Center for Independent Experts (CIE) Independent Peer Review of the Eastern Bering Sea (EBS) Snow Crab Stock Assessment Review 2013

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Billy Ernst

Department of Oceanography

University of Concepción

Chile

Executive Summary

This report is a review of the 2013 Eastern Bering Sea (EBS) snow crab assessment made by staff of the AFSC (Seattle). The assessment of stock dynamics is based on a complex sex- and size-structured model, with explicit modeling of recruitment, survival and growth. Incorporating terminal molt of mature male and female crabs represents an additional challenge to the model. A male-only trap winter fishery mainly targets larger males (>101 mm) and has operated historically on a very short time frame. The assessment is based on several sources of information, including the trap fishery retained catches from the trap fishery and female bycatch, trawl fishery bycatch data and National Marine Fisheries Service data from summer EBS trawl surveys between 1978 and 2012. The latter constitutes an impressive database with ample spatial coverage in the US exclusive economic zone (EEZ). Parameters are estimated on the basis of standard maximum likelihood methods with several likelihood components for the data and penalties for a variety of model parameters.

The current assessment model does not account for spatial structure. It is a major challenge in any assessment of this species to aggregate the spatial information of a vast geographical area and maintain the main properties of the underlying complex dynamics of this stock and its fishery. Nevertheless, there have been attempts recently to generate more spatially complex and flexible models (e.g. Cody Szuvalski), but serious data constraints have restricted their statistical parameterization. Some important aspects associated with this spatial complexity are the potential open population to the north of the assessment area (immigrants from the north), latitudinal patterns in growth and spatial allocation and migration of various mature male and female components creating differential mating opportunities. As well, there are questions about the current metric used in computing mature biomass of the stock.

The current stock assessment model constitutes an important and valuable attempt to incorporate many of the available sources of information to study this stock and its fishery. Because of the lack of age information typical of crustacean populations, the use of a statistical length structured model seems most appropriate. My recommendations, which are derived from fruitful discussions with the assessment team and other reviewer, are as follows:

Recommendations

- The use of this modelling approach (length structured model) seems appropriate for the kind of data and is encouraged to continue.
- There is a need to improve the documentation of the stock assessment model in the assessment report.

- The model currently uses a penalty on F. Effort should be made to remove it from the assessment. Available data on in-season catch rates can be used to estimate annual harvest rates.

- There is uncertainty about the lifespan of the EBS snow crab and therefore its natural mortality. Literature suggests a maximum lifespan of about 14 years for females as opposed to 20, which is used in the model. Sensitivity to this should be investigated.

- The current assessment model should incorporate estimates of immature male and female biomass based on trawl surveys.

- The assumption of the *Nephrops* net catchability of 1 for all size ranges is strong and requires further investigation.

- Weights used for the likelihood components of the assessment model seem to be rather arbitrary and not based on data (except for the cv estimates of mature male and female biomass from trawl surveys). The report did not assess the impact of other weights on results.

- Uncertainty about models often constitutes a major source of uncertainty in stock assessments. Incorporating model uncertainty is critical, but difficult for assuring a robust assessment of actual uncertainty and risk. Develop additional scenarios to fully explore the main axis of model uncertainty for stock status determination and risk evaluation.

- Re-parameterize the logistic selectivity functions by replacing the L_{95}-L_{50} in the denominator by a delta.

- In relation to improving the survey selectivity function with external data, it might be better to fit the assessment model only to experimental selectivity data from 2010. Biomass estimates for the BFRF survey may be of questionable value given the short time series.

- Implement a comprehensive sensitivity (i.e. perturbation) analysis to better assess the effects of different model components (i.e. parameters) on relevant quantities derived from the model and their associated uncertainties.

- Determine on the basis of published literature whether the model's assumptions for yearly molt are appropriate for the entire size range.

- Evaluation of management strategies should continue, especially considering spatially more complex operating and/or assessment models. There is a need to assess to what degree a "spatially free" model can properly represent the complex biological and spatial dynamics of this resource.

- The migratory connectivity between the stock to the north of the assessment area and population regularly assessed by the summer trawl survey should be evaluated.

Conclusions

- The size structured modelling seems to be an appropriate approach for assessing this stock, but there is uncertainty around several parameters.
- Spatial and biological complexities identified for this stock can be problematic for the current assessment model, but the relative importance is yet to be determined and requires attention.
- Further sensitivity analysis is recommended to better understand the interplay of different model components and their effect on the assessment results, as well as to define new model scenarios that better represent the main uncertainties in the model for this assessment.
- The incorporation of additional growth and selectivity data was considered an improvement over previous assessments.

Background

The AFSC (NOAA) Sand Point Office (Seattle), through the Center for Independent Experts (CIE), requested an independent review of the 2013 EBS snow crab stock assessment. Snow crab stocks have supported valuable commercial fisheries in the eastern Bering Sea and are managed under a cooperative state-federal management regime that defers fishery management to the State of Alaska with federal oversight. Stock and harvest levels during the last decade have been low relative to those of the mid-1980s through the late 1990s and the stock was declared to be in an "overfished" condition under federal criteria in 1999. Following the overfished declaration, uncertainties about fundamental questions regarding stock productivity, stock dynamics, stock assessment, and effects of fishery removals on stock productivity were identified. The snow crab stock assessment model has recently been used to determine upper harvesting limits on the stock.

This review included fisheries independent and dependent data and the 2013 stock assessment model of snow crab (*Chionocetes opilio*) in the Eastern Bering Sea. The snow crab assessment was last reviewed by the CIE in 2008. Since that time several improvements have been introduced to the model. The snow crab assessment is a high profile assessment that has undergone significant change in results due to the incorporation of data on catchability of the survey net and the estimation of natural mortality.

