Independent Peer Review of the Stock Assessments for Eastern Bering Sea snow crab and Bristol Bay red king crab

Virtual panel meeting

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Executive Summary

A virtual panel review was undertaken of the stock assessments for Eastern Bering Sea snow crab (EBSSC) and Bristol Bay red king crab (BBRKC). The summary of findings and recommendations of the review for each stock assessment have been presented taking into account five 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.*

BBRKC summary of findings and recommendations:

- The RKC stock was assessed using a size-structured assessment and a general model for assessing crustacean stocks (GMACS) has been successfully developed and adopted for the BBRKC. GMACS presents a standardized platform that will ultimately be used for all crab stocks assessed in the Bering Sea. The successful transition to the GMACS model is one of the strengths of the assessment as it uses a standard framework for Alaskan crab assessments rather than development of bespoke models. Seven GMACS models were compared with model 19.3 identified as the preferred model as it fits the data better with one less parameter.
- Juvenile abundance from NMFS survey identifies good recruitment that can be followed in future years with modal progression. However, these recruitments may be a combination of a number of year-classes. Surveying the juvenile crab abundance in nearshore locations may provide an estimate of younger juvenile abundance where the year-class is better defined.
- The RKC is managed separately from fisheries of RKC outside of this area, i.e., it is assumed to be a separate stock. It would be useful to see what the evidence is for this, e.g., genetic and larval transport model. The larval modelling may provide information on the relevant importance of different spawning areas, e.g., is the spawning stock in the southern part of Bristol Bay an important 'source' area of stock that may need additional protection.
- The stock-recruitment relationship (SRR) showed that recruitment was generally lower when MMB < Bmsy compared to when MMB was larger than Bmsy. However, it is important that the effect of the environmental factors affecting recruitment are also assessed. The SRR could be used to crosscheck whether Bmsy and MSST levels are the appropriate reference levels.
- VAST estimates from the NMFS survey provide an alternative model-based method for the survey estimates that should be examined to see their effect on the stock assessment model.
- Further assessment of the commercial fishery's catch, effort and catch rate is warranted as it could provide valuable information about the fishery's effect on the targeted biomass. This information can be used to assess the spatial distribution of autumn/winter fishing catch and

catch rates compared to the summer survey spatial distribution. A depletion analysis of the 3-month fishery should be assessed as it may provide valuable information on catchability estimates and harvest rate of the legal-size abundance. The comparison of the annual commercial CPUE and NMFS survey area-swept legal male abundances can be used to assess the fishing efficiency. The commercial catch rates may be improved as indices of abundance by standardizing them using a statistical analysis such as GLM.

- Area-swept estimate of NMFS survey biomass should be broken down by different life history stages such as mature, legal size, juvenile (<120 mm) and undersize (120-135 mm) males and estimates for immature and mature females. These estimates could then be compared to the model-based estimates. Monitoring the undersize abundance can be compared with the commercial CPUE the following year.
- There is an increase in the size at 50% maturity for female RKC estimated from NMFS survey data from 80 to 95 mm from 1975 to 2008. This time series should be extended to 2019 data to see if the trend is continuing. The effect of this change on the model-estimate FMB should be assessed. While similar information is not available for changes in male size at maturity, it is likely that something similar is happening for males and that a sensitivity assessment should be undertaken to see what effect it could have on the time series of MMB.
- A model run just using data from 1985 should be assessed given the need to have a much higher M estimate for the early 1980s to explain the drop in biomass that occurred in this period. The trial model would provide a time series of about 35 years and avoids having to assess the different mortalities. The more recent data may have improved data quality in the survey estimates and fishery and observer data.
- The ratio of NMFS survey abundance to the BSFRF side-by-side survey for 2014 is much higher than for the other 3 years and the 2014 NMFS survey appears to be inconsistent with surveys in the years before and after. It also appears anomalous for the EBSSC in 2014. The stock assessment needs to consider estimating survey selectivity without using 2014 as a sensitivity assessment to assess the effect of this change on the stock assessment. The model also assumes catchability of 1 for the BSFRF, however there is no evidence as to whether this assumption is reasonable. An assessment of environmental and biological factors that may have affected the catchability of the NMFS surveys such as may have occurred in 2014 should be undertaken. An assessment of the vessel performance during the survey may also be appropriate to assess whether it performed in the standard manner that was expected.
- A possible weakness in the model is the lack of model fit to the BSFRF survey as all the models underestimate male biomass for all six years of the survey. This may be related to the selectivity of the NMFS survey compared to the BSFRF survey discussed above.
- A strength of the assessment is the retrospective analysis that determined the level of uncertainty of the estimated management quantities including estimating the effect of not undertaking the 2020 NMFS survey. The analysis shows the uncertainty of the recruitment estimate in terminal years therefore the terminal year (2020) of recruitment was appropriately not be used for estimating $B_{35\%}$. Retrospective analysis results in higher terminal MMB in 2014-2019 which indicates an optimistic assessment of MMB. The higher-than-expected NMFS survey of 2014 can be contributing to this bias.

- It is important to continue to monitor key BBRKC ecosystem indicators such as Arctic Oscillation index, chlorophyll a levels, wind stress and abundance of predators such as juvenile salmon sockeye, water temperatures and cold pool. It is important to monitor the annual environmental variability, long-term trends and extreme events as these may have a marked effect on biological parameters and survey catchability estimates that can affect the stock assessment.
- The stock assessment concludes that the stock was above MSST in 2019/20 (i.e., not overfished) and the catch below OFL (i.e., no overfishing). These are important key indicators of stock status but just relying on these indicators may present an optimistic assessment of the stock status without noting some of the other important information that is presented in the stock assessment report. While the Executive Summary of the report mentions the decline in MMB and low recruitment, there are other relevant information that should be highlighted when assessing the overall stock status. These include the recent declining trends in commercial catch and CPUE, legal-size abundance, total survey biomass as well as the projections and near future outlook are important indicators that should be considered in assessing the overall stock status of BBRKC. These highlight that the stock may be in a high-risk area despite the fishery being formally assessed as not overfished and no overfishing.

EBSSC summary of findings and recommendations

- The stocks are assessed using the status quo size-structured model and for the first time a GMACS model has been developed for the EBSSC. Modifications have been made to it to accommodate the life history of terminally molting animals (including snow crab). The move of the modelling framework to the GMACS model is an important development and a strength of the modelling as it uses a standard framework for Alaskan crab assessments rather than developing bespoke models. While there are important concerns about the differences between the OFL estimates between the GMACS and status quo models, these are partly due to the GMACS model providing a better fit to the 2018 and 2019 MMB (resulting in a higher MMB estimate) than the status quo model and the lack of the 2020 NMFS survey that would have provided greater confidence in the estimate of the MMB.
- Three models were presented including the status quo model 20.1 and GMACS model 20.2. These were evaluated based on five criteria: fit to the data, credibility of estimated population processes, stability of the model, retrospective patterns, and the strength of the influence of the assumptions of the model on the outcomes. The author preferred model was the GMACS 20.2 which compared well with the status quo model in terms of its fit to NMFS and BSFRF survey data and MMB estimates, the credibility of population estimates (e.g., M and growth). Therefore, this model should be adopted for future stock assessment modelling.
- The historic MSST estimate has been declining from assessments conducted from 2015/16 to 2019/20 from 75.8 to 56.8 kt. This decline in the MSST needs to be assessed as to whether the recent models represent an improved assessment of the MSST or whether the recent assessments are resulting in a weakening of the standard for assessing the overfished status. The Kobe plot shows that fishing mortality F exceeded $F_{35\%}$ in 2014-2018 years and model-estimate MMB was below MSST in 2014-2017 (i.e., overfished). These high F values may have driven the fishery target male biomass of >101 mm in 2016-2019 to record-low levels. A

weakness of the process is that the fishery maintained this high level of fishing and low MMB for this extended period despite the total catch being well below the OFL and ABC.

