North Pacific Fishery Management Council

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Crab Plan Team

REPORT

January 11-14, 2021
Online Meeting

Members in Attendance

Martin Dorn, **Co-Chair** (AFSC-Seattle)
Katie Palof, **Co-Chair** (ADF&G-Juneau)
Jim Armstrong, **Coordinator** (NPFMC)
William Bechtol (UAF-Homer)
Ben Daly (ADF&G-Kodiak)
Ginny Eckert (UAF/CFOS-Juneau)
Erin Fedewa (AFSC - Kodiak)
Brian Garber-Yonts (AFSC-Seattle)
Krista Milani (AKRO-D.Harbor)
André Punt (U.Washington)
Shareef Siddeek (ADFG-Juneau)
William Stockhausen (AFSC-Seattle)
Cody Szuwalski (AFSC–Seattle)
Miranda Westphal (ADFG-D.Harbor)
Jie Zheng (ADF&G-Juneau

Others in Attendance

Rachel Alinsunurin (ADFG-Dutch Harb)
Jen Bell (ADFG, Nome)*
Adem Bockman (NSEDC/WSAC)
Charles Brazil (ADFG, Anch.)
Ruth Christiansen (UCB)
Kevin Clark (ADFG, Nome)
Sara Cleaver (NPFMC)*
Allie Conrad
Lee Cronin-Fine
Maria Davis (NPFMC)
Kenny Down (Seaquest)
Austin Estabrooks (APA)
Ron Felthoven (AFSC, Seattle)
Bridget Ferriss (AFSC, Seattle)
Angela Forristall (NPFMC)
Sabrine Garcia (ADF&G, Anch.)
Jennifer Gardner
John Gauvin (ASC)
Jamie Goen (ABSC, Seattle)
Scott Goodman (BSFRF, Seattle)*
Gretar Gudmundsson (F/V Valiant)
Kate Haapala (NPFMC)
Terry Haines
Toshihide Hamazaki (ADFG, Anch.)*
Dana Hanselman (AFSC, Juneau)
Madison Heller-Shipley (BSFRF)
Kendall Henry (ADFG, Juneau)
Luke Henslee (ADFG, Nome)
Leonard Herzog (F/V Tempo Sea)
John Hilsinger (AKCR)
Jim Ianelli (AFSC, Seattle)
Tyler Jackson (ADFG, Kodiak)
Wes Jones (NSEDC)
Frank Kelty (City of Unalaska)
Scott Kent (NSEDC)
Nicole Kimball (PSPA)
Linda Kozak (FVOA)
Sarah La Belle (NPFMC)
Charlie Lean (NSEDC)
Cory Lescher (ABSC)*
Zachary Liller (ADF&G, Anch.)
Mike Litzow (AFSC, Kodiak)*
Craig Lowenberg (Arctic Sun)
Heather Mann (MTC)
Sarah Marrinan (NPFMC)*
Steve Martell (SeaState)
Heather McCarty (McCarty Assoc.)
Cole Monnahan (AFSC, Seattle)
Andrew Munro (ADFG, Anch.)
Andy Nault (ADFG, Kodiak)
Brett Paine (UCB)
Edward Poulsen (BSFRF)
Jonathan Richar (NMFS Kodiak)*
Brian Ritchie
Emily Sellinger
Kalei Shotwell (AFSC, Juneau)
Samuel Silvestre Nuernberg
Gary Stauffer (BSFRF)
Mark Stichert (ADFG, Kodiak)
Diana Stram (NPFMC)
Jim Thorson (AFSC, Seattle)
Vicki Vanek (ADFG, Kodiak)
Ernie Weiss (AEB)
Doug Wells
Bo Whiteside (ADFG, Kodiak)
Paul Wilkins (CVRF)
Chris Woodley (UFA)
Leah Zacher (AFSC, Kodiak)*
Stephani Zador (AFSC, Seattle)

1. Administrative

The January 2021 Crab Plan Team (CPT) meeting was held online via the Adobe Connect meeting platform, and connection information was posted to the CPT eAgenda. The meeting began shortly after 8:00 a.m. on Monday, January 11, 2021 with technical set up and overview of the meeting application. The CPT reviewed assignments and timing for meeting deliverables, including finalizing the SAFE introduction section for Norton Sound red king crab and this CPT Meeting Report. CPT Co-Chairs Martin Dorn and Katie Palof reviewed guidelines for the meeting, including public comments.

2. Crab survey planning for 2021

Mike Litzow from the Alaska Fisheries Science Center (AFSC) Kodiak Lab updated the CPT on their annual crab survey planning for 2021. Currently, AFSC is planning to conduct full surveys of the northern and eastern Bering Sea stations in 2021. However, some staffing limitations still need to be worked out for these surveys. The survey team consists of both highly trained AFSC staff who act as chief scientists, and other biologists who come from a variety of agencies and are trained just before the survey. Some staff may have difficulties participating in the 2021 survey due to COVID-19. This is currently being evaluated and, if needed, AFSC is considering bringing industry members or observers onboard to fill some of the biologist positions. A detailed safety protocol has been developed for the surveys, including quarantining and testing survey staff.

Although current planning is to complete the full survey grid, Mike presented some alternatives in case survey time is reduced. One possibility is to drop the St. Matthew Island and Pribilof Islands corner stations, which would save four or five survey days. Because these fisheries are closed and unlikely to open anytime soon, dropping these stations was regarded as a potential way to reduce effort. These corner stations were originally introduced into the survey to reduce the variance on crab abundance estimates. The CPT discussed the impacts of dropping these stations. It might be difficult to deal with survey estimates without these stations, as the survey will not be consistent with the previous time series. It was pointed out that R24, a station with consistently higher catch of St. Matthew blue king crab, is not a corner station and therefore would not be excluded if they have to drop the corner stations in 2021.

The CPT recommends prioritizing stations that might be dropped. St. Matthew blue king crab is under a rebuilding plan, and dropping the corner stations might affect the perception of rebuilding when looked at in September. Because the Pribilof Island blue king crab assessment in May will not include any 2021 survey data, there will not be any impact to the 2021 assessment if the Pribilof Island corner stations are dropped. The CPT asked when the survey team would need to make final decisions regarding the surveys. At this point AFSC does not have a final decision date, but there is an expectation that AFSC will inform the CPT before the May meeting if a full survey cannot be conducted. This would give the CPT an opportunity in May to give input on which stations to drop if necessary.

3. Crab survey data collection – length-weight relationships

Updates to the length-weight relationships of three EBS crab stocks

Jon Richar (AFSC, Kodiak) presented an investigation on shell condition and temperature-derived updates to the length-weight relationships for three eastern Bering Sea crab stocks. He evaluated shell condition as a covariate on size-weight relationships for Bristol Bay red king crab, eastern Bering Sea Tanner crab, and eastern Bering Sea snow crab. He also considered temperature as an additional covariate on the size-weight relationship for Bristol Bay red king crab. Jon reanalyzed the historical EBS summer bottom trawl survey data on weight (g) and carapace size (carapace length / carapace width, 0.1mm) to update the size-weight relationships.

For Bristol Bay red king crab, temperature influenced the size-weight relationship analysis, so he grouped the new shell males by warm/cold year, based on whether a late summer re-tow was conducted. He identified cold years as 2000, 2006-2012, and 2017; and warm years as 2001-2005, 2013-2016, 2018, and 2019. He fitted a log transformed size-weight model, where W is weight and L is carapace length, to estimate the a and b parameters. He used t-tests on the slopes to discriminate the influence of shell condition and temperature against the status quo (baseline) slope estimates. Jon compared the percentage errors in weights over size and biomass over time based on applying re-estimated and baseline length-weight models.

The size-weight relationship parameter estimates were not affected by shell condition for snow and red king crab. The weight anomaly (i.e., the difference in weight-at-size between the two methods) decreased

with size for old- and new-shell snow and red king opilio crab. On the other hand, shell condition had a large impact on Tanner crab; the weight anomaly increased with size for old- and new-shell crab.

For male Bristol Bay red king crab, the slopes of the relationship between carapace length and weight in log space were not significantly different between new- and old-shells and the baseline estimates, but the intercepts were. Slopes were significantly different for warm years compared to baseline estimates. Jon suggested it was appropriate to use estimated parameters for warm years for the new-shell length-weight model. For male Tanner crab, the slopes and intercepts were significantly different between new- and old-shells and the baseline estimates. For male snow crab, the slopes and intercepts were significantly different between new- and old-shells and the baseline estimates. Follow-up work will include blue king crab and snow, Tanner, and red king crab females.

