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Proceedings of the Pacific regional peer review on an update to reference points and harvest advice for the commercial Sea Cucumber (*Apostichopus californicus*) fishery in British Columbia

April 5-6, 2022
Virtual Meeting

Chairperson: Cher LaCoste
Editor: Jill Campbell

Fisheries and Oceans Canada
Science Branch
3190 Hammond Bay Road
Nanaimo, BC V9T 6N7

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Canada

Foreword

The purpose of these Proceedings is to document the activities and key discussions of the meeting. The Proceedings may include research recommendations, uncertainties, and the rationale for decisions made during the meeting. Proceedings may also document when data, analyses or interpretations were reviewed and rejected on scientific grounds, including the reason(s) for rejection. As such, interpretations and opinions presented in this report individually may be factually incorrect or misleading, but are included to record as faithfully as possible what was considered at the meeting. No statements are to be taken as reflecting the conclusions of the meeting unless they are clearly identified as such. Moreover, further review may result in a change of conclusions where additional information was identified as relevant to the topics being considered, but not available in the timeframe of the meeting. In the rare case when there are formal dissenting views, these are also archived as Annexes to the Proceedings.

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Aussi disponible en français :

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SUMMARY

These Proceedings summarize the relevant discussions and key conclusions that resulted from a Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS) Regional Peer Review meeting on April 5-6, 2022 via the online meeting platform Zoom. The working paper presented for peer review focused on providing an update on the range of sustainable annual harvest rates, the limit reference point (LRP), and an upper stock reference (USR), consistent with the Precautionary Approach (DFO 2009) for the commercial Sea Cucumber fishery.

Due to the COVID-19 pandemic, in-person gatherings have been restricted and a virtual format for this meeting was adopted. Participation included DFO Science and Fisheries Management staff as well as representatives with relevant expertise from Kitasoo-Xai'xais First Nation, National Oceanic and Atmospheric Administration, the commercial fishing sector, and academia.

Meeting participants agreed the working paper satisfied all Terms of Reference objectives. The working paper was accepted with revisions. The conclusions and advice resulting from this review will be provided in the form of a Science Advisory Report providing advice to DFO Fisheries Management to inform appropriate harvests for the commercial Sea Cucumber (*Apostichopus californicus*) fishery.

The Science Advisory Report and supporting Research Document will be made publicly available on the Canadian Science Advisory Secretariat website.

INTRODUCTION

A Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS) Regional Peer Review (RPR) was held on April 5-6, 2022 via the online meeting platform Zoom to review the working paper which provides an update on the range of sustainable annual harvest rates, the limit reference point (LRP), and an upper stock reference (USR), consistent with the Precautionary Approach (PA; DFO 2009), for the commercial Sea Cucumber (*Apostichopus californicus*) fishery.

The Terms of Reference (TOR, Appendix A) for the science review were developed in response to a request for advice from DFO Fisheries Management. Invitations to the science review and conditions for participation were sent to DFO Science and Fisheries Management staff as well as representatives with relevant expertise from Kitasoo-Xai'xais First Nation, National Oceanic and Atmospheric Administration, the commercial fishing sector, and academia.

The following working paper (WP) was prepared and made available to meeting participants prior to the meeting (working paper abstract provided in Appendix B):

Hajas, W., Hansen, S.C., and Lochead, J. 2022 Update to reference points and harvest advice for the commercial Sea Cucumber (Apostichopus californicus) fishery in British Columbia. CSAP Working Paper 2017INV01

The meeting Chair, Cher LaCoste, welcomed participants, reviewed the role of CSAS in the provision of peer-reviewed advice, and gave a general overview of the CSAS process. The Chair discussed the role of participants, the purpose of the various regional peer review (RPR) publications (Science Advisory Report, Proceedings, and Research Document), and the definition and process around achieving consensus decisions and advice. Everyone was invited to participate fully in the discussion and to contribute knowledge to the process with the goal of delivering scientifically defensible conclusions and advice. It was confirmed with participants that all had received copies of the Terms of Reference, working paper, written reviews, and agenda.

The Chair reviewed the Agenda (Appendix C) and the Terms of Reference for the meeting, highlighting the objectives and identified Jill Campbell as the Rapporteur for the review. The Chair then reviewed the ground rules and process for exchange, reminding participants that the meeting was a science review and not a consultation. Members were reminded that everyone at the meeting had equal standing as participants and that they were expected to contribute to the review process if they had information or questions relevant to the paper being discussed. In total, 27 people participated in the RPR (Appendix D).

Participants were informed that Sarah Power (DFO Science) and Jessica Sameoto (DFO Science) had been asked before the meeting to provide detailed written reviews for the working paper to facilitate the peer-review process.

The conclusions and advice resulting from this review will be provided in the form of a Science Advisory Report to DFO Fisheries Management to inform appropriate harvest levels for the commercial Sea Cucumber fishery. The Science Advisory Report and supporting Research Document will be made publicly available on the Canadian Science Advisory Secretariat website.

