Center for Independent Experts (CIE)
Independent Peer Review Report on *Aleutian Islands golden king and Norton Sound red king crab Stock Assessment Review*

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Executive Summary

The Aleutian Islands Gold King Crab (AIGKC) was assessed using a male-only length-based model. This model combines commercial retained catch, total catch, standardized observer legal size catch-per-unit-effort (CPUE) indices, fishery retained catch size composition, total catch size composition, and tag recaptures by release-recapture length to estimate stock assessment parameters. The tagging data were used to calculate the size transition matrix. To estimate the male mature biomass (MMB), the knife-edge 50% maturity was used based on the chela height and carapace length data analysis. To include a long time series of CPUE indices for stock abundance contrast, the 1985/86–1998/99 legal size standardized CPUE indices were used as a separate likelihood component in all scenarios. The authors' efforts are very well appreciated and I have very few suggestions regarding the tagging results.

The Norton Sound red king crab (NSRKC) stock was also assessed using a male-only length-based synthesis model (Zheng et al. 1998). The authors of the assessment (Hamazaki and Zheng 2018) updated the model for the male crab abundance that combines multiple sources of survey, catch, and tag-recovery data from 1976 to 1996 using a maximum likelihood approach. The model was used to estimate abundance, recruitment, catchability of the commercial pot gear, and parameters for selectivity and molting probabilities.

Critical assumptions of the model include the male crab mature at CL length 94mm. Here, the size-at-maturity was adjusted from that of BBRKC (CL 120mm) reflecting the slower growth and smaller size of NSRKC. The model also assumed that molting occurs in the fall after the summer fishery. Add to those assumptions, the instantaneous natural mortality *M* is assumed to be 0.18 for all length classes, except for the last length group (> 123mm) where *M* is assumed to be 3-times higher than smaller size classes. With respect to the winter pot survey, selectivity is a dome shaped function: Reverse logistic function of 1.0 for length class CL 84mm, and model estimate for CL < 84mm length classes. Selectivity is constant over time.

This assumption is based on the fact that a low proportion of large crabs are caught in the near-shore area where winter surveys occur. Causes of this pattern may be that (1) large crab do not migrate into near-shore waters in winter or (2) large crab are fished out by winter fisheries where the survey occurs (i.e., local depletion).

Tag recovery data were used to estimate growth increments as a function of length and were found to be constant over time. Tag recovery data were also used to model the molting probability which was found as an inverse logistic function of length for males.

I focused in my discussion during the presentation and in my report on the biological aspect of the model and recommended starting the work on age determination of the crab species in order to provide the stock assessment scientists with age data that will definitely strengthen

the assessment and minimize any uncertainties that may result from using the crab size. I also recommended starting the use of a different kind of tags instead of the spaghetti tags that are currently used. The recommended tag will allow the assessment scientists to obtain more reliable data that would cover longer duration including pre- and post-molting events. This kind of data will increase the accuracy of the molt probabilities and will also minimize the uncertainties of the value of the instantaneous natural mortalities '*M*' at different size classes.

Background

The Alaska Fisheries Science Center (AFSC) Resource Ecology and Fishery Management (REFM) Division requests an independent review of the stock assessment/projection models used to conduct the Aleutian Islands golden king crab (AIGKC) and Norton Sound red king crab (NSRKC) stock assessments. The review meeting took place in Seattle, Washington, between June18 and 21, 2018.

The model and projection framework was primarily presented by Dr. Sadeek and Dr. Hamazaki and the meeting was chaired by William Stockhausen. The review panel consisted of Drs. John Neilson, Canada, Yong Chen, USA, and Raouf Kilada, Canada.

I thank everyone at the meeting for clear presentations and inspiring discussions. I am grateful for Dr. Sadeek and Dr. Hamazaki for their patience during the constructive discussions. I also thank Dr. Stockhausen for his professional and friendly way of chairing the meeting.

This report documents the independent review of Raouf Kilada. The Statement of Work is appended to this report.

Description of the reviewer's role

I, as a reviewer, have independently read the assessment reports, their appendices and all supplementary documents deemed necessary in preparation for the review, traveled and participated actively in the review meeting, identified key issues in the assessment, suggested guidance, and independently authored this review report.

