Bering Sea Snow Crab Assessment Model Sensitivity to Survey Selectivity

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This document presents results of various runs of the Bering Sea snow crab assessment model under different assumptions regarding survey selectivity and natural mortality. Projections evaluating rebuilding are also presented for some model scenarios. Model runs presented here use different data and model weighting than the September 2009 snow crab assessment. Model runs use the “new” survey data, and likelihood weighting of the observed coefficients of variation on survey biomass with no added weight as recommended by the Crab Plan Team (September 2009 assessment used higher weighting on survey biomass likelihood). The new survey data biomass estimates are on average about 87% of the old survey data due to the actual measured net width used (which are larger) instead of a fixed 50 ft net width.

Somerton et al. 2010 (NPFMC document) estimated a survey selectivity curve for male snow crab using the 108 tows conducted by BSFRF in 2009 compared to the standard NMFS survey tows in the same areas (Figure 1). The curve estimated by Somerton was a three parameter model,

$$Selectivity = \frac{a}{1 + e^{(-(b + c * \text{carapace width}))}}$$

Parameter estimates were: a = 0.8418, b= -2.6466 and c = 0.0354. This curve has a selectivity of 0.76 at 140mm and +/- 95% Confidence Interval of 0.56 to 0.95. Somerton et al. 2010, did not present analyses for female snow crab survey selectivity, although preliminary analyses indicate selectivity would be estimated higher than for males of the same size.

The maximum length bin in the snow crab model is 130-135mm cumulative length bin. Survey selectivity by length (same as carapace width) is estimated in the snow crab model as a 3 parameter equation, Q, size at 50% selected and size at 95% selected,

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

In model runs presented, Q was fixed at a range of values from 0.55 to 0.95 to evaluate model fit. These values correspond to the 95% confidence interval around the best estimate of maximum selectivity from Somerton et al. 2010 of 0.76 (95% C.I., 0.56, 0.95) (Figure 1). While the Q was fixed, the size at 50% and size at 95% parameters were estimated in the model for the three time periods 1978-1981, 1982-1988, and 1989 to 2009. Survey selectivity was fixed to be the same for males and females. Values lower and higher than the 95% C.I. were run to compare the likelihood values of Q=0.32 estimated from the side by side experiment(BSFRF report) and to determine where the best fitting model occurred (Table 1 and Figure 2). The best fit (lowest likelihood) occurs at about Q=1.2. As Q declines the model fit degrades substantially. The difference in likelihood at Q = 0.76 is 130 more than at the best fitting Q=1.2. Q = 0.85 is would be approximately equivalent to the September 2009 assessment using the old survey data and Q=1.0 based on the average difference in net widths alone.

Another approach to fitting survey selectivity is to use a prior distribution on Q with mean equal to the Somerton et al. 2010 estimate of 0.76 and the estimated standard deviation of 0.1 assuming a normal distribution (95% C.I. 0.56 to 0.95). The model estimated Q = 1.09 with this prior, slightly less than where the best fit is using fixed Q.

When the complete survey selectivity curve was fixed at the Somerton et al. 2010 curve for both males and females, the fit was considerably worse (5108 total likelihood) than at any of the runs with fixed Q only (Table 1). The assessment model estimate of survey selectivity for the 1989 to 2009 period that gives the best fit to the data is flat down to about 40 mm compared to the Somerton et al. 2010 curve which declines as size decreases (Figure 1).

The fit to the male and female survey biomass improves as fixed Q increases to 1.2 (Figures 3 and 4). The new survey data and changes to weighting factors used in the model runs presented here result in a fit to female biomass that is lower than the observed biomass relative to the September 2009 assessment. The fit to the female survey biomass time series improves as Q increases. The fit to female survey biomass is very poor when the Somerton et al. 2010 selectivity is used in the model (Figure 4). Applying the Somerton et al. 2010 selectivity curve results in a lower capture probability for mature female crab than mature male crab due to their smaller size. Mature female snow crab are generally in the size range of 45-65mm. If selectivity is lower for animals in this size range, we would expect to see lower overall numbers of females in the survey data than males if recruitment and natural mortality are similar. The average abundance over the 1978 to 2009 time period shows the ratio of female to male crab is approximately 1.27 to 1 (Figure 5). The average abundance by length for male snow crab is highest in the 40 to 65 mm range. This size range is also the highest abundance by length for of female snow crab due to their terminal molt at maturity. While a lower abundance of males would be expected due to added fishing mortality, this difference is an average of about 600 million crab (female mean abundance = 2,807 million, mean male abundance=2,219 million), more than can be accounted for by the directed male fishery. If male and female abundance were equal in the survey data, this would imply a similar selectivity for mature females (45-65mm) as for males (45-135mm). The declining survey selectivity curve estimated by Somerton et al. 2010 results in much lower selectivity for female crab than male crab due to size differences that if true, implies that the expected female:male sex ratio in the population would need to be much higher than observed in the survey data.

Somerton et al. 2010 also discusses issues that may result in spatial differences in catchability of the standard survey net, due to bottom type and depth. In many years in the survey data, a few large catches of female snow crab account for a large percentage of the survey abundance estimate. For illustration, in the 2004 survey the highest 3 tows in the survey accounted for about 40% of the abundance of females > 50mm. If females tend to aggregate more than males, and the probability of capture is higher when females are aggregated, then this may account for the flat survey selectivity estimated in the model that gives the best fit to the data. This could be explored further by examining the distribution of tows with high abundance using the 1978 to 2009 time series.