Description of review activities

Before and during the meeting

Documentation

Two weeks before the staff meeting at the Alaska Fisheries Science Center in Seattle, the following five documents were sent by e-mail to the reviewers:

- Main Assessment document:

  Turnock, J. and Rugolo, L. 2013. Stock Assessment of eastern Bering Sea snow crab. National Marine Fisheries Service. Draft document. 132 pages.

- Somerton, D., Goodman, S., Foy, R., Rugolo, L. and Slater, L. 2013. Growth per Molt of Snow Crab in the Eastern Bering Sea. North American Journal of Fisheries Management, 33:1, 140-147.

- Somerton, D., Weinberg, K. and Goodman, S. 2013. Catchability of Snow Crab (*Chionoecetes opilio*) by the eastern Bering Sea bottom trawl survey estimated using a catch comparison experiment. CJFAS 70: 1969-1708.

- Somerton, D. and Otto, B. 1999. Net efficiency of a survey trawl for snow crab, *Chionoecetes opilio*, and Tanner crab, *C. bairdi.* Fish. Bull. 97:617–625.

- Crab Plan Team Report: The North Pacific Fishery Management Council's Crab Plan Team (CPT) met September 17-20, 2013 at the Alaska Fisheries Science Center, Seattle, WA.
- DRAFT REPORT of the SCIENTIFIC AND STATISTICAL COMMITTEE to the NORTH PACIFIC FISHERY MANAGEMENT COUNCIL September 30 – October 1, 2013.

During the meeting Dr. Dorn uploaded additional material to the following link:

https://drive.google.com/folderview?id=0B3-PouR9XAa1SGZEZHIwYkQwX2M&usp=sharing

This includes:

1. Presentations.
2. Results of some additional model runs.
3. A variety of papers and reports about the biology, fisheries and population dynamics of this stock.

Review Activities

The review workshop was conducted at the Alaska Fisheries Science Center (Director's Meeting Room), Sand Point, Seattle, over four days: Tuesday, January 21 to Thursday, January 24 2014. During the workshop five scientists gave presentations on several topics about the snow crab stock, the fishery and modeling:

- *Jack Turnock*. Alaska Fisheries Science Center, Sand Point, Seattle;
- *Bob Foy*. Kodiak Laboratory, Resource Assessment and Conservation Engineering Division, Alaska Fisheries Science Center Kodiak Laboratory;
- *Dan Nichols*. Alaska Fishery Science Center, Sand Point, Seattle;
- *Athol Whitten*. School of Aquatic and Fishery Sciences, University of Washington, Seattle;
- *Cody Szuwalski*. School of Aquatic and Fishery Sciences, University of Washington, Seattle.

Two other scientists were present during the review workshop:

- *Dr. Martin Dorn*. Alaska Fishery Science Center, Sand Point, Seattle;

- *Dr. William Stockhausen*. Alaska Fishery Science Center, Sand Point, Seattle.

The members of the review panel were:

- Dr. Noel Cadigan (Memorial University, Newfoundland, Canada);
- Dr. Billy Ernst (UDEC, Concepción, Chile);
- Dr. Norman Hall (Murdoch University, Perth, Australia).

The agenda for the panel review meeting is included in Annex 3 of this report. Activities included introduction of participants, discussion of terms of reference of the snow crab review, overview of the fishery, biology of this species and survey methodology and analysis, during the first day. Jack Turnock presented a full description of the assessment model during days 2 and 3. During the second day additional material was presented on bathymetric migration of larger snow crab males, snow crab spatial modeling, MSE work and the development of a generalized snow crab model for EBS stocks. Finally, on day 4, the reviewers requested more description of the model and there were further discussions with the assessment author. The review meeting developed in a good working environment and the assessment author and the meeting chair were very responsive to different questions raised by the reviewers.

Findings and recommendations

ToR 1: A statement of the strengths and weaknesses of the Bering Sea snow crab assessment and stock projection models

Strengths

- The current stock assessment model constitutes an important and valuable attempt to incorporate many of the available sources of information to the study of this stock and its fishery. Because of the lack of age information, the use of a statistical length structured model (Sullivan et al 1990) seems most appropriate.
- Parameter estimation is based on formal statistical likelihood methods, within an integrated framework that seems appropriate.
- The assessment is based on an extensive EBS trawl survey database with a fairly consistent methodological sampling approach (systematic sampling).
- Retained catches, which are the major source of mortality in this fishery, seem to be reliable sources of information.
- The model was implemented on a very flexible and powerful modeling platform (ADMB) that easily provides uncertainty on parameter estimates.
- Special efforts have been made in recent years to obtain experimental data to better define trawl survey selectivity/catchability and somatic growth.
- Research associated with this assessment has incorporated very valuable work on MSE.

Weaknesses

- The current spatially aggregated assessment model attempts to capture the complex spatial and temporal dynamics of a highly mobile and reproductively complex species. The potential impacts of these factors on the assessment model have yet to be determined.
- Uncertainty about models often constitutes a major source of uncertainty in stock assessments. Incorporating model uncertainty is critical, but difficult for assuring a robust assessment of actual uncertainty and risk. From the documentation that was provided to us the alternative scenarios probably do not represent the main model uncertainty of the assessment.
- Weights used for the likelihood components of the assessment model seem to be rather arbitrary and not based on data (except for the cv estimates of mature male and female biomass from trawl surveys). The report did not assess the impact of other weights on results.

