Bering Sea snow crab
Total catch 2013/14 28,100 t (24,500 t retained), decreased from 2012/13 32,400 t (30,100 t)

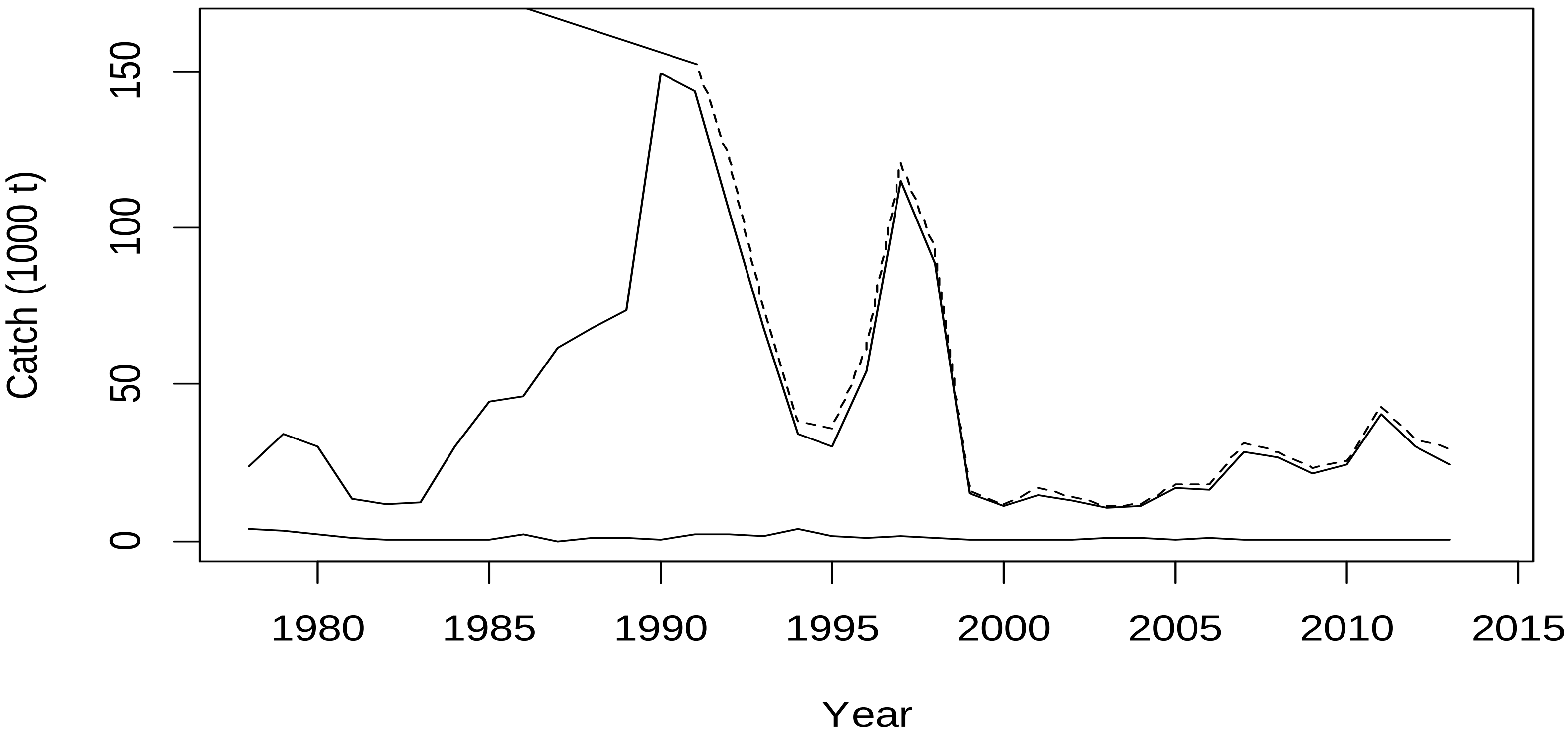


Figure 1. Catch (1000 t) from the directed snow crab pot fishery and groundfish trawl bycatch. Total catch (dashed line) is retained catch(solid line) plus discarded catch after 30% discard mortality was applied. Trawl bycatch (lower solid line) is male and female bycatch from groundfish trawl fisheries with 80% mortality applied.

Model scenarios

- Model 0 – September 2013 model – one linear function by sex to fit growth data
- Model 1 – Two linear functions by sex with a fixed intersection point
- Models 2a, Base model 2b and 2c – Growth data fit in model using two linear segments with a smooth transition by sex (Recommended by CIE review) with weight of 1, 2 and 3 on growth likelihood (sd 0.47, 0.71 and 1.41).
- Models 2d through 2g – Sensitivity to fishing mortality penalties – weights on penalties relative to the Base model 2b of 0.5, 0.25, 0.1 and 0.001.

Changes to Data

- 2014 survey biomass and length frequency data.
- 2013/14 fishery (directed, pot and groundfish bycatch) catch and length frequency data
- New series of fishery length data not used - final revision with revised effort data not available

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

Data component	Years
Retained male crab pot fishery size frequency by shell condition	1978/79-2013/14
Discarded male and female crab pot fishery size frequency	1992/3-2013/14
Trawl fishery bycatch size frequencies by sex	1991-2013/2014
Survey size frequencies by sex and shell condition	1978-2014
Retained catch estimates	1978/79-2013/14
Discard catch estimates from snow crab pot fishery	1992/93-2013/14 from observer data
Trawl bycatch estimates	1973-2013/14
Total survey biomass estimates and coefficients of variation	1978-2014
2009 study area biomass estimates and coefficients of variation and length frequencies for BSFRF and NMFS tows	2009
2010 study area biomass estimates and coefficients of variation and length frequencies for BSFRF and NMFS tows	2010

Base Model

- Immature M estimated for males and females (one parameter)
- Mature male M estimated with prior 0.23
- Availability (2009 and 2010 BSFRF study) estimated as a smooth function.
- Discard Mortality 0.3
- Growth data fit by two linear functions by sex with a smooth transition

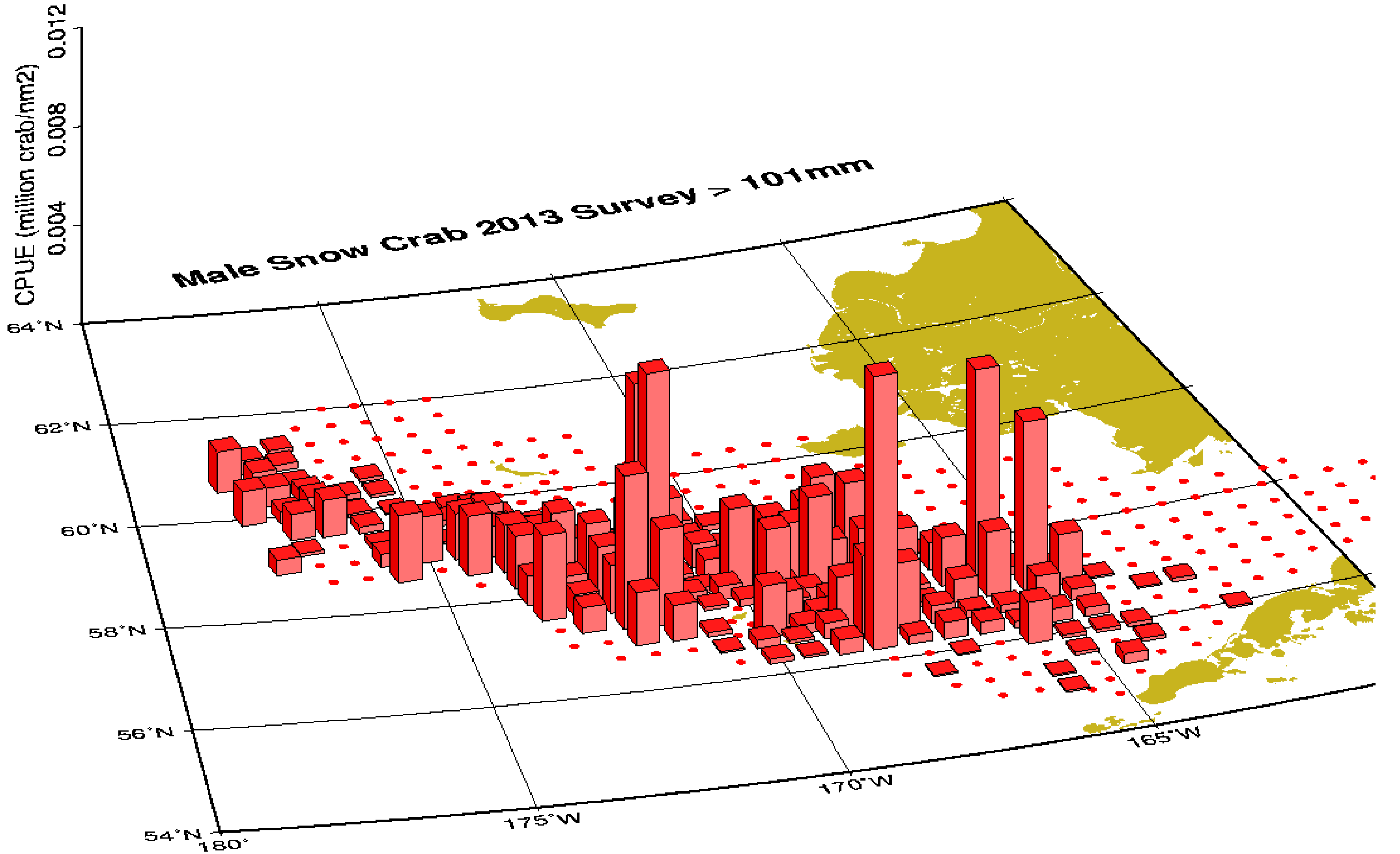


Figure 25d. 2013 Survey CPUE (million crab per nm2) of males > 101mm by tow. Filled circles are tows with 0 cpue.

About 40 million crab from two tows (138 million total survey estimate)

•

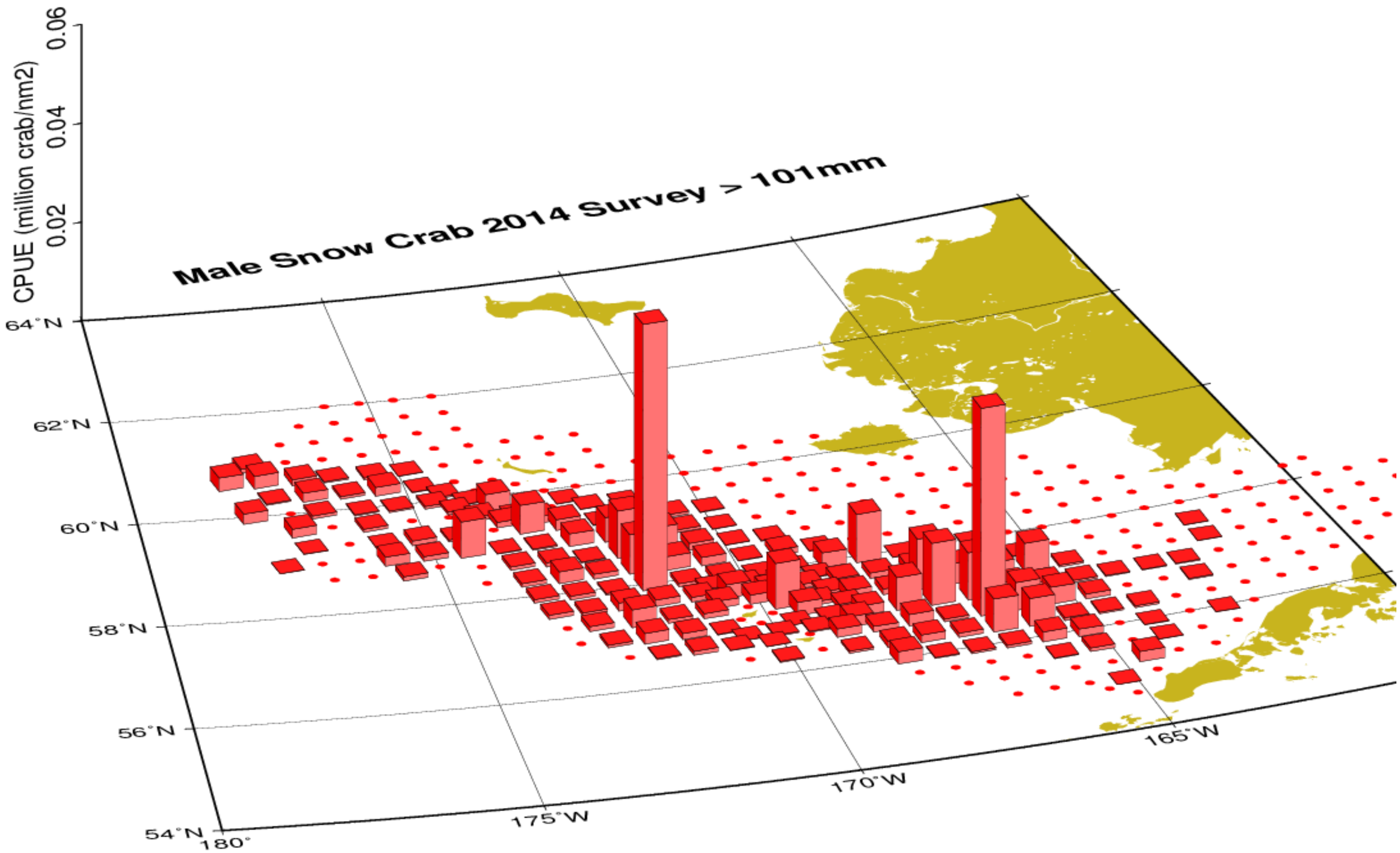


Figure 21. 2014 Survey CPUE (million crab per nm2) of males > 101mm by tow. Filled circles are tows with 0 cpue.

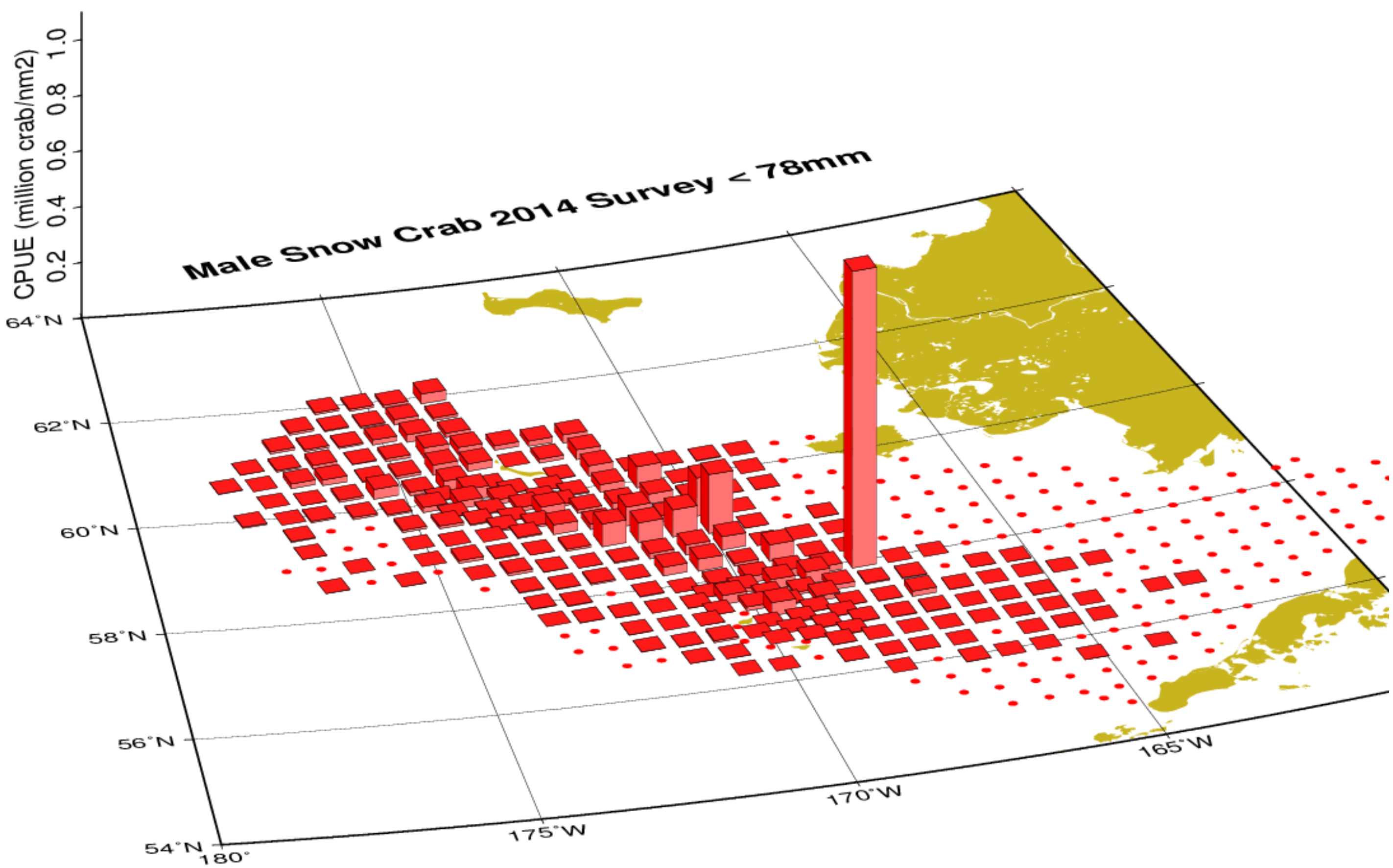


Figure 19. 2014 Survey CPUE (million crab per nm2) of males < 78mm by tow. Filled circles are tows with 0 cpue.