The CPT noted that temperature is more likely to affect female than male Bristol Bay red king crab. The CPT recommended the following for consideration in the follow-up work:

- Temperature is a continuous variable. Consider treating it as such instead of designating years as ‘cold’ or ‘warm’ when performing the analysis.
- Re-evaluate and compare length-weight relationship parameters of immature and mature females of all three stocks.
- Include Bering Sea blue king crab stocks in re-evaluating male and female length-weight relationships and comparing immature and mature length-weight parameters.
- Use all available historical EBS survey data to re-evaluate the length-weight models.
- Make sure to bias-correct all log linear regressions for back-transformation.
- Provide the biological basis for re-evaluating length-weight relationships at the May 2021 meeting.

4. Risk matrix considerations for crab, lessons from groundfish

Martin Dorn provided an overview of the risk matrix approach that is being used to identify buffers for BSAI groundfish stocks. The CPT considered how this approach might be used for BSAI crab stocks.

The BSAI crab FMP specifies that the maximum permissible ABC is set with a P* of 0.49, which results in a very small buffer between OFL and ABC. In past practice, buffers between ABC and OFL have been set within a tier, with larger buffers for lower tiers where there is greater uncertainty. Thus, the ABC for crab is consistently lower than the maximum permissible ABC.

The risk table incorporates four kinds of information: fishery performance, population dynamics considerations, assessment-related considerations, and environmental/ecosystem considerations. Each of these categories is qualitatively scored from 1-4, with an overall score based on the combined input from all categories. Level 1 indicates normal conditions. Level 2 indicates substantially increased concerns. Level 3 indicates major concerns, and Level 4 indicates extreme concerns. The process provides an opportunity to summarize expert evaluation of concerns in different information areas. The risk table should not incorporate concerns or uncertainties (e.g.., parameter estimate variability) that are quantitatively incorporated into the stock assessment, as this would be double counting. How the level affects the buffer is determined on a case-by-case basis. The method was applied to five BSAI groundfish stocks in 2018, and then all full BSAI and GOA groundfish assessments in 2019 and 2020.

If the risk table were applied to BSAI crab, it could provide support and documentation for the choice of buffer in each stock. It may help address the concern that buffers have tended to increase over time and could help identify concerns related to environmental change. The CPT suggested that some draft risk tables could be evaluated in May and finalized in September. Stock assessment authors noted that the timeline for finalizing assessments is quite tight in the fall. Martin suggested that his experience is that assembling this table for pollock takes about a day and is informed by the ESP. One of the side benefits

that occurred with BSAI groundfish is a greater collaboration between stock assessment authors and ecosystem consideration report authors.

Because the state TAC setting is another opportunity to incorporate information, it is also desirable to avoid double counting of concerns in setting the OFL/ABC. The state internally evaluates uncertainty in the stock assessment. Ben Daly suggested this risk table approach could improve incorporation of environmental and ecosystem considerations and welcomed the opportunity for future use.

One CPT concern was that this may be a quantitative veneer on a qualitative approach. Martin noted the CPT practice would not change functionally, and the risk table allows the CPT to be transparent in identifying anticipated risks. Concern was raised regarding how the level relates to the choice of buffer, which is selected on a case-by-case basis for BSAI groundfish. There is a SSC workshop in February to further refine the approach, and the CPT Chairs will follow the results of this workshop.

The CPT supported moving forward with this approach and is asking stock assessment authors to volunteer to prepare draft risk tables. The authors for snow crab and SMBKC volunteered to draft these for May. Other assessments, if the authors have time, include BBRKC, Tanner crab, and NSRKC. ESPs exist for SMBKC and BBRKC, so environmental considerations may be better informed for these stocks.

5. ABSC fishery questionnaire, improving stakeholder input to CPT

Cory Lescher with the Alaska Bering Sea Crabbers (ABSC), an industry representative group, spoke to the CPT about a skipper survey developed by the ABSC and the pilot survey that occurred following the 2020/21 Bristol Bay red king crab fishery. This project was undertaken as part of national priorities for NOAA Fisheries in 2021 to utilize industry and community data collection to help fill data gaps. The survey collects fishery-dependent data from skippers during a time different from the annual trawl survey. The ABSC is also working to build trust with the fleet through communication, collaboration, and education.

The survey consists of ten questions. The first five questions are fishery related, with the goal of obtaining each skipper's impression on perceived crab abundance, areas fished, and interactions with other fishing sectors. The ABSC goal is to keep this first set of questions standard and survey the active skippers twice a year following each fishery season. The second five questions are current events related and solicit the skipper's opinions on issues that ABSC is interested in, with the option for open comments. This set of questions would change yearly or seasonally and be used to facilitate potential research topics. This survey is anonymous with responses collected by ABSC aggregated at the fleet level.

For the pilot study with 2020/21 Bristol Bay red king crab, surveys were electronically sent to approximately 72 skippers (although it is uncertain if all skippers received surveys and if recipients actually participated in the fishery) with 20 surveys completed. Forty seven vessels participated in the 2020/21 Bristol Bay red king crab season. Results from the pilot study indicated that respondents saw an overall increase in crab abundance, mostly attributed to increased catches of young male/pre-recruits. Female red king crab abundance was perceived as average compared to the previous three seasons. The pilot study also found that most respondents encountered tagged crab during the season, and also that very few vessels use the king crab pot storage area due to concerns over gear interactions with other fishing sectors.

The ABSC is seeking guidance from the CPT and agencies on survey implementation and which questions might provide information useful for assessment and management. The CPT suggested tracking how survey information gets used, and then reporting back to participants, so skippers remain motivated to participate. There is a concern that if respondent's impression of stock abundance or other factors contradicts trawl survey or modeling results, this could disincentivize and disenfranchise survey participants. The ABSC is aware of this potential issue and is working to manage expectations, give

skippers an avenue to report observations, and create a database to document trends seen on the fishing grounds as snapshots over time.

The CPT was concerned about the potential for biased responses in this project, such as non-response bias. The set of questions will be asked repeatedly over several seasons to develop a time series, but validity is limited for a low response rate or if there are changes in the group that responds to the survey that are not accounted for in some way. There is no way to account for these biases if survey respondents are anonymous. Since data are aggregated to the fleet level, the CPT recommends adding an identifier to sort out some bias in future surveys. There is also the possibility that since skippers are good at finding crab and tend to stay on productive fishing grounds, there is the potential that this survey could potentially present a more optimistic view of the stock than is warranted.

The CPT appreciates this effort by ABSC, and stock assessment authors would like to have more interaction with harvesters. Harvesters informing potential research studies are valuable and CPT would like ABSC to consider new data applications instead of replicating existing data sets. The ABSC noted that skippers pay attention to changes in temperature, depth, currents, seasonality, and this survey could be the next step to collect information and inform data gaps and research priorities.

It is recommended that the CPT, perhaps through a focus group with ABSC and industry participants, consider questions in the skipper survey to refine and expand on the information being collected. The CPT requested an update and summary of findings from this survey at the September CPT meeting since snow crab fishing will likely be ongoing in May. This information may be best incorporated into the management framework through the federal risk matrix used in the future to help inform the ABC and on the state side during the TAC setting process. Currently, this project is in the pilot phase and is focusing on red king crab and snow crab. There are plans to expand to Tanner crab, and possibly Aleutian Islands golden king crab, in the future.

6. VAST model – updates with diagnostics

Jon Richar gave the CPT an update on work he has been doing to produce VAST (Vector-Autoregressive Spatio-Temporal) estimates of NMFS EBS survey biomass for several BSAI crab stocks. Previously, Jon had presented initial work on VAST estimates for crab at the May 2020 CPT Meeting. At that meeting, the CPT expressed reservations regarding the lack of criteria for adoption of these estimates as substitutes for the standard design-based estimates in crab stock assessments. The CPT requested that Jon explore diagnostics for the VAST estimates more fully than had been done, with the goal of developing criteria by which these could be accepted (or rejected) as improvements on the design-based estimates.

Jon covered four principal topics in his presentation: 1) the use of standard VAST model-fitting diagnostics to aid model selection/rejection; 2) new model-fitting diagnostics based on the "DHARMa" R package; 3) sensitivity of results to VAST model settings (e.g., number of knots); and 4) the implementation of a barrier method for estimating survey biomass for the St. Matthew Island blue king crab (SMBKC) stock.

