Fisheries and Oceans Canada / Pêches et Océans Canada
Ecosystems and Oceans Science / Sciences des écosystèmes et des océans

Canadian Science Advisory Secretariat (CSAS)

Proceedings Series 2019/020

Pacific Region

Proceedings of the Pacific regional peer review on Cumulative Effects Assessment for Northern and Southern Resident Killer Whale Populations in the Northeast Pacific

March 12 - 13, 2019
Nanaimo, British Columbia

Chairperson: Gilles Olivier
Editor: Jocelyn Nelson

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

August 2019

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.

Published by:

Fisheries and Oceans Canada
Canadian Science Advisory Secretariat
200 Kent Street
Ottawa ON K1A 0E6

http://www.dfo-mpo.gc.ca/csas-sccs/
csas-sccs@dfo-mpo.gc.ca

ISSN 1701-1280

Correct citation for this publication:

DFO. 2019. Proceedings of the Pacific regional peer review on Cumulative Effects Assessment for Northern and Southern Resident Killer Whale Populations in the Northeast Pacific; March 12-13, 2019. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2019/020.

Aussi disponible en français :

MPO. 2019. Compte rendu de l’examen par les pairs régional du Pacifique sur l’Évaluation des effets cumulatifs sur les populations d’épaulards résidents du nord et du sud dans le Pacifique Nord-Est; du 12 au 13 mars 2019. Secr. can. de consult. sci. du MPO, Compte rendu 2019/020.

TABLE OF CONTENTS

SUMMARY

A Fisheries and Oceans Canada (DFO), Canadian Science Advisory Secretariat (CSAS) Regional Peer Review meeting was held from March 12 – 13, 2019 at the Pacific Biological Station in Nanaimo to review a working paper focusing on a cumulative effects assessment for Northern and Southern Resident Killer Whale populations in the Northeast Pacific. This Proceedings document includes a summary of the presentations and is the record of the meeting discussions and conclusions.

In-person and web-based participation included Fisheries and Oceans Canada (DFO) Science and Resource Management (Species at Risk) Sectors staff; and external participants included representatives from Environment and Climate Change Canada, Maa-nulth First Nations, Chicago Zoological Society, Raincoast Conservation Foundation, Georgia Strait Alliance, the Center for Whale Research, WA, University of British Columbia, Simon Fraser University, and the University of Victoria.

The Science Advisory Report and Research Document resulting from this meeting will be made publicly available on the Canadian Science Advisory Secretariat (CSAS) website.

INTRODUCTION

A Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat (CSAS), Regional Peer Review (RPR) meeting was held on March 12 – 13, 2019 at the Pacific Biological Station in Nanaimo to review the cumulative effects assessment for Northern and Southern Resident Killer Whale (NRKW and SRKW, respectively) populations in the Northeast Pacific.

The Terms of Reference (TOR) for the science review (Appendix A) were developed in response to a request for science advice from the DFO Species at Risk Program. Notifications of the science review and conditions for participation were sent to representatives with relevant expertise from First Nations, environmental non-governmental organizations 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):

> Cumulative Effects Assessment for Northern and Southern Resident Killer Whale Populations in the Northeast Pacific by Cathryn Clarke Murray, Lucie Hannah, Thomas Doniol-Valcroze, Brianna Wright, Eva Stredulinsky, Andrea Locke, and Robert Lacy. CSAS Working Paper 2017SAR01

Participants also received copies of the Terms of Reference (Appendix A), agenda (Appendix C), written reviews (Appendix D), and list of participants (Appendix E).

The meeting Chair, Gilles Olivier, 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 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, and draft science advisory report (SAR).

The Chair reviewed the Agenda (Appendix C) and the Terms of Reference (Appendix A) for the meeting, highlighting the objectives. The Chair then reviewed the ground rules and process for exchange, reminding participants that the meeting was a science review and not a consultation. The room was equipped with microphones to allow remote participation by web-based attendees, and in-person attendees were reminded to address comments and questions so they could be heard by those online.

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 working paper being discussed. In total, 32 people participated in the RPR (Appendix E). Jocelyn Nelson was identified as the Rapporteur for the meeting.

Participants were informed that Miriam O, Misty MacDuffee, and Paul Paquet had been asked before the meeting to provide detailed written reviews for the working paper to assist everyone attending the peer-review meeting. Similarly, Miriam O, Misty MacDuffee, and Paul Paquet provided written reviews of the working paper and participants were provided with copies.

The conclusions and advice resulting from this review will be provided in the form of a Science Advisory Report to Resource Management, Species at Risk Program to inform Species at Risk Act (SARA) species recovery planning for the Northern and Southern Resident Killer Whales. The Science Advisory Report and supporting Research Document will be made publicly available on the Canadian Science Advisory Secretariat (CSAS) website.

REVIEW

Working Paper:	Cumulative Effects Assessment for Northern and Southern Resident Killer Whale Populations in the Northeast Pacific by Cathryn Clarke Murray, Lucie Hannah, Thomas Doniol-Valcroze, Brianna Wright, Eva Stredulinsky, Andrea Locke, and Robert Lacy. WP2017SAR01
Rapporteur:	Jocelyn Nelson
Presenter(s):	Cathryn Clarke Murray, Lucie Hannah

DAY 1

PRESENTATION: OVERVIEW OF THE WORKING PAPER

The authors present included C. Clarke Murray, L. Hannah, T. Doniol-Valcroze, B. Wright, and E. Stredulinsky. An oral presentation was given by C. Clarke Murray to summarise the working paper. The abstract of the working paper is provided in Appendix B.

Presenter: Cathryn Clarke Murray

Cathryn Clarke Murray introduced the cumulative effects assessment for the Northern (NRKW) and Southern Resident Killer Whales (SRKW). This presentation discussed the Southern and Northern Resident Killer Whale populations, trajectories from census data, and threats to the Resident Killer Whales (RKW). She also outlined the best ways of assessing cumulative effects through discussions and past works, and reviewed the scope of the study (primary threats only, excluding low probability high consequence events, future changes in anthropogenic activities, potential mitigation measures, or management actions). This cumulative effects assessment was done in two steps: a pathways of effects model (PoE) followed by a population viability analysis (PVA). Dr. Clarke Murray reminded the group that they were brought together to improve the working paper and the authors welcomed their input.

DISCUSSION: OVERVIEW OF THE WORKING PAPER

A participant asked why the analyses were done at population level (SRKW and NRKW) rather than at the pod or matriline level given the possibility of their different trajectories and dynamics. The authors responded that the SARA recovery strategies and action plans are focused on the population level, so the objectives for the working paper matched this in order for the assessment to be most useful to the client. Additionally, it isn’t clear if pods can be treated as separate populations because of interbreeding, and many of the effects included in the model are population-level (e.g., carrying capacity). However, the population viability model is individual-based with rules set to replicate what happens in the wild, and pod information is specific to individuals and can be input and output from the model. The authors noted that pod-level analyses were beyond the scope of the current model, but that they will make it clear in the text that the model includes pod information.

One of the reviewers expressed strong appreciation for the thought and work that went into this working paper, which included updating and reanalysing data.

PRESENTATION: PATHWAYS OF EFFECTS MODEL

Presenter: Lucie Hannah

Lucie Hannah presented the first step of the cumulative effects assessment, the pathways of effects (PoE) model. PoE models were described as valuable tools as they provide a science-based foundation for guiding assessments. She outlined that the purpose of the PoE was to define the structure of the threats and elucidate the linkage pathways from threats to population parameters (such as fecundity and mortality), including threat interactions. The PoE conceptual model consisted of a visual representation of threat linkage pathways with supporting justification text. She expressed that she appreciated any input from experts in the room who may know more about relevant literature or data that could refine the conceptual model. She noted that there were other threats identified by SARA that were not included in the PoE due to limited data available with which to assess them.

DISCUSSION: PATHWAYS OF EFFECTS MODEL

General questions

After the presentation, one participant noted that the activities that cause the threats were not included in the PoE model as would be expected in a formal cumulative effects analysis, that this assessment started at the threat level, and wanted the difference acknowledged. The authors explained that historical time series data were not available for all of the necessary activities so that level could not be included, and noted that they would include this explanation in the research document. Additionally, they would acknowledge that this assessment was meant to focus on specific threat impacts, not where threats were originating, which was another reason why this analysis differs from the traditional approach. A participant noted that with the activity level missing from the model, there was a missing component when looking at management implications and how to address the activities that cause the threats.

Prey availability

The difference between prey availability and prey abundance was discussed, noting that abundance was used in the assessment based on past literature relating Chinook salmon abundance to the fecundity and mortality of killer whales. Prey abundance was used to parameterise that part of the model, not prey availability. The use of prey availability is more challenging as it is made up of two components: prey abundance and prey access (such as through the interaction with vessel presence/noise and other stressors). Participants asked for the text to be clear that prey abundance was used in the assessment rather than prey availability due to these differences.

One participant wanted to know if hatchery production and harvest were considered as anthropogenic impacts with the prey abundance information. The authors explained that this aspect was out of the scope of the assessment, but that they could add a discussion on it. Hatcheries and fisheries are captured in prey abundance indices used, just not discussed explicitly. The salmon-mortality relationship in prey abundance is lagged by one year, and the number in the PVA used was the best estimate of fish that were vulnerable to fishing in that calendar year rather than the actual abundance.

