Review of Bering Sea Snow Crab assessment

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Reviewer's Report

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Executive summary of findings and recommendations

ToR a: ***A statement of the strengths and weaknesses of the snow crab population dynamics and harvest strategy models;***

Strengths:

- The assessment model has been specifically designed to reproduce the complex life-history of Snow Crab, its sexual dimorphism and the selectivity of the fishery.
- The use of ADModelBuilder facilitates estimates of large numbers of parameters and their uncertainty.
- The harvest strategy model suggested for Snow Crab is a vast improvement on the previous model and should help safeguard against stock collapse when viewed at the scale of the whole area.

Weaknesses:

- A consequence of the model's biological complexity is the large amount of data required for parameterisation. Although the model is biologically complex, the considerable spatial structuring of both the stock and the fishery is assumed to be inconsequential. Poor model fits in some areas indicate that the data available for parameterisation are either too uncertain or the spatial structuring is in reality highly significant. The likelihood is that both scenarios are true to some extent.
- The harvest strategy model also assumes that the stock operates as one spatially homogeneous unit. Given the concentration of the fishery on a small sub-area, the harvest strategy model will not prevent local depletion.
- The stock-recruit relationship used in the forecasts is uncertain and there is some evidence of a shift to lower productivity in recent years.

ToR b. Recommendations for alternative model configurations or formulations.

- As there is limited scope for larval movement in a southward direction, the area to the north of the fishery will not contribute significantly to recruitment. I recommend performing an assessment on only the area south of the most northerly extent of the fishery.
- The model could be simplified by removing the new/old shell dimension, because the shell staging data used to parameterise this are unreliable.

ToR c. Suggested research priorities to improve the stock assessment.

- Develop new methods for the ageing/staging of snow crab shells. Measures of shell hardness or dactyl length may give far more objective measures of shell age than the visual staging currently employed.
- Develop tagging studies to understand migration patterns better. Spatial processes in both the fishery and the stock would appear to be crucial to the sustainability of the stock, particularly at smaller scales where significant localised depletion is a realistic possibility.
- Develop studies to determine growth rates. Currently, female growth rates are derived from data on Atlantic stocks of snow crab, and male growth rates are estimated from 14 individuals in the eastern Bering Sea. Although I acknowledge that the operational environment is complex and arduous, considerably more data are required on growth rates for a stock of this commercial importance.
- Explore simpler assessment models. The current assessment model is perhaps too biologically complex considering the quantity of underlying data. Simpler models, although not as biologically realistic, may still yield metrics of stock status sufficient to manage the stock in a sustainable manner.
- Create a Management Strategy Evaluation (MSE) tool for Bering Sea snow crab. Although this recommendation comes last, it is perhaps one of the most important. An MSE would provide an excellent platform upon which to test the whole range of biological assumptions, model formulations and management strategies which have been suggested/recommended here. Given the spatial structuring in the stock and the fishery, the MSE would also ideally need a level of spatial structure.

Other comments

- The program code, model description and input files need re-working to make them easily read and transparent. The program code and input files contain a lot of legacy code, which makes the files somewhat confusing and difficult to read. The accompanying model description is occasionally at odds with what appears in the code.
- The model has been constructed to be biologically complex, reflecting the complexities of the ecology of the species and its fishery. However, strong patterns in the model residuals highlight misspecification with respect to the available input data. The model could be simplified by removing the new/old shell dimension, because the shell staging data used to parameterise this are poor.
- The spatial structuring within the population and fishery is considerable, but assumed irrelevant in the assessment. As there is limited scope for larval movement in a southward direction, the area to

the north of the fishery will not contribute significantly to recruitment. I recommend performing an assessment on only the area south of the most northerly extent of the fishery.