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

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

One of the influential data inputs in the stock assessment model is the size-at-maturity of the crab species. Data collection of this variable may be destructive and requires intensive lab work; however, other morphometry methods may enhance the estimation with less effort yet with more precision.

In case of the Aleutian Islands Golden King Crab, the size-at-maturity was estimated using the breakpoint analysis of chela height and crab size which I consider as a good way to maximize the strength of the model. Spatial and temporal changes in the size-at-maturity may need to be investigated to incorporate any changes as demonstrated in Southeast Alaska, where Olson et al. (2018) documented differences in this variable at different areas and depths.

With respect to the Norton Sound Red King Crab, critical assumptions of the model include the male crab mature at CL length 94 mm. Here, the size-at-maturity was adjusted from that of that of BBRKC (CL 120mm) reflecting the slower growth and smaller size of NSRKC. The rationale of adjusting the size-at-maturity from 120 to 94 mm may have a poor biological basis which may have a negative impact on the accuracy of the model.

I recommend some biological and/or morphometric investigations to estimate the size-at-maturity using documented direct methods. Paul (1992) found out that examining the vas deferens for spermatophores coupled with laboratory breeding experiments has proven useful in determining the size at onset of maturity for *P. camtschaticus* males. The author demonstrated that breeding experiments showed that examining vas deferens for the presence of spermatophores was useful for determining the size at physiological maturity for males of Red King Crab. This method is destructive and may not be feasible and hence a morphometric measurement for the male chela would be more applicable. A review by Webb (2014) compared different ways to estimate the value of this parameter and concluded that the allometry of CL vs. chela height was applied successfully in Bristol Bay (Somerton 1980) and in Norway (Rafter et al. 1996).

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

With respect to the AIGKC, the projection models methodology simulated the future male abundances from the 2018 model scenarios 17_0 and 17_0d, estimated abundances by length-class and recruitment. The authors of the model projected the abundances for 30 years with 100 random replicates and estimated various management parameters under F=0 (base) and F=F35% including legal male biomass (LMB), mature male biomass (MMB), OFL (total) catch, retained catch (RETC), CPUE indices, and probability of overfishing under federal Tier 3 overfishing control rule. I agree with the methodology applied here and do not have further suggestions.

Regarding the NSRKC, since adoption of the model, the major challenge is a conflict between model projection and data, and in particular with *M*. The value of *M* has changed from 0.3 in 2011 to 3-4 times higher value for the length crabs (i.e., $M = 1.8$ for length classes ≤ 123mm, and higher M for > 123mm). I suggest here investigating the use of more realistic method of estimating the *M* values; age of the crab. By knowing the age distribution of the species, natural mortality could be calculated by assessing the age-frequency distribution.

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

In case of the AIGKC, three primary fishery-dependent data sources are used in the model, (1) Retained catch sampling, (2) Edited fish tickets, and (3) Pot-lift sampling. All data collected, edited and maintained by ADF&G Westward Region staff in conjunction with ADF&G Dockside Sampling and Crab Observer Programs. This is an efficient method as inputs to the stock assessment and I suggest no change to occur.

With regard to the independent data input, the triennial ADF&G pot surveys for Aleutian Islands golden king crab is the main source for the tag release recapture data to determine the molt increment and size transition matrix by the integrated model. Add to this, tagging recoveries were used to assess the movement of crabs over time. Recoveries during commercial fisheries of golden king crab tagged during ADF&G surveys (Watson 2004, 2007) provided no evidence of substantial movements by crab in the size classes that were tagged (males and females ≥90-mm carapace length [CL]).

The used tags are Isthmus-loop ("spaghetti") tags and are deployed on crabs >90 mm CL. This kind of tags is inserted through the isthmus. Some tags were retained by the animals, yet the potential of losing tags during molting is high. The loss of tags decreases the sample size of the recovered tagged animals.