A concern was raised about the distribution of prey as abundance drops, and whether the authors knew if it became patchy or harder for killer whales to find when abundance was low. The authors were not aware of any research on the topic, and stated that they would add this consideration to the discussion of uncertainties. A clarification question was asked about what the uncertainty around salmon stocks was related to, and the authors explained that there currently isn't research demonstrating what the RKW forage for outside of the Salish Sea.

Acoustic disturbance

As one of the vessel threats, clarification was requested for the types of vessel noise and how they were considered (e.g., sonar). The response was that the authors hope to improve this section with input from ongoing research; the model is currently based on information from a study by Rob Williams on small vessels and a population disturbance model by the Port of Vancouver. Both of these studies examined how vessel noise affects foraging but were limited in size and scope. There are also current projects funded by DFO's Oceans Protection Plan examining acoustic disturbance from vessels. Though there is information on how noise manifests in the environment, its effects on RKW fecundity and mortality is not known, and very little is known about the impact of noise on RKW prey. The University of Victoria presently has a research project investigating the impact of noise on fish. While there was limited information at the time the model was created, many projects are trying to address this and if it is revisited in three years, there will be more information about the role of noise.

There was a request for the text to be clear that this section looks at "vessel noise" and "vessel disturbance," rather than all sources of acoustic disturbance.

Physical disturbance

Physical disturbance was defined for this assessment as injury or mortality resulting from vessel strikes. However, determining the cause of mortality can be difficult since few whale bodies are recovered for necropsy. One participant noted that there are physical disturbances other than vessel strikes that could have impacts. The mortality table (working paper Table 4 – Timeline of known incidents of vessel strikes causing injury in NRKW and SRKW) was discussed, with the absence of whale L112 highlighted. Participants confirmed that L112 mortality by blunt force trauma was conclusive, and the authors thanked the group and agreed to add this information to the working paper (this individual was already included in the table but not identified as L112).

The difficulty of distinguishing the killer whale response to vessel noise from the response to vessel presence was discussed. Chase interference may be missed in limiting physical disturbance to strikes and avoidance of strikes. RKWs may have to abandon a chase due to the presence of a vessel. The authors stated that the prey interaction could include physical disturbance and offered to make it explicit in the documents.

Contaminants

The only contaminants included were polychlorinated biphenyls (PCBs) because of the availability of a dataset going back to the 1990s, and the availability of past research linking PCB contamination to population impacts through calf mortality. PCBs were also highlighted as important because an internal literature review, contracted through SARA, identified them as being in a group of contaminants considered of high concern to RKW (Van Zandvoort 2019). Further, a recent health risk-based evaluation of 25 different contaminants in RKW indicated that in terms of overall chemical exposure, PCBs were the pollutant of greatest concern to RKW (Gobas and Ross 2017 unpubl.). Other contaminants are also of concern, but at the time of writing there wasn't enough research or complete data sets available for other contaminants to support the identification of pathways of effects and also to support links to population parameters.

There was a question about whether there were adjustments for variability in contaminant load between salmon stocks. Research by Sandra O'Neill found that contaminants in different stocks varied, with high PCB load in Puget Sound and Fraser late Chinook. A participant drew attention to Table 10 (Chinook salmon indices used for mortality and fecundity in each of the salmon threat models), which shows that each RKW population has a highly contaminated prey stock that they feed upon. The authors responded that different levels of contamination in salmon stocks weren't considered because the PCB concentration level used was from RKW biopsies. However, Tanya Brown (DFO) has ongoing research on contamination loads that could be included in a few years' time.

Biopsies have found higher PCB levels in SRKWs blubber compared to that of NRKWs, which may reflect the consumption of more contaminated prey than NRKWs. In addition, when RKWs are not consuming enough food to maintain metabolic demands, they metabolise their contaminated blubber fat, releasing stored contaminants such as PCBs into the bloodstream. The higher relative prey abundance for the NRKW population makes this less likely to occur in that population. Clarification was requested about why transient killer whales weren't included, since biopsy samples have shown them to have a higher level of contamination and could help clarify the relationship. The authors responded that this was one reason why they included an interaction between prey and contamination: one hypothesis about why transients are doing well despite the high contamination load is because this population has sufficient prey and so aren't metabolising their contaminated blubber fat, so may not be as affected as the RKWs if the contaminants remain in blubber and are not released into the bloodstream.

PRESENTATION OF WRITTEN REVIEWS: PATHWAYS OF EFFECTS

Reviewer: Miriam O

This reviewer found the assessment interesting because of how clearly defined the priority stressors and endpoints were, which is often not the case in such assessments. The limited inclusion of threats and removal of activity-level from the PoE focused the scope and made it more straightforward. The way authors defined the type of PoE and how it feeds into overall cumulative effects research was very clear to this reviewer, where stressors and endpoints were identified was also very clear, and key in transparent processes. The endpoints are the most complicated piece in creating a pathways of effects model, so this study was a great example of how to use a PoE.

There was a discussion about the two models (direct pathways and interaction pathways) that the reviewer understood was done for clarity, but wanted to hear more about the process of why it was done. The authors explained that the full PoE is the full "spider-webbed" diagram, and as this was complex in appearance, it was shown in two separate figures to make the links clear. The separate figures were not actually two models, they were just shown as separate pieces for clarity. The authors noted that they will add clarification to the paper that the two figures are not two separate PoEs, or edit the figure accordingly.

The reviewer observed that the resulting PoE that includes both direct and interaction effects was quite novel and useful for identifying gaps in knowledge and priorities for research. The PoE and its role in risk assessments was well outlined and described in the working paper. The PoE feeds directly into the next step of assessment, and the reviewer was happy to see this.

Overall, the reviewer understood that there were many unknowns, but felt that the authors had done a good job based on available data. She found that the PoE was a great way of scoping the assessment and identifying gaps, and will be useful for focusing resources.

Reviewers: Misty MacDuffee and Paul Paquet, presented by Misty MacDuffee

This pair of reviewers found that the PoE conceptual model was very important. The authors made things very explicit for how and why interactions work. They highlighted that when authors are familiar with topics, then some of the assumptions may not be well described, but the authors made a point of making it explicit in the document, rather than implicit.

DISCUSSION: PATHWAYS OF EFFECTS

There was a discussion about killer whale gunshot wounds. Section 2.3.1 showed evidence of killer whales regularly suffering gunshot wounds in years before protective regulations, and that this may still be occurring in Alaska. A participant noted the media coverage of necropsies done on stranded whales and asked if this necropsy data could be used to assess if gunshot wounds are still found on whales. Interactions between marine mammals and fisheries were also identified as an important issue, as the loss of one or two individuals could have a large influence on some populations. The authors responded that the NRKW historical photos show evidence of gunshot wounds, but that those conducting fieldwork on the population haven't seen evidence in matrilines that are known to interact with fisheries. Gunshot wound mortality is now effectively zero. The NRKW registry keeps track of gunshot wound evidence but the data have not been summarised formally; archived photos at the Cetacean Research Program may be a source for these data.

The Southern Alaska Resident Killer Whales (SARKW) still show evidence of gunshot wounds, but those wounds have never been found to be the cause of death when bodies were found and investigated. Gunshot wound mortality at this time is assumed to be 0 in this population also. The authors offered to state the current status of gunshot wounds and findings from necropsies more clearly in the text of the paper.

Clarification was requested about whether physical disturbance was defined as only vessel strikes in the PoE and PVA model, or if it was also rolled into the acoustic component of disturbance. The authors explained that physical vessel disturbance was considered in two components in the model: vessel strikes and vessel presence. Vessel strikes were linked to mortality rate, whereas vessel presence is considered together with acoustic disturbance in the model because there wasn't a way to tease apart the effects of vessel presence from vessel noise. It was suggested that the PoE model text could more clearly note that vessel presence was considered together with acoustic disturbance.

The Chair asked if anything was missing from model that should be included. One participant asked if it were possible for vessel strikes to be traumatic enough to influence fecundity but not so severe as to cause mortality, since the current version doesn't have a direct pathway between the physical disturbance threat and birth rate. The authors responded that conceptually it makes sense to include that link but that the relationship could not be quantified because there were no studies directly related to this. The link was not included due to a lack of evidence but that it could be added as a note in the uncertainties and assumptions section. Additionally, it is difficult to distinguish the interaction between vessel presence/noise and the behavioural response, and so instead of a line from vessel disturbance to birth rate, that interaction was captured under acoustic disturbance because the interaction between chronic noise and birth rate has been documented in other animals. Vessel presence causes stress that hasn't been captured well, but it has been documented in other animals that stress affects birth rate, so the authors offered to incorporate that clearly in the conceptual model. The approach was to present the full PoE conceptual model, then a refined PoE outlining clearly what could actually be modelled in the PVA at this time and removing those linkages which could not be quantified. The authors note that they will explain this approach more clearly. It was suggested that the uncertainty in the PoE linkages based on type and amount of data could be documented, including the number of papers, experts consulted, and whether proxies were used to create the links.

Another link that participants thought may be a gap was about potential for loss of foraging habitat due to physical disturbance. The authors explained that this was included in the prey-disturbance interaction because RKWs may be prevented access to a foraging ground due to presence or noise of vessels. The authors offered to make it clearer in the justifications, but it would be difficult to show in the diagram because it was included as part of the acoustic disturbance threat. Areas lost are not noted currently, but could be added to the paper. A participant noted that there are other elements of physical disturbance than vessels, and requested a sentence acknowledging that.