Estimating Natural Mortality

The snow crab assessment current has immature male and female M = 0.23, mature female M = 0.29 and mature male M=0.23. The higher M for mature females is a recommendation by the workshop on OFL revisions (2006) and the crab plan team. Survey selectivity was fixed at the Somerton et al. 2010 curve for both males and females and natural mortality estimated. One model scenario estimated one M for males and one M for females. Estimating M improved the total likelihood from 5108 to 4218 (Table 2). The natural mortality estimated for females was 0.28 and for males 0.45 (Table 2). The value of M=0.45 is not plausible for males given the current information on longevity from tagging data of Canadian snow crab. If male natural mortality is fixed at 0.23, female M is estimated lower at 0.16 (total likelihood = 4661).

Estimating Survey Selectivity Separately for Males and Females

Difference in survey selectivity may result from different behavior of male and female snow crab, or differences in spatial distribution of males and females and selectivity of the survey net due to bottom type or depth. Separate survey selectivity curves were fit for females and males for all three time periods in the model. This adds 9 additional parameters to the model. Natural mortality was fixed at mature female M =0.29, mature male = 0.23 and immature crab M=0.23. The results vary by time period (Figures 6 and 7). The earliest time period has the maximum selectivity bounded by 1.2, as selectivity was not estimated well and went to much higher values. Female selectivity was estimated lower than males at sizes less than 60 mm. The 1981 to 1988 period female selectivity was estimated to be slightly less than males with a maximum of about 1.05 for males and 0.95 for females. The later period from 1989 to 2009 female selectivity was estimated higher than males (Figure 7 has the 1989 to 2009 selectivities only for ease of viewing) (maximum about 1.27 compared to male maximum of 1.0). The selectivity remains near the maximum for both males and females until about 50 mm where it begins to decline. Increasing the survey selectivity of females relative to males improves the female fit to the survey biomass. The higher survey selectivity for females in the 1989-2009 period results in an improved fit to the male and female survey biomass (Figures 8 and 9). Model runs with female Q higher than male Q and natural mortality = 0.23 for all crab result in better fits to the female survey biomass than with survey selectivity equal for males and females. Figures 8 and 9 include runs were female Q was fixed to be 1.0 and 1.1 with male Q fixed at 0.85 and natural mortality fixed to be the same for all crab at 0.23..

Rebuilding Projections

Projections for fixed Q values of 0.85, 0.75 and 0.65 were run to evaluate the sensitivity of reference points and rebuilding times to Q (Tables 3, 4 and 5, and Figures 10 and 11). The survey Q was fixed the same for all three time periods in the model and both sexes with the size at 50% and at 95% estimated by the model. B35% increases from 298 million lbs at Q=0.85, to 310 million lbs at Q=0.75 and to 327 million lbs at Q=0.65. F35% declines as Q declines, from 0.8 at Q=0.85, to 0.78 at Q=0.75, and to 0.75 at Q=0.65. In all three scenarios, the stock would not have rebuilt to B35% within the 10 year time frame. The mean biomass using the new survey data declines from 2009/10 to 2012/13 and then increases thereafter. The time to rebuild (two consecutive years above B35% with > 50% probability) is 2017/18 for Q=0.85, 2016/17 for Q=0.75 and 2015/16 at Q=0.65. While MMB was projected to be above B35% in 2009/10 with Q=0.65, MMB declined over the next few years.

Literature Cited

Somerton, D., K. Wenberg and S. Goodman. 2010. Review of the research to estimate snow crab selectivity by the NMFS trawl survey. Report to NPFMC January 2010.

Table 1. Total likelihood, survey length frequency likelihood and survey biomass likelihood for a range of fixed maximum survey selectivity (Q). Male and female survey selectivity set equal and selectivity at 50% and selectivity at 95% parameters estimated by the model. Some likelihood components not shown may be negative, so that the sum of survey length likelihood and survey biomass likelihood may be greater than the total likelihood. Somerton et al. 2010 run is with survey selectivity fixed for both males and females at the logistic curve estimated in the Somerton et al. 2010 using the 108 additional tows conducted by BSFRF.

Q fixed	Total Likelihood	Survey Length	Survey biomass
0.32	4679.18	4217.81	520.075
0.55	4245.50	4083.99	336.708
0.65	4130.45	4051.91	280.521
0.75	4046.38	4026.95	236.346
0.85	3987.72	4007.53	204.147
0.95	3949.25	3992.78	182.557
1.1	3920.70	3977.46	166.719
1.2	3916.78	3970.70	165.273
1.3	3922.39	3966.05	169.887
1.4	3935.85	3963.09	179.711
Q=1.09 estimated in model with prior mean = 0.76, s.d. =0.1	3917.32	3973.63	163.096
Somerton Selectivity fixed	5108.15	4556.89	710.472

Table 2. Model runs with survey selectivity fixed at the Somerton et al. 2010 estimated curve and with natural mortality fixed and estimated.