MEETING DISCUSSION

Following a presentation by the authors, the reviewers, Sarah Power (DFO Science) and Jessica Sameoto (DFO Science), shared their comments and questions on the working paper. The authors were given time to respond to both reviewers before the discussion was opened to all participants. This proceedings document summarizes the discussions that took place by topic, where points of clarification presented by the authors in their presentations and questions and comments raised by the reviewers and participants are captured within the appropriate topics.

An upcoming CSAP RPR meeting in the summer of 2022 will evaluate the multispecies survey methodology, which may result in the implementation of a new coast wide monitoring program. Currently, the stock is monitored using single species surveys that estimate linear biomass in different Pacific Fishery Management Areas each year, to inform quota setting decisions by fishery managers. If the proposed survey methods are adopted, the coast wide stock will be monitored using multispecies surveys that will estimate spatial densities. The uncertainty of future monitoring methods was brought up a number of times during the meeting.

TERMS OF REFERENCE OBJECTIVE 1

Identify and apply any refinements or error corrections that can be made to the latent productivity model and the implementation of the model published in Hand et al. (2009).

A participant was unsure how the biomass-based harvest rates and the density-based reference points would be implemented. They indicated that there is nuance around how fishery managers estimate biomass on a linear shoreline and then set total allowable catches for the fishery, which was not fully captured in the working paper. The proposed management metrics as the limit reference point (LRP) is moving from being based on virgin biomass to spatial density. The authors clarified that the spatial density applies to the coast wide LRP for stock monitoring, whereas the linear density estimates are used to calculate biomass in order to apply Quota Management Area (QMA) harvest rates. Separate surveys are used to calculate each metric. The authors will ensure the text is clear around this point.

A participant was concerned that since both linear and spatial densities metrics are recommended here, it adds a layer of confusion for fishery managers. The participant noted that some areas of the coast may have steep or shallow slopes which would result in divergence between the linear and spatial densities. The authors responded by saying that the linear and spatial calculations of biomass should be similar as a survey transect trimming process was undertaken to standardize transect length to account for this potential divergence. The authors will ensure the text around this is clear as it has ramifications for model reproducibility, and they will also include any equations and more complete comparisons of the methods used by Hand et al. (2009).

A reviewer noted that a Precautionary Approach framework workshop from 2015 indicated the importance of protecting areas of high density for sedentary species conservation. This workshop suggested that when setting reference points for invertebrate species, consideration should be given to having a strategy to protect higher density areas that have a tendency to be exploited heavily and before other lower density areas. They indicated that as more information on habitat suitability becomes available from the multispecies surveys, a more precautionary approach to managing the fishery that treats source and sink populations differently could be considered. However, a participant indicated that high density areas may not have high productivity if the population is close to carrying capacity. Fishery management also indicated that the long larval period means that even low density areas can be source populations for recruitment. The reviewer added that if an originally high density area is driven to low density, it

may suffer from Allee effects; therefore, protecting high density areas and basing reference points off these areas would be the more precautionary approach. The authors noted that no-harvest reserves that protect high density areas are, and will continue to be, important components of BC's sea cucumber management strategy.

In response to a participant comment about the latent productivity model assumptions, the authors will clarify that the model assumptions have not changed from Hand et al. (2009).

In response to requests from a few participants, the authors will add the equations used to calculate linear and spatial densities and biomass as well as equations used in the productivity modeling to the research document.

In response to a request from a participant, the authors will include a table of the virgin biomass (B_0) estimates.

In response to requests from a few participants, the authors will explore productivity model fits to the data. One participant was concerned about the model behaviour in the area below the truncation and raised the possibility that perhaps there may be issues with the parameter estimates. They were concerned that if the model is estimating parameter values that are close to the posterior distribution boundary that it may affect the probabilities of the reference points and thereby give inaccurate results. They suggested the authors consider estimating parameters on a continuous log scale to get a better sense of parameter posterior distributions. The authors responded by saying they do not require the model to be accurate within the truncated zone for low relative biomass. In response to a request from a reviewer, the authors will also include information on the Markov Chain Monte Carlo (MCMC) runs including number of chains, burn in period, and thinning. The inclusion of model equations may also help to address these concerns.

A participant asked what is known about source-sink dynamics with respect to depth. The authors indicated that remote operated vehicle video data was taken in 2009 at depths below the survey transects, however this video has not yet been analyzed.

TERMS OF REFERENCE OBJECTIVE 2

Achieve a probabilistic estimate of productivity as a function of current biomass using the revised model and the full EFA dataset (1998-2015) and the original 1998-2007 subset. Compare the results from the full and subset data to determine the impact of the additional years of data.

A participant noted that densities were higher in Tolmie than in Laredo, but Laredo showed a higher productivity level. They asked if there could there be an inverse correlation between productivity and biomass at carrying capacity and if this could also be used to gauge stock status. The authors indicated that they do not currently have the data to prove or disprove this observation at a larger scale than Experimental Fishery Area (EFA) level.

TERMS OF REFERENCE OBJECTIVE 3

Using the full EFA time series (1998-2015), update the range of recommended annual harvest rates identified in Hand et al. (2009).