- Shell staging should be dropped from existing sampling protocols. Tests have shown that the shell classification currently employed is too subjective and uncertain to be of any practical use, and continuation of the collection would only serve to give false credence to its utility.
- Mortality estimates from multispecies/ecosystem (ECOPATH) modelling are uncertain, and until some peculiar interactions have been explored/resolved, the values of natural mortality for Eastern Bering Sea snow crab should not be taken from ECOPATH.
- Pathways to facilitate the exchange of survey data between AFSC and the Alaskan Department of Fish and Game should be sought. The apparent unavailability of survey data to the AFSC does not help the common objective of having a sustainably managed snow crab stock.
- Explore the outcomes of assuming an “incorrect” stock–recruit relationship in the forecast. The stock–recruit relationship assumed for the forecast model is the most important element in the model. Sensitivity analyses are required to determine what the risks to the stock are if the wrong relationship, or wrong parameterisation, have been selected. There is evidence of a recent decrease in recruitment productivity, and we need to know what the risk is to the stock of ignoring this issue.

Background

The Alaska Fisheries Science Center (AFSC) requested a review of the stock assessment and harvest strategy models for the Bering Sea snow crab (*Chionoecetes opilio*). The snow crab assessment model was last reviewed by the CIE in 2003, since which time several changes have been made to the model which now require re-evaluation by an independent panel. In addition, industry has requested a review of the snow crab assessment in FY2008. The snow crab is a high-profile assessment and, with the adoption of revisions to the overfishing definitions, it is critical that the stock assessment provides the best available science on the status of this resource. The review is to encompass the Bering Sea trawl survey data, the stock assessment model structure, assumptions, life history data, and harvest control rule.

A panel of two reviewers was selected for the purpose of this review, with the following terms of reference:

- A statement of the strengths and weaknesses of the snow crab population dynamics and harvest strategy models;
- Recommendations for alternative model configurations or formulations.
- Suggested research priorities to improve the stock assessment.

Description of review activities

The following documentation was provided to the reviewers prior to the meeting:

- a description of the model (Appendix 2.1),
- the model code, input and output files (Appendix 2.2)
- the iinitial review draft, Environmental Assessment, for proposed Amendment 24 To the Fishery Management Plan for Bering Sea and Aleutian Islands King and Tanner Crabs to Revise Overfishing Definitions (Appendix 2.3).
- Reproductive Dynamics and Life History of Snow Crab in the eastern Bering Sea. AFSC Quarterly report (Appendix 2.4)
- Biological Field Techniques for *Chionoecetes* Crabs. (Appendix 2.5)

This documentation was sufficient to gain an insight into some of the biological issues and problems concerning the assessment of Bering Sea snow crab, but inconsistencies between the model description and model code meant that understanding the finer workings of the model were only achieved after detailed discussion with the assessment scientists.

The review was held at the ASFC, Sand Point Way NE, Seattle 11th – 14th February 2006, and attended by the two CIE reviewers, staff from both the ASFC and the Alaskan Department of Fish and Game, and an industry representative (Jack Taggart), who attended the first two days of the meeting. The meeting consisted of two days of presentations covering the biology, fishery and assessment of snow crab, from Benjamin Turnock (the principal assessment scientist) and Lou Rugolo (the principal biologist), along with presentations regarding spatial analyses of survey data, the hydrography and ecosystem modelling for the region. Subsequent to this, the reviewers had extensive discussion with the ASFC staff responsible for the assessment, specifically regarding the structure and function of the model.

During the meeting the reviewers made several requests to the assessment team for additional information and model runs, most of which were met. The requests for model runs which not met were due to there being insufficient time to reprocess the basic data.

Following the meeting, copies of the CIE reviews undertaken in 2003 (stock assessment model) and 2006 (overfishing definitions) were received.

Summary of findings

Fishery

The fishery is mainly prosecuted by a potting fleet during winter in the southwest of the region. Historically the fishery was managed as a short-season contest fishery in winter, but has recently undergone a rationalisation programme which has shifted it to a quota-managed fishery. The time constraints have been relaxed, but the requirements of the processing plants are such that the fishery remains a winter fishery. The imposition of a quota system on both capture and processing means that the rigid time constraints are unlikely to change in the near future. The spatial limitations are principally ice-coverage and distance from port. The tight time schedules of the processing plants means that vessels have to keep their allotted slots for unloading and cannot therefore afford to venture further away and risk being unable to return on time.

