Center for Independent Experts (CIE) Independent Peer Review Report

on

Aleutian Islands Golden King and Norton Sound Red King Crab Stock Assessment Review

Prepared by

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I. Executive Summary

The Center for Independent Experts (CIE) review for the ***Aleutian Islands Golden King Crab and Norton Sound Red King Crab Stock Assessments***, held in Seattle, WA from June 18-21, 2018, was aimed to evaluate current stock assessment programs for the Aleutian Islands Golden King Crab (AIGKC) and Norton Sound Red King Crab (NSRKC) stocks and make recommendations for improvement. This review is the first CIE review since 2013. The Alaska Fisheries Science Center (AFSC) and Alaska Department of Fish and Game provided all the necessary logistical support, data, documentation, and background information for the review. The scientists involved in the process were open to suggestions and provided additional information and analyses upon request. The review contact and Chair, Dr. William Stockhausen, accommodated all the requests I had made. The review process was open and constructive, and all the background materials and stock assessment reports were sent to me in a timely manner. As a CIE reviewer, I am asked to evaluate the AIGKC and NSRKC stock assessments with respect to the Terms of Reference.

I would like to commend the effort of the AIGKC and NSRKC stock assessment teams for continuing to refine the stock assessment models based on newly acquired information and understanding, improve methods for developing abundance indices from fisheries data, evaluate the quality and quantity of input data and possible implications, consider alternative model configurations and parameterizations, and address the uncertainty associated with the data and model structure.

Overall, I consider the current modeling framework yields rather robust assessment results for both the AIGKC and NSRKC stocks regarding uncertainties in data and models. The length-structured models can capture well the length-based life history and fishery processes, and quantify the dynamics of AIGKC and NSRKC stocks. The assessment appears to be scientifically sound and adequately addresses management needs. However, I believe there is still room for further improvement of the current stock assessment program for the AIGKC and NSRKC stocks. I divide my specific recommendations/comments into two categories: those require actions in a relative short term (e.g., in the next couple of years or before the next benchmark stock assessment) and those that can be done in a long term. I made these recommendations to address issues raised during the CIE review workshop targeting to reduce uncertainties and improve the quality of AIGKC and NSRKC stock assessments. Justifications for a specific recommendation can be found in the report.

My specific *short-term research recommendations* include (1) continuing to explore spatial delta-GLMM method to standardize CPUE for AIGKC and survey abundance for both AIGKC and NSRKC outside the stock assessment modeling in order to remove possible spatiotemporal trends in selectivity/catchability/availability; (2) conducting more structured modeling diagnosis of the relative importance of various likelihood functions for different input data sets and assessing their weight in model fitting (i.e., quantity versus quality); (3) improving the presentation of retrospective analysis results and conducting retrospective analyses for all models (not just a base case scenario) considered in the stock assessment in order to better understand and evaluate the nature (positive or negative) and magnitude of retrospective errors and determine if they should be corrected while determining stock status and stock SSB projection;

(4) analyzing among-model variations (for all final models used in different years of stock assessment) to improve understanding of model performance and any possible management implications of making changes to the model configurations/parameterizations over time, which can also provide some information about possible structured uncertainty in the stock assessments; (5) evaluating the performance of the projection done in the past assessment, retrospectively, to evaluate their performance in achieving the management objectives; (6) evaluating biological realism of growth parameter estimates (i.e., growth transition matrices) and exploring the possibility of ageing AIGKC and NSRKC to verify the growth transition matrices estimated in the stock assessment modeling; (7) evaluating possible inter-correlations between parameters of different life history parameters (e.g., growth versus natural mortality) and between life history and fishery processes (e.g., growth and natural mortality versus selectivity) to have a better understanding of biological realism and statistical properties of estimated parameters; and (8) using Bayesian inference to better capture the uncertainty in stock assessment modeling for projecting future stock dynamics.

My specific *long-term research recommendations* include (1) using season as a time step to better capture the strong seasonality of AIGKC and NSRKC fisheries and life histories as well as conducting a comparative study to evaluate possible differences in stock assessments with "year" and "season" as time steps; (2) conducting an extensive computer simulation study to optimize the design for the AIGKC and NSRKC survey programs to make them more cost-effective, possibly leading to the expanded survey area coverage for the NSRKC stock and more frequent survey for the AIGKC stock; (3) Analyzing and evaluate possible temporal and spatial variability in key life history parameters such as weight-at-length, and maturity-at-length for a better estimation and projection of stock biomass and SSB; (4) conducting habitat suitability modeling to identify suitable habitats for the AIGKC and NSRKC and using ocean observatory data (or model data) to outline the distribution of potential suitable habitat in the stock areas and help improve survey designs; (5) evaluating effectiveness of CPUE standardization in removing factors influencing fishery CPUE other than stock biomass; (6) conducting studies to better understand stock structure for AIGKC and stock distribution for NSRKC; and (7) incorporating models to quantify female population dynamics because current modeling framework provides no information on the status of female population which is critical in determining the overall stock reproduction potential and dynamics.

Further and more general and specific comments and recommendations can be found in Section V of this report.

II. Background

Populations of the Golden King Crab, *Lithodes aequispinus*, are distributed across the Gulf of Alaska and the Aleutian Islands on the continental slope of the eastern Bering Sea to southeastern Alaska. The Aleutian Islands Golden King Crab (AIGKC), distributed east of the 174°W line of longitude (EAG) and west of the 174°W line of longitude (WAG), has supported an important fishery since the early 1980s. Although there is no sufficient evidence to support two separate stocks within the EAG and WAG, large differences in CPUEs suggest different stock dynamics between the EAG and WAG. Because of their complicated life history and deep depth distribution (Otto and Cummiskey 1985; Somerton and Otto 1986), limited information on the early life history, distribution and movement is available and some of its key life history processes still remain unknown (Watson et al. 2002, Siddeek et al. 2018).

The AIGKC fishery has been managed separately in the EAG and WAG since 1996. AIGKC in these two areas have been managed with a constant annual guideline harvest level or total allowable retained catch. The AIGKC fishery is a male-only fishery with a minimum legal size limit of 152.4 mm CW (around 136 mm CL).

The AIGKC fishery is managed as a Tier 3 stock which assumes that the proxies for F_{MSY} and B_{MSY} can be reliably estimated although no reliable estimation of stock-recruitment relationship is available (NPFMC 2017).

The data used in the AIGKC stock assessment include a time series of retained catch by size in the fishery, discarded catch by size, observer CPUEs and commercial fishery CPUEs, as well as three years of survey data, mark-recapture data, and male maturity at size. Fishery CPUE data were standardized before they were inputted into the stock assessment model. A male-specific, size-structured model has been developed for the quantification of the AIGKC stock dynamics. The model is fitted to commercial retained catch, total catch, discarded catch in the groundfish fishery, standardized observer legal-size CPUE, fishery retained catch size composition, total catch size composition, and mark-recapture data to estimate key stock and fishery parameters. The model configuration/parameterization considers significant changes in fishing practice due to changes in management regulations, pot configuration, and improved observer recording in the AIGKC fisheries (Siddeek et al. 2018).

Norton Sound Red King Crab (NSRKC), *Paralithodes camtschaticus*, is one of the northernmost red king crab populations and supports three main male-only fisheries in Norton Sound, Alaska: summer commercial, winter commercial, and winter subsistence fisheries (Hamazaki and Zheng 2018). The catch in the summer commercial fishery accounts for over 90% of the total NSRKC catch. The NSRKC stock is considered as a unit stock in the assessment, but few studies have been done to evaluate the unit stock assumption.

The NSRKC distribution and movement patterns are largely unknown, but studies suggest that they spend their entire lives in shallow waters. Norton Sound Red King Crab experience seasonal inshore-offshore movement although timing of the inshore mating migration is unknown (Powell et al. 1983). Timing of molting is also unknown, however increased catches of fresh-molted crab later in the fishing season suggests that molting may occur in late August and September.

Fishery-independent surveys suggest that high abundance can be found on the southeast side of the sound.

The NSRKC stock has been managed based on the Alaska Department of Fish and Game (ADFG) guideline harvest level since 1997. NSRKC is a Tier 4 crab stock with B_{MSY} proxy being calculated as mean model estimated mature male biomass from 1980 to present. This time period was chosen based on a hypothesized shift in stock productivity as a result of climatic regime shift in 1976-77. The NSRKC stock status was determined to be Tier 4a until 2013, when it fell to Tier 4b, but came back to Tier 4a after 2015.