I recommend here using a different kind of tag that may continue inside the animal's body for extended period of time and will minimize the loss during molting. This will provide mangers with more valuable and precise data. Examples of tags that are used in different crab species is the passive integrated transponder tag (PIT) (Sato et al. 2013). In this study, the PIT was implanted in each crab using a large gauge (diameter 2.8 mm) single shot implanter. A PIT tag consists of an electronic microchip encased in a biocompatible material; the tag can be pre-programmed with an infinite number of unique codes. Tags used in this study (Item TX-1400L, Destron, South St. Paul, MN) measured 11.0 × 2.1 mm and weighed approximately 0.067 g in air. All tags were implanted into the right hand side of the pleon near the second tergal plate. The study found that in a preliminary laboratory experiment, 10 coconut crabs (28.7 to 53.5 mm ThL) were implanted with PIT tags and reared for 6 months to examine rate of tag loss and mortality due to tag implantation. In this period, no tag loss was observed, and all crabs stayed alive and showed no adverse behavior caused by tag implantation. Although 3 crabs molted within the period, PIT tags were retained in their respective pleons.

Also in case of the NSRKC, two sources of uncertainties in the results of tagging and recapture; (1) the kind of tags used in this work, and (2) the duration of the experiment. The tagged animals were recaptured after about 4-5 weeks of tagging. Although the recaptured animals were about 10% of the tagged samples, yet the duration of this work could not allow the authors to determine the exact molting timing, intermolt increment or the exact molting probabilities. Similar to the AIGKC, I suggest using the PIT instead of the spaghetti tags to minimize those uncertainties. In addition to the results of tagging and recapture, I recommend investigating the possibility of using shell condition to assess molting status of the animal (i.e. occurrence of recently molted, soft-shelled crabs).

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

The AIGKC assessment relied heavily on standardized CPUE indices and size composition information to determine the stock abundance trends. The assessment included some assumptions such as the linear relationship between both the observer and fish ticket CPUE indices and the exploitable abundance. The *M* value was kept constant at 0.21 yr^{-1}. These fixed values invariably reduced the number of model parameters to be estimated and helped in convergence. The authors' input is well appreciated and I do not have suggestions here.

In case of the NSRKC, major modeling issues are related to the high *M* for large (≥ 124mm) crab. Although this improves the model fit, it does not have a strong biological basis. One of the explanations for the high *M* is the absence of large crabs which could not be confirmed by the surveys. Hence, I recommend here (**<u>again</u>**) to use the age distribution to estimate a more realistic and reliable *M*.

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

For the AIGKC, the effect of data re-weighting (i.e., stage-2 weighting) methods on MMB estimates was investigated for this stock in relation to the sensitivity of the trends in MMB to the data re-weighting method and was explained in Siddeek et al. (2017). The McAllister and Ianelli (1997) and Francis (2017) methods were used to re-weight the size-composition data and Punt's method (Punt et al. 2017) was applied to re-weight the tagging data.

Weighting factors were used for catch biomass, recruitment deviation, pot fishery F, and groundfish fishery F. The retained catch biomass was set to a large value (500.0) because retained catches are more reliable than any other data sets. The total catch biomass was scaled in accordance with the observer annual sample sizes with a maximum of 250.0. The total catches were derived from observer nominal total CPUE and effort. Small groundfish bycatch weight (0.2) was used. The best fit criteria were used to choose the lower weight for the groundfish bycatch. The CPUE weights were set to 1.0 for all scenarios. I appreciate this approach and have no suggestions.

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

In 2005, the major Bering Sea and Aleutian Islands crab fisheries were rationalized, including Aleutian Islands golden king crab. This led to a decrease in the number of fishing vessels from approximately 16 to 4 vessels. It also resulted in the increase of average pot soak time from 4 to 15 days in EAG and from 9 to 24 days in WAG.

I recommend here investigating the effect of the prolonged soak time to 24 days and assess whether this period of time would lead to saturation in the pot and as a result, mortality may occur.

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

In the AIGKC assessment, size-at-maturity was estimated in 1984 and 1991 in WAG and EAG, respectively. One L50 value is currently used and this needs to be updated to assess whether there is temporal and spatial differences in the size-at-maturity value. In southeastern Alaska, Olson et al. (2018) found differences in different latitudes which may exist in the AI fishery areas. Fishery-independent survey may also be used to provide managers with more reliable results from tagging-recovery work to investigate the crabs' movement timing and abundance. Finally, the survey may be used to investigate the larval distribution, abundance and drift pattern (see ToR 9).

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

For the AIGKC, the ADF&G uses an efficient system in recording the details of all fishing trips with respect to the area, dates and total catch. Landed catch is also documented on fish ticket covering the fishing season. Add to this, onboard observers are responsible for monitoring the entire bycatch including females, sublegal males, retained legal males, and non-retained legal males.