These constraints on the fishery, particularly the spatial constraint, present significant problems in assessing the stock and the impact of the fishery upon the stock. Stock assessment models assume that the each individual in the population is equally available to the fishing gear (and subsequently subject to gear selectivity) and equally available to all other individuals for the purpose of spawning. The spatially aggregated fishery on eastern Bering Sea snow crab would only satisfy this “dynamic pool” assumption if the crabs happened to aggregate from the whole area into the fished area during winter, but there is no evidence that this is the case.

The theme of spatial structure between the fishery and stock is a crucial element to both understanding and managing fishing mortality, to ensure a sustainable fishery, and it recurs throughout this review report.

Biology/ecology

The reproductive ecology considerably confounds the development of indices of stock status for snow crab. Copulation requires a relatively large size difference between males and females. Males are not thought to be capable of successful copulation in the first year of morphological maturity, whereas this is the stage that the fishery actively seeks. Both male and female reproductive capacity is also considered to change with age past maturity, with first-time spawners (primiparous) having a lower output than multiparous spawners.

It is unclear what minimum sex ratio is required in the population for effective reproduction to take place, because of the polyandrous and polygynous behaviour, and it is further confounded by the ability of females to store spermatophores. Such practice should buffer against increased mortality on the male portion of the stock, but there will still come a point at which the population will become sperm-limited.

Evidence was presented for reduced reproductive capacity in some areas subject to high fishing pressure. This was due to a combination of reduced spermathecal loading in mature females, a reduction in clutch fullness, and an increase in the number of barren females. Although symptomatic of an unsustainable population (and hence fishery), the consequences for the stock as a whole will depend upon the redistribution processes of both larvae and adults.

The results of hydrographic modelling for the area were presented and showed a general drift northwest during the main larval phase for snow crab. Some areas had greater retention probabilities, but there was no evidence for larval transport in a southwesterly direction to repopulate the main fishing grounds.

Some evidence exists for a general movement of snow crab in a southwesterly direction as they grow, which may be a movement to deeper water, but the speed and magnitude of such movement are unknown. Tagging studies are confounded by the recapture effort (i.e. the fishery) being concentrated in the southwest of the area.

As a result of the information provided regarding fishery location and the potential for snow crab redistribution, I am concerned that managing/assessing the stock as a single unit is unlikely to deliver the sustainable fishery being sought. On the scale of multiple generations, the eastern Bering Sea snow crab probably does function as a single stock, and I doubt very much whether genetic studies would find any differences over the region (~1% annual transfer between areas is sufficient to obscure genetic differences). The fishery operates on a much finer time scale and appears able to inflict relatively high rates of mortality on localised areas in short time periods, and the ability of the wider stock to replenish these localised areas appears to be limited. The models used for both assessment and projection have the underlying assumption of a dynamic pool, i.e. the ability of each animal to interact with each another animal and the fishery within the time step being considered (annual) and an equal redistribution of recruiting individuals. These assumptions are almost always violated to some extent, but in this situation the violations are considerable, so the results (particularly the projection of yield) are questionable.

My suggested solution would be to develop a spatially disaggregated model that can model the aggregated fishery in a much more rational manner. A first step would be to assess only that part of the stock which is fished and contributes to the immediate recruitment of the fished area, and I would suggest restricting the assessment area to that south of about 58.5°N. The next development would be to include a model for the remaining area and to parameterise migration rates, which I acknowledge is going to be challenging. As previously mentioned, tagging studies rely upon recapture by the fishery, which is spatially limited by, *inter alia*, winter ice-cover. My suggestion for a tagging study would be to release tagged animals in an area northeast of the main fishery grounds, but which is unlikely to be covered by sea ice. Recapture effort would then be achieved by providing incentives to a vessel (either through direct charter and/or by allowing it to fish off-quota) to fish using a specific search pattern around the release site. This would then provide information regarding movement rates in all directions, rather than biasing detection to the southwest, where the fishery operates. I am unsure as to whether tidal cycles are detectable under ice-cover, but should pressure changes still exist then use of electronic data storage tags (DSTs), coupled to tidal geo-location models, may also provide valuable information regarding movement rates and directions, an approach currently being trialled with *Cancer pagurus* in the UK.