Data used in the NSRKC stock assessment include summer trawl survey abundance index and length composition data; winter pot survey length composition data; retained catch, length composition and standardized CPUEs from summer commercial fishery; summer commercial discard length composition (sublegal); winter subsistence fishery total catch; winter commercial fishery retained catch; and mark-recapture data.

The NSRKC stock is assessed using a male-specific and length-structured model (Zheng et al. 1998). A series of model configurations/parameterizations (e.g., size-specific natural mortality, fishing effort weights, and effective sample sizes for commercial catch and winter survey) have been considered since 2011 (Hamazaki and Zheng 2018). Maximum likelihood approach is used to fit the model to the data in estimating key stock and fishery parameters.

This review is the first CIE review since 2013. The AFSC has provided all the necessary logistics support while the ADFG provided all the documentation, data, and background information for the review. The scientists involved in the process were very open to suggestions and provided additional information and analyses upon request. Dr. William Stockhausen, who is the review contact and Chair, worked hard with the stock assessment authors to accommodate requests made by the CIE reviewers as well as led and engaged in constructive dialogues between stock assessment authors and CIE reviewers. The entire process was open and constructive.

As a CIE reviewer, I am charged to evaluate the Aleutian Islands Golden King and Norton Sound Red King Crab stock assessments with respect to the Terms of Reference provided by the CIE. This report follows the required format and includes an executive summary (Section I), background introduction (Section II), description of my review activities (Section III), my comments on each item listed in the Terms of Reference (ToRs, Section IV), summary of my comments and recommendations (Section V), and references (Section VI). The final part of this report (Section VII) includes a collection of appendices including the Statement of Work (SoW).

III. Description of the Individual Reviewer's Role in the Review Activities

My role as a CIE independent reviewer is to conduct an impartial and independent peer review of the AIGKC and NSRKC stock assessments with respect to the pre-defined Terms of Reference.

About two to four weeks prior to the review workshop in the AFSC in Seattle, I received the AIGKC and NSRKC stock assessment reports and relevant appendices and information including background papers/reports on various monitoring programs, CPUE standardizations, model descriptions, information on how management systems work for the crab fisheries in Alaska, previous stock assessment reports, peer-reviewed scientific papers addressing various scientific and technical issues identified in previous studies and stock assessments, and previous replies/comments from the Crab Plan Team and the Scientific and Statistical Committee (SSC).

I read the AIGKC stock assessment report by Siddeek et al. (2018) and the NSRKC stock assessment report by Hamazaki and Zheng (2018) and all other relevant background documents that were sent to me (see the list in Appendix I). I also collected and read the references relevant to the topics covered in the reports and the SoW prior to my trip to the ASFC.

The CIE review workshop was held from June 18 to 21, 2018, in the AFSC in Seattle, WA (see Appendix II for the schedule). The review was attended by scientists, managers and industry representative from various organizations in addition to the three CIE reviewers (see the List of Participant in Appendix III).

Presentations were given during the review to provide the CIE reviewers with background information on AIGKC and NSRKC with regards to the development of fisheries, a fishery-dependent monitoring program, fishery-independent bottom trawl survey programs (both federal and state of Alaska), a 5-Tier assessment and management system, federal-state cooperative management arrangement, stock structure, Gold King Crab and Red King Crab life histories, and stock assessment history and current status (see the list of presentations in Appendix I). I was actively involved in the discussion during the presentation by (1) asking for clarifications; (2) asking questions and commenting on presented materials; (3) making observations of the process; (4) requesting for additional analysis and information; and (5) suggesting alternative approaches and analyses. I had also asked for further clarifications and references during the review and requested for additional information and analyses which were presented during the last day of review (June 21, 2018, see Appendix I for additional information and analyses requested at the CIE review). After all the presentations and discussions had ended, the CIE reviewers met to go through the TORs to ensure we had all necessary information as well as good understanding of the AIGKC and NSRKC stock assessments and management for writing an independent CIE report.

IV. Summary of Findings

My detailed comments on each item of the ToRs are provided under their respective subtitles from the ToRs (see below).

(1) *Statements assessing the strengths and weaknesses of the current Aleutian Islands golden and Norton Sound red king crab stock assessment models with regard to population dynamics, data (fishery-independent surveys, CPUE indices, etc.), likelihood components, and model evaluation.*

<u>Aleutian Islands Golden King Crab</u>

I would like to commend the efforts of the AIGKC assessment team for developing and updating the stock assessment model, evaluating the quality and quantity of input data, considering alternative model configurations and parameterizations, and addressing the uncertainty associated with the input data and model structure.

The AIGKC stock assessment uses a male-specific length-structured model to quantify the dynamics of males. The model-predicted and observed fisheries statistics were linked using observational models with some assumed error structures. In formulating likelihood functions, log-normal distributions were assumed for errors associated with observed fishery catch and then standardized CPUEs; multinomial distributions were assumed for errors associated with observed size composition data. The model parameters were estimated by maximizing the overall likelihood function. This modeling approach is sound and solid with regard to population dynamics, data, likelihood components, and model evaluation, and appears adequate for the assessment and management of the male Golden King Crab stock. This most recent stock assessment suggests that the AIGKC stock is not overfished and overfishing is not occurring. This conclusion seems to be robust regarding various assumptions made on the model configurations and parameterization.

Overall, I consider that the current stock assessment modeling framework provides rather robust assessment results for the AIGKC stock regarding uncertainties in the data and models. The assessment appears to be scientifically sound and adequately addresses management needs.

However, based on our discussions during the CIE review workshop, I believe that the modeling framework can be further improved to reduce the uncertainty associated with the stock assessment by the following research: (1) exploring possibility of using finer time step (e.g., season) in the dynamic models to better capture strong seasonality in fish life history and fishery; (2) incorporating models to quantify female population dynamics because current modeling framework provides no information on its status which is critical in determining the overall stock reproduction potential and dynamics; (3) developing various outputs to evaluate the biological realisms of some key life history parameters (e.g., growth) estimated in modeling; (4) conducting more in-depth and structured model diagnoses to evaluate potential issues in model fitting (e.g., residual distributions of model fitting for standardized CPUEs and size composition data); (5) better quantifying uncertainties in modeling using bootstrap or Bayesian inference; and (6) presenting retrospective errors in a more informative way in stock assessment reports (see Legault 2009).

The assessment model had been changed over the last few stock assessments based on the recommendations from various review panels and the SSC. I support the assessment team's effort to continue improving the stock assessment model.

However, I would suggest that the assessment model structure and configuration be kept relatively stable over time. If a new model or new model configuration needs to be developed in future, it should be run parallel to the old model to identify changes in stock assessment results resulting from changes in model configurations.

Norton Sound Red King Crab

Overall, the current stock assessment modeling framework provide rather robust assessment results for the NSRKC stock regarding uncertainties in data and models. The assessment appears to be scientifically sound and adequately addresses management needs for the NSRKC stock.

However, I believe the stock assessment could be better documented and the focus could be more on the interpretation of biological realism for some key model parameters (e.g., natural mortality and growth). The uncertainty associated with the assessment could also be better quantified. Unlike the AIGKC, no jittering was done to evaluate possible impacts of initial model parameter values on modeling results. Given the issues raised above, I believe the stock assessment can be further improved by taking the following steps: (1) improving documentation and organization of already completed work; (2) conducting more diagnoses to evaluate model fitting; (3) conducting more evaluations of biological realisms of estimated parameters; (4) conducting more structured sensitivity analyses to evaluate potential impacts of different data sets on the stock assessment; (5) better quantifying uncertainties using Bayesian inference or bootstrap method; (6) using statistical methods consistent with the survey design in the estimation of uncertainties for design-based abundance indices; (7) conducting retrospective analysis; and (8) conducting jittering for the NSRKC stock assessment in order to evaluate sensitivity of model convergence.

I suggest that the assessment model structure and configuration be kept relatively stable over time. If a new model needs to be developed in the future, it should run parallel to the old model, so changes in stock assessment results resulting from changes in model configurations can be more easily identified.

(2) Statements assessing the strengths and weaknesses of the current Aleutian Islands golden and Norton Sound red king crab stock projection models, with regard to methodology.