A participant asked for background context on how the fishery is currently managed and what changes this work proposes. Hand et al. (2009) recommended using annual harvest rates derived from B_0 (virgin biomass) but applied to estimates of current biomass and this is currently how the fishery is being managed. The authors instead recommend harvest rates be derived from pre-harvest (current) biomass, therefore harvest rates would be applied more effectively,

especially since B_0 is often not known in areas outside of EFAs. The authors will clarify this change in recommendation in the Research Document.

There was some confusion about the terminology of harvest rate versus harvest amount. The authors clarified that harvest rate is suitable for annual harvest whereas harvest amount is suitable for multi-year harvests. The harvest amount is the harvest rate divided by the harvest interval. A participant noted that the term 'harvest amount' may not be the best choice for what the authors are describing. The authors will ensure the definitions of these terms are clear in the Research Document.

In response to a reviewer comment, the authors will add the caveat that 'upper ranges of harvest rates may only be appropriate for "highly productive areas"'. The reviewer was concerned that populations do not appear to reach an equilibrium biomass or densities as production and harvest rates balance each other during the EFA experiment and that migration may be influencing productivity estimates.

In the author presentation, they showed graphs of hypothetical harvest amounts or rates as a function of equilibrium post-harvest biomass for the various harvest intervals. Participants found these graphs very useful in interpreting the results and requested similar graphs be developed using the data. The authors agreed to add these figures to the Research Document.

TERMS OF REFERENCE OBJECTIVE 4

Using the full EFA time series (1998-2015), update the Limit Reference Point (LRP) and identify a range for the Upper Stock Reference (USR).

There was discussion around the rationale for including both linear and spatial densities for the LRPs rather than only recommending one metric. In addition to the discussion under TOR Objective 1, the authors will provide clarity and justification around the inclusion of both linear and spatial estimates. However, the authors would like to keep the linear density estimates in the recommendations since they are the units most commonly used by harvesters and managers. A participant was concerned that the linear and spatial densities are not equivalent and it is conceivable that linear densities might be above the LRP but spatial densities may not, which might compromise the ability of the fishery to avoid serious harm to the stock. The authors and fishery managers responded that since there is still uncertainty around how the stock will be monitored in the future, including both linear and spatial densities makes this work more relevant. It was agreed that the authors will indicate that spatial density is the recommended metric for the LRP, but will still provide both the linear and spatial density estimates in the discussion.

The data from Jervis is the same from 1998-2007 and 1998-2015 which caused some confusion among a few participants since the values were very similar but not the same. The authors will add a footnote to Tables 5 and 6 indicating that the results are different due to random elements in the modeling process (such as a fixed random seed that may differ from the fixed seed used in Hand et al. (2009). The two data sets are also indicating differences in the model used by Hand et al. (2009) and the model used here.

In response to requests from participants, the authors will make changes to Figures 2 and 3 to reverse the axis (year on the x-axis) and make the plots larger and these will be included in the Science Advisory Report (SAR) as well. This will make it easier to see the data and determine when the populations satisfy the definition of $D_{recover}$.

There was considerable discussion around how $D_{recover}$ was defined and calculated. The authors considered many definitions of $D_{recover}$, however they found the literature on this topic to be vague. Some definitions were 'recovered readily' or 'recovered from B_{min} to B_{avg}' which is subject

to shifting baselines. They defined $D_{recover}$ as the lowest stock level from which recovery was observed, which is a conservative definition. This is not necessarily the point at which there is "a high probability that productivity will be so impaired that serious harm will occur" (DFO 2009), but it is easy to rationalize that the Allee threshold is likely lower that $D_{recover}$ because of the historic proof of concept in observed recovery. The LRP is intended to be set at the limit that avoids serious harm, and the definition of $D_{recover}$ chosen here meets this. This meant that $D_{recover}$ was based on data from Laredo Channel only. This channel has very low sustained densities and is not considered to be commercially viable. The author's original recommended LRP (spatial) was calculated from site 8 at Laredo Channel and was 0.019 cucumbers m^{-2}.

