Center for Independent Experts (CIE) Eastern Bering Sea Snow Crab and Bristol Bay Red King Crab Stock Assessments Independent Peer Review 2020

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Billy Ernst

Department of Oceanography

University of Concepción

Chile

Executive Summary

The Alaska Fisheries Science Center (AFSC – Seattle) through the Center for Independent Experts (CIE) requested an independent review for the 2020 Bristol Bay red king crab (BBRKC) and EBS snow crab stock assessments. This review includes the stock assessment models implemented in GMACS for red king crab (*Paralithodes camtschaticus*) and EBS snow crab (*Chionoecetes opilio*). This online review was carried out in four-hour sessions from 22nd to 25th of March 2021. The other CIE members of the review panel were Drs. Nick Caputi and Yong Chen.

GMACS is a generic stock assessment model designed to study and provide management advise for exploited populations of crustaceans in Alaska. The implementation of this model for the EBS snow crab and Bristol Bay red king crab assessments has been an excellent choice, and I recommend it be maintained as the main assessment tool and encourage its development and documentation. Both assessments represent an improvement with respect to their predecessors.

Undoubtedly, the annual NMFS trawl survey represents a fundamental tool for collecting systematic spatial and temporal data for both resources and for many key components of the EBS benthic ecosystem. Unfortunately, some aspects of the spatial dynamics of each species and the survey characteristics may affect resource availability, adding further interannual uncertainty in assessing key demographic traits. In the short term more uncertainty can be incorporated in the model estimation procedure using the biomass indices of the survey. Spatial analysis based on EBS survey data is recommended and simulation testing in future to test the impact of relevant spatial dynamics on GMACS model.

Both assessments show high retrospective patterns in relevant management statistics, which requires some careful and systematic inspection of the model to unravel the generating factors.

The snow crab model requires data-weighting work with most of the size composition data. I recommend including additional variance terms for male and female survey likelihoods. Taking advantage of the great flexibility of the GMACS model, new scenarios should be implemented to capture an ample variety of model uncertainty.

Data collection for important biological traits should continue for both species, including growth increments and natural mortality.

Because of the great relevance of survey data to both assessments, I recommend further research on survey selectivity/catchability considering the depth and bottom type.

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 the USA 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.

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 in the BBRKC assessment. GMACS presents a standardized platform that will ultimately be used for all crab stocks assessed in the Bering Sea. Modifications have been made to this model 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.

Description of review activities

Documentation

Two weeks before the online meeting, the following documents were sent by e-mail to the reviewers:

Main Assessment documents:

- J. Zheng and M.S.M. Siddeek. 2020. Bristol Bay red king crab stock assessment in fall 2020. C1 BBRKC SAFE October 2020. 204 p.
- Szuwalski, C. 2020. A stock assessment for eastern Bering Sea snow crab. C1 Snow Crab SAFE September 2020. 89 p.

- Zacher, L.S., Richar, J.I., Foy, R.J. 2019. The 2019 eastern Bering Sea Continental Shelf Trawl Survey: Results for commercial crab species. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC, 190 p.

Narrated PPT presentations

- *Bristol Bay Red King Crab Model History and Responses to CIE Recommendations in 2008 and Recent CPT and SSC Comments* by J. Zheng and M.S.M. Siddeek.
- *Eastern Bering Sea Continental Shelf Bottom Trawl Survey: Commercial Crab Species Data Collection* by Chris Long, Jen Gardner, Christie Lang, Jon Richar, SAP staff.
- *Survey data processing and analysis: The SAP coffee subsidization program* by Jonathan Richar.
- *North Pacific Observer Program Alaska Fisheries Science Center Fisheries Monitoring and Analysis Division* by Alexandra Dowlin.
- *Snow crab assessment history since 2014 CIE review* by Cody Szuwalski.
- *BSFRF Cooperative Research Industry Sponsored Trawl Surveys* by Scott Goodman.

During the meeting, Dr. Szuwalski sent additional material by e-mail and uploaded it to the following website:

https://archive.fisheries.noaa.gov/afsc/refm/stocks/plan_team/2021_crab_cie/

This included:

1. Presentations.

2. Results of some additional model runs for both assessments.

3. Previous Snow Crab presentation from 2017-2019 and other documents.

Review Activities

The virtual review workshop was conducted over the internet via *Google Meets* in four-hour sessions (1 am to 5 pm PCT) from Monday the 22nd to Thursday the 25th of March 2021.

Before the meeting:

Review documents and narrated presentations of a variety of topics particular to both assessments were provided and analyzed by the CIE reviewers.

During the online workshop scientists gave presentations on snow crab and red king crab assessment topics including the stocks, their fisheries and modelling work. The following scientists presented or participated in the virtual workshop:

– *Cody Szuwalski*. Alaska Fisheries Science Center, Sand Point, Seattle.

- *Jie Zheng*. Alaska Department of Fish and Game. Division of Commercial Fisheries. Juneau, AK.
- *M.S.D Siddeck*. Alaska Department of Fish and Game. Division of Commercial Fisheries. Juneau, AK.
- Alexandra Dowlin. Data Management Specialist 2 with Pacific States Marine Fisheries Commission.
- Melanie Rickett. Alaska Fisheries Science Center. North Pacific Observer Program.
- Katie Palof. Alaska Department of Fish and Game. Crab Plan Team. Juneau, AK.
- William Stockhausen. Alaska Fisheries Science Center, Sand Point, Seattle.
- Scott Goodman. Bering Sea Fisheries Science Foundation. Bothell, WA.
- Benjamin Daly. Alaska Department of Fish and Game. Division of Commercial Fisheries. Kodiak. AK.