- A large recruitment is moving through the size classes and contributing to the recovery of MMB in 2019 and 2020 and as a result the GMACS 2020 OFL was 184.9 kt, about double the status quo model. There was a large difference in modelled 2015 recruitment between the models and the increased estimate of recruitment in the 2020 assessment could be spurious as there was no survey data to confirm the estimate. This creates some uncertainty in the setting of the TAC and a precautionary approach is required, e.g., use the previous year's lower estimate until there is some confirmation from the next NMFS survey. Good recruitments appear to occur every 5-7 years with 6 good recruitments occurring since the early 1980s.

- The connection between the snow crab stock in the EBS and the northern Bering Sea (NBS) needs to be understood better. For example, is there migration of the NBS stock to the EBS and is there larval flow north. This is particularly important now with the good recruitment in 2015 and it would be good to assess this recruitment year-class in the NBS. NMFS survey data from 2017-2019 on snow crabs in the NBS should be examined as part of this analysis.

- An assessment should be undertaken of how often waters colder than 1.5^{o}C occur in the EBS and whether this causes female crabs spawning every 2 years as suggested in laboratory studies. For example, does this cause an increase in the proportion of barren females?

- An assessment of the commercial fishery's catch, effort and catch rate could provide valuable information about their effect on the targeted biomass which would also affect the MMB. The commercial CPUE can be compared to the NMFS survey abundance >101 mm, the fishery target size. This information can also be used to assess the spatial distribution of fishing catch and catch rates compared to the NMFS survey spatial distribution. Depletion analyses could be conducted to provide valuable information on the catchability estimates of the pot fishery and harvest rates on the target size component of the stock.

- As the fishery targets new shell males >101 mm, it is important to assess the biomass of this component of the stock as it provides an indication of the proportion of this target component that is removed which should be relevant to the setting of the TAC. The importance of this is currently highlighted as the male biomass of >101 mm in 2016-2019 being at record-low levels while the observed 2018-2019 MMB is the highest since 1998, resulting in a high OFL estimate (184.9 kt). This emphasizes the need for the abundance of male >101 mm (particularly new shell) being a key model output.

- The discard biomass of 5.07 kt in 2020 (25% of catch) from the pot fishery was the highest since 1997. This may be due to the high rate of undersize abundance because of large 2015 recruitment and the high fishing mortality may have also contributed. The discards should be continued to be monitored closely particularly in the next few years as the 2015 recruitment moves through into the fishery.

- Monitoring the percentage of mature males that are old shell may be important as this may represent the component that is mating. Shell condition is an important component of the biology and fishery and it should be assessed whether shell condition should be a formal component of the model or assessed outside the model.

- The long time series of the NMFS survey data is one of the strengths of the stock assessment and is the key component of the stock assessment models. The value of this time series was highlighted in 2020 as one of the difficulties in the assessment was the lack of the NMFS trawl survey that was not undertaken because of COVID. The stock assessment included additional Retrospective analyses that evaluated the effect of this missing survey on the uncertainty associated with the model outputs.
- Time-varying survey catchability may cause poor model fit to the NMFS survey in some years. An assessment of environmental and biological factors that may have affected the catchability of the survey, such as may have occurred in 2014 and 2018, should be undertaken. An assessment of the vessel performance during the surveys may also be appropriate to assess whether it performed in the standard manner that was expected. For example, the NMFS survey estimate for MMB for 2014 appears to be unexpectedly high therefore a sensitivity assessment putting a high CV on this survey should be undertaken as done for the BBRKC during the review. This issue may also be contributing to the retrospective patterns.
- VAST estimates from the NMFS survey provide an alternative model-based method for the survey estimates that should be examined to see their effect on the stock assessment model.
- The high proportion (50-60%) of bitter crabs in the population should be assessed further as it would affect the discard rate and could affect the population rates such as growth and survival. A sensitivity analysis assuming a higher rate of mortality for bitter crabs could be undertaken as a preliminary analysis of the issue. This could also be contributing to some of the retrospective patterns being observed.
- The marked decline in the weight at length for females that was calculated in 2016 requires further assessment as to whether this represents a decline in the condition of female crabs.
- A model run just using data from 1989 should be assessed as it still provides a time series of 30 years and avoids having to assess a different catchability for 1982-1988 because of a change in net. The more recent data may have improved data quality in the survey estimates and fishery and observer data.
- The spatial distribution between large males in surveys and the spatial distribution of the fishery should be assessed. Is the difference between the two, due to crabs' migration or fishers fishing in their preferred locations? This could be examined by seeing whether fishers' catch rate close to survey centroid are higher than those in areas away from centroid.
- The stock-recruitment relationship between the MMB and recruitment should be presented even if it is not statistically significant. This may provide some insight as to whether the Bmsy and MSST estimates are the appropriate reference levels. The effect of any environmental factors such as the Arctic Oscillation which is significantly related to recruitment should also be assessed. While the relationship of recruitment and the winter Pacific Decadal Oscillation is not significant, 8 of the 9 highest recruitment classes occur when the PDOw > 0 and similarly for when the Arctic Oscillation is < 0. Even if environmental conditions are not an integral part of the stock assessment, it is important to monitor their annual variability, long-term trends

and extreme events as these may have a marked effect on biological parameters and survey catchability estimates that can affect the stock assessment.

- The ‘exploratory’ projection analysis uses random historical recruitments. The stock assessment should consider dropping recruitment from 1980s and early 1990s as these have not been replicated in recent years except for 2015 whose level is still to be confirmed.
- Two Retrospective analyses were undertaken with the first analysis assessing the changes in management quantities when an additional year’s data are added and the second assesses the additional effect of the missing NMFS survey in the terminal year. The patterns are of concern as they would have consistently translated into higher OFL (i.e., overharvesting). Hence it is important that this model uncertainty is acknowledged and that the observed estimates of MMB are taken into account in assessing the stock status and determining the OFL rather than totally relying on the model-estimates.

Background

Stock Assessments have been conducted for Eastern Bering Sea snow crab (EBSSC) by Cody Szuwalski (Alaskan Fishery Science Center) and Bristol Bay red king crab (BBRKC) by Jie Zheng and Shareef Siddeek (Alaska Department of Fish and Game).

The stocks are assessed using size-structured assessments and a general model for assessing crustacean stocks (GMACS) has been developed and adopted for the BBRKC. GMACS presents a standardized platform that will ultimately be used for all crab stocks assessed in the Bering Sea. Modifications have been made to it to accommodate the life history of terminally molting animals (including snow crab) and GMACS was one of the models used for the assessment of snow crab.

A CIE review of the stock assessment was requested with the materials provided listed in Appendix 1. The specified format and contents of the individual peer review reports are found in Annex 1 of Appendix 2. The Terms of Reference (TORs) of the peer review are listed in Annex 2. The agenda of the panel review meeting is Annex 3.