- The authors suggested adding wording to indicate that Site 8 in Laredo 'recovered to estimates of B_0 indicating that serious harm did not occur'. They also pointed out that the density estimates did not indicate the stocks crashed at any of the survey sites within the four EFAs. However, participants noted that at another EFA site, the population recovers in one year, but declines in the next year. There was a rebuttal from other participants that recovery did not need to be sustained for multiple years for the definition of $D_{recover}$ to be met. Participants asked the authors to provide more clarification of the $D_{recover}$ definition in the Research Document and re-emphasize that $D_{recover}$ is not intended to be used for rebuilding plans. The authors will also add references to Figures 9 and 10 in this section which explore the distributions of minima in all EFAs.
- A few participants were concerned that since the LRP is based off a $D_{recover}$ value derived from Laredo Channel, a low density area that is unlikely to be a commercially viable harvest area, that it may have ramifications for the coast wide fishery (e.g., a LRP so low it is never triggered). Some participants were concerned that the LRP is based off a 10km stretch of Laredo Channel that is not representative of the entire coast and that this value was recommended to be applied to the entire BC coast wide stock. A reviewer indicated that little is known about sea cucumber life history and source-sink dynamics which makes it difficult to apply stock assessment models. Therefore it is difficult to determine why recovery was observed at Laredo and so the rationale for using this EFA to set a coast wide LRP was concerning. They were worried that setting a LRP based on a low productivity area may not be appropriate for high productivity areas. These high productivity areas are key to sedentary species persistence. A participant was concerned that the EFA experiment was meant to be representative of the entire coast and therefore the LRP should be based on an average across all EFAs that met the recovery definition.
- A reviewer suggested calculating the LRP for each EFA and then using the highest value (i.e., the maximum $D_{recover}$) as the recommended coast wide LRP. They noted that the definition of $D_{recover}$ is variable in the literature and the definition they proposed could also be applied. However, fishery management indicated that the LRP is based on the coast wide stock and that not all areas of the coast will be open to the fishery. The authors also indicated that the TOR asked the authors to consider the whole time series and all of the sites which accounts for variations in habitats, densities, and productivities. If this approach were to be taken it would be outside of the scope of the TOR. As well, this approach may result in a LRP that is higher than the USR.
- Several participants were concerned about setting a definition of $D_{recover}$ prior to the coast wide density estimates from the multispecies surveys are available. If the surveys are conducted in poor sea cucumber habitat, this may result in a higher LRP and a closure of the fishery. The authors reminded the participants that the methods proposed in the working paper are what is being approved in this meeting, not the multispecies survey results. The authors also indicated that they have done some analyses of the preliminary multispecies survey data and have found considerable variability along the BC coast. The authors will

indicate that the recommended LRP and USR values are intended to be applied over areas of suitable sea cucumber habitat. This will ensure that only multispecies survey transects conducted over sea cucumber habitat will be included in the data set used to assess stock status. Many participants agreed this addition would be helpful.

- The authors will add additional content to the Research Document to explain why their choice of LRP and USR are reasonable. The authors indicated the LRP is intended to be applied on a coast wide basis and the multispecies surveys will be conducted in areas both open and closed to the sea cucumber fishery. They also indicated that there are other measures in place to ensure the LRP is not breached such as the conservative harvest rates and that setting the LRP at the original proposed lower value (0.019 m^2; from which recovery had been observed) is preferred at this time until coast wide density estimates are determined. Fishery managers also indicated that the fishery is managed to avoid reaching the LRP and potential serious harm. The LRP is currently based on observations of the stock recovering, not necessarily on the point at which serious harm occurs, which makes the recommended LRP more conservative than others in the literature. Many other elements of the fishery are precautionary: biomass calculations (lower 90% CI), harvest rates, limited openings, and closed areas, for example. They cautioned the group against making the LRP too conservative and instead to rely upon the other levers in place to protect the stock. The authors will add text to clarify how the fishery works, the closures in place, depth reserves, etc.
- A participant suggested that the definition of recovery be altered from 'significant recovery to a point where the 95% confidence intervals do not overlap' to ' a return to B_0'. After further discussion it was agreed that 'a return to B_0' could be problematic (for example defining B_0) and participants and authors settled on the wording 'a return to values in the range of the original survey estimates'. This would still result in Laredo being the observed minimum density, but would also allow data from Zeballos site 8 to be included in the LRP calculation. Some participants preferred this definition as they were not comfortable with only using data from one site in Laredo to determine the coast wide LRP. There was dissent over whether using the original LRP based on the Laredo $D_{recover}$ or the averaged value from Laredo and Zeballos was appropriate. There was some discussion about providing two equally plausible LRP values, the original LRP using data from Laredo only and a second LRP value using an average of the LRP values from Laredo and Zeballos. However, the group settled on a LRP based on the upper 99% confidence intervals from Laredo and Zeballos, with the caveat that the LRP values only apply to sea cucumber habitat.
- Using this revised definition of $D_{recover}$, the authors will average the two upper 99% confidence intervals from Zeballos site 8 and Laredo site 8. This resulted in a LRP of 0.029 cucumbers m^2. The authors pointed out that this new method results in the LRP and USR (0.038 cucumbers m^2) being very close together, which may be problematic. However, the USR remained based off data from all four EFAs since this reference point is not defined in relation to avoiding serious harm to the stock. Some participants expressed dissatisfaction with changing the LRP during the meeting and would have preferred more time to consider the implications in hindsight.

In response to a comment from fishery management, the authors will clarify that the coast wide scale of the LRP ensures that this value will be conservative, however due to variability along the coast, not all areas will be above the LRP. The fishery only occurs on 50% of the coast and there are closures within open management areas. New areas will only be opened if linear densities are above 2.5 cucumbers/m of shoreline, a value which is based on social, economic, and logistical considerations, as well as science advice from the published Assessment

Framework (Duprey et al. 2011). The fishery does not occur at the same scale as the LRP and USR reference points.