The estimates of natural mortality used have recently changed from a uniform 0.2 to sex-stage-differentiated values of 0.29 (mature females) and 0.23 (all other stages). The presentation of ECOPATH modelling for the eastern Bering Sea suggested that snow crab are preyed upon at a low level by a wide variety of species, but at a much higher rate by one species. Estimates of consumption by this one species are highly variable and much research effort is being expended to understand the reality of this estimate. Until the veracity of the estimate has been established, I do not recommend changing the values of *M* to reflect the ECOPATH estimates of mortality.

Survey

As the fishery is concentrated on a small area, the only information regarding stock status and dynamics for the majority of the eastern Bering Sea snow crab comes from the annual surveys undertaken by AFSC/NMFS. As is often the case, this is a general survey aimed at a wide variety of species; it is therefore not specifically tailored to the measurement of snow crab abundance. The survey design (grid-pattern @ 20 nautical miles) reflects the compromises required to estimate simultaneously the abundance of many species, but it is suboptimal for snow crab, which appears to have a contiguous distribution that is not adequately covered at the 20-mile scale. Attempts have been made to quantify better the highest density stations by incorporating additional stations, but this is inconsistent with the methodology used to raise the survey data.

Aspects of the methodology used to create survey biomass indices caused some concern. During each trawl, data are recorded with respect to the width of the trawlnet, which averages around 60 ft, but when determining the swept area for each station, a fixed value of 50 ft is used. This underestimate is used to compensate for the reduced catchability estimated to exist for smaller snow crabs. It would be far preferable to have a measure of selectivity for the survey gear, and to use the true value of swept area for each tow. This would also be of enormous help to the assessment model, which attempts to estimate survey selectivity, which is one of the crucial factors determining absolute population abundance. Some work on survey selectivity was presented, and it was clear that further work should be afforded high priority.

During the description of the survey gear, it was mentioned that the footrope is unweighted and that a gap exists between the footrope and the belly of the net. This is somewhat surprising given that the survey is used for population estimates of benthic organisms such as crabs and flatfish. Consistency is the key factor in surveys, and it is not therefore advised that the gear be changed to select benthic organisms better unless it is demonstrated that the selectivity of the net is so low that abundance signals are masked by survey noise.

Plots of abundance at length suggest that the survey is poor at tracking cohorts through time; peaks of numbers at larger lengths often appear without having been tracked up through the younger sizes. This presents real problems to the assessment model, which is attempting to fit population estimates to these survey numbers. The apparent inability to track cohorts does change when subareas are investigated, because some lower density subareas appear to track cohorts quite well, indicating that the selectivity of the net is adequate. The apparent relative inability of the higher density areas to track cohorts perhaps reflects the sparseness of the survey station density in relation to the scale of patchiness in snow crab. The spatial analyses of the survey data being undertaken in the PhD programme of James Murphy should generate greater understanding of the spatial structuring of the population, and should then feed directly into the assessment process.

The standard operating procedure for snow crab includes measuring, sexing and staging the individuals. Staging is on a scale of 1–5, 1 being soft, 2 freshly moulted, and 3–5 indicating time since moult, dependent upon the level of shell wear, discolouration and bio-fouling. Stage 5 individuals are considered to be very old and to contribute little to spawning. *Chionoecetes opilio* are considered to have a terminal moult at morphometric maturity, and staging studies were undertaken using tagged animals which were at liberty for up to several years after initial tagging. It should, therefore, have been impossible to reclassify individuals at a lower stage, yet this occurred with alarming regularity. Classification of individuals into shell stages is therefore highly subjective and error-prone, and it is suggested that shell staging is dropped from the protocol for both the survey and market sampling. Reluctance to drop a procedure which has been part of the protocol for a long time is understandable, of course, because it means the end of a long time-series, but given that the data are too unreliable for practical purposes, the continuation of collecting the data simply gives false credence to their utility. There was discussion of two alternatives for the estimation of shell age: measuring shell hardness with callipers and measuring dactyl length. These means of estimation seem to be more promising in terms of deriving an unbiased estimate of age, but their calibration against individuals of known age will still prove to be challenging.

