Center for Independent Experts (CIE) Independent Peer Review Report

Virtual Panel Review of the Stock Assessments
for Bristol Bay Red King Crab and Eastern Bering Sea Snow Crab
(March 22-26, 2021)

Prepared by

Dr. Yong Chen

June 2021

Contents

SECTION **Page**

I. Executive Summary……………………………………………………………...3

II. Background……………………………………………………………………5

III. Description of the Individual Reviewer's Role in the Review Activities……7

IV. Summary of Findings…………………………………………………………...8

V. Conclusions and Recommendations…………………………………………….17

VI. References…………………………………………………………………...19

VII. Appendices……………………………………………………………………….20

VII-1. Bibliography of Materials Provided for Review...…………..……......20

VII-2. List of Participants ……………………………………………………….22

VII-3. Performance Work Statement………...……………………………..23

I. Executive Summary

The Virtual CIE Review of the Stock Assessments for Bristol Bay Red King Crab and Eastern Bering Sea Snow Crab was held online from March 22-26, 2021. The Review aimed to evaluate the assumptions, fits and performance of the Bristol Bay red king crab stock assessment and the Eastern Bering Sea snow crab stock assessment using the General Model for Assessing Crustacean Stocks (GMACS); discuss the use of data derived from selectivity experiments within each assessment; and assess and recommend approaches to reduce retrospective patterns for each assessment. The Review also aimed to identify potential data gaps for both assessments and make recommendations to fill these gaps.

National Marine Fisheries Service (NMFS) Alaska Fisheries Science Center (AFSC) provided all the necessary logistics, technical support, stock assessment documentation, background information, and online access to the model description, computer codes and stock assessment outputs prior to and during the Review. Dr. Martin Dorn of NMFS AFSC chaired the Review. Dr. Cody Szuwaski of AFSC presented the Bering Sea snow crab stock assessment, and Dr. Jie Zheng of Alaska Department of Fish and Game presented the Bristol Bay red king crab stock assessment. The relevant fisheries-dependent and fisheries-independent monitoring programs were also presented by various presenters from NMFS AFSC and Alaska Department of Fish and Game. Dr. Szuwaski, Dr. Zheng and other members were open to questions and suggestions in the Review and provided additional analyses and information upon request. The whole process was open and constructive, and all materials were sent to me in a timely manner. As a CIE reviewer, I am charged to evaluate the 2021 Stock Assessments for Bristol Bay Red King Crab and Eastern Bering Sea Snow Crab stocks with respect to a set of pre-defined ToRs.

Overall, I was impressed by the careful consideration and justification for stock assessment model configuration; state-of-the-art modeling approach; breadth and depth of expertise; degree of effort spent to compile all the data and parameterize the models; considerations of plausible model scenarios; the openness of discussion on potential issues; the willingness to consider alternative approaches and suggestions; and the constructive dialogues between the reviewers, stock assessment scientists, and other presenters and participants during the Review. Based on the materials I received, the information presented, and our discussion during the Review, I believe that the Bristol Bay red king crab and the Bering Sea snow crab stock assessments are scientifically sound. The stock assessment teams adequately compiled available fisheries-independent data, fisheries-dependent monitoring data, and biological data for these two stock assessments. Several alternative model configurations and parameterizations were considered for evaluating impacts of uncertainty associated with data quality and quantity on the stock assessments. The adoption of GMACS in both stock assessments improves the transparency and consistency of assessment processes. The use of the Bering Sea Fisheries Research Foundation (BSFRF) data improves our understanding of NMFS survey catchabilities and stock assessments.

However, large positive retrospective errors existed in both stock assessments, raising concerns about the appropriateness of using the assessment results to determine stock and fisheries statuses, and providing catch advice for the management of the Bristol Bay red king crab and the Eastern Bering Sea snow crab. Although it is difficult to pinpoint the sources of retrospective patterns, unaccounted temporal trends in key life history parameters (e.g., natural mortality and growth) and the mismatch between the temporal trends in assumed and actual survey catchabilities may be the main two causes of strong retrospective patterns. Future studies need to explore alternative scenarios of temporal trends in key life history parameters, such as natural mortality growth, and evaluate temporal patterns of survey catchability to analyze and reduce relevant retrospective patterns.

I recommend that the stock assessment teams continue developing the GMACS to (1) improve its model diagnostics, which include the plots of estimated sizes at relative ages, and plots of input effective sample size and implied (calculated) effective sample sizes for each size composition data set; and (2) facilitate jittering (for the Bering Sea snow crab) and easy retrospective analysis. I would like to encourage more research/experiments to address data/knowledge gaps in our understanding of the spatio-temporal changes in stock distributions, survey catchability and selectivity, and key life history parameters (e.g., natural mortality, growth, maturation, diseases and possible consequences). Given the observed changes in the North Pacific ecosystem, it is also important to identify and develop indicators to quantify the ecosystem dynamics and incorporate them in the future stock assessment. I provide a list of research recommendations (see Section V for details) for the stock assessment teams to consider in addressing the concerns/comments raised during the Review.

II. Background

The snow crab, *Chionoecetes opilio*, is widely distributed in the Bering Sea over shelves shallower than 200 meters, with smaller crabs inhabiting inshore northern regions and mature individuals inhabiting deeper waters. The Eastern Bering Sea snow crab stock within U.S. waters is managed as a unit stock, although its distribution may extend into Russian waters. The Eastern Bering Sea snow crab is a male-only fishery with a minimum legal size of 78 mm. However, the snow crab market generally only accepts crab greater than 101 mm, and only males can reach this size (Szuwalski 2020).

Retained catches were low in the early 1980s, but increased greatly in the 1990s. In the late 1990s, the retailed catch dropped to a 1980s level, and the stock was considered overfished by 1999. Retained catches have increased slowly since 1999 as the stock is rebuilt. Discard mortality is the next largest source of mortality, with temporal patterns similar to those of retained catch. The most recent estimated discard mortality was 33% of retained catch.

The input data for the 2020 Eastern Bering Sea snow crab stock assessment include retained male crab pot fishery size frequency by shell condition (1982-2019), discarded pot fishery size frequency by sex (1992-2019), trawl fishery bycatch size frequency by sex (1991-2019), survey size frequencies by sex and shell condition (1982-2019), retained catch (1982-2019), discard catch from crab pot fishery (1992-2019), trawl bycatch (1993-2019), and survey biomass estimates (1982-2019). The information on the key life history parameters, such as natural mortality and growth, were derived from previous studies (Szuwalski 2020).

