Report on the 2007 Bering Sea snow crab assessment

Author
C.M. Dichmont
CSIRO Marine Research, Cleveland, Australia

Prepared for
Center for Independent Experts

1 Contents

2 Executive summary

The Center for Independent Experts and The Alaska Fisheries Science Center (AFSC) requested a review of the snow crab population dynamics and harvest strategy models for the Bering Sea snow crab (*Chionoecetes opilio*) assessment. The review was held in Seattle, Washington, February 11-15, 2008 to consider the stock assessment of the Bering Sea snow crab. Presentations by staff at AFSC were made on the fishery, biology, field experiments, the survey, larval movement, spatial modelling, ecosystem work, the assessment and the forward project model used for calculating the harvest strategy. Additional analyses were requested and carried out, and the results discussed during the week. This report should be read in conjunction with my fellow reviewer, Dr Ewen Bell.

The workshop was well run, and presentations and responses to queries were clear and helpful.

Documentation that describes the model in accurate mathematical detail is poor – particularly when compared to the actual code. This hampered a full review of the mathematical details and accuracy of the model. As a result, the re-modelling of the assessment into Excel by industry consultants, Drs Maunder and Tagart is likely to ultimately be of great benefit to the assessment authors. The healthy debate that will ensue with other parties who have detailed knowledge of the model is likely to produce an improved overall result.

Key issues discussed in the report include, amongst other aspects, the spatial patterns in the data compared to a Bering Sea-wide model, recruitment patterns, strong residual patterns in the fit to size-frequency data, and the value of shell condition data.

Although there is still a lot of process and observation uncertainty in the model, it is an improvement on previous methods and several recommendations from past reviews have been incorporated. The detailed part of this report comments on the various input data, model assumptions and model estimates. Throughout the review, it was clear that a Management Strategy Evaluation should be undertaken so as to help prioritise further research, review key model assumptions and test alternative models. This is the highest priority recommendation. Below is a list of recommendations. They are best read in context.

2.1 Recommendations

Below is a list of recommendations. An attempt has been made to prioritise them starting with the highest.

1. It is strongly recommended that a Management Strategy Evaluation be undertaken. This is the highest priority recommendation. This work should include:

a. the effects of environmental variables on recruitment and attempt to provide independent data that allows these environmental effects to be modelled internal to the assessment,
b. investigation of various alternative model options,
c. investigation of changes to the model that address the strong residual patterns in the fit to the size-frequency data, and
d. prioritising field research (including growth data) and model change options in terms of their effect on management advice.

When combined with the spatial work being undertaken by J. Murphy – much should be clarified in the future.

2. A detailed mathematical description of the model is needed. Past reviews have mentioned this as well. Also, figures of model estimates should include parameter variances. I can not emphasise this enough – from investigation of the Turnock and Rugolo (2007) model description and the actual code, there is a large discrepancy between the code and the associated descriptions.

3. It is essential that the raw survey data are transferred onto an accessible system so that detailed analyses and data mining could easily be undertaken by a broader group including the present assessment team.

4. It is recommended that the small spatial distribution of the fishery compared to the size of the survey area needs to be investigated especially in the context of the assessment assumptions.

5. If a size-based model remains the basis of an assessment, reliable growth data need to be collected through a well designed tagging study.

6. It is recommended that the model not use new and old shell categories. This will reduce the number of parameters.

7. It is recommended that an investigation should be undertaken of whether a form of post stratification of the survey data would be useful for the index CVs and the size-frequency data.

8. It is unclear whether there is a time varying trend in the survey catchabilities or selectivities. This would occur, for example, if the distribution of the crab changes over time and the gear catchability or selectivity differs spatially. It is recommended that this needs to be investigated first as part of a desk top exercise.

9. The discussion regarding whether local depletion or large scale movement is occurring should be progressed further. An indirect (and rough) calculation of the scale of movement onto the fishing ground implied by the model can be made by comparing 1) the ratio of mature male biomass in the survey area relative to the whole survey area, and 2) the ratio of the mature male biomass in the catch compared to the mature male biomass estimated in the model at the time of the fishery (provided in this report).

10. It is recommended that studies on Durometer measures of shell hardness and dactyl length should be further investigated. However, it is unlikely that this information will allow re-classification of shell condition data already collected.

11. The survey index uses a simple swept area estimate for animals greater than 25 mm. This index is therefore different to that presented in the annual survey report and it is recommended that this is clarified in the model description.

12. It is recommended that the correct average swept width is used in the input data and the calculation of a clear and obvious catchability and selectivity function is used in the model.

13. For three years in the early 1980s, the actual observed survey index variance inputted into the model is doubled to down weight the importance of those surveys years. In terms of clear communication, this aspect needs to be clearly stated in any stock assessment report text and the appropriate figure legends including the reasons why this step was taken.

14. The plots of size frequency residuals presented in the report uses a method that tends to not show the residuals clearly or accurately. It is recommended that a different method is used to plot the residuals of the model fit to observed size data.

15. As a small model test, it is recommended that the following sensitivity test is undertaken. Test the estimated 9 selectivity parameters by removing the northern sites from the last survey period but still fit the model to 3 survey series. In theory the 2nd and 3rd survey selectivity functions should be comparable.

16. The commercial pot fishery catch rates are included in the model unstandardised. It is also included in the likelihood with low weighting compared to the other components of the likelihood. It is recommended that the fit to pot fishery catch rates is removed from the likelihood while the data remain unstandardised.

17. It is further recommended that the catch rates are standardised and then added to the model with more appropriate weighting. However, this is only suggested at this stage as a sensitivity test, given the added complication that the fishery often covers a much smaller spatial scale relative to the distribution of the crabs.

18. In the case of females, as a minor issue it is recommended that a logistic function is fitted to remove the inconsistency that a larger female may have a lower probability of maturing than a smaller female due to what appears to be noise in the data.

3 Background

The Center for Independent Experts (see Appendix 1) and The Alaska Fisheries Science Center (AFSC) requested a review of the snow crab population dynamics and harvest strategy models for the Bering Sea snow crab (*Chionoecetes opilio*) assessment.

The snow crab assessment model was reviewed by the CIE in 2003 by Dr Maunder. In 2006 there was a three-person CIE review of the Alaskan crab overfishing definitions and simulation models used to evaluate biological reference points for Bering Sea and Aleutian Islands King and Tanner crab stocks. Since that time, several improvements to the model have been undertaken. Drs E. Bell and C. Dichmont reviewed the present Bering Sea snow crab assessment and projection models in Seattle in 2008. The snow crab assessment is a high profile assessment.

This review encompassed the Bering Sea trawl survey data, the stock assessment model structure, assumptions, life history data, the projection model and the harvest control rule.