In response to a reviewer comment, the authors will add context around the definition of an operational control point (OCP) and its use.

A reviewer asked the authors to compare the reference points they recommend to those recommended by Hand et al. (2009) and reference points in use in other countries. The authors indicated that since the B_0 is estimated on a site scale and the LRP is estimated on a coast wide scale, there will be a wide range of values that may make it difficult to compare different definitions of reference points between jurisdictions.

In response to a participants comment, the authors will further clarify that the grey bars in Figures 2 and 3 in the research document refer to the lowest density observed in each EFA, regardless of site. The other changes requested to these figures will also improve clarity.

In response to participant comments, the authors will add data tables showing the data points, confidence intervals, and minima used to create Figures 2 and 3.

TERMS OF REFERENCE OBJECTIVE 5

Examine and identify uncertainties in the data and methods.

The authors will indicate in the Research Document that defining and calculating reference points is an iterative process.

There are many knowledge gaps with respect to sea cucumber life history.

How and when the data are collected may be a source of uncertainty as seasonality and natural variability will likely affect this work. A reviewer suggested additional data tables based on the data used to create Figures 2 and 3 be included to help examine this uncertainty.

The authors will add more text to indicate the uncertainty of sea cucumbers recruiting or migrating into the survey sites from the sides or from depth, which would alter estimates of productivity and the ability to detect recovery.

The authors will ensure any model uncertainties are discussed.

$D_{recover}$ definition and the various considerations of this parameter will be discussed in the Research Document.

The authors will ensure the impacts of Sea Otters (*Enhydra lutris*), climate change, and disease are discussed in the Research Document as sources of uncertainty and as potential trigger points for reference point reassessment. Climate change has a number of components – temperature, stratification, hypoxia, acidity so tracking and even linking oceanographic events that contribute to localized mortality might be informative over the medium to longer term for interpreting survey results/trends.

The authors can indicate that the magnitude of pycnopodia predation on sea cucumbers is unknown, as is the impact of potentially reduced predation on sea cucumbers due to sea star wasting disease.

FUTURE RESEARCH RECOMMENDATIONS

- Consider and re-evaluate the reference points when new data from the multispecies surveys become available.
- Potentially consider regionally-derived reference points.

- Use model estimates of stock status to determine the LRP rather than using empirical methods.
- Consider negative productivity in the models.
- In future assessments, the authors could provide reference point estimates based on B_0 and B_{MSY} and compare these estimates to $D_{recover}$. By comparing these three metrics, the reader will be better able to put $D_{recover}$ values into context.
- Future research could also include source and sink dynamics.

CONCLUSIONS

Meeting participants agreed the working paper satisfied all Terms of Reference objectives. The working paper was accepted with revisions (see Appendix E for a list of agreed upon revisions).

ACKNOWLEDGEMENTS

We appreciate the time contributed to the RPR process by all participants. In particular, we thank the reviewers, Sarah Power (DFO Science) and Jessica Sameoto (DFO Science) for their time and expertise. We also thank Cher LaCoste as Chair of the meeting and Jill Campbell as the Rapporteur.

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Duprey, N.M.T., Hand, C. M., Lochhead, J., and Hajas, W. 2011. Assessment framework for sea cucumber (Parastichopus californicus) in British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc 2010/105. vi + 38 p.

Hand, C.M., Hajas, W., Duprey, N., Lochead, J., Deault, J., and Caldwell, J. 2009. An evaluation of fishery and research data collected during the Phase 1 sea cucumber fishery in British Columbia, 1998 to 2007. DFO Can. Sci. Advis. Sec. Res. Doc 2008/065. x + 115 p

APPENDIX A: TERMS OF REFERENCE

UPDATE TO REFERENCE POINTS AND HARVEST ADVICE FOR THE COMMERCIAL SEA CUCUMBER (*APOSTICHOPUS CALIFORNICUS*) FISHERY IN BRITISH COLUMBIA

Regional Peer Review Process – Pacific Region

Date: April 5-6, 2022
Virtual Meeting

Chairperson: Cher LaCoste

Context

The Giant Red Sea Cucumber (*Apostichopus californicus*) fishery in British Columbia (BC) is managed by Fisheries and Oceans Canada (DFO) using a rotational triennial harvest of ~10% of current biomass in some Quota Management Areas and an annual harvest of 3.3-4.2% in others. This adaptive management strategy is based on recommendations in Hand et al. (2009), derived from analyses of harvest data, density survey data and experimental fishing area (EFA) data. Notably, Hand et al. (2009) developed a latent productivity model with estimates of maximum sustainable harvests using EFA data collected from 1998-2007. This experiment continued for another seven years and was discontinued in 2015, yielding a 17-year time series, of which only the first 10 years have been analysed to date.