With regard to quality control of the fishery data, efficient steps were taken to make sure there are no simple errors that created massive errors. For example: Is the total number of males in the original "Crab data dump" equal to the total number of males in the other files created?

For the NSRKC, the CPUE data set relies on fish tickets that are filled by the boat's captain. This means that there is no significant role for an observer which makes the accuracy of the fish tickets questionable. Add to this, commercial buyers started accepting only legal crab of ≥ 5 inch CW in 2005. This action would have been expected to lead to increased discards. Unfortunately, the impact of this change on discards is unknown as discards were not monitored due to the absence of an efficient system involving observers. I recommend here the assessment of how accurate the fish tickets are. I also recommend allocating some fund to cover the expenses of more observers on fishing boats. This will strengthen the quality control of the data used in the stock assessment model.

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

The biology of the red king crab and golden king crab is widely unknown. Life history is essential to understand the different phases that the animal passes through before reaching the size-at-catch. Larvae, growth, molt timing, reproduction, maturity, natural mortality, are some examples for the parameters that need to be known in order to improve stock assessment of the species.

Larval dispersion and duration: After hatching the crab's larvae spend time in the planktonic stage. The duration of the planktonic stage varies in different species. For example, although larvae of the American lobster spends about three weeks in the planktonic stage, their dispersion were found to cover vast distances (Chassè and Miller, 2010).

Larval dispersion: In the case of GKC and RKC, larvae biology needs to be investigated in terms of abundance, duration of planktonic stage, dispersion, settlement timing, and mortality. Fukuara (1982) found that the king crab larvae distribution and abundance differ by time due to various factors (see the attached figures). I recommend starting a similar study to update the results.

This study will be the base of assessment of whether the NSRKC and AIGKC are one or more than one stock. This is important information that should be considered in the stock assessment of each species.

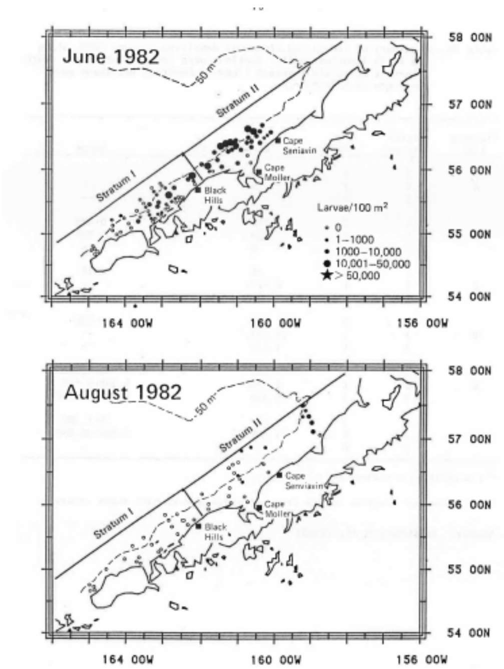

Figure 1: Distribution and relative abundance of red king crab larvae in June and early August 1982 (Fukuhara, 1982).

Age and growth: Crustacean growth can be considered a product of the size increment gained at molt, and the frequency of molting and knowledge of growth are essential for the scientific management of red king crabs. This was first investigated by McCaughran and Powell (1977) and Fukuhara (1985) who measured the intermolt growth in reared immature crabs collected from southeastern Bering Sea as shown in the following graph.

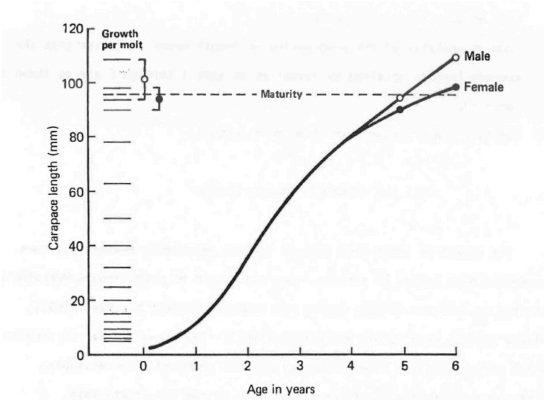

Figure 2: Growth curve of immature king crab from southeastern Bering Sea (Fukuhara, 1985)

I recommend investigating the feasibility of direct age determination of various crab species in the Aleutian Islands and in Norton Sound. This work started in 2017 on Tanner crab and Red King Crab from Bristol Bay (Kilada et al. 2017) and will be helpful if completed. The promising results (see the attached plot) indicate the high potential of having size-at-age relationship which should reduce the uncertainty associated with the growth parameters in the assessment model. This work will involve validation of the band counts in the gastric mill to confirm the annual deposition of growth bands. Validation will be more feasible by using known-age animals that may be reared in Kodiak experimental hatchery.