4 Review activities

4.1 Documentation

The reviewers were provided beforehand and during the meeting with various documents as listed:

Documents received before the workshop

1. Turnock, B.J. and Rugolo, L.J. 2007. Stock assessment of eastern Bering Sea snow crab. (filename snowcrab.assess.sept2007.final.doc)
2. Plan team, 2007. Stock assessment and fishery evaluation report for the king and tanner crab fisheries of the Bering Sea and Aleutian Islands Regions. http://www.fakr.noaa.gov/npfmc/SAFE/2007/CRABSAFE07.pdf
3. Document of the Overfishing Control Rules (http://www.fakr.noaa.gov/npfmc/current_issues/crab/KTC24907.pdf)
4. The 2006 full report on the Bering sea trawl survey http://www.afsc.noaa.gov/Publications/ProcRpt/PR%202006-17.pdf
5. Jadamec, L.S., Donaldson, W.E. and Cullenberg, P. 1999. Chionoecetes Crabs Biological Field Techniques for Chionoecetes Crabs. (Chionoecetes Crabs_Jadamec et al_AK-SG-99-02.pdf)
6. Gravel, K.A., Watson, L.J. and Pengilly, D. 2006. The 2005 Eastern Bering Sea snow crab *Chionoecetes opilio* tagging study. (fmr06-31.pdf)
7. The ad model code for the stock assessment model (scmysrfut2006s3mtbio.tpl), the report files (scmysrfut2006s3mtbio.rep), a control file (sc.ctl), data file (scmysrfut2007allareaimmataugust.dat) and the parameter file (scmysrfut2006s3mtbio.par).

8. Field guide on chionoecetes crab (Chionoecetes Crabs_Jadamec et al_AK-SG-99-02.pdf)
9. An updated agenda,
10. Statement of work including the Terms of Reference of the review.

Documents received during the workshop

1. R code to read ad model report file
2. Presentations of the assessment, new review process for crab stock assessments and OFL determination (Turnock), ageing (Rugolo) and spatial distributions (Murphy)
3. Project application of Punt and Turnock (PlanPunt.doc)

Documents obtained after the workshop

Past CIE reviews relevant to the EBS snow crab:

1. 2003 Bering Sea snow crab Maunder report - final.pdf
2. Bell Alaska king and tanner crab review report - final.pdf
3. Caputi Alaska king and tanner crab review report - final.pdf
4. Cordue Alaska king and tanner crab review report - final.pdf

4.2 Review in Seattle

The review was held in Seattle, Washington, February 11-15, 2008 to consider the 2007 stock assessment of the Bering Sea snow crab. The meeting was chaired by Dr Hollowed. Various presentations from AFSC staff were made (see Appendix 1 for the agenda) – which provided an overview of the fishery, biology, field experiments, age determination, the survey, larval movement, spatial modelling, ecosystem work, economics, the assessment and the forward projection model used for calculating the harvest strategy. Debate and questioning occurred throughout these presentations.

The first two days of the review were open to the public. An independent industry consultant was present who also participated in the debate and questioning. So too were staff from the Alaska Department of Fish and Game, and Dr Punt as a member of the Plan team.

Dr Ewen Bell, CEFAS, Lowestoft, UK was the other CIE member on the review panel. Several requests were made of the assessment team and results of most of these were presented during the week. A draft presentation of Dr Bell and my preliminary findings were provided on 14th February. The final day was spent writing the report. Some small amounts of further interaction by e-mail occurred after the workshop leading up to the final hand-in dates.

5 General comments

The snow crab assessment is data rich but information poor. Data are available from surveys, and from the pot and the trawl fishery. There are sufficient size (carapace width) data, from both the annual summer surveys and industry catch data. On the other hand, the trawl surveys are not directly designed for crabs, nor use gear optimised for the capture of crab. The survey size data do not show clear modal progression even considering that it is a moulting species. These data have therefore not contributed to an understanding of the specie's growth rate nor allow for easy use in an assessment model. There are data on shell condition which should provide shell age but have been shown to be so unreliable that they are practically unusable in their present form. The fishery occurs on a varying spatial scale, in part due to the extent of the sea ice during the season. The actual distribution of Bering Sea snow crabs can at times be much larger than the fishery spatial scale. Little is known about snow crab migration rates. Larval modelling is showing complex movement and environmental influences. The end result is that the Bering Sea snow crab is an extremely complex resource to model given that key information (e.g. growth) is incomplete or unknown.

The daily interactions with the reviewed staff were excellent and there were good discussions during the week. Much was clarified in this process. It was at times difficult to obtain all documentation requested and some have still not been received by the time the report was due (for example, we have not received all the PowerPoint files that were presented by AFSC staff during the review week). The authors kindly made their R code available during the week to assist us to interpret the very large output file produced by the assessment model.

A key issue that has hampered this and past reviews is that there is not an exact and detailed description of the model. For example, the full likelihood (including constraints and restrictions) are not adequately described. This is evident if one compares the text to the code. In some of the plots in the documents provided, parameter variances were not included. Some tests of model sensitivity beyond that provided in the Plan team document should be undertaken. It is essential and recommended that this is provided in the near future. The *AD Model Builder* code we were provided with also had a lot of legacy code within it that has been commented out and was therefore extremely difficult to review.

Another factor that made the process difficult for the reviewers is that the stock assessment team did not themselves have ready access to the raw survey data. It is essential that the data are transferred onto a system so that detailed analyses and data mining could easily be undertaken by the assessment team and others. As a result, certain requests to the assessment team could not be undertaken – not, however, due to the team's error.

6 Stock assessment model

A size-based (carapace width) assessment model, disaggregated by male and female, new and old shell, and immature and mature is fitted to survey, commercial size and catch data. A separate model that describes the same population dynamics as the assessment model is used to forward project the population. The fishery targets clean shell males above 101 mm shell width. Female fishing mortality only occurs through incidental bycatch and subsequent discard mortality.

Comments below are divided broadly into input information and output results.

6.1 Bering Sea trawl survey index

The Bering Sea survey data used in the model start at 1978. Prior to this period, the survey area did not adequately cover the snow crab distribution. It uses trawl gear, different to the targeted pot fishery. The survey targets both crab and fish species and is designed as a simple grid survey with a few extra sites for other species. In 1982, the fishing gear was modified which resulted in a change in catchability. After 1988, the survey was extended further north to capture areas with small snow crabs. This means that the survey index is correctly fitted in the assessment model as 3 separate and distinct series. The model estimates survey catchability and selectivity by size.

The survey index uses a simple swept area estimate for animals greater than 25 mm. This index is therefore different to that presented in the annual survey report and it is recommended that this is clarified in the model description. In the calculation of survey swept area of the raw data, rather than use the actual individual site's trawl width or the actual average trawl width (about 56 ft), a value of 50 ft is used. This was at the time used to adjust the overall trawl catchability. A later experiment where a beam trawl followed the survey trawl confirmed that the survey catchability is less than one. However, the model itself also estimates survey catchabilities and the interpretation of this estimated parameter is complicated by the adjustment in the input data. It is recommended that the correct average swept width is used in the input data and the calculation of a clear and obvious catchability and selectivity function is calculated in the model.