Two size-structured stock assessment models were used in the 2020 Eastern Bering Sea snow crab stock assessment: the Status quo model and the General Model for Assessing Crustacean Stocks (GMACS). Both models are integrated size-structured models following Fournier and Archibald (1982) methods. The model was implemented using the AD Model Builder, which can estimate a large number of parameters in a non-linear model. For both models, the snow crab population dynamics model tracked the crab abundance by length, sex, shell condition, maturity state, and year. A terminal molt was modeled, in which crabs move from an immature to a mature state with no further molting. The mid-points of the size bins tracked in the model ranged from 27.5 to 132.5mm carapace width, with an interval of 5 mm. The estimated parameters include those driving the population dynamics: recruitment, growth, natural mortality (historically with an informative prior), fishing mortality, selectivity for the fishery and surveys, catchability, and maturity. Weight at length, discard mortality, bycatch mortality, and parameters associated with variance in growth and proportion of recruitment allocated to size bin were either estimated outside of the model, or specified. The time blocks with different life history and fishery processes were also defined by the stock assessment scientist. The key differences in the Status quo model and the GMACS are identified in Table 1 (Szuwalski 2020).

Process	Status quo	GMACS
Natural mortality	Estimate mature M for both sexes, one immature M, same prior for all (N(0.27,0.54); 3 parameters)	**Estimate M for immature and mature for both sexes, same prior for all (N(0.27,0.54); 4 parameters)**
Growth	Kinked growth for females	**Linear growth**
Survey selectivity	Embedded in BSFRF	same
Survey q	Estimated for females and males, no prior	same
Molting	Smooth probability of terminal molt; all immature crab molt	same
BSFRF availability	Free parameters males; logistic for females	**Free parameters for males and females**
Recruitment	Estimated devs by sex	One estimated recruit time series + estimated time series for sex ratio

Table 1: key differences between the Status quo model and GMACS configured for the Eastern Bering Sea snow crab stock assessment (copied from Szuwalski 2020).

Four models were considered in the 2020 Bering Sea snow crab stock assessment:

- 19.1: Status quo fit to 2018/2019 data with updated bycatch
- 20.1: 19.1 fit to 2019/2020 data
- 20.2: GMACS fit to the same data as 20.1
- 20.3: 20.2 + increased weight on 2010 BSFRF data to 'force' catchability

The stock assessment scientist preferred Model 20.2, citing a better model fit for the data, credibility of estimated life history processes (e.g., growth and natural mortality), and the strength of impacts of model assumptions on the outcomes of the assessment (e.g., assumptions about BSFRF availability and growth functional forms). The Crab Plan Team (CPT) elected to increase the buffer to 50% for this year, given assessment uncertainties and the impacts of a missing terminal year of survey data.

The red king crab (RKC), *Paralithodes camtschaticus*, is distributed along wide depths of the North Pacific Ocean, from British Columbia, Canada to the Bering Sea, and south to Hokkaido, Japan. In the state of Alaska, the species is divided into three stocks: Bristol Bay, Aleutian Island and Bering Sea (ADFG 2012). This stock assessment focuses on the Bristol Bay RKC, which is considered a unit stock in the waters north of Cape Sarichef (54°36' N lat.), east of 168°00' W longitude, and south of the latitude of Cape Newenham (58°39' N lat.).

The Bristol Bay RKC supports one of the most valuable fisheries in the U.S. The Japanese fishing fleet mainly used tanglenets to fish the Bristol Bay RKC from the early 1930s to 1940, and then from 1953 to 1974. The Russian fleet used tanglenets to fish the Bristol Bay RKC from 1959 to 1971. The US trawlers started fishing the Bristol Bay RKC in 1947, but shifted to a pot fishery in the late 1960s, which peaked at 58,943 mt in landings in 1980. The landings declined dramatically in the early 1980s and has since remained low. After the stock collapse in the early 1980s, the RKC fishery was only allowed during a short period in the fall (usually lasting about a week) each year, with the catch quota determined based on the stock assessment conducted the previous summer (Zheng and Kruse 2002). Beginning with the 2005/2006 season, new regulations associated with fishery rationalization resulted in an increase in the duration of the fishing season (October 15 to January 15). With the implementation of crab rationalization, historical guideline harvest levels (GHL) were changed to a total allowable catch (TAC). Before fishery rationalization, the implementation errors were quite high for several years, with total actual catch from 1980 to 2007 decreasing by 6% from the sum of GHL/TAC over that period.

The Bristol Bay RKC stock is managed by the State of Alaska through a federal king and Tanner crab fisheries management plan (FMP). The State of Alaska is responsible for determining and establishing the GHL/TAC under the framework defined in the FMP. Two major management objectives include maintaining a healthy stock to ensure reproductive viability, and providing for sustained levels of harvest over the long term (ADFG 2012). In attempting to meet these objectives, the GHL/TAC is coupled with size-sex-season restrictions. Only males ≥ 135-mm carapace length may be harvested, and no fishing is allowed during molting and mating periods (ADFG 2012). Harvest rate strategy, used to determine the TAC, has changed over the years (Schmidt and Pengilly 1990; Pengilly and Schmidt 1995; Zheng et al. 1996, 1997a, 1997b). The current harvest strategy was developed in 2003 by adding a mature harvest rate of 12.5% when the ESB is between 34.75 and 55.0 million lbs, and the harvest strategy was further reformed in 2012 with the elimination of the minimum GHL threshold in 2012. The data used in the 2020 Bristol Bay RKC are described in Figure 1.

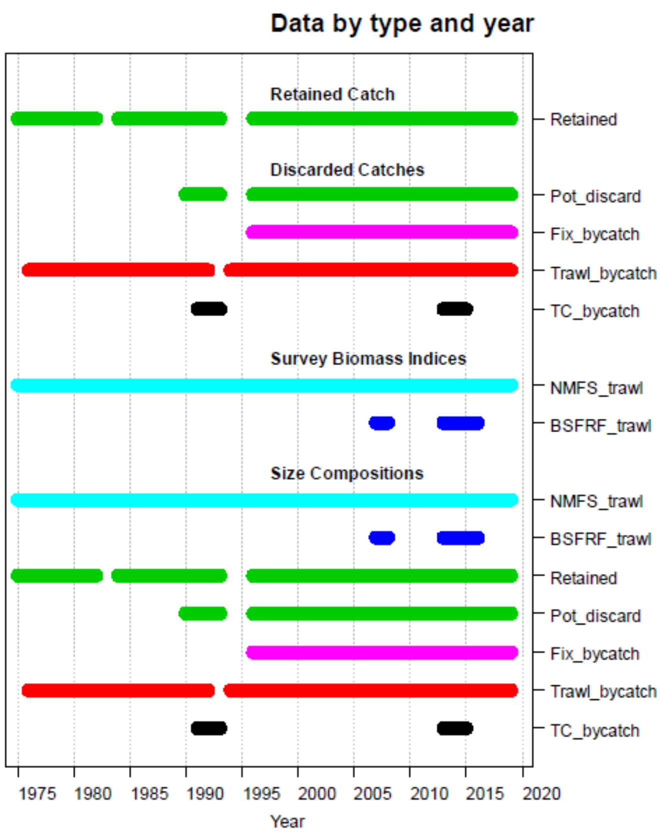

Figure 1. Data types and time period used in the 2020 Bristol Bay red king crab stock assessment (copied from Figure 2; Zheng and Siddeek 2020).