AFSC's RACE Groundfish Assessment Program has been producing VAST estimates and diagnostics for EBS and GOA groundfish stocks for several years. Diagnostics include observed vs. estimated and maps of spatial residuals for encounter rates as well as qq-plots and maps of Pearson residuals for log-scale positive catches. Jon noted that the Groundfish Plan Teams (GPTs) have not rejected any of the groundfish applications of VAST outright based on the diagnostics provided by VAST. Instead, the GPTs have left it up to assessment authors to decide whether or not to use the VAST results in place of the design-based results. Jon contrasted diagnostics from VAST models for BSAI yellowfin sole (YFS) and northern rock sole (NRS) with those for Bristol Bay red king crab (BBRKC) and Norton Sound red king crab (NSRKC). The YFS VAST estimates are used in its assessment while the NRS ones are not. The observed vs. estimated encounter probability and positive catch quantile-quantile (qq) residuals plots were fairly similar for YFS and BBRKC, but those for NSRKC differed substantially from the others. Maps of

spatial Pearson's residuals for BBRKC had a few large outliers, but otherwise patterns of spatial residuals were similar for YFS and BBRKC, with encounter rate residuals larger on the borders of the respective stock areas and no patterns in the positive catch residuals. Jon suggested that the BBRKC diagnostics might represent those for minimally-acceptable VAST results, while the NSRKC diagnostics clearly indicated a VAST application that should be rejected.

Jon also provided results from a new approach to residuals diagnostics, recommended by Jim Thorson, using the R package DHARMa (https://cran.r-project.org/web/packages/DHARMa/index.html). DHARMa uses a conditional simulation residual to define the probability density/mass function for each datum, and then calculates Probability Integral Transform (PIT) quantile residuals. Using DHARMa, one is able to run valid statistical tests (e.g., K-S test, dispersion test, outliers test) on these residuals—which is not possible using the Pearson's residuals—although rejection criteria for the DHARMa statistics have yet to be developed for models such as VAST.

Jon also presented results from a set of exploratory model runs conducted to determine the sensitivity of VAST results to the choice of different probability distributions (five types, but only the gamma model with Poisson-link and lognormal models were discussed) and different numbers of knots (150-750) to fit the observations. Jon presented results (males only) for BBRKC, Tanner crab, snow crab, and SMBKC, including the new DHARMa diagnostics. For BBRKC, the lognormal model appeared to exhibit somewhat better DHARMa diagnostics than the gamma model, but Jon preferred the latter because it was more in line with the design-based estimates. The number of knots had little impact on either estimates or CIs for this stock. Similar results were obtained for Tanner crab and snow crab, although diagnostics favored the gamma model for snow crab. Jon also considered a gamma model with near bottom temperature (NBT) as a covariate; the estimates were only slightly different from the model without NBT, and the CIs were only slightly smaller. For the SMBKC models, Jon ran into convergence issues and had to turn off the "epsilon2" model component in all gamma models and in lognormal models with more than 250 knots. Jim Thorson indicated that this was the correct approach to take in this situation and noted that it was good practice to turn off parameters and simplify the model when the corresponding variances were zero. The resulting biomass estimates were highly dependent, though, on the number of knots chosen, regardless of model type. Although the DHARMa diagnostics seemed to be slightly better for the lognormal models, Jon was concerned about the current reliability regarding the interpretation of these diagnostics and provisionally recommended using a gamma-with-Poisson-link model.

For SMBKC, a "Barrier" method has also been implemented, which allows for an intervening landmass to influence the spatial correlation between two points. This should reduce the likelihood of biased estimates associated with extrapolating across St. Matthew Island. The CPT noted that this may have a small effect relative to that of the large interannual variability in catches at NMFS survey station R-24 because R-24 is not particularly close to the island in terms of the stock area. Jon presented results from a gamma-with-Poisson-link model using 500 knots that incorporated the Barrier method. The results, both estimates and CIs, were very similar to, though for some years slightly smaller than, results from the corresponding model that did not account for land barriers.

As a procedural step in providing survey biomass estimates to assessment authors for inclusion in models presented at the May CPT Meeting for consideration in September, Jon suggested that an *ad hoc* group, to include at least 2 VAST GAP personnel, be formed to review the VAST estimates produced for crab stocks in early March. The CPT expressed its appreciation to Jon for the work he has done on this issue. He was very diligent in addressing the issues raised at the May 2020 CPT Meeting. It also expressed its appreciation to Jim Thorson, (AFSC) the principal developer of the VAST software, for attending (virtually) Jon's presentation and providing his perspective and expertise as part of the overall discussion.

In discussion, CPT members suggested that, despite the progress made thus far, the VAST diagnostics were not yet characterized well-enough to provide the basis for selecting the VAST estimates for use in crab stock assessments over design-based estimates. Jim stated that he is working with Cole Monnahan

(AFSC) and Andrea Havron (AFSC) to improve DHARMa residuals diagnostics and anticipates that they are already more useful than the Pearson residuals diagnostics previously provided by VAST, with more improvements expected in the next 1-2 years. Pearson residuals do not account for higher moments in the probability density/mass function (and thus perform poorly as presence/absence diagnostics for locations at which encounter probability approaches 0 or 1). In addition, one cannot jointly visualize diagnostics for both components of the delta-model; this is now feasible using PIT residuals. The Pearson residuals also require binning or ranking across data to develop an expectation for model performance, while PIT residuals from conditional simulations are likely to be more useful for small data sets (e.g., NSRKC). However, PIT residuals calculated from conditional simulations do not propagate the variance of random effects, and therefore tend to lead to a lower p-value for any given diagnostic test than should occur.

Jim, Cole, and Andrea are working to explore "leave-one-out" residuals in TMB, as well as joint predictive residuals to propagate random-effect variance when calculating PIT residuals. The latter will likely improve the usefulness of p-values arising from DHARMa testing algorithms. The CPT agreed with Jim that it would be useful to identify some reference values or "cut-offs" for the p-values calculated by DHARMa, but also noted that the p=0.05 rejection threshold was likely not appropriate for VAST models.

In other discussion, CPT members questioned how to deal with the tighter confidence intervals (CIs) on biomass estimates that VAST frequently provides. Citing the snow crab results, it was suggested that the CIs were not reflective of biologically-possible changes in annual snow crab abundance. In response, Jim noted that additional weighting parameters frequently need to be estimated when fitting VAST estimates in a stock assessment due to the reduction in their CIs over the associated design-based estimates. The CPT observed that VAST estimates were typically not fitted as well as design-based indices in Alaska groundfish assessments. It also discussed differences in the use of VAST estimates between West Coast and North Pacific assessments, noting that VAST estimates are used in West Coast assessments but that the typical design-based CVs for these stocks are quite large (>0.4) while the typical CVs for North Pacific stocks are smaller (<0.2). Jim suggested that it may not be worth using VAST estimates if the only result is a reduction in the CIs, but that VAST may be better when combining indices from different sources (e.g., NMFS and BSFRF) or from different areas (e.g., the EBS and NBS).

The CPT had the following recommendations related to VAST diagnostics:

- Use DHARMa diagnostics, but also provide maps of spatial Pearson's residuals (the latter are more easily interpreted than DHARMa's spatial residuals).
- Scale maps comparing spatial residuals between models to the same scale.
- Increase the size of spatial residual maps for better visual clarity.
- Continue to evaluate how to better define model acceptability.

Finally, the CPT requested that Jon provide VAST estimates to assessment authors prior to the May CPT Meeting to allow the authors and CPT to consider their use in assessment model runs proposed for the fall assessments.

7. Norton Sound red king crab - final SAFE

Toshihide ("Hamachan") Hamazaki (ADF&G, Anchorage) presented the assessment for Norton Sound red king crab. A single model was presented at the request of the CPT from the September 2020 meeting (Model 19.0). The CPT appreciates Hamachan's responsiveness to the numerous requests made (including VAST GMACS explorations and providing pot loss data). Jen Bell (ADF&G, Nome) also presented information on the extent and future direction of research efforts aimed at understanding NSRKC population dynamics. For instance, pot loss data were presented in response to a CPT request, and Jen also described studies to understand where lost pots are moved by shifting ice. Other areas of investigation are the high abundances of male crab that track consistently from one year to the next in both surveys and harvests, infrequent but significant occurrences of barren females, and male functional

maturity. Analyses of tagging data in years during which surveys were not available were particularly useful in better understanding cohort dynamics. The CPT expressed enthusiastic support for continued investigations of the research questions presented. Several members of the public also contributed to productive discussion around OFL calculations and historical perspectives.

The CPT accepted model 19.0 for use in management. Although the assessment author supported continued use of a retained catch OFL, the CPT endorsed the LNR2 method for accounting for discards to support calculation of a total catch OFL. The various methods for accounting for discards gave similar results, and the LNR2 method produced an OFL close to the median of the various methods. The author updated the relationship between carapace width and carapace length used to determine what crab are legal, but the CPT recommends that the methods be better described. The CPT recommended continuing the 30% buffer on ABC chosen by the SSC last year. The SSC justified the 30% buffer based on ten points (see table below). Some of these points are less of a concern this year, which might suggest reducing the size of the buffer would be appropriate. However, the CPT identified several new issues that should be addressed within the assessment such as fishery timing with respect to cohort progression, estimates of growth, changes in the definition of legal crab based on updated data used to translate between carapace length and width, and the way in which the OFL is calculated using 'legal' size (≥4 ¾" CW) crab, rather than a selectivity curve reflecting the 'exploited' crab (≥5" CW). The CPT considers that these points, at the very least, are a counterbalance to the issues that might be excluded from the SSC's list of concerns in the table below, which informed the CPT decision to retain the 30% buffer.