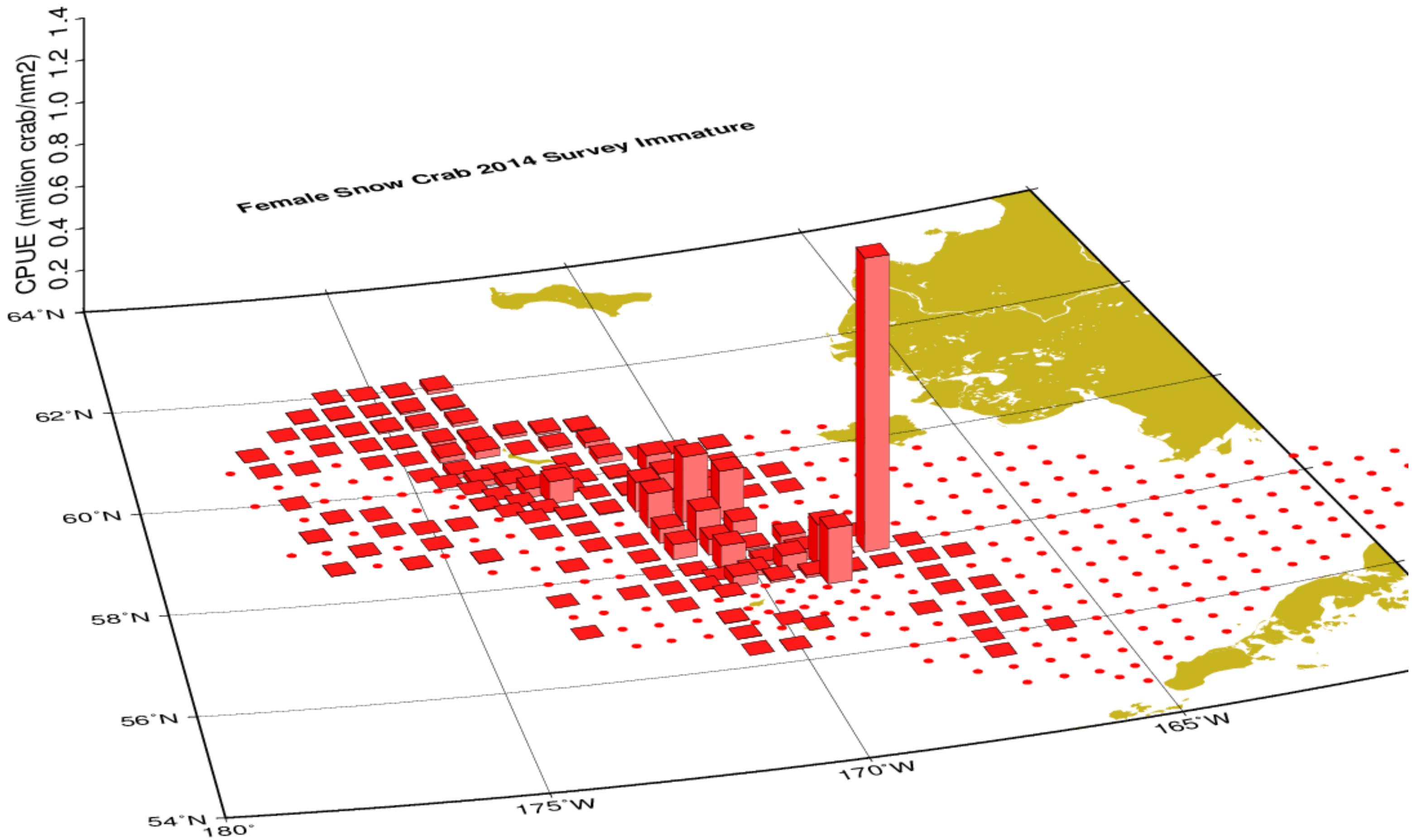


Figure 22. 2014 Survey CPUE (million crab per nm2) of immature females by tow. Filled circles are tows with 0 cpue.

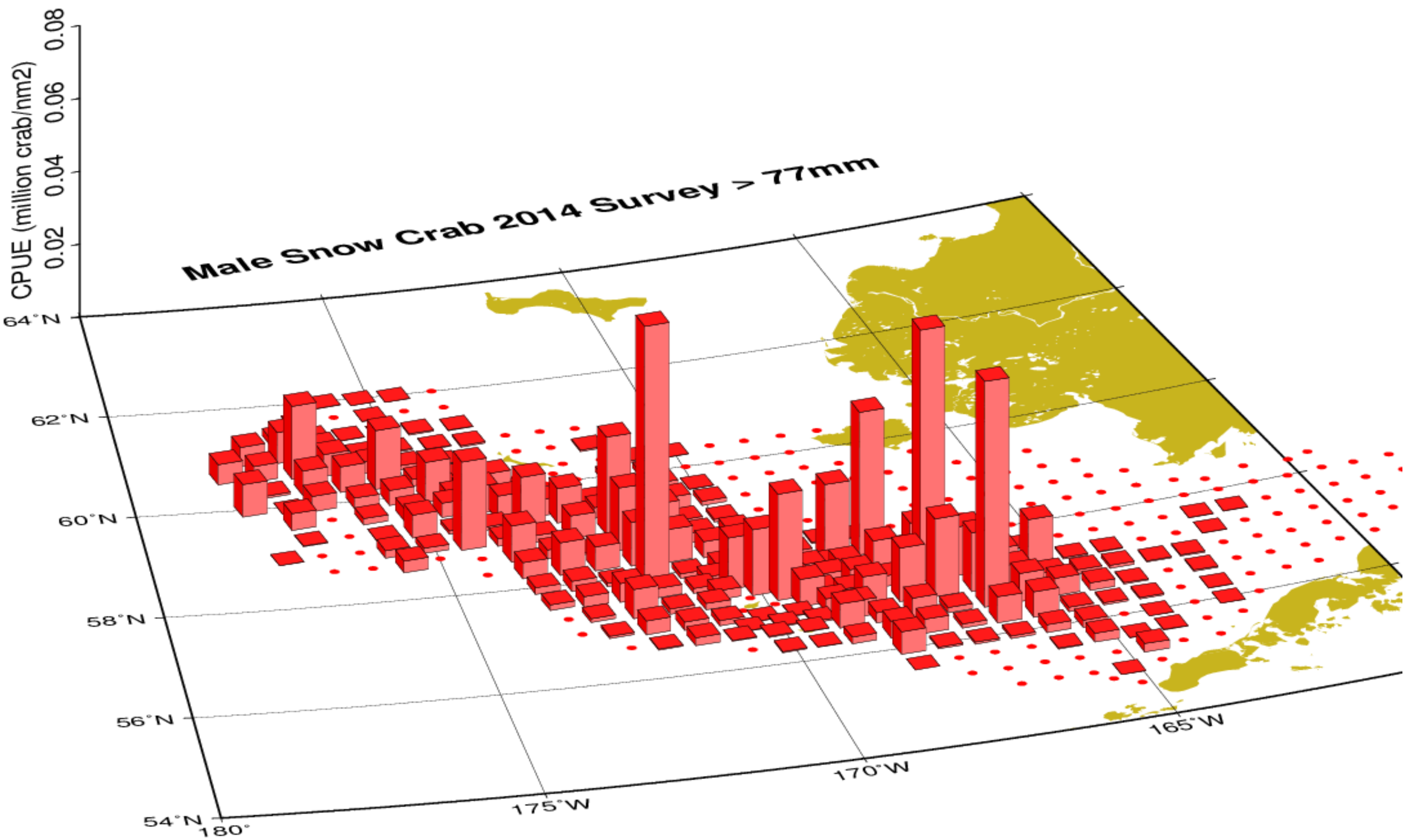


Figure 20. 2014 Survey CPUE (million crab per nm2) of males > 77mm by tow. Filled circles are tows with 0 cpue.

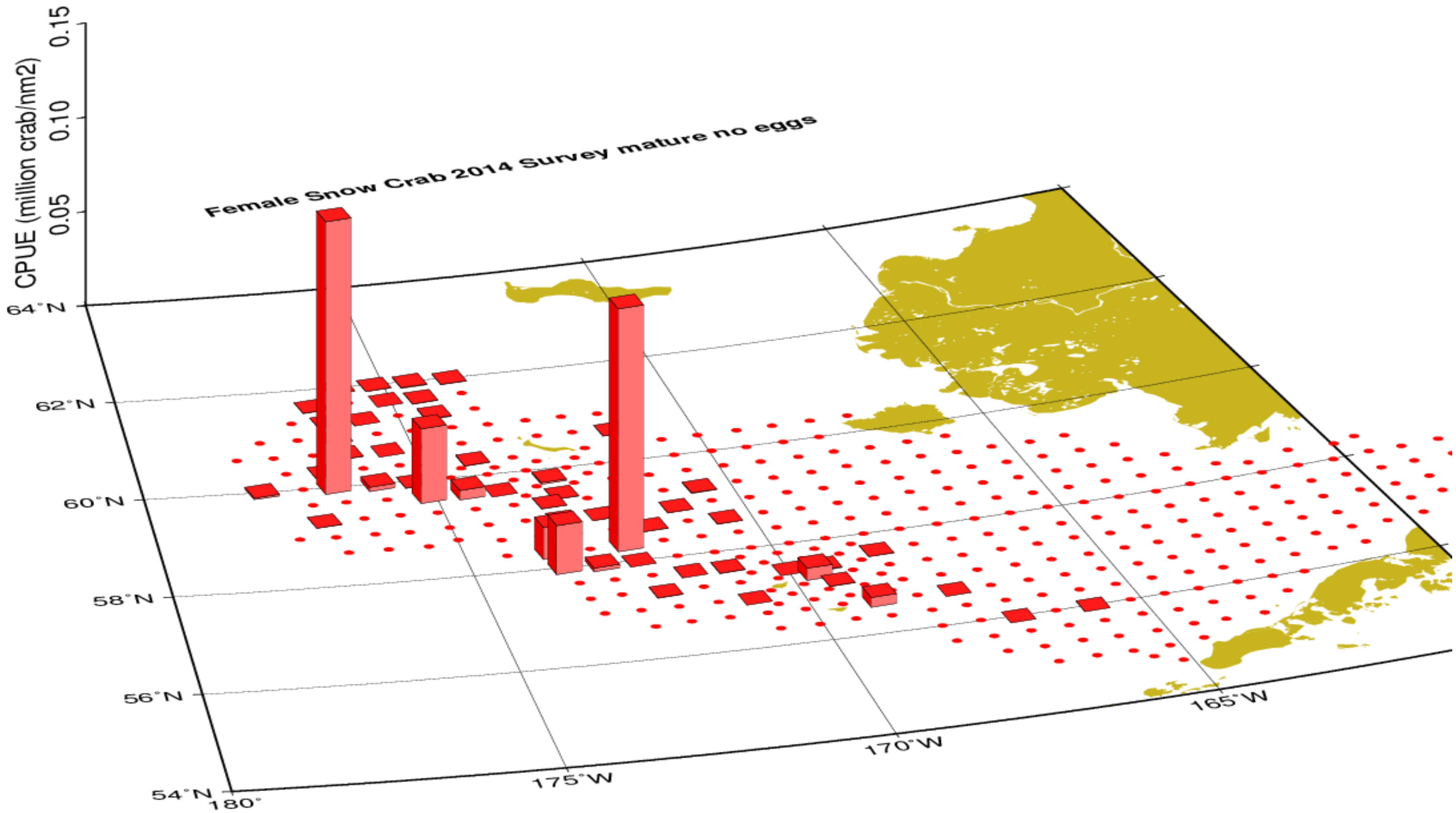


Figure 23. 2014 Survey CPUE (million crab per nm2) of mature females with no eggs by tow. Filled circles are tows with 0 cpue.

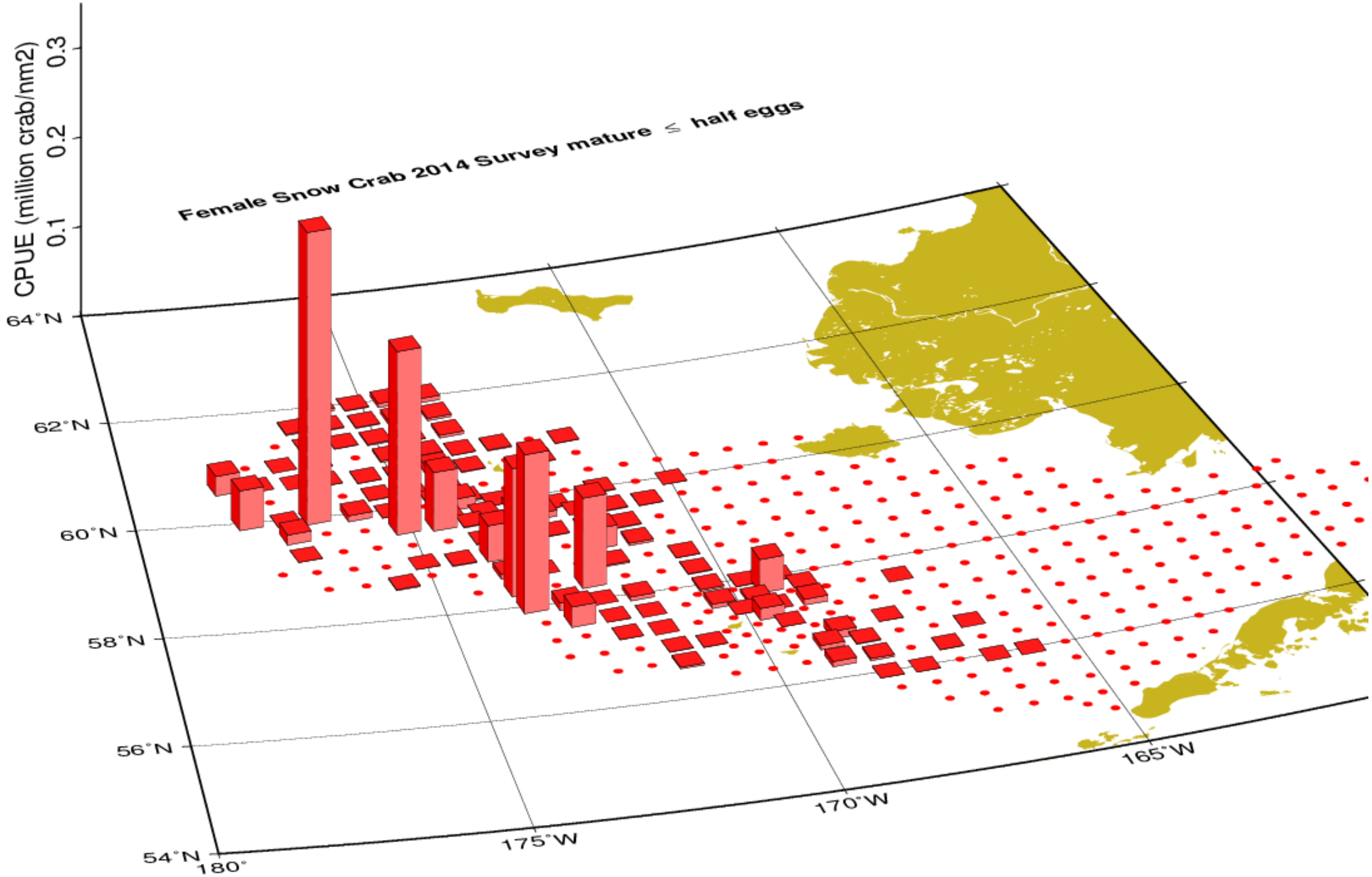


Figure 25. 2014 Survey CPUE (million crab per nm2) of mature females with <= half clutch of eggs by tow. Filled circles are tows with 0 cpue

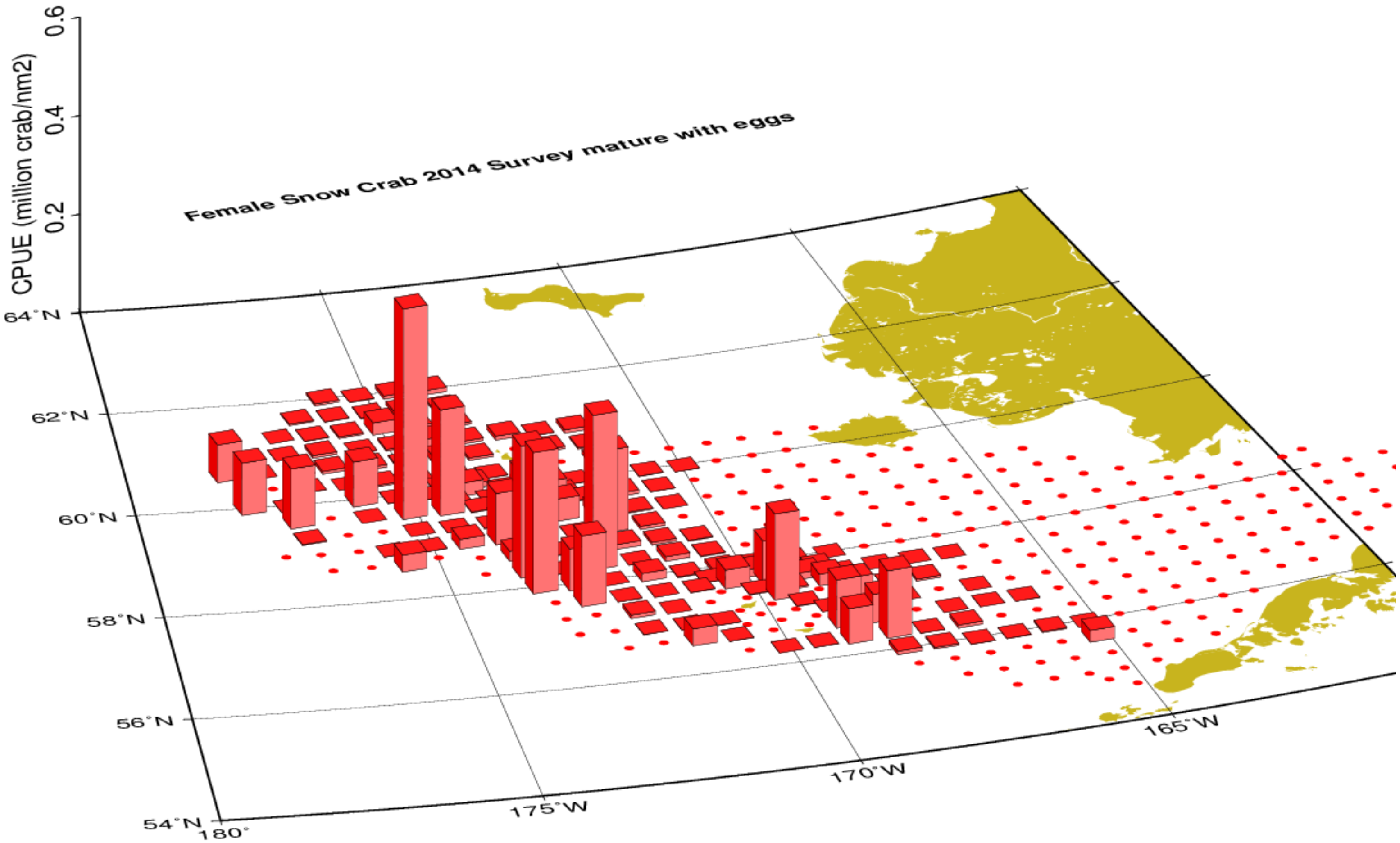


Figure 24. 2014 Survey CPUE (million crab per nm2) of mature females with eggs (all clutch sizes) by tow. Filled circles are tows with 0 cpue.