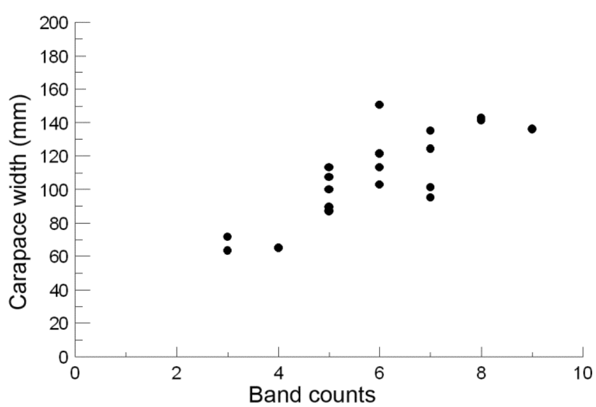

Figure 3: Size-at-band counts observed in the endocuticle region of thin sections (180 µm) of the meso-cardiac ossicle in the gastric mill of female red king crab collected from Bristol Bay (Kilada, unpublished data).

The same method was applied successfully (Review paper: Kilada and Driscoll, 2017) on other crab and lobster species that werecollected from different locations in the world such as snow crab *Chionoecetes opilio* and American lobster, *Homarus americanus* (Kilada et al., 2012), Chilean squat lobster *Paralithodes camtschaticus* (Kilada and Acuña, 2015), Mediterranean swimmer blue crab *Portunus pelagicus* (Kilada and Ibrahim, 2017), and Australian mud crab *Scylla serrata* (Leland and Bucher, 2017).

Molting: Molting probability is a main input in the stock assessment model and until now it has not been studied to provide a reliable biological result. I recommend here investigating the molting timing and frequency in a study similar to Sainte-Marie et al. (1995) on the snow crab. The authors managed to use the shell condition as indicator of the molting activity of the animal.

Connectivity: Research on golden king crab genetics could reveal stock structure and provide management information to create biologically representative management areas to better manage the fishery. For example, genetic studies of red king crabs in the North Pacific revealed three distinct genetic groupings: (i) Adak Island, (ii) Bering Sea–Gulf of Alaska and (iii) Southeast Alaska, with Southeast Alaska having the lowest levels of genetic diversity and mtDNA, but significant genetic heterogeneity among populations over a small geographic scale (Vulstek et al., 2013, Grant et al., 2014). This result suggests that the glacial fjord system and enclosed bays of Southeast Alaska may result in decreased connectivity among king crab populations, with potentially limited larval dispersal and limited gene flow resulting in self-recruiting populations (Grant and Cheng, 2012, Vulstek et al., 2013, Grant et al., 2014). Future genetic studies of golden king crabs in the Aleutian Islands could determine whether heterogeneity among management areas exists and inform whether the current management areas in the Aleutian Islands truly represent separate stocks.

ToR10. Suggested priorities for future improvements to the stock assessment/projection models for Aleutian Islands golden king crab and Norton Sound red king crab.

I strongly recommend the enforcement of more data having more reliable biological basis with respect to age and growth, molting frequency and intermolt growth, updated size-at-maturity in the stock assessment models in both AIGKC and NSRKC stocks. I also recommend investigating the life history of both species with respect to larval duration in planktonic phase. Add to this, I recommend starting intensive tagging-recovery work using more reliable tag kinds.

With respect to the AIGKC, it will be helpful to invest some funds for independent surveys to cover more western areas; this will definitely enhance the understanding of the species distribution and abundance in the larger area.

My recommendations (in addition to the above) for the NSRKC include the elimination of some confusion in the preparation of assessment reports. It was tiring to receive different versions of the same report on different days. This happened even during the presentation when the reviewers received updated versions of the report.

