Bering Sea Snow Crab

May 2014

Benjamin J. Turnock

NMFS

Three model scenarios were run for comparison with the September 2013 accepted model. A set of plots for each model run are in pdf files. Model 1 (plots in model.1.2014may.pdf ) fits mean growth as two linear segments by sex as recommended by the Crab Plan Team in September 2013. The use of fishing mortality penalties in the snow crab assessment model has been shown to introduce bias (Szuwalski 2012). Model 2 (plots in model.2.2014may.pdf ) is the September 2013 model with all fishing mortality penalties removed. Model 3 (plots in model.3.2014may.pdf ) is model 1 with fishing mortality penalties only on the 1978/79 to 1992/93 directed fishery. The model accepted in September 2013 is model 0 (plots in model.0.2013sept.pdf ). Figure titles for the pdf files are included at the end of this document.

**Growth**

The September 2013 Base model fits the growth data by sex reported by Somerton (2013) within the assessment model by adding a sum of squared deviations likelihood component. Sample sizes were 17 for males and 18 for females. A linear function for each sex was estimated resulting in four parameters (an intercept and slope by sex) (Figures 25-27 in separate files for each model run).

Somerton’s (2013) estimates of growth for Bering Sea snow crab combined several data sets as well as female and male data. The best model determined by Somerton(2013) included the following data :

1. Transit study; 14 crab
2. Cooperative seasonality study (Rugolo); 6 crab
3. Dutch harbor holding study; 9 crab
4. NMFS Kodiak holding study held less than 30 days; 6 crab

Total sample size was 35 crab. Somerton(2013) excluded data from the NMFS Kodiak holding study where crab were held more than 30 days and also for the ADF&G Kodiak holding study where crab were collected during the summer survey and held until molting the next spring because growth was lower significantly lower than the above four data sets.

Some data points were excluded from 1, 2 and 3 above (35 is the final sample size). Females molting to maturity were excluded from all data sets, since the molt increment is usually smaller. Crab missing more than two limbs were excluded due to other studies showing lower growth. Crab from Rugolo’s seasonal study were excluded that were measured less than 3 days after molting due to difficulty in measuring soft crab accurately. Somerton fit each data set starting with (1) above and testing the next data set for significant difference. Two linear models were fit that joined at 36.1 mm (males and females combined),

For < =36.1mm

Postmolt = -4.0 + 1.46 \* Premolt

>= 36.1 mm

Postmolt = 6.59 + 1.17 \* Premolt

The postmolt size is 48.8 mm at premolt size of 36.1 mm.

Model 1 estimates two linear segments similar to Somerton (2013), except by sex with the intersection of the lines fixed at 36.1 mm (premolt) and 48.8 mm (postmolt). This results in four parameters total (two parameters estimated per sex). The parameters of the intersection point are not estimable in the assessment model due the equation being nondifferentiable.

Premolt < 36.1mm

Postmolt s= a1 s + Premolt s \* (48.8-a1 s)/36.1

Premolt > 36.1mm

Postmolt s = a2 s + Premolt s \* (48.8-a2 s)/36.1

Where a1 s and a2 s are estimated parameters by sex.

Likelihood equations were added for the sum of squares fit with the new growth data by sex,



Where gi is post-molt size from growth data (Somerton 2013) and g^i is predicted post-molt size.

**Fishing Mortality Penalties**

The September 2013 Base model contains penalties on high fishing mortality estimates for the entire time series (1978/79 to 2012/13),

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



Fishing mortality deviations for males (λ =0.1),



Female bycatch fishing mortality penalty (λ = 1.0).



Trawl bycatch fishing mortality penalty (λ = 1.0)



Model 3 contains fishing mortality penalties for the directed fishery 1979/80 to 1992/93 only in the last phase,

 .

**Results of Model Runs**

A set of figures for each model run are in separate pdf files with figure titles at the end of this document. Model 1, with the two connected lines, fits growth data better than a single line (Table 1). However, length data including survey and fishery data are not fit as well with Model 1 as the September 2013 model.