Reviewers' roles

Three CIE reviewers (Appendix 3) conducted the peer review in accordance with the ToRs listed below and provided individual reports on their findings. The meeting was chaired by Dr Martin Dorn. Two weeks before the peer review the reviewers were provided access to a number of documents as background information and the two stock assessment reports for the peer review (Appendix 1). There was a virtual meeting test to confirm that the technical (hardware, software, etc.) capabilities was working for the reviewers to participate in the virtual panel in advance of the review meeting. A few days before the meeting the reviewers were provided eight pre-recorded PowerPoint presentations that were relevant components to the review. These presentations were viewed by the reviewers before the meeting and there was an opportunity to ask questions of the presenters on the first day of the review. The viewing of some of the presentations before the meeting enabled the virtual meeting to be four hours per day. The reviewers participated in a virtual panel review over four days, 22-25 March 2021 (1-5 pm Seattle time), via Google Meets video conferencing to conduct the peer review. This time was selected as a compromise for the different time zones of the presenters and reviewers. This was the first time a virtual panel review has been conducted by the CIE.

The meeting was attended by scientists, managers and industry involved in the fishery and the stock assessment modeling. The scientists presented the key aspects of their research according to the agenda. Copies of the presentations were provided to the reviewers via google drive. Throughout the presentations the CIE panel and others asked questions on issues of management, data collection, biology, the stock assessment modeling and related research that was presented. All presenters answered questions and expanded on some aspects of their research. There were some formal requests from the reviewers for additional information from the presenters which were presented later and provided on google drive. The reviewers undertook some discussions regarding their review of the stock assessment. The panel then prepared to write their individual reports.

The panel received excellent support from the scientists involved in the review and the Chair. This included timely provision of documents, the organization and conduct of the meeting, the presentations during the meeting and the response to questions and formal requests for additional analyses. While the virtual meeting was not ideal for conducting the review, the process worked and the review was successful.

Summary of Findings

The review was undertaken of the stock assessments for Eastern Bering Sea snow crab and Bristol Bay red king crab. The findings of the review have been presented according to the five Terms of References (TOR) set of the panel (*in italics*) and the summary of findings for each TOR in which the weaknesses and strengths are described, and conclusions and recommendations in accordance with the TORs. The figures and tables referred to in this report are referencing those in the two stock assessment reports on BBRKC and EBSSC to make it explicit the issue that is being referred to.

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

Background

- The Bristol Bay red king crab (RKC), *Paralithodes camtschaticus*, has a wide distribution in North Pacific Ocean in depths of >200m. The RKC is managed separately from fisheries of RKC outside of this area, i.e., it is assumed to be a separate stock. The evidence (genetic, larval transport) for this to be a separate stock should be assessed.
- The USA pot fishery of RKC expanded in late 1960s and peaked in 1980 with 58 943 t and declined dramatically in the early 1980s. In 2005/06 crab fishery rationalization was implemented with introduction of individual fishery quota (IFQ) and season extended (15 Oct - 15 Jan). The fleet reduced from 274 vessels in 1998 to 89 after rationalization and there were 56 vessels operating in 2019/20.
- The fishery has two major objectives: (a) maintain healthy stock that ensure reproductive viability and (b) sustained level of harvest. The current harvest strategy (HS) has mature male harvest rate of 0, 10, 12.5 and 15% depending on effective spawning biomass (ESB) (Figure 1 in BBRKC report). The males are estimated to mature at 119 mm carapace length (CL) and females at 89 mm CL. The male legal size is set at 135 mm CL.
- Biomass and fishing mortality reference levels include $B_{35\%}$ and $F_{35\%}$ which were calculated using the stock assessment model parameters in a mature male biomass-per-recruit analysis. These reference levels are proxies for Bmsy and Fmsy. If the biomass is below 0.5 Bmsy (minimum stock size threshold - MSST) then the stock is classified as 'overfished'. The overfishing limit (OFL) is determined using the proxies for biomass and fishing mortality reference points and control rule. The acceptable biological catch (ABC) is set as a proportion of the OFL. This was set at 0.75 OFL in 2020 due to the stock being close to overfished and the lack of survey in 2020. The TAC is set lower than ABC taking all relevant factors into account and after consultation with industry.

NMFS survey

- The long time series of the fishery-independent NMFS survey data is one of the strengths of the stock assessment and is the key component of the stock assessment models used to assess the fishery. Resurveys in some years (1999, 2000, 2006-2012, 2017) when high proportion of mature females have not molted or mated is also a strength of the assessment as it provides a backup to the original survey data.

- The value of this time series was highlighted in 2020 as one of the difficulties in the 2020 assessment was the lack of the NMFS trawl survey that was not undertaken in 2020 because of COVID. The stock assessment included additional Retrospective analyses that evaluated the effect of this missing survey on the uncertainty associated with the missing survey.
- An area-swept estimate of NMFS survey biomass is provided for all males and females >64 mm (Fig. 10a, Table 6b) and compared to the model estimates. The comparison of area-swept estimate of males and females shows that male biomass was consistently greater than females until 2008 whereas since 2009 the male and female biomass is similar (Fig. 6). It would also be useful to see the time series of area-swept estimates broken down by different life history stages such as mature, legal size, juvenile (<120 mm) and undersize (120-135 mm) males and estimates for immature and mature females. These could then be compared to the model-based estimates.
- Egg clutch fullness was below average for 2011-2013 and 2016-2018 with a small increase in proportion of empty clutches in 2011, 2013 and 2017 (Fig. 15). This period coincides with a decline in mature male biomass (MMB) and should be continued to be monitored closely as MMB is expected to be low in the near future.
- The size at 50% maturity for female RKC has been estimated from NMFS survey data. This has increased from about 80 to 95 mm from 1975 to 2008 (Fig. A3). However, a fixed 89 mm is used in the model as the basis for estimating the abundance of mature females. The effect of the smaller size of maturity in the 1970s and 1980s would result in a larger size range that would have been mating and spawning in 1970s, 1980s and 1990s compared to the 2000s. If the increasing length of maturity was applied to the time series of model-estimated female mature biomass (FMB) (Table 6b), it would result in a larger FMB in the early period compared to the recent years and exacerbate the decline that has currently been estimated. This time series of length at maturity should be extended to the years after 2008 to see if the trend is continuing. A similar time series estimate is not available for changes in size at maturity of males over the years to test whether the current estimate of 120 mm is applicable over the whole time series. However, it should be assessed whether it is likely that there is a similar trend occurring for males as it can have major implications to the time series of MMB that is the focus of the assessment. A model sensitivity assessment with a possible trend in the size of maturity for male should be examined.

Stock assessment model

- The RKC stock was assessed using a size-structured assessment and a general model for assessing crustacean stocks (GMACS) has been successfully developed and adopted for the BBRKC. GMACS presents a standardized platform that will ultimately be used for all crab stocks in assessed in the Bering Sea. Since 2019 GMACS has been used as stock assessment model for RKC. The successful transition to the GMACS model is one of the strengths of the assessment as the move of the modelling framework to the GMACS model is an important development and a strength of the modelling as it uses a standard framework for Alaskan crab assessments rather than development of bespoke models that are dependent on the individual scientist's model development approach.