The estimated survey indices are fitted in the model to an inverse variance weighted observed survey index. For three years in the early 1980s, the actual observed survey variance inputted into the model is doubled to down-weight the importance of those survey data points. This is due to anecdotal information (e.g. the catch was greater than survey index) that the surveys were not accurate in those years. In terms of clear communication, this aspect needs to be clearly stated in the figure legend and in the text (that double the variance was used for specific years than was shown) including the reasons why this step was taken.

It is not clear whether the survey data do or do not track the status of the stock, but given that projects are underway to investigate the data, especially the spatial aspects of the survey (e.g. James Murphy), it is recommended that the survey should continue to be used as an index of abundance in the model. We were not given the raw survey data so were unable to explore options ourselves. It is recommended that an investigation should be made of whether a form of post stratification of the survey data would be useful for the index CVs but especially the size-frequency data. The survey is general in respect to target species and area, and not specific to snow crab. It is recommended that the small spatial distribution of the fishery compared to the survey needs to be investigated to show whether it is possible to obtain a more consistent index and better CVs.

Furthermore, it is unclear whether there is a temporal trend in the survey catchabilities or selectivities. This would occur, for example, if the distribution of the crab changes over time and the gear catchability or selectivity differs spatially. It is recommended that this be investigated first as part of a desk top exercise.

There was much discussion as to whether the crab assessment would benefit from a dedicated survey designed for crabs (but then this could only happen every two years) and keeping the present annual grid survey. It is unclear what the trade-offs would be regarding:

a) moving from an annual survey to a bi-ennial one,
b) moving from a grid survey to a specifically designed survey using gear targeting crab, and
c) adding a new survey series into the model and therefore new catchability and size selectivity parameters.

One method to investigate these options prior to making a change, is to investigate these options in a management strategy evaluation (MSE) framework. Also to check whether it is possible to calibrate the new and old trawl survey or overlap the old and new survey methods for a few years.

6.2 Survey size-frequency

Survey size data is entered into the model in 5 mm bin classes. In the model, size frequencies are calculated/fitted for males and females, mature and immature, old and new animals – although not every combination of these are modelled.

The survey size data do not show clear modal progression notwithstanding that the snow crab is a moulting species (e.g. Figure 1). This probably contributes in large part to some of the strong residual patterns evident in the plots of the fitted survey female and male size frequency (e.g. Figure 2) indicating the difference between the observed size frequencies and those predicted by the model.

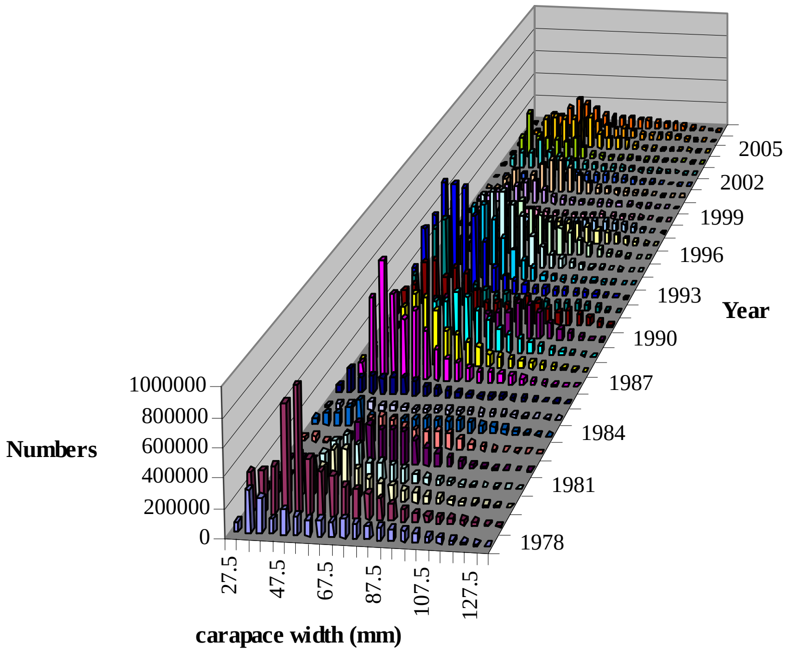

Figure 1: Observed survey male size-frequency in numbers (source: presentation given by J. Turnock during review).

Overall, there are very strong residual patterns in most of the fitted size frequency information (not just the survey data). Given the number of reviews of this model in various forms, it is clear that a MSE would be useful to prioritise research and model change options in light of the sensitivity on management advice. Also, as recommended above, an investigation regarding post stratification (or standardisation) of the survey is needed to see if clearer size distribution data can be obtained (of course without biasing the data). The work being undertaken by James Murphy on the spatial aspects of the survey selectivity and possible migration patterns is therefore crucial.

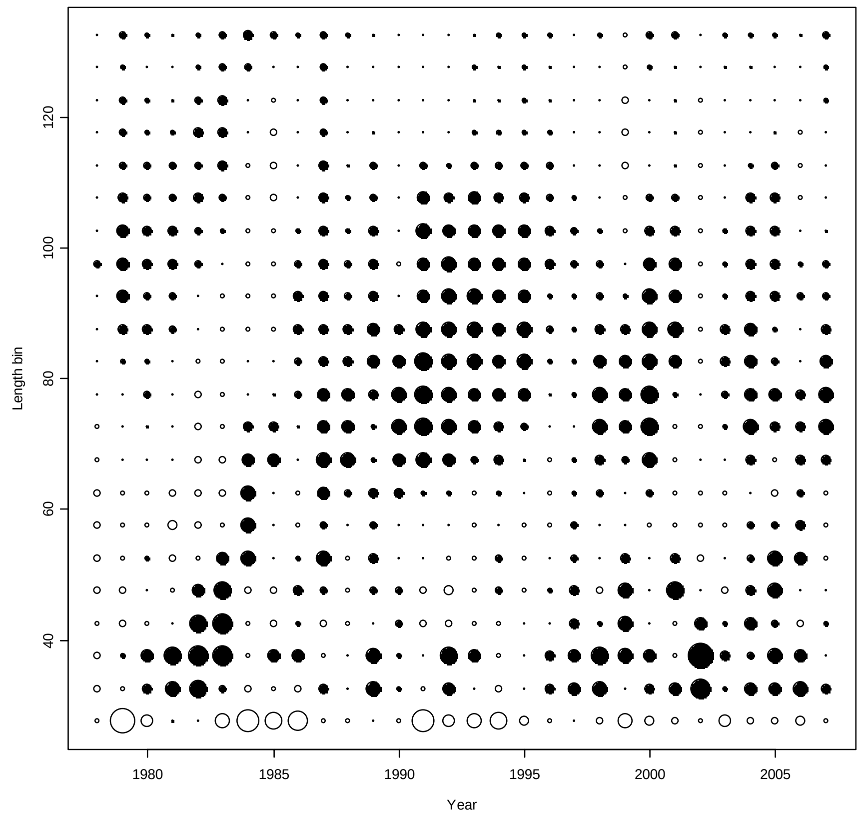

Figure 2: Residuals of the fit to survey male size frequency. Filled circles show predicted higher than observed. (Source: Turnock and Rugolo 2007)

The plots of size frequency residuals presented in the report (and Figure 2) uses a method that tends to not show the residuals clearly or accurately. It is recommended that a different method is used to plot the model residuals to the size data.