The removal of F penalties results in very high fishing mortality estimated in 1981 and 1982. The retained catch estimates are still fit well, however, the high F’s result in very high estimates of discard from the directed fishery since the estimated F’s are the same for the retained and total catch and there is no discard catch data for the model to fit before 1992.

Model 3 has growth with two line segments by sex and has fishing mortality penalties on the directed fishery in 1979/80 to 1992/93 only. This results in estimates of discard catch that are more reasonable than model 2 with no F penalties. The removal of F penalties after 1993 should reduce any bias in current F estimates, however, estimates of F35% and B35% may still be affected since selectivities, M and maturity do not change over time and the recruitments for 1978/79 to present is used in the estimate of B35%.

**Chela Height Data**

Chela height data are currently used in the snow and tanner crab assessments to estimate maturity by size and shell condition and split survey data into immature and mature crab. An average curve over all years is used, however, there is considerable variability by year. Chela height measurements for Bering Sea snow crab have been collected since 1989 on the summer survey (see chelamaps.doc file). No measurements were taken in 2008, 2010, 2012 or 2013. Fewer measurements were taken in 2009 and 2011 than previous years. Measurements have been assumed to be representative of the surveyed population and the male crab with chela data used to develop maturity curves by carapace width (see Figure 1 this document). The average maturity curve by new and old shell for 1989 to 2007 has been used to separate the survey data into mature and immature males for input into the assessment model (Figure 2 this document). The spatial distribution of the sampling relative to the spatial distribution of male crab by shell condition and maturity will affect the maturity curve. In many years a larger fraction of the catch was sampled for chela heights in the southern part of the range than in other areas. Other methods of using this data may be:

1. Use population estimates instead of simple sample numbers to estimate maturity curves.

Estimate length frequency of immature and mature males similar to using age-length key and length frequency.

1. Don’t split survey data by immature and mature as input to the model. Instead construct a likelihood for the fit of the estimates of the fraction mature by size from chela height data to the probability of maturing estimated in the model. A problem here is that the fraction mature by size for new shell males is a biased estimate of the probability of immature crab maturing, because new shell mature males include shell ages greater than 1 year from molting (Figure 2 this document). Also should maturity by year be used or some average over all years?
2. Other methods?

**References**

Szuwalski, C., and Punt A. E. 2012. Fisheries management for regime-based ecosystems: a management strategy evaluation for the snow crab fishery in the eastern Bering Sea. – ICES Journal of Marine Science, doi:10.1093/icesjms/fss182.

Table 1. Likelihood values for three model scenarios compared to the model accepted in September 2013.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Likelihood Component | | Model 0 | Model 1 | Model 2 | Model 3 |
| Scenario | | Sep-13 | Two line growth | No F penalties | F penalties 80-93 only |
| Discard mortality | | 0.3 | 0.3 | 0.3 | 0.3 |
| Recruitment | | 30.2 | 29.48 | 32.96 | 31.55 |
| Initial numbers old shell males small length bins | | 2.23 | 2.22 | 2.59 | 2.28 |
| ret fishery length | | 346.48 | 346.23 | 315.81 | 345.20 |
| total fish length | | 747.09 | 748.83 | 741.71 | 748.68 |
| female fish length | | 200.73 | 201.02 | 201.11 | 200.90 |
| survey length | | 3571.4 | 3609.65 | 3597.07 | 3632.25 |
| trawl length | | 257.74 | 264.75 | 255.06 | 263.19 |
| 2009 BSFRF length | | -81.14 | -80.98 | -81.28 | -87.15 |
| 2009 NMFS study area length | | -70.42 | -69.22 | -69.72 | -71.67 |
| M prior | | 3.29 | 3.03 | 3.85 | 3.24 |
| maturity smooth | | 45.71 | 58.10 | 41.71 | 57.93 |
| growth males | | 35.76 | 10.74 | 42.46 | 11.50 |
| growth females | | 52.09 | 9.87 | 52.44 | 9.72 |
| 2009 BSFRF biomass | | 0.12 | 0.13 | 0.16 | 0.13 |
| 2009 NMFS study area biomass | | 0.03 | 0.03 | 0.07 | 0.06 |
| retained catch | | 0.98 | 1.24 | 2.50 | 2.73 |
| discard catch | | 86.14 | 104.59 | 122.73 | 147.28 |
| trawl catch | | 9.53 | 9.73 | 2.78 | 8.43 |
| female discard catch | | 3.78 | 3.79 | 0.24 | 0.36 |
| survey biomass | | 189.73 | 192.85 | 184.48 | 184.12 |
| F penalty | | 83.22 | 84.68 | 0.00 | 19.18 |
| 2010 BSFRF Biomass | | 0.47 | 0.39 | 0.70 | 0.52 |
| 2010 NMFS Biomass | | 1.25 | 0.87 | 2.03 | 1.37 |
| initial numbers fit | | 506.63 | 508.21 | 508.05 | 507.70 |
| 2010 BSFRF length | | -60.48 | -58.98 | -60.63 | -59.34 |
| 2010 NMFS length | | -73.24 | -68.76 | -73.34 | -69.06 |
| male survey selectivity smooth constraint | | 3.62 | 3.87 | 3.49 | 4.00 |
| init nos smooth constraint | | 39.04 | 38.13 | 42.38 | 38.49 |
| Total | | 5931.96 | 5954.48 | 5871.40 | 5933.60 |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