There was a suggestion to add a figure to the paper showing the removed links from the PoE, essentially Figure 9 (Modified PoE conceptual model for Resident Killer Whales used for population viability analysis) with the removed links shown, with an explanation of why each of them were removed to add clarity.

A participant asked if the authors had considered using data from other species where killer whale data were not available for a link. The authors responded that when relevant data were available, they were used.

The Chair asked for more comments on the PoE, but no more were offered.

PRESENTATION OF WRITTEN REVIEW OF OVERALL WORKING PAPER

Reviewer: Miriam O

This reviewer expressed that the authors had done a great job with this document. The approach was well researched and thought out, built on previous research, thorough and clear. She offered kudos to the authors for building on past works and giving them credit.

The reviewer had a few comments directed at the usability of the approach to inform management decision processes. The process for decision making and how science informs those decisions is critical. This paper is a really good example of integrating information. A couple of questions remained after reading the working paper:

- Is there a structured decision process, and where does this fit in?
- Which piece of a structured decision model (SDM) does this address?

Ms. O emphasised the need to co-develop structured decisions models between management and science, so that questions can be addressed in a direct manner and DFO management understands what DFO Science can and cannot address.

It was noted that the SARA recovery measures (RM) are not independent. Could the proposed approach and outputs from RM 11 be used to inform some of the others? Focussing on process (SDM) could get to how RM 11 could fit into 6 and 17. The reviewer observed that the objectives from the SARA action plan gave the assessment a clear purpose.

The reviewer noted that different methods are needed for different purposes. A single approach for cumulative effects assessment doesn’t exist. The reviewer found that this method was a good demonstration of a tool for the cumulative effects toolbox. The overview ended with a question: could it be beneficial to have more elaboration on whether the PVA could be expanded to community or ecosystem model?

DISCUSSION OF THE WRITTEN REVIEW

A participant asked the reviewer how management can move forward on where to apply management levers given the absence of activities in framework. The reviewer responded that one of key benefits of PoE models is that they are good communication tools. Even without specific information this tool can be used to inform management. Clients will have to decide how to use this assessment approach.

The Chair asked if there were any remaining questions on the PoE, and there were none.

PRESENTATION: POPULATION VIABILITY ANALYSIS

Presenter: Cathryn Clarke Murray

Cathryn Clarke Murray described the second step of the cumulative effects assessment, the population viability analysis (PVA). During this section of her presentation, she described the modelling approach and how it was selected, the different modelled trajectories of the RKW populations and their data sources, and the individual and cumulative threat scenarios of aquarium removals, prey abundance, vessel noise/presence, vessel strikes, and contaminants.

GENERAL DISCUSSION

Clarification was requested for why 1979 was chosen as start date. The authors explained that the RKW life history data extends back to 1973-4 for the two populations, but the Chinook data only began in 1979.

A participant requested that the baseline growth rate adapted from SARKW data be called something other than “unimpacted” because these killer whales are also exposed to stressors, and suggested “reference” or “comparatively undisturbed” instead. Authors agreed to change this to “reference”.

Modelling approach

A participant requested adding a section with the key assumptions stated in the beginning of the documents, including that the fecundity and mortality rates were taken from the SARKW as a presumably nearly pristine reference baseline, with the addition of threats and NRKW and SRKW genealogy data to build the models. Both the NRKW and the SRKW are fish-eating RKW groups occupying a similar part of the NE Pacific, focused on Chinook as prey. This lead the authors to expect the effects of threats would be same for these two populations, though the exposure to threats may differ.

Resident Killer Whale populations

A participant asked whether the changes in the growth rate of the RKW populations (Figure 2 – Resident Killer Whale population time series (data shown 1979-2017)) could be attributed to changes in observer effort. The authors explained that there was no pre-set growth rate in the model, it was all based on census data and that the increase in numbers after the 1980s or 1970s was population growth rather than increased observation effort (i.e., it wasn’t the discovery of new groups that lead to the increased census estimates). The last new group was discovered in 1978, and census data were retroactively backfilled when new groups were found. All population growth of the RKWs was due to new calves being born. The flat growth curve trajectory before the early 2000s in NRKW population growth was likely prey-related because of low Chinook abundance. It was suggested that this could be clarified by adding additional text explaining that the increase in RKW population size starting in 2001 was not due to new groups being found, and how NRKW births/deaths are not known as quickly as for SRKWs. It was noted that uncertainty wasn't included in RKW population growth because the populations were fully censused.

A participant asked about possible mating failure in the SRKW population since it was noted in the working paper that only two males have sired half the calves born since 1990. In Table 9 (Age-specific vital rates (mortality and fecundity) for each Resident Killer Whale population), fecundity rates for females aged 31-50 was much lower for SRKW than for NRKW and SARKW. Could there a connection there? The authors responded that it's not known why there is a low male contribution to breeding in SRKW or if another male could assume this role if one dies. It is not known how mate choice works in KWs. The model doesn't currently account for mate choice or male limitation. However, it does account for the number of males because no males would result in no mating, and the impact of inbreeding was reflected in the lethal equivalents. It is possible to include male limits in the model, including limiting reproduction to the two oldest males, but it hasn't been included at this time due to lack of research. There isn't complete, up-to-date paternity information for NRKW and SARKW for comparison. It is likely that that some males dominate reproduction in other populations, but because of the low numbers in SRKW, it has a more dramatic effect. More research is being conducted on NRKW and we should at some point know more. It was suggested to add this clarification to support the text in the paper regarding paternity.

Aquarium removals

This historic threat was not part of the cumulative effects assessment but was investigated to examine how this threat impacted the population by determining what the predicted population trajectories would have been, had these types of removals not occurred. For aquarium removals, the population was modelled using vital rates from Vélez-Espino et al. (2014) and this will be clarified in the text.

A participant asked if the difference between the plot for the observed SRKW population and the plot for the model with no aquarium removals could be related to carrying capacity. The authors responded that the carrying capacity was not something that could be limiting in this model because it was set at an arbitrarily high level. The flat abundance model line was due to the observed vital rates, and during that time period the population increase was relatively low.

Prey abundance

The relationship between RKW vital rates and different combinations of Chinook salmon ocean abundance stock indices were examined. Further exploration of the choice of stocks (Table 10 - Chinook salmon indices used for mortality and fecundity in each of the salmon threat models) was requested. The rationale for the choice of stocks, and grouping of stocks, comes from both statistical and field evidence (collecting fish scales after RKW kills to see which Chinook stock was consumed). Most diet information was based on summer and spring feeding events. For clarity, in terms of stocks selected in Table 10, these were not based solely on the findings from the prey analysis, but on statistical correlations with those salmon stock aggregates. Authors were requested to expand the description and citations of the threat scenario sections starting with 3.3.1 (aquarium removals/live capture fishery, 3.3.2 prey availability, and noting 3.3.3 mortality especially) and stocks selected, definitions of stocks, the rationale for indices, etc. The authors offered to make this clearer in the research document.

A participant asked if the size of Chinook salmon was addressed in the dataset since their size has been decreasing since 1920s, as noted in the Ricker papers from the 1980s. One participant wanted to know if there was evidence for a change in Chinook salmon size, or difference in sizes in DFO data sets, because acoustic signals are stronger with larger fish, suggesting it is harder for RKW to hunt smaller fish, especially in a noisy environment. If not, the authors could add it as a source of uncertainty that size, not only abundance, is important but could not be included in the current PVA model. Authors responded that the working paper did include a reference to the decline in size observed in the older age classes of Chinook salmon, but they didn't have information about the difference in prey size availability between southern and northern killer whale populations. A participant added that in British Columbia, this pattern can be observed in some stocks (Skeena, Fraser Northern Vancouver Island). The authors cited CSAS Science Response 2018/035 which has a lot of information. John Ford and Eric Ward have looked at size selectivity in RKWs showing that they target predominately age 4 and 5 fish, which make up less than 20% of the prey stock. RKW go after the biggest, oldest fish selectively. This is the same target as fisheries. Even if abundance was higher for smaller, younger fish, they are less likely to select them.

There was a discussion about the measure of Chinook abundance used in the model (ocean abundance). Ocean abundance includes reconstructed estimates of numbers of fish removed in fisheries as well as those that make it to spawning grounds to estimate the total number. The modelled ocean abundance is a measure of fish sufficient in size to be vulnerable to fishing gear (larger than the minimum size limit) and is therefore not an estimate of the total number of fish. Terminal run estimates are a measure of fish abundance after fishery removals, but also after killer whale and other predators' consumption. In section 3.3.2 (Threat scenario prey abundance), it was noted that ocean abundance estimates may be a better measure for RKW prey availability than terminal run estimates, supported by a communication with Antonio Vélez-Espino. However, a participant thought that Antonio Vélez-Espino may have been misquoted in the text on this issue. The authors agreed that this had been a misunderstanding and corrected correction will be made to explain that both measures have value (see also follow-up discussion and clarification on pg. 12 of these Proceedings). In half of cases ocean abundance estimates are better related to RKW vital rates, but terminal run estimates are also related well, and can also be a good indicator of size and age of Chinook as well as of timing of different stocks coming through the area. Vélez-Espino et al (2014) results showed that terminal run estimates were better for 4/7 vital rates for SRKW, and 6/12 for NRKW. One author asked if terminal run estimates varied in the same way as ocean abundance. The response was that this would depend on how much fishing occurs, and could vary a lot by year. The authors suggested that ocean abundance would better reflect what RKWs had access to than terminal run estimates. A participant responded that the prey base of NRKW may be better reflected by ocean abundance, but that of SRKW might be better reflected by terminal runs. SRKWs focus on adult Chinook returning in the fall, so while the NRKWs may have better access to Chinook and therefore have prey abundance reflected well by ocean abundance, for SRKWs, the terminal abundance might be a better measure. A participant noted that terminal run estimates could also address fishery take of Chinook before they're available to RKW.