6.3 Survey selectivities

There was some discussion during the review week about whether survey selectivities varied within the periods 1978 to 1981, 1982 to 1988, and 1989 to the present. Despite this discussion, it is unlikely the model could estimate any more parameters. Also, given the uncertainty in other input data (such as growth), it is not likely to be a priority area for further modification of the model.

As a small model test, it is recommended that the following sensitivity test is undertaken – to test the estimated 9 selectivity parameters by removing the northern sites but still fitting to 3 survey series. In theory the 2nd and 3rd survey selectivity functions should be comparable.

6.4 Natural mortality

Natural mortality in the model was set at 0.29 for mature females, and 0.23 for all other crab, to be consistent with the crab overfishing analyses. Similar to many other species, there is no reliable external information on natural mortality.

A suggestion was made during the two-day public session that time-varying natural mortality estimates should be implemented in the model. At present, this is not recommended and we support the assessment authors that the model as yet has no further information that could assist in estimating additional selectivities (discussed above) and time-varying natural mortality without seriously confounding in the model.

6.5 Commercial catch rates

The commercial pot fishery catch rates are included in the model as unstandardised data. They are also included in the likelihood calculation with low weighting relative to other components of the likelihood with the result that these data have little influence on the parameter estimates. The argument given by the authors that the low weighting is due to the recent changes in the management of the fishery is supported given that unstandardised data are included. At present, it is recommended that the unstandardised commercial catch rate is removed from the likelihood calculation.

It is further recommended that the catch rates are standardised and then incorporated into the model with more appropriate weighting. However, this is only suggested at this stage as a sensitivity test, given the added complication that the fishery often covers a much smaller spatial range relative to the actual distribution of the crabs and it is unknown how well the commercial catch rate data indicate overall abundance.

6.6 Growth

The growth transition matrix is a crucial input to size-based models. Yet for this fishery there is minimal tagging information. In the model, the growth of females is based on studies undertaken in Canada; that of males is based on 14 observations. The model provided uses a gamma distribution to model growth variance. As explained during the presentations, one of the parameters, beta, is fixed in the model using the same values as used for tanner crab estimates. If a size-based model remains the basis of an assessment, reliable growth data need to be collected through a well designed tagging study. Based on discussions during the review in Seattle, it does not seem feasible to keep snow crab alive long enough in tanks for growth rate studies.

Again, it is also a priority to undertake an MSE that quantifies the impact of using different growth functions and the value of added growth data, and that also investigates using a simpler model that remains applicable to this fishery.

In the model, a 1:1 sex ratio is assumed for recruitment. The growth function used in the model may be incompatible with the assumption of equal recruitment for males and females as females' growth is slower. The assumption that the vector of sizes entering the model are the same for males and females may be incompatible with the above growth function. However, Canadian studies have shown no real differences in the growth of small male and female crabs so this is unlikely to be a major issue.

6.7 Space and its effect on movement, growth, size frequencies and indices of abundance

James Murphy, University of Washington and AFSC, gave a very informative presentation entitled "Spatial dynamics and structure of EBS snow crab". The factors affecting the spatial movement of crabs are not known in any detail. In general terms, using survey data, animals move south-west to deeper waters with mature males moving to deeper waters than females. The degree of movement changes with depth, as shown by the changes in the latitudinal centroids of male and female crabs between 1982 and 2007. The size-frequency distribution also changes between years spatially. Upon visual inspection, there also seems to be some degree of correlation (although this was not tested) between latitude centroids and the relative abundance of new shell mature females (Figure 3). James Murphy also showed spatial patterns in maturity. His study is attempting to identify spatial patterns and relate these to various processes such as oceanography, fishing, regime shifts etc. This work is essential.

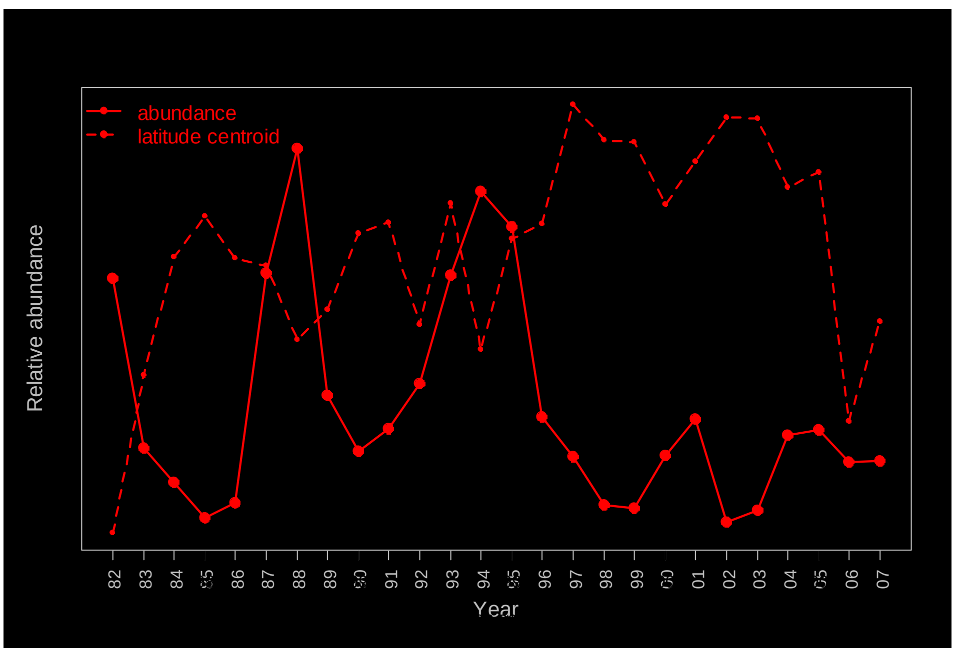

Figure 3: Relative abundance of female relative abundance and latitude centroids of new shell mature females (Source: presentation J. Murphy during review in Seattle).

During the review week, there was much debate about the effect of the lack of spatial assumptions in the model and the strong spatial features apparent in the data. There is also a time gap between the survey and the fishery, which further strengthens the debate as no spatial distribution data beyond the fishery is available at the time the fishery occurs.