- The assumption of the *Nephrops* net catchability of 1 for all size ranges is strong and requires further investigation.

- The current assessment model should incorporate estimates of immature male and female biomass based on trawl surveys.

- There is uncertainty about the lifespan of the EBS snow crab and therefore its natural mortality. Literature suggests a maximum lifespan of about 14 years for females (Ernst et al. 2005) as opposed to 20, which is used in the model.

- The model currently uses a penalty on F. Available data on in-season catch rates can be used to estimate annual harvest rates.

- Untested assumptions of the frequency of molting are equal to 1 throughout the modeled size range.

- There is a need to improve the documentation of the stock assessment model in the assessment report.

ToR 2: Recommend for alternative model configurations or formulations if required

Adopt an alternative model configuration that would allow for greatly reducing the number of parameters from the initial conditions that would need to be to re-parameterized. Currently the model uses about 88 constrained parameters to construct the initial size structure of the model. Alternatively about 20 recruitment parameters could be estimated before the model starting year.

Re-parameterize the logistic selectivity functions by replacing the L_{95}-L_{50} in the denominator by a delta (=L_{95}-L_{50}). This should reduce correlations among selectivity parameters.

In relation to improving the survey selectivity function with external data, it might be better to fit the assessment model only to experimental selectivity data from 2010. Biomass estimates for the BFRF survey may be of questionable value given the short time series.

ToR 3: Recommendations of alternative models assumptions and estimators if required

The current assessment model does not use any fishing effort data, presumably because the fishery operated historically in a very short time frame during winter. Nevertheless, the short time frame and intensive harvesting offer conditions to apply Leslie/DeLuri models that use daily catch rates and cumulative catch to estimate yearly pre-season abundance and harvest rates. The state of Alaska has maintained an extensive in-season catch and effort database since the early 1990s (with a spatial resolution for areas of 30x30 nautical miles). This data can be used to obtain annual harvest rates, which in turn are used for the assessment model to provide an objective approach to establishing limits fishing mortality rates rather than the arbitrary penalties currently in use.

In the 2013 stock assessment model each size frequency has the same assigned multinomial sample size. The overall assigned value of 200 seems arbitrary, especially because sampling procedures vary greatly among the different information sources. The assessment results need to be subjected to a sensitivity analysis based on different weighting levels. Francis (2011) provided a post-model fitting approach to determine the weights for data for individuals of different sizes. This approach should be used to explore effective sample size for each data component. More effort needs to be made to analyze potential temporal variations in weighting for each source of data. The recommended sensitivity analysis of relative weights should also be extended to the different catch components. The weighting might not only impact the assessment but the risk analysis as well.

It is necessary to compare estimated or presumed parameters of mean instar size to data in published literature to determine whether model estimates are reasonable (see the literature presented below).

Model fits to the size compositional data, especially trawl data on discarded groundfish, could be improved by fitting males and females separately.

As far as can be inferred from the available documents and from the discussion with the assessment group, immature male and female biomass from the trawl survey is not being fitted to the 2013 snow crab assessment (only mature male and female biomass). This should be changed and two new likelihood components should be incorporated into the assessment or a more comprehensive biomass estimate should be constructed for each sex.

ToR 4: A review of fishery dependent and fishery independent data inputs to the stock assessment

EBS trawl survey data

Most of the independent fishery information used in this study consists of time-series data collected between 1978 and 2013 by NMFS trawl surveys. The 1975–1977 surveys were not used in the assessment because they covered only the southern end of the geographic range of interest. Systematic sampling surveys had consistent spatial coverage after 1978, with some variation north of 61°N where a cluster of northern stations was consistently occupied after 1988. Surveys follow a systematic sampling design in which stations are regularly spaced over a 20-nmi-by-20-nmi grid that is sampled every year. The core temporal window of the surveys is June–July. Several observations are made on all individual crabs caught in a haul, or from a subsample when the catch is too large. These observations include carapace width (CW, in millimeters), a shell condition index, sexual maturity (immature/mature, females only), and chela height (males only, recorded only since 1989). Abundance estimates and associated variances are obtained from a stratified sampling procedure. Some important temporal changes associated with the sampling procedure are a gear change since 1981, net mensuration for the period 1982-2013, and the incorporation of a bottom contact sensor since 1996.

This assessment does not use any information about effort from the fishery to create a time series of CPUE data. Therefore the EBS summer trawl survey constitutes the only source of information on relative abundance for this stock. Mature male and female biomass time series are constructed, but surprisingly no time series for immature male and female biomass are used in this assessment. This is considered a shortcoming because valuable information is being ignored.

The trawl survey data also provides information on size frequency by sex and shell condition (males). This is probably the best source of structural data for the assessment model to estimate recruitment strength.

Additional experimental data on growth

In order to improve estimates of growth per molt in the EBS, immature snow crabs were collected north of the Pribilof Islands in April of 2011 by a commercial trawling vessel using a Nephrops net. This experiment provided valuable information on growth, but the sample size was small and further research is needed.

Catch data

There are three main sources of crab removals used in this model, retained male crab from pot fishery, discarded male and female crab from pot fishery and bycatch male and female from trawl fishery. Total retained catch represent annually the main source of crab removals and the discarded catch of snow crab is about 1/3 of the catch of retained crab; the discarded snow crab are mainly males smaller than the size preferred by processors (4 inches carapace width). In the past an ad-hoc 50% mortality estimate and more recently a 30% agreed value have been used to compute discard mortality. This represents the main source of uncertainty in the total catch estimates. Short and long-term mortality have been identified and very valuable empirical work has been done to estimate short term mortality (Apendix A from Turnock and Rugolo 2013). The 1990/91-2010/11 average handling mortality estimates were around 4%, this being substantially less than the 0.3 or 0.5 that is being used. Nevertheless these numbers do not account for long-term mortality. The assessment should continue to incorporate this source of model uncertainty and assess the consequences in terms of stock status and risk.