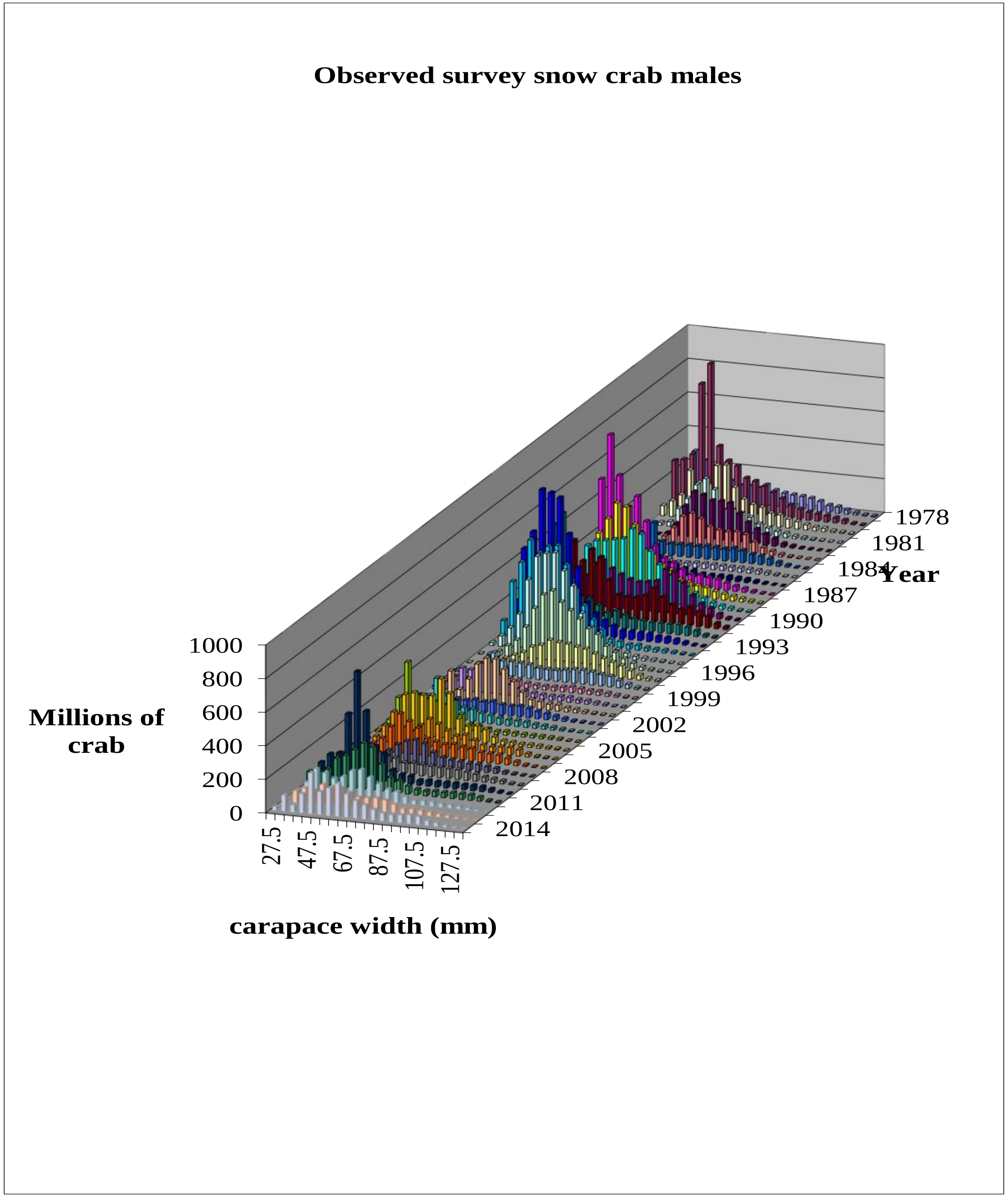


Figure 6. Observed survey numbers (millions of crab) by carapace width and year for male snow crab.

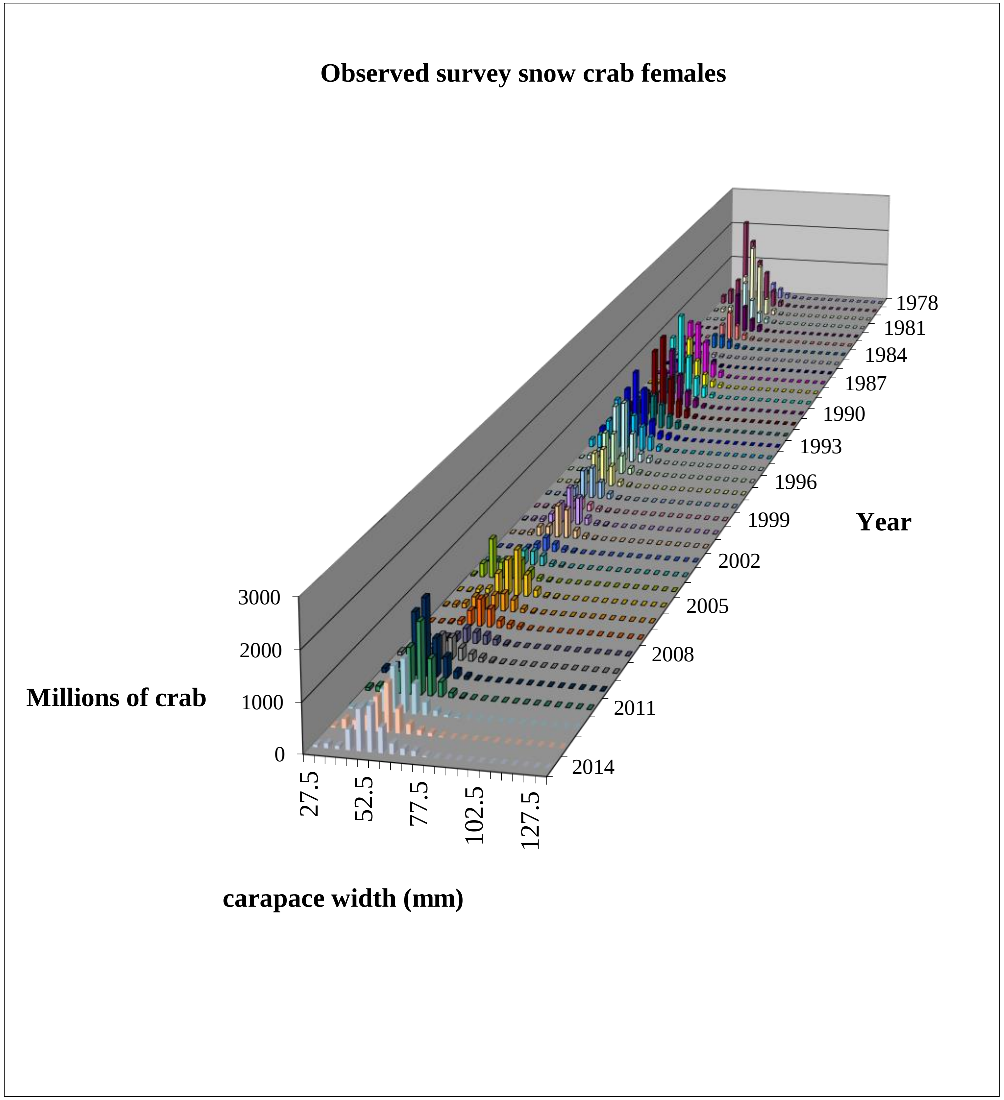


Figure 7. Observed survey numbers (millions of crab) by carapace width and year for female snow crab.

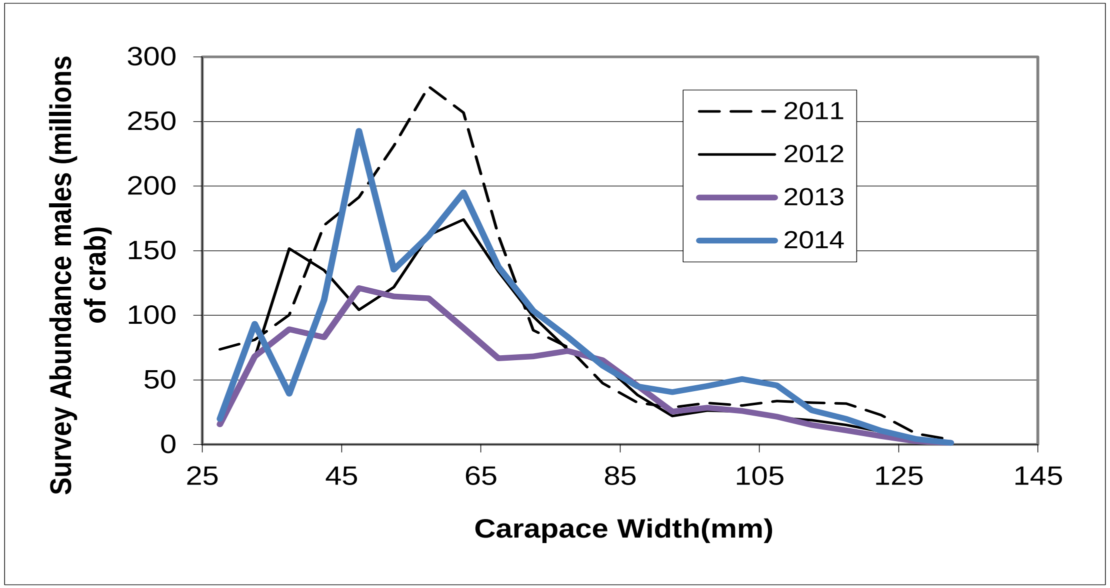


Figure 8a. Survey male abundance by length for 2011 to 2014.

Growth

The base model in the current assessment has growth modeled as two linear segments with a smooth transition recommended by the 2014 CIE review (Cadigan 2014),

$$f_i(x) = a_i + b_i\, x, \qquad i = 1,2\ ,$$

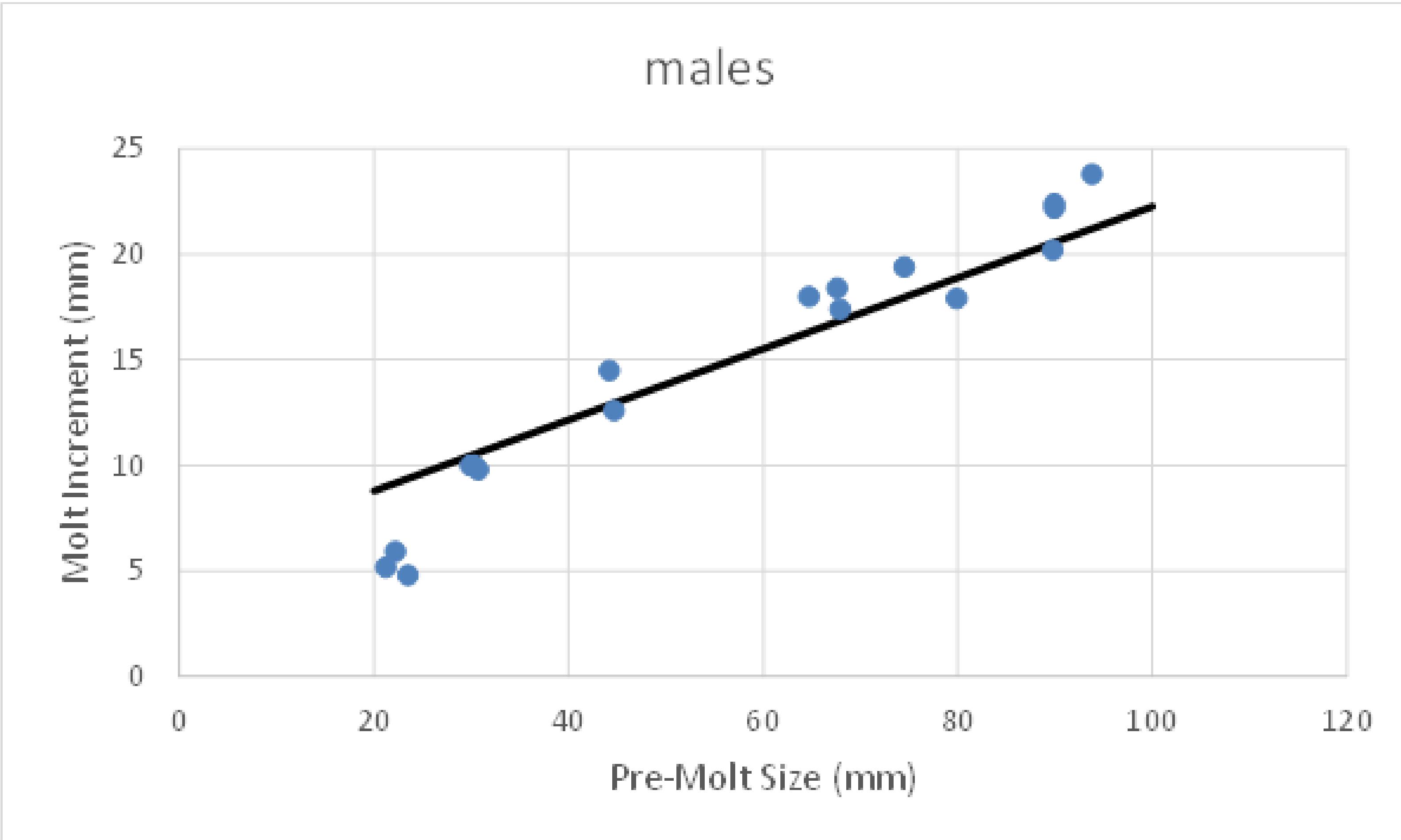
$$a_2 = a_1 + (b_1 - b_2)\delta$$

$$f(x) = f_1(x)\left\{1 - \varphi\left(\frac{x-\delta}{s}\right)\right\} + f_2\,(x)\left\{\varphi\left(\frac{x-\delta}{s}\right)\right\}$$

Where φ is the cumulative distribution function for a standard normal random variable. δ constrains the breakpoint, and s is a scale parameter determining how smooth the transition is between equation segments.

Growth parameters

- Estimated 9 growth parameters. a_1, b_1, b_2 and δ by sex and s combined for both sexes
- Cadigan recommended fixing the s parameter
- Separate s parameters by sex did not converge
- Fixing s resulted in difference join points


males
Molt Increment (mm)
0
5
10
15
20
25
0
20
40
60
80
100
120
Pre-Molt Size (mm)

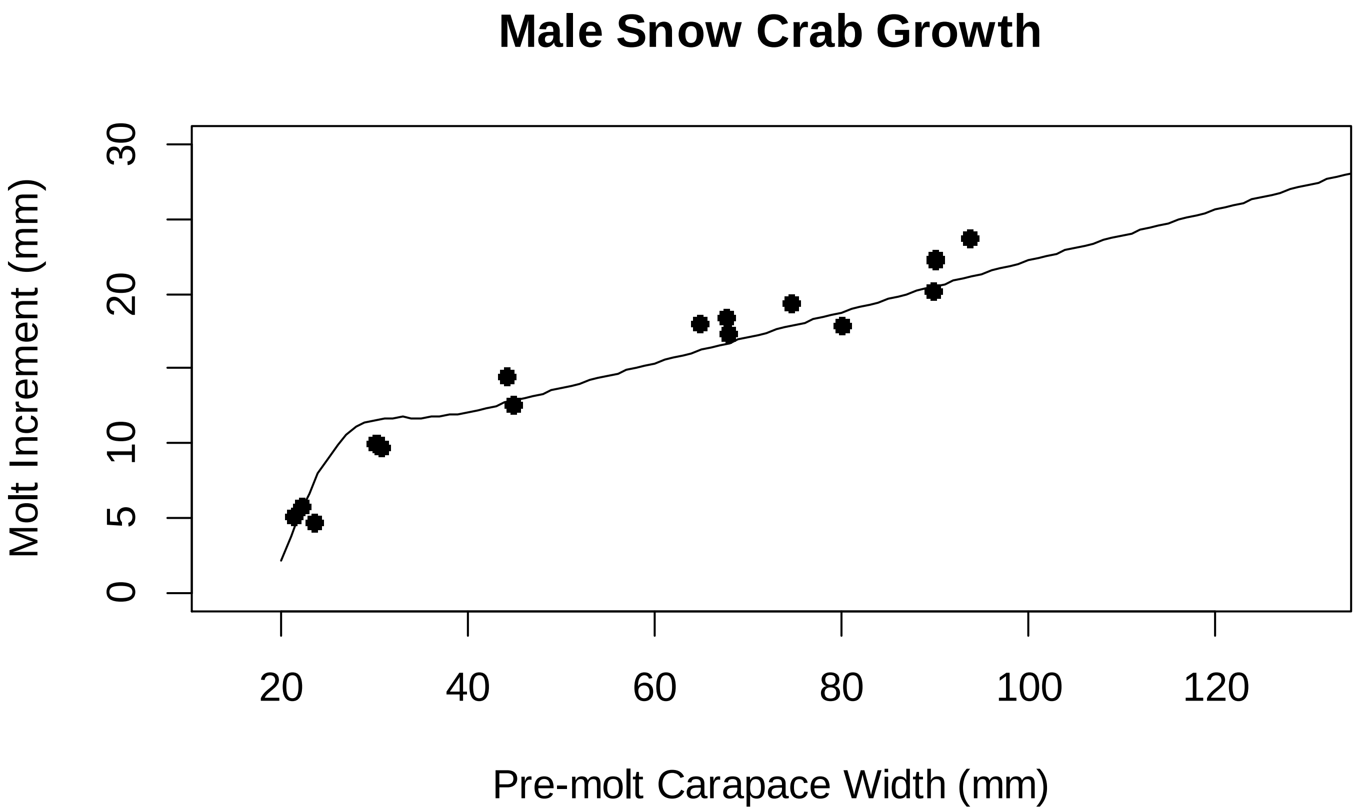


Figure 54b. Male growth data from 2011 growth study with estimated linear growth function (top panel last year’s assessment - September 2013 assessment base model) and using the Cadigan method (Base model this assessment – Model 2b).