	Total Likelihood	Male M	Female M	
Somerton selectivity fixed	5108.15	Fixed 0.23	Fixed 0.29	
Somerton selectivity fixed	4218.87	Estimated 0.45	Estimated 0.28	
Somerton selectivity fixed	4661.85	Fixed 0.23	Estimated 0.16	

Table 3. Rebuilding projections at 75% F35% for Q=0.85. B35% = 298.3, F35% = 0.80. Prob. 2 yr. > B35% is the probability of rebuilding to two years in a row above B35%.

	Total catch	Lower 95% C.I. total catch	Upper 95% C.I. total catch	Retained catch	Maximum F (full selection)	Mature male biomass at mating time	Male Biomass (>101mm) at beginning of Fishery	Total survey mature biomass	prob B35%	prob 2yr >B35%
2009	53.7	53.4	54.1	48.0	0.45	240.5	163.4	398.2	0.083	0
2010	53.0	21.3	96.7	47.7	0.45	226.0	155.4	384.0	0.083	0.017
2011	42.4	19.5	75.2	38.0	0.41	208.2	135.4	374.1	0.083	0.017
2012	37.3	18.1	65.8	32.4	0.39	205.0	118.8	387.1	0.083	0.017
2013	51.5	25.4	89.1	44.3	0.46	237.0	142.5	447.8	0.117	0.017
2014	74.8	32.5	142.1	65.4	0.52	283.7	189.5	527.1	0.351	0.058
2015	89.9	31.3	193.4	79.6	0.54	317.3	222.5	586.3	0.504	0.311
2016	96.1	28.3	222.6	85.3	0.54	335.4	235.3	621.5	0.58	0.452
2017	98.7	25.0	236.8	87.4	0.53	349.4	241.6	646.3	0.651	0.53
2018	103.5	23.4	241.4	91.6	0.54	363.4	250.6	669.2	0.712	0.603

Table 4. Rebuilding projections at 75% F35% for Q=0.75. B35% = 310.4 million lbs, F35% = 0.78. Prob. 2 yr. > B35% is the probability of rebuilding to two years in a row above B35%.

	Total catch	Lower 95% C.I. total catch	Upper 95% C.I. total catch	Retained catch	Maximum F (full selection)	Mature male biomass at mating time	Male Biomass (>101mm) at beginning of Fishery	Total survey mature biomass	prob B35%	prob 2yr >B35%
2009	53.8	53.5	54.2	48.0	0.37	285.4	193.6	399.8	0.289	0
2010	67.0	28.3	112.7	60.4	0.48	257.7	185.6	387.2	0.289	0.088
2011	50.8	23.7	89.1	45.5	0.43	232.0	154.6	369.2	0.289	0.088
2012	43.4	21.5	75.8	37.5	0.41	225.7	132.5	378.2	0.289	0.088
2013	58.7	29.3	98.2	50.1	0.47	259.7	157.0	435.8	0.324	0.09
2014	83.5	37.3	155.5	72.6	0.52	311.3	208.2	512.2	0.53	0.158
2015	99.5	35.1	212.9	87.7	0.54	348.7	245.0	569.2	0.653	0.428
2016	106.0	31.8	243.9	93.6	0.54	368.3	259.0	601.7	0.709	0.555
2017	108.3	27.7	258.5	95.5	0.53	382.6	265.3	623.0	0.768	0.619
2018	112.8	26.0	260.7	99.5	0.54	396.0	274.0	641.4	0.805	0.689

Table 5. Rebuilding projections at 75% F35% for Q=0.65. B35% = 327.3 million lbs, F35% = 0.75. Prob. 2 yr. > B35% is the probability of rebuilding to two years in a row above B35%. MMB is above B35% in 2009/10, however, declines until 2012, so the probability of being above B35% two years in a row is still below 0.5 until 2015/16.

	Total catch	Lower 95% C.I. total catch	Upper 95% C.I. total catch	Retained catch	Maximum F (full selection)	Mature male biomass at mating time	Male Biomass (>101mm) at beginning of Fishery	Total survey mature biomass	prob B35%	prob 2yr >B35%
2009	54.0	53.6	54.4	48.0	0.29	347.4	235.6	404.2	0.614	0
2010	86.0	38.4	134.8	77.6	0.51	301.3	227.4	393.1	0.614	0.256
2011	62.6	29.4	106.4	56.0	0.45	264.5	181.4	366.3	0.614	0.256
2012	51.8	25.7	89.2	44.6	0.42	253.9	151.4	370.8	0.614	0.256
2013	68.3	34.6	110.7	57.9	0.48	290.4	176.8	424.8	0.64	0.257
2014	94.8	43.9	173.9	81.9	0.52	348.2	233.5	497.6	0.762	0.337
2015	111.7	40.1	237.2	97.9	0.53	390.2	274.7	551.4	0.834	0.587
2016	118.4	36.3	270.7	104.1	0.53	411.0	290.0	580.4	0.87	0.684
2017	120.1	31.2	286.9	105.5	0.52	424.9	295.8	597.2	0.886	0.742
2018	124.0	29.1	285.6	108.8	0.52	436.7	303.4	610.3	0.905	0.781