In general, the AIGKC and NSRKC projection models are scientifically sound and adequate to provide management advice. The length-structured models realistically reflect the length-based life history and fishery processes. The incorporation of the assessment and projection models in a single computer program ensures the use of parameters estimated in the assessment model in the projection models in a consistent way. However, as uncertainties may not be fully captured in the current stock assessment models, uncertainties associated with projections may not be fully captured for both AIGKC and NSRKC stocks. I recommend using Bayesian inference to better quantify uncertainties in the stock assessment modeling to improve quantification of uncertainties for the projection models for both AIGKC and NSRKC stocks. It is also important to develop guidelines to determine if the retrospective errors in the assessment modeling need to be corrected before using the projection models to project AIGKC and NSRKC stock dynamics (e.g., Legault 2009). There is also a need to evaluate the performance of the projection models in the assessment conducted in previous years in order to evaluate if the projected stock biomass in the past had been achieved.

(3) A review of the fishery-dependent and -independent data inputs to the stock assessment with regard to quality of information and appropriateness to the assessment for Aleutian Islands golden king crab and Norton Sound red king crab.

The AIGKC assessment team has presented biological and statistical assumptions that had been made regarding to the input data in the AIGKC stock assessment modeling. Some key assumptions associated with the fishery-independent and fishery-dependent input data may not be realistic. For example, constant discard mortality rates over time and space are assumed, which may not be biologically realistic because discard mortality may vary with many factors that change over time and space (e.g., surface temperature and fishing depth). Some key life history process data such as length at maturity and weight-length data were assumed to be unchanging over time which again may not be realistic because of changes in the ecosystems and stock. Potential spatial variability was also not fully and explicitly considered. Time-invariant catchability and selectivity assumed in modeling may also be unrealistic. The current setting of catchability q for the bottom trawl survey assumes a mean of 0.85 with a narrow range defined. This value was derived from experts' opinions, but the process and selection of experts are not well documented. A wide range of values should be given to this q (or freely estimated in the model) in the estimation.

Standardized CPUE data play a key role in the AIGKC assessment. The temporal pattern of the standardized CPUE is very similar to that for the nominal CPUE. Although the standardization follows typical CPUE standardization protocol and selection of variables seems to be reasonable, the effectiveness of the standardization is unknown. There is a need to design a simulation study to evaluate the effectiveness of CPUE standardization. The AIGKC and NSRKC stock assessment team has an excellent understanding of the inadequate quantification of uncertainties defined in the CPUE standardization, and added an additional uncertainty term for the standardized CPUE in modeling. I applaud this approach.

The tagging data used in the stock assessment for the AIGKC have good size range and temporal range (i.e., time at large for tagged AIGKC). Together with size composition data, I think this provides robust and sound estimation of parameters for growth transition matrices. For the NSRKC stock, however, lack of large crabs and assumption on the maximum size assumed in the stock assessment resulted in a long discussion during the CIE review. Different hypotheses for lack of large individuals were discussed including movement of large individuals and size-specific distribution, inadequate spatial-temporal coverage of habitats for large individuals, and/or different life histories from those of the same species in other areas where large individuals have been observed. More extensive spatio-temporal coverage of the monitoring program may be needed to evaluate these hypotheses.

Size at functional maturity for males is not well defined for the NSRKC stock. More extensive sampling and some lab study are needed to understand how the NSRKC functional maturity changes with size.

The importance of size composition data in stock assessment modeling depends on its effective sample sizes used in the stock assessment modeling. I commend the stock assessment teams for exploring different approaches in defining effective sample sizes for size composition data. However, it is necessary to evaluate if current sampling program can yield high quality of size composition data. A well-designed simulation study may be necessary to evaluate possible quality issues related to size composition data estimated from different monitoring programs, which can be used to optimize the monitoring programs (Cao et al. 2014, Li et al. 2015).

Given the development of technology for ageing crustacean species (Kilada et al. 2012), it is possible to explore the possibility of ageing AIGKC and NSRKC. This can greatly improve understanding of their body growth dynamics, leading to improved estimation of growth parameters and spatio-temporal variability in growth and subsequently stock assessment modeling.

The size intervals currently used in the NSRKC stock assessment may be too wide. It may be necessary to explore the use of smaller size intervals in modeling. Given the wide size interval, the use of midpoint value of a size interval in calculating weight may under-estimate weight by size because of experiential weight-length relationship.

More studies and/or more extensive surveys need to be done to understand why the largest individuals currently observed for the NSRKC is much smaller than other red king crab stocks. Male functional maturity at size also needs to be better estimated.

Although no study has been done, the handling mortality is assumed to be 20% for all NSRKC fisheries. This assumption needs to be carefully evaluated with a well deigned field study. Alternatively, some sensitivity analyses should be done to evaluate the robustness of the modeling results regarding this assumption.

Different values of natural mortality were considered and evaluated in the NSRKC stock assessment. High M is assumed for large length classes compared to that for small size classes, which improves the model fitting. However, such an approach is rather subjective. Maybe an approach similar to that used in the AIGKC stock assessment can be used for estimating M for NSRKC. Biological justification may be needed to assume size-specific natural mortality rates.

(4) *Recommendations for alternative approaches to evaluate model convergence and compare*

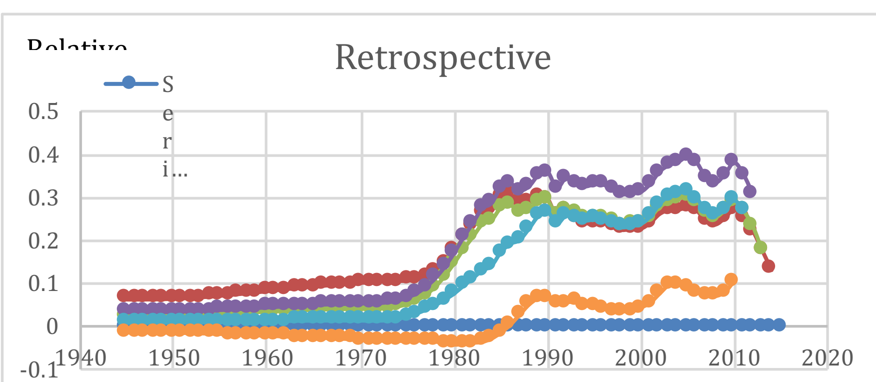
multiple models for Aleutian Islands golden king crab and Norton Sound red king crab.

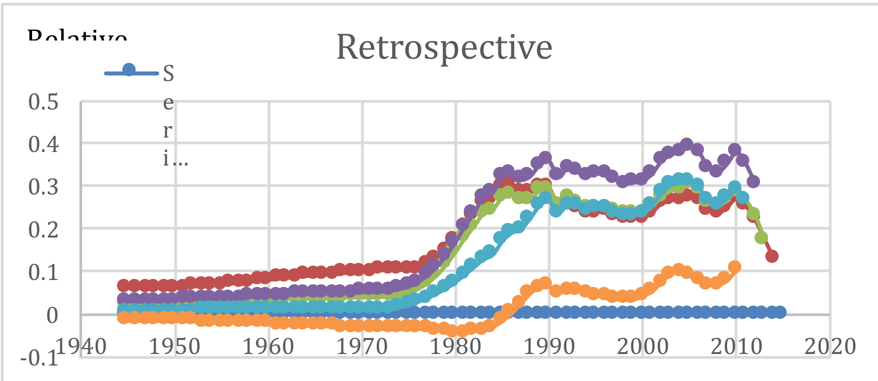
Jittering was done for the AIGKC stock to evaluate if the model converged at a global minimum value and the sensitivity of modeling results regarding the initial guess values of model parameters. The assessment team concludes that the AIGKC can converge well in jittering, indicating the robustness of model estimation regarding the initial guess values and good performance in model convergence. However, jittering has not been done for the NSRKC stock. I suggest that jittering be done for the NSRKC stock to evaluate its stock assessment model convergence.

Both the AIGKC and NSRKC stock assessments considers the base-case model and alternative models which were designed to evaluate sensitivity of the stock assessment models on alternative values/assumptions/hypotheses for life history parameters (e.g., growth, natural mortality), various selectivity patterns, and model configurations/parameterizations. The choice of the base case scenario is reasonable for both the AIGKC and NSRKC stocks. However, I would suggest that a formal guideline/protocol/criteria be developed for the selection of the base case scenario, which can provide more objective guidance for the selection of a base case scenario. The sensitivity analysis is rather well structured for the purpose of evaluating potential impacts of various assumptions/configurations/parameterizations on the stock assessment modeling results. A jackknifing approach was used to evaluate potential impacts of different data sets on stock assessment results.