Hand et al. (2009) also recommended reference points for the commercial Sea Cucumber fishery, in keeping with the DFO Sustainable Fisheries Framework (SFF); namely a Limit Reference Point (LRP) of 50% B_0 (virgin biomass) and a potential range of 60-80% B_0 for the Upper Stock Reference (USR). Although DFO began implementing the SFF in 2009, amendments to the Fisheries Act (Bill C-68) pertaining to sustainability have only been passed into legislation more recently (2019). The provisional Precautionary Approach (PA; DFO 2009) components for the commercial Sea Cucumber fishery proposed in Hand et al. (2009) have not been evaluated within the current assessment framework. Indeed, the resources required to monitor the many Sea Cucumber harvest areas (~200 subareas) at regular intervals are currently prohibitive.

DFO Fisheries Management has requested that Science Branch update the range of sustainable annual harvest rates, the LRP and a range for the USR, consistent with the Precautionary Approach (DFO 2009) for the commercial Sea Cucumber fishery. The assessment and advice arising from this Canadian Science Advisory Secretariat (CSAS) Regional Peer Review (RPR), will be used to inform fisheries management decisions to establish appropriate harvests for the commercial Sea Cucumber fishery. Several metrics of Sea Cucumber abundance will be considered in order to facilitate the development of reference points that can be used under current management measures and tailored to the coastwide multispecies benthic invertebrate monitoring program currently under development.

Objectives

The following working paper will be reviewed and provide the basis for discussion and advice on the specific objectives outlined below.

Hajas, W., Hansen, S.C., and Lochead, J. Update to reference points and harvest advice for the commercial Sea Cucumber (Apostichopus californicus) fishery in British Columbia. CSAP Working Paper 2017INV01

The specific objectives of this review are to:

1. Identify and apply any refinements or error corrections that can be made to the latent productivity model and the implementation of the model published in Hand et al. (2009).
2. Achieve a probabilistic estimate of productivity as a function of current biomass using the revised model and:
   a. the full EFA dataset (1998-2015);
   b. the original 1998-2007 subset.

   Compare the results from the full and subset data to determine the impact of the additional years of data.
3. Using the full EFA time series (1998-2015), update the range of recommended annual harvest rates identified in Hand et al. (2009).
4. Using the full EFA time series (1998-2015), update the Limit Reference Point (LRP) and identify a range for the Upper Stock Reference (USR).
5. Examine and identify uncertainties in the data and methods.

Expected Publications

- Science Advisory Report
- Proceedings
- Research Document

Participation

- Fisheries and Oceans Canada (DFO) (Ecosystems and Oceans Science, and Fisheries Management sectors)
- First Nations (e.g. Kitasoo-Xai'xais Nation)
- Industry (e.g. Pacific Sea Cucumber Harvesters Association)
- Other organizations (e.g. National Oceanic and Atmospheric Administration)

References

Bill C-68 Fisheries Act Amendments.

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APPENDIX B: WORKING PAPER ABSTRACT

The Giant Red Sea Cucumber, *Apostichopus californicus*, is the subject of a lucrative commercial dive fishery in British Columbia, Canada. Despite considerable research, the life history of this species is poorly understood and many biological parameters cannot be estimated, preventing the use of typical fisheries models. As a result, Four Experimental Fishing Areas (EFAs) were established in BC in 1998 to study the effects of harvest on sea cucumber densities. After 10 years, EFA data were analysed, a latent productivity model was developed, and recommendations were made regarding harvest rates and provisional reference points (Hand et al. 2009). The EFAs continued until 2015, generating another 8 years of data. This document updates harvest advice based on the original latent productivity model (with some updates) and the full time series of EFA data. Recommendations are to continue using 0.01 quantiles for harvest rates as per Hand et al. 2009. For example, for a post-harvest stock level of 0.6 B_0 the annual harvest rate range would be 2.0 - 8.0% of pre-harvest biomass (pre-harvest biomass is the biomass estimated with the most recent survey data). The upper ranges of the harvest amounts from the four EFAs may only be appropriate for areas with high productivity.

The recommended coast wide Limit Reference Point is 0.029 sea cucumbers m^{-2} on sea cucumber habitat (spatial) and the Upper Stock Reference Point is 0.038 sea cucumbers m^{-2} on sea cucumber habitat.

APPENDIX C: AGENDA

Update to reference points and harvest advice for the commercial Sea Cucumber (*Apostichopus californicus*) Fishery in British Columbia

April 5-6, 2022

Virtual Meeting

Chair: Cher LaCoste

DAY 1 – Tuesday, April 5, 2022 (All times below in Pacific Standard Time)

Time	Subject	Presenter
0900	Introductions Review Agenda & Housekeeping CSAS Overview and Procedures	Chair
0915	Review Terms of Reference	Chair
0930	Presentation of Working Paper	Authors
1030	***Break***	
1045	Overview Written Reviews	Chair + Reviewers & Authors
12:00	***Lunch Break***	
1300	Overview Written Reviews	Chair + Reviewers & Authors
1430	Identification of Key Issues for Group Discussion	Group
1445	***Break***	
1500	Discussion & Resolution of Technical Challenges, Results & Conclusions	RPR Participants
1530	Develop Consensus on Paper Acceptability & Agreed-upon Revisions (TOR objectives)	RPR Participants
1600	Adjourn for the Day	