Although the assessment has used the abundance of legal male to define OFL/ABC, the CPT recommends that future assessments use standard methods with estimated selectivity and retention curves to define the OFL/ABC. Industry selection for larger than legal crab could result in higher F than F_{OFL} for retained crab and unaccounted discard for legal crab under market size. The CPT noted that the total catch OFL was very similar across all model scenarios examined.

The CPT had several requests for the author:

- Explore and document the reasons for the changes in the relationship between carapace length and carapace width. Document which data sources are excluded or included and for what reason.
- Plot the legal biomass over time using the different proportions of legal size crab to better understand the magnitude of the impact of the change.
- The OFL should be specified based on total catch including retained catch and non-surviving discard. Specifying the OFL based on legal crab would result in higher OFLs than if based on retained crab. This would then translate to higher exploitation rates on the exploitable crab than the target rates and increased discard mortality on non-preferred size crab that must be sorted through to achieve the OFL.
- Revisit growth assumptions. Growth appears to be consistently overestimated in the assessment, producing too many large crab. The CPT looks forward to seeing the results from the laboratory studies on growth for NSRKC at the next meeting.
- Revisit natural mortality assumptions. Both the assumed natural mortality for small crab and the larger natural mortality for crab greater than 123 mm CL should be better justified. The author noted that the maximum age observed in the tagging studies was 12 years, which is much lower than the assumed value of 25 years. Further, the "1% method" used by the authors to calculate a natural mortality generally provides lower estimates of M than empirical studies (see the tool at Barefoot Ecologist Toolbox for examples).
- Future figures of clutch fullness should include confidence bounds.
- Further consider which of the methods to account for discards are most appropriate for NSRKC given probable future data availability. The CPT realizes that no method will be perfect, but an imperfect consideration of discards is better than ignoring them.
- Explore having Jon Richar work on a VAST model for Norton Sound trawl surveys.

A list of SSC concerns that directed the adoption of a 30% buffer in 2020 with indications of whether the concern was still an issue and a brief explanation if it is not.

SSC concern	2021?	Explanation
1. Considerations of other stocks with similar levels of uncertainty	Yes	
2. Concerns with model specification in part indicated by a positive retrospective pattern, whereby successive assessments indicate increasingly pessimistic estimates of stock size for the same years. The full magnitude of the retrospective bias is unknown given that peels of the data go back only a few years. The cause(s) of the pattern are unknown	No	Retrospective patterns are relatively small compared to other stocks and within commonly cited acceptable ranges. The retrospective pattern was characterized for 10 years of peels.
3. Shortage of discard data and resultant inability to manage the stock based on total catch, which is the standard for federal fisheries	Less	Hamachan presented methods to account for total catch; the LNR2 method was chosen by the CPT.
4. Unresolved issues associated with the apparent high *M* for the largest size class	Yes	
5. Discrepancies in stock size estimates between ADF&G and NMFS surveys as well as concerns about the spatial distribution of crab relative to the survey footprint	Yes	
6. Very low fishery CPUE and inability of the fishery to attain the ABC in 2019	Yes	
7. Unusually large numbers of old-shell males in the fishery in 2018-2019	Yes	
8. High proportions of barren females in survey and fishery observations indicating some reproductive failures in 2019	Less	Fewer barren females in 2020 and males are reaching the appropriate size for mating.
9. Below-average numbers of prerecruits (<94 mm CL) in 2015-2018 suggesting that below-average recruitment to the fishery will be experienced for several more years	Yes	
10. Large uncertainty in the magnitude of the most recent year class (prerecruits in 2019), preliminarily estimated to be large. However, these small crab are several years away from recruiting to the fishery as legal crab and they are challenged by unprecedented recent increases in Pacific cod, a crab predator, in Norton Sound.	Less	The year class is tracking and uncertainty is less now that the year class has been observed several times.

8. Aleutian Islands golden king crab – model discussion, scenarios for May 2021

Shareef Siddeek (ADF&G, Juneau) provided an overview of model scenarios he intends to include for the May 2021 CPT review of the Aleutian Islands golden king crab assessment, as well as his responses to prior year CPT and SSC recommendations. Seven models were proposed for the EAG (East of 174°W and four models for the WAG (West of 174°W), along with the model on which the May 2019 and May 2020 assessments were based. The following represent the models the CPT recommends be provided for the May 2021 meeting, and includes the model numbers that reflect the agreed upon numbering convention.

- Model 19.1. This is the model on which the May 2019 and May 2020 assessments were based. It should be updated with new data.
- Model 21.1a. As for model 19.1, except that the period for defining the mean number of recruits is modified to 1987-2017. The CPT was provided with results for a range of periods for defining mean recruitment and the assessment outcomes were robust to the choice of period.
- Model 21.1b. As for model 21.1a, but with three total selectivity periods (1960-2004; 2005-2015; 2016+). The analysts should use figures and other analyses to justify the reasons for allowing for time-varying selectivity – which reduces the size of the retrospective patterns [but allowing virtually any population process to be time-varying could achieve this goal].
- Model 21.1c. As for model 21.1a, but with the observer CPUE data standardized including Year:Area interactions.

The CPT was also provided with results for three other models for the EAG (19.1c: GMACS implementation; 19.1d: model 21.1a, but with the EAG cooperative survey CPUE indices for 2015-2019; 19.1e, as for 19.1d, but using the fish ticket CPUE data for the entire period). The current GMACS model has some unexpected behavior (e.g., an inability to fit the catch data and unrealistically good fits to the CPUE data) so is not viable for adoption. However, progress on a GMACS-based assessment should be included as an appendix to the assessment report. Models 19.1d and 19.1e both include undesirable features: model 19.1d had cooperative survey and CPUE data for same years (which could lead to double use of some data) and model 19.1e made no use of the observer CPUE data, even though these data are preferable to the fish ticket CPUE data. The CPT recommends that the results of an exploratory model in which model 21.1a is modified to use the EAG cooperative survey data, and the observer CPUE data from 2015 are ignored, be provided in an appendix to the assessment report. This model could be considered for use in the 2022 assessment. The analysts need to document and justify how selectivity for the cooperative survey is specified (e.g., equal to fishery selectivity [the assumption on which models 19.d and 19.1e in the assessment report was based] or estimated based on the survey length-composition data).

The approach to selecting the range of recruitments to define mean recruitment involves comparing the standard errors of estimated recruitments in log-space with the (assumed) extent of inter-annual variation in recruitment (defined by R_{sigma}). The results were shown to be robust to the selection of the percentage of R_{sigma} used to select the range of years and the CPT is satisfied with the proposed approach.

The CPT has the following additional technical comments on the assessment:

- The CPT was unclear why a predicted CPUE from the CPUE standardization with Year:Area interaction could be negative. Also, the formulae used to compute the variances for years*areas with no data should be provided and a bias correction factor should be applied to Equation A.15.
- The analysts should consider a range of alternative standardization models for the EAG cooperative survey data (including that suggested by the SSC) and provide a rationale (including model fit, whether the analysis converged, etc.) for the selected model.

- The assessment should more clearly provide the rationale for separate EAG and WAG assessments, including consideration of differences in trends in CPUE and age-compositions between the EAG and the WAG.
- Results should be presented only for the best fit (lowest objective function). If a best fit model exhibits unusual features (e.g., outlying F estimates or parameters on bounds), this can often be rectified by implementing bounds or smoothing penalties on some of the parameters.
- The runs used to create the retrospective plots should be checked as one run (2013 for WAG) appears to be a case where the minimizer has failed to converge.

Other suggestions (presentational)

- Add the historical TACs to the plot of catches and CPUEs.
- When plotting MMB, the x-axis value should be the second of the two years (e.g., the MMB for 2019/20 should be plotted against 2020, not 2019).
- Provide a figure that shows the size composition data for the fleet with time-varying selectivity in a vertical manner (e.g., Figure 12 in the snow crab assessment) to see changes in the data over time. This can be done using the R package *ggridges*. Additionally, a plot that shows the fits to the aggregate size-composition data would be useful.
- Include plots of the estimates of the smoothing functions (soak for the observer CPUE; depth and soak for the cooperative survey data) when conducting the CPUE and survey standardizations to check that these behave sensibly. Also plot the data on CPUE vs. depth and CPUE vs. soak time to allow the underlying patterns to be identified.