One obstacle to the review process was the inaccessibility of the raw survey data to the AFSC scientists and the resulting inability to reprocess survey indices rapidly. There would appear to be significant communication difficulties between the AFSC and the Alaskan Department of Fish and Game, which for the sake of the resource should be sorted out as a matter of priority. There is no logic for two government departments ostensibly working towards the same goal of sustainably managing a fishery not to share information freely.

Assessment

The use of AD Model Builder as a modelling tool as a platform for stock assessment is an established method, and it should provide robust and reliable parameter estimates with uncertainty estimates and parameter correlations. It was disappointing to see little emphasis of these uncertainties and parameter correlations in the material presented at the meetings.

Program code is rarely written with other users in mind (not an unusual situation worldwide), but in instances where the program is likely to be examined and reviewed by others (such as in stock assessments), care needs to be taken to make comments relevant and names meaningful, and to operate version control, ensuring that only relevant code is retained. The program code supplied was complex and contained much legacy code (which had been commented out), but made the reading of the code difficult. The use of integer names i, j, and k to index arrays is potentially confusing and using "*age", "maturity",* and "*sex"* would have made the code slightly lengthier but easier to interpret.

In a similar vein, the input files also contained a lot of legacy code, which was again commented out but made the files difficult to read. Each line of input data is accompanied by a comment line explaining what it was. This practice is to be commended, but unfortunately the comments do not match up with the parallel comments in the input section of the ADModelBuilder code. In order for both code and model to be fully transparent, these problems need to be resolved, because they do not engender confidence that the program is performing as intended. There was not time within the scope of this review process to interpret and check each line of code fully.

The output files from the assessment are complex structures, and specific tools to extract and display the data are required. A routine has been created in the R programming language to extract and display the results, which relies upon the user downloading and installing a number of routines that mimic Unix-style stream editing. Despite the fact that I already use a number of these routines, incompatibility issues that could not be resolved meant that I could not get the R routines to function. It would be preferable to have a stand-alone program that splits the report file into separate files, which R (or any other statistical / plotting program) can then pick up. It was noted that the routine for plotting size-frequency residuals contained an inconsistency, in that the circle size for large negative residuals was not commensurate with that for large positive residuals of the same magnitude.

The assessment model is biologically complex, attempting to track numbers at **length**, **shell stage**, **sex** and **maturity**. Shell stage was limited to new/old, rather than the full 1–5 stages, and was included to capture the fact that the fishery prefers to take clean-shelled animals. It was assumed that individuals moved from shell stage new to old in one year, but there is little evidence that such a distinction is possible from field data. Given the reliability of the basic staging data and the fact that current management does not utilise shell stage, this is an unnecessary dimension, and it should be dropped from the model.

The parameters the model estimates cover:

- Initial numbers at length.
- Mean (log) recruitment and log(annual deviants).
- Mean (log) fishing mortality and log(annual deviants).
- Selectivity of survey and fisheries.
- Linear growth increment model.

The model is fitted to survey biomass estimates, commercial catches, commercial catch rates, and length frequencies from both survey and fishery sources.

The most crucial element of any size-based model is the growth transition matrix. In this model, the matrix is created using a linear shell increment model linked to a gamma function, and parameterised both inside and outside the assessment model. The linear growth parameters for females were taken from Canadian data on Atlantic snow crabs, whereas the parameters for the males came from 14 tagged animals. This level of growth data is unsatisfactory for a length-based assessment model which covers such a large geographical area, and may go some way to explaining the strong residual patterns observed in the model fits.