I suggest that more effort be put towards model diagnosis and residual analysis. Potential temporal trends in residuals for various input data sets should be carefully evaluated for evaluating model fitting.

Retrospective analysis was only conducted and presented for the base case scenario. Retrospective errors may result in large biases in estimates of current stock biomass. The retrospective errors should be carefully evaluated for estimates of stock biomass, fishing mortality, and recruitment. However, retrospective errors presented in the assessment are not only difficult to read, but may also be misleading. I would suggest the NOAA guideline (Legault 2009) to present retrospective errors be followed (see example below).





Mohn's pho value (Mohn 1999) should also be calculated to quantify the retrospective errors.

(5) *Recommendations on how various data sets should be weighted, relative to one another, in the Aleutian Islands golden king crab and Norton Sound red king crab models*

Overall, I believe that the AIGKC and NSRKC stock assessment teams weighted different data sets in the stock assessment adequately.

Effective sample sizes determine the importance of size composition data in model fitting. The assessment team explored and compared different approaches to determine effective sample sizes. I consider their choices of effective sample sizes for size composition data in the AIGKC and NSRKC stock assessments reasonable and sound.

The AIGKC and NSRKC stock assessment teams realized the inadequacy of CPUE CVs in the CPUE standardization in quantifying the uncertainty associated with CPUEs. An additional uncertainty term is incorporated and estimated in the model. This approach adequately addresses potential under-estimation of uncertainty associated with standardized CPUEs in the CPUE standardization.

Each data set was jackknifed in the sensitivity analysis to evaluate impacts of individual data set on stock assessment modeling. I encourage the AIGKC and NSRKC stock assessment teams to continue this analysis in the future.

Robust multinomial likelihood was used in fitting size-composition data to remove any possible outliers (Chen et al. 2000). I commend the AIGKC and NSRKC stock assessment teams for using this approach and would like to encourage them to also use fat-tail likelihood function (e.g., t-distribution with low degree of freedom) for CPUE and/or abundance index data, so as to reduce the impacts of possible outliers (Chen et al. 2000).

(6) *Recommendations on how the reduction in number of vessels and fishing area shrinkage can be addressed in the Aleutian Islands golden king crab model.*

A reduction in the number of vessels and fishing area shrinkage in the AIGKC fishery resulted in changes in fishing fleet dynamics, which changed the catchability and selectivity of the fishery. Various variables, reflecting such a reduction, were included in CPUE standardization (Maunder and Punt 2004) in an attempt to remove factors resulting from changes in fishing fleet dynamics caused by a reduction in vessels and fishing area shrinkage. Although I am not certain of the effectiveness of the CPUE standardization, I consider the model developed for the CPUE standardization appropriate.

A reduction in the number of vessels and fishing area shrinkage may result in some temporal patterns in model fitting, and I would encourage the AIGKC stock assessment teams to carefully evaluate temporal patterns of residuals in relations to this timeline of fishery rationalization. Any systematic temporal pattern regarding the timeline may indicate inadequacy of the current models in the face of the reduction of vessels and fishing area shrinkage.

(7) *Recommendations for integrating fishery-independent survey data into the Aleutian Islands golden king crab assessment.*

Only 3 years of fishery-independent survey data are available for the AIGKC stock. The current approach used to integrate the survey data is adequate. However, this needs to be re-evaluated when additional information becomes available with time.

(8) *Recommendations for quality control of input fishery-dependent and -independent data for Aleutian Islands golden king crab and Norton Sound red king crab.*

I recommend that a computer simulation study (e.g., Cao et al. 2014; Li et al. 2015) be conducted for both the AIGKC and NSRKC fishery-independent survey programs to optimize their design and potentially expand survey areas. Such a simulation study can also provide insights on what factors influence the quality and quantity of the data that can be derived from a survey program.

The standardized CPUEs play an important role in the assessment of AIGKC and NSRKC stocks. Although the stock assessment teams explored some cutting-edge methods and follow typical CPUE standardization protocol, I believe the effectiveness of the CPUE standardization remains unknown. A well-designed simulation study based on past data can provide insights on how CPUE standardization may remove factors other than stock biomass in influencing fishery catchability. Such a study can provide confidence in the quality of standardized CPUEs with regards to indexing the temporal trend of AIGKC and NSRKC stock biomasses in their stock assessments.

Although the AIGKC life history (especially early life history) is still not well understood, based on what we know, it seems that the EAG AIGKC should have relatively independent dynamics from the WAG AIGKC. The lack of good understanding of AIGKC stock structure may influence the design of fishery-dependent and fishery-independent monitoring programs, which may influence the quality of input data collected in these stock programs for stock assessment. More studies need to be done to improve our understanding of the AIGKC stock structure and potential differences in key life history parameters between the EAG and the WAG stock areas. Information derived from such studies may help better capture possible spatial variability in the AIGKC stock, leading to improved data quality and stock assessment.

For the NSRKC stock, survey areas and/or seasons may need to be expanded and some alternative survey gears may need to be explored to cover all types of habitats, which may help improve our understanding of NSRKC size-dependent spatial distribution, leading to improved size coverage of the samples. This may improve the quantification of size-at-maturity.

The NSRKC fishery-independent survey follows a systematic survey design. However, the current variance calculation follows a simple random survey design. Thus, the method used to calculate the variance for the design-based abundance index is inconsistent with the survey design, which needs to be corrected. The following formula should be used to calculate variance for the design-based mean survey abundance index ***v(X-bar)*** for data collected from a survey program following systematic survey design (i.e., the square-root of ***v(X-bar)*** is standard error):

$$\boldsymbol{v}(\bar{\boldsymbol{X}}) = \frac{1-\boldsymbol{f}}{\boldsymbol{n}} \sum_{\boldsymbol{i}=1}^{\boldsymbol{n}-1} \frac{(\boldsymbol{y_i} - \boldsymbol{y_{i+1}})^2}{2(\boldsymbol{n}-1)}$$

$$\boldsymbol{v}(\bar{\boldsymbol{X}}) = \frac{1-\boldsymbol{f}}{\boldsymbol{n}} \sum_{\boldsymbol{i}=1}^{\boldsymbol{n}-1} \frac{(\boldsymbol{y_i} - \boldsymbol{y_{i+1}})^2}{2(\boldsymbol{n}-1)}$$

where ***f*** is finite population correction $f = \frac{n}{N}$ $f = \frac{n}{N}$, ***n*** is the number of sampled stations, ***N*** is the total number of stations available for selection, and $\boldsymbol{y_i}$ is abundance index at station ***i***.

(9) <u>*Recommendations for research that would reduce the uncertainty associated with key parameters assumed or estimated in the assessment models for Aleutian Islands golden king crab and Norton Sound red king crab.*</u>

- Although much effort has been spent to reduce the uncertainties associated with the AIGKC and NSRKC stock assessments, I believe the following research can be done in a relatively short time period (e.g., before the next benchmark stock assessment) to further reduce the uncertainty in the stock assessment:
- Continue to explore spatial delta-GLMM method to standardize CPUE for AIGKC and survey abundance outside the stock assessment modeling in order to remove possible spatiotemporal trends in selectivity/catchability/availability;

- Conduct more structured modeling diagnoses of the relative importance of different likelihood functions for different input data sets and how they should be weighted in model fitting (i.e., quantity versus quality);
- Analyze among-model variations (for all the final models used in different years of stock assessment) to improve understanding of model performance and possible management implications of making changes to the models over the time;
- Evaluate possible inter-correlations between different life history parameters (e.g., growth versus natural mortality) as well as between life history and fishery processes (e.g., growth and natural mortality versus selectivity) to better understand the biological realism of estimated parameters and statistical properties of estimated parameters.

- Use Bayesian inference to better capture the uncertainty in stock assessment modeling for projecting future stock dynamics.

More recommendations can be found in Section V: Conclusion and Recommendations.

(10) *Suggested priorities for future improvements to the stock assessment/projection models for Aleutian Islands golden king crab and Norton Sound red king crab.*

Suggested short-term and long-term research priorities for future improvement to the stock assessment/projection models for Aleutian Islands golden king crab and Norton Sound red king crab can be found in Section V: Conclusion and Recommendations.