DAY 2 - Wednesday, April 6, 2022

Time	Subject	Presenter
0900	Introductions Review Agenda & Housekeeping Review Status of Day 1 (*As Necessary*)	Chair
0915	Carry forward outstanding issues from Day 1	RPR Participants
1030	***Break***	
1045	*Science Advisory Report (SAR)* Develop consensus on the following for inclusion: • Summary bullets • Sources of Uncertainty • Results & Conclusions • Figures/Tables • Additional advice to Management (as warranted)	RPR Participants
1200	***Lunch Break***	
1300	*Science Advisory Report (SAR) cont'd*	RPR Participants
1445	***Break***	
1500	Next Steps – Chair to review • SAR review/approval process and timelines • Research Document & Proceedings timelines • Other follow-up or commitments (*as necessary)*	Chair
1545	Other Business arising from the review	Chair & Participants
1600	***Adjourn meeting***	

APPENDIX D: PARTICIPANT LIST

Last Name	First Name	Affiliation
Anderson	Erika	DFO Centre for Science Advice Pacific
Bureau	Dominique	DFO Science
Burton	Meghan	DFO Science
Campbell	Jill	DFO Centre for Science Advice Pacific
Cripps	Ken	Kitasoo-Xai'xais Nation
Curtis	Lyanne	DFO Science
Dalton	Alex	DFO Science
Duprey	Nick	DFO Science
Fong	Ken	DFO Science
Ganton	Amy	DFO Fisheries Management
Hajas	Wayne	DFO Science
Hankewich	Sandie	Kitasoo-Xai'xais Nation
Hansen	Christine	DFO Science
Kanno	Roger	DFO Fisheries Management
Krause	Geoff	Pacific Sea Cucumber Harvesters Association
Lacoste	Cher	DFO Science
Liptrot	Tom	Pacific Sea Cucumber Harvesters Association
Lochead	Janet	DFO Science
McDonald	Raphael	DFO Science (Maritimes, Student)
Obradovich	Shannon	DFO Science
Power	Sarah	DFO Science
Ridings	Pauline	DFO Fisheries Management
Sameoto	Jessica	DFO Science (Maritimes)
Spencer	Paul	National Oceanic and Atmospheric Administration
Thiess	Mary	DFO Science (National Headquarters)
Watkins	Hannah	Simon Fraser University (Student)
Wylie	Erin	DFO Fisheries Management

APPENDIX E: AGREED UPON REVISIONS TO THE WORKING PAPER

Section	Comment	Topic	Revision
Sarah Power review	Trends in Fig. 2 increase in harvest, decrease in density (generally). Zeballos highly variable trend, site 0 (no harvest) increasing density. Resiliency in cucumber population or product of experimental design? E.g. Jervis is the highest range of harvest recommendations, but the model may be influenced by the design. Caution warranted around how the information is applied	Model results - *Productivity* Equilibrium point in Jervis is below the minimum point. Is it sustainable? It decreased under experimental harvest rate, but did not recover. Why is it leveling off in the higher harvest rate sites? How robust is the method for Jervis? Concern over application of the models higher range outputs.	Add cautionary language – add caveat to the recommendations.
Jessica Sameoto review	Further context needed in the reference point section if authors are content with recommended reference points. Context in PA may strengthen authors argument.	-	Provide clarification on LRP and USR choice (see points on two slides that Janet shared and include in the specifics). Include population connectivity, etc.
Jessica Sameoto review	High productivity areas are likely sourcing low productivity areas. Yet, LRP is based on a low productivity area. Risk: drive down overall stock that inhibits stock recovery.	-	See below, clarify distinction that Laredo is moderate productivity.
Jessica Sameoto review	OCP additional layer of management. Unusual to see a USR lower than the OCP. Why? More context needed. *Issue of which density used where	-	Add clarification that OCP is only on the opening of areas and its objectives in relation to the USR, including difference between use of density-derived USR and biomass-derived OCP.

Section	Comment	Topic	Revision
Authors response to review (Day 1 morning)	What is the metric of productivity? The model output or the estimates from the data.	Table 1. Differences btw productivity and density. Language needs to correction in the paper.	Clarify language around low density areas.
General discussion	Inclusion of equations, input parameters and Hand et al. (2009) to help readers understand exactly what has changed and how things are calculated and used throughout.	-	Section 2.3.4 add equations or consider annex.
TOR 1	TOR 1: Catch data not shown in the data. Critical piece is to see how the model fits the data. Equations for the model were not included.	-	The TOR was not asked to re-do the model but to update – assumption that there was a good fitness of original data set. Wayne to review fit but not to necessarily include in the paper.
TOR 1	TOR 1: Model outputs.	Model fit. Is virgin biomass, estimated? Answer: Yes. Are credible intervals/estimates of virgin biomass in the document? No	Put a table of those values in: table of virgin biomass with credible intervals for each site.
TOR 1	TOR 1: Source and sink dynamics, is proportions of stock found at depth known or was a depletion estimate put into the model?	-	Put language about this into the paper and note the fishing zone depth range limits harvest to that upper depth so likely a conservative as those deeper populations will not be harvested and serve as a source.