The model forces the numbers of recruits to be equal for males and females, and although there is no evidence of sex-bias at the egg stage, different growth rates between the sexes have the potential to skew the initial sex ratio.

The catch rate (CPUE) of the pot fishery was not standardised, and given the drastic changes to fishery management in the past couple of years, this is a serious inconsistency. Quotas for the coming year are determined on the current status of the stock, so an artificially inflated (or deflated) CPUE index will push the model away from the true value and potentially result in unsustainable management advice. In the model run presented, the commercial CPUE index was given a very low weight, so would make little impact upon the final assessment. Given the complexity of the model, though, it would be preferable if data which are not considered suitable for inclusion into the objective function were omitted.

The fitting of length frequency data was always going to be problematic given the apparent inability of the survey to track cohorts, and examination of the residuals from these fits confirms the existence of a number of problems with this procedure. There are both temporal and time-invariant patterns within the length-frequency residuals. Both males and females exhibit strong temporal patterns as cohorts' progress through the model. This may be due to the sudden appearance/disappearance of strong cohorts within the survey data, although changes in growth rates would also give rise to similar patterns. There are always negative residuals at the smallest size for both males and females.

Model estimates of survey selectivity appear to be quite high (q_{max}= 0.8–1.0), given the selectivity experiments during which a beam-trawl was towed behind the standard otter trawl and recorded significant numbers of animals missed. During the meeting, a request to run the model with the survey selectivity set at 0.5 was made. It was expected that this change in selectivity would simply have a scaling effect on the population estimates, and that the stock status relative to its historical trajectory would remain unchanged. The results of this alternative assessment were then fed into the forecasting model under the existing Harvest Control Rule. The long-term (~5 year) harvest levels were similar, but the initial harvest levels were considerably different. Examination of the recruitment estimates showed that the pattern and scale of recruitment was significantly altered using the lowered selectivity plateau, resulting in a different picture of relative stock status in the terminal assessment year. There is no information to indicate that one or other level of survey selectivity is more "right" than the other, the purpose of this exercise being rather to test the robustness of the model to different assumptions. Clearly, the model needs careful and extensive sensitivity testing.

I have several proposals for modifications to the model.

- Reduce the dimension space within it by removing the new shell / old shell distinction. It might also be possible to remove the mature/immature dimension within the model. Although the presence of a terminal moult places a cap on the growth of an individual, the instar number at which this occurs is variable, as is the terminal size. One option might be to have an extended "plus group" coinciding with the length at 50% maturity. This would decrease the precision of mature biomass estimates while reducing the bias.
- In order to capture the spatial aspects of the fishery and the data, I suggest performing an assessment using data only from the area south of 58.5° (or the most northern latitude that encompasses the fishery). This would have the advantage of producing an assessment only of the spawning biomass likely to contribute to the recruits arriving in the fished area, and it would also give a better indication of exploitation rates in the fished area. Its downside, however, would be that it would violate the closed population assumption by any migration into the area from the non-assessed area to the north. A solution to this (for the future) would be to create a two-area assessment model linked with migration, but as yet, there are no data available to parameterise such a linkage.
- At present, whole-area survey length frequencies are input for each year and sex. I suggest adjusting the model to take multiple series of length frequencies, inputting more spatially disaggregated datasets.

The model could then automatically weight the series using some goodness-of-fit criteria. Although this represents an increase in model complexity, it would allow the model to use those parts of the length frequency data which contain genuine information.

There is an obvious attraction for models which capture more biological realism; this model seeks to do just that, and it authors should be commended for attempting to do so. More biologically realistic models allow reference points to be determined with less uncertainty, management can afford to be less precautionary. There is always a price to be paid for such an increase in complexity, an almost exponential requirement for input data. The biology, ecology and habitat of eastern Bering Sea snow crab make the acquisition of such basic data as growth rates and migration rates incredibly time-consuming, costly, and at times dangerous. There would be considerable merit in exploring a range of alternative simpler models which would utilise the available data more effectively, to complement and contrast the biologically complex model presented here.