The authors noted that other papers have used ocean abundance indices to model RKW mortality and fecundity. John Ford's work used ocean abundance, and Eva Stredulinsky's work on social cohesion fit better with ocean abundance than terminal runs. A paper by Ward et al. (2009) used ocean abundance from the Pacific troll fishery (Pacific Salmon Commission West Coast Vancouver Island biomass index). However, the West Coast Vancouver Island Index looks at spawning on the west coast of Vancouver Island, and the authors used different data. A participant suggested that the authors use fecundity to compare the Chinook data for this working paper with the data of Ward et al. (2009), and make it clear in the text that these are different. One participant noted that such clarification would be needed because inferences developed in this working paper are not comparable to Ward et al. because a different dataset was used. In response, the authors stated that ocean abundance was converted into an index;

the model uses a comparison to average abundance, not absolute numbers, and these averages vary by population.

The Chair asked whether the group would be satisfied on this point by the authors agreeing to add text to clarify why ocean abundance is used, and that it is relative to the long-term average. Participants asked to see justification for using ocean abundance rather than terminal runs added to the research document, and also a clarification of what ocean abundance does and doesn't represent. When asked if using terminal run data would make a big difference in the model results, the authors responded that the model draws randomly from a distribution of that index around a mean, not absolute numbers. Since the trend was not used, it shouldn't cause a large difference in the model results. Running a comparison between terminal runs and ocean abundance to see which is most closely related to vital rates was suggested.

On a follow-up question, the authors were asked where killer whales take most of their food, whether it is from the ocean or from river mouths. They responded that the choice of stocks was based on an analysis of prey data, and that it's not always enough to know where the the killer whales feeding. However, killer whales feed mostly away from the mouths of rivers. Ford mapped predation event locations, showing that RKWs were feeding on returning fish. Hanson's 2010 publication showed that Chinook stock composition of prey samples mirrored return timing, and described how many locations of predation events were along the southern part of Vancouver Island (Port Renfrew to Victoria, and through the southern Gulf Islands and San Juan Islands), suggesting that RKWs feed on fish as they return to Puget Sound and the Strait of Georgia.

A participant wanted to revisit how the model draws from the index, noting that randomly drawing values from the distribution doesn't reflect what happens in Chinook population trends. There can be a lot of autocorrelation from one year to the next because cohorts recruit on a four year period. In addition to prey population dynamics, some stocks are themselves threatened due to decreases in abundance. There was concern that the recent pattern of Chinook abundance wasn't being well represented. The authors responded that this wasn't a salmon model – the aim was to define a model that can be used for RKW. This model won't do well under continually decreasing prey populations. Once real numbers (rather than random draws around the means) were put back into the data for the model, the model matched the real populations' trajectories for RKWs more closely. It is difficult to project salmon populations, but the model could draw from a narrower range of values or from different stock types if this information is available.

A definition of the SRKW and NRKW Chinook index was requested. For NRKW fish aggregations, it was asked if there were no stocks in the north identified and if it was related to sampling. The response was that some of these stocks spawn in the south but live in the north (e.g., Up River Brights). In the Fraser, there are five stock groups with different ocean distributions. Some of these stocks go far north, while others just stay in the southern area. Many of the stocks that spawn in southern areas migrate through southeast Alaska and Haida Gwaii. Sampling effort for northern Haida Gwaii has been quite high. Most prey samples from that northern study area were from Fraser River stock. Whales have been seen following those stocks south as the fish return south.

It was observed on Figure 10 (Relationship between Chinook salmon index and mortality index) that updating Ford's (2009) index brought down the R^2, and a participant asked whether the authors had been able to replicate his analysis before the updates. The authors explained that Ford's data only went to 2003, while the current working paper has 14 years of extra data. The R^2 decrease could be due to the fact that Ford's data reflected a time when salmon populations were crashing, and because RKW populations declined at the same time, the relationship was stronger. Now the SRKW have less prey and more threats. There wasn't data for pristine populations, other threats were working concurrently and those change over time. One threat may decrease, while another becomes more important. The relationship may not be linear, there may be threshold effects, and this is an area of further investigation.

The authors were asked if it were possible to incorporate uncertainty associated with the Chinook data used as input in the model. The authors responded that it can't be done on the data themselves, but that uncertainty in the linkages can be incorporated using a regression coefficient, and that uncertainty included in Vortex models.

A participant observed that for NRKWs, the model that takes into account only prey abundance for mortality and fecundity does a good job of matching the observed population. However, using only prey abundance resulted in the model not matching the SRKW population.

The authors explained the prey abundance data further:

The Pacific Salmon Commission's (PSC) Chinook model estimates the number of "model fish" available from each of the 30 model stocks to six fisheries (Alaska Troll, BC North Troll, BC Central Troll, West Coast Vancouver Island Troll, Georgia Strait Sport, and Washington/Oregon Troll). Three different sources of data have been used to represent Chinook salmon abundance: the Chinook Technical Committee (CTC) terminal run, the Coded Wire Tag (CWT) terminal run reconstruction estimates, and ocean abundance model estimates.

- The Chinook Technical Committee's (CTC) Chinook Model terminal run estimates include both hatchery and natural production plus terminal catch estimates, and is available for a small group of Canadian stocks.
- Coded Wire Tag (CWT) terminal run reconstruction estimates stock abundance for runs from northern BC through California. It uses escapement information and coded wire tag data from fisheries across the coast to reconstruct abundance from spawning areas as well as ocean fisheries to estimate fish abundance in terminal run areas.
- Ocean abundance includes reconstructed estimates of numbers of fish removed in fisheries as well as those that make it to spawning grounds to estimate the number in the ocean. The ocean abundance is a measure of fish sufficient in size to be vulnerable to fishing gear (larger than the minimum size limit) and is therefore not an estimate absolute abundance. Therefore, relative rather than absolute changes in abundance should be used.

To clarify why ocean abundance was selected, the authors explained that Vélez-Espino had suggested that the CWT terminal run reconstruction index was the best to use but the data were only available up to 2010. The considerable amount of work needed to update it was more than the salmon program could support. In light of this, he had suggested using ocean abundance instead and recommended against using the CTC terminal run data. A quick comparison of the CWT reconstructed terminal run data to ocean abundance, in the time frame that has comparable data, showed that they are very highly correlated. The authors agreed to incorporate this explanation, and a recommendation to update the CWT terminal run reconstruction, into the research document. A participant noted that an important recommendation would be to further investigate the relationship between the updated terminal run and ocean abundances with vital rates.

Disturbance (vessel presence/noise)

A proportional difference between northern and southern areas was used to quantify vessel traffic in the PVA model. The impact of disturbance from vessel presence and noise was modelled as a 25% reduction in prey availability, with a threshold measure where interactions were more important when prey abundance was low (double the vessel presence/noise impact on mortality when prey was below average).

To support the quantification of vessel traffic, Norma Serra-Sogas (University of Victoria) gave a brief presentation on work done for a contract to evaluate the size of the whale watching industry. Norma researched whale watching websites and collected data on where they are based in BC and Washington State looking only at day trips, not at multi-day trips. She looked at the number of operators (74) and number of vessels for each operator. Tofino had the highest number of operators, then Campbell River, then Victoria, then Port McNeill while Friday Harbour had highest in Washington State. Tofino had 31 vessels, Victoria had 29, Campbell River had 14 vessels, and Friday Harbour had 11 vessels. She also looked at the number of trips per day. The Friday Harbour fleet was mostly larger boats with a wider range.

A participant asked if other ecotourism vessels were examined and Serra-Sogas responded that she was tracking fishing boats that also do whale watching as well as kayaking companies, but these weren't included in the presented data. Another participant wanted to know if the distribution of other ecotourism companies were the same as where whale watchers were concentrated. This had not been analysed yet, but Serra-Sogas understood that there was a large overlap. It was noted that the map of whale watching distribution will change as more companies open or increase operations.

It was asked if this work had been compared to a study using Marine Communications and Traffic Services (MCTS) data to track vessels (possibly Lachmuth study from 10 years ago). Ten years ago a graduate student developed maps of vessel exhaust, which might be used to compare the increase over 10 years. A participant offered to send this paper to the authors.

The model showed that vessel presence/noise by itself didn't explain the observed population dynamics in the killer whale system, even when including the high thresholds.

Participants were keen to see how the model would work with updated vessel presence/noise information.

A participant noted that background noise in northern areas has been historically higher than in the south due to storms, wind, and wave actions, so the impact of anthropogenic noise could be expected to be lower there. Svein Vagle (Fisheries and Oceans Canada, Institute of Ocean Sciences) should have data from research this summer that could clarify this trend.