Appendix 1

BIBLIOGRAPHY

Chassè, J. and Miller R.J. 2010. Lobster larval transport in the southern Gulf of St. Lawrence. Fisheries Oceanography, 19:319–338.

Francis, R.I.C.C., 2017. Revisiting data weighting in fisheries stock assessmentmodels. Fishery Research 192:5–15.

Fukuhara, F.M., 1985. Biology and fishery of south-eastern Bering Sea red king crab (*Paralithodes camtschatica*, Tilesius). NWAFC Processed Report 85–11.

Grant, W.S., and Cheng W., 2012. Incorporating deep and shallow components of genetic structure into the management of Alaskan red king crab. *Evol. Appl.* **5**, 820–837. (doi:10.1111/j.1752-4571.2012.00260.x).

Grant, W.S., Zelenina, D.A., and Mugue, N.S., 2014. Phylogeography of red king crab: implications for management and stock enhancement. In *King crabs of the world: biology and fisheries management* (ed. BG Stevens), pp. 47–72. Boca Raton, FL: CRC Press.

Kilada, R. and Acuña, E. 2015. Absolute age of three commercially important crustacean species in Chile. Fish Res. 170: 134-143.

Kilada, R. and Ibrahim N.K. 2016. Preliminary investigation of direct age determination using band counts in the gastric mill of the Blue swimmer crab (*Portunus pelagicus* Linnaeus, 1758) in two salt-water lakes in the eastern Mediterranean. J Crustacean Biol. 36: 119-126.

Kilada, R. and Driscoll, J. 2017. Age determination in crustaceans: a review. Hydrobiologia 799:21–36.

Kilada, R., Sainte-Marie, B., Rochette, R., Davis, N., Vanier C., and Campana, S. 2012. Direct determination of age in shrimps, crabs, and lobsters. Can J Fish Aquat Sci. 69: 1728–1733.

Kilada R., Webb J.B., McNeel K.W., Slater L.M., Smith Q., and Ferguson J. 2017. Application of a direct method of age determination using band counts in three commercially important crustaceans in Alaska. Fishery Bulletin 115: 42-49.

Leland, J. and Bucher, D. 2017, Direct age determination with validation for commercially important Australian lobster and crab species: Western, Eastern, Southern and Ornate Rock Lobsters and Crystal, Giant and Mud Crabs, Fisheries Research and Development

Corporation, Canberra, NSW and Southern Cross University, Lismore, NSW. ISBN: 9780646957845.

McAllister, M.K., and Ianelli, J.N., 1997. Bayesian stock assessment using catch-age dataand the sampling/importance resampling algorithm. Can. J. Fish. Aquat. Sci. 54:284–300.

McCaughran, D.A., and Powell, G.C. 1977. Growth model for Alaska king crab (*Paralithodes camtschatica*). J Fish Res Bd Can. 34: 989–995.

Olson, A.P., Siddon, C.E. and Eckert, G.L., 2018. Eckert Spatial variability in size at maturity of golden king crab (*Lithodes aequispinus*) and implications for fisheries management. Royal Society openScience 5: 171802. http://dx.doi.org/10.1098/rsos.171802.

Paul, A.J. 1992. A Review of Size at Maturity in Male Tanner *(Chionoecetes bairdi)* and King *{Paralithodes camtschaticus)* Crabs and the Methods Used to Determine Maturity. AMER. ZOOL., 32:534-540.

Punt, A.E., Roy, A.D., Siddeek, M.S.M., Buckworth, R.C., and Vanek, V., 2017. Data weighting for tagging data in integrated size-structured models. Fishery Research 192:94–102.

Rafter, E, Nilssen, E.M. and Sundet, J.H. 1996. Stomach content, life history, maturation and morphometric parameters of red king crab, *Paralithodes camtschaticus,* from Varangerfjord area, North Norway. ICES CM 19961K:I0 Shellfish Committee.

Sainte-Marie, B., Raymond, S., and Brêthes, J.C. 1996. Growth and maturation of the benthic stages of male snow crab, *Chionoecetes opilio* (Brachyura: Majidae). Canadian Journal of Fisheries and Aquatic Sciences 52: 903-924, https://doi.org/10.1139/f95-091

Sato, T., Yoseda, K., Abe, O., et al. 2013. Growth of the coconut crab *Birgus latro* estimated from mark-recapture using passive integrated transponder (PIT) tags. Aquatic Biology 19: 143–152.