The assessment model uses also a substantial amount of size frequency data from these fisheries. Size composition data from male pot fishery is extremely stable over time, which raises the question of the degree of information that it will provide towards recruitment strength estimation. This pattern probably emerges from combining a very size selective fishery and a terminal molt, which precludes conspicuous year classes to appear at larger sizes over time.

ToR 5: Recommendation on research needs that would reduce uncertainty in key parameters used or estimated in the assessment

It is necessary to improve the documentation of the stock assessment model to be able to produce a fully stand-alone document (e.g. initial conditions were not specified in the model, male and females size frequency data were fitted simultaneously). Only the interaction during the review workshop allowed us to fully understand all details of the model.

Given the complexity of size-structured assessment models (i.e. the additional need to explicitly model growth) and the fact that some input parameters are used as fixed quantities with values based on other stocks, there is a need to employ comprehensive sensitivity (i.e. perturbation) analysis to better assess the effect of different parameters on relevant quantities of the model and their associated uncertainties.

Model uncertainty often constitutes a major source of uncertainty in stock assessments. Incorporating model uncertainty is critical, but difficult for assuring a robust assessment of actual uncertainty and risk. More work is needed to better assess and document the principal axis of structural uncertainty (e.g. growth and mortality) for stock status determination and risk evaluation. Some of this work might have been documented in previous reports, but was not provided during the assessment review.

Two presentations were made at the review workshop on management strategy evaluation (MSE) of EBS snow crab stock and spatial analysis (Cody Szuwalski). As part of his PhD thesis, Dr. Szuwalski modeled the snow crab population in four large subareas of the EBS to incorporate spatial structure into the analysis. Unfortunately, there was not enough information to fully condition the operating model. Nevertheless, these difficulties should not discourage the search for other configurations to provide a functional spatial operating model to evaluate current assessments under more realistic scenarios that include spatial structure in snow crab population dynamics.

Under the current assessment model and management configuration, statistics on mature male biomass (MMB) are important as reference points and for calculating status. Female maturity can be directly measured from the summer survey data, but male morphological maturity and maturity-at-length ogives require an extra step of separating the two clusters (morphologically mature and immature males) in the chela-height and carapace width dimensional space, for example by means of a clusterwise regression analysis (Hoenig 2000). Sampling in the EBS for male chela-height data started in 1989, but with a more or less ad-hoc procedure. This makes it difficult to obtain an annual male maturity function that has been weighted properly by the abundance estimates of each station, mainly because the two samplings (density and male maturity) are not integrated. Given the importance of MMB estimates, it is recommended that an extra effort be made to provide chela-height measurement for every male whose carapace width has been measured. A subsequent clusterwise regression analysis could provide a morphological maturity status for all males at all the survey stations. This would provide an accurate male maturity ogive across the wide geographic range and produce very valuable spatial data on male morphological maturity.

Ernst et al (2005) and Ernst et al (2012) documented female spatial distribution and ontogenetic migration of mature females from the middle domain (primiparous) towards the upper portion of the outer (multiparous) domain in the EBS. Using historic survey and fisheries data Orensanz et al. (2005) and Gravel et al. (2005) tagging data documented an important offshore migration of larger males from the middle domain towards the fishing grounds in the outer domain (between the survey and the time of the fishery). Dan Nichol (AFSC) presented results from recaptured data storage tagging (DST) devices attached to males, showing that no larger males marked and recaptured in the outer domain returned to the middle domain during the mating season. This presents an interesting scenario for mating opportunities, where the vast majority of primiparous females mate in the middle domain with morphologically immature, but physiologically mature males (> 40 mm) (Saint-Marie et al. 1995) and multiparous females mate with morphologically mature males in the upper portion of the outer domain. Additionally, based on larval transport and IBM modeling, Parada et al. (2010) highlighted the important relative contribution of primiparous females to renewing the EBS snow crab population. In light of these results, the use of the MMB as a proxy of current reproductive potential should be questioned. Further research on assessing mating opportunities is required to fully understand the reproductive dynamics of this species in the EBS.

Estimating the size transition matrix in a fully length-structured model (Sullivan et al 1990) often requires auxiliary data on growth increments provided from tagging or other types of experimental data (Somerton et al. 2013). The 2013 snow crab stock assessment uses observed mean increments at size to estimate linear growth parameters in an integrated way. Figures 54b (males) and 54c (females) of the assessment report show the fit of the estimated growth functions to the observed values for the base case. The fit to the data is not satisfactory in either of the two cases. Further modeling is required to understand the nature of this inconsistency. This is important because these data points are the only direct measurements of growth provided to the model and it is important to evaluate what other data is impeding a better fit to the growth data.

Orensanz et al. (2007) presented a compilation of mean size-at-instar data from several snow crab stocks: northwestern Gulf of St. Lawrence (Sainte-Marie et al. 1995 and Alunno-Bruscia and Sainte-Marie 1998); southeastern Gulf of St. Lawrence (Robichaud et al. 1989); Newfoundland (Comeau et al. 1998); the Okhotsk Sea (Ito 1970), the Japan Sea (Kon 1980) and the EBS (their Figure 11). There is a high degree of consistency of mean size-at-instar across these wide geographic areas. This published information should be used to check whether estimated growth patterns within the size transition matrix are consistent with those from the published literature. The mean size-at-instar and its variability (e.g. in Saint-Marie 1998) can also be used to assess whether the shape of the recruitment-at-length function is consistent with the variability associated with the instars at which the recruitment should be occurring.