9. Crab Economic SAFE

Brian Garber-Yonts (AFSC, Seattle) provided an update on the Crab economic SAFE. The SAFE is based on an annual economic survey of crab processors and harvesters. The document is still being completed for the February SSC meeting, but should be posted by next week. The SAFE includes historical data but is focused on the five years 2014–2019 including; TACs; landings (ex-vessel and processed product volume), ex-vessel and first wholesale revenue and average prices; income and employment values for both harvesting and processor sectors; review of operating costs in the harvesting sector; quota market and holdings; fishing capacity and effort; and some information on international trade. One new aspect recommended by the SSC was to include information on income and operating costs for processors. However only labor costs are currently collected from the processing sector and not overall operating costs.

Per an SSC request, a summary of ownership and leaseholder composition for individual ownership instead of cooperative ownership is being developed and will be useful for a crab rationalization review. However, disaggregation to the individual and community level may be difficult due to confidentiality issues. The SSC also expressed interest in information regarding community impacts, such as wage and employment impacts, from both the processing and harvesting sectors. A new report, The Annual Community Participation and Engagement Overview, will be posted with the economic SAFE and presented at the February Council meeting. A summary of report card style metrics is also being developed for the May CPT meeting.

Brian noted that one exception to the 5-year timeline in the SAFE was the trend in TACs, which are a driving component of economic decisions for the different crab fisheries. In general, the 2019 TACS, and corresponding production and value in 2019 represented increases over the previous several years. Production across all crab fisheries was up 22% in 2019 to 39 million lb, mainly due to an increase in the snow crab TAC. Bristol Bay red king crab was down ~10%. Ex-vessel revenue and first wholesale revenue for all crab species were up by 18%. This was mostly driven by a 42% increase in the snow crab fishery. Prices, adjusted for inflation, have generally increased across most fisheries since 2014 with the

exception of snow crab. Tanner crab has been on a considerable upward trend. Ex-vessel price as percent of first wholesale price has generally increased in recent years. Processing capacity has steadily declined over the past few decades, and in 2019 only 9–10 plants operated and no C/Ps operated. However, custom processors have steadily increased. Crab processing hours increased 18% overall in 2019, and wages also increased by about 29%.Crew positions declined slightly, but crew pay increased by 23%.

The quota lease rate versus the ex-vessel price has been consistent over time, especially for snow crab and red king crab. For the red king crab fishery, 81-88 % of the quota is leased and 39-42% of aggregate ex-vessel value of landings are paid out in quota lease royalties. Gross vessel profit generally increased slightly from 2018 to 2019 across fisheries, notably in the snow crab fishery, but was flat in the red king crab fishery. Gross profit is usually around 40% in most years.

Priorities for the 2020 SAFE include: development of report card metrics for ESP integration; updating price forecasts and 2020 estimates, evaluating community level demographic information; and providing a processing sector income analysis. Both the crab and groundfish economic SAFEs will be presented to the SSC in February 2021. Some potential metrics for ESP development were presented.

10. IBM snow crab model - update on progress

William (“Buck”) Stockhausen (AFSC, Seattle) presented initial results from a spatially-explicit, biophysical individual-based model (IBM) for eastern Bering Sea snow crab. The IBM embeds individuals within a time-varying, spatially-explicit, biophysical environment to examine individual characteristics, behavior, and variability in different life stages and investigate the linkages between the environment and population dynamics, especially on early life stages. The physical environment may include currents, temperature, salinity, pH, light, etc., and the biological environment may include prey fields, predator fields, etc.

For eastern Bering Sea snow crab IBM, the physical environment was generated from a 10-layer ROMS model with 10-km horizontal resolution and weekly-averaged output. The version of the snow crab IBM presented to the CPT included several early life stages: two zooeal stages, a megalopal stage, and seven sex-specific, early benthic instar stages. The intent is to develop additional benthic stages and “close the loop”. Intermolt durations for stages were temperature-dependent or fixed. Model parameter values were mainly derived from literature. The model was initiated with about 11,000 equally-spaced individuals released as first zooeal (“Z1”) stage larvae on May 1 each year for 1971-2004 just above bottom in eight spatial zones defined on the middle and outer domain of the EBS shelf at depths < 250 m to hindcast individual larval trajectories, larval settlement patterns and connectivity. Overall, larvae released in the middle zones of the eastern Bering Sea shelf were hindcasted to have good successful settlement rates and those released in the edge shelf zones to have high chances to be carried away from suitable settlement areas. If the larval intermolt durations were fixed, as in previous work with a similar IBM by Parada et al. (2010), settlement patterns in cold and warm years were found to be fairly similar. If the larval intermolt durations were temperature-dependent, the larval intermolt durations were hindcasted to be much longer, and settlement patterns were more spatially spread out in cold years than in warm years. In general, temperature-dependent intermolt durations for larvae resulted in more spatially spread out dispersal patterns than fixed intermolt durations.

Buck continues to work on forecasting changes in connectivity using downscaled CMIP6 ROMS models, integrate spatial patterns of primiparous and multiparous females into connectivity calculations to predict benthic settlement patterns, and simulate temperature-dependent intermolt duration trends for early benthic instars C1-C7 to see whether or not the IBM can predict/estimate annual mixtures of cohorts recruiting to the assessment model. Buck also plans to add bioenergetics and mortality to the model and to interface the model with spatially-explicit snow crab assessment models under development by Maxime Olmos and Cody Szuwalski.

The CPT discussed the validation and usefulness of this kind of model. Currently, there are no adequate data to validate the model. Due to data limitations, model parameter values and biological processes could be wrong and the detailed model results need to be treated carefully for application. Also, the model currently lacks starvation and predation mortality. Generally speaking, qualitative results are more important than quantitative results from such models, and the usefulness of the model is on hypothesis generation. In the future when the data and model are improved, it may be possible to generate indices for crab recruitment for stock assessment models, but it may be a challenge to generate an index that is significantly correlated to crab recruitment.

11. Bering Sea Fishery Research Foundation update on projects

Scott Goodman of BSFRF gave an update on their research plans for 2021 related to growth, standardization of BSFRF data, movement/tagging, an upcoming snow crab cooperative workshop, and a bycatch reduction project. The 2020 growth project was cancelled due to COVID-19, but planning is underway to collect pre-molt snow crab during spring 2021. Crab will be collected via trawl and transported to Kodiak.

Areas targeted for collections will be refined in the coming weeks and will target various crab sizes, including those anticipated to molt to maturity, not just small crabs. The BSFRF will continue tagging work in support of crab movement research using acoustic sail drones and, in collaboration with NOAA and ADF&G, include satellite tagging research to supplement and compare to the acoustic tagging work. Current efforts are focused on exploring options for a summer charter for tagging work that coordinates with other efforts such as supplemental crab survey project work (specifics TBD). As such, BSFRF is working with NMFS and ADF&G in planning possible charter efforts. The BSFRF is compiling BSFRF survey data (e.g., Tanner and snow crab side-by-side survey data) into a consistent format so that data will be readily available to research partners. Efforts include cleaning up the data for broad distribution, recalculating area-swept estimates, and reviewing changes associated with the recalculations. The hope is to house the data in an open-access database such as RACEBASE or AKFIN in a format similar to the NMFS EBS bottom trawl survey data.

The bycatch reduction research (funded by NOAA's Bycatch Reduction Engineering Program) is ongoing with a second year of research underway. The project includes both lab and field components to evaluate various gear modifications to reduce crab bycatch in cod and halibut pot fisheries. The plan is to test gear modifications in upcoming fisheries.

The BSFRF is hosting a cooperative snow crab workshop during January 21-22, 2021. Invitees include harvesters, processors, and cooperative research partners. The workshop will review available information from a research perspective (data on maturity, growth, etc.) and identify options for further research and next workshop steps (two workshops planned now). The intent is to build on past Tanner crab workshop (Dec 2017) methods and outcomes as a pattern for successful collaboration. In general, BSFRF is seeking input on other research options and broadening scope of projects.

12. Tagging studies update by NMFS, ADF&G

Leah Zacher (AFSC, Kodiak) gave an update on ongoing Bristol Bay red king crab (BBRKC) tagging efforts. The overall goal of the project is to determine BBRKC distribution, movement, and essential habitat use with acoustic tags and autonomous surface drones for relocation. Leah reviewed 2019 tagging efforts, highlighting that 148 mature male BBRKC were tagged in one location on a June cooperative industry tagging charter. In October 2019, two sail drones were deployed for a 30 day relocation effort and covered approximately 6.5% of the search area. Of the 148 males tagged, 34% were relocated and traveled 50-100 km on average from June to October. Leah noted that the majority of males moved into deeper waters with finer substrate while at liberty, although analyses linking movement and habitat associations are difficult due to the coarse spatial resolution of benthic sediment composition data. The

CPT recommended contacting Bob McConnaughey regarding his recent efforts to develop finer resolution benthic sediment maps.