Siddeek, M.S.M., Zheng, J., Puntc, A.E., and Pengilly, D. 2017. Effect of data weighting on the mature male biomass estimate for Alaskan golden king crab. Fisheries Research, 192:103-113.

Somerton, D.A., 1980. A computer technique for estimating the size of sexual maturity in crabs. *Can. J. Fish. Aquatic Sci.* **37**, 1488–1494. (doi:10.1139/f80-192).

Watson, L.J. 2004. The 2003 triennial Aleutian Islands golden king crab survey and comparisons to the 1997 and 2000 surveys (revised October 17, 2005). Alaska Department of

Fish and Game, Division of Commercial Fisheries, Regional Information Report 4K04-42, Kodiak. [Revised 10/17/2005].

Watson, L.J. 2007. The 2006 triennial Aleutian Islands golden king crab survey. Alaska Department of Fish and Game, Fishery Management Report No. 07-07, Anchorage.

Webb. J. 2014. Reproductive ecology of commercially important Lithodid crabs. Pages 285-314 In B.G. Stevens (ed.): King Crabs of the World: Biology and Fisheries Management. CRC Press, Taylor & Francis Group, New York.

Vulstek, S.C., Linderoth, T.P., Guyon, J.R., and Tallmon, D.A. 2013. Spatio-temporal population genetic structure andmating systemof red king crab (*Paralithodes camtschaticus*) in Alaska. *J. Crust. Biol.* **33**, 691–701. (doi:10.1163/1937240X-00002173).

Zheng, J., Kruse, G.H. and Fair, L.. 1998. Use of multiple data sets to assess red king crab, *Paralithodes camtschaticus*, in Norton Sound, Alaska: A length-based stock synthesis approach. Pages 591-612 In Fishery Stock Assessment Models, edited by F. Funk, T.J. Quinn II, J. Heifetz, J.N. Ianelli, J.E. Powers, J.F. Schweigert, P.J. Sullivan, and C.J. Zhang, Alaska Sea Grant College Program Report No. AK-SG-98-01, University of Alaska 6 Fairbanks.

Appendix 2

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

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

Background

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

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

Scope

The Alaska Fisheries Science Center (AFSC) Resource Ecology and Fishery Management (REFM) Division requests an independent review of the stock assessment/projection models used to conduct the Aleutian Islands golden king crab (AIGKC) and Norton Sound red king crab (NSRKC) stock assessments. Both stocks are managed by the North Pacific Fishery Management Council (NPFMC) under the Fishery Management Plan (FMP) for the Bering Sea

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

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

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

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

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

Requirements

The selected three (3) CIE reviewers shall have the necessary qualifications to complete an impartial and independent peer review in accordance with the tasks and ToRs described in the Statement of Work (SoW) herein. The CIE reviewers shall have expertise in conducting stock assessments for fisheries management and be thoroughly familiar with various subject areas involved in stock assessment, including population dynamics, size-structured models, harvest strategies, and the Automatic Differentiation (AD) Model Builder programming language to complete the tasks of the scientific peer-review described herein. Familiarity with invertebrate stock assessment, knowledge of crab life history and biology, and harvest strategy development is desirable.

Tasks for Reviewers

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

A. General

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

[Review the "Stock Status Definitions" and "Status Determination Criteria" for background information on the NPFMC's status criteria and

approach to OFL determination for crab stocks.]

B. Norton Sound red king crab specific

B.1 Hamazaki and Zheng. 2017. Norton Sound red king crab assessment chapter. In: 2017 Stock Assessment and Fishery Evaluation Report for the King and Tanner Crab Fisheries in the Bering Sea and Aleutian Islands. North Pacific Fisheries Management Council, Anchorage, AK. Report compiled by the CPT. https://www.npfmc.org/fishery-management-plan-team/bsai-crab-plan-team/

C. Aleutian Islands golden king crab specific

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

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

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

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

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

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

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

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

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

Foreign National Security Clearance
When reviewers participate during a panel review meeting at a government facility, the NMFS Project Contact is responsible for obtaining the Foreign National Security Clearance approval for reviewers who are non-US citizens. For this reason, the reviewers shall provide requested information (e.g., first and last name, contact information, gender, birth date, passport number, country of passport, travel dates, country of citizenship, country of current residence, and home country) to the NMFS Project Contact for the purpose of their security clearance, and this information shall be submitted at least 30 days before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations available at the Deemed Exports NAO website: http://deemedexports.noaa.gov/ and http://deemedexports.noaa.gov/compliance_access_control_procedures/noaa-foreign-national-registration- system.html. The contractor is required to use all appropriate methods to safeguard Personally Identifiable Information (PII).