ToR 6: Suggested research priorities to improve the stock assessment

In the short term

- Implement a comprehensive sensitivity (i.e. perturbation) analysis to better assess the effects of different model components (i.e. parameters) on relevant quantities derived from the model and their associated uncertainties.
- Develop additional scenarios to fully explore the main axis of model uncertainty (e.g. growth, mortality) for stock status determination and risk evaluation.
- Compare implicit growth schedules (mean and variance) used in the size transition matrix to published mean size-at-stage estimates available from several papers as suggested above, to check for inconsistencies.
- Use published growth schedule information to better define the shape of the recruitment-at-length function in the length-structured model. The one used in Figure 75 of the stock assessment report is rather broad, and probably includes several age groups.
- Determine on the basis of published literature whether the model's assumptions for yearly molt are appropriate for the entire size range.

- Assess the potential for crab ageing using direct readings of eyestalks or gastric mills using the approach of Kilada et al. (2013). This can provide useful information on maximum lifespan and indirectly yield overall natural mortality estimates, thus reducing uncertainty around this parameter.

- Explore the use of in-season catch and effort data (especially before 2000) to estimate annual harvest rates based on depletion estimators (Leslie/DeLury). A report on this topic should be available from Dr. Penguilli at the ADF&G. These estimates should provide the necessary information to remove arbitrary penalties on historic F values.

- Incorporate into the assessment likelihood components for immature male and female biomass from the trawl survey and assess the effect of doing this with respect to the base model.

In the longer term

- The work by Somerton et al. (2013) on snow crab growth per molt in the EBS constitutes a mayor advance towards characterizing growth used in the assessment model. Increasing sample size across an extended size range by sex should be a priority. If possible, a southern and a northern region should be selected to assess potential geographic differences in growth schedules. This kind of data should provide information to estimate not only mean increments, but also the variability around them (fixed parameter used in the gamma distribution of the size transition matrix).

- Evaluation of management strategies should continue, especially considering spatially more complex operating and/or assessment models. There is a need to assess to what degree a “spatially free” model can properly represent the complex biological and spatial dynamics of this resource.

- The migratory connectivity between the stock to the north of the assessment area and population regularly assessed by the summer trawl survey should be evaluated.

- Nephrops net efficiency is assumed to be 1 for all sizes. This seems rather a strong assumption and needs to be evaluated. Further comparative studies are encouraged to check the estimated NMFS trawl survey selectivity.

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I would like to thank Martin Dorn from the AFSC (NOAA) Sand Point (Seattle) for chairing the workshop in Seattle. He was very helpful and supportive. Jack Turnock (AFSC) did a good job summarizing the assessment structure and results and in his role in fruitful discussions, Bob Foy provided a detailed overview of the EBS trawl survey, and Dan Nichol, Cody Szuwalski and Athol Whitten contributed with their insightful presentations. Finally, I would like to thank Manoj Shivlani and Roberto Koeneke (CIE), for contacting me and taking care of contractual and practical arrangements in an efficient manner.

Bibliography

Alunno-Bruscia, M., and Sainte-Marie, B. 1998. Abdomen allometry, ovary development, and growth of female snow crab, *Chionoecetes opilio* (Brachyura, Majidae), in the northwestern Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 55 (2): 459-477. doi:10.1139/cjfas-55-2-459.

Comeau, M., and Conan, G.Y. 1992. Morphometry and gonad maturity of male snow crab, *Chionoecetes opilio*. Can. J. Fish. Aquat. Sci. 49 (12): 2460-2468. doi:10.1139/f92-271.

Ernst, B., Armstrong, D.A., Burgos, J. and Orensanz, J.M. 2012 Cyclic recruitment and the life history schedule of female snow crab (*Chionoecetes opilio*) in the Eastern Bering Sea. Canadian Journal of Fisheries and Aquatic Sciences 69: 532-550.

Ernst, B., Orensanz, J. and Armstrong, D. 2005. Spatial dynamics of female snow crab (*Chionoecetes opilio*) in the Eastern Bering Sea. CJAFS 62:250-268.

Francis, R.I.C.C., 2011. Data weighting in statistical fisheries stock assessment models. Can. J. Fish. Aquat. Sci. 68, 1124-1138.

Gravel, K.A., Watson, L.J. and Pengilly, D. 2006. The 2005 eastern Bering Sea snow crab *Chionoecetes opilio* tagging study. Alaska Department of Fish and Game (Anchorage), Fishery Management Report No. 06-31, 41 pp.

Hennig, C. 2000. Identifiability of models for clusterwise linear regression. Journal of Classification 17: 273-296.

Ito, K. 1970. [Ecological studies of the edible crab *Chionoecetes opilio* (O. Fabricius) in the Japan Sea. III. Age and growth as estimated on the basis of the seasonal changes in the carapace width frequencies and the carapace hardness]. Bulletin of the Japan Sea Regional Fisheries Research Laboratory 22: 81-116 (In Japanese; translation in Fisheries Research Board of Canada Translation Series 1512).

Kilada R, Sainte-Marie B, Rochette R, Davis N, Vanier C & Campana S (2012). Direct determination of age in shrimps, crabs, and lobsters. Canadian Journal of Fisheries and Aquatic Sciences, 69(11): 1728-1733.