Review panel chair: Martin Dorn, Alaska Fisheries Science Center, Sand Point, Seattle.

The members of the review panel were:

- Dr. Yong Chen (University of Maine, USA)
- Dr. Billy Ernst (UDEC, Concepción, Chile)
- Nick Caputi (Western Australian Fisheries and Marine Research Laboratory, Australia)

The agenda for the panel review meeting is included in Annex 3 of this report. Activities included the introduction of participants, discussion of the terms of reference of the snow crab and red king crab reviews. During the first day of the online meeting, there were discussions on previously distributed material (narrated presentations) which covered data collection programs common to both assessments. These were fisheries sampling programs, EBS NMFS trawl surveys, and BSFRF program. A full description of the snow crab assessment model was presented by Cody Szuwalski. During the second day, Jie Zheng presented the BBRKC assessment, leaving lots of time for questions by CIE reviewers. On day three, the discussion went back to the snow crab assessment, and finally, on day four, Dr. Zheng presented information on BBRKC assessment again. On days 2, 3, and 4, the assessment authors presented results on specific CIE reviewer´s requests. The review meeting developed in a good working environment, and the assessment authors and meeting chair were very responsive to different questions raised by the reviewers.

Findings and recommendations

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

GMACS is a generic stock assessment model designed to study exploited populations of crustaceans in Alaska. Its development led by a group of researchers and maintenance in an environment open to the scientific community (Github) reduces the risk of coding mistakes, common in single resource stock assessment models. Therefore, the modeler can focus on the assessment itself and its scenarios rather than spending a significant amount of time debugging the code. GMACS´s implementation has been an excellent choice, and I suggest maintaining and encouraging its development and documentation. The use of GMACS in both assessments seems to be a better choice than previous individual resource-based models.

The assessment documents were informative and well written, providing valuable information on resource and fishery background information, model configuration, estimation procedure, and assessment scenarios.

Model Assumptions

The Stock

The BBRKC assessment comprehends only the stock of the Bristol Bay area, because the Bering Sea (near the Pribilof) and Aleutian Islands (south west) stocks are managed separately. From the information provided in the assessment report, the degree of biological connection among them is not clear. Daly et al. (2020) present a larval advection model that links them to some degree during the planktonic stages. Density maps from the trawl survey catches (Zacher et al. 2019) suggest that Pribilof and Bristol Bay stocks are two separate units during their benthic phases. In the absence of further information, it seems a fair assumption to treat BBRKC as an individual stock.

Dynamics

Representing the population dynamics of BBRKC with a modified length-based assessment model (Sullivan et al. 1990) seems appropriate because it captures relevant population processes, namely survival, recruitment, and growth, without dealing explicitly with age, which is not available for the crustacean stock in general.

Natural Mortality

For this stock, the assumed natural mortality value is 0.18 yr^{-1} over sex, shell condition and length, based on the 1% rule and a maximum age of 25 years. This procedure has been applied since the 2005 assessment. Because of the relevance of this parameter for stock assessment purposes (Punt et al. 2021) it is important to review/update this estimate and its estimation procedures. In this assessment´s scenarios, natural mortality was estimated for particular time blocks, for male and female crabs. No specific information was provided on the rationale behind the chosen time blocks for scenarios 19.0 and

19.3. It is probably related to model unaccounted mortality (large drop in the survey biomass) in the early 1980s, but it is necessary to indicate the criteria used for the time block definition. During the early 1980s there was a major change in the survey gear, therefore a change in survey catchability might be a good alternative way to explain the sudden change in survey biomass, or at least part of it.

On the other hand, to account for the decline in female and male abundance during the early 1980s, mechanistic scenarios associated to bycatch might be used. This will allow to incorporate length dependent mortality (e.g., selectivity). Dew and McConnaghey (2005) and Dew (2008) suggested that much of the sudden BBRKC decline could be explained by massive bycatch mortalities induced by trawl and red king and tanner crab pot fisheries between the mid-1970's and 1980's. I recommend exploring such scenarios.

Somatic Growth

BBRKC growth is modeled using a size transition matrix and a molting probability function. Females are assumed to molt annually, and males molting probability to decay using an inverse logistic function. These are reasonable assumptions, but are not well explained and supported throughout the document. Mean male growth increments at size are estimated based on a lot, but are relatively outdated and variable mark-recapture data, suggesting that mean growth increments remain reasonably constant in the 70-170 mm span. Comparing these results with more recent mark-recapture data for the same species from the Barents Sea (Nielssen and Sundet 2006, Figure 1) and Norton Sound (Bell et al. 2016, Figure 2) we can see some similarities and differences. Male increment data tend to vary between 10 and 20 mm for the full-size range, not showing a decline in the Barents Sea data, but it does for the Norton sound, showing a negative trend. Bell et al. (2006) also show differences in the increment-at-size of release for new and old shell crab. On the other hand, Nielssen and Sundet (2006) use a large amount of mark-recapture data to show a growth discontinuity for females between 100-120 mm, with a less pronounced increment decline for larger females. I recommend implementing a mark-recapture program soon in order to update male and female increment and molting probability data for BBRKC. For the time being, and in the absence of new data, model parameter estimates seem to be within the range of other stocks.