Leah also reviewed 2020 summer field work, which focused on tagging 305 mature male BBRKC across four regions. ADF&G observers tagged an additional 50 mature females during the October 2020 fishery. Unfortunately, the spring and fall 2020 sail drone relocation efforts were cancelled due to COVID-19 complications, so there are no new relocation data. Project plans for 2021 include a 43-day sail drone deployment this spring, which will include an expanded search area. A summer 2021 cooperative tagging charter is funding-dependent and will focus on tagging female BBRKC and relocating in April-May 2022. The proposed work will also deploy pop-up satellite tags with release dates in October and January. The CPT applauds Leah's efforts to continue data collection despite unprecedented challenges due to COVID-19, and looks forward to future project updates on seasonal movement of BBRKC.

Ben Daly and Andy Nault (ADF&G-Kodiak) gave an update on ADF&G pop-up satellite tagging projects. Ben summarized satellite tag methodology and pilot studies conducted by the Kodiak lab. A 2019 Tanner crab tagging study was carried out by ADF&G staff to examine movement patterns and spatial stock structure relative to the Pribilof Islands Closure Area. Andy presented results from the study, which tagged 140 legal male Tanner crab using satellite tags, and an additional 1,339 crab with spaghetti tags both inside and out of the closure area. Andy reviewed data processing steps involved for pop-up location and uncertainty estimates, as well as providing an overview of methods used to classify the reliability of the location data. Movement rates of tagged Tanner crab at liberty for 90-146 days were highly variable and results suggested that most individuals moved in a southerly direction. Andy reported that the study found no relationship between movement rate and crab size, although new-shell crab moved at a higher rate than old-shell crab, likely due to differences in metabolic demand and potential effects of senescence. Recapture data from spaghetti tags were also reviewed as a means to ground-truth movement rates estimated from satellite-tagged crab. Overall, the study concluded that Tanner crab are capable of moving at rates necessary to emigrate from the Pribilof Closure Area between the summer survey and winter fishery, although there was minimal net transfer across the closure area boundary in 2019. Results emphasize that while Tanner crab TAC's are based on the entire population, they place a higher exploitation rate on large males outside the closure area.

Ben also gave a brief overview on ADF&G's BBRKC satellite tagging efforts in 2020. This past summer, 84 satellite tags and 1,631 spaghetti tags were deployed on legal male RKC. Males were tagged at the same location as Leah's tagging efforts to examine where crab not detected by the drone may be moving to, and advance our understanding of seasonal movement patterns. Data processing from this effort is still underway. Ben briefed the CPT on a planned 2021 NSRKC tagging study aimed at characterizing distribution and migration patterns of large male NSRKC relative to survey and fishery timing. The plan is to deploy 75 satellite tags on large males, with additional tagging of smaller males and females pending additional funding from a NOAA grant. Ben concluded by highlighting future research interests involving BBRKC mature female tagging. The CPT looks forward to updates on NSRKC and BBRKC tagging efforts as the results are synthesized.

13. Climate change and crab management considerations

Cody Szuwalski gave a presentation on the issues associated with the impact of climate change on management of BSAI crab stocks. Recent environmental conditions in the Bering Sea are a signal that climate change has already begun in the Bering Sea, but projected changes to the end of this century are very likely to be greater than anything we have already experienced. Adaptation at multiple levels will be needed to respond to the challenges of climate change. BSAI crab are managed at the federal level using harvest control rules that specify the harvest associated with the overfishing level (OFL) as a function of current stock size. The acceptable biological catch is set below the OFL to account for scientific uncertainty. The two reference points that define the shape of a harvest control rule are the target stock size B_{MSY}, and the F_{MSY} fishing mortality rate. As the climate departs from past experience, assessment

scientists and fisheries managers will increasingly grapple with the question of whether to modify these reference points to account for changes in stock productivity. These decisions will in some cases determine whether or not a fishery can continue to be prosecuted in the future in a changed environment. The CPT already recommends a "current regime" when setting B_{MSY} based on changes in productivity.

Cody described a phenomenon that he called the "productivity paradox," whereby climate-adaptive harvest control rules result in higher exploitation rates, instead of more conservative management. This can arise when reference points respond to changes in growth, maturation, and natural mortality. In addition, a change in mean recruitment can change the stock's placement on a sloping control rule, resulting in change in the exploitation rate. The CPT also discussed the varying ways in which the term "productivity" is used with respect to fish stocks. Cody offered the definition that it is the "rate at which biomass accumulates in the ocean." André Punt thought that productivity could be equated with MSY (i.e., reflecting per-capita productivity as well as biomass in absolute terms). Productivity involves both overall stock abundance, shape of the stock recruit curve (i.e., steepness), and life history characteristics such as maturation, growth, and mortality. André emphasized the need to map out the full yield curve before and after the productivity shift, since spawning biomass-per-recruit metrics only reflect life history changes.

Cody discussed several examples for BSAI crab stocks that help to frame the fisheries management issues associated with an apparent shift in stock productivity. The stock of blue king crab in the Pribilof Islands was declared overfished in 2002 and has been under a rebuilding plan since 2003. Despite a fishery closure and strict management measures to reduce bycatch, there is no evidence of stock recovery toward a B_{MSY} target that is based on historical abundance levels. At the same time, red king crab have increased in abundance in the Pribilof Islands, potentially displacing the blue king crab population. A different approach was used for Tanner crab in 2012, where an overfished stock was determined to have been rebuilt based on a recalculated B_{MSY} using a more recent (and lower) recruitment time series, acknowledging a change in the productivity of the stock.

These issues were also considered for the recent St. Matthews blue king crab rebuilding plan adopted by the NPFMC in 2020. Although recruitment has been reduced in recent years for St. Matthews blue king crab, the rebuilding target was based on the average for the full time series. Different projections under alternative recruitment assumptions included recruitment for the recent low period, the full time series, and an intermediate assumption. At this point the CPT does not consider that any single approach for establishing reference points is the correct approach that should be used in all cases, and instead recommends a flexible case-specific approach to deal with these issues. It is worth mentioning that the two cases where the rebuilding target was based on historical abundance were smaller stocks with a limited distribution and specialized habitat requirements. These stocks may require greater protection under climate change than stocks with wider distributions and generalist characteristics. It was also noted that a paper by Neil Klaer et al. (2015, https://doi.org/10.1016/j.fishres.2015.03.021) provides useful guidance on criteria to use when deciding when a stock productivity change has occurred.

Cody referred to a recent paper (Szuwalski 2020, doi:10.1093/icesjms/fsaa140) on climate change and Bering Sea crab. Initial results indicate that Tanner crab may become more productive and shift to the west, while snow crab productivity may decrease and the stock may shift northwards due to reduced ice cover. Research on these likely impacts of climate change on crab stocks is ongoing and it is difficult to know how robust these results are. Although crab could generally be considered higher risk than groundfish due to potential negative impacts of ocean acidification on shell calcification, it is likely that even among BSAI crab there will be stocks that benefit from climate change as well as those that are adversely impacted. This again highlights the need to have a flexible approach for dealing with the impacts of climate change on crab management.

14. Crab PSC in groundfish fisheries – Plan Team feedback to analysts

Sarah Marrinan and Sara Cleaver (NPFMC staff) gave an update on a preliminary/initial review of crab prohibited species catch (PSC) limits in the BSAI groundfish trawl fisheries. The Council received public testimony on this issue and initiated a preliminary/ initial review analysis in December 2019. The CPT was then briefed on the issue in May 2020 followed by a sensitivity analysis done by assessment authors for September 2020. Following this update, Council staff will present the initial/preliminary analysis to the Council at the February 2021 meeting. The presentation was meant to give the CPT opportunity to provide feedback.

The analysis consisted of two alternatives: 1) no action, and 2) reduced PSC limits for BSAI trawl CDQ and non-CDQ groundfish fishing when the corresponding directed crab fishery is closed. The goal of the action is to ensure consistency in management measures among the directed fisheries and groundfish bycatch fisheries to better balance the impacts on depressed stocks. The Council requested that the analysis include source numbers for the abundance estimates used to calculate the PSC limits and clearly state whether estimates are from raw data from the NMFS bottom trawl survey or from the stock assessment models.

There was discussion among the CPT about inconsistencies across stocks in PSC inputs and calculations, but it was acknowledged that inconsistencies are largely based on how/when the PSC limits were developed. For BBRKC, thresholds for PSC calculations match those used in the state harvest strategy, whereas those for snow and Tanner crabs were based on industry negotiations.