Table 1. Continued.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Likelihood Component |  | Model 1 | Model 2 | Model 3 |
| Scenario | Sep-13 | Two line growth | No F penalties | F penalties 80-93 only |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
|  | Q Survey 1989-Present | 0.546 | .55 | 0.60 | .56 |
|  | no. parameters | 311 | 311 | 311 | 311 |
|  | immat M | 0.386 | .40 | .37 | .42 |
|  | M mature females | 0.23 | .23 | .23 | .23 |
|  | M mature males | 0.261 | .26 | .26 | .26 |
|  |  |  |  |  |  |
|  | F35% | 1.58 | 1.56 | 2.32 | 1.75 |
|  | B35% | 154.2 | 158.7 | 146.1 | 151.7 |



Figure 1. Fraction mature by size for new shell male snow crab by year (1989-2007,2009,2011) from chela height data measurements from the summer trawl survey.



Figure 2. Average fraction mature for new shell males from chela height data 1989-2007 and the probability of an immature male maturing by size estimated in the September 2013 assessment model.

**Figure titles for pdf files with model runs. Model.0.2013sept.pdf, Model.1.2014may.pdf, Model.2.2014may.pdf, Model.3.2014may.pdf**

Figure 1. Population total mature biomass (millions of pounds, solid line), model estimate of survey mature biomass (dotted line) and observed survey mature biomass with approximate lognormal 95% confidence intervals.

Figure 2. 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 3. 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 4. 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 5. Model fit to length frequency for BSFRF and NMFS females and males in the study area.

Figure 6. Fits to 2009 study area mature biomass by sex for BSFRF and NMFS data.

Figure 7. Fits to 2010 study area mature biomass by sex for BSFRF and NMFS data.

Figure 8. Model fit to the survey female size frequency data. Circles are observed survey data. Solid line is the model fit.

Figure 9. Residuals of fit to survey female size frequency. Filled circles are negative residuals.

Figure 10. 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 11. Model fit to the survey male size frequency data. Circles are observed survey data. Solid line is the model fit.

Figure 12. Residuals for fit to survey male size frequency. Filled circles are negative residuals (predicted higher than observed).

Figure 13. 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 14. Summary fit to retained male length.

Figure 15. Residuals for fit to retained male size frequency. Filled circles are negative residuals (predicted higher than observed).

Figure 16. 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 17. Summary fit to total fishery length frequency male catch.

Figure 18. Residuals for fit to total fishery male size frequency. Filled circles are negative residuals (predicted higher than observed).

Figure 19. 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 20. Summary fit to directed fishery female discards.

Figure 21. 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 22. Model fit to the groundfish trawl discard male size frequency data. Solid line is the model fit. Circles are observed data. Year is the survey year.

Figure 23. Summary fit to groundfish length frequency.