Seven models were developed and compared in this assessment:

- 19.0a: the model 19.0 in September 2019 but using mean recruitment sex ratio during the reference period to estimate B35%. This model replaces the previous GMACS version that had the sex ratio only in the terminal year to estimate B35%.
- 19.0b: the same as model 19.0a except for fixing the recruitment in the terminal year to be the mean recruitment during the seven years prior to the terminal year.
- 19.3: the same as model 19.0a except for a constant M being estimated for males during 1980-1984, a constant M of 0.18 for males during the other years, and an estimated constant multiplier being used to multiply male M for female M.
- 19.3a: the same as model 19.3 except for fixing the recruitment in the terminal year to be the mean recruitment during the seven years prior to the terminal year.
- 19.3b: the same as model 19.3 except for doubling the CV of the prior for trawl survey catchability.
- 19.3l: the same as model 19.3 except for adding a low trawl survey biomass for 2020 (at 25 percentile).
- 19.3h: the same as model 19.3 except for adding a high trawl survey biomass for 2020 (at 75 percentile).

All seven models fit the catch and bycatch biomasses very well. Models 19.0b and 19.3a were models 19.0a and 19.3, respectively, with a reasonable terminal year recruitment estimate for potential forward projections. Model 19.3b was a sensitivity run for a trawl survey catchability prior, and models 19.3l and 19.3h were used for examining uncertainty without the trawl survey in 2020. The CPT preferred Model 19.3, which fit the data better with one less parameter than model 19.0a, thus 19.3 was suggested as the preferred model for overfishing definition determination. The CPT accepted the GMACS implementation for determining stock and fishery status and catch advice.

The Review was conducted online via webinar from 4:00 pm to 8:00 pm, March 22-25, 2020 because of Covid-19 concerns and the different time zones of the CIE reviewers and stock assessment scientists (a total of four different time zones span Seattle, Maine, Chile, and Perth Australia). All sessions were open to the public. Dr. Martin Dorn of AFSC chaired the meeting. The process ran smoothly, with little technical difficulty. Dr. Cody Szuwalski of AFSC (the lead assessment scientist for the Bering Sea snow crab) and Dr. Jie Zheng of the Alaska Department of Fish and Game (the lead assessment scientist for the Bristol Bay RKC) presented the stock assessments during the Review (see the list of presentations in Appendix I). The Review Panel made several requests for clarifying additional information and further analysis during the Review, which were provided to further improve our understanding of the stock assessment results, model performance and diagnostics, and possible sources of uncertainty and retrospective patterns. The Review was also attended by the NOAA NMFS Fisheries scientists and other stakeholders (see the List of Participants in Appendix II). All the participants were given opportunities to be engaged in the discussion (see the Review schedule in Appendix III). Dr. Martin Dorn chaired the Review Panel, which consisted of him and three CIE reviewers.

I was provided with all necessary documentation, access to data and computer codes, simulation outputs, background information and logistics support. Documentation for the meeting was provided via Google Share Drive https://drive.google.com/drive/u/0/folders/1YxkoQ-J-3E09MlSAnVdbEu-xtl1PffaA and the NEFSC Data Portal https://archive.fisheries.noaa.gov/afsc/refm/stocks/plan_team/2021_crab_cie/ .

All relevant computer simulation source code and model inputs and outputs for the Eastern Bering Sea snow crab were available via a GitHub site https://github.com/szuwalski/CIE_2020 developed by Dr. Cody Szuwalski. The stock assessment teams were very responsive and open to suggestions, and provided additional information and analysis upon request. The whole review process was open and constructive.

As a CIE reviewer, I am charged to evaluate the 2020 Bristol Bay RKC and Eastern Bering Sea snow crab stock assessments with respect to the following pre-defined Terms of References:

1. Evaluate the assumptions, fits, and performance of the Bristol Bay red king crab assessment using GMACS
2. Evaluate the assumptions, fit, and performance of the Bering Sea snow crab assessment using GMACS
3. Comment on the use of data derived from selectivity experiments within each assessment.
4. Comment on retrospective patterns for each assessment; recommend approaches to reduce any retrospective patterns
5. Identify potential data gaps for both species and assessments; recommend methods to fill these gaps.

This report includes an executive summary (Section I), a background introduction (Section II), a description of my role in the review activities (Section III), my comments on each item listed in the ToRs (Section IV), a summary of my conclusion and recommendations (Section V) and references (Section VI). The final part of this report (Section VII) includes a collection of appendices including the Performance Work Statement.

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 Bristol Bay Red King Crab and Eastern Bering Sea Snow Crab stock assessments with respect to the pre-defined Terms of References.

I received the draft report and other relevant background papers, reports and pre-recorded presentations about two weeks prior to the Review. I read the reports, background reports and papers, and other relevant documents that were sent to me (see the list in Appendix I). I have also searched, collected and read references relevant to the topics covered in the reports and the Performance Work Statement (PWS) prior to the Review.

I was actively involved in the discussion during the Review by (1) questioning and asking for clarification and (2) commenting on the stock assessments and making suggestions for alternative approaches and additional analyses. This report summarizes my independent findings and recommendations for the Review.

IV. Summary of Findings

My independent findings and comments on each item of the ToRs are provided under the respective subtitles of the ToRs (see below).

1. Evaluate the assumptions, fits, and performance of the Bristol Bay red king crab assessment using GMACS

I would like to commend the stock assessment team (led by Dr. Jie Zheng) for listing biological and statistical assumptions used in the stock assessment report. The comprehensive list of the key assumptions in the stock assessment report (Zheng and Siddeek 2020) was really helpful.

The stock assessment team had explored various options for the model parameterizations and sensitivity analyses to evaluate the impacts of different choices of input data and model configurations on the stock assessment. Sensitivity analyses were completed to evaluate uncertainties resulting from different trawl survey catchability priors (Model 19.3b) and from different methods for addressing the missing the 2020 trawl survey (i.e., Models 19.3l and 19.3h). This study suggested that missing the 2020 trawl survey data had only a small impact on the stock assessment. Implied effective sample sizes were found to be similar to the input sizes for most size composition data sets, implying weighting for most size composition data may be appropriate. However, the input sample size for retained catch may need to be increased (Zheng and Siddeek 2020). All the seven models fit the catch and bycatch biomasses very well. Model 19.3 fits the data better than Model 19.0a and is considered the preferred model for determining stock/fishery status. I support this decision.

The GMACS implementation for the Bristol Bay RKC uses consistent formulations to develop its likelihood functions for different models, making different likelihood functions/models comparable. The status quo models, however, tended to have inconsistent likelihood formulations among likelihood functions (e.g., some likelihood functions had no constants), making the comparisons among likelihood functions less consistent. The GMACS has dynamic binning to avoid fitting the models to size classes with no available observations. A jittering algorithm, similar to that used in the Stock Synthesis, was used in the Bristol Bay RKC GMACS stock assessment, which helped identify the "global" optimization of the likelihood functions.

During the Review, all estimated parameters were calculated and evaluated for their coefficients of variations (CVs, as a ratio of the parameter standard error and estimate saved in the STD file). Model parameter estimates with unusually large or small CVs were identified, evaluated and justified. No unusual patterns were found in the CVs of estimated model parameters, suggesting the model parameters were estimated reasonably well.

