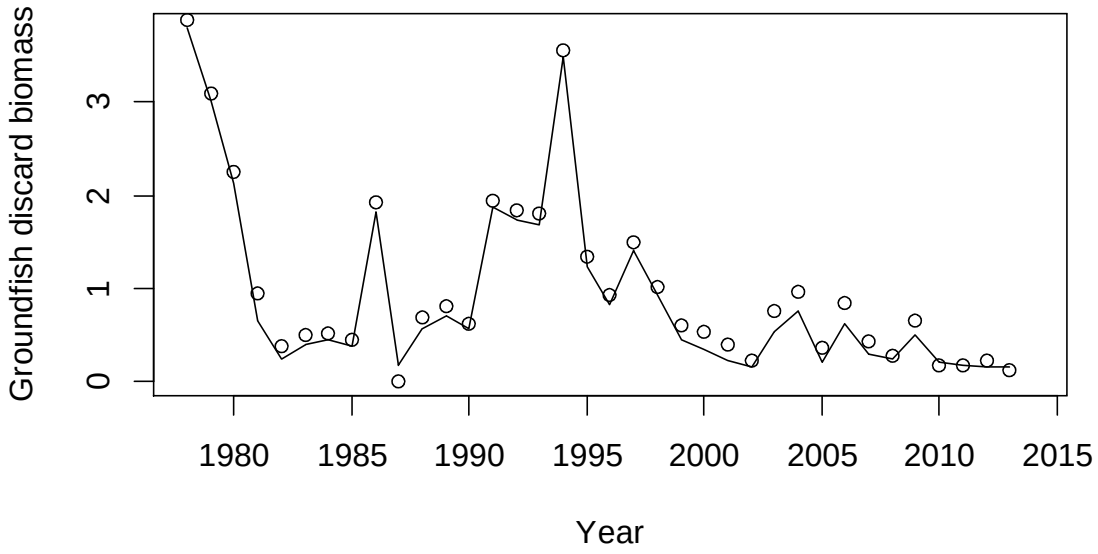

Figure D-32. 2014 Model. Model fit to groundfish bycatch. Circles are observed catch, line is model estimate.

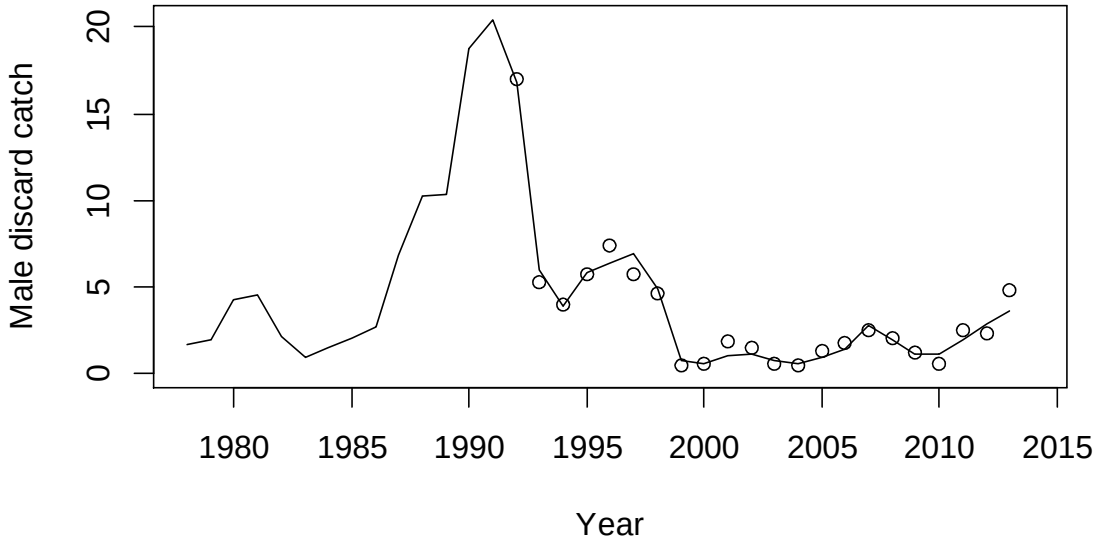

Figure D-33. 2014 Model. Model fit to male directed discard catch for 1992/93 to present and model estimated male discard catch from 1978 to 1991.