Kon, T. 1980. Studies on the life history of the zuwai crab (*Chionoecetes opilio* (O. Fabricius)). Special Publications of the Sado Marine Biological Station, Niigata University, Series 2, 64 pages.

Orensanz, J. M., Ernst, B., Armstrong, D.A., Stabeno, P., and Livingston, P. 2004. Contraction of the geographic range of distribution of snow crab (*Chionoecetes opilio*) in the eastern Bering Sea- an environmental ratchet? CALCOFI Reports 45: 65-79. Available from http://www.calcofi.org/newhome/publications/CalCOFI_Reports/v45/Vol45_Orensanz.pdf [accessed 26 November 2010].

Orensanz, J.M., Ernst, B., and Armstrong, D.A. 2007. Variation of female size- and stage-at-maturity in snow crab (*Chionoecetes opilio*) (BRACHYURA: MAJIDAE) from the eastern Bering Sea. Journal of Crustacean Biology 27 (4): 576-591. doi: 10.1651/S-2790.1

Parada, C., Armstrong, D.A., Ernst, B., Hinckley, S. y Orensanz, J.M. 2010. Spatial dynamics of snow crab (*Chionoecetes opilio*) in the Eastern Bering Sea- Putting together the pieces of the puzzle. Bulletin of Marine Science 86: 413-437.

Robichaud, D. A., R. F. J. Bailey and R. W. Elner. 1989. Growth and distribution of snow crab, *Chionoecetes opilio*, in the southeastern Gulf of St. Lawrence. Journal of Shellfish Research 8: 13-23.

Sainte-Marie, S. Raymond and J.-C. Brethes. 1995. Growth and maturation of the benthic stages of male snow crab, *Chionoecetes opilio* (BRACHYURA: MAJIDAE). Canadian Journal of Fisheries and Aquatic Sciences 52: 903-924.

Somerton, D., Goodman, S., Foy, R., Rugolo, L. and Slater, L. 2013. Growth per Molt of Snow Crab in the Eastern Bering Sea. North American Journal of Fisheries Management, 33:1, 140-147.

Somerton, D., Weinberg, K. and Goodman, S. 2013. Catchability of Snow Crab (*Chionoecetes opilio*) by the eastern Bering Sea bottom trawl survey estimated using a catch comparison experiment. CJFAS 70: 1969-1708.

Sullivan, P., Han-Lin Lai., and Gallucci, V. 1990. A catch-at-length analysis that incorporates a stochastic model of growth. Canadian journal of fisheries and aquatic sciences 47(1):184-198.

Statement of Work

External Independent Peer Review by the Center for Independent Experts

Bering Sea Snow Crab Stock Assessment Review

Scope of Work and CIE Process: The National Marine Fisheries Service's (NMFS) Office of Science and Technology coordinates and manages a contract providing external expertise through the Center for Independent Experts (CIE) to conduct independent peer reviews of NMFS scientific projects. The Statement of Work (SoW) described herein was established by the NMFS Project Contact and Contracting Officer's Representative (COR), and reviewed by CIE for compliance with their policy for providing independent expertise that can provide impartial and independent peer review without conflicts of interest. CIE reviewers are selected by the CIE Steering Committee and CIE Coordination Team to conduct the independent peer review of NMFS science in compliance the predetermined Terms of Reference (ToRs) of the peer review. Each CIE reviewer is contracted to deliver an independent peer review report to be approved by the CIE Steering Committee and the report is to be formatted with content requirements as specified in **Annex 1**. This SoW describes the work tasks and deliverables of the CIE reviewer for conducting an independent peer review of the following NMFS project. Further information on the CIE process can be obtained from www.ciereviews.org.

Project Description: The snow crab assessment was last reviewed by the CIE 2008. Since that time, the analyst has made a number of improvements to the model. These changes should be reviewed by an independent panel. The snow crab assessment is a high profile assessment which has undergone significant change in results due to incorporation of data on catchability of the survey net and estimation of natural mortality. This review would encompass the Bering Sea trawl survey data, additional survey data used in estimation of catchability, the stock assessment model structure, assumptions, life history data, and harvest control rule. The Terms of Reference (ToRs) of the peer review are attached in **Annex 2**.

Requirements for CIE Reviewers: Three CIE reviewers shall have the necessary qualifications to complete an impartial and independent peer review in accordance with the tasks and ToRs described in the SoW herein. The CIE reviewers shall have expertise in conducting stock assessments for fisheries management, and be thoroughly familiar with various subject areas involved in stock assessment, including population dynamics, size-structured models, harvest strategies, survey methodology, and the AD Model Builder programming language to complete the tasks of the scientific peer-review described herein. Familiarity with invertebrate stock assessment, knowledge of crab life history and biology, harvest strategy development is desirable. Each CIE reviewer is requested to conduct an impartial and independent peer review in accordance with the ToRs herein. The CIE reviewer's duties shall not exceed a maximum of 14 days conducting pre-review preparations with document review, participation in the panel review meeting, and completion of the CIE independent peer review report in accordance with the ToR and Schedule of Milestones and Deliverables.

Location of Peer Review: Each CIE reviewer shall participate and conduct an independent peer review during the panel review meeting scheduled at the Alaska Fisheries Science Center (AFSC) in Seattle, Washington during the tentative dates of January 21-24, 2014.

Statement of Tasks: Each CIE reviewer shall complete the following tasks in accordance with the SoW and Schedule of Milestones and Deliverables herein.