In recent years, a mismatch occurred in the centroids of large male abundances found in the survey and fishery. This might have resulted from seasonal changes in the RKC distributions and/or possible differences in catchability and selectivity between the survey and fishery. More studies are needed to understand underlying causes and possible impacts on the parameterization of population dynamics models and stock assessment results.

The logistic function was assumed for the survey and fishery selectivity. Given possible changes in stock distributions and phonology, other selectivity curves with more flexible selectivity patterns (e.g., double logistic, dome shape selectivity, or double log-normals) may be necessary to evaluate alternative selectivity patterns. There may be a need to evaluate alternative time blocks for different selectivities to account for spatio-temporal changes in selectivity in the Bristol Bay RKC fishery, which might be one of the sources for the strong retrospective patterns observed in the assessment. An analysis of spatio-temporal distribution of the Bristol Bay RKC (e.g., Vector-Autoregressive Spatio-Temporal, VAST, Model) may be helpful to identify possible shifts in spatio-temporal distributions over the assessment time period.

The Arctic Oscillation (AO) was found to be related to the Bristol Bay RKC recruitment. The AO data could potentially be used in the stock assessment as a covariate to constrain recruitment dynamics.

The growth transition matrix was internally estimated in the assessment. This is likely to result in correlations in the estimation of growth transition matrices and selectivities, which may influence the estimation of growth parameters. A plot of sizes at relative ages derived in the stock assessment model may be helpful for evaluating the biological realism of derived growth curves.

Strong retrospective patterns were observed in the stock assessment, and the estimated stock abundance, fishing mortality and recruitment were subject to large biases. This raises concerns regarding stock assessment quality, and how the biased estimates may influence catch advice and stock/fishery status determination. A protocol needs to be developed to help determine how large retrospective patterns should be dealt with, in addition to increasing the "buffers" proposed by the CPT (Zheng and Siddeek 2020). Strong retrospective patterns can influence the stock and fishery status determination, which cannot be addressed by increasing the "buffers".

The stock assessment suggests that stock abundance and recruitment have been in low in recent years. However, the fishery is not subject to overfishing and the stock is not overfished. Does this suggest that the Bristol Bay RKC has been in a low productivity phase? The current approach for determining the status of the stock and fishery may need to be evaluated. There is a need to consider dynamic reference points, which can be adjusted to accommodate climate-induced changes in productivity.

2. Evaluate the assumptions, fit, and performance of the Bering Sea snow crab assessment using GMACS

Four models were considered in the 2020 Eastern Bering Sea snow crab stock assessment. The four models were compared for model fitting and statistical diagnoses. Model 20.2, which uses GMACS to fit the same data as Model 20.1 (the Status quo model), was found to have the best fit. The GMACS (Model 20.2) performs well in capturing temporal trends of various data sources for the Eastern Bering Sea snow crab stock assessment. However, the main issue with GMACS model is overestimation of the retained size length composition data in the initial model years, which should be further examined. However, this does not appear to have large impacts on the assessment results in recent years.

The GMACS, with its standard and consistent model structures and formulations, promotes consistency, transparency and comparability during and among assessments. Several crab assessments have been developed in GMACS and subsequently approved for use in management by the CPT. GMACS was developed with king crab-like life histories in mind, but has recently been modified to accommodate terminally molting life histories. The structure of the population dynamics model in GMACS is very similar to the status quo assessment model, and can precisely reproduce the dynamics of the male component of the status quo model with the correct configuration. Implementing GMACS can overcome issues of heterogeneity among assessment methodologies and different stock assessment authors when the Status quo models are used. The use of GMACS can avoid possible inconsistencies in implementing the stock assessment model to provide management advice. Based on the information on the GMACS model, its performance evaluated in the Review and the needs to standardize assessment methodologies across platforms, I recommend that the GMACS platform be adopted for the assessment and management of snow crab.

The growth transition matrix was internally estimated in the assessment. This is likely to result in correlations in the estimation of growth transition matrices and other model parameters (e.g., survey and fishery selectivities), which may influence the estimation of growth parameters. I recommend that the GMACS include a plot of size at relative age derived in the stock assessment model, which may be helpful for evaluating the biological realism of estimated growth parameters/growth transition matrix.

During the Review, all the estimated parameters were calculated and evaluated for their coefficients of variations (CVs, as the ratio of the parameter standard error and estimate saved in the STD file). Model parameter estimates with unusually large or small CVs were identified, evaluated and justified. No unusual patterns were found in the CVs of estimated model parameters, suggesting the model parameters were estimated reasonably well.

In the past, a ‘jittering’ approach was used with the Status quo models to find the estimated parameter vector producing the smallest negative log likelihood for the assessment model (Turnock, 2016). Jittering was not implemented for the snow crab because its functionality in GMACS is still in development. Incorporating the “jittering” functionality into the Bering Sea snow crab GMACS is highly recommended.

Estimated survey selectivity increased greatly from 1982-1988 and 1989-present. The two survey catchability periods were justified by the expansion of survey areas, but the expansion may not justify the observed large differences in the observed differences in the selectivity between the two time periods. It would be interesting to evaluate how combining selectivity may influence the stock assessment results. Another possible alternative run is to start the model in 1989.

The logistic function was assumed for the survey and fishery selectivity. Given possible changes in stock distributions and phonology, other selectivity curves with more flexible selectivity patterns (e.g., double logistic, dome shape selectivity, or double log-normals) may be explored to evaluate alternative selectivity patterns. There may be a need to evaluate alternative time blocks for different selectivities to account for spatio-temporal changes in selectivity in the Eastern Bering Sea snow crab fishery, which might be one of the sources for the strong retrospective patterns observed in the assessment. An analysis of spatio-temporal distribution of the Eastern Bering Sea snow crab (e.g., VAST Model) may be helpful to identify possible shifts in spatio-temporal distributions over the assessment time period.

The GMACS model configuration and implementation include many biological and statistical assumptions. I would recommend that all explicit and implicit biological and statistical assumptions be listed (similar to those listed for the Bristol Bay RKC stock assessment), with justifications given for key assumptions. This can help identify the needs to conduct sensitivity analyses to evaluate the impacts of violating the assumptions on the stock assessment.

The implied effective sample sizes for discards, bycatch, and NMFS immature females for both time periods were much smaller than the input sample sizes. This may suggest that the models considered for these size composition data were less precise and should be weighted less than what the input effective samples implied. I suggest that the model be re-run, with implied sample sizes replacing input sample sizes to evaluate the possible impacts on stock assessment results.

A model run with an additional CV being estimated for the NMFS survey was conducted in the Review to evaluate alternative weighting scheme for the NMFS survey data. This run resulted in lower recent recruitment, higher SSB over the general time period with an exception of a lower SSB in recent years, and large differences in male survey index. Small differences were observed in selectivity, and size composition fitting was similar. For this run, the predicted biomass index did not fit the biomass index from the last 5 years because predicted index was much lower than the observed survey abundance index. This observation suggests that a model run with additional variability in the survey abundance index may not perform as well as a model run without this additional variability term, which supports the original model run (i.e., Model 20.2).