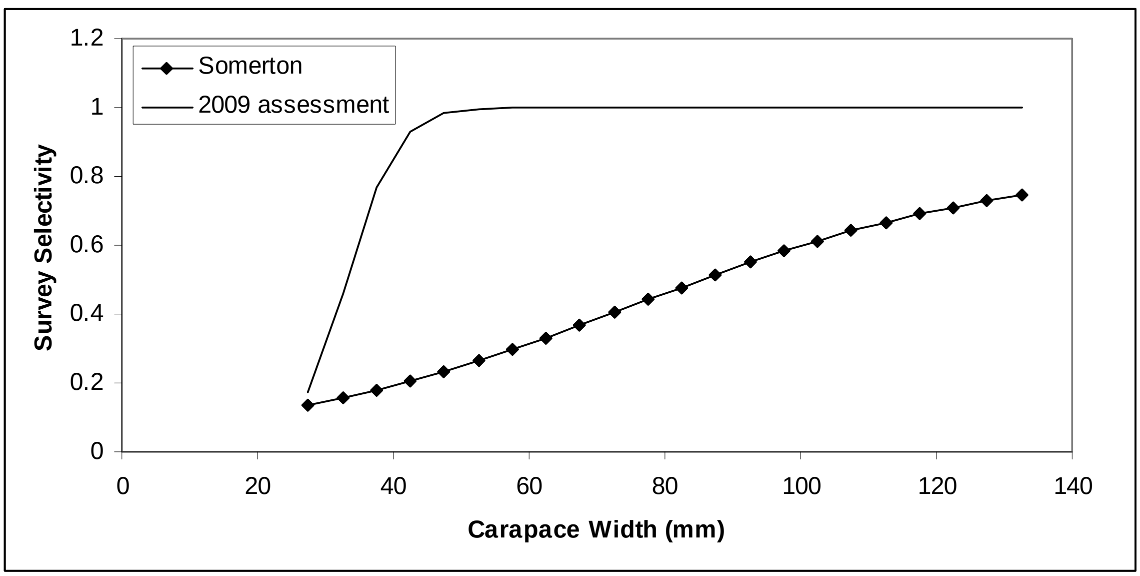

Figure 1. Survey selectivity estimated for the period 1989 to 2009 in the 2009 assessment and the survey selectivity curve estimated by Somerton et al. 2010 from the 108 tows by BSFRF and NMFS standard survey tows.

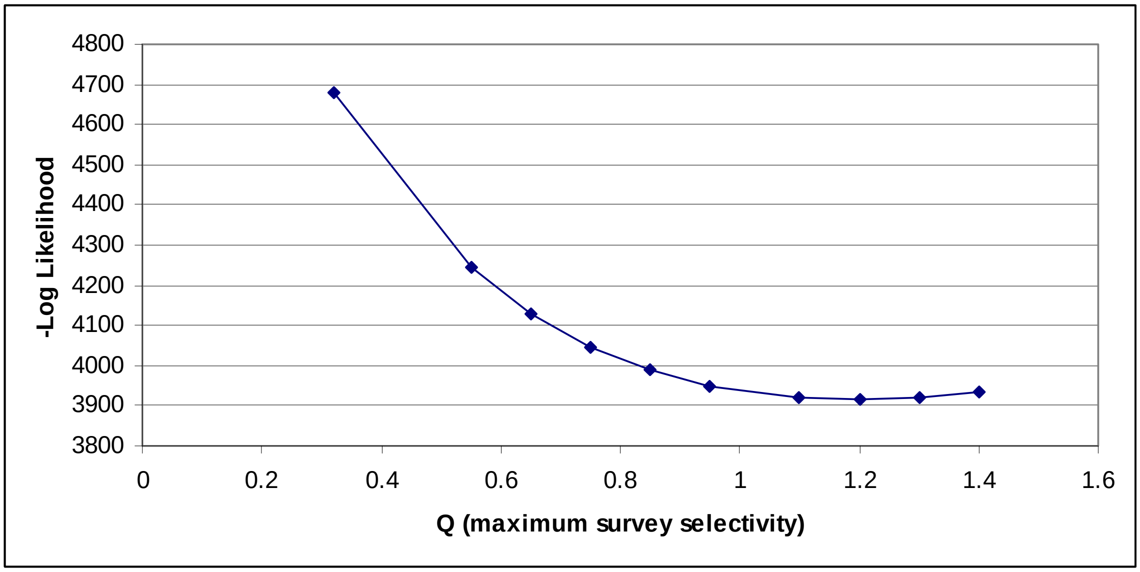

Figure 2. Total likelihood values at fixed maximum survey selectivity (Q) from 0.32 to 1.4. Best fit occurs at the lowest values at about Q=1.2.