- Seven GMACS models were compared with model 19.3 identified as the preferred model by CPT as it fits the data better with one less parameter. The mean recruitment sex ratio during the reference period used to estimate $B_{35\%}$ which represents an improvement on using the sex ratio of the terminal year. Terminal year recruitment analyses suggest the estimated recruitment in the last year should not be used for estimating $B_{35\%}$.
- Constant mortality M estimated for males during 1980-84 and M of 0.18 for males in other years. M for females assumed to be proportional to M for males. Consideration should be given to starting the model in 1985 to avoid the need to try and explain the major decline in the early 1980s by having a high estimate of M.
- The retained proportion by length for the pot fishery appears to be similar before 2005 and after 2004 (time of fishery rationalization) (Fig. 8d). The two relationships could be examined to see if they are statistically different and combined if they are not different.
- It is important that the fishery-dependent commercial crab per potlift (CPUE) be assessed as it may provide valuable information on the effect of the fishery on the legal biomass that complements the NMFS survey data. This information can be used to assess the spatial distribution of autumn/winter fishing catch and catch rates compared to the summer survey spatial distribution. A depletion analysis of the 3-month fishery should be assessed as it may provide valuable information on the annual estimates catchability and harvest rate on the legal-size abundance that can complement the model estimates.
- The annual commercial CPUE that are compared to the annual NMFS survey area-swept legal male abundances shows a widening gap in the trends since 1984 (Fig. 4). This difference in trends between the two-time series over 36 years can be used to estimate the increase in fishing efficiency which appears to be about 2-3% pa. The commercial CPUE estimates before and after 2005 may be affected by the move to crab rationalization (use of IFQ). de Lestang et al. (2018) undertook as similar analysis to estimate the annual fishing efficiency for the western rock lobster fishery and they estimated the effect on CPUE efficiency change of moving from an effort-controlled fishery management to an IFQ type fishery. The annual commercial catch rates may be improved as indices of abundance by standardizing them using a statistical analysis such as GLM.
- A strength of the modelling is that the modal progressions of good recruitment year classes are tracked well for the NMFS survey in the following 5 years and indicates that reliable estimates of future MMB and legal-size biomass may be made 3-4 years ahead. The last good recruit cohorts were in 2005 and 2010 to a lesser extent.
- Some additional information that should be added to the stock assessment report includes: (a) a plot of model and survey based MMB as per Fig. 10b for total male biomass; and (b) add Bmsy and MSST for model 19.3 on Fig. 11; and 13b.

Stock status

- The current stock assessment based on the author-preferred model 19.3 concludes that the stock was above MSST in 2019/20 and hence not overfished, and that the catch was below the OFL so there was no overfishing. These are important key indicators of stock status but just relying on these indicators may present an optimistic assessment of the stock status without noting some of the other important information that is presented in the stock assessment report. While the Executive Summary of the stock assessment report also mentions that 'mature male biomass has steadily declined since 2009' and that 'recruitment was extremely low in the last 12 years', there are other relevant information presented in the document that should be highlighted in the Executive Summary when assessing the overall stock status.
- The 2018 and 2019 RKC catch was the lowest since the stock collapse of 1983 and the closure of the pot fishery in 1994 and 1995. The commercial catch rate (CPUE) has been declining since 2007 with the 2019 CPUE being the lowest since 1999.
- The 2018-2019 area-swept total biomass (>64 mm) was the lowest on record, even lower that the biomass in the 1980s when the stock collapse. Model estimates of total survey biomass shows a persistent decline for males and females since mid-2000s (Fig. 10b).
- The model estimates of MMB and numbers of legal-size for 2017-2020 are the lowest since the early 1980s and 1993 (Fig. 11, Table 6b) which are both periods that are associated with the closure of the fishery because of low abundance. MMB is less than Bmsy for last 5 years with the 2020/21 level being 41% below Bmsy and close to the MSST.
- Estimated male recruits since 2011 have all been below the average recruitment over 1984-2019 (Fig. 12a). Average recruitment during 1984-2019 (after the regime shift of 1976/77) and MMB per recruit are used to estimate $B_{35\%}$, a proxy for Bmsy. If the more recent average recruitment is used to assess Bmsy it results in a lower estimate of Bmsy and hence a lower estimate of MSST which may result in the stock being classified as overfished.
- The stock-recruitment relationship (SRR) between total recruits and MMB shows the usual high level of variability (Fig. 14a) of an SRR. However, when MMB < Bmsy the range of recruits is about 0-30 million with most years <20 million but when MMB > Bmsy, the range of recruits is 0-60 million for all years except 1982. The MMB for 2014-2020 are all below Bmsy and these will give rise to recruits during 2020-2026. This SRR assessment supports the estimate of Bmsy being an appropriate reference level in the stock assessment given the range of recruits less than and greater than Bmsy. High recruitment in the late 1960s and 1970s occurred when the spawning stock was primarily located in the southern Bristol Bay whereas now it is located in the middle. If this assessment is correct and that the southern Bristol Bay is an important 'source area', should there be some spatial protection for the southern part of the stock?
- Under current harvest strategy, $F_{35\%}$ is proxy for Fmsy in the assessment of the OFL. While fishing mortalities (F) have been declining for the last 6 years (2014-2019) they were still at or above $F_{35\%}$ limits for model 19.3 (Fig. 13b) and this has not resulted in the MMB moving to Bmsy in recent years as MMB has continued to decline.

- Future projections are a strength of the assessment as it provides an understanding of the effects of different levels of fishing mortality on MMB. The analysis is based on random selection of estimated recruitments during 2012-2019 which has been a low recruitment period. This is appropriate given the current consistent low levels of MMB and recruitment in recent years. Four levels of fishing mortality are used for the projections. MMB projections to 2030 show that fishing at the Fofl level for 2020 of 0.167 will result in a further decline in MMB (Table 7). F at 0.083 maintains the MMB at about the current level so that F would have to be set below 0.083 to achieve an increase in MMB.
- Near future outlook is for a declining trend as the last above-average year-class occurred in the hatching year of 2000 with recruitment peak in 2005. It reached maturity in 2009 and legal size by 2014 (Fig. 33). The recruitment has been relatively low since this year class.
- The recent declining trends in commercial catch and CPUE, MMB, legal-size abundance, recruits, and total survey biomass as well as the projections and near future outlook are important indicators that should be considered in assessing the overall stock status of BBRKC. These are referred to as 'lines of evidence' in a risk-based weight-of-evidence assessment (Fletcher et al. 2015) that would highlight that the stock may be in a high-risk area despite the fishery being formally assessed as not overfished and no overfishing.

BBRKC Ecosystem considerations

- Appendix E of the BBRKC stock assessment report provides an overview of ecosystem and socioeconomic profile of the BBRKC stock. Some key ecosystem observations included: (a) high Arctic Oscillation index in 2020 winter may be favourable for BBRKC productivity; (b) low chlorophyll a levels, above average wind stress and high abundance of juvenile salmon sockeye could be indicative of poor larval conditions; (c) northerly spatial shift in stock distribution associated with warmer temperatures and high Pacific Decadal Oscillations during summer; (d) in warm years crabs tend to aggregate in centre of Bristol Bay which has implication for 'fixed closure areas'; (e) low recruitment in recent years may be associated with above-average temperatures and reduced cold pool. It is important to monitor the annual environmental variability, long-term trends and extreme events as these may have a marked effect on biological parameters and survey catchability estimates that can affect the stock assessment.
- Monitoring of BBRKC biomass in the size range, 110-134 mm biomass that will likely enter the fishery the following year is a good indicator to assess and compare with the commercial CPUE the following year.