I would like to encourage further GMACS development to promote modeling transparency, collaboration and communications. More diagnostic analyses may be needed to evaluate model performance and retrospective analysis. These may include plots of input and implied effective sample sizes for all composition data, plots of size at relative age represented by the estimated size transition matrices, and the functionality for jittering and retrospective analyses.

3. Comment on the use of data derived from selectivity experiments within each assessment.

For the Eastern Bering Sea snow crab stock assessment, the Bering Sea Fisheries Research Foundation (BSFRF) selectivity experiment data tended to have large impacts on the NMFS survey catchability. Without the selectivity experiment data, the NMFS survey q was close to 1. After the inclusion of the data, the NMFS survey catchability was estimated lower than 1, suggesting that the NMFM survey might not be as efficient as suggested in the model without the BSFRF data. This re-scaled the population sizes, which has a large impact on catch advice. In general, the inclusion of the BSFRF data tended to improve stock assessment, although Model 20.3 (which is Model 20.2 + increased weight on 2010 BSFRF data to 'force' catchability) seemed not to yield less feasible stock assessment results, compared with the preferred Model 20.2.

For the Bristol Bay RKC, the NMFS survey catchability was also reduced after including the BSFRF data. However, the impact on the survey catchability were not as large as that of the Eastern Bering Sea snow crab.

The BSFRF selectivity experiment uses industry vessels to conduct a side-by-side bottom trawl survey with the NMFS bottom trawl surveys. The experiment helps evaluate NMFS survey program performance, engage the industry in the surveys, and build the industry's trust in the NMFS surveys. The BSFRF data can help cross-check the quality of data from the NMFS surveys. The BSFRF program also provided a platform to collect more biological data and samples to improve the estimation of life history parameters (e.g., growth, maturation and fecundity). Thus, I support the continuation of the BSFRF program and the use of BSFRF data in the two stock assessments.

4. Comment on retrospective patterns for each assessment; recommend approaches to reduce any retrospective patterns

The quality of a stock assessment, which is often evaluated based on various model diagnostics, is critical in determining if the assessment results can be used to provide catch advice for fisheries management. An erroneous stock assessment with large uncertainty may lead to fisheries mismanagement. Thus, it is important to conduct model diagnostics to evaluate the quality of stock assessments. One of such diagnostics is an evaluation of the retrospective pattern, which is defined as a systematic inconsistency in assessment estimates with additional data used in model fitting (Mohn 1999; Miller and Legault 2017).

Both Eastern Bering Sea snow crab and Bristol Bay RKC stock assessments are found to have large positive retrospective patterns, wherein stock biomass was estimated downward and fishing mortality estimated upward as additional data were included. The large positive retrospective pattern poses a challenge for providing catch advice and determining the stock and fisheries status for the Eastern Bering Sea snow crab and Bristol Bay RKC. Large persistent retrospective patterns may result from mismatches between model assumptions/configurations, and the quality of data used in model fitting. Three key sources that may result in the retrospective pattern problem in a stock assessment include unaccounted catch resulting from unreported discards and bycatch (and/or under-reported catch); unaccounted temporal trends in natural mortality; and mismatch between the model assumptions on temporal trends in survey catchability and actual survey catchability (Legault 2009; Miller and Legault 2017). I would like to commend Dr. Jie Zheng and Dr. Cody Szuwalski for their efforts in evaluating retrospective patterns and exploring different model configurations to reduce retrospective patterns in the Bristol Bay RKC and Eastern Bering Sea snow crab assessments. However, like many other stock assessments, it is often difficult, if not impossible, to precisely determine the source(s) of retrospective pattern in these two stock assessments. Despite the efforts, we still see very strong retrospective patterns in reparametrizing and/or reconfiguring the models.

The strong positive retrospective patterns associated with the Bristol Bay RKC and Bering Sea snow crab call for future research to (1) reduce the retrospective patterns by identifying their sources and reconfiguring the models accordingly and/or (2) develop protocols and/or alternative approaches to overcome the retrospective problems.

For both Bristol Bay RKC and Bering Sea snow crab, the main source of retrospective patterns is likely to be unaccounted temporal trends in natural mortality and mismatch between the model assumptions on temporal trends in survey catchability and actual survey catchability. More alternative hypotheses about temporal trends in survey catchability and natural mortality may need to be considered. For example, given the changes in thermal habitats, both Bristol Bay RKC and Bering Sea snow crab showed evidence of changes in their distributions, a phonology and time varying life history and fishery processes (e.g., selectivity, growth, maturation etc.), which may result in temporal changes in natural mortality and survey catchability. Such changes might be continuous and gradual, and might not be well-quantified by the time blocks used in current assessments. A linear gradual temporal change in natural mortality and survey catchability linked to changes in the thermal habitat may need to be tested.

In the case that the retrospective patterns cannot be alleviated by the above approach, I recommend that a standard protocol be developed to address the retrospective issues in providing catch advice (use recruitment in the projection) and determining stock and fisheries status. I would recommend that if its rho-adjusted (divide the terminal year estimate by one plus Mohn's rho) value is outside the 90% confidence interval of the terminal year estimate of stock biomass, recruitment, or fishing mortality rate, then the retrospective pattern is considered strong. In this case, the rho-adjusted values are used to determine stock status and modify starting stock size for projections used to provide catch advice (Brooks and Legault 2016).

The existence of strong retrospective patterns and the inability to pinpoint the sources and remove them in assessments might lead to the rejection of future stock assessments. Although large buffers can be built into developing catch advice to account for possible retrospective errors, the potential impacts on the determination of stock and fisheries are unknown. We may have to rely on data-limited approaches, such as index-based methods, if a stock assessment is rejected because of strong and persistent retrospective patterns. These concerns point to the need for identifying and evaluating appropriate index-based approaches for setting catch advice and determining stock status for the Bristol Bay RKC and Bering Sea snow crab if their strong retrospective patterns persist and their sources cannot be identified.

5. ***Identify potential data gaps for both species and assessments; recommend methods to fill these gaps.***

For both the Bristol Bay RKC and Bering Sea snow crab, climate-induced changes in key life history parameters need to be closely monitored. Continued experiments to better quantify the Bering Sea snow crab should be encouraged. For both stocks, more data are needed to better define the growth of females and males. Spatio-temporal variability in growth also needs to be evaluated to determine if a temporally-stationary growth is a reasonable assumption in the stock assessment models. I appreciate the efforts to explore uncertainty associated with natural mortality in both stock assessments. Continuous evaluation of possible changes in natural mortality, as a result of changes in thermal habitat, spatio-temporal distributions and predator and prey abundances, should be encouraged. The impact of warming habitats on the maturation of both crab stocks also needs to be evaluated.

A large south-north gradient in size at maturity exists for female snow crabs in the Bering Sea. This presence may indicate large spatial variability in growth, which has not been well considered in the stock assessment. Collecting growth data across different thermal gradients is necessary.