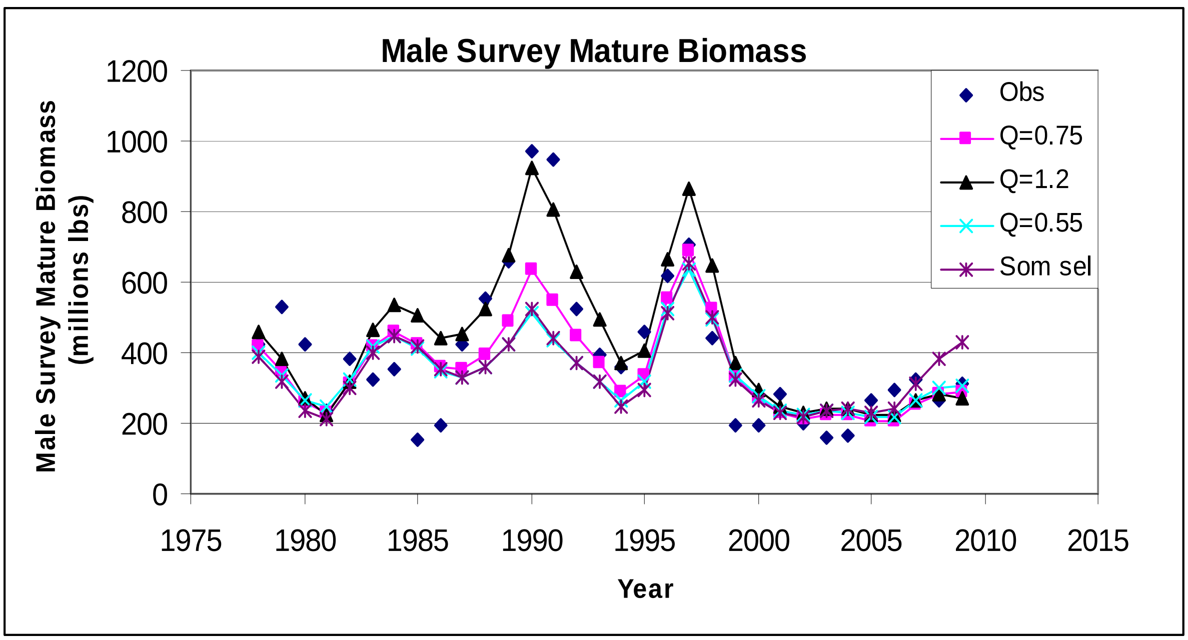

Figure 3. Fit to male mature survey biomass for various levels of fixed Q and for Somerton et al. 2010 selectivity curve.

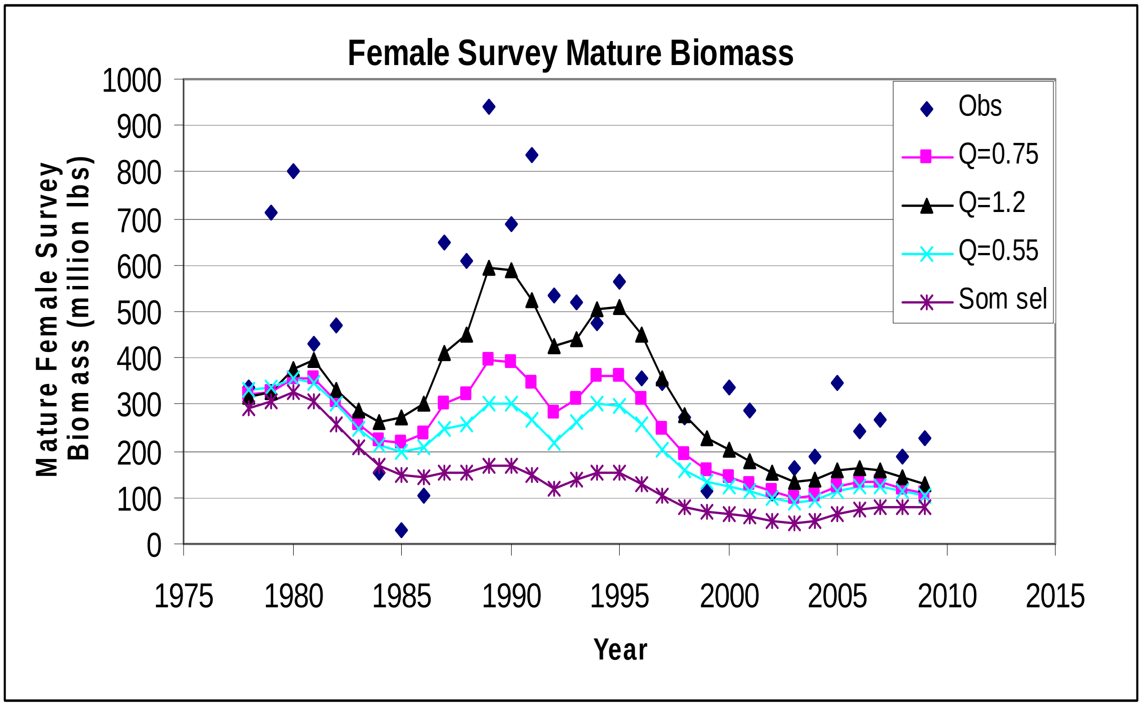

Figure 4. Fit to female mature survey biomass for various levels of fixed Q and for Somerton et al. 2010 selectivity curve.