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

Background

- The distribution of the eastern Bering Sea snow crabs (EBSSC) is in depths of <200 m with smaller crabs more abundant in the inshore northern regions and mature crabs occurring more in deeper areas south of the juveniles. It is managed as a single stock in the eastern

Bering Sea but there is good abundance of mainly juvenile snow crabs in the adjacent northern Bering Sea (NBS) and the population may extend to Russian waters.

- It would help the understanding of the stock status of the EBSSC if the connection of the EBSSC stock with the northern Bering Sea stock was better understood. For example, is there migration of the NBS stock to the EBS and is there larval flow north. This is particularly important now as a good recruitment occurred in 2015 and it would be good to assess this recruitment year-class in the NBS as well. NMFS survey data from 2017-2019 on snow crabs in the NBS should be examined as part of this analysis.
- Laboratory studies indicate that female crabs in waters colder than 1.5°C spawn every 2 years. An assessment should be undertaken of how often these conditions occur in the EBS and whether there is any correlation between water temperature and the proportion of barren females.
- The retained catch reached historical high catches in 1990s with a peak of 149 kt in 1990. The 1998 catch was 88 kt but stock was assessed as overfished in 1999 (below the minimum stock size threshold - MSST). The retained catches then increased to 2011 to 40 kt before declining again to 9 kt in 2017 and then increasing to 15 kt in 2019.
- The discard biomass of 5.07 kt in 2020 (25% of catch) from the pot fishery was the highest since 1997 and it may be due to the high rate of undersize abundance because of large 2015 recruitment year class. The high fishing mortality may have also contributed. With an assumed discard mortality rate of 39% this makes a large contribution to the total catch that needs to be taken into account in the TAC setting. The discards should be continued to be monitored closely particularly in the next few years as the 2015 recruitment moves through into the fishery.
- Besides the assessment of the retained catch, bycatch and discard mortality there was little assessment of the commercial fishery's data such as the catch rate. It is important that the fishery-dependent commercial crab per potlift (CPUE) be assessed as it may provide valuable information on the effect of the fishery on the legal biomass. The commercial CPUE can be compared to the NMFS survey male abundance >101 mm, the fishery target size. This information can also be used to assess the spatial distribution of fishing catch and catch rates compared to the summer NMFS survey spatial distribution. During the review there was mention of historic depletion analyses being conducted on the fishery that should be reassessed as it may provide valuable information on the annual estimates catchability of the pot fishery and annual harvest rates on the legal-size component of the stock that can complement the model estimates.
- Fishery targets mainly new shell males that molt to maturity and are an acceptable market size (>101 mm). While the assessment is appropriately based on the MMB, it is relevant to know the abundance of males 101+ mm that are new shell as this is target component. This will provide an indication of the proportion of this target component that is removed which should be relevant to the setting of the total allowable catch (TAC). One of the requests during the review was to obtain an estimate of the proportion of males >101 mm that are old shell (discussed below).

- Currently Bmsy set using spawning biomass per recruit of 35% of unfished levels. Recruitment used to calculate Bmsy is from 1982 but not including the last year.
- It is not clear why the minimum size was 78 mm CW when the size of 50% maturity is about 90-100 mm and the industry target size is 101+ mm.

NMFS Survey data

- The long time series of the fishery-independent NMFS survey data is one of the strengths of the stock assessment and is the key component of the stock assessment models used to assess the fishery. The value of this time series was highlighted in 2020 as one of the difficulties in the 2020 assessment was the lack of the NMFS trawl survey that was not undertaken in 2020 because of COVID. The stock assessment included additional Retrospective analyses that evaluated the effect of this missing survey on the uncertainty associated with the model outputs.
- There are spatial gradients by size and maturity for both sexes in the NMFS survey. The centroids of NMFS survey abundance have moved with the mature females and large males having moved north during 1990s and then south in the early 2000s. There was also a difference in distribution of large males in surveys and the spatial distribution of the fishery and it is important to assess spatial distribution of fishing and catch relative to the survey particularly under a changing climate that can affect the spatial distribution of the stock and where fishing can occur. The spatial distribution of harvesting will affect the spatial distribution of abundance of the target size that remains for mating.

Stock assessment model

- The stocks are assessed using the status quo size-structured model and for the first time a GMACS (general model for assessing crustacean stocks) model has been developed and adopted for the EBSSC. GMACS presents a standardized platform that will ultimately be used for all crab stocks assessed in the Bering Sea. Modifications have been made to it to accommodate the life history of terminally molting animals (including snow crab). The move of the modelling framework to the GMACS model is an important development and strength of the modelling as it uses a standard framework for Alaskan crab assessments rather than developing of bespoke models that are dependent on the individual scientist's model development approach. While there are concerns about the differences between the OFL estimates between the GMACS and status quo models, these are partly due to the GMACS model providing a better fit to the 2018 and 2019 MMB (resulting in a higher MMB estimate) than the status quo model and the lack of the 2020 NMFS survey that would have provided greater confidence in the estimate of the MMB.
- Three models were presented including the status quo model 20.1 and GMACS model 20.2. The models were evaluated based on five criteria: fit to the data, credibility of estimated population processes, stability of the model, retrospective patterns, and the strength of the influence of the assumptions of the model on the outcomes. The author preferred model was the GMACS 20.2 (based on fit to data, particularly MMB, credibility of population estimates (e.g., M and growth) with the GMACS model fitting the NMFS and BSFRF survey data better that status quo model.

- The model tracks number of crabs by sex, shell condition, maturity, year and length and takes into account the terminal molt from immature to mature state. Smallest crab in the model are about 4 years old. However, shell conditions are not tracked within the model. Shell condition appears to be an important component of the biology and fishery, e.g., it affects mating and the retention of crabs in the fishery. Therefore, it should be assessed whether shell condition should be a formal component of the model or assessed outside the model.
- The study by Sainte-Marie et al. (2002) stated that only old shell males take part in mating in North Atlantic. If this applies to the stock for EBSSC then it is important to monitor the percentage mature males that are old shell as this represents the component that is mating.
- The current model doesn't account for proportion of old and new shell with the data input with shell condition and then combined. However, understanding these proportions may be important as it affects mating and the retained component of the fishery. This could be undertaken by including shell condition within the model or assessing the shell condition from estimates outside the model and applying it to the estimates of interest such as males >101 mm. The request during the review meeting to assess the proportion of old shell in NMFS survey of crabs >101 mm showed that this varied considerably between years, generally between 20 and 60%, but with an estimate of about 15% in 2019. The dockside sampling of the landed catch showed an annual variation of 5-30% of old shell being landed, with about 18% landed in 2019.
- The provision of estimates of the variation about the current estimates of MMB and OFL using an MCMC approach is a strength of the analysis and they show that the confidence limits are relatively narrow.
- The stock assessment considered multiple studies and methods for determining the natural mortality estimates that suggests a large range of possible values including estimates with a high annual variability (Figure 7, Murphy et al. 2018). However, typical of most stock assessment models, the level of natural mortality was a major level of uncertainty, but the assessment represents an appropriate approach. The estimated natural mortality in the GMACS model for immature crabs was higher than for mature crabs which is reasonable from a biological perspective. This trend did not occur in the status quo model.
- There was a difference in the way female growth was modelled between the GMACS model and the status quo model with the former using a linear relationship between premolt length and growth increment while the latter used a kinked growth curve. The evidence presented supported the linear relationship. However, the model fit to the female growth data appears to underestimate the growth increments for the premolt lengths 30-50 mm (Fig. 25).
- The marked decline in the weight at length for females that was calculated in 2016 requires further assessment as to whether this represents a decline in the condition of the female crabs? Interestingly there was little change for the weight at length of males so there is little effect on the estimates of MMB that are the basis of management.
- There was considerable discussion during the review about the proportion of bitter crabs syndrome in the population. A request was made to see the estimates of bitter crabs in recent years. This showed an increase in north-east Bering Sea from 7.5% in 2014 to 49.3% in 2017 with the north Bering Sea having a 69.8% of bitter crabs in the population. These high