There appear to be two points of view regarding the amount of animal movement that occurs between the time of the survey and the fishing season, and therefore the risk of local depletion in the area of the fishery. A plot of the ratio of the commercial catch relative to the relevant population biomass at the time of the fishery was requested during the review (Figure 4). This plot shows that the catch relative to the model large male biomass varies from about 15% to 86%. This was contrary to a statement made by Dr Zheng that the catch is generally about 80% of the model population biomass estimate. Due to lack of access to the raw data, Drs Turnock and Rugolo were unable to provide us with the ratio of the survey biomass in the area of the fishery and the total survey biomass of large males. This would have provided some anecdotal information on how much movement would have to occur to support the model estimates. It is recommended that this still be investigated.

A test was also undertaken where the survey catchabilities were artificially decreased. The fit of this model to the data was poor, although little tuning of the model was undertaken. This did affect the final overfishing/upper catch levels, especially in the short term, contrary to what was argued by Drs Turnock and Rugolo during the discussions in Seattle, but probably not as much as was argued by those with differing views. There was absolutely no basis for the catchability value chosen in the test other than testing the sensitivity of the model to this parameter. It is recommended that these kinds of tests be openly undertaken to progress the debate.

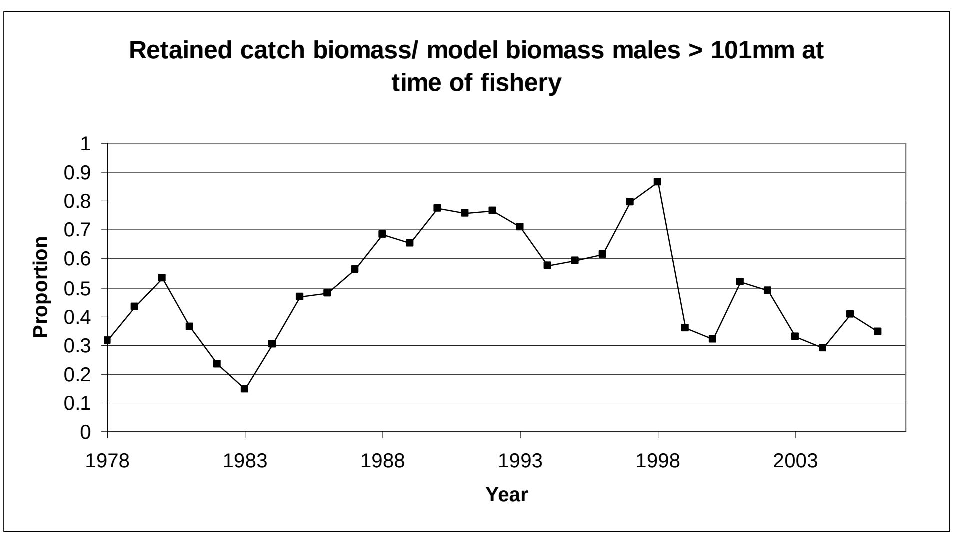

Figure 4: Ratio of the retained catch biomass relative to the model biomass of males greater than 101 mm CW at the time of the fishery (Source: results J. Turnock during review).

There is little information on the movement of snow crabs – a key issue since the fishery occurs in only a very small part of the animals' distribution especially in cold years. Tagging data available are biased as tag returns come from the industry and so only show animals that moved onto the fishing ground and not those that moved elsewhere. I support the assessment authors, Turnock and Rugolo, on this point.

6.8 Maturity

Maturity is assumed in the model to be based on length. In the model, the indicator of spawning biomass is mature male biomass at the time of mating. The model estimated survey mature biomass is fit to the observed survey mature biomass time series by sex. The model also fits the size frequencies of the survey by immature and mature individuals separately for each sex. The fraction of males and females morphometrically mature by year for a given size from survey data is used to calculate the probability of a crab maturing. In the case of new shell males (Figure 5), there is a range of sizes in which the values remain reasonably constant. The actual reason for this remains unclear. This feature appears to be absent for females.

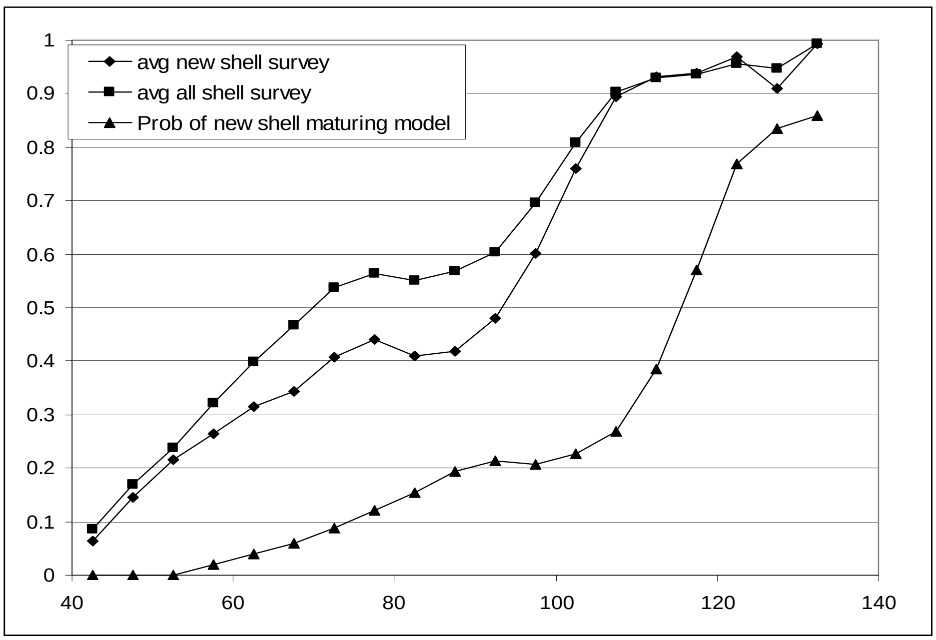

Figure 5: Fraction of males morphometrically mature based on survey data as well as the probability of males maturing (Source: presentation by J. Turnock during review). The x-axis is carapace width and the y-axis is probability or fraction.

In the case of females (Figure 6), as a minor issue it is recommended that a logistic function is fitted to remove the inconsistency that a larger female may have a lower probability of maturing than a smaller female due to what looks more like noise in the data.