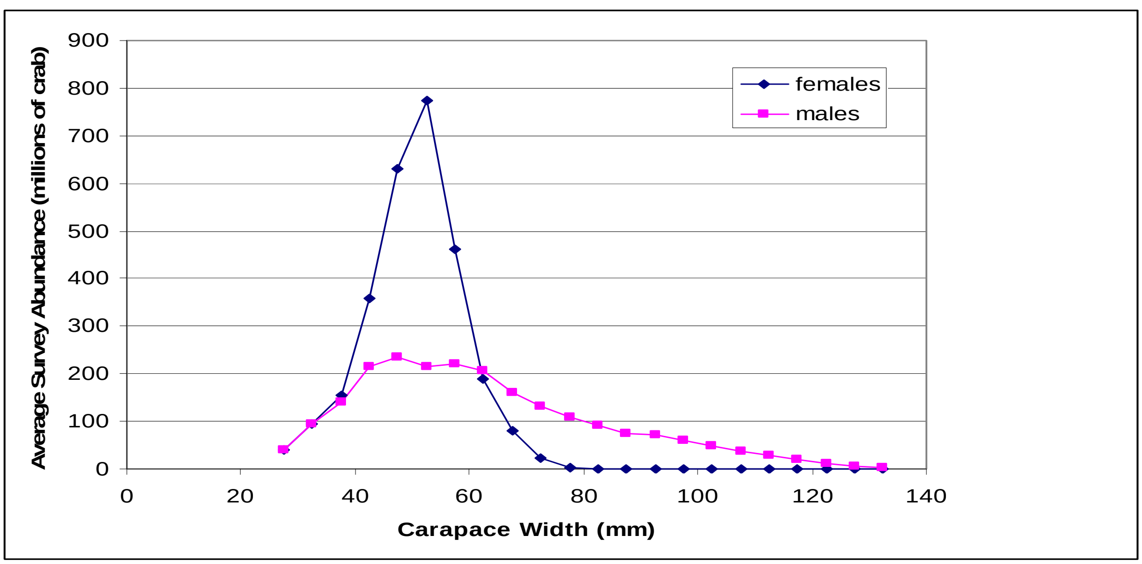

Figure 5. Average observed survey abundance by length from 1978 to 2009 for male and female snow crab.

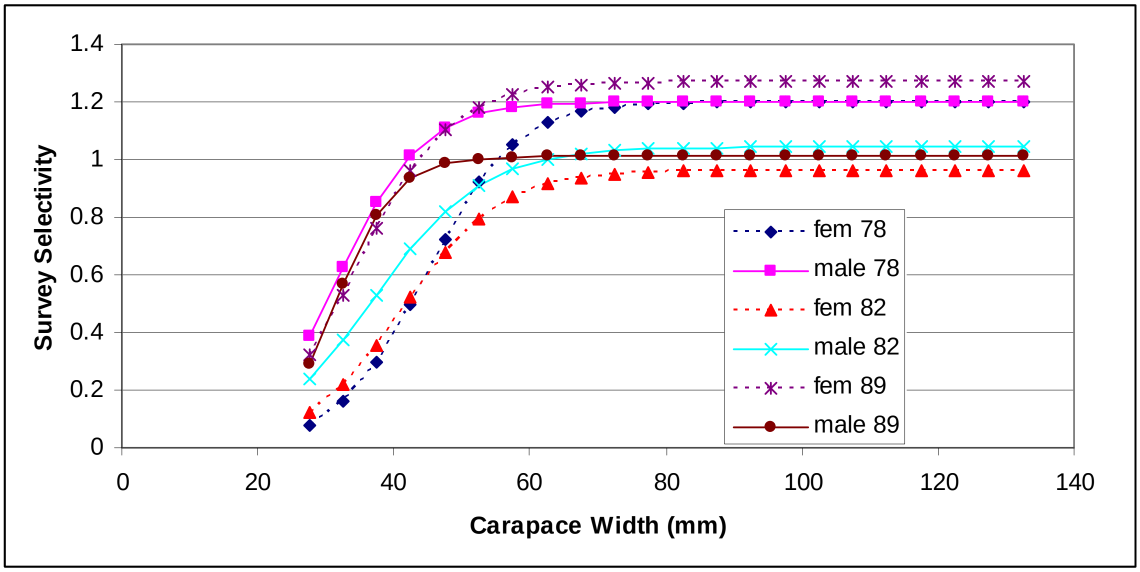

Figure 6. Survey selectivity curves estimated separately for males and females and three time periods. Three parameters were estimated for each curve: 1) Q, 2) size at 50% selected, 3) size at 95% selected. Except the early period 1978-1981 where Q was bounded by 1.2.