Clarification was requested about the methods used to estimate the five times less magnitude of vessel traffic in the north compared to south. Are the differences in movement of vessel traffic between north and south included? Northern traffic hugs the coast and traffic in the south is concentrated in the Strait of Georgia. The authors responded that MCTS data were used to reach this number, looking at the overlap shown on the range map at the start of the working paper. This was necessarily inexact since the range map is an approximation. The cut-offs for NRKW range were calling-in points 7 and 29, and this will be clarified in the text. A participant added that nearshore traffic was higher in the north than south, where traffic goes offshore. The authors reiterated that this was estimated using call in points, and that it was an estimate and not an absolute value. A participant added that higher frequencies and impacts of human noise were expected to be less in the north but NRKWs also have the advantage that they live in a place that was always noisy, unlike SRKW which was less noisy historically. Data from acoustic moorings should be available soon to provide more insights.

More explanation for the vessel presence/noise disturbance section was requested, with the description of commercial vessel types, and clarification about how the five times higher in the south number was reached. The paper should include MCTS data, sources, and what went into the five times estimate. MCTS call-ins are only required for some vessels, and the requirements could be noted in text since not all vessels are captured. Automatic Identification System class A (AIS-A) data were used. MCTS data does not include whale watching boats in Canada, usually. USA whale watching requires AIS-A. Canada will soon require larger whale watching boats to have AIS. Clarification about MCTS data versus AIS data were requested, including the limitations and scope of the data from MCTS (which vessel types), and it was noted that the MCTS threshold may be higher. It is important to know if the MCTS data included were Class A AIS. It was noted that the amount of vessels with AIS class B has been increasing, even in recreational vessels, due to the affordability of units.

One of the participants disagreed with Lacy's estimates on how sound affects RKW behaviour (25% feeding reduction in presence of a vessel, with RKWs in presence of a vessel 85% of the time, and feeding around vessels 78% of the time), but noted that there currently isn't anything better. In three years there should be better information available from ongoing research.

Vessel presence/noise disturbance could affect breeding, stress responses, etc. whereas this section only addressed prey availability. There may be other vessel presence/noise disturbance pathways that could lead to population parameter impacts. The authors were asked to highlight that these alternate pathways may have a contribution. It was suggested that a subsection on underlying assumptions could be included at the end of each threat section.

Though the participants understood that this assessment could not achieve the level of detail needed to assess all possible noise impacts, it was emphasised that not all underwater noise generates similar types of disturbance responses, depending on the exposure context and hearing abilities of different marine biota. The document could discuss the frequencies in which these killer whales communicate and anthropogenic activities whose noise overlaps that range. The text should be more descriptive of the noise qualities (amplitude, frequency, duty cycle etc.), particularly for noise that is relevant to the animals.

Types of vessels were not mentioned in the working paper, although different types of vessels feature different noise characteristics. The authors could delve deeper into these differences in the future, but were not able to for this assessment. For example, the different vessel types could be disaggregated in the analyses. Large ships are the primary noise issue in the Juan de Fuca strait, while smaller boats are more common in the Gulf islands.

In section 3.3.6, it would be helpful to clarify that for NRKW critical habitat areas vessel presence may be a stronger issue that currently described, and that while the NRKW arrange throughout a larger area than SRKW, some areas of significance might not be represented in the currently designated core areas.

A participant challenged that given the range of data examined for prey (1979-2017), one year of marine traffic data might not be sufficient to understand its potential effects. The authors explained that this was not meant to be a time series, simply comparative between the north and south, and that the recent vessel traffic pattern was consistent according to the MCTS. While only one year of vessel traffic was used, there was low inter-annual variability. Any changes in the vessel activity patterns over time were not captured, as only the comparison between shipping traffic in the north and south is input into the model.

It was noted that it is not currently known if RKWs feed at night. There is much less whale watching at night, which could reduce disturbance from vessels while feeding. However a study of this is in progress, being investigated using digital acoustic recording tags.

A recommendation was that this assessment could be an iterative process. Since there is so much research going on at present, this framework could be revisited in three to five years to update the analysis.

Disturbance (vessel strike)

The physical disturbance threat in the PVA model focused on vessel strikes. There was not much data available for killer whales, and what was found was included in Table 4 (Timeline of known incidents of vessel strikes causing injury in NRKW and SRKW) and Table 5 (Timeline of reported mortalities resulting from ship strikes in NRKW and SRKW) in the working paper. Participants asked for the rate of vessel strikes (10 percent probability of whale strike annually, i.e., approximately one animal dies every 10 years) to be clarified in the research document. A participant asked if it made sense for both RKW populations to be modelled using the same rate, given that there were five times as many vessels in the southern range, not even including the whale watching vessels that are more common in the southern range. The authors responded that Patrick O'Hara and Rob Williams analysed the ship strike risk and found to be higher in the southern range (9.5% for SRKW and 7.1% for NRKW), but the authors used the data available at the time. However, this was tested in the sensitivity analysis and the strike threat didn't have a large impact even when varying ship strike probabilities. The sensitivity testing was done from 5% to 50%, and a participant suggested that the sensitivity testing could also look at a further reduced probability of strikes.

One participant mentioned that rate of vessel strike was vastly overestimated, however, mortality due to vessel strike was a very rare event in the model. Another participant countered this, noting that the two SRKW deaths in the last seven to eight years due to vessel strikes show that they are vulnerable to this threat.

There was a discussion about whether there were other proximate causes that could lead to a strike. There could be differences in vulnerability of whales to vessel strikes, such as slower, bigger whales being more likely to be hit. Anecdotally, one participant shared that a BC Ferries employee observed that with noisy ferries the killer whales were seen further away; and now with quieter ferries, whales have been seen much closer and this could lead to increased ship strike risk.

Contaminants

In the PVA model, the impact of contaminants on killer whale vital rates only included PCBs. Please refer to page 4 for an explanation as to why PCBs were the only contaminants included in the study. PCBs were modelled using an accumulation-depuration model from Hall et al. (2018), which was itself based on a land mammal (mink). One model scenario used a threshold based on prey abundance because contaminants are stored in killer whale body fat and are only metabolised when there is insufficient prey available to meet metabolic needs.

The dose response curve from lab experiments on mink and was used because experiments on RKWs to define a specific dose response cannot be done (Hall et al. 2018).

There was a discussion about how the contaminants component of the model only links PCBs to calf mortality, but PCBs can also affect adults. This hasn't been quantified yet so could not be included in the PVA model.

Reasons for the differences in PCB levels between NRKWs and SRKWs were discussed (NRKWs tend to have lower PCB levels than SRKWs), and it was suggested that this could be because of PCB offloading from females to calves since NRKWs have higher fecundity. However, this wouldn't explain the lower PCB concentration in male NRKWs compared to male SRKWs. Other influences may include differences in PCB loads in the environment and in prey, and research is ongoing examining the contaminant load in various Chinook stocks.

It was noted that the contaminant loads in transient killer whales are higher than in RKW, but they aren't experiencing the same population declines. This may be due to transients having high prey abundance, and so are not metabolising their contaminated blubber and releasing stored contaminants.

Cumulative effects

The authors clarified that the main models drew annual salmon abundance data from a normal distribution, but at random. The models that used actual annual salmon numbers, termed “real salmon index” models, more closely matched the observed RKW abundance. These used the ocean abundance index as well, but without drawing from a random distribution.

Figure 24 (Mean model simulations of the cumulative effects scenario with modelled Chinook abundance) showed a good fit for the NRKW population, while Figure 25 (Mean model simulations of the cumulative effects scenario with historical Chinook index values) showed a good fit for the SRKW population. A participant wanted to know if there was any way to select indices and get good fit for each using different approaches. The authors responded that the range was still within the bounds of uncertainty, and there could be many reasons why the fits are different.

Attention was drawn to the prey scenario figure from the presentation, which illustrated that prey alone was a good match for the observed NRKW population whereas for SRKW other factors may be important drivers as well. Recent historic Chinook abundance in the south was lower than the historic abundance in the north, and NRKW had access to those stocks at a higher abundance because those stocks are depleted as they migrate south.

The authors explained that the solid line on the graph was the mean of the 10,000 runs, and the reported error term was the standard deviation. A participant wanted to know if it were possible to use the confidence intervals or quantiles of the realised runs instead, since standard deviation makes the assumption that the relationship is based on a normal distribution.

Clarification was requested for Figure 21 (Model simulations of PCB impacts on RKWs), which includes PCB concentrations taken from whales in both Canada and the USA. A participant asked for the authors to make the source of the data clear, and acknowledge all authors in the text and not just the appendix.

DAY 2

CHECK IN FROM DAY 1

Before continuing with the PVA presentation, the Chair asked the group to identify key issues for the day 2 discussion, check-in on the process, and confirm topics that needed to be addressed.

More clarifications and explanations were suggested for the research document, with some changes in wording, and clarification of the linkages in the PoE.

Participants agreed that the killer whale vessel strike rate as a rare event, with an average of one animal affected every 10 years in the model (though at shorter scales it may seem higher), was acceptable and captures observed data.

The Chair asked if there were any changes or comments that were missed in the summary. A participant drew attention to Figure 2 (Resident Killer Whale population time series) where the population appeared fairly stable over time. The contributions of the three pods to the total numbers over time were lost. L pod was driving the concerns about the downturn in total SRKW numbers and they spend a lot of time outside of the Salish Sea on the west coast of the USA and return to Salish Sea with suboptimal body condition. If this is the case, this is beyond

Canada's area of influence, and it was suggested that it would be important to acknowledge this. The authors responded that the Vortex model does incorporate pod information and it can be an output, but that for now the threats are assumed to apply equally to all pods. Foraging methods and areas are not captured, however the assumption is that they are similar between pods. The authors will acknowledge the different spatial distribution of different pods as a source of uncertainty in the research document.