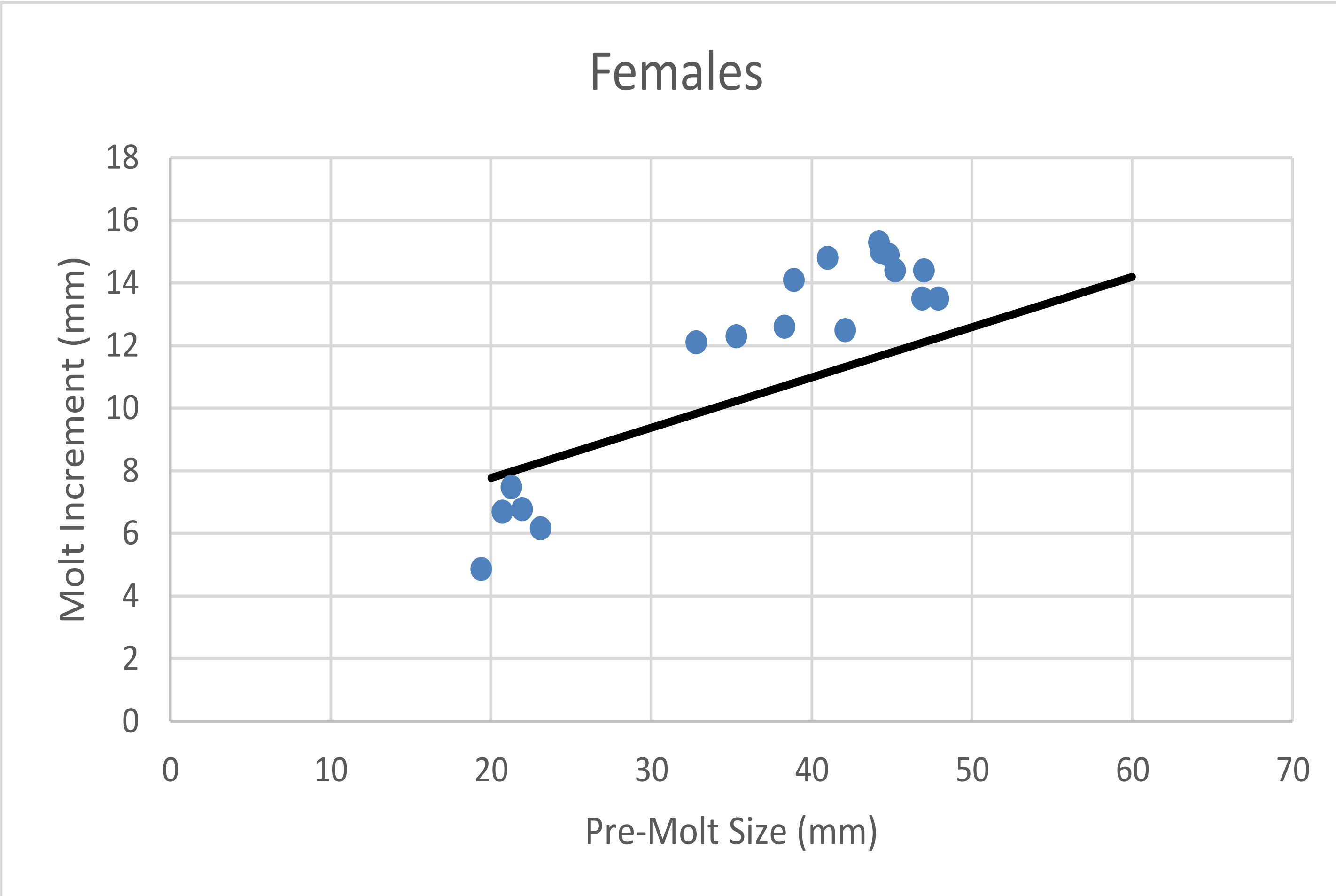
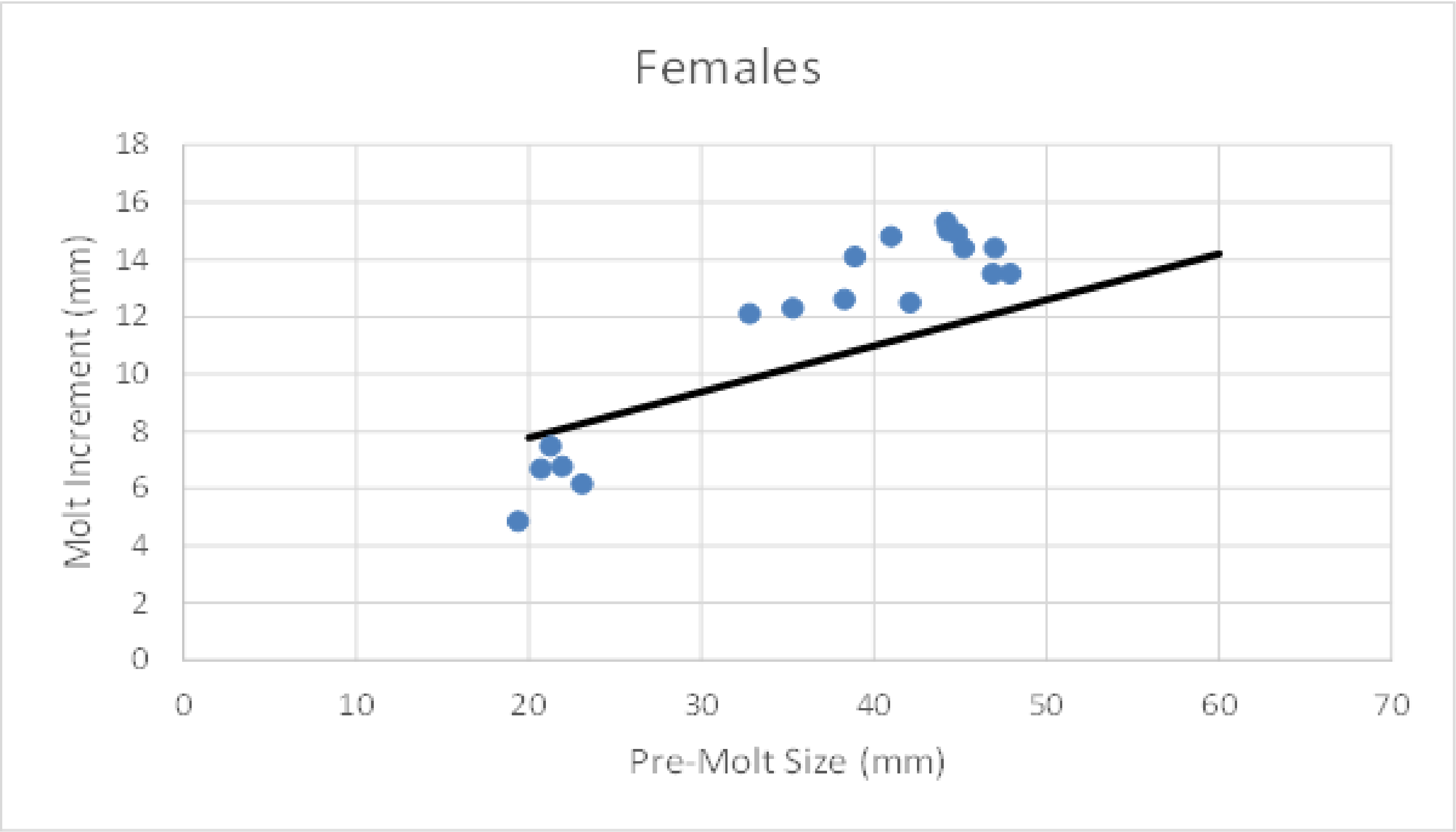


Figure 54c. . Female growth data from 2011 growth study with estimated linear growth function from Base model.


Females
Molt Increment (mm)
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
Pre-Molt Size (mm)

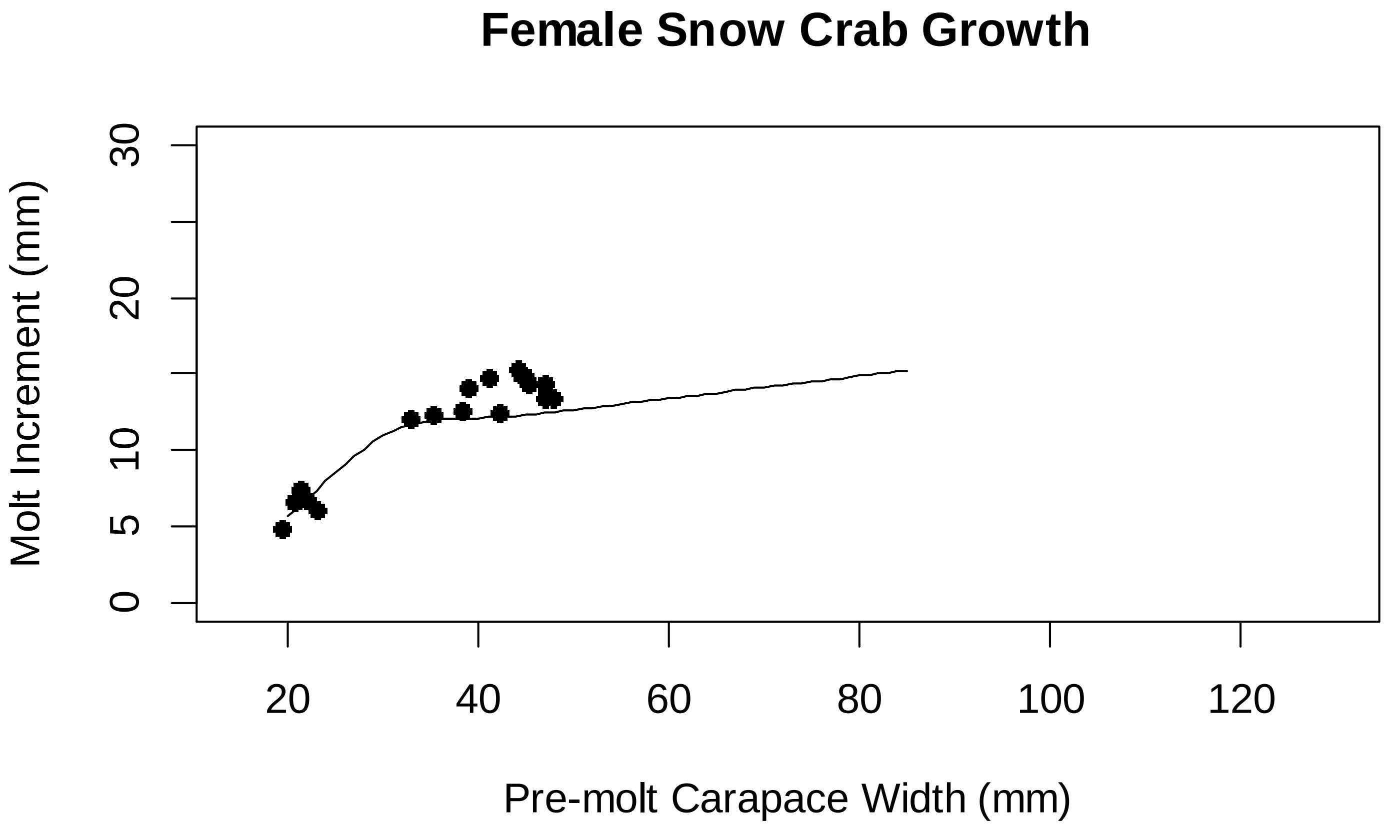


Figure 54c. Female growth data from 2011 growth study with estimated linear growth function (top panel last year's assessment - September 2013 assessment base model) and using the Cadigan method (Base model this assessment, model 2b).

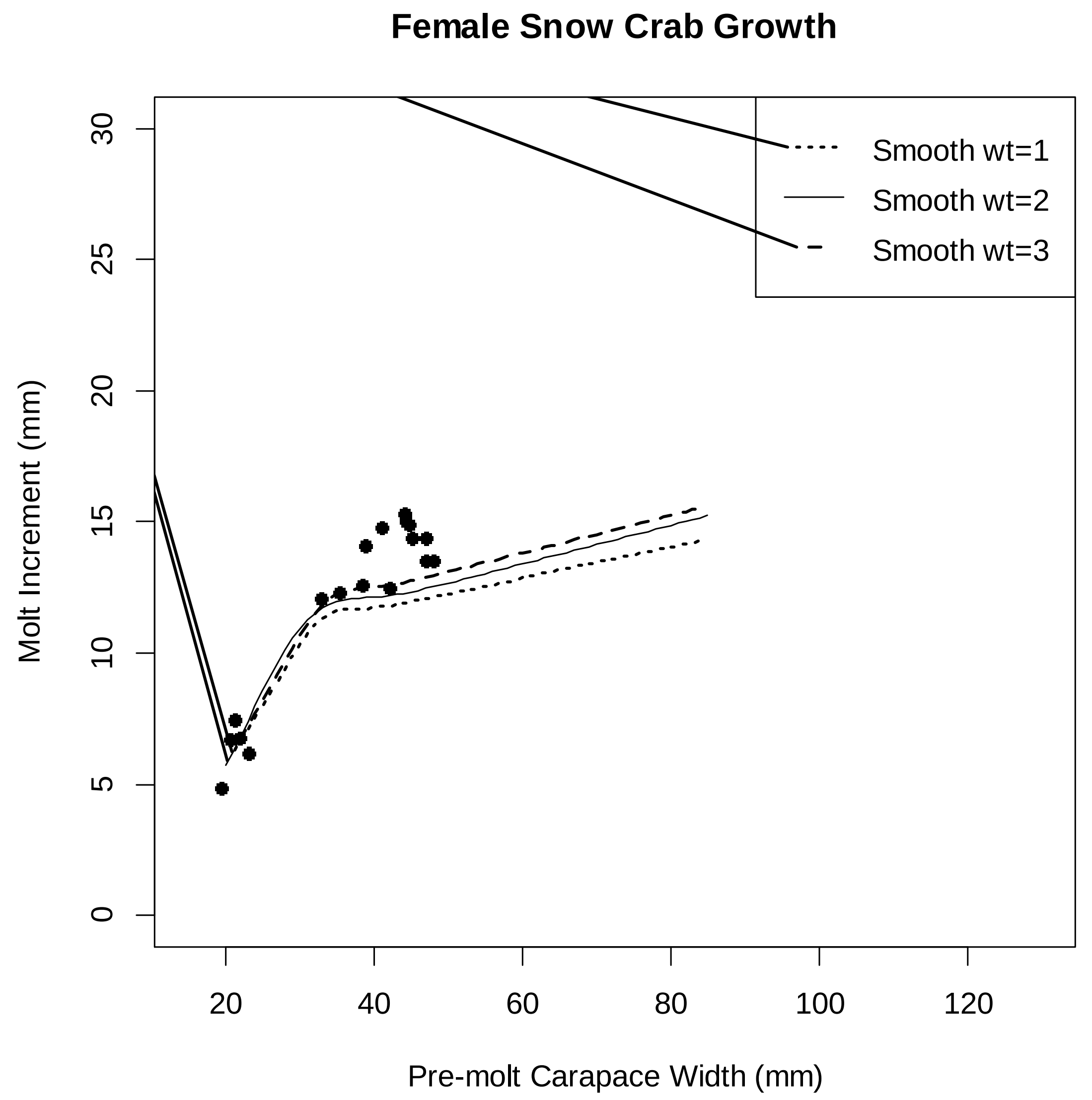


Figure 54d. Estimated female growth for cardigan smooth with weights 1, 2 and 3 on growth likelihood(2a, 2b and 2c model scenarios).

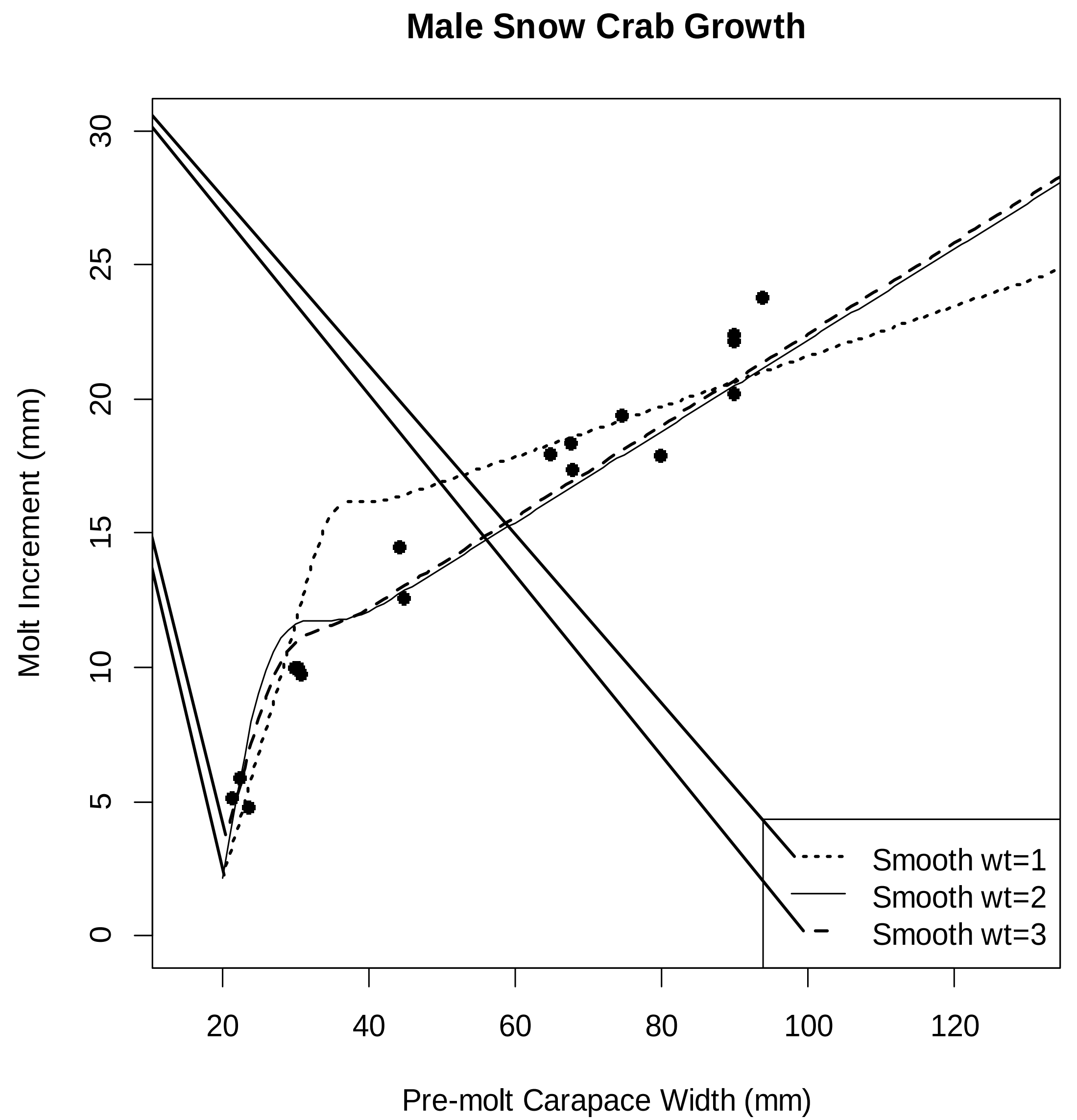


Figure 54e. Estimated male growth for cardigan smooth with weights 1, 2 and 3 on growth likelihood (2a, 2b and 2c model scenarios).