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

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

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

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

Approximately 3 weeks later	CIE receives draft reports
Within 2 weeks of receiving draft reports	CIE submits final reports to the Government

Applicable Performance Standards
The acceptance of the contract deliverables shall be based on three performance standards: (1) The reports shall be completed in accordance with the required formatting and content (2) The reports shall address each ToR as specified (3) The reports shall be delivered as specified in the schedule of milestones and deliverables.

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

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

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

Annex 1: Peer Review Report Requirements

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

2. The report must contain a background section, description of the individual reviewers' roles in the review activities, summary of findings for each ToR, in which the weaknesses and strengths are described, and conclusions and recommendations in accordance with the ToRs.

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

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

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

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

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

3. The report shall include the following appendices:

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

Annex 2: Terms of Reference for the Peer Review

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

The report generated by the consultant should include:

1. Statements assessing the strengths and weaknesses of the current Aleutian Islands golden and Norton Sound red king crab stock *assessment* models with regard to population dynamics, data (fishery-independent surveys, CPUE indices, etc.), likelihood components, and model evaluation.
2. Statements assessing the strengths and weaknesses of the current Aleutian Islands golden and Norton Sound red king crab stock *projection* models, with regard to methodology.
3. A review of the fishery-dependent and -independent data inputs to the stock assessment with regard to quality of information and appropriateness to the assessment for Aleutian Islands golden king crab and Norton Sound red king crab.
4. Recommendations for alternative approaches to evaluate model convergence and compare multiple models for Aleutian Islands golden king crab and Norton Sound red king crab.
5. Recommendations on how various data sets should be weighted, relative to one another, in the Aleutian Islands golden king crab and Norton Sound red king crab models
6. Recommendations on how the reduction in number of vessels and fishing area shrinkage can be addressed in the Aleutian Islands golden king crab model.
7. Recommendations for integrating fishery-independent survey data into the Aleutian Islands golden king crab assessment.
8. Recommendations for quality control of input fishery-dependent and -independent data for Aleutian Islands golden king crab and Norton Sound red king crab.
9. Recommendations for research that would reduce the uncertainty associated with key parameters assumed or estimated in the assessment models for Aleutian Islands golden king crab and Norton Sound red king crab.
10. Suggested priorities for future improvements to the stock assessment/projection models for Aleutian Islands golden king crab and Norton Sound red king crab.

Annex 3: Tentative Agenda

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

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

Dates:
June 18-21, 2018

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

Monday: June 18 2018

8:00 -8:30am

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

Review of Aleutian Islands golden king crab (AIGKC)

8:30–9:40 am

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

9:40-9:50 am: Tea Break

9:50-11:30 pm

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

11:30 -1:00 pm: Lunch Break

1:00-2:45 pm

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

2:45-3:25 pm

a. Harvest control rules and overfishing definitions

3:30 pm: Adjourned

Tuesday: June 19, 2018

8:00-10:00 am

a. Stock assessment and projection models

10:00-10:10 pm: Tea Break

10:10-12:00 pm

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

12:00-1:30pm: Lunch break

Review of Norton Sound Red King Crab (NSRKC)

1:30-3:25 pm

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

3:30 pm: Adjourned

Wednesday: June 20, 2018

8:00-9:45 am

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

9:45-10:00 am: Tea Break

10:00-11:30 pm

a. CPUE standardization
b. Stock assessment and projection models

11:30-1:00pm: Lunch Break

1:00-2:30 pm

a. Stock assessment and projection models continued

2:30-2:40 pm: Tea Break

2:40-3:25 pm

a. Stock assessment and projection models continued

3:30 pm: Adjourned

Thursday: June 21, 2018

8:00am–11:30pm

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

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

1:00-3:25 pm

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

3:30 pm: Adjourned

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