Forecast

The code for the forecast model was not supplied with the documentation of the review.

The principal component of any fisheries forecast model is the stock–recruit relationship used, and the outcome of the recent OverFishing Level (OFL) debate bears this out.

The stock–recruit plot generated by the assessment model contains no information near the origin, and is therefore inconclusive with regards to what type of stock–recruit relationship to use. There is a scatter of points at mid-range biomasses, whereas the upper range of biomasses has only low recruitment values. It is understandable therefore that some favour a Ricker-type relationship. However, the life history of crabs tends towards later maturity and slower growth, so the Beverton–Holt-type curve seems more ecologically plausible. Although it is currently unclear which is the “better” curve, the practice of taking the mean steepness of the two curves and then applying it to the Beverton–Holt curve seems fundamentally wrong (steepness meaning different things in the two models). Of far greater concern to me is the temporal trend in the data. Most recruitments since 1989 have been low despite a broad spread of biomass, and the possibility of a downward shift in productivity (perhaps a regime shift) appears tangible. If there has been a shift in productivity, then the use of stock–recruit data from outside this period will overestimate potential recruitment, and management will run the risk of advising catch levels that are unsustainable. The flip side to a decrease in productivity is that B_{MSY} will decrease, so the current status of the stock in relation to B_{MSY} would improve, and changes in TAC may therefore not be as drastic as industry may fear.

The results of the HCR simulations showed that the adopted $F_{35\%}$ rule actually results in a slower rebuilding time than a F_{MSY} rule, does not reach B_{MSY}, and is therefore less precautionary than an F_{MSY} regime. In practice, these differences might not be detectable and the system is a substantial improvement upon the previous management plan. What has not been properly explored yet, though, is the risk to the stock when a wrong stock–recruit function is chosen for the forecasts, e.g. a Ricker function is chosen when in fact the true relationship should be Beverton–Holt. This model uncertainty has huge implications for the level of risk to the stock and by excluding this uncertainty from the management projections essentially places the acceptance of this risk onto the scientists. This is a dangerous route for science; a scientist's job is to be completely objective and to provide management with the information and tools that managers require to make decisions based upon **their** acceptance of risk. Once elements of uncertainty are excluded at a scientific level, managers can absolve themselves of blame should problems arise, and science loses credibility in terms of being objective and impartial.

One area the management plan does not explicitly address is the issue of safeguarding against local depletion. Above I have voiced concern that the eastern Bering Sea snow crab population is unlikely to operate as a single stock at the temporal scale at which the fishery is operating, and that more regional assessment should be explored. The current management plan in conjunction with the single-area assessment is incapable of preventing overfishing of localised areas. However, should regional assessments become possible, then the management plan structure should be applicable independently to each area, and therefore better suited to reduce the risk of local depletion.

Conclusions / Recommendations

Much of this report has highlighted areas of uncertainty and requirements for further data, and has suggested changes to programmes and methodologies. It was not, however, my intention to present a negative review of the existing situation. There has obviously been a great deal of work put into the assessment of the stock, and it involved close collaboration between biologists and modellers. The resulting assessment model represents a credible balance between biological complexity, the operational mode of the fishery, and the requirements of stock assessment. The fitting problem which the model seems to have is more likely the result of there being insufficient data for effective parameterisation, and it is for this reason that the exploration of simpler models has been suggested.

There are a number of areas of uncertainty both within the perception of the biological system and the ability to assess the status of the stock(s) of eastern Bering Sea snow crab. By far the best way to formalise these uncertainties and to determine their impact upon the methods used to manage the fishery is to have a Management Strategy Evaluation (MSE) program developed. Essentially MSEs are linked models of the biology, the scientific assessment, management, and the fishery in which the effects of changes in any of the elements can be explored through simulation. I understand that a proposal for the creation of an MSE for eastern Bering Sea snow crab has been submitted, and I sincerely hope that the application is successful, because it offers the best route to exploring the numerous uncertainties surrounding this stock. My only regret is that the proposed MSE will not be designed to explore the spatial structuring of the stock and its fishery, which to me seems to be fundamental in understanding the eastern Bering Sea snow crab better.