A participant was concerned that this process may be premature, since there is much that we don't know about many of the relationships for model parameters, especially for contaminants and vessel presence/noise. Did the model match the observed by chance? Is it right for the wrong reasons? Could we mislead management based on this model? The participant stressed the need to be mindful about how the linkages to population consequences are presented. The authors agreed and highlighted that there wasn't a way to look at combined impacts of threats on the populations before but this needs to be an example of adaptive management. This analysis should be revisited when more information becomes available to update the source data and re-examine uncertainties for the model. This work was about creating a useful framework and recognising that data were limited, so others can input new data as it becomes available. This was a starting point for the model, not the end. Another participant remarked that this was a really good first step for looking at cumulative effects. It does need to be very clear what the results of the CSAS represent and what they do not. The group knew there would be data gaps, but this process illustrates that this is a framework that can work. This framework can be revisited when new evidence for how to quantify relationships becomes available, not just when new data is available. Beyond that, data layers can also be added to the model, including spatially explicit ones, e.g., if there is evidence that matrilines are exposed to threats in X place for Y amount of time.

It was discussed that there is a step between building the model and what can be done with it, i.e., the layout of the model and structure, and the inputs to the model and how confident we are about those data. If there is an input parameter that the model suggests isn't as important as others, should we continue to investigate that parameter? What can managers be less concerned about? There are many uncertainties and assumptions in the model that can be tested to be confident in its application. Additional information was requested for the research document on how the model can be improved in the future and which aspects could be expanded, e.g., new relationships, interaction quantifications, new data, etc.

There was a quick revisit of the gunshot wound discussion. While there are limited data, the data for the NRKW population did suggest that suspicious injuries were largely in the first half of the time series, with only one in the last 10 years. Two thirds of the injuries were prior to 2000.

Before continuing with the PVA presentation and discussion, the group discussed their thoughts about the PVA presentation so far. The model fit the observed SRKW population data much better when actual salmon indices were used compared to sampling from randomly from a uniform or a normal distribution. If there were a salmon model that would give trajectories that could represent the size, age structure, and amount of autocorrelation for salmon populations, that could be fed into the model for better projections. There is a coastwide Chinook model by the Pacific Salmon Commission, but it's set up for four-year projections, so it would need modification to integrate it into the PVA. However, this could be a suggestion for future work. The authors responded that if the mean correlation in the time series was known, the model could draw random values that have a correlation structure and use this for the projections. The authors wanted to return to this point after discussing the projections.

The quantification of the vessel presence/noise threat was also revisited, due to concerns about having only one year of data input into the calculation for the difference between the northern and southern regions. The authors responded that they were only able to get one or two years of data even after trying to obtain data from previous studies. The authors could only get commercial vessel information for a few years and there is no recreational vessel historical information. This was a good start that we can work on refining further. It was asked if historic shipping data could be tied to past studies on vessel traffic, including a 2014 study for the expansion of Roberts Bank, and Patrick O'Hara's study from 10 years ago that examined AIS data. Another suggestion was the reconstruction of large vessel data from shipping information. From the mid-1970s to early 1980s, there was a lot of commercial fishing near to the killer whales. When recording underwater sounds at the time it was nearly impossible to hear whale sounds. The authors responded that in the model, a 16% impact on prey in the south and a 3% impact for the north were used as fixed numbers. The one year of data were only used to calculate the difference in vessel presence/noise between the north and south, and it doesn't change with time or season. A question was asked about vessel types and how type affects the noise produced, and it was noted that there wasn't data available about how vessel type changes noise, but that the list of ships from the MCTS data can be included in the research document. A participant asked if there was existing information that could be used to introduce this uncertainty about noise effects into Vortex. It was suggested that the fixed 16% could be changed to a variable that changes in time using the curve of increased shipping over time. Another suggestion was to include stochasticity to the vessel presence/noise value, which could be a good compromise to address this. The authors suggested that the section of the presentation on sensitivity analyses may address this concern.

PRESENTATION: POPULATION VIABILITY ANALYSIS CONTINUED

Presenter: Cathryn Clarke Murray

More detail was provided by Cathryn Clarke Murray about the second step of the cumulative effects assessment, the population viability analysis, moving into using the cumulative effects PVA model to predict population trajectories. Dr. Clarke Murray finished her presentation, describing the cumulative effects scenarios, sensitivity analyses, model projections, and the uncertainties associated with the assessment.

Dr. Clarke Murray presented recently updated work using the cumulative effects PVA model to project population trajectories for NRKW and SKRW into the future (10,000 model simulations), based on recent threat levels, best available knowledge, and the assumption that no future mitigation will take place. The model outputs indicated that the average modelled NRKW population trajectory increased to the carrying capacity set in the model within 25 years. In contrast, the average modelled SRKW population trajectory declined, with a 26% probability of population extinction (defined in the model as only one sex remaining), and in those projections extinction was estimated to occur after 75-97 years.

DISCUSSION

Cumulative effects

It was noted that the point of this assessment was to create a cumulative effects model that the group could accept how it does and does not represent the available knowledge and data.

The method for the sensitivity analyses in Vortex was further explained. Sensitivity analyses on the model can be run to examine how varying each of the parameters affects the model simulation results. For this analysis, three parameters were held at their base levels while the fourth was varied across a large range of values, and this was done for each parameter. One participant suggested that it could be done by holding the three parameters at minimum and maximum values to look at the interactions. This may capture how the models interact in different ways. The authors explained that while a single parameter was held constant at a single value, the other parameters used the full model structure, which included stochasticity. It is possible to allow every combination to be tested in Vortex, but this needs weeks of computer running time and statistical analysis. The current version of the sensitivity analysis required an entire day to run.

It was noted that Figure 27 (Sensitivity of SRKW projected population size in the cumulative effects scenario to changes in the threat parameters) was a bit difficult to read, and a different colour was requested for the error bar.

The authors explained that prey abundance adjusted how much vessel presence/noise affected the model: when prey was abundant, vessel presence/noise had little effect, however when prey was scarce, vessel presence/noise had a large effect. It was requested that the authors make it clear that vessel presence/noise was assumed to be a driver of prey availability. A participant suggested that it could be modelled without vessel presence/noise to look at whether vessel presence/noise was relevant, but the authors replied that vessel presence/noise was part of the system and played a role.

A participant asked why the model only included females in the PCB sensitivity analysis. The authors explained that this was because, in the model, PCB contamination affected the first year of calf mortality, which arose from the females' contaminant load at time of the calf's birth; male contaminant loads do not affect calf mortality. Contamination in the males was in the model itself, accumulating through time, and was checked that it was matching field data, but does not influence this impact in the model. A participant described J18, who was 18 years old but had not developed testes yet (this is unusual), and who had high PCB concentration. This was reported by DFO from a necropsy and could be evidence of a contaminant effect in males. It was recommended that this be included in the research document as an uncertainty. A participant asked if Vortex would be able to deal with different sex ratios if more data becomes available in the future that would allow quantification of the effect of PCBs on males. The authors responded that currently the model uses a 50/50 sex ratio, but it can be changed in Vortex, along with differential mortality for males or females.

There was a discussion about the projections of the model. These projections are presented as examples of how the model could be used. The client mentioned that they would use this for projecting into the future to look at management and mitigation options. It would be useful for the SARA program to use this to see where they can potentially make a difference in the population trajectories. A question about a small change in the modelled population size in 2040 was explained as a generation effect since many whales had an assigned age in the genealogy data of around the same age, and those whales would have reached the maximum age at that point and so removed from the model.

One of the authors suggested replacing the original projection that shows an increase of SRKWs based on non-decreasing Chinook, with the updated projection that used recent Chinook levels (decreasing), since this was a more realistic scenario. A participant agreed and noted that even using an average over the last 10 years of Chinook data would be an optimistic input because Chinook salmon stocks have been declining rapidly, with many Chinook stocks in trouble in the last 10 years. A participant agreed with the proposal to replace the Chinook projection with an updated one, but that instead of calling it "low Chinook", call it "recent Chinook."

There was a question about why the error bars didn't get larger over time in the effect of prey on SRKW graph. The authors explained that they got smaller with time because more of the simulations showed the SRKW population going extinct. The error bars got larger for NRKWs over time, though they were limited by the carrying capacity.

Based on the recent/low Chinook scenario, across the 10,000 simulations, 26% of simulations had SRKWs go extinct within 100 years with the mean time to extinction 85.8 years +/- 11 years. The group asked that this be included in the research document. A participant asked if the conclusion to draw from this was that if Chinook abundance does not increase, that SRKW will go extinct. The authors responded that this model also included interactions such as vessel presence/noise, which reduced prey availability. A participant asked if it were possible to project the model with vessel presence/noise removed to see whether Chinook alone will cause extinction. The explanation was that the amount of Chinook needed to keep SRKW population from extinction would be lower with vessel presence/noise removed. A participant noted that since shipping was likely to be increasing, not decreasing, it might be worth looking at a worst case scenario of increased shipping vessel presence/noise. The authors responded that this was out of scope for this study, but the model could be used for this in the future. The model was not parameterized to allow increased Chinook abundance into the future, but rather it was projecting it based on the long-term mean and based on the more recent mean. This model did not make a projection of what Chinook abundance will be in the future, just projected the current status forward.