Tasks prior to the meeting: The contractor shall independently select qualified reviewers that do not have conflicts of interest to conduct an independent scientific peer review in accordance with the tasks and ToRs within the SoW. Upon completion of the independent reviewer selection by the contractor's technical team, the contractor shall provide the reviewer information (full name, title, affiliation, country, address, email, and FAX number) to the contractor officer's representative (COR), who will forward this information to the NMFS Project Contact no later than the date specified in the Schedule of Milestones and Deliverables. The contractor shall be responsible for providing the SoW and stock assessment ToRs to each reviewer. The NMFS Project Contact will be responsible for providing the reviewers with the background documents, reports, foreign national security clearance, and other information concerning pertinent meeting arrangements. The NMFS Project Contact will also be responsible for providing the Chair a copy of the SoW in advance of the panel review meeting. Any changes to the SoW or ToRs must be made through the COR prior to the commencement of the peer review.

Foreign National Security Clearance: The reviewers shall participate during a panel review meeting at a government facility, and the NMFS Project Contact will be responsible for obtaining the Foreign National Security Clearance approval for the reviewers who are non-US citizens. For this reason, the reviewers shall provide by FAX (not by email) the requested information (e.g., first and last name, contact information, gender, birth date, passport number, country of passport, travel dates, country of citizenship, country of current residence, and home country) to the NMFS Project Contact for the purpose of their security clearance, and this information shall be submitted at least 30 days before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations available at the Deemed Exports NAO website: http://deemedexports.noaa.gov/.

Pre-review Background Documents: Approximately two weeks before the peer review, the NMFS Project Contact will send (by electronic mail or make available at an FTP site) to the COR the necessary background information and reports (i.e., working papers) for the reviewers to conduct the peer review, and the COR will forward these to the contractor. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the COR on where to send documents. The reviewers are responsible only for the pre-review documents that are delivered to the contractor in accordance to the SoW scheduled deadlines specified herein. The reviewers shall read all documents deemed as necessary in preparation for the peer review.

Tasks during the panel review meeting: Each reviewer shall conduct the independent peer review in accordance with the SoW and stock assessment ToRs, and shall not serve in any other role unless specified herein. **Modifications to the SoW and ToRs shall not be made during the peer review, and any SoW or ToRs modifications prior to the peer review shall be approved by the COR and contractor.** Each reviewer shall actively participate in a professional and respectful manner as a member of the meeting review panel, and their peer review tasks shall be focused on the stock assessment ToRs as specified herein. The NMFS Project Contact will be responsible for any facility arrangements (e.g., conference room for panel review meetings or teleconference arrangements). The NMFS Project Contact will also be responsible for ensuring that the Chair understands the contractual role of the reviewers as specified herein. The contractor can contact the COR and NMFS Project Contact to confirm any peer review arrangements, including the meeting facility arrangements.

Tasks after the panel review meeting: Each reviewer shall prepare an independent peer review report, and the report shall be formatted as described in **Annex 1**. . If any existing Biological Reference Point or their proxies are considered inappropriate, or if an inappropriate model formulation is identified, the report should include recommendations and justification for suitable alternatives. If such alternatives cannot be identified, then the report shall indicate that the existing BRPs are the best available at this time. Additional questions and pertinent information related to the assessment review addressed during the meetings that were not in the ToRs may be included in a separate section at the end of an independent peer review report.

<u>Contract Deliverables - Independent CIE Peer Review Reports</u>: Each CIE reviewer shall complete an independent peer review report in accordance with the SoW. Each CIE reviewer shall complete the independent peer review according to required format and content as described in Annex 1. Each CIE reviewer shall complete the independent peer review addressing each ToR as described in Annex 2.

Specific Tasks for CIE Reviewers: The following chronological list of tasks shall be completed by each CIE reviewer in a timely manner as specified in the **Schedule of Milestones and Deliverables**.

1) Conduct necessary pre-review preparations, including the review of background material and reports provided by the NMFS Project Contact in advance of the peer review.
2) Participate during the panel review meeting at Seattle, Washington during FeJanuary 21through January 24, 2014.
3) Conduct an independent peer review in accordance with the ToRs (**Annex 2**).
4) No later than February 7, 2014, each CIE reviewer shall submit an independent peer review report addressed to the "Center for Independent Experts," and sent to Mr. Manoj Shivlani, CIE Lead Coordinator, via email to

shivlanim@bellsouth.net, and CIE Regional Coordinator, Dr. David Die via email to ddie@rsmas.miami.edu. Each CIE report shall be written using the format and content requirements specified in Annex 1, and address each ToR in **Annex 2**.

Schedule of Milestones and Deliverables: CIE shall complete the tasks and deliverables described in this SoW in accordance with the following schedule.

17 December 2013	CIE sends reviewer contact information to the COR, who then sends this to the NMFS Project Contact
23 December 2013	NMFS Project Contact sends the stock assessment report and background documents to the CIE reviewers.
21-24 January 2014	Each reviewer shall conduct an independent peer review during the panel review meeting in Seattle, Washington
7 February 2014	CIE reviewers submit draft CIE independent peer review reports to the CIE Lead Coordinator and CIE Regional Coordinator
21 February 2014	CIE submits CIE independent peer review reports to the COR
28 February 2014	The COR distributes the final CIE reports to the NMFS Project Contact and regional Center Director

Modifications to the Statement of Work: This 'Time and Materials' task order may require an update or modification due to possible changes to the terms of reference or schedule of milestones resulting from the fishery management decision process of the NOAA Leadership, Fishery Management Council, and Council's SSC advisory committee. A request to modify this SoW must be approved by the Contracting Officer at least 15 working days prior to making any permanent changes. The Contracting Officer will notify the COR within 10 working days after receipt of all required information of the decision on changes. The COR can approve changes to the milestone dates, list of pre-review documents, and ToRs within the SoW as long as the role and ability of the CIE reviewers to complete the deliverable in accordance with the SoW is not adversely impacted. The SoW and ToRs shall not be changed once the peer review has begun.