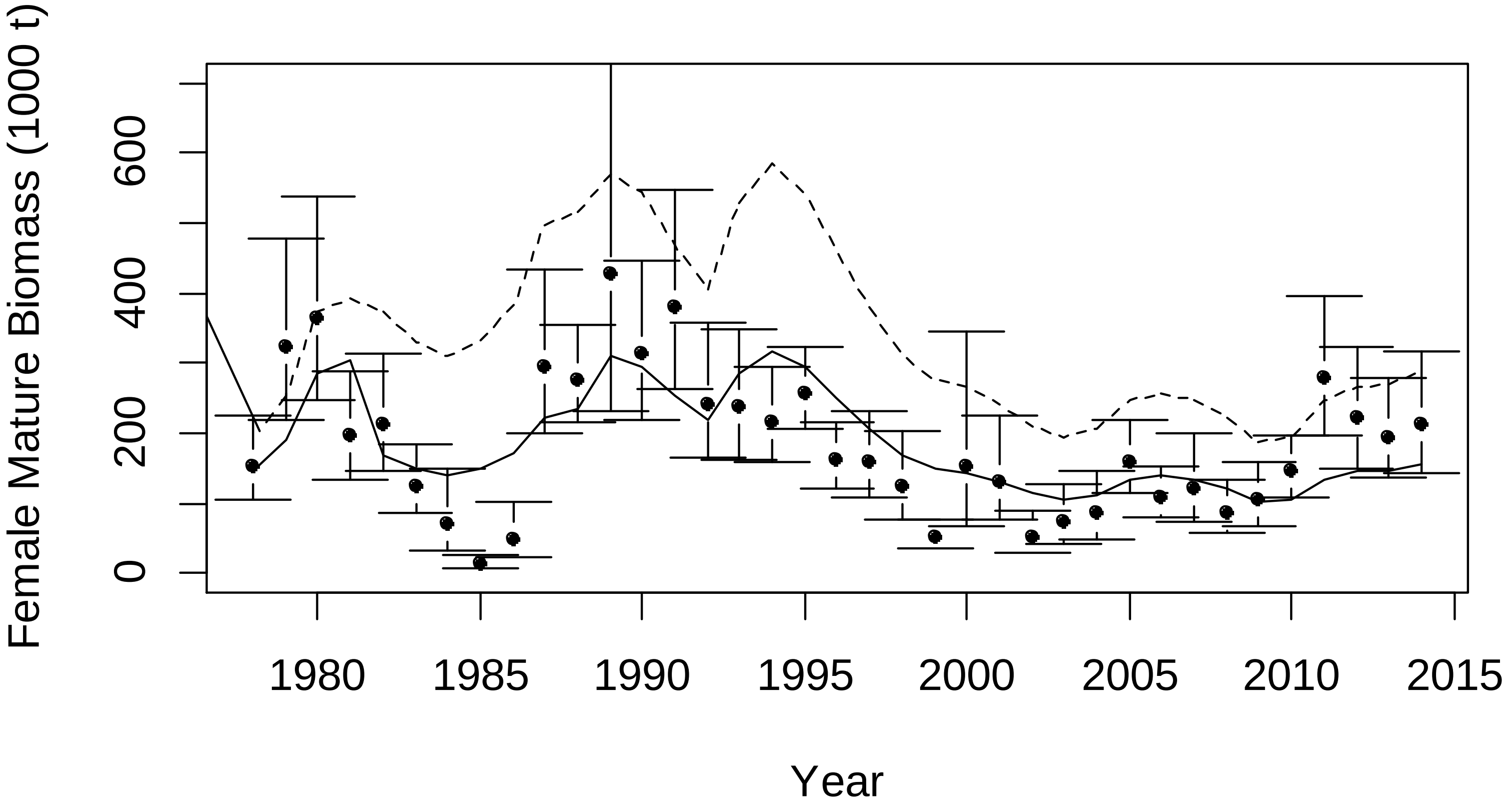


Figure 62. Base Model. Population female mature biomass (1000 t, dotted line), model estimate of survey female mature biomass (solid line) and observed survey female mature biomass with approximate lognormal 95% confidence intervals.

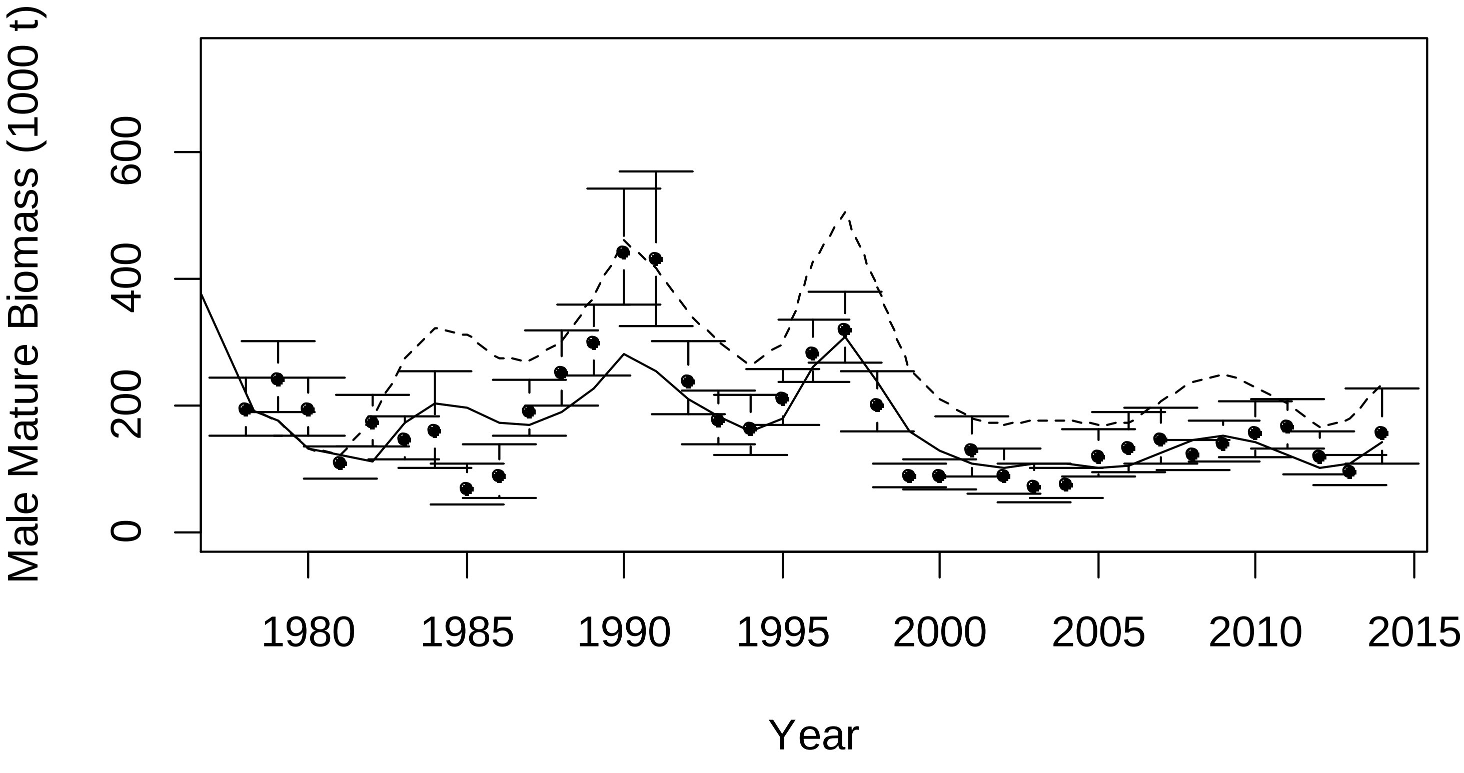


Figure 64. Base Model. Population male mature biomass (1000 t, dotted line), model estimate of survey male mature biomass (solid line) and observed survey male mature biomass with approximate lognormal 95% confidence intervals.

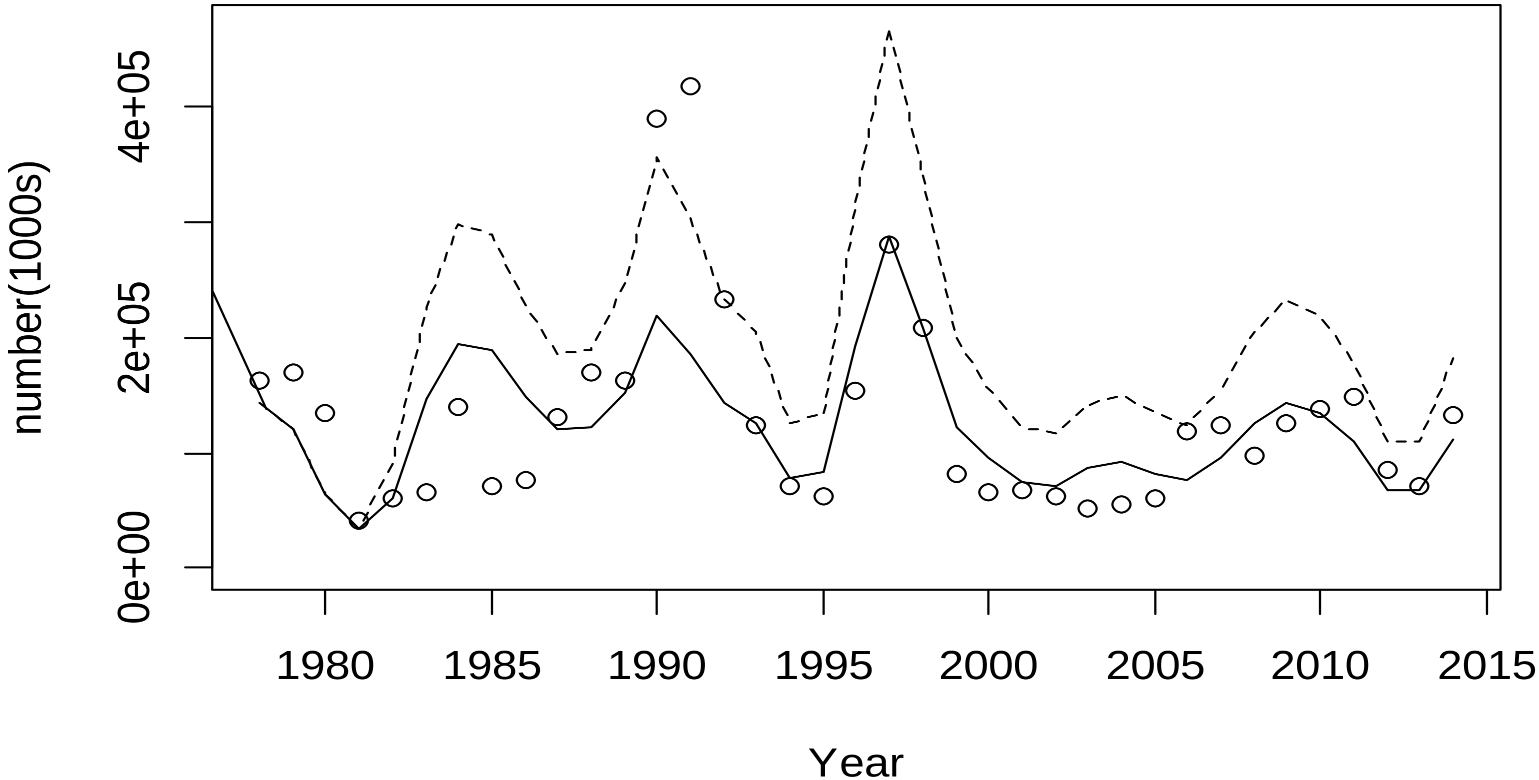


Figure 73. Base Model. Observed survey numbers of males >101mm (circles), model estimates of the population number of males >101mm(solid line) and model estimates of survey numbers of males >101 mm (dotted line).

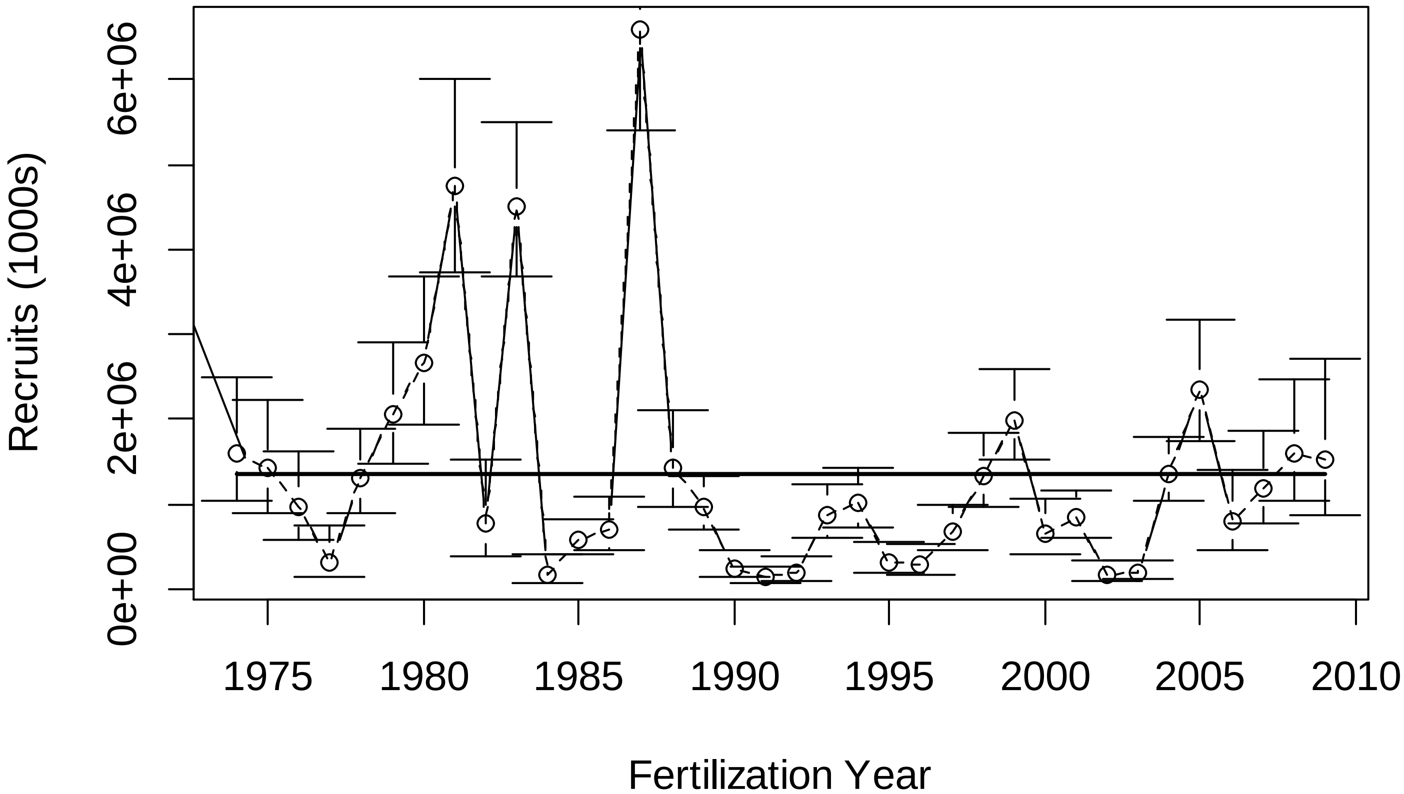


Figure 74. Base Model. Recruitment to the model for crab 25 mm to 50 mm. Total recruitment is 2 times recruitment in the plot. Male and female recruitment fixed to be equal. Solid horizontal line is average recruitment. Error bars are 95% C.I.

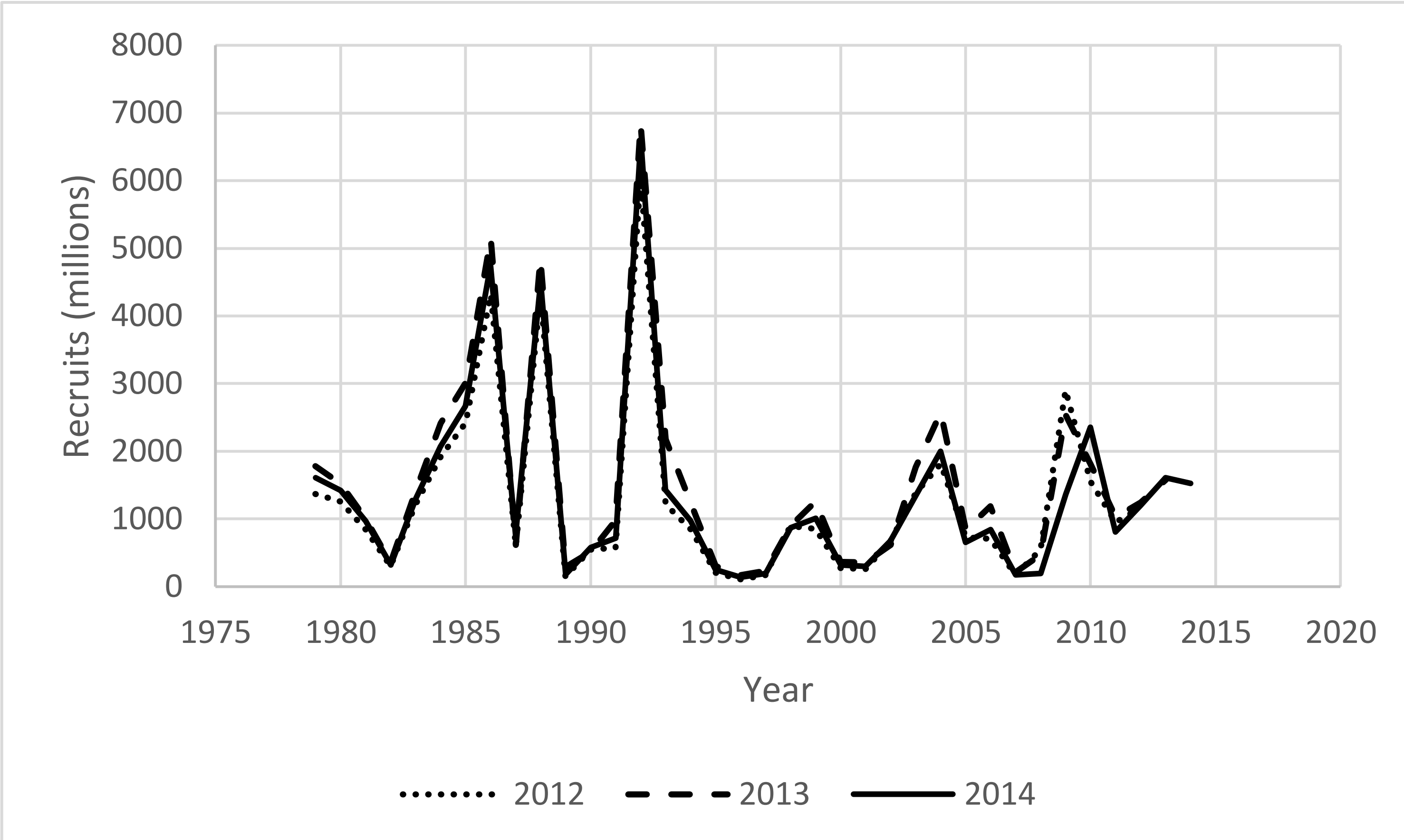


Figure 104. Recruitment estimates from the 2012 and 2013 assessments, and the Base model (2014).