Given changes in the thermal habitats, it appears that there is evidence of spatio-temporal changes in the size distributions of both the Bristol Bay red king crab and the Eastern Bering Sea snow crab. There may also be changes in the crab abundance distributions, and possible movements between the stock areas and neighboring stocks. These changes may result in temporal changes in survey catchability and fisheries selectivities, leading to retrospective patterns if not accounted for in stock assessments. Information is needed to better define possible climate-induced spatio-temporal changes in abundance, size composition and movements for both the Bristol Bay RKC and Bering Sea snow crab. For the snow crab, spatial distributions of mature and immature males seemed to change in the eastern and northern Bering Sea, with few large males found in the northern Bering Sea in the past, but more large males found in 2019. More data need to be collected to monitor possible changes in large male distributions. The possible connectivity between the US and Russian Bering Seas may also need to be evaluated.

Bitter crab syndrome prevalence data were collected in the observer program for the Eastern Bering Sea snow crab. Bitter crab syndrome prevalence increased over time from 7.5% in 2014, to 49.3% in 2017. Not much information is available for the potential impacts of bitter crab syndrome on other life history parameters (e.g., mortality, growth and maturation). The increasing temporal trend needs to be closely monitored and the impacts on the key life history parameters and discards need to be studied.

Comparing the proportion of old shells between the survey (>101 mm) and retained catch suggests that NMFS surveys have more large old shell carbs, suggesting changed industry behavior of discarding old shell crabs with the industry tending to only retain new shell crabs and discarding the old shell crabs, which may be subject to high discard mortality. More data need to be collected to better quantify such changes.

Rapid change is occurring in the North Pacific ecosystem, resulting in shifting productivity and environmental conditions. It is critical to reflect such changes in the stock assessments of any species in this ecosystem. I would encourage the development of ecosystem indicators which can capture and quantify such changes to be explicitly incorporated into the future Bristol Bay RKC and Eastern Bering Sea snow crab stock assessments.

V. Conclusions and Recommendations

Overall, based on the stock assessment reports, background information, materials presented, and additional information provided during the Review, I believe that the stock assessment models used for the Bristol Bay RKC and the Eastern Bering Sea snow crab are state-of-the-art. In general, the derived stock assessment results are scientifically sound and adequately address the needs for the management of the Bristol Bay RKC and the Eastern Bering Sea snow crab stocks.

Having said all of the above, I have concerns with regard to the strong retrospective patterns observed in both stock assessments. Large biased errors were observed in the estimation of stock biomass, fishing mortality and recruitment for both stocks, which significantly reduced the quality of the stock assessment outputs, resulting in large uncertainties in catch advice and stock/fisheries status determination. Future research needs to identify the possible sources of the large retrospective patterns and/or develop alternative approaches to provide catch advice if retrospective patterns persistent and biased errors are too large for the assessments to be considered reliable. One of the sources for the retrospective patterns in these two stock assessments is the mismatch between the assumed and real temporal trends in key life history processes (e.g., natural mortality and growth) and fisheries and survey processes (e.g., catchability and selectivity). Most life history and fisheries processes were assumed to be temporally stationary in these stock assessments, while these processes were likely non-stationary in practice. More studies need to be conducted to identify temporal trends and/or time blocks of similar trends for these processes to be incorporated in future stock assessments. This adjustment may help reduce retrospective patterns. It is also important to develop a standard protocol or alternative approach (e.g., index-based assessment) for stock assessments with retrospective patterns too severe to be useful for catch advice and stock/fisheries status determination. The work by the NOAA Index Based Methods Working Group, chaired by Dr. Chris Legault of Northeast Fisheries Science Center, may be helpful (https://www.fisheries.noaa.gov/event/index-based-methods-working-group).

Large changes have been observed in fish (and crustacean species) distributions in the North Pacific ecosystems. The spatio-temporal changes in abundance distribution, size composition, stock structure, and phenology may call for studies to evaluate the survey performance/efficacy in capturing the stock dynamics of the Bristol Bay RKC and Bering Sea snow crab. Computer simulations based on past data and species distribution modeling can be used for the evaluation (Cao et al. 2014, Li et al. 2015).

The BSFRF experiment program has provided valuable information to evaluate the NMFS catchability for the two stock assessments. The program also provides an opportunity to collect data and samples for better quantification of key life history parameters (e.g., growth, maturation and fecundity). The experiment helps evaluate NMFS survey program performance, engage the industry in the surveys, and build the industry's trust in the NMFS surveys. I support the continuation of the BSFRF program and the use of BSFRF data in stock assessments. However, the need for increasing weights of the BSFRF data in model fitting may not be necessary and should be carefully evaluated.

The logistic function was assumed for the survey and fishery selectivity. Given possible changes in stock distributions and phonology, other selectivity curves with more flexible selectivity patterns (e.g., double logistic, dome shape selectivity, or double log-normals) may be necessary to evaluate alternative selectivity patterns. There may be a need to evaluate alternative time blocks for different selectivities to account for spatio-temporal changes in selectivity for both the fisheries, which might be one of the sources for the strong retrospective patterns observed in the assessment. An analysis of spatio-temporal distribution of the Bristol Bay RKC and eastern Bering Sea snow crab (e.g., VAST Model) may be helpful to identify possible shifts in spatio-temporal distributions over the assessment time period.

Given the large changes observed in the North Pacific ecosystem, it is necessary to identify and develop ecosystem indicators to quantify and incorporate the dynamics of the ecosystem in the assessment of the Bristol Bay RKC and Bering Sea snow crab. Understanding spatio-temporal dynamics of key life history processes and corresponding fleet dynamics is a requirement for including explicit ecological indicators in the stock assessment. Such considerations may improve the observed retrospective patterns.

Bitter crab syndrome prevalence for the snow crab increased over time from 7.5% in 2014, to 49.3% in 2017. Little information is available covering the potential impacts of bitter crab syndrome on other life history parameters (e.g., mortality, growth and maturation). The increasing temporal trend needs to be closely monitored, and its impact on key life history needs to be further studied.

I would like to encourage the continuous development of the GMACS, which can provide a consistent and transparent framework for the assessment of fish stocks with a crab-like life history. The implementation of the GMACS for the Bristol Bay RKC and the Eastern Bering Sea snow crab has appeared to work well. I encourage the continuous development of various functionality and model diagnostic tools for the GMACS.

VI. References

Alaska Department of Fish and Game (ADFG). 2012. Commercial king and Tanner crab fishing regulations, 2012-2013. Alaska Department of Fish and Game, Division of Commercial Fisheries, Juneau. 170 pp.

Brooks, E.N. and Legault, C.M., 2016. Retrospective forecasting—evaluating performance of stock projections for New England groundfish stocks. Canadian Journal of Fisheries and Aquatic Sciences, 73(6), pp.935-950.

Cao, J., Y. Chen, J. Chang, X. Chen. 2014. An evaluation of an inshore bottom trawl survey design for American lobster (*Homarus americanus*) using computer simulations. Journal of North Atlantic Fisheries Science 46: 27–39.