Section	Comment	Topic	Revision
TOR 1	Clarification on some of the assumptions in the model about productivity.	A pop'n will always increase, assumes no depensation. This was included in Hand 2009 model, is it in the current model? Introduction into the model types used, what is contained in the paper and how it relates to other models.	Authors will add some additional text to connect to other model types. Relate latent productivity model to surplus models.
TOR 1	Production curve at stock almost depleted is almost the same as at maximum. Fig. 8 Where there is no data, productivity increases. Something strange going on?	Investigation of model fit. Could be thematic of other things going on in the model.	Authors to review fit but not to necessarily include in the paper.
TOR 1	Comment on use of 4 survey areas even though 1 is not commercially viable.	-	Add context about why value of retaining all data sets as this is intended to provide coastwide harvest advice and having densities and productivities on the low and high side continue to contribute to the conservativeness.
TOR 1	Trigger to review LRP	-	Discussion of when LRP should be considered for review – i.e., population dynamic change (otters), invert disease, new Science Advice is requested. Tie in short sentence of new multispecies work occurring and publishable in coming months.

Section	Comment	Topic	Revision
TOR 3	Harvest curves (hypothetical): Slide 17. Not in the paper (I think).	Could something visual be added to the document with actual data to help readers? Something to help guide readers through the tables.	Authors will add one similar to slide 17 but with true data set.
TOR 3	Section 2.3.5 difficulty interpreting it.	Add equations.	Previously agreed to.
TOR 3	Terminology: harvest amount, harvest rate. Consistency in language used needed. Adds confusion.	3.2 amount and rates used in the same paragraph.	Yes. Authors will double check that the terms harvest amount and harvest rate are used correctly throughout the document.
TOR 3	Clarification: harvest rate. Was there in a change in approach.	More background information around what is currently being done.	Yes, they will add some clarity around that.
TOR 3	Expected more information on burn in times, auto-correlations, Monte Carlo (MC) chains.	Methods - Section 2.3.3 does not address burn ins and MC chains run. More detail desired.	-
TOR 3	Jervis datasets. Both the datasets are the same, but the results in Tab 5 & 6 are not the same. Why?	Authors stated there is a bit of a randomness. There are fixed set seeds but also two sets are run in different model (i.e. 2008 vs current).	Small explanation that slight variations are expected.
TOR 4	Clarification: reference points (RP) in two units.	Recommendations - Conversion between units (linear vs spatial) is only applicable to this dataset. Suggest that the RPs recommendations be spatial density only.	Day 2: Authors talked and agreed to put only spatial density in the recommendations for reference points.
TOR 4	Fig 2 and 3	-	Authors agree to revise figures.

Section	Comment	Topic	Revision
TOR 4	Spatial scale disconnection of the application of the LRP and regional harvest.	-	Add some language around this.
TOR 4	Spatial scale disconnection of the application of the LRP and regional harvest.	-	Clarification in the document about how the LRP will be applied at a different scale than the fishery.
TOR 4	Definition of recovery in the paper – sign. increase in density. No justification of definition, i.e., references.	-	Janet suggests adding language couching $D_{recover}$ around the definition of serious harm.
TOR 4	Each EFA encompasses different habitats, what were the minimums for other EFAs that did not have $D_{recover}$. How were 95% conf. intervals calculated. What data used? Fig. 3 grey bars - discussion	-	Add text referring Fig. 10 in section 3.3. Fig. 3 changes previously agreed to that should help with confusion about grey bars.
TOR 4	Suggestion: Issue may be how recovery is defined in the paper.	Incorporation of recovery toward original survey density into the definition may be a solution.	Clarification to be added to the definition. Authors will clearly state that this is the definition for choosing the LRP, not for defining recovery of a stock, as would be done in a recovery plan.

Section	Comment	Topic	Revision
TOR 4	Data-rich ways to develop reference points ($B_{msy,}$ $B_{0)}$, data rich: misunderstanding in the purpose of the comparison with latent model. Idea is to increase confidence in the density based reference point developed. This was brought up by several participants.	What is missing in the data to be able to do a data-rich methods and how does the new monitoring program address this?	Address in future directions: in the future, one could compare how the current LRP compares with Bmsy and B0, or other data-rich methods; and what would trigger a review of the reference points
TOR 4	Set LRP as the mean of upper 99% confidence level of minimum spatial density of Laredo and Zeballos that showed subsequent recovery within the range of the first survey estimate (i.e., the proxy for virgin biomass). This equates to an LRP of 0.029 sea cucumbers per m^2 on sea cucumber habitat.	-	Authors and committee agree to this LRP.
TOR 5	Immigration from depth and how it may impact the population and its recovery from harvest.	-	Authors will add.
TOR 5	More references in 4.4, Pycnopodia interaction. Seastar wasting disease, predator-prey linkages.	-	More references on Pycnopodia predator response in sea cucumbers will be added; authors do not have references on seastar wasting disease and sea cucumber, or predator-prey linkages with Sea Otters.