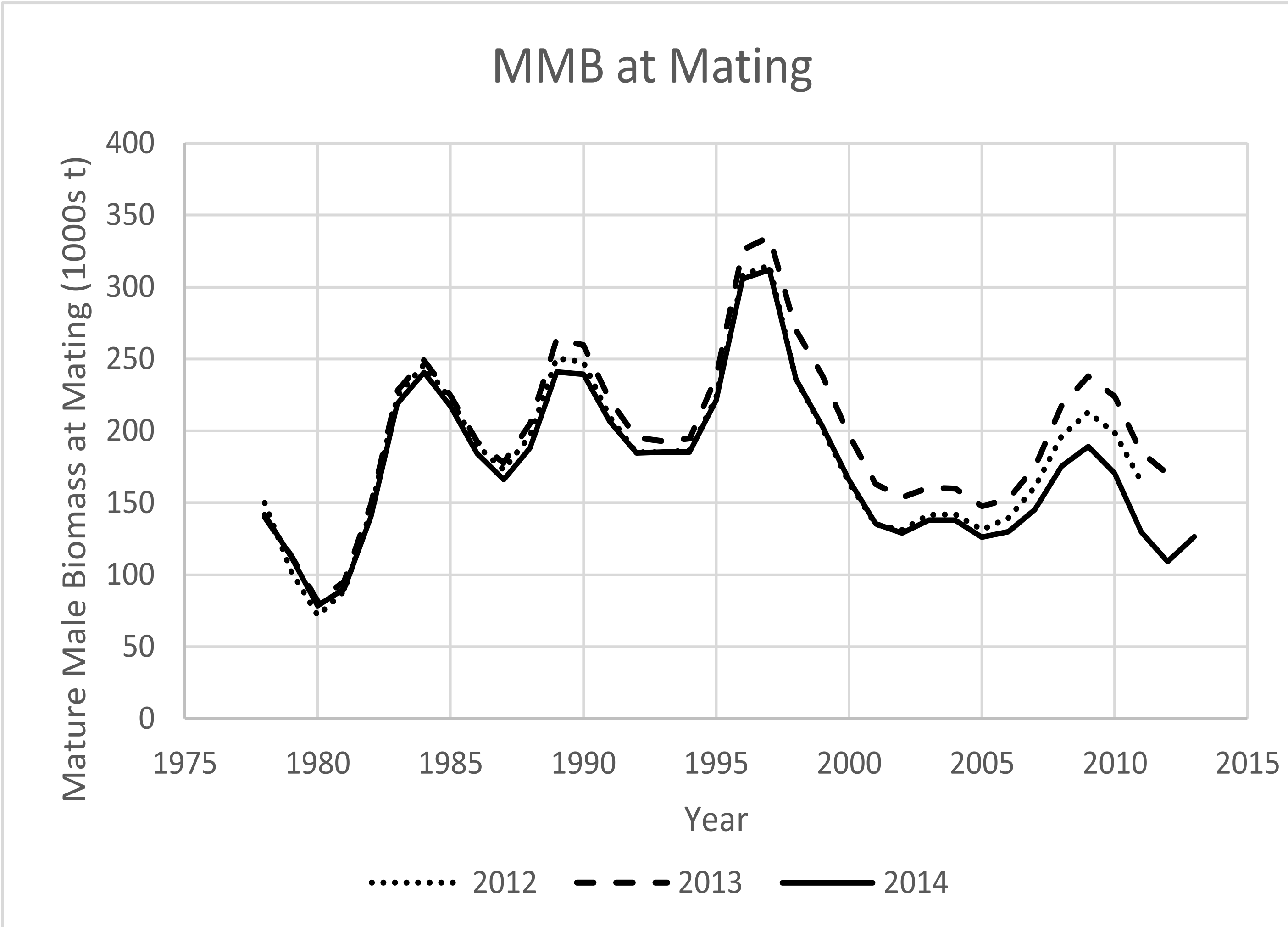


Figure 103. MMB at mating from the 2012 and 2013 assessments, and the Base model (2014).

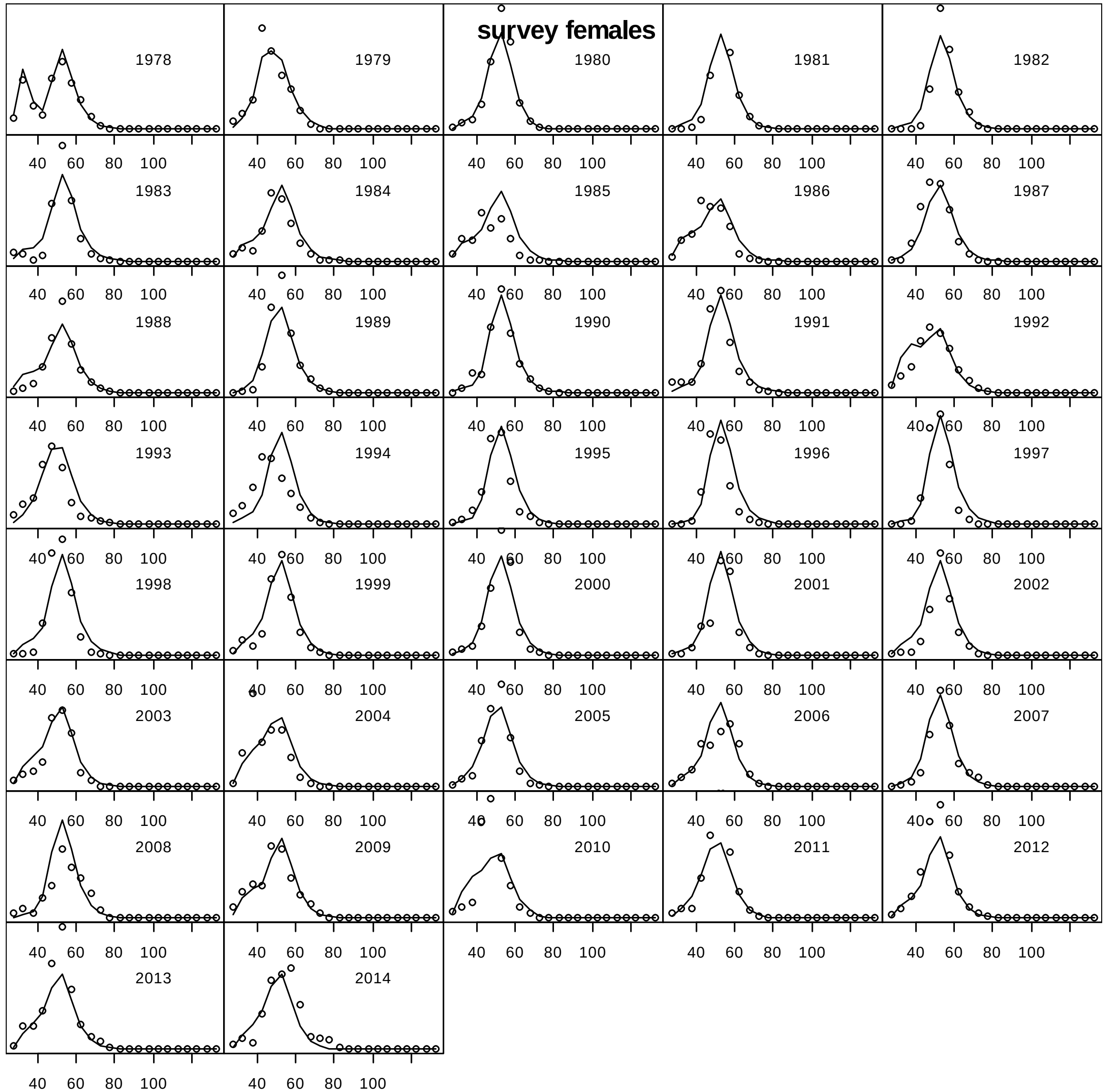


Figure 68. Base Model. Model fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

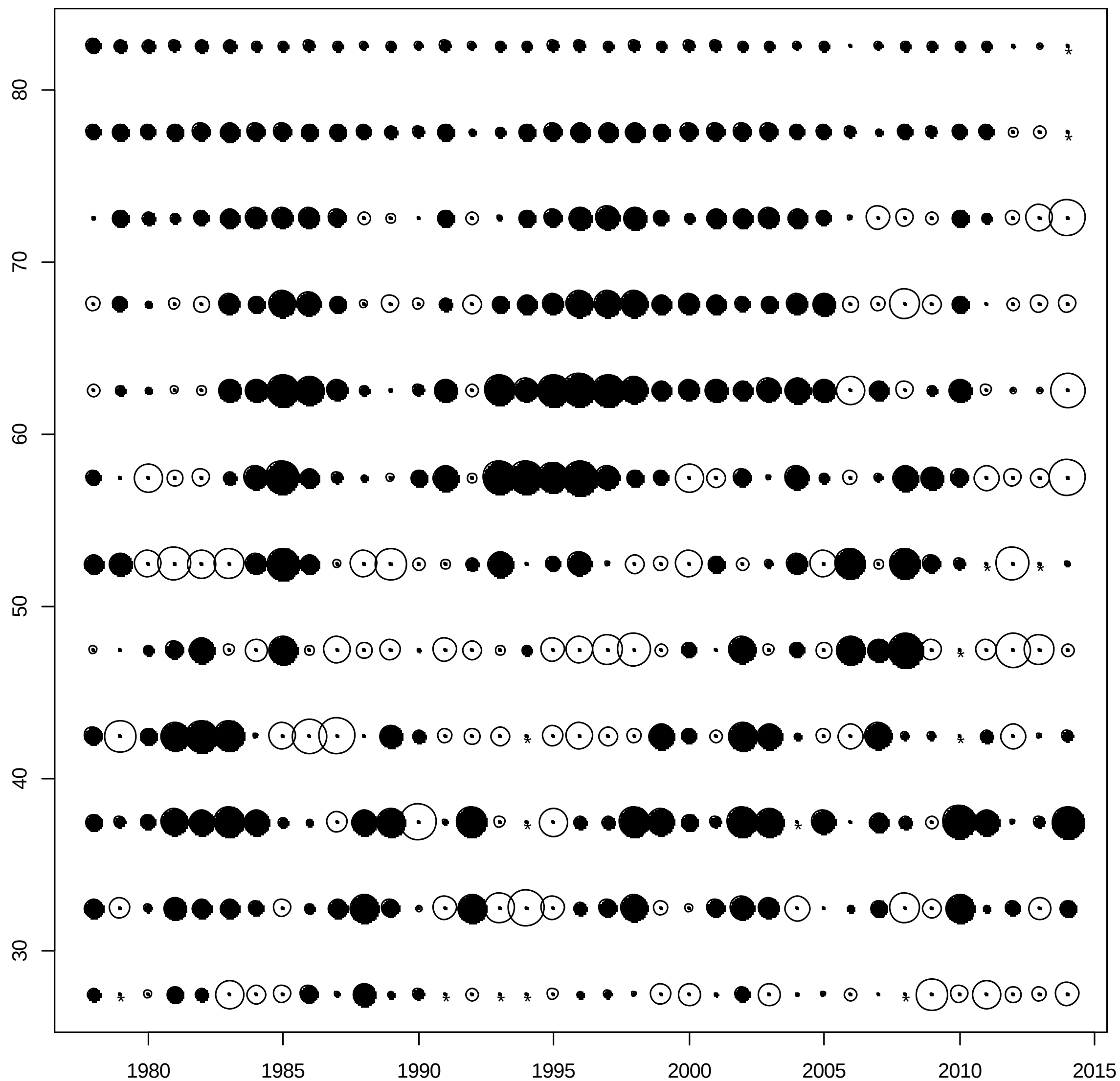


Figure 69. Base Model. Residuals of fit to survey female size frequency. Filled circles are negative residuals.

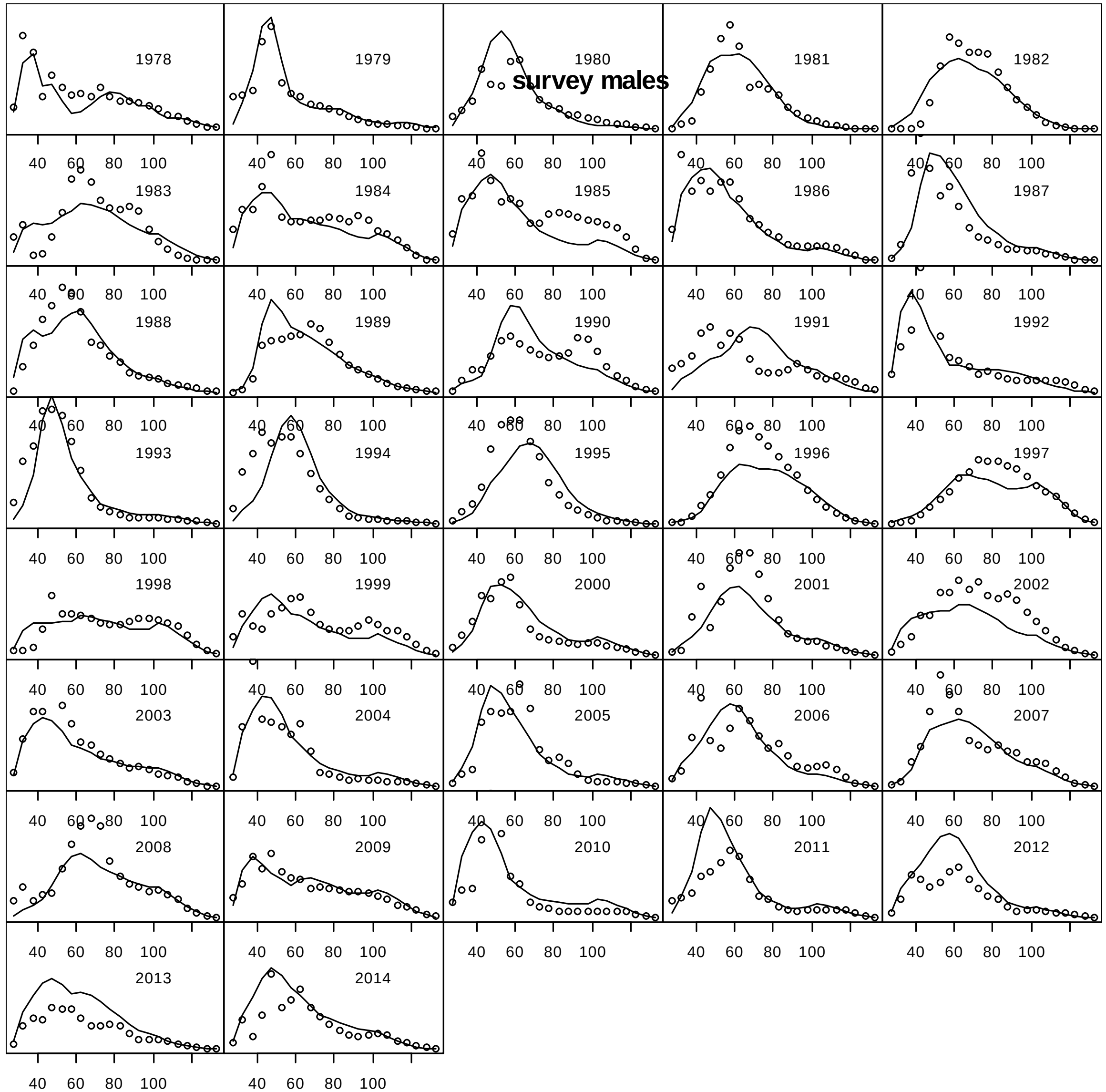


Figure 70. Base Model. Model fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

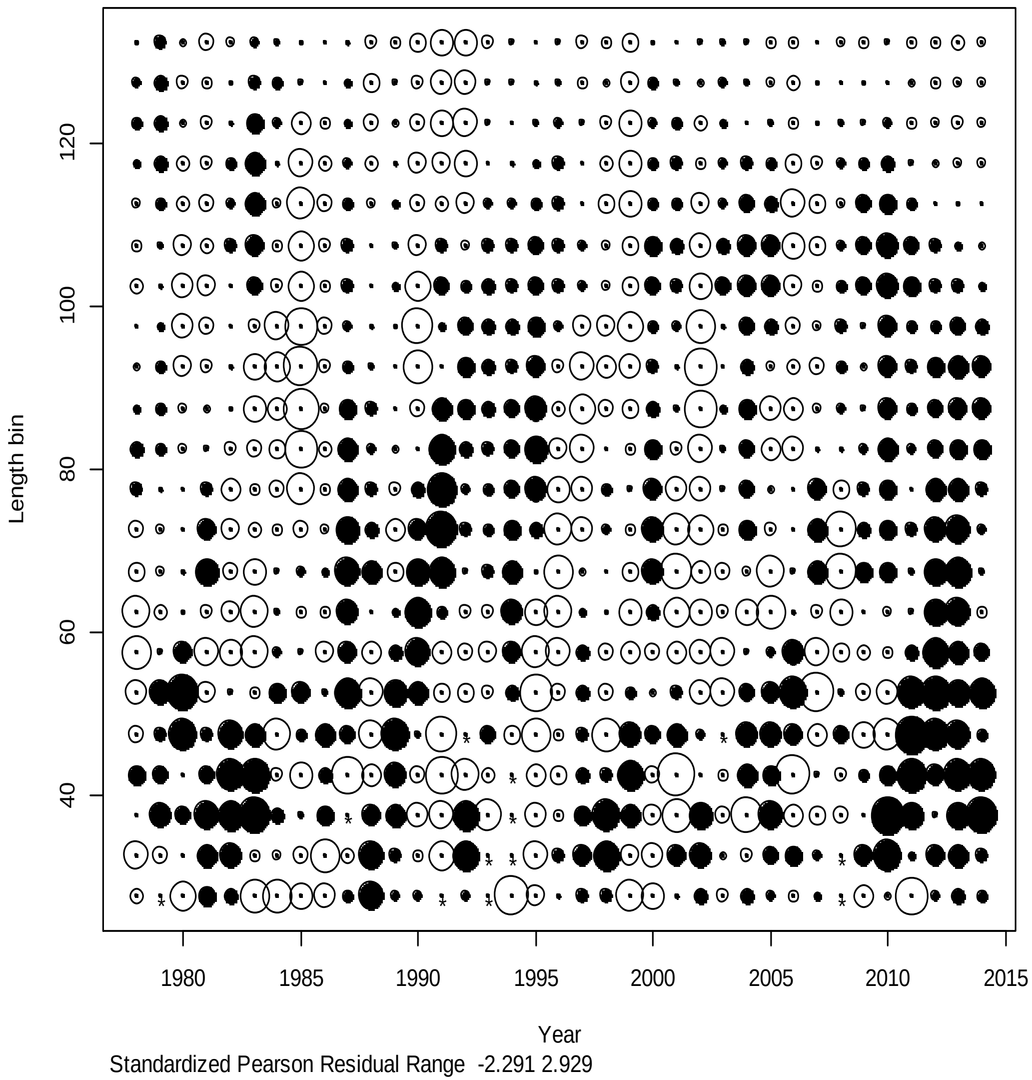


Figure 71. Base Model. Residuals for fit to survey male size frequency. Filled circles are negative residuals (predicted higher than observed).