Legault CM, Chair. 2009. Report of the Retrospective Working Group, January 14-16, 2008, Woods Hole, Massachusetts. US Dept Commer, Northeast Fish Sci Cent Ref Doc. 09-01; 30 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026, or online at http://www.nefsc.noaa.gov/nefsc/publications.

Li, B., J. Cao, J. Chang, C. Wilson, Y. Chen. 2015. Evaluation of effectiveness of fixed-station sampling for monitoring American Lobster settlement. North American Journal of Fisheries Management 35(5): 942-957.

Miller, T. and C. Legault. 2017. Statistical behavior of retrospective patterns and their effects on estimation of stock and harvest status. Fisheries Research 186:109-120. DOI: 10.1016/j.fishres.2016.08.002.

Mohn, R. 1999. The retrospective problem in sequential population analysis: An investigation using cod fishery and simulated data. ICES J. Mar. Sci. 56: 473-488.

Szuwalski, C. 2020. A stock assessment for eastern Bering Sea snow crab (89 pages).

Turnock, B.J. 2016. Snow crab assessment model scenarios and convergence testing. Alaska Fishery Science Center.

Zheng, J., and G.H. Kruse. 2002. Retrospective length-based analysis of Bristol Bay red king crabs: model evaluation and management implications. Pages 475-494 in A.J. Paul, E.G. Dawe, R. Elner, G.S. Jamieson, G.H. Kruse, R.S. Otto, B. Sainte-Marie, T.C. Shirley, and D. Woodby (eds.). Crabs in Cold Water Regions: Biology, Management, and Economics. University of Alaska Sea Grant, AK-SG-02-01, Fairbanks.

Zheng, J. and M.S.M. Siddeek. 2020. Bristol Bay Red King Crab Stock Assessment in Fall 2020. (204 pages).

VII. Appendices

VII-1. Bibliography of materials provided for review

- Zheng, J. and M.S.M. Siddeek. 2020. Bristol Bay Red King Crab Stock Assessment in Fall 2020. (204 pages).
- Szuwalski, C. 2020. A stock assessment for eastern Bering Sea snow crab (89 pages).
- Cahalan, J., J. Gasper, and J. Mondragon. 2015. Evaluation of Design-Based Estimators in Federal Groundfish Fisheries off Alaska. In: G.H. Kruse, H.C. An, J. DiCosimo, C.A. Eischens, G.S. Gislason, D.N. McBride, C.S. Rose, and C.E. Siddon (eds.), Fisheries Bycatch: Global Issues and Creative Solutions. Alaska Sea Grant, University of Alaska Fairbanks. http://doi.org/10.4027/fbgics.2015.09.
- Cahalan, J.A., J. Gasper, and J. Mondragon. 2015. Catch estimation in the federal trawl fisheries off Alaska: a simulation approach to compare the statistical properties of three trip-specific catch estimators. Can. J. Fish. Aquat. Sci. 72: 1024–1036 dx.doi.org/10.1139/cjfas-2014-0347.
- Cahalan, J., J. Gasper, and J. Mondragon. 2014. Catch sampling and estimation in the federal groundfish fisheries off Alaska, 2005 edition. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-286, 46 p.

Presentations (some were pre-recorded) included in the Review

- Goodman, Scott, Bering Sea Fisheries Research Foundation - BSFRF Cooperative Research Industry Sponsored Trawl Surveys (pre-recorded).
- Szuwalski, C., Alaska Fisheries Science Center – A stock assessment for eastern Bering Sea snow crab.
- Szwalski, C. Snow crab assessment history since 2014 CIE Review (pre-recorded).
- Dowlin, A., Alaska Fisheries Science Center - North Pacific Observer Program (pre-recorded).
- Long, C. et al. Alaska Fisheries Science Center – Eastern Bering Sea Continental Shelf Bottom Trawl Survey: Commercial Crab Species Data Collection (pre-recorded).
- Daly, B. Alaska Department of Fish and Game – Bering Sea snow crab CIE review: crab fisheries catch data (pre-recorded).
- Richar, J. Alaska Fisheries Science Center – Survey data processing and analysis (pre-recorded).
- Punt, A., University of Washington – GMACS Overview (pre-recorded).
- Szuwalski, C. and J. Turnock. 2016. An assessment for the eastern Bering Sea snow crab fishery.
- Szuwalski, C. and J. Turnock. Sept. 19, 2017. Eastern Bering Sea snow crab stock assessment brief.
- Szuwalski, C. and J. Turnock. May 4, 2017. Estimation of selectivity, growth, and natural mortality in the assessment for EBS snow crab.
- Szuwalski, C. May 7. 2018. Bimodality in management quantities and additional growth data in the assessment for snow crab in the Eastern Bering Sea.
- Szuwalski, C. and Crab Plan Team. Sept. 12, 2018. Eastern Bering Sea snow crab stock assessment.

- Szuwalski, C. April 29, 2019. Eastern Bering Sea snow crab.
- Szuwalski, C. and Crab Plan Team. Sept. 17, 2019. Eastern Bering Sea snow crab stock assessment.
- Szuwalski, C. May 6, 2020. A comparison of the status quo assessment for eastern Bering Sea snow crab to an assessment developed in GMACS.
- Szuwalski, C. Sept. 12, 2020. A stock assessment for eastern Bering Sea snow crab.
- Zheng, J. and M.S..M Siddeek. ASF&G. Bristol Bay Red King Crab Assessment in Fall 2020 (presented at the Review).
- Zheng, J. and M.S.M Diddeek. ASF&G. Data for Bristol Bay Red King Crab Model (presented at the Review).
- Zheng, J and M.S.M. Siddeek, ADF&M - Bristol Bay Red King Crab Model History and Responses to CIE Recommendations in 2008 and Recent CPT and SSC Comments (presented at the Review).
- Zheng, J and M.S.M. Siddeek, ADF&M – Model Structure of Bristol Bay Red King Crab. (presented at the Review).
- Szuwalski, C., Alaska Fisheries Science Center - A stock assessment for eastern Bering Sea snow crab (presented at the Review).

Appendix VII-2. List of Participants (via online meetings or pre-recorded presentations**)**

- Martin Dorn Alaska Fisheries Science Center (Review Chair)
- Nick Caputi, CIE Reviewer
- Yong Chen, CIE Reviewer
- Benjamin Daly, Alaska Department of Fish and Game
- Alexandra Dowlin, Alaska Fisheries Science Center
- Billy Ernst, CIE Reviewer
- Scott Goodman, Bering Sea Fisheries Research Foundation
- Chris Long. Alaska Fisheries Science Center
- Katie Palof, Alaska Department of Fish and Game
- Andre Punt, University of Washington (pre-recorded presentation)
- Jonathan Richar, Alaska Fisheries Science Center
- Shareef Siddeek, Alaska Department of Fish and Game – Bristol Bay red king crab stock assessment scientist
- Cody Szuwalski, Alaska Fisheries Science Center – Eastern Bering Sea snow crab stock assessment scientist.
- Jie Zheng, Alaska Department of Fish and Game – Lead Bristol Bay red king crab stock assessment scientist

Appendix VII-3. Performance Work Statement

Performance Work Statement (PWS)

National Oceanic and Atmospheric Administration (NOAA)

National Marine Fisheries Service (NMFS)

Center for Independent Experts (CIE) Program

External Independent Peer Review

Virtual Panel Review of the Stock Assessments for Bristol Bay Red King Crab and Bering Sea Snow Crab

March 22-26, 2021

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. (http://www.cio.noaa.gov/services_programs/pdfs/OMB_Peer_Review_Bulletin_m05-03.pdf). Further information on the CIE program may be obtained from www.ciereviews.org.