rates would affect the discard rate and could affect the population rate such as growth and survival. It is important that the proportion of bitter crabs in the population is monitored and its possible effect on the stock is assessed. A sensitivity analysis assuming a higher rate of mortality for bitter crabs could be undertaken as a preliminary desktop analysis of the issue. This could be contributing to some of the retrospective patterns observed.

Stock status

- The historic MSST estimate has been declining from the stock assessments conducted from 2015/16 to 2019/20 from 75.8 to 56.8 kt (Table 1 of EBSSC report). This decline in the MSST needs to be assessed as to whether the recent models represent an improved assessment of the MSST (and Bmsy) level or whether the recent assessments are resulting in a weakening of the standard for assessing the overfished status. The MMB during the first three of these years (91.6 to 99.6 kt) was above the MSST (i.e., not overfished) but below Bmsy. These levels can be compared to survey estimate for MMB of 96 kt in 1999 that was assessed as overfished.
- The 2020 model-estimated MMB has been in a long-term declining trend since the 1980s with 3 peaks and fourth potential peak occurring in 2020 (Fig. 37). Stock was rebuilt in 2011 when MMB>$B_{35\%}$ but MMB declined to a survey-estimated 63 kt in 2016 (lower that model estimate of 92 kt) and increased again to now be above $B_{35\%}$.
- The Kobe plot for GMACS Model 20.2 provides a good summary of the stock relative to the current estimate of the overfishing and overfished standards. It shows that fishing mortality F exceeded $F_{35\%}$ in 2014-2018 years and model-estimate MMB was below $B_{35\%}$ from 2011-2018 and below MSST in 2014-2017 (Fig. 38). The model estimated fishing mortality has been much higher over 2012-2018, particularly in 2014 and 2015, compared to the previous 13 years (Table 10). The high F values over 2014-2018 may have driven the fishery target male biomass of >101 mm in 2016-2019 to record-low levels. The four years, 2014-2017, are shown as being above the overfishing standard and MMB overfished. A weakness of the process is that the fishery maintained this high level of fishing and low MMB for this extended period despite the TAC and total catch being well below the OFL and ABC. The recovery of the MMB in 2019 is mainly due to the good 2015 recruitment reaching maturity.
- A large recruitment is moving through the size classes and contributing to the higher MMB and as a result the GMACS 2020 OFL was 184.9 kt fishing at Fofl of 1.65 which was 100% of $F_{35\%}$. This estimate of the OFL is about double the status quo model 20.1 as a result of GMACS model having a higher estimated recruitment and MMB. This creates some uncertainty in the setting of the TAC and a precautionary approach is required.
- There was a large difference in modelled 2015 recruitment between the models, with the GMACS model indicating a very high recruitment, with the addition of 2019/20 catch data. This uncertainty may have been resolved if the 2020 NMFS survey had occurred. This recruitment is an important driver for the estimates of the terminal year of MMB and OFL. The increased estimate of the recruitment with the addition of 2019/20 catch and bycatch data could be spurious as there was no survey data to confirm the estimate. It may be precautionary to use the previous year's lower estimate until there is some confirmation for

any revised estimate from the next NMFS survey. Good recruitments appear to occur consistently every 5-7 years with 6 good recruitments occurring since the early 1980s.

- The high 2015 recruitment has resulted in the observed 2018-2019 MMB being the highest since 1998 and as a result there is high OFL estimate (184.9 kt). This creates a mismatch with the observed 2016-2019 male biomass >101 mm being the lowest on record (Table 7 in report). This raises the question as whether the abundance of male >101 mm (particularly new shell) needs to be a key output of the stock assessment model given its relevance to TAC setting.
- Acceptable biological catch (ABC) was set with a 50% buffer from the OFL due to uncertainty due to the retrospective patterns, missing terminal year survey and around the level of 2015 recruitment event. The retrospective patterns would have resulted in higher OFLs. However, the concern in the process is that even though the retained catches have generally been well below the ABC and OFL (i.e., no overfishing), there has been a continual decline in the MMB since 2011, with a number of years now classified as overfished. This decline has now stopped with the 2015 recruits reaching maturity in 2018.
- The stock assessment indicates that the survey numbers in 2019 decreased more rapidly than expected. However, this could be due to 2018 survey estimate appearing to increase rapidly compared to the 2017 estimate. This is a similar situation to the 2014 survey estimate possibly being anomalously high. In any case, the use of a larger model-estimate MMB than the observed MMB would result in larger OFL than may be appropriate. Given the ‘difficult time fitting the observed composition of MMB in these years (2018 and 2019)’ and the lack of 2020 survey, there is uncertainty associated with the estimate of OFL and requires a precautionary approach.
- The ‘exploratory’ projection analysis at $F_{35\%}$ using random historical recruitments show MMB peaking the next 1-2 years followed by a large decline to below Bmsy. The projections at different fishing levels should be assessed to see what is the appropriate to level to maintain MMB above Bmsy in the near future. The stock assessment should consider dropping recruitment from 1980s and early 1990s in this analysis as these have not been replicated in recent years except for 2015 whose level is still being assessed.

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

Survey selectivity BBRKC

- The ratio of NMFS survey abundance to the BSFRF side-by-side survey (Figure 7c of BBRKC report) is used to estimate the weighted average ratio of 0.891 for crabs ≥ 135 mm CL from all four years, 2013-2016. The model assumes catchability/selectivity of 1 for the BSFRF, however there is no evidence as to whether this assumption is reasonable. The modelling assumes NMFS survey catchability is constant over time and estimated in model assuming a prior of 0.896.
- The ratio for 2014 is much higher than for other 3 years (Fig. 7c) and NMFS survey for 2014 appears to be anomalous in a number of ways. The high abundance in NMFS in 2014 appears

to be inconsistent with RKC surveys in the years before and after. It also appears anomalous for the EBSSC in 2014. The stock assessment needs to consider estimating survey selectivity without using 2014 as a sensitivity assessment as this ratio appears to peak at about 0.7-0.8 and assess the effect of this change on the stock assessment. Some additional work on this issue was undertaken during the CIE review by placing a much high CV on the 2014 NMFS survey. This resulted in a lower MMB in recent years, particularly 2018 and 2019, which results in a more precautionary management settings with a more conservative OFL that may be more appropriate if the 2014 is anomalous.

- A possible weakness in the model fits is the lack of model fit to the BSFRF survey as all the models underestimate male biomass for all six years of the survey (Fig. 10c). This may be related to the selectivity of the NMFS survey compared to the BSFRF survey that is discussed above.