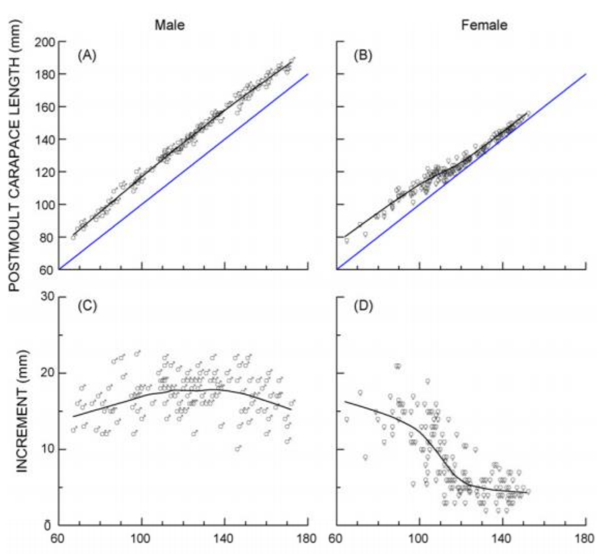

Figure 1: Paralithodes camtschaticus from Varanger, North Norway. Postmoult carapace length (mm) (A, B), increment (mm) (C, D) vs. premoult carapace length (mm) for male and female. Trend lines in solid. Modified from Nielssen and Sundet (2006).

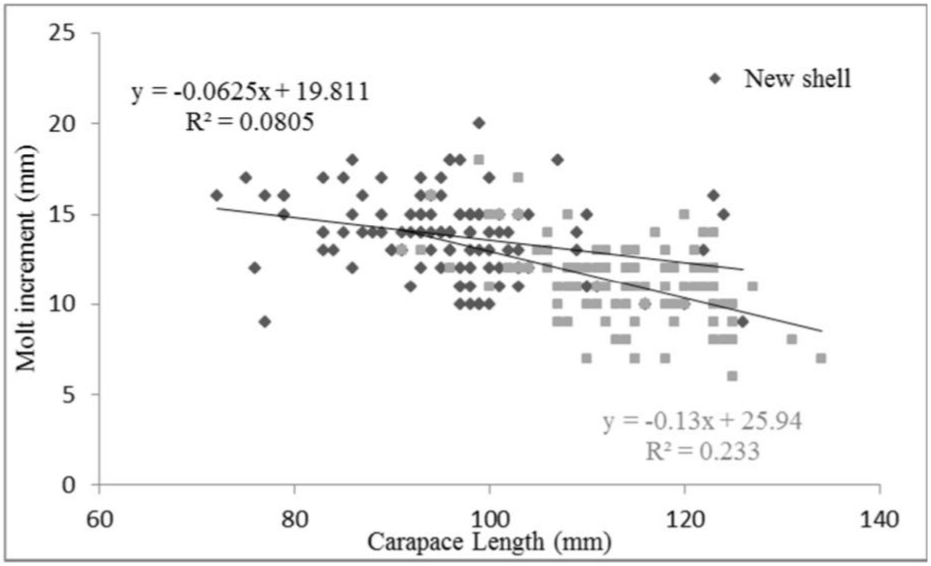

Figure 2: Red king crab molt increment by carapace length and shell condition (at time of tagging). Source: Bell et al. 2016.

NMFS survey data

The BBRKC assessment relies significantly on the NMFS summer survey data. Depending on environmental conditions (e.g., Near Bottom Temperature), an unknown fraction of the population remains unavailable to the survey during normal sampling conditions. If this is detected, some stations are revisited (retows) at the end of the survey. Zacher et al. (2017) indicate that in cold years the spatial distribution of BBRKC is closer to the Aleutian Islands, and in warmer years the centroid tends to be associated with the center of Bristol Bay. This information comes from the fishery (before the survey) but highlights the fact that NBT affects the spatial distribution of red king crab and may affect the availability of crab to the survey.

In the documentation provided for this review (Assessment report and 2019 EBS trawl survey), no information was available to clearly understand the protocol that the survey team applies to decide when retows will occur and how the data is statistically treated to provide final abundance, biomass, and size-structure estimates and uncertainty. This spatial process error that affects the survey may add some additional uncertainty to the biomass estimates and justify incorporating a CV (estimated in the model) in addition to the fixed uncertainty estimates provided by the survey team. During the review meeting, the CIE panel requested Dr. Zheng to run the model with an extra CV. The model run (19.3-adv) estimated an additional CV of 0.255 for NMFS and 0.345 for the BSFRF survey biomass. I recommend reviewing the plausibility of adding this additional variance term to the assessment and evaluate its impact.

Estimation, Fit and Performance

The BBRKC assessment model is based on GMACS and ADMB software, which allow for simultaneous estimation of hundreds of parameters. Even though this modeling environment enables us to deal with highly parameterized models, the nonlinearity of these models and the parameter correlation can lead to a lack of convergence or local minima. This assessment implemented a Jitter procedure, highly recommended to assure convergence for various model configurations. During the meeting, the CIE panel requested Dr. Zheng to provide uncertainty estimates of model parameters for the base case scenario. The reported coefficients of variation were at low or moderate levels.

In addition to this request, the CIE panel also asked for the calculation of the implied weights for all the likelihood components used in the assessment. Table 1 shows that most of the size composition likelihoods were using weights near or below the implied values, which is found appropriate.

Table 1: Implied effective sample size and input sample size used in the BBRKC assessment. Data provided by Dr. Jie Zheng during the review meetings.