There was discussion about whether the PSC calculations should account for survey catchability (Q parameter), which is mostly relevant for snow and Tanner crab since Q for BBRKC is close to 1. Because Q is generally small for snow and Tanner crab, incorporating Q could substantially increase (e.g., double) PSC limits for those stocks based on the formulae. While it appears that the intent was to account for catchability, this should be clarified by the SSC/Council. It is assumed that survey selectivity should be accounted for, but catchability (Q) should be further clarified. It was recommended that if catchability is to be used for PSC calculations, then the current threshold calculations should be revisited with an analysis. Related to this, the CPT would like feedback from the SSC on: 1) clarification about the inclusion of catchability, Q, in PSC calculations; 2) clarification about how to incorporate selectivity and catchability in PSC calculations as selectivity and Q are estimated in the model and thus change each time the assessment is updated (e.g., Tanner crab had a change in catchability estimates in 2019 which impacted PSC limit calculations); 3) define PSC calculations (e.g., a % of mature male abundance? Other?). A suggested approach was to fix Q at 1.0 for snow and Tanner calculations, although there was not a consensus among CPT members on this as a recommendation. It was noted that the Council has asked that future SAFE documents include PSC values and calculations to help with record keeping. Sara noted that the current PSC regulations indicate data as that of the "NMFS bottom trawl survey" and are not specific as to whether raw area-swept or model-based estimates are to be used. The CPT seeks guidance from the SSC on this issue.

The Alternative 1 (no action) analysis was presented for BBRKC, Tanner crab, and snow crab relative to the triggered area closures (Zones 1 and 2 for BBRKC and Tanner crab, and COBLZ for snow crab). For BBRKC, PSC limits were not set to the lowest threshold during 2008-2020. Had the PSC been reduced, some sectors may have reached their limit and been closed out of Zone 1 in some years. It was noted that if the directed fishery is not opened and the lowest PSC limits were in place, the Red King Crab Savings Area would be closed to the groundfish sector, the A80 sector limit would be reduced, and a Zone 1 closure would likely result in additional forgone revenue and increased costs associated with fishing. It was noted that trawl PSC still represents a small portion of the total BBRKC fishery mortality, other gear types are estimated to represent a greater portion of the crab PSC, and crab PSC limits at their lowest levels may have a modest impact on the ability of BBRKC to rebuild. Given the expectation for modest

stock impacts, BBRKC PSC limits set to lower thresholds are expected to have limited indirect impacts to the directed fishery.

Trawl crab PSC is a small portion of observed fishing mortality for snow and Tanner crab. Snow crab PSC limits hit the lowest threshold in 2017 and the Tanner crab PSC limit hit the lowest threshold in 2008-2010. It is expected that reaching snow or Tanner crab PSC limits would rarely occur, even at reduced PSC levels. Reduced Tanner and snow crab limits would likely have limited impacts to the groundfish sectors, associated processors, and communities, based on past PSC use. The A80 vessels have some flexibility to shift fishing locations and species targets, but lower PSC limits could create negative impacts depending on the time of year, distribution of other PSC species the fleet needs to avoid, and directed species spatial distribution.

A sensitivity analysis was conducted by the stock assessment authors to evaluate the potential impacts of unobserved trawl mortality. For BBRKC, when bycatch biomass increases by 500% or more, estimated MMB values in the terminal years could decrease about 14% or more; the decreases might be much larger for some years. For Tanner crab, based on previous catch rates, increasing bycatch by 1,000% would have lowered the MMB in the 1970s by an estimated ~100,000 t, while in recent years it would have been estimated to be ~6,000 t less. For snow crab, bycatch has been small enough that increasing the bycatch input by 1,000% resulted in only a ~2% change in the terminal year of MMB (with largest changes in the mid-1990s through mid-2010). Overall, less than doubling bycatch mortality would have little overall effect on stock dynamics.

The effect of Alternative 2 (i.e., reduced PSC limits when the directed fishery is closed) was presented, and it was noted that PSC catches did not reach the lowest PSC threshold for any fisheries for 2008-2020, except for Tanner crab (Zone 2) in 2017 and snow crab (COBLZ) in 2008-2010. The expected impacts under Alternative 2 are essentially the same types of impacts highlighted under Alternative 1 (above paragraph). However, Alternative 2 may increase the likelihood crab PSC would be applied at lowest abundance-based thresholds, particularly for Zone 1 and 2 Tanner crab PSC limits. Changes in groundfish trawl fishing behavior, and thus changes in resource components, are expected to be limited, relative to no action. Limited impacts are expected for BBRKC because thresholds are already aligned with the state harvest strategy (not because lower PSC limits would have no effect), and a limited set of impacts are expected for snow and Tanner based on past PSC relative to lowest PSC limits.

Jamie Goen (Alaska Bering Sea Crabbers, ABSC) submitted a comment letter about concern for the health of crab stocks, especially BBRKC. She noted a concern for unobserved mortality, which is not included in assessments or catch accounting. Cory Lescher (ABSC) described a white paper he and others authored which takes a closer look at unobserved mortality and includes a literature review highlighting other research efforts. None of the research addresses rates for unobserved mortality. As such, research is needed on unobserved gear interactions and resulting mortality rates. It was also noted that different life stages may have varying mortality rates (e.g., during molting periods), and this should be considered.

15. Research priorities – Update, discussion

Jim Armstrong (NPFMC) updated the CPT on NPFMC research priorities, which have historically been updated and reviewed annually. The SSC convened a workshop in February 2020 to re-evaluate and discuss the research priorities review process. Jim shared a few examples of proposed approaches to organizing research priorities from the workshop, which will be reviewed again during an April 2021 SSC Research Priorities Workshop. The CPT noted that a hierarchical approach seems to be an effective way to organize priorities by broad research themes while outlining specific research needs under sub-categories. At the January 2020 CPT meeting, the top five crab research priorities were identified as:

- 147/171--Acquire basic life history information (e.g., natural mortality through radiometric aging or other methods, growth, size at maturity) needed to inform the crab assessment models.
- 148--Spatial distribution and movement of crabs relative to life history events and fishing.

- 225--Develop projection models to evaluate management strategies under varying climate, ecological, and economic conditions and evaluate impacts to managed resources and coastal communities.
- 592--Maturity estimates for Bering Sea and Aleutian Island crab stocks.
- 715-- "Studies on physiological responses to climate stressors". Description: "Investigate how observed environmental changes (temperature, OA, etc.) affect physiological condition & survival of multiple life stages and reproductive output. Consider interactions among multiple stressors."

The CPT took comments and input on the existing five research priorities. Public testimony from Jamie Goen (ABSC) flagged concern over potential fishing impacts on BBRKC spawning grounds and suggested that an explicit research priority outlining EFH research would be helpful. The CPT agreed and modified Research Priority 148 to: "Spatial distribution, habitat use, and movement of crabs relative to life history events and fishing." The CPT decided to keep the existing 2020 Research Priorities until the SSC formalizes the prioritization process.

The CPT requests input from the SSC regarding research prioritization and organization methods. The CPT also requests guidance on the intended audience for research priorities, and emphasizes the importance in developing effective research priorities to assist researchers in securing funding.

16. Terms of Reference for crab stock assessments- discussion

Martin Dorn introduced updating the terms of reference (TOR) for the crab assessment SAFE documents. Currently, there is a draft document from 2016 with detailed TOR for the SAFE documents. However, this document was never finalized or posted on the NPFMC website. Most of the lead assessment authors stated that they were familiar with the document, but also suggested that updates were needed. There was some concern that the document might be overly detailed. Therefore, the CPT requested the lead authors review the document and suggest specific changes to Martin Dorn and others assisting in updating the draft.

The proposed timeline for updating this document was to create a list of proposed changes at this meeting, revise the document working towards a draft version to be adopted at the May 2021 meeting. The CPT would like to request that the SSC also review this document to confirm that the information they need is included.

Revisions or additions to the documents:

- Table for data used in the PSC bycatch calculations (council requested).
- Naming conventions for models/model numbering (with example).
- Revise harvest specification tables to match SSC and Council needs.
- Required model runs – specifically requiring last years accepted model with and without new data.
- Buffer history in recent years for each stock in the SAFE.
- Max ABC needs to be explicit in the document – how it is calculated and the resulting value.
- Environmental considerations – in the form of an ESP, scorecard or other.
- History of fishing section included in history of management.
    - Periods of opening/closure of fishery.
    - Harvest guideline revisions.
    - Changes to access of fishery.
- Section or instructions for off-year SAFE updates. Usually this is just an update of harvest specification tables.
- 5-year stock projections – from our recommendations in Sept. 2020.

- OFL description: male only, all crab, catch and discards, etc. would be helpful to be explicitly stated in the document.
- OFL calculation: explicitly stating what selectivity is included in the calculation.