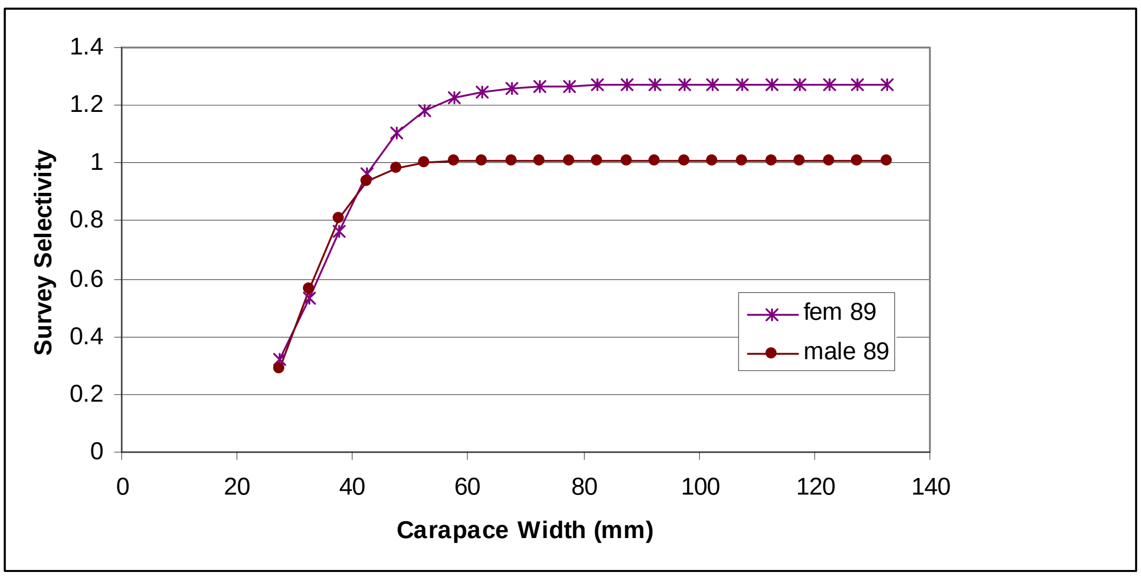

Figure 7. Survey selectivity estimated for males and females separately for 1989-2009.

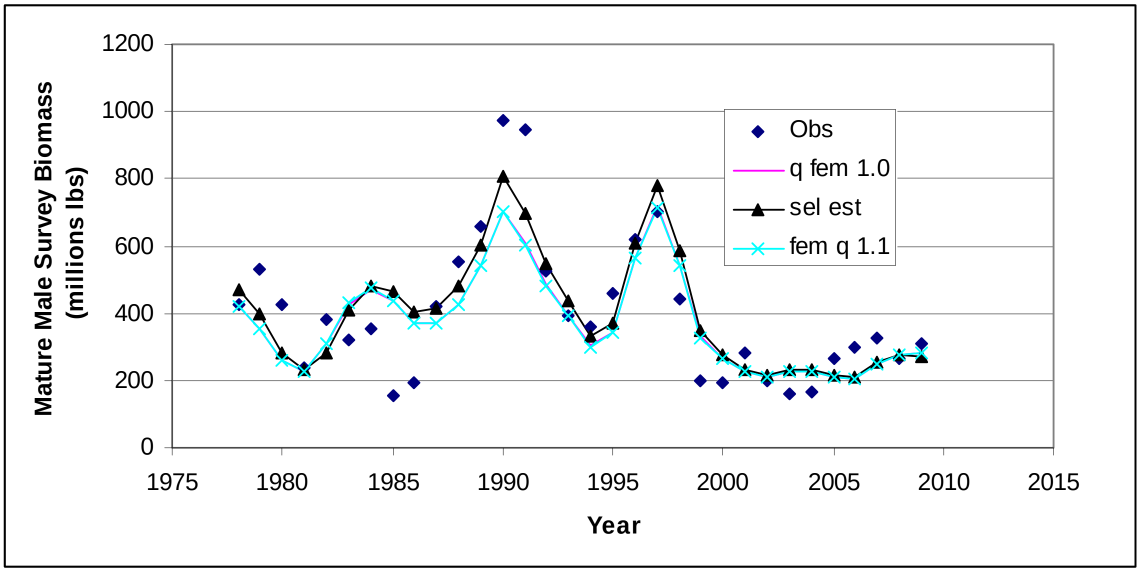

Figure 8. Fit to Mature male survey biomass with survey selectivity estimated separately for male and females (sel est). The curves marked q fem 1.0 and q fem 1.1 have all natural mortality = 0.23 and male Q fixed at 0.85.

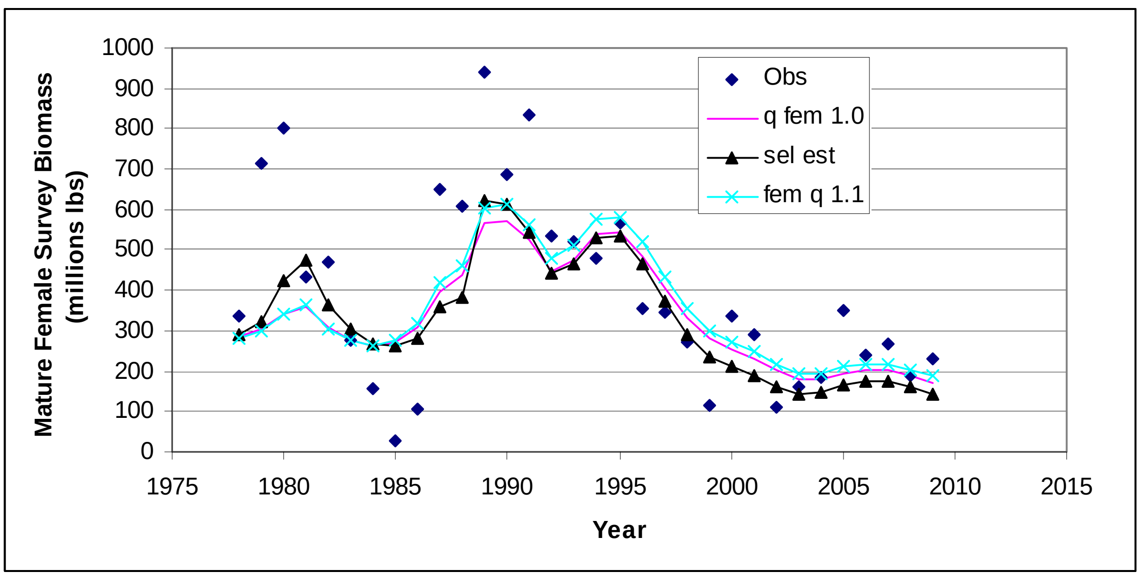

Figure 9. Fit to Mature female survey biomass with survey selectivity estimated separately for male and females (sel est). The curves marked q fem 1.0 (female Q fixed at 1.0) and q fem 1.1(female Q fixed at 1.1) have all natural mortality = 0.23 and male Q fixed at 0.85.