Geometric Mean of Effective Sample Sizes

	Implied ESS	Max N
Retained C.	178	100
Total Males	199	100
Disc. Females	29	50
Trawl BC	62	50
TC BC	66	50
Fixed G BC	46	50
NMFS Trawl	181	200
BSFRF Trawl	133	200

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

As indicated above, the use of GMACS is definitely a step forward, as well as for the purposes of the EBS snow crab assessment, considering that it reduces the risk of coding mistakes, and allows the modeler to maximize the time dedicated to the assessment itself and its scenarios, rather than spending a significant amount of time debugging the code. GMACS´s implementation has been an excellent choice, and I suggest maintaining and encouraging its development and documentation. The use of GMACS for the snow crab assessments seems to be a better choice.

Model Assumptions

The stock

Snow crabs are distributed over the extensive shelf of the EBS, including the coastal, middle, and outer domains (Ernst et al., 2005). Research on the early life history of snow crab (Parada et al., 2010) has postulated that the EBS stock is likely to be connected through larval drift of planktonic stages with the northern stock (St. Lawrence) in a source-sink relationship. In the last decade, northward expansion of the EBS trawl survey sampling frame has shown in some years a continuous distribution of small crab between the northern and EBS stocks. Additionally, in the last EBS trawl survey (2019), high densities of large and small size crab were detected north of St. Matthew Island, indicating that a relevant fraction of the EBS snow crab stock probably remained outside the survey area (Figure 3).

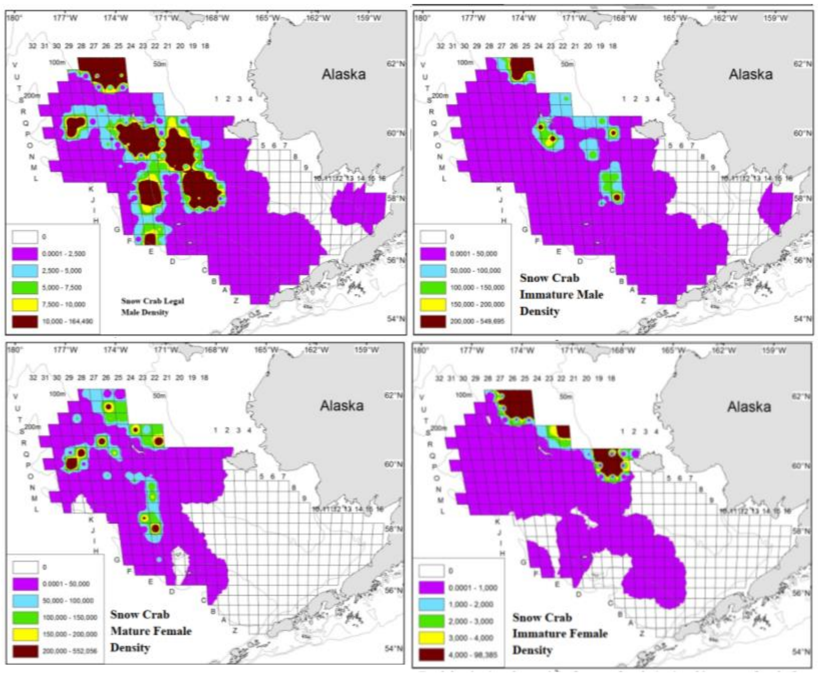

Figure 3: Total density (number nmi-2) of mature male (top) and immature male (bottom) snow crab (Chionoecetes opilio) at each station sampled in 2019. Modified from Zacher et al. (2019).

These results indicate that both stocks are not only connected through larval stages, but also through benthic crab that might move in and out of the survey area (in the north). If small crabs move from the north into the assessment area, the signal would be detected as recruitment by the survey and the model. Alternatively, if small crabs leave or larger crabs move in-out the survey area, this would only be a process error in the model. The concept of closed-population for the EBS stock becomes weaker in light of this evidence. It is important to investigate the impact of this spatial processes on the assessment, firstly by doing spatial-temporal analysis of EBS trawl survey data of relevant crab components, with emphasis on the size structure, sex, maturity and abundance of crab at the northern range of EBS trawl survey sampling frame. This analysis would allow to understand how often (at least during the summer) the split- stock hypothesis is violated and assess if the connection is established mainly through smaller crab or older components as well (2019 survey). After this effort is completed, a simulation testing framework (spatial model) can be crafted to test the impact of a variety of hypothesis on the aggregated GMACS model performance.

Growth data and modelling

The 2020 EBS snow crab assessment uses male and female size increment data collected from holding studies to model growth and parameterize mean size increments of the size transition matrix. New increment data of larger females provided information to change the model from a kinked to linear growth. This is consistent with the available data and is a better choice. I advise continuing collecting this increment data for both sexes.

Alternative models for the assessment

In the year 2020, it was probably the first time that GMACS model was implemented for snow crab stock assessment and management purposes. Presumably, most of the implementation effort was geared toward replicating the previous assessment model and making sure the model was working correctly. The alternative cases chosen for the 2020 assessment (19.1, 20.1, 20.2, 20.3) explore only a minor range of assessment uncertainty; mostly related to basic underlying model configuration hardwired to each model (old vs GMACS). Model 20.3, which represented a change in model assumptions with respect to BSFRF catchability did not fully converged (page 6 from assessment report).

I recommend for the next assessment cycle generating a set of scenarios to explore the various axes of model uncertainty fully, including natural mortality, catchability, selectivity and growth.