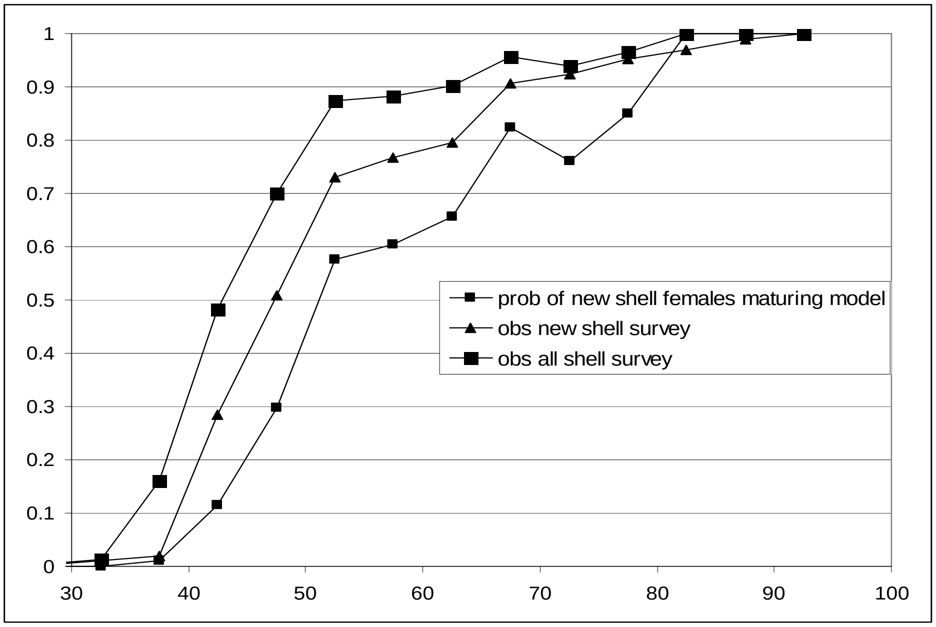

Figure 6: Fraction of new and all shell females morphometrically mature based on survey data and as well as the probability of females maturing (Source: Presentation by J. Turnock during review).

6.9 Shell age

The fishery targets “clean” crab and is only allowed to retain male crabs. As a result, the model separates numbers into males and females, and new and old shell. The model, however, does not fit to new and old shell data separately. In the model, new shell move to old shell after a year. This is a broad assumption and without direct and validated shell age it is unclear how accurate this assumption is.

However, the larger issue is how accurate the definition of shell age is (even at the scale of old and new). For example, studies have shown that biologists themselves incorrectly classify shells (Rugolo presentation). In the model new shells are classified as Shell Condition 2 and Old shell are classified as shell condition 3 to 5. In these studies, the shell mis-classification error also occurs between these new and old shell categories. This error appears to be even larger for the commercial data gathered by observers. Comparisons of observer-rated shell conditions with those made by staff at landing show large discrepancies in both directions. It is not possible with the available data to estimate this error and include this in the model – therefore it is recommended that the model not use new and old shell categories. This issue is particularly highlighted when the calculated fit to new and old shell numbers are shown (Figure 7 and Figure 8). This can not be a great loss in information as the fishery really targets clean shell which may be animals that have a shell age greater than 1 year.

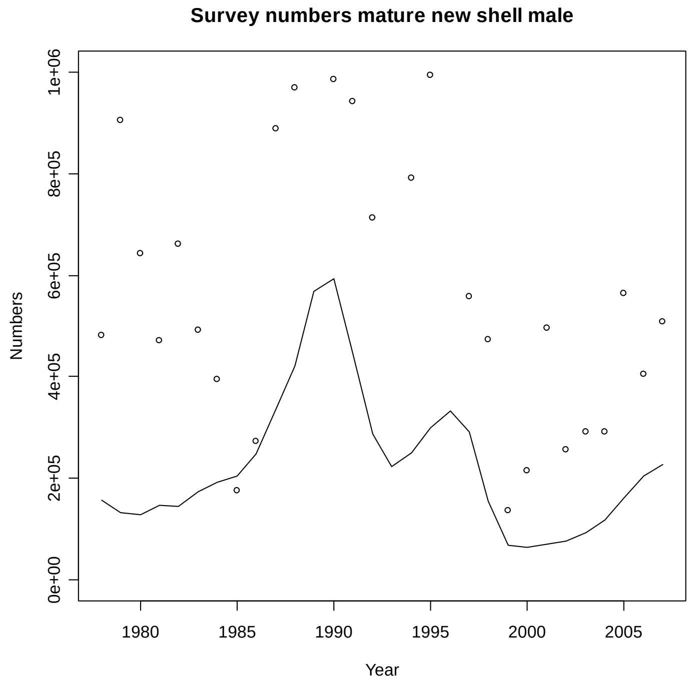

Figure 7: Male mature new shell numbers calculated by the model (solid line) fit to survey data (open circles) (Source: output file from model given by J. Turnock during review).

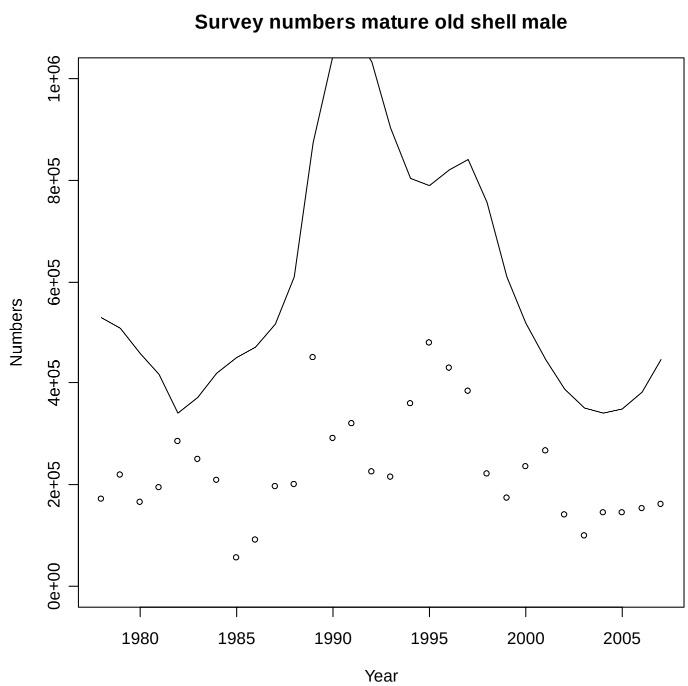

Figure 8: Male mature old shell number calculated by the model (solid line) to survey data (open circles) (Source: output file from model given by J. Turnock during review).

It is recommended that studies on Durometer measures of shell hardness and dactyl length should be further investigated. However, it is unlikely that this information will allow re-classification of data already collected.

6.10 Discard mortality

Industry believes discard mortality is much lower than the 50% mortality assumed with the model. Since independent information does not seem to be available and detailed sensitivity tests were undertaken it is precautionary to retain this feature until alternative information is available.

6.11 Recruitment estimates

The recruitment estimates show large inter-annual variation, autocorrelation as well as a possibility of some form of regime shift. There is also some indication of patterns in recruitment residuals. An investigation of the model output files, the standard deviation on the recruitment deviations are fairly large. In the report, errors around the recruitment estimates are not presented. Studies and presentations during the review week also state that temperature affects, amongst other things, recruitment, larval movement and settlement. Aspects that affect recruitment (including regime shift) should be a large component of an MSE project. This work should include the effects of environmental variables on recruitment and attempt to provide independent data that allows these environmental effects to be modelled internally within the assessment. When combined with the spatial work being undertaken by J. Murphy – much should be clarified in the future.