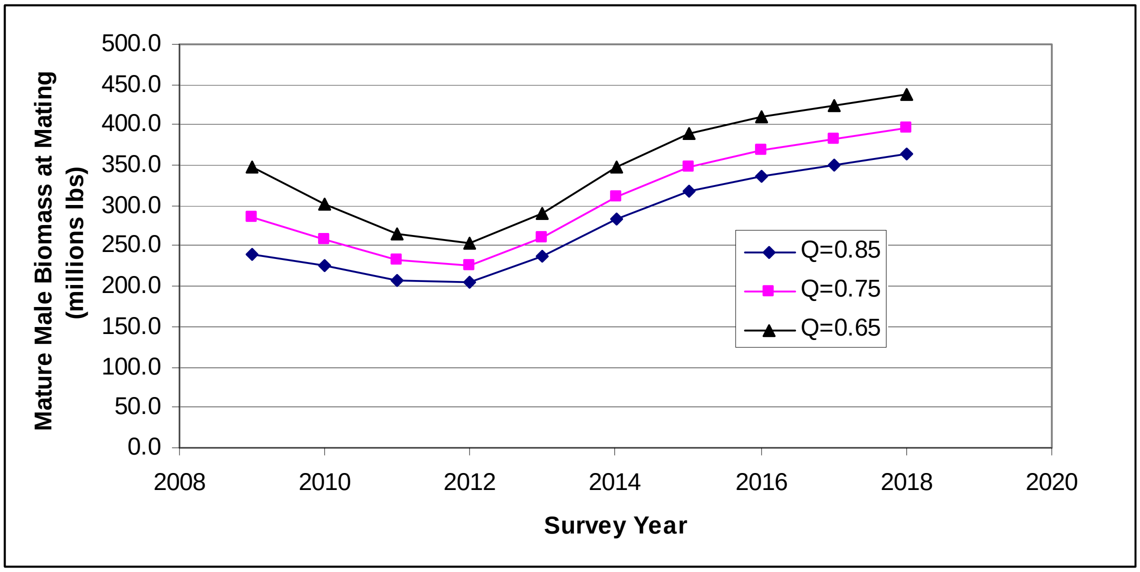

Figure 10. Mature male biomass at mating fishing at 75% F35% projected from 2009/10 to 2018/19 for three values of fixed Q: 0.85, 0.75 and 0.65.

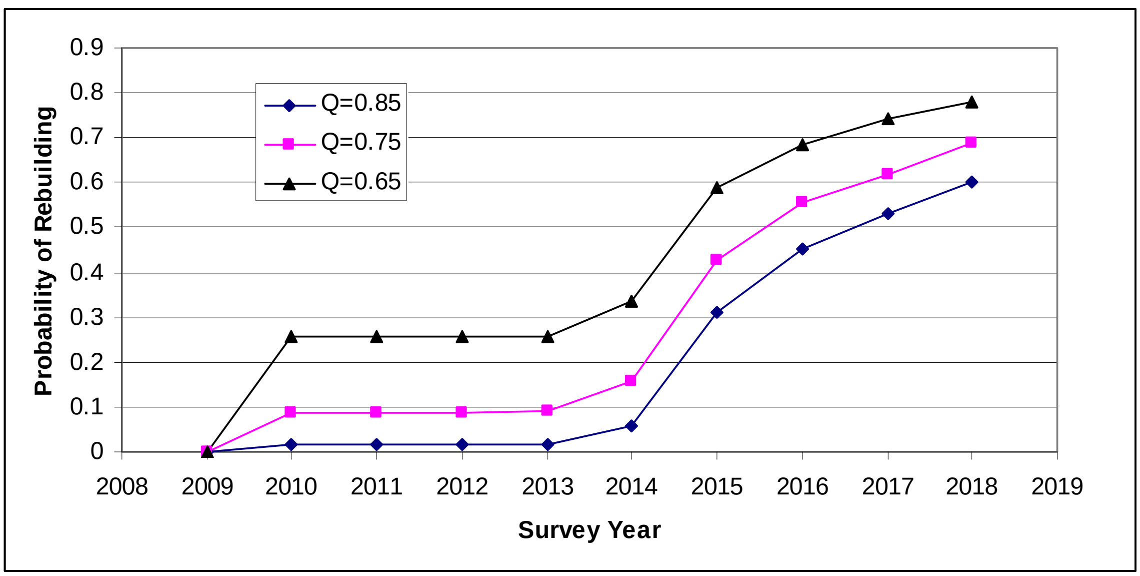

Figure 11. Probability of rebuilding fishing at 75% F35% projected from 2009/10 to 2018/19 for three values of fixed Q: 0.85, 0.75 and 0.65.