V. Conclusions and Recommendations

I commend the efforts the stock assessment teams and participants in the AIGKC and NSRKC CIE review took in providing necessary background information on AIGKC and NSRKC life history, fishery-dependent and fishery-independent monitoring programs, stock assessment history, and management issues. The breadth and depth of expertise and experience of the stock assessment team and participants, amount of effort spent processing and compiling the data, openness of discussion for considering alternative approaches/suggestions, and constructive dialogs with the CIE reviewers throughout the review left me truly impressed. Most materials were also sent to me in a timely manner.

Overall, I believe the AIGKC and NSRKC stock assessments provide robust assessment results, especially with regards to various uncertainties in data and models on temporal trends. The assessment appears to be scientifically sound and adequately addresses management requirements. However, I believe some important questions still need to be addressed and there is still room to further improve on the current stock assessment. The following are my general comments and specific recommendations.

General comments

Life histories (especially early life history) for both AIGKC and NSRKC are still not well understood. The stock structure for AIGKC remains unclear even though the EAG and WAG stocks are considered to have different productivities and are thus separately estimated. More studies are needed to better understand early life history and possible connectivity between the EAG and WAG areas. The NSRKC stock area is still not well defined, which might have introduced uncertainty in the fishery-independent survey. More studies should be done to improve our understanding of stock structure and distribution for AIGKC and NSRKC.

The introduction and discussion about biology/ecology is rather limited in the CIE review and the stock assessment teams may need to improve their knowledge about the AIGKC and NSRKC life histories and biology.

The current stock assessment model is developed, configured and parametrized for the King Crabs. It is a standard statistical length-structured model and easy to understand. Built-in constraints and assumptions are readily defined and easy to see and understand. Seeing if the model fits the data poorly is not difficult with some relatively simple model diagnoses. The sensitivity of modeling results with respect to model assumptions, and quality and quantity of input data can be evaluated relatively easily. In summary, this model is not a black-box type of models, and is a relatively simple and straightforward stock assessment model with its behavior and performance well understood. Yet, it is also quite flexible incorporating data from various sources and of different quality and quantity. The model can also yield all the necessary information for fishery management.

Because the model is in-house-developed, revisions to the model to account for possible changes in the fishery assessment and management are relatively easy. It can also serve as an avenue for training a new generation of stock assessment scientists who can develop their own models based on the needs rather than use canned software to do stock assessments. Thus, this type of models is good for training and education purposes, and can carry forward the institutional memory of how a stock assessment evolves over time.

The CIE was instructed to review the AIGKC and NSRKC stock assessment program (including assessment and projection models, monitoring programs, and data quality and quantity) rather than to evaluate this particular stock assessment and decide if it is acceptable for determining the stock and fishery status and developing management regulations. An important issue that needs to be addressed is how the final model can be determined for the determination of stock status and development of management regulations. I see limited discussion on this topic in the current stock assessment reports for both AIGKC and NSRKC. The following four criteria were used to select the final model for some other fisheries (e.g., Gulf of Alaska pollock stock):

- *"Does the model make full use of the information in the size composition data?*
- *Has the structure of the model been justified statistically?*
- *Is the model sufficiently parsimonious?*
- *Does the model make plausible estimates of model parameters and stock biomass?"*

These measures would be good candidates for the use in the selection of final stock assessment models for the AIGKC and NSRKC. Based on these criteria, the stock assessment teams may need to discuss and recommend a set of well-defined and measurable criteria for determining the final stock assessment model and scenarios for sensitivity analysis.

Both AIGKC and NSRKC have fishery-dependent and fishery-independent monitoring programs. However, I have seen limited effort in evaluating the effectiveness of these monitoring programs with regards to providing abundance and biological information for the stock assessment. Some well-planned and structured simulation studies are needed to evaluate the performance of the monitoring programs. For example, a habitat suitability modeling approach (e.g., Tanaka and Chen 2016) can be used to identify suitable habitats for the AIGKC and NSRKC, based on ocean observatory data (or physical oceanographic model data), to outline potential habitat maps in the AIGKC and NSRKC stock areas and evaluate whether survey sampling stations cover all the effective habitat for AIGKC and NSRKC in different size classes. Such an approach can also be used to project possible changes in the AIGKC and NSRKC spatial distribution if key habitat variables (e.g., temperature) change. The estimated spatial distribution from such a study can help evaluate and improve survey designs.

The current stock assessment framework uses year as a time step. However, given the strong seasonality of fishery and life history, the model with season as its time step may better capture the dynamics of fishery and life history for the AIGKC and NSRKC stocks. Some of the stock assessments conducted for other fisheries with strong seasonality have suggested that using an appropriate time step can greatly improve the quality of the stock assessment (Cao et al. 2016). I would suggest to modify the stock assessment model and computer codes to include a “season” option for the time step and conduct a comparative study to evaluate possible differences in stock assessments using “year” and “season” as time steps.

Outliers may exist in input data used in the AIGKC and NSRKC stock assessment given that the data are derived from different sources and are thus subject to different levels of errors. They may bias parameter estimation in stock assessment (Chen et al. 2000). Robust likelihood functions can reduce the impacts of outliers in size composition and abundance index and/or standardized CPUEs.

A Bayesian approach has not been fully incorporated in the AIGKC and NSRKC stock assessments. Thus, uncertainties in the assessments have not been fully captured in the assessment and stock projection. I would encourage the use of full Bayesian estimator in future stock assessment.

I support the effort to use the spatial delta-GLMM to develop standardized abundance indices from the fishery-dependent and fishery-independent survey data for the AIGKC and NSRKC stocks.

Although both the AIGKC and NSRKC stocks support male-only fisheries, it is also important to understand the dynamics of female populations because they play a key role in regulating stock productivity and recruitment dynamics. The exiting stock assessments provide no information on the status of female populations for AIGKC and NSRKC. I would encourage the stock assessment team to consider females in the stock assessment. For example, the stock assessment model can be made as sex-specific with both sexes included.

Specific recommendations

Although I have provided some detailed comments and recommendations with justifications under each TOR, I would like to summarize all the recommendations. I divide my specific recommendations/comments into two categories: those require actions in a relative short term (e.g., in the next couple of years or before the next benchmark stock assessment) and those that can be done in a long term. I made the following recommendations to address issues raised during the CIE review workshop targeting to reduce uncertainties and improve the quality of AIGKC and NSRKC stock assessments. The specific justifications for these recommendations can be found in Section IV where each TOR is addressed.

Specific recommendations for short-term research

- There is a need for more in-depth and structured diagnosis of relative importance of different likelihood functions for different input data sets and how they should be weighted in model fitting. A careful examination of potential temporal trends in residual distributions may be also needed.

- Multiple model configurations were used over the time, which reflect different assumptions on the fishery dynamics. I recommend analyzing among-model variations (for all the final models used different years) to better understand the structural uncertainty and possible management implications of making changes to the models over the time.

- Projections had been done in each stock assessment. It would be interesting to evaluate if projections made in previous stock assessments are realistic with the new information available in recent stock assessments. Because projection plays a critical role in formulating management advice, it is important to evaluate the performance of the projection done in the past assessment. Such an exercise can also help evaluate the performance of projection models in achieving the management objectives.

- I suggest that the assessment model structure be kept relatively stable over time. If a new model or new model configurations/parametrizations need to be used, it should be run in parallel to the old model to identify changes in stock assessment outcomes resulting from changes in model configurations.

- It is good that retrospective error is not an issue for AIGKC and NSRKC. However, the potential for this stock assessment to have retrospective errors is rather high because of possible temporal changes in natural mortality, fishery selectivity and survey selectivity. I suggest that a retrospective analysis be performed for all of the scenarios (not just for the base-case scenario as is done in the current assessment). It is also important to develop and follow a formal guideline (e.g., Legault 2009) to present retrospective errors and to decide if retrospective errors should be corrected in the determination of stock status and before using projection models to project future male stock biomass dynamics.

- The AIGKC and NSRKC stock assessments currently estimate model parameters using maximum likelihood function and is not a full Bayesian model. Uncertainty estimates may not be reliable (tend to be under-estimated), which limits the full consideration of uncertainty in stock assessment and management. A full Bayesian model may be more desirable and suitable for incorporating uncertainty of different sources (e.g., uncertainty associated with natural mortality).