Fit to the Data

Data weighting

This assessment, as many other integrated approaches, uses several sources of information and likelihood functions. Data weighting is an essential part of stock assessment modelling and refers to decisions made by the modeler that affect the relative influence of each data type on model outputs. The current stock assessment model uses a length composition sample size of 100 for all data sources and scenarios. The CIE panel asked Dr. Szuwalski to compute the effective sample size ($ESS = \frac{\sum \hat{p}(1-\hat{p})}{\sum(\hat{p}-p)^2}$) for all composition data. This is summarized in Table 2.

Table 2: Effective sample size computed for all composition data in the EBS stock assessment (Scenario 20.2).

Size component	Input	ESS
Retained	100	84.75
Total	100	98.63
Discard (f)	100	10.67
Tbycatch (f)	100	20.27
Bycatch (m)	100	49.91
NMFS (imm f)	100	12.30
NMFS (imm f)	100	15.99
NMFS (imm m)	100	42.81
NMFS (imm m)	100	56.50
NMFS (mat f)	100	80.40
NMFS (mat f)	100	51.13
NMFS (mat m)	100	181.50
NMFS (mat m)	100	135.15
BSFRF (2009)	100	121.94
NMFS sm(2009)	100	226.89
BSFRF (2010)	100	39.21
NMFS sm(2010)	100	82.92

It shows that weighting of length composition data needs significant consideration in this assessment, down-weighting several components, including NMFS trawl, BSFRF, and fisheries data. The impact of the latter could influence derived parameter point estimates or its uncertainty. The CIE panel also requested to re-run the model (20.2) with an additional estimated cv for the male survey data. Model 20.2 was using cv estimates obtained directly from the survey, which seem to be low (e.g., cv=0.08). The model estimated an additional cv of 0.36, which means increased uncertainty than previously expected. The extra cv did not significantly affect the fit to the data, except for MMB, which shows higher biomass values from the beginning of the series through 2016. Subsequently, the base model shows higher MMB values (Figure 4). The assessment team should discuss the proper uncertainty level accepted for the NMFS survey data (males and females).

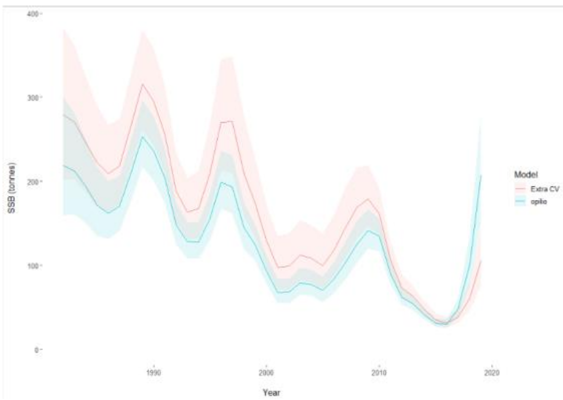

Figure 4: Mature male Biomass estimates under based model and the extra cv-model for male NMFS trawl survey.

Estimated Survey Selectivity

EBS NMFS trawl survey gear had a significant net width change in 1982. In 1988 the survey sampling frame expanded a bit to the north, including a few new stations to the north of St. Matthews Island. In the assessment model, this was interpreted as a change in survey catchability, which seems appropriate (change in availability). Selectivity parameter estimates provided in the assessment report (Szuwalski 2020, their Figure 39) indicate that for model 20.2, preferred by the assessment author, the catchability almost doubles in 1989-present concerning 1982-1988. This significant increase can probably not be explained by a change in survey availability, given that probably not more than 20% of stations were added to the sampling frame. I recommend doing a profile of the catchability parameters by likelihood component to understand what piece of information is being informative for these parameter estimates.

Diagnostics

The diagnostics procedure provided in the assessment report seems appropriate and represents a standard way of analyzing residuals and the fit in general. Model 20.2 fits catch data almost perfectly, which is an improvement concerning the old model that overestimated the discard catch data (Figure 26 of the assessment report).

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

EBS snow crab and BBRKC stock assessments rely heavily on information provided by the annual NMFS trawl survey. Undoubtedly, the assumptions made by the modeler about selectivity and catchability will have a relevant impact on the assessment and require careful attention. In the last decades, two major initiatives were put in place to assess NMFS 83-112 Eastern trawl efficiency for Alaskan crabs, (i) by incorporating an auxiliary net attached under the trawl net (Somerton and Otto, 1999) and (ii) side-by-side trawling experiments using a *Nephrops* trawl (BSFSF) run in parallel with NMFS standard trawl summer survey (Somerton et al. 2013, Kotwicki et al. 2017). The side-by-side experiment was implemented in 2009 and 2010 surveys and was primarily oriented towards gear efficiency estimation for EBS snow crab, yielding large sample sizes for the calculations (Szuwalski 2020, Figure 20).

In 2016, 2017, and 2018 further side-by-side experiments were conducted, but oriented more towards other Alaskan crab species.

Snow Crab Assessment

Published work based on side-by-side trawl net experiments indicate that depth and bottom type (e.g., sand and mud) are both significative factors affecting NMFS 83-112 Eastern trawl efficiency for catching snow crab. In shallow and sandy areas, the gear is more efficient than in deeper and muddier zones. This is not considered in the assessment. Because the model is not spatially explicit, to factor this in, it would probably require an adjustment before the data goes into the current assessment model. Because snow crab distributes on the coastal, middle, and outer domains, it seems important to assess bathymetry and sediment type on gear efficiency and abundance estimates.