Survey selectivity EBSSC

- There was a change of net in the 1982 NMFS survey and additional sites were added in 1989. Survey selectivity in the stock assessment model was estimated 1982-1988 and after 1989. There was a lower catchability in survey era 1 (1982-1988) relative to era 2 (after 1989). A model run just using data from 1989 should be assessed as it still provides a time series of 30 years and avoids having to assess the different catchabilities in the two periods.
- NMFS survey estimate for MMB for 2014 appears to be unexpectedly high (Fig. 28) and a similar result occurred for the BBRKC survey. A sensitivity assessment putting a high CV on this survey should be undertaken as done for the BBRKC.
- The 2009-2010 BSFRF survey focused on snow crab areas while the 2016-2018 survey was not focused on snow crabs but still caught some snow crabs. BSFRF survey generally caught higher abundance than NMFS, particularly for the smaller-sized crabs so that the selectivity of NMFS is less than that of the BSFRF survey. The model assumes catchability/selectivity of 1 for the BSFRF, however there is no evidence as to whether this assumption is reasonable. A comparison of the selectivity of NMFS for 2009 and 2010 relative to the BSFRF survey shows a similar selectivity for larger sizes (>80 mm) between the two years but with the 2010 NMFS there was a higher selectivity of the smaller crabs compared to 2009. This difference may have been affected by the different size distributions with a higher abundance of small crabs in 2010.
- The status quo model estimates logistic availability curves for some sex/year combinations, but the empirical data suggests this may not be appropriate and a more flexible approach as tried in the GMACS model appears to be more appropriate and should be examined further.

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

Retrospective analyses BBRKC:

- A strength of this assessment has been the retrospective analysis that determined the level of uncertainty of the estimated management quantities including estimating the effect of being without 2020 NMFS trawl survey data (Appendix D). The Retrospective analysis shows the uncertainty of the recruitment estimate in terminal years (Fig. 28). This issue was also identified in the previous assessment, therefore the terminal year (2020) of recruitment was appropriately not be used for estimating $B_{35\%}$.

- Retrospective analysis results in higher terminal MMB in 2014-2019 which indicates an optimistic assessment of MMB (Fig. 27). The higher-than-expected NMFS survey of 2014 can be contributing to this bias (see discussion on this under TOR 3).
- The retrospective patterns and other indicators are unexpectedly better with the trawl survey in the terminal years than with the trawl survey. This is a reflection of the 2014 survey being higher than expected and 2018 and 2019 being lower than expected.
- Historic model analysis using models since 2004 and the 2020 model performed reasonably well with model 19.3 resulting in relatively low abundance in recent years.

Retrospective analyses EBSSC

- Two Retrospective analyses were undertaken for the EBSSC. The first retrospective analysis assesses the changes in management quantities when an additional year's data are added. The second analysis assesses the additional effect of the missing NMFS survey in the terminal year.
- While model 20.2 fits the survey data best, it also displayed a retrospective pattern. Analyses suggest there is a process varying over time that is not allowed to vary within the model (e.g., catchability). The pattern appears to be affected by an anomalously high NMFS survey MMB in 2014 (a similar situation to that in the BBRKC). An assessment lowering the influence of the 2014 survey (higher CV) should be undertaken as was done for the BBRKC assessment. The 2018 MMB may also be anomalous as it spiked in 2018 before declining again in 2019. The GMACS and Status quo models differed in their fits to the 2018 and 2019 MMB with the status quo model underestimating both years and the GMACS model fitting them better.
- An assessment of environmental and biological factors that may have affected the catchability of the survey such as may have occurred in 2014 and 2018 should be undertaken. An assessment of the vessel performance during the surveys may also be appropriate to assess whether it performed in the standard manner that was expected.
- The Retrospective patterns are of concern as they would have translated into higher OFL (i.e., overharvesting). Hence it is important that this model uncertainty is acknowledged and that the observed estimates of MMB are taken into account in assessing the stock status and determining the OFL rather than totally relying on the model-estimates.

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

BBRKC Research priorities

- Juvenile abundance from NMFS survey identifies good recruitment years that can be followed in future years in the modal progression. However, these recruitment abundances may be a combination of a number of year-classes. Surveying the juvenile crab abundance in nearshore (if that is the key location for the post larval settlement phase) may provide an estimate of younger juvenile abundance where the year-class may be better defined.

- The RKC is managed separately from fisheries of RKC outside of this area, i.e., it is assumed to be a separate stock. It would be useful to see what the evidence is for this, e.g., genetic and larval transport model. The larval modelling may provide information on the relevant importance of different spawning areas, e.g., is the spawning stock in the southern part of Bristol Bay an important 'source' area of stock that may need additional protection.
- The stock-recruitment relationship (SRR) showed that recruitment was generally lower when MMB < Bmsy compared to when MMB was larger than Bmsy. However, it is important that the effect of the environmental factors affecting recruitment are also assessed in a stock-recruitment-environmental relationship. The SRR should also be used to crosscheck whether the Bmsy and MSST levels are the appropriate reference levels.
- The VAST estimates from the NMFS survey provide an alternative model-based method for the survey estimates that should be examined to see their effect on the stock assessment model.
- Further assessment of the commercial fishery's catch, effort and catch rate is warranted as it could provide valuable information about the fishery's effect on the targeted biomass. This information can be used to assess the spatial distribution of autumn/winter fishing catch and catch rates compared to the summer survey spatial distribution. A depletion analysis of the 3-month fishery should be assessed as it may provide valuable information on the annual estimates catchability and harvest rate on the legal-size abundance that can complement the model estimates. The comparison of the annual commercial CPUE and NMFS survey area-swept legal male abundances can be used to assess the fishing efficiency (discussed in TOR 1). The annual commercial catch rates may be improved as indices of abundance by standardizing them using a statistical analysis such as GLM.
- The area-swept estimate of NMFS survey biomass should be broken down by different life history stages such as mature, legal size, juvenile (<120 mm) and undersize (120-135 mm) males and estimates for immature and mature females. The time series of these area-swept estimates could then be compared to the model-based estimates.
- There is an increase in the size at 50% maturity for female RKC estimated from NMFS survey data from 80 to 95 mm from 1975 to 2008. This time series of length at maturity should be extended to the more recent years to see if the trend is continuing. The effect of this change on the estimated model-estimate FMB should be assessed. While a similar time series estimate is not available for changes in size at maturity of males over the years, it is likely that something similar is happening for males and that a sensitivity assessment should be undertaken to see what effect it could have on the time series of MMB.
- A model run just using data from 1985 should be assessed given the need to have a much higher M estimate for the early 1980s to explain the drop in biomass that occurred in this period. The consistent higher recruitment in the late 1970s and early 1980s has never been repeated since. The trial model would still provide a time series of about 35 years and avoids

having to assess the different mortalities. The more recent data may have improved data quality in the survey estimates and fishery and observer data.