- A fishery-independent survey is often expected to yield reliable abundance index, which is linearly proportional to the targeted fish stock biomass over time. This assumption is critical for the development and use of design-based abundance index in stock assessment. However, this assumption is likely to be violated because of changes in charted vessels, differences in capacity of the vessels used over time, large areas covered by the survey programs, and limitation of trawlable areas in certain areas. Thus, a design-based abundance index or swept-area stock biomass estimates may not be suitable for the AIGKC and NSRKC. This calls for standardizing survey abundance index over space and time to remove factors influencing survey catchability to develop a model-based abundance index (Helser et al. 2004; Thorson et al. 2015). A general linear model (GLM) and/or general additive model (GAM) are often developed to include variables that are considered to be important in influencing survey catchability (e.g., temperature, bottom type, location, depth, etc.) for developing a standardized survey abundance index. I believe such indices may remove annual variations in catchability, thus improving the quality of input data. However, such an approach does not consider possible autocorrelations over space and time of survey stations, which exist in the survey program. The delta-GLMM models (Thorson et al. 2015) consider the autocorrelations over space and time for a survey and are considered to be better for a traditional GLM and GAM. In studies done for other species (e.g., Cao et al. 2017), the delta-GLMM model derived abundance indices have shown to capture the dynamics of fish populations more effectively. I support continuing to explore the use of spatial delta-GLMM models to develop abundance index for the survey programs. However, some comparative studies may need to be done to evaluate difference and identify possible implications of using the model-based abundance index in the AIGKC and NSRKC stock assessments.

- Jittering should be done for the NSRKC stock assessment in order to evaluate sensitivity of model convergence.

Specific recommendations for long-term research

- Given strong seasonality of fishery and life history, a model with season as its time step may better capture the dynamics of fishery and life history for AIGKC and NSRKC. A comparative study may be needed for evaluating possible differences in stock assessments using "year" and "season" as time steps.

- Given the importance of the survey data in the assessment, I suggest conducting an extensive computer simulation study based on past data to evaluate the effectiveness of the current survey designs in capturing the spatio-temporal dynamics of AIGKC and

NSRKC, and to identify alternative survey designs. I recommend a computer simulation study be conducted to evaluate and optimize the designs for the AIGKC and NSRKC survey programs.

- I suggest conducting habitat suitability modeling to identify suitable habitats for AIGKC and NSRKC in order to outline potential habitat maps and help improve survey design.

- There is a need to evaluate temporal and spatial variability in key life history parameters such as weight-at-length and maturity-at-length. Because of the dynamics of the ecosystem over time and space in the AIGKC and NSRKC stock areas, the spatio-temporal variability may be large and need to be considered in the stock assessment. The mix-effect model developed by Ianelli et al. (2016) for projecting weight-at-length and maturity-at-length data for the population projection is a good way to count for possible factors that may influence the weight-at-length and maturity-at-length data, which may yield better estimates of stock biomass (Ianelli et al. 2016). However, it is important to have a retrospective evaluation of the performance of this model when data become available with time.

- Constant discard mortality rates over time and space are assumed, which may not be biologically realistic. Some key life history process data such as length at maturity and weight-length data were assumed to be unchanged over time. Potential spatial variability was also not fully and explicitly considered. I recommend more studies be developed to improve our understanding of key biological processes and their spatio-temporal variability.

- The survey for the AIGKC should be expanded to cover the WAG area, and more information on small crabs need to be collected, in particular for the WAG area. Given relatively small fishing fleet involved in the AIGKC fishery and huge stock area, industry-involved cooperative research program may be a cost-effective way for future research projects and monitoring programs.

- It is highly likely that outliers may exist in fisheries data, which may introduce biases or large errors in stock assessment because log-normal and multinomial likelihood functions tend to be sensitive to outliers in data. Using robust likelihood functions may be more appropriate because they are not sensitive to outliers yet yield similar results as log-normal and multinomial functions when there is no outlier (Chen et al. 2000). Some simulation studies can be done to evaluate possible impacts of using different likelihood functions in the absence and presence of outliers in various input data sets.

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Aleutian Islands Golden King Crab

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- Appendix G: CPUE standardization Diagnostic

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(2) <u>Additional documents/information received during the review</u>

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- Aleutian Islands golden king crab harvest by statistical area, 2000/01 –2017/18

- Aleutian Islands golden king crab harvest by month, 2000/01 –2017/18

(3) <u>Presentations at the review</u>

<u>Aleutian Islands Golden King Crab</u>

- Overview of Aleutian Islands golden king crab fishery, catch, bycatch, independent surveys
- Biology (molting, growth, natural mortality, and maturity)
- Fishery history and current operation
- Fishery catch, effort, observer sampling procedures and data processing
- Fishery industry collaborative survey procedure and data processing
- CPUE standardization
- Future outlook for observer and fishery CPUE standardization
- Harvest control rules and overfishing definitions
- Stock assessment and projection models
- Current research studies: genetics

<u>Norton Sound Red King Crab</u>

- Overview of fishery, catch, bycatch, surveys
- Biology (molting, growth, natural mortality, and maturity)
- Fishery history and current operation
- Harvest control rules and overfishing definitions
- Fishery catch, effort, observer sampling procedures and data processing
- NMFS and ADF&G surveys and data processing
- CPUE standardization
- Stock assessment and projection models

(4) <u>Additional information and analyses requested at the CIE review</u>

CIE Panel requested homework on the AIGKC assessment

- Homework I: Growth Matrix Plots
- Homework IIA: Observed mean length by relative age, Aleutian Islands golden king crab, EAG17_0. Relative age 0 refers to arbitrarily set initial age for each release size.
- Homework IIB: Observed mean length by relative age, Aleutian Islands golden king crab, WAG17_0. Tagging data from EAG were used. Relative age 0 refers to arbitrarily set initial age for each release size.
- Homework IIC: Predicted mean length by the estimated size transition matrix over six year projection, Aleutian Islands golden king crab, EAG17_0. Relative age 0 refers to arbitrarily set initial age for each release size.
- Homework IID: Predicted mean length by the estimated size transition matrix over six year projection, Aleutian Islands golden king crab, WAG17_0. Relative age 0 refers to arbitrarily set initial age for each release size.
- Homework IIE: Predicted mean length by the estimated size transition matrix superimposed over observed mean length over six year projection, EAG17_0. Relative age 0 refers to arbitrarily set initial age for each release size.
- Homework IIF: Predicted mean length by the estimated size transition matrix superimposed over observed mean length over six year projection, WAG17_0. Relative age 0 refers to arbitrarily set initial age for each release size.

CIE Panel requested homework on the NSRKC assessment

- Table of data CVs for survey and standardized CPUE
- Model run which excludes 2014 survey data point
- Model run without the pre-1994 standardized CPUE
- mean size at age based on projecting “cohort” forward using the growth matrix
- summary of critical deficiencies in the assessment from a global perspective
- list of steps already taken to address issues with the assessment model
- correlation between growth parameters and M estimates from ADMB .cor file

VII-2. Appendix 2: Statement of Work for Dr. Yong Chen

Statement of Work
Alaska Department of Fish and Game
Center for Independent Experts
(CIE) Program External Independent
Peer Review

Aleutian Islands Golden King and Norton Sound
Red King Crab Stock Assessment Review

Background

The National Marine Fisheries Service (NMFS) is mandated by the Magnuson-Stevens Fishery Conservation and Management Act, Endangered Species Act, and Marine Mammal Protection Act to conserve, protect, and manage our nation's marine living resources based upon the best scientific information available (BSIA). NMFS science products, including scientific advice, are often controversial and may require timely scientific peer reviews that are strictly independent of all outside influences. A formal external process for independent expert reviews of the agency's scientific products and programs ensures their credibility. Therefore, external scientific peer reviews have been and continue to be essential to strengthening scientific quality assurance for fishery conservation and management actions.

Scientific peer review is defined as the organized review process where one or more qualified experts review scientific information to ensure quality and credibility. These expert(s) must conduct their peer review impartially, objectively, and without conflicts of interest. Each reviewer must also be independent from the development of the science, without influence from any position that the agency or constituent groups may have. Furthermore, the Office of Management and Budget (OMB), authorized by the Information Quality Act, requires all federal agencies to conduct peer reviews of highly influential and controversial science before dissemination, and that peer reviewers must be deemed qualified based on the OMB Peer Review Bulletin standards[1]. Further information on the Center for Independent Experts (CIE) program may be obtained from www.ciereviews.org.