Acceptance of Deliverables: Upon review and acceptance of the CIE independent peer review reports by the CIE Lead Coordinator, Regional Coordinator, and Steering Committee, these reports shall be sent to the COR for final approval as contract deliverables based on compliance with the SoW and ToRs. As specified in the Schedule of Milestones and Deliverables, the CIE shall send via e-mail the contract deliverables (CIE independent peer review reports) to the COR (William Michaels, via William.Michaels@noaa.gov).

Applicable Performance Standards: The contract is successfully completed when the COR provides final approval of the contract deliverables. The acceptance of the contract deliverables shall be based on three performance standards:

(1) The CIE report shall completed with the format and content in accordance with **Annex 1**,

(2) The CIE report shall address each ToR as specified in **Annex 2**,

(3) The CIE reports shall be delivered in a timely manner as specified in the schedule of milestones and deliverables.

Distribution of Approved Deliverables: Upon acceptance by the COR, the CIE Lead Coordinator shall send via e-mail the final CIE reports in *.PDF format to the COR. The COR will distribute the CIE reports to the NMFS Project Contact and Center Director.

Support Personnel:

William Michaels, Program Manager, COR
NMFS Office of Science and Technology
1315 East West Hwy, SSMC3, F/ST4, Silver Spring, MD 20910
William.Michaels@noaa.gov Phone: 301-427-8155

Manoj Shivlani, CIE Lead Coordinator
Northern Taiga Ventures, Inc.
10600 SW 131st Court, Miami, FL 33186
shivlanim@bellsouth.net Phone: 305-383-4229

Roger W. Peretti, Executive Vice President
Northern Taiga Ventures, Inc. (NTVI)
22375 Broderick Drive, Suite 215, Sterling, VA 20166
RPerretti@ntvifederal.com Phone: 571-223-7717

Key Personnel:

NMFS Project Contact:

Jack Turnock
Resource Ecology and Fisheries Management Division
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, WA 98115
jack.turnock@noaa.gov Phone: 206-526-6549

Douglas Demaster, Science Director

Alaska Fisheries Science Center
17109 Pt Lena Loop Rd.
Juneau, AK 99801
douglas.demaster@noaa.gov Phone: 907-789-6517

Annex 1: Format and Contents of CIE Independent Peer Review Report

1. The CIE independent report shall be prefaced with an Executive Summary providing a concise summary of the findings and recommendations, and specify whether the science reviewed is the best scientific information available.

2. The main body of the reviewer report shall consist of a Background, Description of the Individual Reviewer's Role in the Review Activities, Summary of Findings for each ToR in which the weaknesses and strengths are described, and Conclusions and Recommendations in accordance with the ToRs. The CIE independent report shall be a stand-alone document for others to understand the weaknesses and strengths of the science reviewed. The CIE independent report shall be an independent peer review of each ToRs.

3. The reviewer report shall include the following appendices:

   Appendix 1: Bibliography of materials provided for review

   Appendix 2: A copy of the CIE Statement of Work

Annex 2: Terms of Reference for the Peer Review

Bering Sea Snow Crab Stock Assessment Review

The report generated by the consultant should include:

1. A statement of the strengths and weaknesses of the Bering Sea snow crab stock assessment and stock projection models.

2. Recommend for alternative model configurations or formulations if required.

3. Recommendations of alternative model assumptions and estimators if required.

4. A review of fishery dependent and fishery independent data inputs to the stock assessment.

5. Recommendation on research needs that would reduce uncertainty in key parameters used or estimated in the assessment.

6. Suggested research priorities to improve the stock assessment.

Annex 3: Final Agenda for Panel Review Meeting

Bering Sea Snow Crab Stock Assessment Review

Center Director's Meeting Room
NOAA Alaska Fisheries Science Center
7600 Sand Point Way NE, Seattle, WA 98115
Contact: jack.turnock@noaa.gov Phone: 206-526-6549

21-24 January 2014

Tuesday, January 21

09:00 Welcome and Introductions (Martin Dorn)
09:15 Role of chair and reviewers, terms of reference (Martin Dorn)
09:30 Overview (surveys, fishery, catch levels, bycatch) (Jack Turnock)
10:30 Biology (growth, natural mortality, maturity curves, mating, molting frequency) (Jack Turnock)
12:00 Lunch
13:00 Survey methodology and analysis (Bob Foy)
Kodiak lab research (Bob Foy)
16:00 Biology continued

Wednesday, January 22

09:00 Description of stock assessment and projection model (Jack Turnock)
Harvest control rules and overfishing definition (Jack Turnock)
11:00 Snow crab Tagging results (Dan Nichol)
12:00 Lunch
13:00 Management Strategy Evaluation (Cody Szuwalski)
Recruitment and Environment (Cody Szuwalski)
Spatial Modeling (Cody Szuwalski)
15:00 Development of Generic crab model and subroutines (Athol Whitten)
16:00 Continued description of stock assessment (Jack Turnock)

Thursday, January 23

9:00 Survey selectivity studies
Continued description of stock assessment (Jack Turnock)

Friday, January 24

9:00 Reviewer discussions with assessment authors.
Review of requested model runs if required.