- The ratio of NMFS survey abundance to the BSFRF side-by-side survey for 2014 is much higher than for other 3 years and NMFS survey for 2014 appears to be inconsistent with RKC surveys in the years before and after. It also appears anomalous for the EBSSC in 2014. The stock assessment needs to consider estimating survey selectivity without using 2014 as a sensitivity assessment to assess the effect of this change on the stock assessment. The model also assumes catchability/selectivity of 1 for the BSFRF, however there is no evidence as to whether this assumption is reasonable.
- An assessment of environmental and biological factors that may have affected the catchability of the NMFS survey such as may have occurred in 2014 should be undertaken. An assessment of the vessel performance during the survey may also be appropriate to assess whether it performed in the standard manner that was expected.
- It is important to continue to monitor key BBRKC ecosystem indicators such as Arctic Oscillation index, chlorophyll a levels, wind stress and abundance of predators such as juvenile salmon sockeye, water temperatures and cold pool. It is important to monitor the annual environmental variability, long-term trends and extreme events as these may have a marked effect on biological parameters and survey catchability estimates that can affect the stock assessment. Monitoring of BBRKC biomass in the size range, 110-134 mm that will likely enter the fishery the following year is a good indicator to assess and compare with the commercial CPUE the following year.

EBSSC Research priorities

- The new GMACS model 20.2 compared well with the status quo model in terms of its fit to data such as NMFS and BSFRF survey data and MMB estimates, the credibility of population estimates (e.g., M and growth). Therefore, this model should be adopted for future stock assessment modelling.
- The connection between the snow crab stock in the EBS and that of the northern Bering Sea needs to be understood better. For example, is there migration of the NBS stock to the EBS and is there larval flow north. This is particularly important now as there appears that a very good recruitment occurred in 2015 and it would be good to assess this recruitment year-class in the NBS as well. NMFS survey data from 2017-2019 on snow crabs in the NBS should be examined as part of this analysis.
- An assessment of how often waters colder than 1.5^{o}C occur in the EBS and whether this results in female crabs spawning every 2 years. For example, is any correlation between water temperature and the proportion of barren females?
- An assessment of the commercial fishery's catch, effort and catch rate could provide valuable information about their effect on the targeted biomass which would also affect the MMB. The commercial CPUE can be compared to the NMFS survey abundance >101 mm, the fishery target size. This information can also be used to assess the spatial distribution of fishing catch and catch rates compared to the summer NMFS survey spatial distribution. Depletion analyses could be conducted to provide valuable information on the annual estimates of

catchability of the pot fishery and annual harvest rates on the legal-size component of the stock that can complement the model.

- As the fishery targets new shell males >101 mm, it is important to assess to biomass of this target component of the stock. This will provide an indication of the proportion of this target component that is removed which should be relevant to the setting of the total allowable catch (TAC). The importance of this is currently highlighted as the male biomass of >101 mm in 2016-2019 being at record-low levels while the observed 2018-2019 MMB is the highest since 1998 and as a result there is high OFL estimate (184.9 kt). This emphasizes the need for the abundance of male >101 mm (particularly new shell) being a key output of the stock assessment model given its relevance to TAC setting.
- Monitoring the percentage of mature males that are old shell may be important as this may represent the component that is mating.
- The VAST estimates from the NMFS survey provide an alternative model-based method for the survey estimates that should be examined to see their effect on the stock assessment model.
- The high proportion (50-60%) of bitter crabs in the population should be assessed further as it would affect the discard rate and could affect the population rates such as growth and survival. A sensitivity analysis assuming a higher rate of mortality for bitter crabs could be undertaken as a preliminary analysis of the issue. This could also be contributing to some of the retrospective patterns being observed.
- Time-varying survey catchability may cause poor fit to the NMFS survey to some years, e.g., 2014. An assessment of environmental and biological factors that may have affected the catchability of the survey, such as may have occurred in 2014 and 2018, should be undertaken. An assessment of the vessel performance during the surveys may also be appropriate to assess whether it performed in the standard manner that was expected. For example, the NMFS survey estimate for MMB for 2014 appears to be unexpectedly high therefore a sensitivity assessment putting a high CV on this survey should be undertaken as done for the BBRKC. This issue may be contributing to the retrospective patterns.
- The marked decline in the weight at length for females that was calculated in 2016 requires further assessment as to whether this represents a decline in the condition of the female crabs.
- A model run just using data from 1989 should be assessed as it still provides a time series of 30 years and avoids having to assess the different catchabilities in the two periods (1982-1988, 1989 onwards). The more recent data may have improved data quality in the survey estimates and fishery and observer data.
- The spatial distribution between large males in surveys and the spatial distribution of the fishery should be assessed. Is the difference between the two, due to crab migration or fishers preferring to fish in their preferred locations? The latter hypothesis could be examined by seeing whether fishers' catch rate close to survey centroid are higher than those in areas away from centroid. This analysis can also be used to assess the spatial distribution of

harvesting as this affects the spatial distribution of abundance of the target size that remain for mating.

- The stock-recruitment relationship between the MMB and recruitment should be presented even if it is not statistically significant. This may provide some insight as to whether the Bmsy and MSST levels are the appropriate reference levels. The effect of any environmental factors such as the Arctic Oscillation which is significantly related to recruitment should also be assessed. While the relationship of recruitment the winter Pacific Decadal Oscillation is not significant, 8 of the 9 highest recruitment classes occur when the PDOw > 0 and similarly for when the Arctic Oscillation is < 0.
- The 'exploratory' projection analysis is using random historical recruitments. The stock assessment should consider dropping recruitment from 1980s and early 1990s as these have not been replicated in recent years except for 2015 whose level is still to be confirmed.
- The Retrospective patterns are of concern as they would have consistently translated into higher OFL (i.e., overharvesting). Hence it is important that this model uncertainty is acknowledged and that the observed estimates of MMB are taken into account in assessing the stock status and determining the OFL rather than totaling relying on the model-estimates.
- Even if environmental conditions are not an integral part of the stock assessment, it is important to monitor their annual variability, long-term trends and extreme events as these may have a marked effect on biological parameters and survey catchability estimates that can affect the stock assessment.

References

de Lestang, S, JW Penn, N Caputi (2018) Changes in fishing effort efficiency under effort and quota management systems applied to the Western Australian rock lobster fishery. Bulletin of Marine Science 94(3), 1077-1094.

Fletcher WJ (2015) Review and refinement of an existing qualitative risk assessment method for application within an ecosystem-based fisheries management framework. ICES J. Mar. Sci. 72: 1043-1056.

Appendix 1: 2021 EBS snow crab and Bristol Bay red king crab CIE Review documents

EBS snow crab assessment
Github repository for code related to EBS snow crab assessment
Bristol Bay red king crab assessment

Other background documents

Management documents

Bering Sea crab plan team: NPFMC website.

Survey documents

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.

Ecosystem

Bering Sea Ecosystem report: link to past and present reports

Bering Sea Integrated Ecosystem Research Plan bsierp.nprb.org/

Background presentations to CIE Review Panel

Crab fishery data, Ben Daly

Survey data collection overview (with voiceover), C, Chris Long

Survey data processing and analysis, Jon Richar

Introduction to the GMACS framework, Andre Punt

Observer data explanation, Alexandra Dowlin

Progress from 2014 CIE review for snow crab, Cody Szuwalski

Bering Sea Fisheries Research Foundation surveys, Scott Goodman

Bristol Bay red king crab model history and responses to CIE recommendations in 2008 and recent CPT and SSC comments, Jie Zheng and Shareef Siddeek

Historical snow crab presentations

2020: September, May

2019: September, May

2018: September, May

2017: September, May

Appendix 2: 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
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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	

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

The review panel consisted of:

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