Crab size is also a relevant factor affecting NMFS 83-112 Eastern trawl efficiency. Based on Somerton et al. (2013) and Szuwalski (2020, Figure 19), the efficiency may be categorized in three size ranges: (i) in the 20-50 mm range, the gear efficiency increases from 0 to 0.4, (ii) from 50 -100 mm it oscillates between 0.4 and 0.5, and (iii) above 100 mm, the efficiency increases towards 0.8. Large male snow crab (>= 120 mm) seems to have a similar efficiency than large red king crab. Some of this information is captured by the assessment estimated survey selectivity's (Scenarios 20.2 and 20.3), however above 100 mm, the gear does not increase the efficiency with size, as expected from the experimental data. This is important since it affects the efficiency of crab targeted by the fishery.

BBRKC

The BSFSF has also conducted research on trawl efficiency for BBRKC using a small-mesh trawl net. Side-by-side tows concurrent with the EBS NMFS trawl survey were conducted for 2007, 2008, and the 2013-2016 time period. This information has been integrated into the assessment in two different ways. On the one hand, the stock assessment model was fitted to a relative index of abundance and size composition data derived from this alternative survey. Despite the short extension of the time series, it is valuable to have a second index of abundance to track population trends.

In addition, the BSFSF side-by-side tow experiments provided information on NMFS gear efficiency. Zheng and Siddeek (2020), using all available data, computed an overall catchability coefficient for red king crab > 135 mm (q=0.891). This value is compared to the estimate provided by Weinberg et al. (2004) using double-bag experiments and concluded that there was only a minor difference (q=0.896 for crab > 162.5 mm) between the two estimates. Finally, in the assessment, a prior based on Weinberg´s result was used on the survey catchability coefficient. This means that the efficiency ratio was not quantitatively used in the assessment, but rather as a reference to support the chosen prior value for the survey catchability. Because of the importance of the survey selectivity and catchability estimates for the assessment, I recommend a formal comparison (through modeling) of the side-by-side and double-bag experiments and their estimates, to provide an updated prior estimate or to integrate the comparison into the assessment.

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

Conspicuous retrospective patterns in fisheries stock assessments are problematic for determining stock status and quotas because current estimates of stock size or fishing mortality are consistently lower or higher than those when new data is added to the assessment model. For the last 20 years, Mohn´s statistics (Mohn 1999) has been regularly used to quantify the severity of the retrospective pattern. In this CIE review an average version of Mohn´s statistic was presented (Hurtado-Ferro et al. 2015). Both assessments show positive retrospective patterns in Mature Male Biomass, but the magnitude is different.

Snow Crab

The 2020 EBS snow crab assessment shows a strong positive retrospective pattern, with an average rho statistic of 0.66 for the author's preferred model. This is probably an indication of inconsistency in the data or model. In addition, the assessment author reported a scenario excluding the last year assessment, which generated a larger rho value (1.04, Figure 23).

From the analysis presented in the assessment, the main drivers behind this retrospective pattern are not clear. Generally, it arises from time-varying unaccounted processes in the assessment and/or contradictory data. EBS Snow crab population dynamics is extremely complex (Ernst et al. 2005, Orensanz et al. 2005, Parada et al. 2010) with strong spatial (e.g., extension of biennial reproductive cycle, intermittent connection with northern snow crab population) and time-varying components (e.g., interannual variation in NBT extension driven by the cold-pool extension). The GMACS model is a good effort to represent snow crab dynamics and is flexible to incorporate several configurations and levels of complexity, but it lacks spatial representation. It is important to identify what aspects of this spatial dynamics could be relevant to the spatial free model. This requires some dedicated work in the short and medium time frame to identify the sources causing this pattern and implementing modifications to reduce it.

Recommendations

Short time frame:

- Prioritize work on data weighting for length structured data and additional uncertainty for survey biomass estimates. Survey CVs are provided as fixed quantities in the assessment and are probably higher than the ones assumed in the current assessment. Estimating a CV for survey MMB had a strong influence on current male biomass status.
- Redo current retrospective pattern analysis.
- Investigate if time-varying changes in survey catchability, growth and connectivity to the northern stock (recruitment) influence the retrospective pattern of the model.

Medium time frame:

- Implement a sized-based spatial simulation model for EBS and northern stocks snow crab using conceptual elements provided by published work (Ernst et al. 2005, Orensanz et al. 2004, Orensanz et al. 2007, Parada et al. 2010, Ernst et al. 2012, Fedewa et al. 2020).
- Develop a simulation testing framework (Spatial model - GMACS) under different configurations and assumptions to evaluate what spatial aspect of the dynamics are more relevant for retrospective patterns.

BBRKC

The BBRKC assessment report presents retrospective patterns based on historical assessments and a standard retrospective analysis using the 2020 GMACS model. As expected, in the time period from the starting year through the start of the retrospective analysis window, the variability in the metrics of legal males between assessments is higher for the historic (Figure 29 of the BBRKC report) than for the GMACS retrospective analysis (Figure 28a). This is probably due to changes in model assumptions, data weighting, and model structure from year to year. Nevertheless, positive retrospective bias is present in both analyses, indicating that this has been present in the BBRKC assessment for over a decade.

The 2020 BBRKC assessment reports an average rho statistic of 0.29, much smaller than for the snow crab assessment. Nevertheless, this is still a high value and needs consideration and thoughtful analysis. This bias also affects management quantities and is persistently indicating that there is more crab in this assessment than estimated in the following year's assessment.

The information available in the BBRKC report or provided during the CIE online meeting was not specific enough to diagnose possible causes for this retrospective pattern. During the review, the CIE panel requested an additional model run down-weighting the 2014 Survey Biomass estimate (seems to be positive bias), to assess impact on current MMB estimates and on the retrospective pattern.