17. Stock assessment prioritization and frequency- discussion

The SSC requested that the CPT review the assessment frequency for BSAI crab stocks to potentially reduce the SSC workload, and specifically to evaluate if there are stocks that could be assessed less frequently while still providing adequate support for Council management (see table below).

The CPT considered moving SMBKC to a biennial cycle (now annual). Currently this stock is at very low levels and is at the start of a multi-year rebuilding plan. Moving to a biennial cycle would allow for consistency in survey results before declaring it rebuilt and reopening the target fishery. Because variability in survey results for this stock are high, the model smooths survey results across years and a single year increase in survey biomass would not likely result in a substantially higher model biomass estimate. Moving this stock to a biennial cycle temporarily while under the rebuilding plan, with the next assessment in 2022, would align the assessment cycle with the requirements to report on the rebuilding progress. The change in assessment frequency would also help to align the assessment years with the next two expected ADF&G trawl surveys, which have now moved to a triennial cycle (next expected in late 2021 and 2024).

Additionally the CPT considered moving PIRKC to a triennial cycle from its current biennial cycle. This stock is currently closed to fishing due to conservation concerns over the PIBKC stock in the same area, which is currently under a rebuilding plan. While PIBKC is on a biennial cycle due to the reporting requirements for the rebuilding plan, PIRKC could be assessed less frequently. The lead author for PIRKC also suggested that there is little model development potential for this stock and a less frequent cycle would not impact potential harvest or opportunities to improve understanding of the stock. This stock is scheduled for assessment in Sept. 2021, and the proposed changes would move the subsequent assessment to Sept. 2022. The CPT requests SSC input on these two potential changes in stock assessment frequency before adopting them for the current assessment cycle.

SAFE chapter assessment frequency	Latest SAFE Update	Next SAFE Update
1 Eastern Bering Sea snow crab-annual	Oct 2020	Oct 2021
2 Bristol Bay red king crab-annual	Oct 2020	Oct 2021
3 Eastern Bering Sea Tanner crab-annual	Oct 2020	Oct 2021
4 Pribilof Islands red king crab -biennial	Oct 2019	Oct 2021
5 Pribilof Islands blue king crab –biennial	Jun 2019	Jun 2021
6 Saint Matthew Island blue king crab-annual	Oct 2020	Oct 2021
7 Norton Sound red king crab -annual	Feb 2020	Feb 2021
8 Aleutian Islands golden king crab-annual	Jun 2020	Jun 2021
9 Pribilof Islands golden king crab -triennial	Jun 2020	Jun 2023
10 West. Aleutian Islands red king crab -triennial	Jun 2020	Jun 2023

18. New business

Proposed 2021 meeting dates:
May 17-21, 2021 Juneau (remote likely).
Tentative September 13 - 17, 2021.

May 2021 proposed agenda topics:
AIGKC - final SAFE.
PIBKC - final SAFE, update on rebuilding progress.
Proposed model runs for September: Snow crab, Tanner crab, BBRKC, SMBKC (?), PIRKC.
Draft risk tables: snow, SMBKC, Tanner, BBRKC, and possibly NSRKC, pending available resources.
Survey planning updates.
Length-weight relationship updates from survey (J. Richar).
Modeling survey availability and catchability using BSFRF side-by-side data.
VAST updates?
TOR for SAFE documents: accepted updates, finalize draft.
ESP updates: draft snow crab ESP?
BSFRF update, snow crab workshop report.
Research priorities update from SSC.
Updates on catch timeseries standardization from ADF&G.
Research updates: NSRKC growth data.
CPT meeting minutes, format and terminology (how we refer to crab stocks and individuals).

19. Modeling workshop

After the CPT meeting adjourned, a modeling workshop was held to assist crab assessment authors with modeling approaches for specific assessment concerns. CPT members, assessment authors, and the public were invited to participate. Holding the workshop “virtually” proved to be a challenge for productive discussion, and participants are looking forward to future workshops being held in person.

The first topic covered was a review of Mohn’s rho used for retrospective patterns that are now displayed in all the assessments. The assessment authors held a discussion over the method used, reviewing the equations in a recently published paper (Legault 2020, doi.org/10.1093/icesjms/fsaa184), and sharing their methods/code for calculating these values.

Concerns over recruitment estimates in the GMACS snow crab model presented in fall of 2020 were addressed at this workshop. Cody Szuwalski (AFSC and snow crab lead author) led a discussion showing model runs to determine the sensitivity of the GMACS snow crab model to changes in the smoothing parameter on recruitment. Currently in GMACS, annual recruitment is modeled as one recruitment deviation that is then allocated by sex using an annual proportion, which is modelled in logit-space. The runs to examine the recruitment smoothing were compared to the status quo model, showing that the GMACS runs overall fit the MMB and female numbers better than the status quo model. The GMACS model does this by allowing recruitment to be larger and more variable than the status quo model.

Cody also performed model runs to examine the sensitivity to the smoothing parameters, both the one on the recruitment deviations and the one of the logit proportion by sex. He found that the smoothing on the recruitment deviations behaved as expected. However, the smoother on the logit proportion by sex is harder to interpret. Cody suggested coding recruitment in GMACS to estimate a separate set of recruitment deviation by sex, therefore allowing the variability between male and female recruitment to be independent. André Punt reinforced that the smoothing penalty on the logit proportion was not straightforward, and it maybe more appropriate for this stock to estimate deviations by sex. Cody

volunteered to code this change in recruitment parameterization into GMACS for future model runs of the snow crab model. It was suggested that authors of other GMACS assessments look at the smoothing penalties in their assessments, and review how they are treating recruitment estimation in their models.

The modeling workshop participants then moved on to GMACS updates and improvements for all stocks. We reviewed those items that were completed after last January's workshop and the status of those items still on the to do list. Listed below is the updated "to do" list, separated out into short-term tasks – those that need to be completed in the next year or so to progress the model, and long-term – those tasks that the users would like to see in GMACS but are not vital to its continued use or inclusion of most stocks into this modeling framework.

Updated To Do list for GMACS:

Short-term:

- Recruitment: terminal year recruitment options, using an average of recruit years
- Recruitment deviations by sex (snow crab)
- Unit testing: to confirm same results for other GMACS assessments when large changes to code are made, i.e. terminal molt implementation in the snow crab model
- Merging snow crab model updates to currently used code for assessments on github to update current working version (see unit testing)
- Warning or check to see if parameter inputs are within 5% of the bounds (issue André found with inputting AIGKC parameters)
- Tag likelihood needs to be edited (NSRKC issues, Cody will fix)
- Review how selectivity is normalized to 1 in the .tpl file if it does not equal 1, option to say if it should be normalized or not (NSRKC issue)
- Selectivity options: option 4 (double normal)
- Jittering: programmed into GMACS but it needs to be tested
- Gmr package: update so that visualization works with code, currently waiting on merging snow crab updates.
- Ensure that likelihoods can handle maturity partitions (Cody – somewhat completed, needs to be tested)

Long-term:

- Additional recruitment parameterization in the projection file
    - Input mean and SE instead of sampling from a period
- Additional state harvest strategies in the projection file by stock
- SBS data incorporated (Buck's work on incorporating BSFRF work on availability)
- Tanner crab incorporation and associated code needed for this
- Retrospective analysis (need more stable code before this is finalized)
- Estimating stock-recruitment relationship internally
- Options to fit "observed maturity" ogives (long term Cody/Buck)
- Growth – add growth data type based on pre-molt, post-molt sizes and add corresponding likelihood component (as in Tanner assessment)

The remainder of the modeling workshop was spent assisting the AIGKC and NSRKC lead authors with troubleshooting their GMACS models. Current GMACS users offered their assistance to these authors both during the workshop and on a continuing basis over email, video chats, and virtual meetings. André Punt suggested some steps forward for these two stock assessments that included: 1) specifying selectivity, retention, and growth as inputs (use results from current model), then running one model iteration to make sure the parameters are correctly read in and in the correct transformation. 2) specifying

R_0 and initial N and making sure these are correctly read in. 3) “Turning off” all data except catch and running the model to estimate F - the model should match catch exactly. 4) Once these are input correctly, “turning on” other likelihoods in the model and running it with parameters fixed to determine if the underlying population model is estimated similar to the “status quo” model. André and Cody, who went through this transition to GMACS for BBRKC and snow crab, emphasized that each model is unique in its steps to transition, but that a model similar to status quo should be achievable for each and is the first step toward moving to GMACS as the modeling platform for all BSAI crab stock assessments.

CPT members suggested the authors bring GMACS model comparisons to upcoming CPT meetings with the eventual objective of using GMACS for harvest specification in 2022: Jan 2022 for NSRKC and May 2022 for AIGKC. The current GMACS user group also suggested that lead authors reach out to the group along the way for periodic “check-ins' ' to provide feedback and help troubleshooting setbacks.