Scope

The Alaska Fisheries Science Center (AFSC) Resource Ecology and Fishery Management (REFM) Division requests an independent review of the stock assessment/projection models used to conduct the Aleutian Islands golden king crab (AIGKC) and Norton Sound red king crab (NSRKC) stock assessments. Both stocks are managed by the North Pacific Fishery Management Council (NPFMC) under the Fishery Management Plan (FMP) for the Bering Sea and Aleutian Islands King and Tanner Crabs, which was established in accordance with the Magnuson-Stevens Fishery Conservation and Management Act. This FMP establishes a cooperative State/Federal

[1] http://www.cio.noaa.gov/services_programs/pdfs/OMB_Peer_Review_Bulletin_m05-03.pdf

management regime that defers management of ten crab stocks to the State of Alaska with Federal oversight. Under this cooperative regime, researchers with the Alaska Department of Fish and Game (ADFG) are responsible for preparing draft stock assessments for the AIGKC and NSRKC stocks and presenting them to the NPFMC's Crab Plan Team (CPT) and the Science and Statistical Committee (SSC) for review. The assessments for both stocks utilize size-based, integrated assessment models that have been under continuous development both prior to, and following, approval for use by the NPFMC. The NSRKC stock assessment model was approved before the current FMP was implemented in 2008, whereas the AIGKC stock assessment model was approved in 2017.

AIGKC is the only stock in the FMP that relies exclusively on fishery-dependent data for its size-structured assessment model. In the absence of annual fishery-independent trawl or pot surveys, the model counts on fishery catch, effort, size composition, and tagging information to assess the stock in two adjacent management areas (east of 174^o W. longitude [the Eastern Aleutian Islands golden king crab fishery (EAG)] and west of 174^o W. longitude [the Western Aleutian Islands golden king crab fishery(WAG)]). Standardized observer and fishery catch-per-unit-effort (CPUE) indices and independently-estimated size-specific probabilities of maturity play an important role in the model's estimation of abundance and mature male biomass (MMB). The CPT and SSC accepted the model in 2016 and recommended using it, together with a harvest control rule based on "Tier 3" criteria, to set the overfishing level (OFL) and allowable biological catch (ABC) for the 2017/18 fishing season. Thus, the assessment level was upgraded from "Tier 5" (which uses mean catch over a specified time period to determine the OFL, rather than an assessment model) to "Tier 3" (which uses a size-structured model to determine OFL based on $F_{35\%}$ and $B_{35\%}$ proxies for F_{MSY} and B_{MSY}). The model was rather controversial throughout its initial development, and it continues to evolve. Although a new fishery-independent pot survey data set is limited to three years (2015-2017), and is only from the EAG area, it is planned to be incorporated into the model as separate abundance indices. A scientific peer review that is strictly independent of all outside influences will enhance the credibility of the model and contribute to further refinement of the model. The reviewers will be asked to address issues related to the use of fishery dependent and independent CPUE as true abundance indices and reduction in number of vessels and area since crab rationalization in 2005, and recommends way to improve the model to address those issues.

The NSRKC assessment model differs from other assessment models used for stocks under the FMP in terms of the timing of fisheries and life-history events. Fisheries occur in winter (Feb – April) near the coastal area of Norton Sound and in the summer (July – September) further offshore where about 80% of harvests occur. The fishery is currently managed using "Tier 4" considerations (the B_{MSY} proxy is based on an average mature male biomass over some time period while the proxy for F_{MSY} is based on natural mortality rates) and the OFL is calculated as retained catch for both winter and summer fisheries combined. For this stock, molting occur in late September, as opposed to other red king crab stocks where molting occurs in the spring. An important, but problematic, feature of the assessment model for NSRKC is the estimation of size dependent mortality; the model estimates that natural mortality of large (> 123mm CL) mature crab is about 3 times higher than for crabs in other length groups. This has been used primarily to improve model fit (i.e., the model would otherwise overestimate the proportion of large crab), but is not well-supported by what is known of the stock. Researchers have examined alternative model scenarios such as: 1) large crabs moving out of the area, 2) higher natural mortality across all crabs, and 3) faster or arrested molting and growth. However, none of these alternative model scenarios have produced better or more reasonable results than the current model with size-dependent natural mortality. Reviewers will be asked to address this unique assumption and suggest further alternative scenarios.

The individual review reports are to be formatted with content requirements as specified in **Annex 1**. The Terms of Reference (ToRs) of this peer review are attached in **Annex 2**. The tentative agenda of the panel review meeting is attached in **Annex 3**.

Requirements

The selected three (3) 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 Statement of Work (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, and the Automatic Differentiation (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, and harvest strategy development is desirable.

Tasks for Reviewers

Pre-review Background Documents: Two weeks before the peer review, the NMFS Project Contact will send (by electronic mail or make available at an FTP site) to the CIE reviewers the necessary background information and reports for the peer review. CIE reviewers are responsible only for the pre-review documents that are delivered to the reviewer in accordance to the SoW scheduled deadlines specified herein. The CIE reviewers shall read all documents in preparation for this peer review.

A. General

A.1 Stram, D. et al. 2017. Introduction chapter. In: *2017 Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries in the Bering Sea and Aleutian Islands. North Pacific Fisheries Management Council, Anchorage, AK.* Report compiled by the CPT. https://www.npfmc.org/fishery-management-plan-team/bsai-crab-plan-team/

[Review the "Stock Status Definitions" and "Status Determination Criteria" for background information on the NPFMC's status criteria and approach to OFL determination for crab stocks.]

B. Norton Sound red king crab specific

B.1 Hamazaki and Zheng. 2017. Norton Sound red king crab assessment chapter. In: 2017 Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries in the Bering Sea and Aleutian Islands. North Pacific

Fisheries Management Council, Anchorage, AK. Report compiled by the CPT. https://www.npfmc.org/fishery-management-plan-team/bsai-crab-plan-team/

C. Aleutian Islands golden king crab specific

C.1 Siddeek et al. 2017. Aleutian Islands golden king crab assessment chapter. In: 2017 Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries in the Bering Sea and Aleutian Islands. North Pacific Fisheries Management Council, Anchorage, AK. Report compiled by the CPT. *https://www.npfmc.org/fishery-management-plan-team/bsai-crab-plan-team/*

C.2 Siddeek et al. 2017. Aleutian Islands golden king crab model discussions and scenarios for May 2018 Assessment. Draft report for the September 2017 Crab Plan Team meeting. granicus.com/npfmc/meetings/2017/9/964_A_Crab_Plan_Team_17-09-19_Meeting_Agenda.pdf

C.3 Siddeek et al. 2017. Effect of data weighting on the mature male biomass estimate for Alaskan golden king crab. CAPAM Data weighting Workshop, San Diego, California. Fisheries Research, 192: 103-113.

C.4 Siddeek et al. 2016. Standardizing CPUE from the Aleutian Islands golden king crab observer data. In: T.J. Quinn II, J.L. Armstrong, M.R. Baker, J. Heifetz, and D. Witherell (eds.), Assessing and Managing Data-Limited Fish Stocks. Alaska Sea Grant, University of Alaska Fairbanks, Alaska, USA, pp. 97-116.

C.5 Siddeek et al. 2016. Estimation of size–transition matrices with and without molt probability for Alaska golden king crab using tag–recapture data. Fisheries Research. 180:161-168.

C.6 May 2017 CPT minutes; June 2017 SSC minutes; and September 2017 CPT minutes (minutes will be submitted).

C.7 Siddeek et al. 2013. Standardization of CPUE from Aleutian Islands Golden King Crab Fishery Observer Data. Presented at the September 2013 CPT meeting (document will be submitted)

Panel Review Meeting: Each CIE reviewer shall conduct the independent peer review in accordance with this SoW and ToRs, and shall not serve in any other role unless specified herein. Each CIE 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 ToRs as specified herein. The NMFS Project Contact is responsible for any facility arrangements (e.g., conference room for panel review meetings or teleconference arrangements). The meeting will consist of presentations by ADFG stock assessment authors and other scientists to facilitate the review, to provide any additional information required by the reviewers, and to answer any questions from reviewers.