Scope

The Bristol Bay red king crab (BBRKC) fishery and the eastern Bering Sea snow crab fishery are two of the largest and most economically important crab fisheries in the United States. They are assessed using size-structured assessments because of the difficulty aging crab. Recently, a general model for assessing crustacean stocks (GMACS) has been developed and adopted for use the BBRKC assessment. GMACS presents a standardized platform that will ultimately be used for all crab stocks in assessed in the Bering Sea. Modifications have been made to it to accommodate the life history of terminally molting animals (including snow crab) and in the near future, GMACS will be adopted for the assessment of snow crab. The goal of this CIE review is to both review GMACS and the resulting applications of GMACS to BBRKC and snow crab to ensure that the stock assessments represent the best available science to date and that any deficiencies are identified and addressed. The specified format and contents of the individual peer review reports are found in **Annex 1**. The Terms of Reference (TORs) of the peer review are listed in **Annex 2**. Lastly, the tentative agenda of the panel review meeting is attached in **Annex 3**.

Requirements

NMFS requires three **(3)** reviewers to conduct an impartial and independent peer review in accordance with the PWS, OMB guidelines, and the TORs below. The reviewers shall have:

- a working knowledge of size-structured assessment methodology (i.e. the assessment models crab numbers at size, rather than numbers at age),
- previous experience of with assessment of exploited crustacean stocks,
- familiarity with measure of model fit, identification, uncertainty, and forecasting
- An understanding of biological reference points
- Knowledge of ADMB
- Familiarity with fisheries science requirements under the Magnuson-Stevens Fishery Conservation and Management Act
- Excellent oral and written communication skills to facilitate the discussion and communication of results.

Tasks for Reviewers

1. Review the following background materials and reports prior to the review meeting:

   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 reviewer all necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the CIE on where to send documents. The CIE reviewer shall read all documents in preparation for the peer review.

2. Additionally, two weeks prior to the peer review, the CIE reviewers will participate in a test to confirm that they have the necessary technical (hardware, software, etc.) capabilities to participate in the virtual panel in advance of the review meeting. The AFSC NMFS Project Contact will provide the information for the arrangements for this test.

3. Attend and participate in the virtual panel review meeting. The meeting will consist of presentations by NOAA and other scientists including:

Jie Zheng (Alaska Department of Fish and Game), Shareef Siddeek (Alaska Department of Fish and Game), Katie Palof (Alaska Department of Fish and Game), and Cody Szuwalski (Alaska Fishery Science Center, National Marine Fisheries Service).

4. After the review meeting, reviewers shall conduct an independent peer review report in accordance with the requirements specified in this PWS, OMB guidelines, and TORs, in adherence with the required formatting and content guidelines; reviewers are not required to reach a consensus.

5. Each reviewer should assist the Chair of the meeting, NMFS AFSC Dr. Martin Dorn, with contributions to the summary report.

6. Deliver their reports to the Government according to the specified milestone dates.

Place of Performance
The place of performance will be held remotely, via Google Meets video conferencing.

Period of Performance
The period of performance shall be from the time of award through **May 2021**. The CIE reviewers' duties shall not exceed 14 days to complete all required tasks.

Schedule of Milestones and Deliverables
The contractor shall complete the tasks and deliverables in accordance with the following schedule.

Within two weeks of award	Contractor selects and confirms reviewers
Approximately 2 weeks later	Contractor provides the pre-review documents to the reviewers
March 22-26 2021	**Virtual Panel Review Meeting**
Approximately 3 weeks later	Contractor receives draft reports
Within 2 weeks of receiving draft reports	Contractor 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; and (3) The reports shall be delivered as specified in the schedule of milestones and deliverables.

Travel

No travel is necessary, as this meeting is being held remotely.

Restricted or Limited Use of Data

The contractors may be required to sign and adhere to a non-disclosure agreement.

NMFS Project Contact:

Cody Szuwalski, AFSC Resource Ecology and Fisheries Management Division
Alaska Fisheries Science Center
7600 Sand Point Way NE, Seattle, WA, 98115
cody.szuwalski@noaa.gov

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 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 Performance Work Statement
Appendix 3: Panel membership or other pertinent information from the panel review meeting.

Annex 2: Terms of Reference for the Peer Review

1. Evaluate the assumptions, fits, and performance of the Bristol Bay red king crab assessment using GMACS
2. Evaluate the assumptions, fit, and performance of the Bering Sea snow crab assessment using GMACS
3. Comment on the use of data derived from selectivity experiments within each assessment.
4. Comment on retrospective patterns for each assessment; recommend approaches to reduce any retrospective patterns
5. Identify potential data gaps for both species and assessments; recommend methods to fill these gaps.

Annex 3: Tentative Agenda

Tentative CIE Review of the EBS snow crab and Bristol Bay red king crab assessments
To be held virtually March 22-25, 2021

Review panel chair: Martin Dorn, martin.dorn@noaa.gov
Lead assessment authors: Cody Szuwalski, cody.szuwalski@noaa.gov; Jie Zheng, jie.zheng@alaska.gov
Google meet link: meet.google.com/zog-dpxh-zug
CIE reviewers:

- Billy Ernst, University of Concepcion
- Yong Chen, University of Maine
- Nick Caputi, Western Australian Fisheries and Marine Research Laboratory

Website for meeting materials:
https://archive.fisheries.noaa.gov/afsc/refm/stocks/plan_team/2021_crab_cie/

Sessions will run from 1am to 5pm PCT daily. Discussion will be open to everyone, with priority given to the panel and senior assessment authors. Several pre-recorded presentations will be available on the website to be discussed on Monday. The website will be updated continually until the meeting.

Seattle	Maine	Chile	Perth
1:00PM	4:00PM	5:00PM	4:00am
5:00PM	8:00PM	9:00PM	8:00am

Monday, March 22

1:00	Introductions and agenda	Martin Dorn
1:15	Questions on recorded presentations	Everyone
2:30	Snow crab presentation + assignments	Cody Szuwalski
5:00	Adjourn	

Tuesday, March 23

1:00	BBRKC presentations + discussion + assignments	Jie Zheng
5:00	Adjourn	

Wednesday, March 24

1:00	Snow crab presentations + discussion + wrap up	Cody Szuwalski
5:00	Adjourn	

Thursday, March 25

1:00	BBRKC presentations + discussion + wrap up	Jie Zheng
5:00	Adjourn	