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Strengths:

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- The use of ADModelBuilder facilitates estimates of large numbers of parameters and their uncertainty.
- The harvest strategy model suggested for Snow Crab is a vast improvement on the previous model and should help safeguard against stock collapse when viewed at the scale of the whole area.

Weaknesses:

- A consequence of the model's biological complexity is the large amount of data required for parameterisation. Although the model is biologically complex, the considerable spatial structuring of both the stock and the fishery is assumed to be inconsequential. Poor model fits in some areas indicate that the data available for parameterisation are either too uncertain or the spatial structuring is in reality highly significant. The likelihood is that both scenarios are true to some extent.
- The harvest strategy model also assumes that the stock operates as one spatially homogeneous unit. Given the concentration of the fishery on a small sub-area, the harvest strategy model will not prevent local depletion.
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- As there is limited scope for larval movement in a southward direction, the area to the north of the fishery will not contribute significantly to recruitment. I recommend performing an assessment on only the area south of the most northerly extent of the fishery.
- The model could be simplified by removing the new/old shell dimension, because the shell staging data used to parameterise this are unreliable.

ToR c. Suggested research priorities to improve the stock assessment.

- Develop new methods for the ageing/staging of snow crab shells. Measures of shell hardness or dactyl length may give far more objective measures of shell age than the visual staging currently employed.
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- Develop studies to determine growth rates. Currently, female growth rates are derived from data on Atlantic stocks of snow crab, and male growth rates are estimated from 14 individuals in the eastern Bering Sea. Although I acknowledge that the operational environment is complex and arduous, considerably more data are required on growth rates for a stock of this commercial importance.
- Explore simpler assessment models. The current assessment model is perhaps too biologically complex considering the quantity of underlying data. Simpler models, although not as biologically realistic, may still yield metrics of stock status sufficient to manage the stock in a sustainable manner.
- Create a Management Strategy Evaluation (MSE) tool for Bering Sea snow crab. Although this recommendation comes last, it is perhaps one of the most important. An MSE would provide an excellent platform upon which to test the whole range of biological assumptions, model formulations and management strategies which have been suggested/recommended here. Given the spatial structuring in the stock and the fishery, the MSE would also ideally need a level of spatial structure.

Appendix 1: Statement of Work for Dr Ewen Bell

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 molt), growth per molt, natural mortality, discard mortality and age post-terminal molt. 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.

<u>Prior to the Peer Review</u>: 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 pre-review documents to the CIE reviewers as indicated in the SoW.

<u>Foreign National Clearance</u>: 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 pre-review 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):

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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.

ANNEX 2

Tentative Agenda

Bering Sea snow crab assessment review

NMFS Alaska Fisheries Science Center
7600 Sand Point Way NE, Building 4, Seattle, Washington
February 11-15, 2008 (Tentative Date)

Day 1

09:00 Welcome and Introductions
09:15 Overview (species, surveys, fishery, catch levels, bycatch)
10:00 Biology (growth, natural mortality, diets, spawning areas, nursery areas, maturity curves)
11:00 Field experiments on escapement, discard mortality, fertilization rate, tagging
11:30 Age Determination
12:00 Lunch
13:00 Harvest control rules and overfishing definition
15:00 Summary of on-going research
    Larval drift
    Spatial modeling
    Management Strategy Evaluation

Day 2

09:00 Ecosystem considerations
    Predation, prey
10:00 Economics
    Crab rationalization
10:30 Description of snow crab assessment model
12:00 Lunch
13:00 Continued discussions

Day 3

09:00 Examination of the harvest control rules
12:00 Lunch

Day 4 and 5

Reviewer discussions with assessment authors