Contract Deliverables - Independent CIE Peer Review Reports: After the review meeting, reviewers shall conduct an independent peer review in accordance with the requirements specified in this SOW, OMB guidelines, and ToRs, in adherence with the required formatting and content guidelines. Reviewers are not required to reach a consensus.

Foreign National Security Clearance
When reviewers participate during a panel review meeting at a government facility, the NMFS Project Contact is responsible for obtaining the Foreign National Security Clearance approval for reviewers who are non-US citizens. For this reason, the reviewers shall provide 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/ and http://deemedexports.noaa.gov/compliance_access_control_procedures/noaa-foreign-national-registration- system.html. The contractor is required to use all appropriate methods to safeguard Personally Identifiable Information (PII).

Place of Performance
The place of performance shall be at the contractor's facilities, and Seattle, Washington.

Period of Performance
The period of performance shall be from the time of award through August 2018. Each reviewer's duties shall not exceed 14 days to complete all required tasks.

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

Within two weeks of award	CIE selects and confirms reviewers. Reviewer contact information is sent to the NMFS Project Contact
Approximately 2 weeks prior to the review	NMFS Project Contact sends the pre-review documents to the CIE reviewers
June 2018	Each reviewer participates and conduct an independent peer review during the panel review meeting
Approximately 3 weeks later	CIE receives draft reports
Within 2 weeks of receiving draft reports	CIE submits final reports to the Government

Applicable Performance Standards
The acceptance of the contract deliverables shall be based on three performance standards: (1) The reports shall be completed in accordance with the required formatting and content (2)

The reports shall address each ToR as specified (3) The reports shall be delivered as specified in the schedule of milestones and deliverables.

Travel
All travel expenses shall be reimbursable in accordance with Federal Travel Regulations (http://www.gsa.gov/portal/content/104790). International travel is authorized for this contract. Travel is not to exceed $13,000.

Restricted or Limited Use of Data
The contractors may be required to sign and adhere to a non-disclosure agreement.

NMFS Project Contact:
William Stockhausen
Alaska Fisheries Science Center
Email: william.stockhausen@noaa.gov
Phone: 206-526-4241

Annex 1: Peer Review Report Requirements

1. The report must be prefaced with an Executive Summary providing a concise summary of the findings and recommendations, and specify whether or not the science reviewed is the best scientific information available.

2. The report must contain a background section, description of the individual reviewers' roles 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.

   a. Reviewers must describe in their own words the review activities completed during the panel review meeting, including a brief summary of findings, of the science, conclusions, and recommendations.

   b. Reviewers should discuss their independent views on each TOR even if these were consistent with those of other panelists, but especially where there were divergent views.

   c. Reviewers should elaborate on any points raised in the summary report that they believe might require further clarification.

   d. Reviewers shall provide a critique of the NMFS review process, including suggestions for improvements of both process and products.

   e. The report shall be a stand-alone document for others to understand the weaknesses and strengths of the science reviewed, regardless of whether or not they read the summary report. The report shall represent the peer review of each TOR, and shall not simply repeat the contents of the summary report.

3. The report shall include the following appendices:

   Appendix 1: Bibliography of materials provided for review
   Appendix 2: A copy of this Statement of Work
   Appendix 3: Panel membership or other pertinent information from the panel review meeting.

Annex 2: Terms of Reference for the Peer Review

Aleutian Islands golden king and Norton Sound red king crab Stock Assessment Review

The report generated by the consultant should include:

(1) Statements assessing the strengths and weaknesses of the current Aleutian Islands golden and Norton Sound red king crab stock *assessment* models with regard to population dynamics, data (fishery-independent surveys, CPUE indices, etc.), likelihood components, and model evaluation.

(2) Statements assessing the strengths and weaknesses of the current Aleutian Islands golden and Norton Sound red king crab stock *projection* models, with regard to methodology.

(3) A review of the fishery-dependent and -independent data inputs to the stock assessment with regard to quality of information and appropriateness to the assessment for Aleutian Islands golden king crab and Norton Sound red king crab.

(4) Recommendations for alternative approaches to evaluate model convergence and compare multiple models for Aleutian Islands golden king crab and Norton Sound red king crab.

(5) Recommendations on how various data sets should be weighted, relative to one another, in the Aleutian Islands golden king crab and Norton Sound red king crab models

(6) Recommendations on how the reduction in number of vessels and fishing area shrinkage can be addressed in the Aleutian Islands golden king crab model.

(7) Recommendations for integrating fishery-independent survey data into the Aleutian Islands golden king crab assessment.

(8) Recommendations for quality control of input fishery-dependent and -independent data for Aleutian Islands golden king crab and Norton Sound red king crab.

(9) Recommendations for research that would reduce the uncertainty associated with key parameters assumed or estimated in the assessment models for Aleutian Islands golden king crab and Norton Sound red king crab.

(10) Suggested priorities for future improvements to the stock assessment/projection models for Aleutian Islands golden king crab and Norton Sound red king crab.

Annex 3: Tentative Agenda

Aleutian Islands Golden King and Norton Sound Red King Crab Stock Assessment Review

Venue:
Alaska Fisheries Science Center
7600 Sand Point Way NE
Seattle, WA USA 98115

Dates:
June 18-21, 2018

Point of Contact:
William Stockhausen
Alaska Fisheries Science Center
Email: william.stockhausen@noaa.gov
Phone: 206-526-4241

Monday: June 18 2018

8:00 -8:30am

a. Welcome and introduction (Chair)
b. Role of chair and reviewers, terms of reference (Chair)
c. Review of agenda items (Chair)

Review of Aleutian Islands golden king crab (AIGKC)

8:30–9:40 am

a. Overview of Aleutian Islands golden king crab fishery, catch, bycatch, independent surveys
b. Biology (molting, growth, natural mortality, and maturity)
c. Fishery history and current operation

9:40-9:50 am: Tea Break

9:50-11:30 pm

a. Fishery catch, effort, observer sampling procedures and data processing
b. Fishery industry collaborative survey procedure and data processing

11:30 -1:00 pm: Lunch Break

1:00-2:45 pm

a. CPUE standardization
b. Future outlook for observer and fishery CPUE standardization

2:45-3:25 pm

a. Harvest control rules and overfishing definitions

3:30 pm: Adjourned

Tuesday: June 19, 2018

8:00-10:00 am

a. Stock assessment and projection models

10:00-10:10 pm: Tea Break

10:10-12:00 pm

a. Stock assessment and projection models continued
b. Current research studies: genetics

12:00-1:30pm: Lunch break

Review of Norton Sound Red King Crab (NSRKC)

1:30-3:25 pm

a. Overview of fishery, catch, bycatch, surveys
b. Biology (molting, growth, natural mortality, and maturity)
c. Fishery history and current operation
d. Harvest control rules and overfishing definitions

3:30 pm: Adjourned

Wednesday: June 20, 2018

8:00-9:45 am

a. Fishery catch, effort, observer sampling procedures and data processing
b. NMFS and ADF&G surveys and data processing

9:45-10:00 am: Tea Break

10:00-11:30 pm

a. CPUE standardization
b. Stock assessment and projection models

11:30-1:00pm: Lunch Break

1:00-2:30 pm

a. Stock assessment and projection models continued

2:30-2:40 pm: Tea Break

2:40-3:25 pm

a. Stock assessment and projection models continued

3:30 pm: Adjourned

Thursday: June 21, 2018

8:00am–11:30pm

a. NSRKC: Reviewer discussion with stock assessment authors. Review of requested model runs, if required
b. AIGKC: Reviewer discussion with stock assessment authors. Review of requested model runs, if required

11:30 am-1:00 pm: Lunch break

1:00-3:25 pm

a. Independent discussion among reviewers on findings, recommendations, reports, etc.

3:30 pm: Adjourned

NOTE: The review will start at 8:00 am each day and will conclude at 3:30 pm on Thursday, June 21. All other specific times are tentative and

VII-3. Appendix III: List of Participants

	First	Last	E-mail	Organization
1	William	Stockhausen	william.stockhausen@noaa.gov	AFSC
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13	Yong	Chen	ychen@maine.edu	CIE

AFSC = Alaska Fisheries Science Center, ADFG = Alaska Department of Fish and Game, NPRB = North Pacific Research Board, NPFMC = North Pacific Fishery Management Council