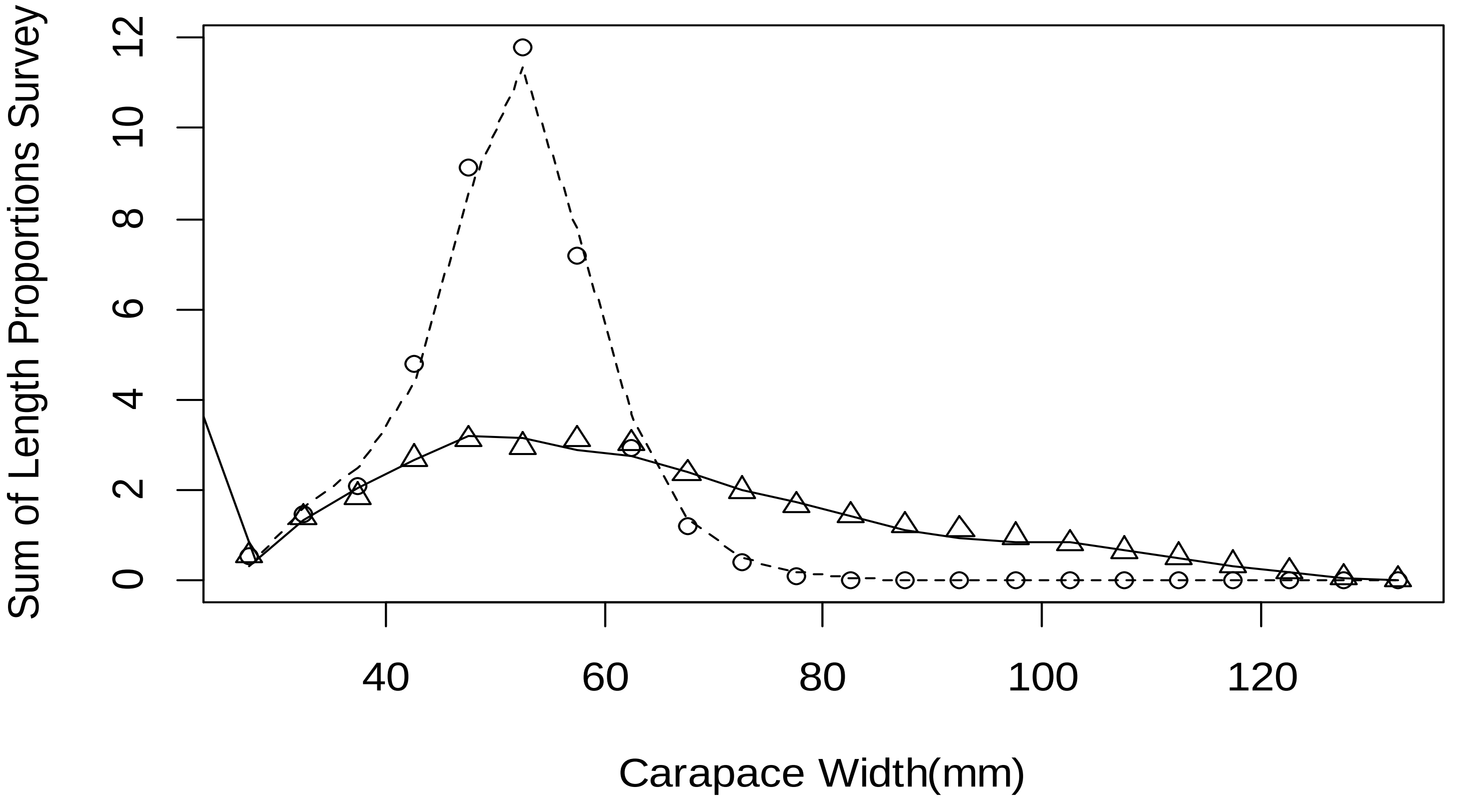


Figure 72. Base Model. Summary over years of fit to survey length frequency data by sex. Dotted line is fit for females, circles are observed. Solid line is fit for males, triangles are observed.

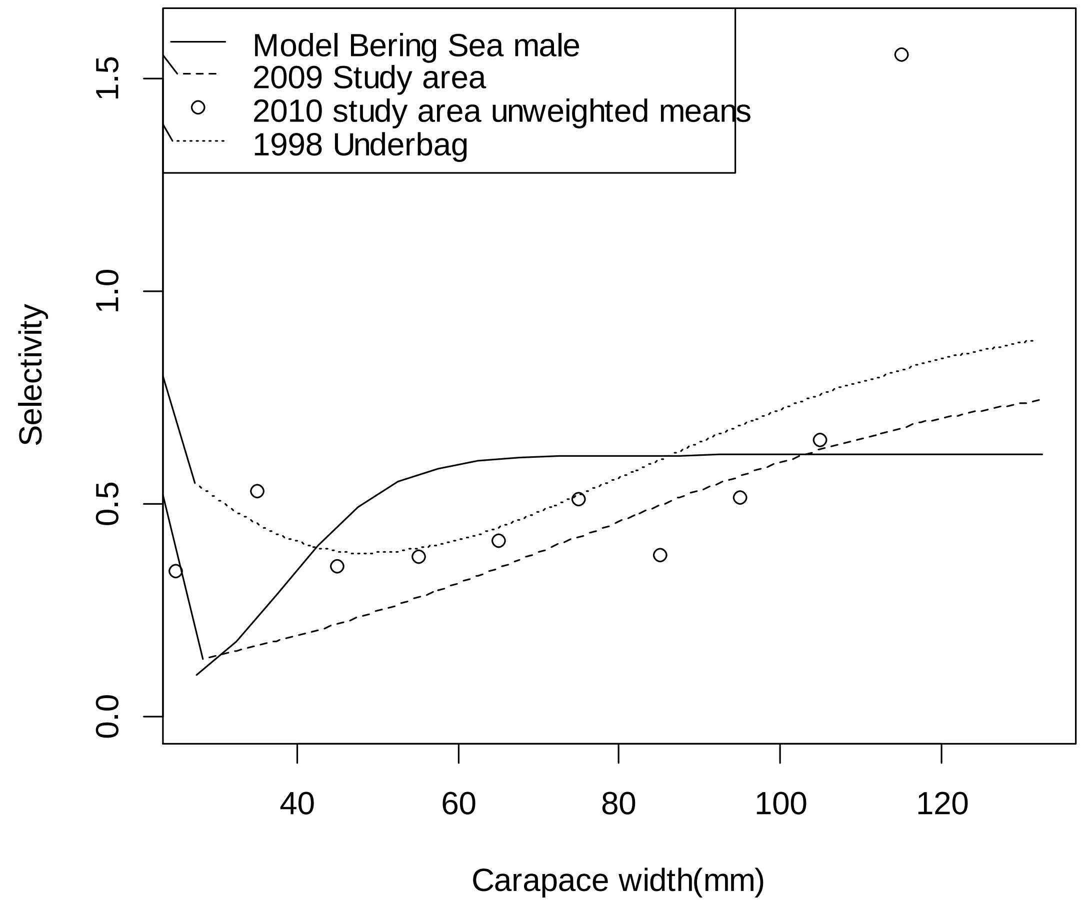


Figure 92. Base Model. Survey selectivity for male crab 1989- present (Model Bering Sea male), with selectivity curves estimated outside the model. 2009 study area is the curve estimated by Somerton from the 2009 study area data.

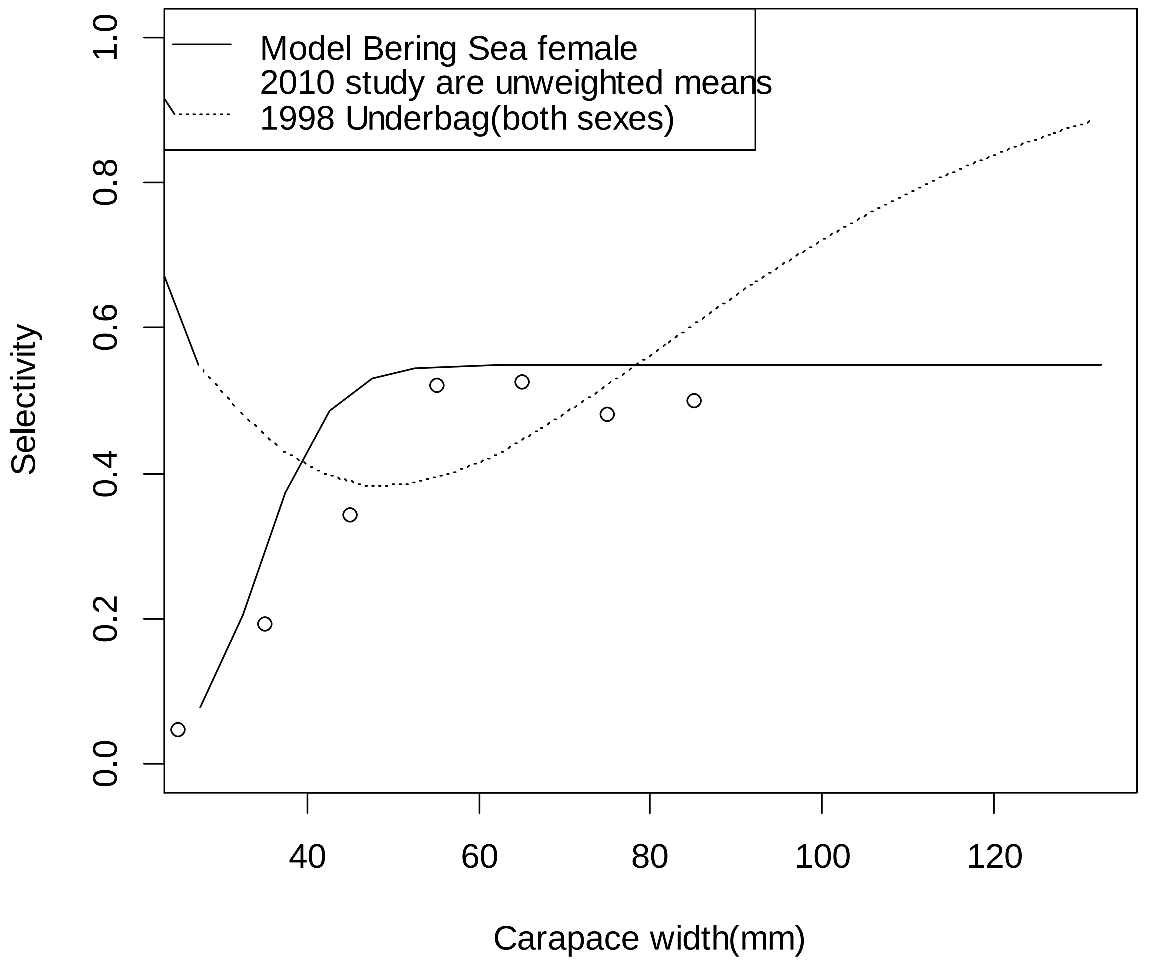


Figure 93. Base Model. Survey selectivity for female crab 1989- present (Model Bering Sea female).

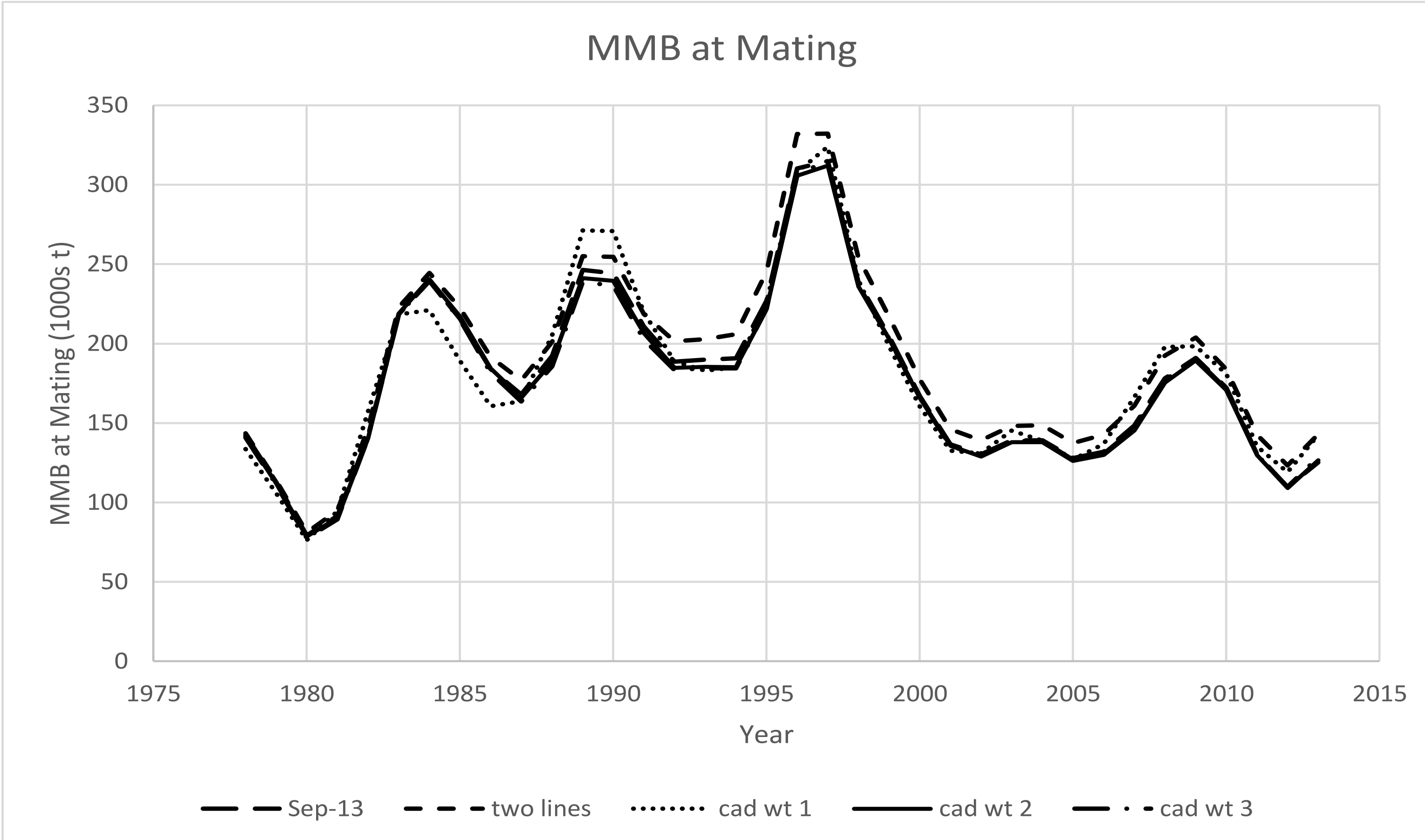


Figure 86. Mature male biomass at mating for the Base model (2b) and scenarios 0, 1, 2a and 2c.

Sensitivity to Fishing mortality penalties

Penalty on average F for males (λ = 2 in last phases),

$$\lambda \sum_{t=1}^{T} (F_t - 1.15)^2$$

Fishing mortality deviations for males (λ = 0.1),

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

Female bycatch fishing mortality penalty (λ = 1.0).

$$\lambda \sum_{t=1}^{T} (\varepsilon_{female,t})^2$$

Trawl bycatch fishing mortality penalty (λ = 1.0).

$$\lambda \sum_{t=1}^{T} (\varepsilon_{trawl,t})^2$$

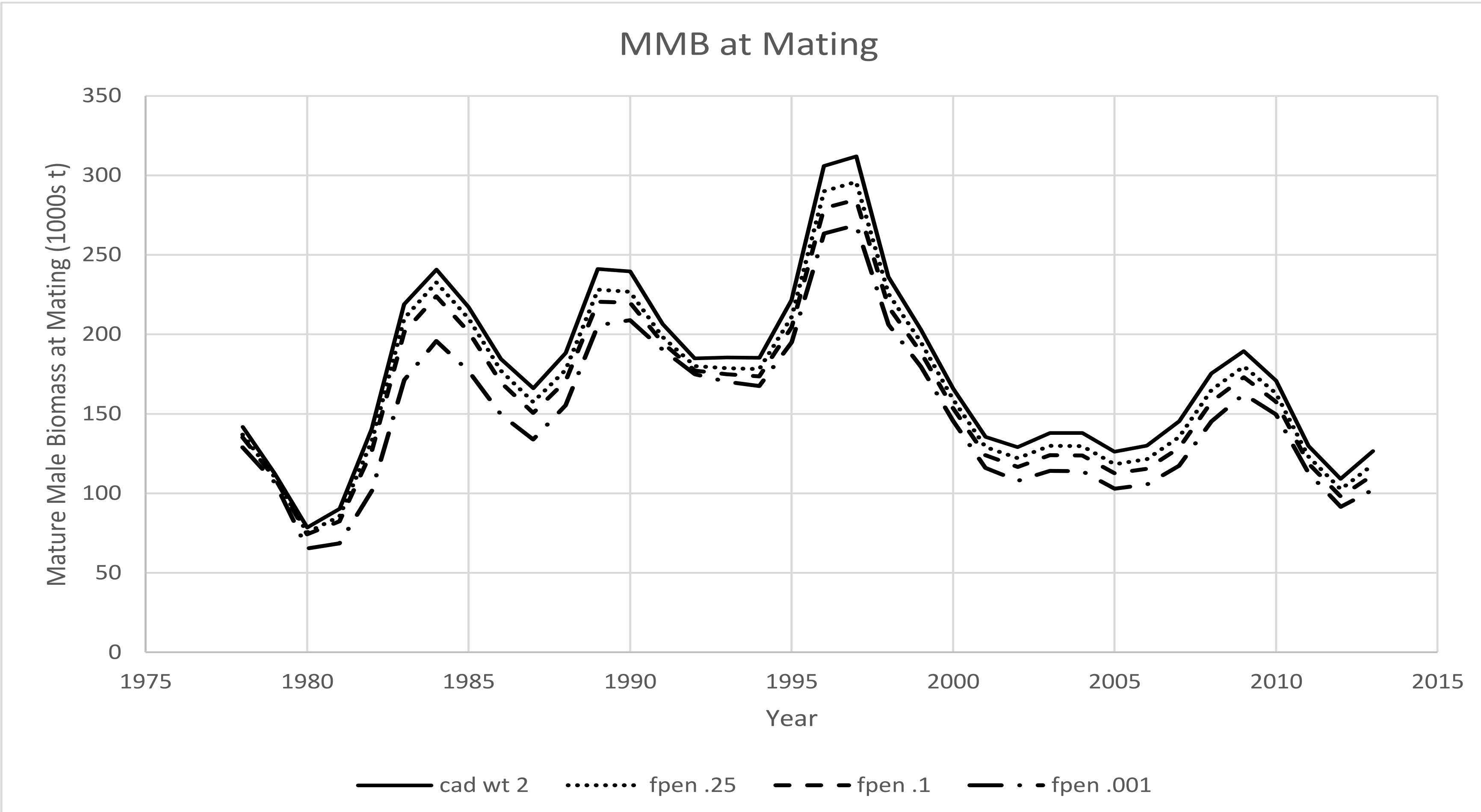


Figure 87. Mature male biomass at mating for the Base model (2b) and scenarios 2e, 2f and 2g.