It was suggested that the paper would benefit from a discussion on the difference in results between this working paper and other studies, elaborating why authors think the discrepancy exists and what evidence there was that this was an improvement over past studies. In this model, the definition of extinction was that only one sex remained. How extinction was defined was important to clarify. In Vortex the standard was when only one sex remained, but quasi-extinction (a level at which the number of adults may be insufficient to assure survival of the species) could also be used if there was enough information on what this should be. Extinction might be difficult to define in this population because the complex matrilines may lead to dead ends even if both sexes were represented; a participant wanted to know if this could be modelled in Vortex. An author responded that it could be done by specifying that a lack of reproductive-aged females in a pod was extinction. Acknowledging that deciding what this value is would be difficult, a participant asked if it were possible to include the likelihood of the population dropping to a threshold size from where they could not recover as being functionally extinct. The client mentioned that the definition of extinction used in the assessment needed to be clear, and how it compared to the definition used by SARA, and they requested that the specific detail on when extinction occurs (the range based on the runs) be included in the research document.

PRESENTATION OF WRITTEN REVIEWS: POPULATION VIABILITY ANALYSIS

Miriam O

- Nothing more to add; points already addressed.

Misty MacDuffee

- Nothing more to add; points already addressed.

DISCUSSION OF THE TERMS OF REFERENCE

The Terms of Reference for this meeting (Appendix A) were reviewed, and there was a discussion about whether the group agreed that the following objectives had been met.

Terms of reference point 1

Minor revisions and changes to the working paper were needed, but once completed, it will become a research document. There was a four month window for the completion of this, and the group will get a chance to make sure the changes were made appropriately. The Chair confirmed that the group agreed with this motion.

Terms of reference point 2

The Chair asked the group if they could apply the tool. One participant responded that it was an informative tool, not a decision tool. The tool was very applicable in this case since it was data-rich situation. The tool was especially useful for finding a mix of variables that was able to match the real population curve. The participant was looking forward to using this in the future. A PVA was used for this assessment because this situation was data rich, but a Population Consequences of Disturbance (PCoD) model or risk matrix could instead be used to look at risk likelihood versus severity of impacts as the final step. A participant remarked that this assessment was a great step in bringing greater certainty and clarity to the known threats to RKWs, and a great advancement to the Lacy et al. paper. It has taken a lot and has advanced the work from what was done before.

A participant had an issue with the assumptions for vessel presence/noise disturbance for RKWs. Figure 1 (General ranges of Northern Resident and Southern Resident Killer whales) in the working paper showed a portion of the distribution of SRKW from Central California to BC, and the participant disagreed with the assumption that a PoE conceptual model of stressors from only a small portion of this range (Salish Sea) could lead to valid PVA outputs for these wider ranging populations. The participant stated that each individual SRKW was only in the Salish Sea a few days a year, with differential visitation by pods. The same participant noted that they had an issue with the extrapolation of vessel presence/noise stressor parameters from a small area of the Salish Sea to their entire range. The authors responded that those limitations were explained and clarified in the text. They offered to be clearer in the research document since the evidence in the model used a limited spatial scope, based on research happening in the Salish Sea and in the southern range of the NRKWs. Most observations happened in the summer or early fall. The authors will add that these data were used but that it was limited in spatial and temporal scope. The authors agreed to increase the clarification in the documents on the assumptions of the model inputs, with respect to the extrapolation of threats from the Salish Sea, or in a limited time period to the full range observed in the population. A participant reiterated that matriline data were not included, since if the matrilines were not in proximity to one another, breeding didn’t happen. The lack of reproductive females, however, was taken into account in the model. In theory the model could take into account differential pod/matriline exposure to spatially and temporally explicit information, but there would still be gaps in winter and other times for which there was no observation data. Applying Salish Sea threats to the rest of time and space was a conservative estimate, since threats outside of that time and space may differ. It was a big assumption, but it can hopefully be improved and refined over time.

Another participant concern was that while the PVA does incorporate potential effects of pollution and prey resources, if management actions to increase availability of salmon are not cost-effective, it might not work. However, management choices based on the model are issues that will come up, but they were not in the scope of this science peer review. It was noted that the broader application of threats with less specificity could be deemed to be a precautionary approach, as threat information/exposure was not known consistently.

There was a question about how the model dealt with the NRKW and SRKW populations more or less independently, but the NRKW get to feed on Chinook prior to SRKW when they return, and so wanted know if the model accounted for increased predation on that salmon stocks if there was an increase in the abundance of NRKWs. While the NRKWs and SRKWs do not feed on the exact same stocks of salmon, the models do not currently take into account the possibility of competition. The authors will acknowledge this in the research document as an uncertainty. Interaction with transients killer whales and pinnipeds that feed on Chinook, were also not included in the model because cumulative effects on salmon were not taken into account.

A participant questioned whether the RKW projections could be too far into the future when there are so many parameters that are changing. It was noted that the document needed to be explicit that these projections were under current input parameter scenarios, not with threats or stressors changing. The projections were useful for looking where the populations are heading based on current conditions, rather than looking at where we'll be in 100 years. The authors suggested that they could replace absolute numbers (e.g., 65 animals in x years) of animals in the figure with another representation, such as effect size or as relative projections, in order to evaluate options.

The Chair summarised these discussions, and noted that the tool could be used, but has limitations.

Next, the Chair wanted to have a discussion on the limitations of the assessment. The group asked that the key limitations for the model be summarised in the documents. It was also recommended to have the assumptions foremost in the relevant section in the research document, with the key assumptions identified in the science advisory report. However, it was noted that the document should not become merely a series of listed assumptions. It was suggested as a general limitation/consideration that with any model of this type there will be tension between making it more specific, detailed, and including many parameters, but getting more and more uncertainty in the variables and output. It may seem desirable to add in all the threats we have data for, but the more variables we add, the more uncertainty there will be in the model outputs. In summary, the danger of adding complexity was that it could make the model respond unexpectedly, and make seemingly reasonable projections for the wrong reasons.

It was noted that for the identified challenges with data and data gaps, there were programs underway to provide new data streams. A participant asked what it would take to operationalise the existing model so that it could be run on a yearly basis, and with significantly reduced Science involvement. The authors responded that the team learned quickly how to run the model and that they were able to refine and extend it to include new threats and new data. It takes some expertise, but that exists within DFO.

Next, it was asked if the model should be operationalised by the client, considering that the clients have some of the same training as the authors. Vortex is a tool that is relatively user friendly, and therefore the model could be transferred to the trained clients to run projections. Changing the model structure or adding statistical relationships would probably be the responsibility of DFO Science, but Vortex is a user-friendly tool otherwise. A participant noted that we need to be careful that the outputs of the model are not being misinterpreted. Just because the client can run the model doesn't mean they understand the assumptions or the outputs, so there a role for Science will remain. Another participant countered that if the assumptions were listed in the research document and science advisory report, it should make it clear for users. Interpretation of outputs was more complex than simply running the model. Science would have a significant role in utilising this component. Until the model becomes more robust it should remain a Science tool, however collaboration between all these groups is important. The client noted that they were willing to work with the model, but would like science input – SARA does not make decisions alone. The implementation of recovery would not happen based on SARA alone implementing the model, it happens in conjunction with DFO colleagues, academia, etc. to make sure changes support the recovery target. They encouraged keeping Science involved going forward. Structured decision-making, and how the PVA usage and updating would fit within this, will be a cooperative effort of Science, SARA, management, etc. The cumulative effects assessment tool could be used to provide some evidence for the proposed decisions that may be made by SARA, based on a request to Science to apply the tool to specific scenarios that needed to be tested.

The Chair asked if there was agreement that the tool was applicable. The participants agreed that is was applicable and that it should remain a Science tool to continue to be developed to full potency. The Chair queried if there was consensus on this. An author believed that the client (SARA team) understood how the model was being used because they have done the training, and that the understanding was that SARA may ask Science for model scenarios and runs for exploring different options in the future. Two of the authors were hired as cumulative effects experts with the idea was that they would support and develop tools for cumulative effects assessment, so there was potential for them to keep working on this particular framework.

The consensus was that the model was applicable, given limitations, and that the tool could be applied to other data. One participant mentioned interest in applying this model to beluga whales. It was noted that it seemed that the tool would be useful for other species, but data streams would be different. As is, it was good for species such as stellar sea lions or harbour seals in British Columbia. One observation was that although the Resident Killer Whales are one of the most data-rich species that DFO manages, there were still many information gaps. There is potentially a use for the model in data-limited applications. When there is less data on how threats influence population dynamics, the model could be used as a template for testing ideas, e.g., what if a factor becomes worse? Simple relationships could be used as placeholders. The tool could be used to identify what is not known and help guide research. The tool could be used in different ways based on the amount of data available. In some cases it is a good tool for science, with more data it can be used for management, but there needs to be a judgement call on the value of the model in each situation. The model works best when used in collaboration between Science, management, and clients to have open conversations over issues and application.

The Chair asked if the group agreed that Terms of Reference points 1 and 2 had been met, and no one voiced disagreement.

Terms of reference point 3

This section was discussed during the presentations, and the group agreed that that the preceding discussions were sufficient to address this.

SCIENCE ADVISORY REPORT AND MEETING CONCLUSION

All participants and authors discussed the Science Advisory Report (SAR), and agreed to the content of the summary points. As the Chair explained, the SAR should convey the essence of the meeting and needed to include sources of uncertainty, results and conclusions of the CSAS review, and any additional science advice to management.