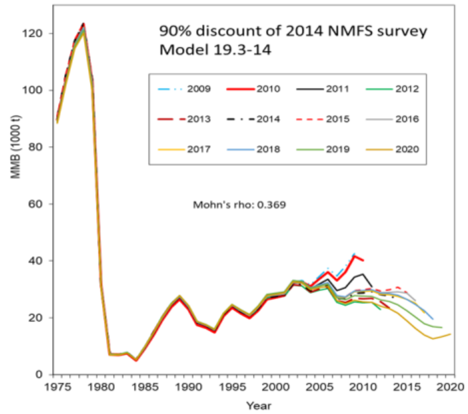

Figure 5: Retrospective analysis on MMB for model 19.3-14. Provided by Dr. Zheng during the meeting.

Downweighing the 2014 survey produced a lower series of MMB estimates and a higher average rho statistic (0.369, Figure 5). These results and the fact that the historical retrospective pattern has shown consistent positive bias at least in the 16 previous assessments, may suggest that the misspecification might be more on the model structure/assumptions than on the data side.

Recommendation:

- Taking advantage of the great flexibility available to the GMACS model, a series of configurations should be tested to assess which factors are the most probable cause of this positive retrospective pattern, this should include time-variant survey catchability, natural mortality, among other factors.
- Using an MSE type approach may facilitate determining the relevant structural factors that generate the consistent positive bias in this assessment.

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

Snow Crab

Historic in-Season Catch-Effort Data

Depletion and catch dynamic models (Seber (1982), Roa-Ureta (2018)) are promising tools for analyzing high-frequency in-season catch and effort data of the EBS snow crab stock and assessing pre-harvest snow crab *abundance*, *catchability*, and *harvest rates*. Ernst et al. (2011) used a 1985-2010 fish ticket database (provided by ADF&G) and a Leslie depletion model (Hilborn and Walters, 1992) to analyze the changes in nominal catch per unit effort (CPUE) as a function of cumulative catch. Their results indicate a high contrast in the in-season catch rate time series (Figure 6), very informative to fit these models to the data. In the context of the EBS snow crab assessment, these results can be used to compare GMACS pre-season stock size estimates (e.g., MMB) or to fit this data internally in the model via an integrated approach (Maunder and Punt 2013). In addition, it is possible to use the available spatial information of catch and effort (and therefore pre-season abundance) data and its comparison to EBS Survey data to analyze movement or survey catchability. Although the current exploitation conditions are not the same as they were prior to the rationalization of the fishery, and that they have eventually modified the intensity with which the CPUE varies during the fishing season, the historical information might still proof to be relevant in the parameter estimation of the model.

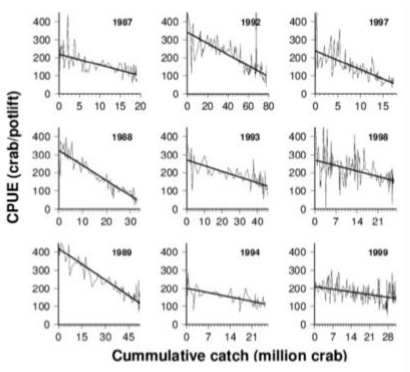

Figure 6: Depletion plots (catch per unit effort against cumulative catch) from the core western snow crab fishing grounds in the EBS from 1985-1999. Modified from Ernst et al. (2011).

Spatial aspects of EBS snow crab dynamics

EBS snow crab stock is distributed in an extensive geographical area with strong environmental gradients (Ernst et al. 2005) and influenced by strong biophysical forces (Parada et al. 2010). Under the parsimony principle, it makes sense to use a non-spatial assessment model for tactical purposes. Nevertheless, several spatial aspects that influence snow crab dynamics should be investigated in parallel outside the assessment model via spatial analysis (EBS NMFS survey data exploration and spatial models, MSE). These factors should include at least annual/biennial spawning schedule, the spatial distribution of primiparous/multiparous with respect to mature/morphometrically mature/old shell male crabs in the middle and outer domains (Ernst et al. 2012), and connectivity between EBS and northern stocks, to investigate large potential biases if spatial components are ignored.

Connection of EBS stock with Northern stock

The expansion of the EBS survey sampling area during the last decade to the north of St. Matthew Island has demonstrated relevant distributional spatial continuity of the EBS stock with the population to the north. Parada et al. (2010), using EBS survey data and biophysical modeling, conceptualized two major connected subsystems. A sink population in the north receives propagules advected away from the EBS stock through predominant currents, and Immigrants from the northern section of the middle domain, mostly outside the region regularly covered by the surveys, are suspected of giving origin to conspicuous pulses of SCI 3 female abundance in the EBS outer domain. This would imply that much of the action-driving fluctuations of the stock appear to occur in regions and involve stages beyond the fishery's reach. Even though it might not be suitable to use a spatial assessment model to provide management recommendations, it is crucial to study the role of the northern stock in the EBS snow crab stock dynamics. Parada et al. (2010) suggested that potentially large males of the same pulses molting into maturity during the summers of 1989–1991 and 1997–1998 contributed to the high winter landings of the 1990–1992 (historical maximum) and 1998–1999 fishing seasons. Therefore, a thorough spatial analysis should be performed to assess if, in years of high recruitment to the model, the distribution of small crab is significatively represented to the north of St. Matthew Island. A more comprehensive spatial analysis can be implemented in years with an extended northward survey (last decade). This analysis should include environmental covariates (e.g., NBT) to assess possible drivers that determine changes in the spatial distribution of the northern stock.