Figure 24. 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 25. Growth (mm) for male (dotted line) and female snow crab (solid line) estimated from the base model. The priors for the growth curve used in Scenarios 3 and 4 are circles (males) and triangle (females). Heavy dotted line is the growth curve estimated by Somerton for males and females from the 2011 growth study (Somerton 2012).

Figure 26. Estimated growth curve for female snow crab with 2011 growth study data.

Figure 27. Estimated growth curve for male snow crab with 2011 growth study data.

Figure 28. Probability of maturing by size estimated in the model for male(solid line) and female (dashed line) snow crab (not the average fraction mature). Triangles are values for females used in the 2009 assessment. Circles are values for males used in the 2009 assessment.

Figure 29. Distribution of recruits to length bins estimated by the model.

Figure 30. Selectivity curve for total catch (discard plus retained, solid line) and retained catch (dotted line) for combined shell condition male snow crab.

Figure 31. Model estimated fraction of the total catch that is retained by size for male snow crab combined shell condition.

Figure 32. Survey selectivity for male snow crab estimated for three periods: 1) 1978-1981, 2) 1982-1988 and 3) 1989-Present.

Figure 33. 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 34. 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 35. Survey selectivity for female crab 1989- present (Model Bering Sea female).

Figure 36. Survey selectivity curves for male crab in the entire Bering Sea 1989-present (BS male), 2009 study area BSFRF male and 2009 study area NMFS male.

Figure 37. Survey selectivity curves for male crab in the entire Bering Sea 1989-present (BS male), 2010 study area BSFRF male and 2010 study area NMFS male.

Figure 38. Survey selectivity curves for female crab in the entire Bering Sea 1989-present (BS female), 2009 study area BSFRF female and 2009 study area NMFS female.

Figure 39. Survey selectivity curves for female crab in the entire Bering Sea 1989-present (BS female), 2010 study area BSFRF female and 2010 study area NMFS female.

Figure 40. Survey selectivity curves entire Bering Sea survey for female (upper dashed line) and male snow crab (solid lines) estimated by the model for 1989 to present. Survey selectivities estimated by Somerton(2010) from 2009 study area data are the circles. Lower lines are survey selectivities in the study area for BSFRF male and female crab and NMFS male and female crab.

Figure 41. 2010 study area survey selectivity curves (BSFRF and NMFS). BS are survey selectivity curves for the entire Bering Sea. Som is the selectivity curve estimated by Somerton from the 2009 study area data.

Figure 42. Selectivity curve estimated by the model for bycatch in the groundfish trawl fishery for females and males.

Figure 43. Exploitation fraction estimated as the catch biomass (total or retained) divided by the mature male biomass from the model at the time of the fishery (solid line is total and dotted line is retained). The exploitation rate for total catch divided by the male biomass greater than 101 mm is the solid line with dots. Year is the year of the fishery.

Figure 44. Estimated total catch (discard + retained) (solid line), observed total catch (solid line with circles) (assuming 50% mortality of discarded crab) and observed retained catch (dotted line).

Figure 45. 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.

Figure 46. Discard catch as a fraction of retained catch by year.

Figure 47. Model fit to groundfish bycatch. Circles are observed catch, line is model estimate.

Figure 48. Model fit to male directed discard catch for 1992/93 to 2012/13 and estimated male discard catch from 1978 to 1991.

Figure 49. Model fit to female discard bycatch in the directed fishery from 1992/93 to 2012/13 and model estimates of discard from 1978 to 1991.

Figure 50. Full selection fishing mortality estimated in the model from 1978/79 to 2012/13 fishery seasons.

Figure 51. Mature Male Biomass at mating with 95% confidence intervals. Top horizontal line is B35%, lower line is ½ B35%.

Figure 52. Fishing mortality estimated from fishing years 1979 to 20012/13 (labeled 13 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.

Figure 53. Spawner recruit estimates using male mature biomass at time of mating (1000t). Numbers are fertilization year assuming a lag of 5 years. Recruitment is half total recruits in thousands of crab.

Figure 54. Phase plot of fishing mortality relative to F35% and MMB relative to B35%.