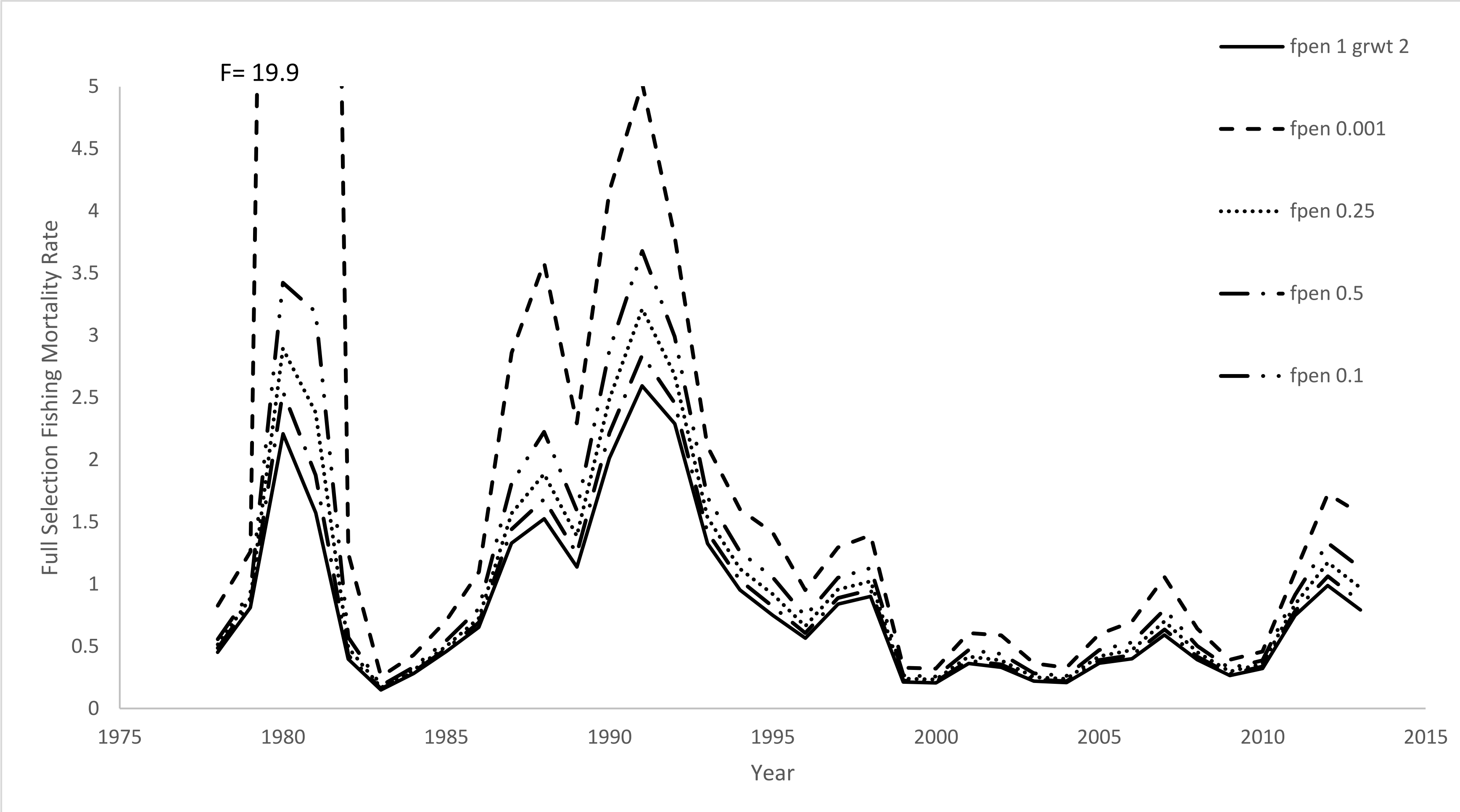


Figure 107. Full selection fishing mortality rate for models 2b (base model), 2d, 2e, 2f and 2g.

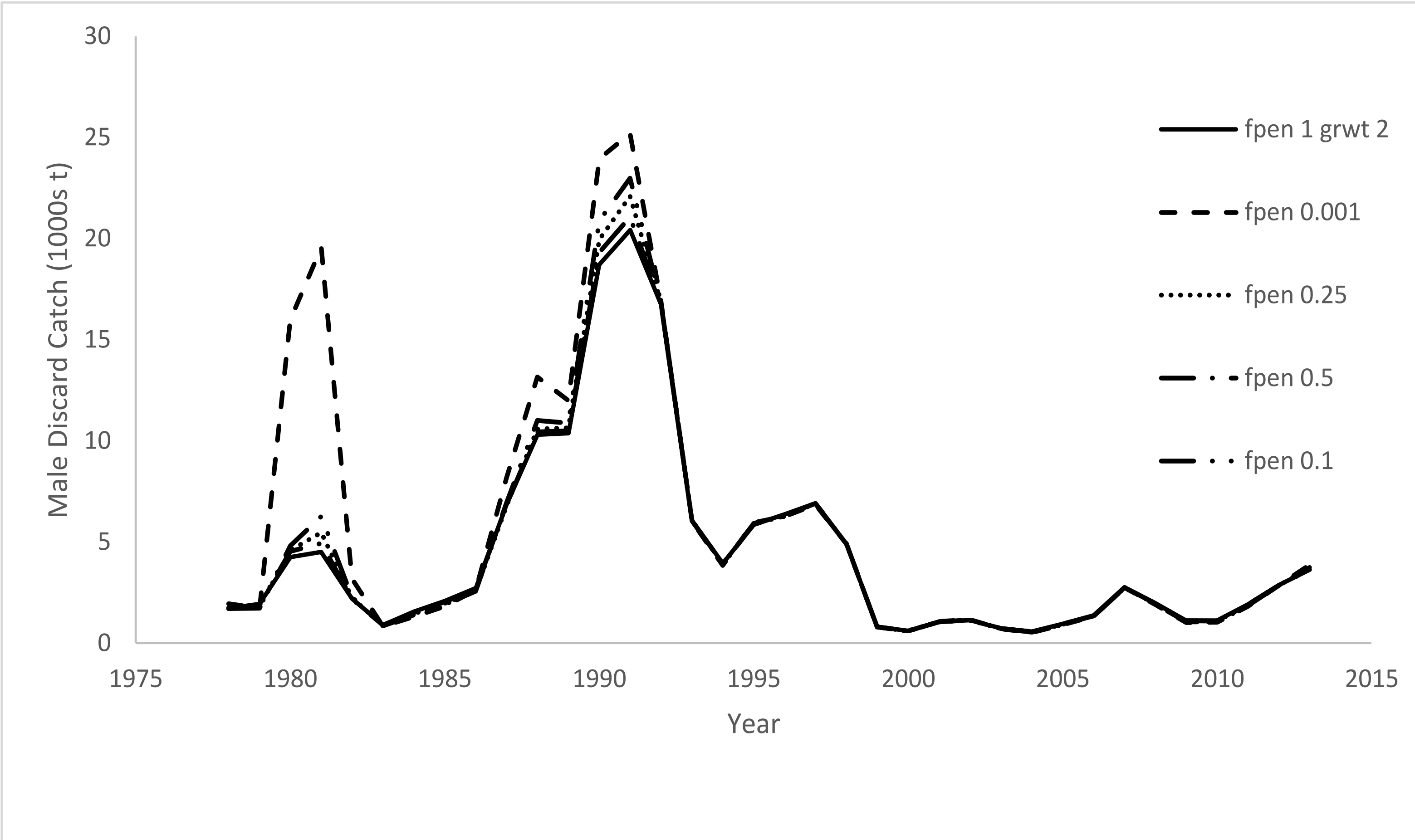


Figure 108. Male discard catch estimates from models 2b (base model), 2d, 2e, 2f and 2g.

Table 13. Differences in Likelihood values for 9 model scenarios relative to Base model (negative values are better fits than Base Model).

Likelihood Component	Model 0	Model 1	Model 2a	Model 2b Base Model	Model 2c	Model 2d	Model 2e	Model 2f	Model 2g
Scenario	13-Sep	Two line growth	grwt 1	grwt 2	grwt 3	0.5 fpen	.25 fpen	.1 fpen	.001 fpen
Discard mortality	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Recruitment	0.39	-0.59	0.60	0.00	0.13	0.21	0.62	1.08	2.13
Initial numbers old shell males small length bins	-0.02	0.00	-0.05	0.00	0.01	0.10	0.07	0.11	0.33
ret fishery length	-2.63	-8.09	-3.35	0.00	1.63	-4.30	-7.31	-11.36	-29.66
total fish length	0.20	0.99	-2.00	0.00	1.87	-1.81	-2.93	-4.92	-7.86
female fish length	-0.73	4.96	4.24	0.00	-0.30	0.47	-0.75	-0.86	-0.91
survey length	-4.42	9.36	7.34	0.00	14.06	7.81	-6.95	-7.70	-5.16
trawl length	-2.94	-0.38	15.94	0.00	1.06	-1.99	-4.34	-5.66	-6.89
2009 BSFRF length	-0.30	-0.10	-2.29	0.00	-0.16	-0.06	-0.29	-0.47	-0.95
2009 NMFS study area length	-0.36	-0.20	-0.93	0.00	0.25	0.05	0.11	0.19	0.31
M prior	-4.75	0.78	7.04	0.00	-0.15	-0.17	-0.62	-1.02	-1.50
maturity smooth	-4.06	9.20	0.97	0.00	2.59	-1.04	-3.53	-5.21	-8.66
growth males	0.46	-11.23	-14.86	0.00	1.60	0.67	0.69	2.63	6.81
growth females	4.63	-27.51	-15.70	0.00	2.11	-0.34	2.55	3.26	5.08
2009 BSFRF biomass	-0.01	-0.03	-0.01	0.00	0.00	0.01	0.02	0.04	0.08
2009 NMFS study area biomass	-0.01	-0.03	-0.02	0.00	0.00	0.01	0.02	0.04	0.08
retained catch	0.11	0.14	0.19	0.00	0.15	0.04	0.13	0.19	0.31
discard catch	4.07	12.87	-4.51	0.00	8.55	0.30	1.89	0.04	-6.04
trawl catch	-0.36	-0.15	-0.06	0.00	-0.01	-1.90	-2.76	-5.13	-8.89
female discard catch	0.10	-0.07	0.16	0.00	-0.07	-0.98	-2.53	-3.08	-3.37
survey biomass	1.59	0.46	-7.65	0.00	0.42	-0.33	1.98	2.13	6.10
F penalty	-0.10	0.50	-2.95	0.00	-0.12	-31.05	-48.01	-59.91	-77.86
2010 BSFRF Biomass	0.12	-0.32	0.44	0.00	0.09	0.10	0.17	0.36	0.67
2010 NMFS Biomass	-0.04	-0.44	-0.39	0.00	-0.08	0.13	0.30	0.51	0.90
initial numbers fit	-1.32	51.27	-4.41	0.00	0.33	17.34	0.08	-0.16	1.80
2010 BSFRF length	1.43	2.64	4.89	0.00	1.65	-0.15	-0.55	-0.78	-1.54
2010 NMFS length	-1.07	2.10	2.39	0.00	1.54	0.02	0.10	0.27	0.37
male survey selectivity smooth constraint	0.09	0.33	0.64	0.00	0.13	-0.04	-0.09	-0.14	-0.26
init nos smooth constraint	0.21	-5.26	-1.15	0.00	0.18	-3.87	0.61	0.84	2.95
Total	-9.73	41.18	-15.48	0.00	37.47	-20.76	-71.28	-94.71	-131.64

Table 14. Reference values for 9 model scenarios.

Model	0	1	2a	2b	2c	2d	2e	2f	2g
	Sept 2013 model	Two line model	Model gr wt 1	Base Model Gr wt 2	Model gr wt 3	0.5 F penalty	0.25 F penalty	0.1 F penalty	0.001 F penalty
B35%	141.9	148.9	141.3	142.9	143.7	141.3	139.7	137.3	134.1
F35%	1.5	1.6	1.5	1.4	1.4	1.5	1.5	1.6	2.0
OFL 2014/15	67.1	81.2	83.6	69.0	70.6	66.9	63.6	59.3	52.7
ABC(p*=.49) 2014/15	66.9	80.9	83.3	68.8	70.3	66.6	63.4	59.1	52.6
ABC(90%OFL) 2014/15	60.4	73.1	75.2	62.1	63.5	60.2	57.2	53.4	47.4
Percent MMB/B35% 2013/14	94.7	99.9	99.9	96.3	97.3	95.4	93.4	91.7	87.8
Survey Q 1989-present	0.61	0.57	0.59	0.61	0.61	0.63	0.64	0.65	0.68
M mature males	0.27	0.27	0.28	0.27	0.27	0.27	0.27	0.27	0.27

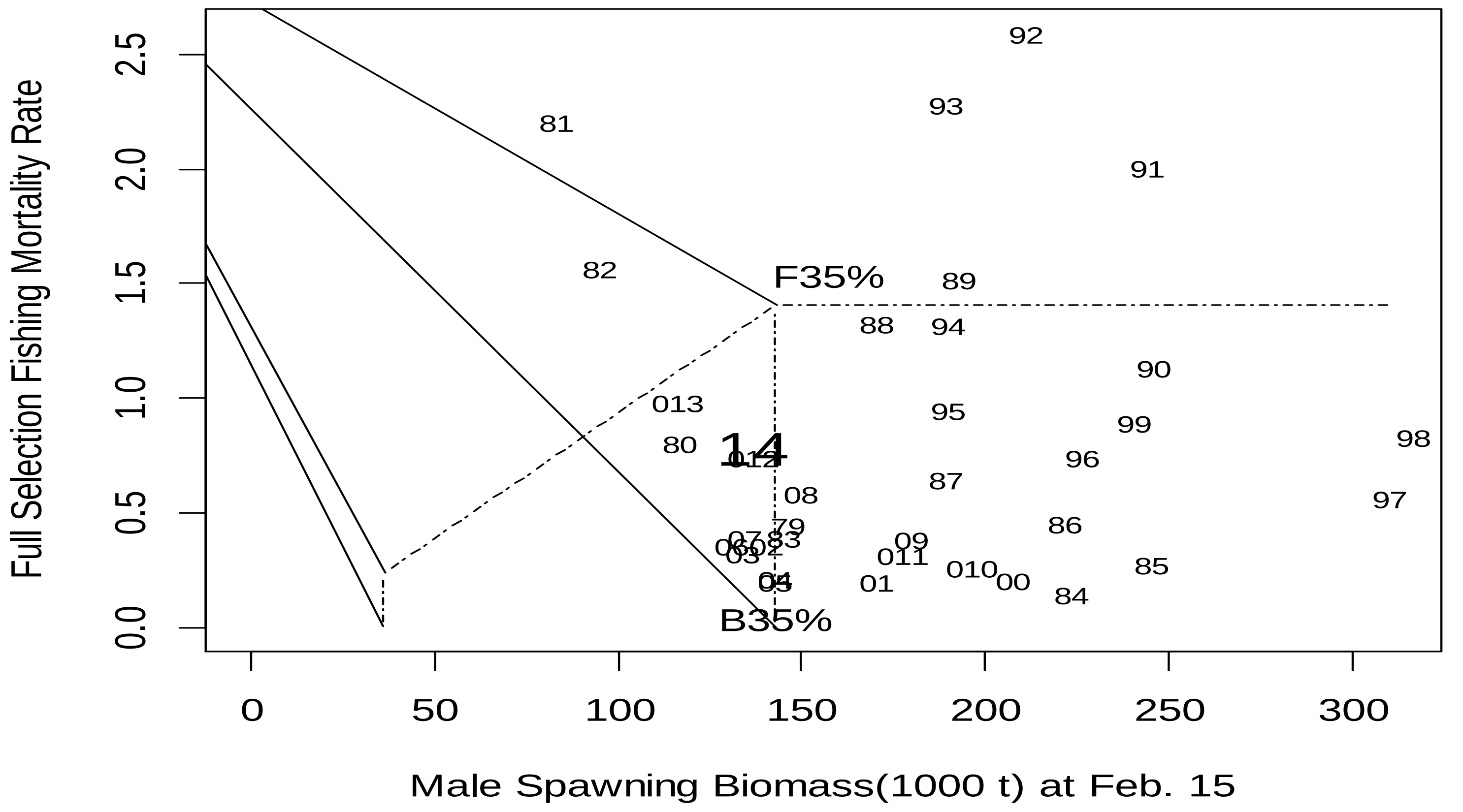


Figure 101. Base Model. Fishing mortality estimated from fishing years 1979 to 20013/14 (labeled 14 in the plot). The OFL control rule (F35%) is shown for comparison. The vertical line is B35%, estimated from the product of spawning biomass per recruit fishing at F35% and mean recruitment from the stock assessment model.

Tables 9a-b. Projections using a multiplier on the F35% control rule for 2014/15 to 2024/25 fishery seasons. Median total catch (ABC_{tot} 1000 t), median retained catch (C_{dir} 1000 t), Percent mature male biomass at time of mating relative to B35. Values in parentheses are 90% CI. F is full selection fishing mortality. Base model $B_{35\%}$ = 142,909 t. $F_{35\%}$ = 1.40.

a) 100%OFL Base Model, 100% $F_{35\%}$ B35% = 142,909 t F35%=1.40

Year	**ABC_{tot} (1000t)**	**C_{dir} (1000t)**	**Percent MMB/ $B_{35\%}$**	**Full Selection Fishing Mortality**
2014/15	69(57.2,81.8)	60.3(50,71.3)	96.3(87.9,109.6)	1.34
2015/16	68.2(45.3,87)	60.5(40.7,76.3)	98.8(84.5,116.1)	1.32
2016/17	58.2(39.4,74.8)	49.7(34.6,64.2)	99(83,118.9)	1.32
2017/18	62.6(40.8,79.5)	52.6(35.4,67)	106.8(86.8,134)	1.34
2018/19	70.9(46.7,94.2)	60.2(41.6,77)	116.6(87.3,169.2)	1.33
2019/20	78.7(45.7,142.8)	67.4(40.6,117.8)	125.9(81.8,224.5)	1.33
2020/21	84.7(35.2,210.5)	73.7(30.6,179.5)	127.8(74.5,276.2)	1.32
2021/22	82(25.1,213.7)	71.1(21.9,189.7)	126.7(67.8,288.2)	1.29
2022/23	74.1(21.9,207.5)	64(19.2,181.9)	120.3(63.6,294.4)	1.29
2023/24	66.9(19.8,205.1)	57.2(16.7,178.3)	117.5(63.8,292)	1.27
2024/25	68.3(18.8,198.7)	57.3(15.9,171.2)	118.5(61.4,297.9)	1.28

b) 90% Catch at FOFL Base Model, B35% = 142,909 t. $F_{35\%}$ = 1.40.

Year	**ABC_{tot} (1000t)**	**C_{dir} (1000t)**	**Percent MMB/ $B_{35\%}$**	**Full Selection Fishing Mortality**
2014/15	62.1(51.3,71.5)	54.4(45.1,62.7)	100.3(91.3,115.6)	1.15
2015/16	64.8(42.6,81.8)	58(38.5,72.6)	105.5(90.9,123.1)	1.12
2016/17	56.2(37.5,70.9)	48.8(33.4,61.5)	105.7(89.1,126.3)	1.12
2017/18	58.8(38.9,75.3)	50.6(34.1,63.8)	113.8(93.6,142.2)	1.12
2018/19	66.3(44.9,87.9)	57.3(40.1,73.4)	124.8(94.4,178.8)	1.11
2019/20	73.8(44.6,131.9)	64(40,111.6)	135.2(88.5,239.9)	1.11
2020/21	79.9(34.6,191.3)	70.1(30.6,170.4)	138(80,297.7)	1.1
2021/22	77.6(24.7,200.4)	68.6(21.8,178.7)	137.4(72,316.3)	1.08
2022/23	72.5(21.7,195)	63.1(18.7,173.1)	131.1(67.8,325.3)	1.08
2023/24	64.9(19.5,195.1)	56.1(16.8,171.1)	127.8(68.1,321.1)	1.06
2024/25	66.5(18.4,187.1)	56.8(15.9,165)	129(66.4,327.6)	1.07

- End