Model Parameters

Natural mortality

Natural mortality is an important parameter but difficult to estimate for the vast majority of stock assessments worldwide, and the situation with EBS snow crab modelling is not an exemption. In this assessment, maximum crab-age (17 and 23 years) and an empirical method based on longevity is used to estimate an average natural mortality rate for the population. Because snow crab cannot be directly aged, these numbers are inferred from Eastern Canada snow crab stocks for adolescent individuals and old radiometric studies for terminally molted crabs. Since in this assessment, natural mortality represents one of the main axes of uncertainty (stated by the assessment author), efforts should be oriented to improve the knowledge of the maximum age in these two periods of snow crab life history. An updated radiometric aging study on very old shell male and female crabs is of high priority, samples should be relatively easy to obtain from the NMFS survey and/or the winter fishery. Efforts on ageing and validation of snow crab age (Rebert, 2019 and Rebert et al. 2020) via growth band count should continue, with emphasis on near terminally molted crabs (e.g., primiparous females).

Growth increment study

Somatic Growth is an essential component of size-based model dynamics. In the last decade, efforts have been made in the EBS to obtain ex-situ molt increments-at-size estimates for crab captured right before molting. These crabs are typically caught during the winter fishery and translocated to ADF&G rearing facilities. Despite small sample sizes, these data increments seem very consistent for snow crab females compared with Eastern Canada's field data (Alumno-Bruscia and Saint-Marie, 1998). I encourage the scientific group to continue with this work, but also to provide a detailed description of the methodology involved in this analysis to assess potential methodological biases.

Selectivity Catchability studies

Somerton et al. (2013) show that substrate type can influence selectivity. Further understanding of the implications of these experiments is a research priority for snow crab.

Crab Disease

During the workshop, there was some discussion about the increasing proportion of bitter crab disease incidence in snow crab across the EBS. The provided information suggests that close monitoring on this disease expansion should continue.

Bristol Bay Red King Crab

Growth

A mark recapture program for estimating growth increments for sexes and shell condition should be put in place to update the very outdated data used in this assessment. This can be implemented using the methodology presented by Bell et al. (2016) for Norton Sound (AK).

Better knowledge of the spatial dynamics of red king crab in Bristol Bay and the influence of environmental factors on its distribution is of great importance. Recent work by Zacher et al. (2017) used high-resolution fish ticket data to unravel the spatial distribution of the harvested stock during winter /spring in multiple years of the last two decades. Combining this information with the spatial distribution of crab in the summer and physical variables might provide especially useful insights on the impact of survey timing and possible availability issues. For the moment, it may be used for analyzing historical data, but in the future, this in-season information could be used as a spatial distributional predictor of crab during the survey time and may be used to adjust survey timing for red king crab in a less ad-hoc way.

Acknowledgements

I would like to thank Martin Dorn from the AFSC (NOAA) Sand Point (Seattle) for doing a great job at chairing the virtual workshop. He was very helpful and supportive. Cody Szuwalski (AFSC) and Jie Zheng did a great job summarizing the assessment structure, input data, and results. Both assessment scientists were very responsive to the CIE reviewer's requests and often joining in fruitful discussions. I would like to thank Alexandra Dowlin, Melanie Rickett, Katie Palof, Benjamin Daly, M.S.D Siddeck, and Scott Goodman for their participation in the workshop. Finally, I would like to thank Manoj Shivlani and Roberto Koeneke (CIE) for contacting me for this review.

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Zheng, J. and M.S.M. Siddeek. 2020. Bristol Bay red king crab stock assessment in fall 2020. C1 BBRKC SAFE October 2020. 204 p.

Appendix 1: Material provided for the review

Main Assessment documents:

- J. Zheng and M.S.M. Siddeek. 2020. Bristol Bay red king crab stock assessment in fall 2020. C1 BBRKC SAFE October 2020. 204 p.
- Szuwalski, C. 2020. A stock assessment for eastern Bering Sea snow crab. C1 Snow Crab SAFE September 2020. 89 p.
- Zacher, L.S., Richar, J.I., Foy, R.J. 2019. The 2019 eastern Bering Sea Continental Shelf Trawl Survey: Results for commercial crab species. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC, 190 p.

Narrated PPT presentations

- *Bristol Bay Red King Crab Model History and Responses to CIE Recommendations in 2008 and Recent CPT and SSC Comments* by J. Zheng and M.S.M. Siddeek.
- *Eastern Bering Sea Continental Shelf Bottom Trawl Survey: Commercial Crab Species Data Collection* by Chris Long, Jen Gardner, Christie Lang, Jon Richar, SAP staff.
- *Survey data processing and analysis: The SAP coffee subsidization program* by Jonathan Richar.
- *North Pacific Observer Program Alaska Fisheries Science Center Fisheries Monitoring and Analysis Division* by Alexandra Dowlin.
- *Snow crab assessment history since 2014 CIE review* by Cody Szuwalski.
- *BSFRF Cooperative Research Industry Sponsored Trawl Surveys* by Scott Goodman.

Additional material uploaded to following website:

https://archive.fisheries.noaa.gov/afsc/refm/stocks/plan_team/2021_crab_cie/

Appendix 2

Statement of Work

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

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

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 22-25 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: Agenda

Virtual CIE Panel 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
Point of contact: Cody Szuwalski; cody.szuwalski@noaa.gov

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 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	