7 Forward projections

The same population dynamics in the estimation component of the assessment are used in the forward projections, although this is undertaken in separate code. No clear and accurate stock-recruitment model can be estimated from the stock and recruitment output of the estimation component of the assessment model. The Ricker model supports the view by some sectors that the resource is weakly fished but that the resource size is low due to the depensatory effect in the high spawning biomass part of the Ricker stock-recruitment curve. As a result, Ricker estimates of steepness describes a productive stock. On the other hand, the Beverton and Holt function describes an overexploited stock with poor productivity. Recruitment estimates show autocorrelation over time. The results of the forward projections are sensitive to whether autocorrelation is included or not. It is recommended that a Management Strategy Evaluation method should be used to evaluate strategies using existing control rules directly addressing the uncertainty in the trends and variability in future recruitment. The following references comprise a selected list of articles on the method:

Punt, A.E., 1992. Selecting management methodologies for marine resources, with an illustration for southern African hake. S. Afr. J. Mar. Sci. 12, 943-958.

Butterworth, D.S., Punt, A.E., 1999. Experiences in the evaluation and implementation of management procedures. ICES J. Mar. Sci. 56, 985-998.

Punt, A. E., Smith, A.D.M., 1999. Harvest strategy evaluation for the eastern stock of gemfish (Rexea solandri). ICES J. Mar. Sci. 56, 860-875.

Smith, A.D.M., Sainsbury, K.J., Stevens, R.A., 1999. Implementing effective fisheries-management systems - management strategy evaluation and the Australian partnership approach. ICES J. Mar. Sci. 56, 967-979.

Punt, A.E., Smith, A.D.M., Cui, G., 2002. Evaluation of management tools for Australia's South East Fishery 1. Modelling the South East Fishery taking account of technical interactions. Mar. Freshw. Res. 53, 615-629.

Kell, L.T., Mosqueira, I., Grosjean, P., Fromentin, J.M., Garcia, D, Hillary, R., Jardim, E., Mardle, S., Pastoors, M.A., Poos, J.J., 2007. FLR: an open-source framework for the evaluation and development of management strategies. ICES Journal of Marine Science 64, 640 - 646.

There is little in the data and model output that allows any choice between the two stock-recruitment forms. The final steepness values used in the assessment is the average between the two steepness values – with the Ricker curve calibrated so that it also is restrained between 0.2 and 1 and is therefore on the same scale as the Beverton and Holt function. Although this is an agreed value from much negotiation, the average between the two methods does not have much scientific backing and should be clearly stated as the best compromise in a situation where little independent information is available to support either case.

Appendix 1: Statement of Work for Dr. Catherine Dichmont

8 Statement of work

8.1 External Independent Peer Review by the Center for Independent Experts Bering Sea snow crab assessment review

Project Background:

The Alaska Fisheries Science Center (AFSC) requests review of the snow crab population dynamics and harvest strategy models for the Bering Sea snow crab (*Chionoecetes opilio*) assessment. The snow crab assessment model was reviewed by the CIE in 2003. Since that time, the analyst has made several improvements to the model. These changes should be reviewed by an independent panel. In addition, industry has requested a review of the snow crab assessment in FY08. The snow crab assessment is a high profile assessment and with the adoption of revisions to the overfishing definitions it is critical that this assessment provide the best available science on the status of this resource. This review would encompass the Bering Sea trawl survey data, the stock assessment model structure, assumptions, life history data, and harvest control rule. Proposed overfishing definitions for Bering Sea crab stocks, which may be implemented for the 2008-09 fishery seasons, require the use of the snow crab stock assessment model to estimate reference points and the status of the stock relative to those reference points. Management has used estimated survey abundance from the stock assessment to set quotas in the last two years, however, has not used proposed overfishing definitions and reference points estimated from the model. Uncertainty exists in the survey selectivities, maturity functions (which determine size at terminal moult), growth per moult, natural mortality, discard mortality and age post-terminal moult. This review will help in the decision process as to which alternative model is most appropriate, given the current state of knowledge of Bering Sea snow crab.

Overview of CIE Peer Review Process:

The Office of Science and Technology implements measures to strengthen the National Marine Fisheries Service's (NMFS) Science Quality Assurance Program (SQAP) to ensure the best available high quality science for fisheries management. For this reason, the NMFS Office of Science and Technology coordinates and manages a contract for obtaining external expertise through the Center for Independent Experts (CIE) to conduct independent peer reviews of stock assessments and various scientific research projects. The primary objective of the CIE peer review is to provide an impartial review, evaluation, and recommendations in accordance to the Statement of Work (SoW), including the Terms of Reference (ToR) herein, to ensure the best available science is utilized for National Marine Fisheries Service management decisions. The NMFS Office of Science and Technology serves as the liaison with the NMFS Project Contact to establish the SoW which includes the expertise requirements, ToR, statement of tasks for the CIE reviewers, and description of deliverable milestones with dates. The CIE, comprised of a Coordination Team and Steering Committee, reviews the SoW to ensure it meets the CIE standards and selects the most qualified CIE reviewers according to the expertise requirements in the SoW. The CIE selection process also requires that CIE reviewers can conduct an impartial and unbiased peer review without the influence from government managers, the fishing industry, or any other interest group resulting in conflict of interest concerns. Each CIE reviewer is required by the CIE selection process to complete a Lack of Conflict of Interest Statement ensuring no advocacy or funding concerns exist that may adversely affect the perception of impartiality of the CIE peer review. The CIE reviewers conduct the peer review, often participating as a member in a panel review or as a desk review, in accordance with the ToR producing a CIE independent peer review report as a deliverable. The Office of Science and Technology serves as the COTR for the CIE contract with the responsibilities to review and approve the deliverables for compliance with the SoW and ToR. When the deliverables are approved by the COTR, the Office of Science and Technology has the responsibility for the distribution of the CIE reports to the Project Contact.

Requirements for CIE Reviewers:

Two CIE Reviewers are requested for a maximum of 14 days, including pre-review preparations, participation at a 5 day panel review meeting in Seattle WA, and completion of CIE independent peer review reports in accordance to the Terms of Reference (ToR) herein. The CIE reviewers shall have expertise to be thoroughly familiar with various subject areas involved in the stock assessment, including population dynamics, length based models, knowledge of crab life history and biology, harvest strategy models for invertebrates, and the AD Model Builder programming language.