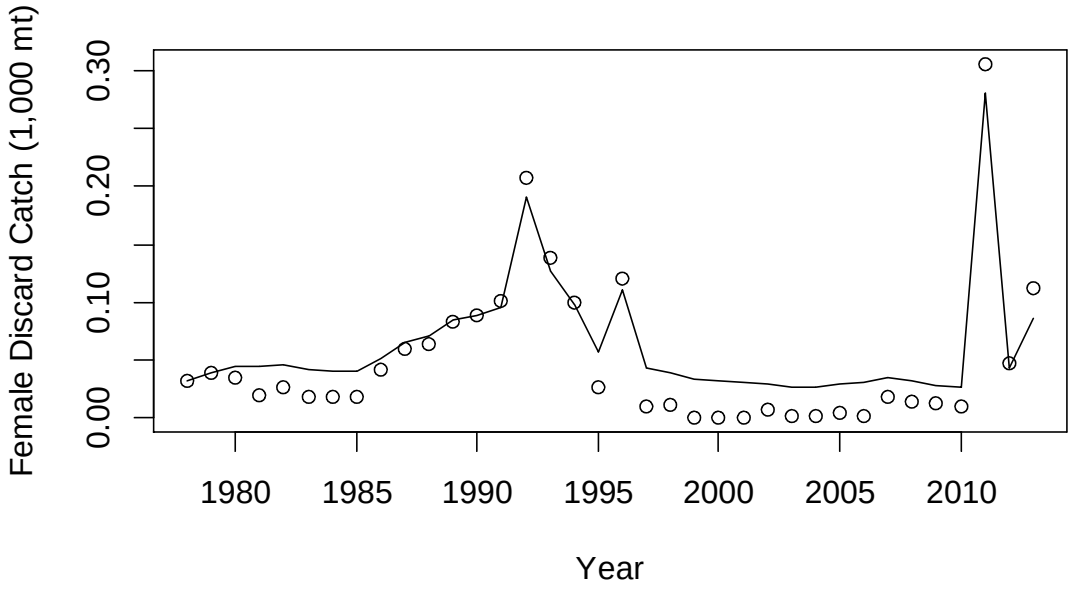

Figure D-34. 2014 Model. Model fit to female discard bycatch in the directed fishery from 1992/93 to present and model estimates of discard from 1978 to 1991.

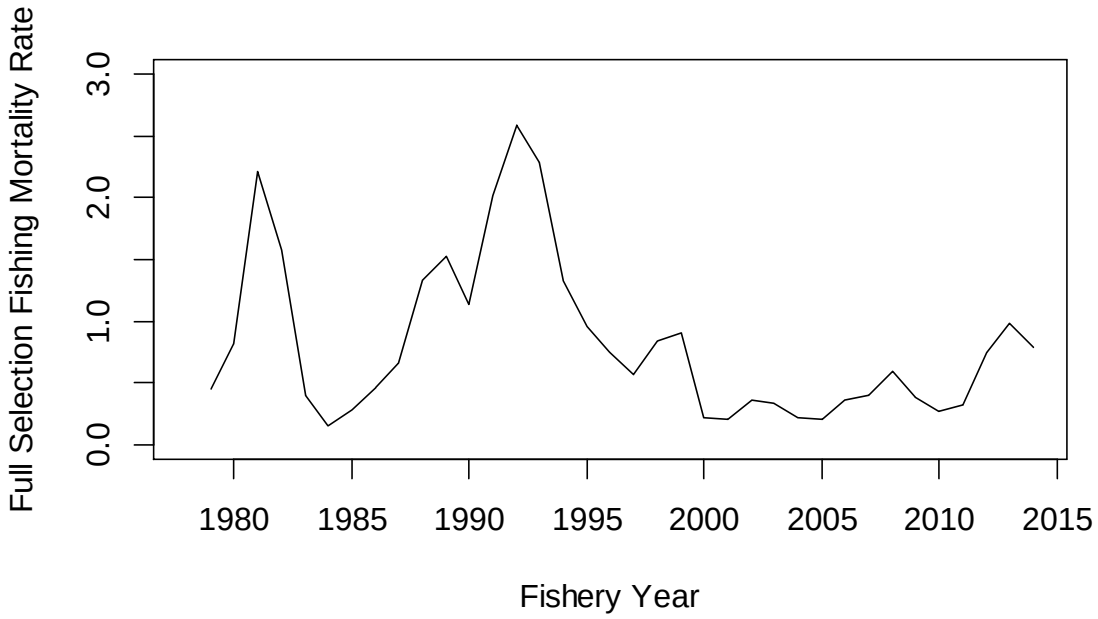

Figure D-35.2014 Model. Full selection fishing mortality estimated in the model from 1978/79 to present.