Statement of Tasks for CIE Reviewers:

The CIE reviewers shall conduct necessary preparations prior to the peer review, conduct the peer review, and complete the deliverables in accordance with the ToR and Schedule of Milestones and Deliverables herein. Prior to the Peer Review: The CIE shall provide the CIE reviewers contact information (name, affiliation, address, email, and phone), including information needed for foreign travel clearance when required, to the Office of Science and Technology COTR no later than the date as specified in the SoW. The Project Contact is responsible for the completion and submission of the Foreign National Clearance forms (typically 30 days before the peer review), and must send the prereview documents to the CIE reviewers as indicated in the SoW. Foreign National Clearance: If the SoW specifies that the CIE reviewers shall participate in a panel review meeting requiring foreign travel, then the CIE shall provide the necessary information (e.g., name, birth date, passport, travel dates, country of origin) for each CIE reviewer to the COTR who will forward this information to the Project Contact. The Project Contact is responsible for the completion and submission of required Foreign National Clearance forms with sufficient lead-time (30 days) in accordance with the NOAA Deemed Export

Technology Control Program NAO 207-12 regulations at the Deemed Exports NAO link http://deemedexports.noaa.gov/sponsor.html

Pre-review Documents: Approximately two weeks before the peer review, the Project Contact will send the CIE reviewers the necessary documents for the peer review, including supplementary documents for background information. The CIE reviewers shall read the prereview documents in preparation for the peer review. AFSC will provide:

a) the most recent Stock Assessment Report,
b) a copy of the Environmental Assessment for Crab Overfishing Definitions,
c) copies of relevant articles from peer reviewed journals,
d) a technical memorandum on AFSC crab groundfish trawl surveys,
e) ADMB code for stock assessment and data files.

Panel Peer Review Meeting: The CIE reviewers shall participate and conduct the peer review participate during a panel review meeting as specified in the dates and location of the attached Agenda and Schedule of Deliverable. The Project Contact is responsible for any facility arrangements (e.g., conference room for panel review meetings or teleconference arrangements). The CIE Program Manager can contact the Project Contact to confirm the facility arrangements.

Terms of Reference:

The CIE reviewers shall conduct an impartial peer review in accordance to the Terms of Reference (ToR) herein, to ensure the best available science is utilized for the National Marine Fisheries Service (NMFS) management decisions The CIE reviewers shall travel to Seattle, Washington from February 11-15, 2008 to discuss the stock assessment with the authors of the snow crab assessment. The reports generated by the CIE reviewers should include: a. A statement of the strengths and weaknesses of the snow crab population dynamics and harvest strategy models; b. Recommendations for alternative model configurations or formulations. c. Suggested research priorities to improve the stock assessment. Each CIE reviewer will complete a final CIE independent peer review report after the completion of the meeting in accordance with the ToR and the Schedule of Milestones and Deliverables with a copy each sent to Dr. David Die at ddie@rsmas.miami.edu and Mr. Manoj Shivlani at shivlanim@bellsouth.net no later than February 29, 2008.

Schedule of Milestones and Deliverables:

January 14, 2008 CIE shall provide the COTR with the CIE reviewer contact information, which will then be sent to the Project Contact January 28, 2008 The Project Contact will send the CIE Reviewers the pre-review documents 11-15 February 2008 Each reviewer shall participate and conduct an independent peer review during the panel review meeting February 29, 2008 Each reviewer shall submit an independent peer review report to the CIE March 14, 2008 CIE shall submit draft CIE independent peer review reports to the COTRs March 17, 2008 CIE will submit final CIE independent peer review reports to the COTRs March 31, 2008 The COTRs will distribute the final CIE reports to the Project Contact

Acceptance of Deliverables:

Upon review and acceptance of the CIE reports by the CIE Coordination and Steering Committees, CIE shall send via e-mail the CIE reports to the COTRs (William Michaels William.Michaels@noaa.gov and Stephen K. Brown Stephen.K.Brown@noaa.gov) at the NMFS Office of Science and Technology by the date in the Schedule of Milestones and Deliverables. The COTRs will review the CIE reports to ensure compliance with the SoW and ToR herein, and have the responsibility of approval and acceptance of the deliverables. Upon notification of acceptance, CIE shall send via e-mail the final CIE report in *.PDF format to the COTRs. The COTRs at the Office of Science and Technology have the responsibility for the distribution of the final CIE reports to the Project Contacts.

Request for Changes:

Requests for changes shall be submitted to the Contracting Officer at least 15 working days prior to making any permanent substitutions. The Contracting Officer will notify the Contractor within 10 working days after receipt of all required information of the decision on substitutions. The contract will be modified to reflect any approved changes. The Terms of Reference (ToR) and list of pre-review documents herein may be updated without contract modification as long as the role and ability of the CIE reviewers to complete the SoW deliverable in accordance with the ToR are not adversely impacted.

Key Personnel:

Contracting Officer's Technical Representative (COTR):
William Michaels
NMFS Office of Science and Technology
1315 East West Hwy, SSMC3, F/ST4, Silver Spring, MD 20910
William.Michaels@noaa.gov Phone: 301-713-2363 ext 136

Stephen K. Brown
NMFS Office of Science and Technology
1315 East West Hwy, SSMC3, F/ST4, Silver Spring, MD 20910
Stephen.K.Brown@noaa.gov Phone: 301-713-2363 ext 133

Contractor Contacts:
Manoj Shivlani, CIE Lead Coordinator
10600 SW 131st Court, Miami, FL 33186
Shivlanim@bellsouth.net Phone: 305-383-4229

Roger Peretti, NTVI Regional Director
Northern Taiga Ventures, Inc., 814 W. Diamond Ave., Ste. 250, Gaithersburg, MD 20878
rperetti@ntvifed.com Phone: 301-212-4187

Project Contact:
Jack Turnock

NMFS Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115
Jack.Turnock@noaa.gov

Anne Hollowed
NMFS Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115
Anne.Hollowed@noaa.gov

ANNEX 1 CIE REPORT GENERATION AND PROCEDURAL ITEMS

1. The report should be prefaced with an executive summary of findings and/or recommendations.

2. The main body of the report should consist of a background, description of review activities, summary of findings, and conclusions/recommendations.

3. The report should also include as separate appendices the bibliography of materials provided by the Center for Independent Experts and the center and a copy of the statement of work.

4. Individuals shall be provided with an electronic version of a bibliography of background materials sent to all reviewers. Other material provided directly by the center must be added to the bibliography that can be returned as an appendix to the final report.

9 Updated agenda

NMFS Alaska Fisheries Science Center
7600 Sand Point Way NE, Building 4
Seattle, Washington
Observer Training Room
Tentative Agenda February 11-12, 2008

Day 1

9:00	Welcome and Introductions
9:15	Overview (species, surveys, fishery, catch levels, bycatch)
10:00	Biology (growth, natural mortality, diets, spawning areas, nursery areas, maturity curves, mating, sperm reserves)
11:00	Field experiments on escapement, discard mortality, tagging
11:30	Age Determination, shell condition
12:00	Lunch
1:00	Biology continued
2:00	Harvest control rules and overfishing definition
3:00	Survey methodology and analysis
4:00	Summary of on-going research
	Egg viability and sperm reserves
	Larval drift
	Spatial modeling
	Management Strategy Evaluation

Day 2

9:00	Ecosystem considerations - Predation, prey
10:00	Description of snow crab assessment model
12:00	Lunch
1:00	Continued discussions

Day 3

9:00	Examination of the harvest control rules and Continued discussion of assessment model
12:00	Lunch

Day 4 and 5

Reviewer discussions with assessment authors