While the SAR was written, there was a desire for the requests from SARA to be kept clear, with what the assessment was able to capture noted separately. It was also requested that the SAR include a clear description of the total number of identified linkages that were sensible for the framework (not just the brainstormed number), and which linkages could not be used because of data or knowledge limitations (grey-coloured links).

A participant asked if there was a model that looked only at real prey data, not including the other threats. The response was that they wouldn't want to do a whole report based only on modelling prey because it eliminates the cumulative aspect of the study. It was asked if it were possible to include a line on Figure 23 (Mean model simulations of single threat scenarios and the cumulative effects model scenario) for the real prey data. However, the authors responded that of the individual models, prey based on historic Chinook salmon abundance was the best, but that it still did not do as well as the cumulative effects model.

There was a discussion on how a cumulative effects assessment differs from a multivariate statistical analysis. Multivariate statistical analysis would require the full time series from all the threats, which was not available at the time, and would only show which was the most explanatory variable. The cumulative effects framework was not a single statistical model or test and it can be implemented using other models. The framework included the scoping, the PoE, and the way inputs were tested and framed. The cumulative effects framework was not a specific type of model. It does not have to incorporate a PVA, but needed only the framework structure to be a cumulative effects assessment. To do a correlative analysis, you would need to be able to test a full time series. To do a cumulative effects assessment you also need look at interactions, and it is difficult to do both at once. It was noted that the authors need to be careful to be consistent with the expressions “cumulative effects assessment,” “cumulative effects framework,” and “cumulative effects model”.

There was a discussion as to which figures to include in the SAR; the group recommended that the SAR include the framework figure, the PoE linkages, and the cumulative effects model and observed trends. The group also asked if it was possible to include the projection figures, specifically the modelled population decline over time. One participant suggested that the projection be limited to 10 years, but the authors' response was that they wanted to include at least one generation time for killer whales, because while the standard is three generations, that was not set with killer whales in mind.

Sources of uncertainty to be included in the SAR were the assumption that threats affected both NRKW and SRKW populations in the same way, plus one bullet per threat for data and knowledge sources that were missing.

It was noted that the conclusions and advice could draw from those stated in the working paper.

Another consideration that was out of scope, but needed to be considered, was adaptive management. The model would benefit from iterative refinement when more data becomes available and understanding improves.

The Chair asked if the group accepted the working paper, and the group agreed. The group was also asked if everyone agreed with ending the meeting a day early since discussions were ahead of schedule, and no one disagreed with the decision.

The Chair ended the meeting by surveying the group on what they liked about the meeting and what they would suggest changing. The group enjoyed that the process was greatly collaborative and very constructive. One participant commented that this was the most helpful group of people that had ever been in a CSAS room. Another noted that the flexibility of the authors was appreciated – they were willing to change figures based on the discussion. The Chair's timeliness and strong facilitation was appreciated as well. One participant thanked the authors for the working paper, and noted that the product came from a lot of work and many discussions, and wanted to commend everyone who participated. In terms of changes to the process, one recommendation was that the working paper should be sent out for review further in advance of the meeting. A participant noted that there needed to be a discussion on peer review approaches for this type of paper, and thanked the authors for dealing with this process. Another participant remarked that it would have been helpful to have received by email the new materials that the authors developed (noting that all documents seen in room were also shared to the virtual group) and would like the presentations distributed. A final note was that it would be beneficial to have more consultation before and during the development of the model, and the authors agreed.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the invaluable contributions of our meeting Chair, Gilles Olivier, our three formal reviewers, Miriam O, Misty MacDuffee, and Paul Paquet, our rapporteur, Jocelyn Nelson, as well as each of the meeting participants. These people spent significant time reviewing the working paper, participating in the regional peer review process, and/or working with the authors to produce a robust final product.

REFERENCES CITED

Ford, J. K., Ellis, G. M., Olesiuk, P. F., & Balcomb, K. C. 2009. Linking killer whale survival and prey abundance: food limitation in the oceans' apex predator? Biology Letters, 6(1): 139-142.

Gobas, F., and Ross, P.S. 2017. Health risk-based evaluation of emerging pollutants in Killer whales (*Orcinus orca*): priority setting in support of recovery. Unpublished research report.

Hall, A.J., McConnell, B.J., Schwacke, L.H., Ylitalo, G.M., Williams, R., and Rowles, T.K. 2018. Predicting the effects of polychlorinated biphenyls on cetacean populations through impacts on immunity and calf survival. Environmental Pollution 233: 407-418.

Lacy, R.C., Williams, R., Ashe, E., Balcomb III, K.C., Brent, L.J.N., Clark, C.W., Croft, D.P., Giles, D.A., MacDuffee, M., and Paquet, P.C. 2017. Evaluating anthropogenic threats to endangered killer whales to inform effective recovery plans. Scientific Reports 7(1):14119.

Van Zandvoort, A. 2019. Review of contaminants of concern to Southern Resident Killer Whales and/or Chinook salmon. An evergreen report prepared for Environment and Climate Change Canada. Last modified April 4, 2019.

Vélez-Espino L.A., Ford, J.K., Araujo, H.A., Ellis, G., Parken, C.K. and Sharma, R., 2014. Relative importance of Chinook salmon abundance on Resident Killer Whale population growth and viability. Aquatic Conservation: Marine and Freshwater Ecosystems, 25(6): 756-780.

Ward, E.J., Holmes, E.E. and Balcomb, K.C., 2009. Quantifying the effects of prey abundance on killer whale reproduction. Journal of Applied Ecology, 46(3): 632-640.

APPENDIX A: TERMS OF REFERENCE

Cumulative Effects Assessment for Northern and Southern Resident Killer Whale Populations in the Northeast Pacific

Regional Peer Review Process – Pacific Region

March 12-13, 2019
Nanaimo, British Columbia

Chairperson: Gilles Olivier

Context

Under the Species at Risk Act (SARA), the federal government has a commitment to prevent wildlife species from being extirpated or becoming extinct, to provide for the recovery of wildlife species that are extirpated, endangered or threatened as a result of human activity and to manage species of special concern to prevent them from becoming endangered or threatened. The Minister of Fisheries and Oceans Canada is the competent minister for the recovery of aquatic species at risk.

Three distinct ecotypes of killer whales (*Orcinus orca*) inhabit the waters off the Canadian Pacific coast: offshore, transient (or Bigg's), and resident. The resident fish-eating ecotype is further divided into the Northern and Southern Resident Killer Whale populations (NRKW and SRKW). These two populations were listed as Threatened (NRKW) and Endangered (SRKW) respectively under the SARA in 2003. A cumulative effects assessment (CEA) is required in order to address recovery measure 11 in the SARA Action Plan for these populations (DFO 2017a). This recovery measure states "Assess cumulative effects of potential anthropogenic impacts on Resident Killer Whales using an appropriate impact assessment framework for aquatic species". Cumulative effects are the combined, incremental impacts that threats/stressors from multiple human activities can have on an individuals, populations, communities and ecosystems through space and time. The three primary threats to NRKW and SRKW have been identified as:

1. reduced prey availability,
2. acoustic and physical disturbance, and
3. environmental contaminants (DFO 2017a).

Fisheries and Oceans Canada (DFO) Species at Risk Program has requested that Science Branch provide an assessment of the cumulative effects of the three primary anthropogenic threats on NRKW and SRKW populations. To date, most research on threats to killer whales has studied these threats in isolation, for instance focusing solely on acoustic disturbance or availability of prey. Cumulative effects assessments evaluate the effects of multiple threats by transforming impacts into a single currency or metric, thereby allowing for comparisons among threats and their combined impact on long-term population viability. In collaboration with U.S. and Canadian marine mammal and science experts, this study will update and advance upon previous methods of analysing the three primary threats to Resident Killer Whales (Lacy et al. 2017). For example, the current study will evaluate the threat of acoustic disturbance posed by both commercial as well as recreational vessels and include updated salmon abundance data on the specific stocks which NRKW and SRKW prey upon. New contaminants research, such as that from Simon Fraser University and Washington State Department of Fish and Wildlife, will be considered to improve the treatment of contaminants in the model.

The species-focused cumulative effects assessment will be composed of two phases. The first phase is the development of a Pathways of Effects (PoE) conceptual model describing the impacts of threats on the mortality and fecundity of the species. The second phase involves the parameterization of the impacts (e.g. effect size for each threat and its impact on vital rates) and conducting a quantitative population viability analysis (PVA) to assess the cumulative effects. This project will build upon the methods and results of previous work (Taylor & Plater, 2001; Ward et al 2009; Velez-Espino et al 2014; Williams et al 2017; Lacy et al. 2017) and include recent research advances. The effects of low probability high impact events, such as catastrophic oil spills, are out of scope for this assessment. In addition, potential mitigation measures and management actions will not be evaluated. More information on ongoing initiatives to help recover killer whales can be found on the DFO website (DFO 2019).

The cumulative effects assessment arising from this Canadian Science Advisory Secretariat (CSAS) Regional Peer Review (RPR) further expands the cumulative effects tools available for DFO, and the advice may be used to inform the SARA program in its effort towards survival and recovery of these two populations. This study provides an opportunity to incorporate best available science into a single assessment that includes all three threats, the interactions between them, and the resulting long-term impacts on the population.

Objectives

The following working paper will be reviewed and provide the basis for discussion and advice on the specific objectives outlined below. The structure of the pathways of effects model and the data inputs for the quantitative population viability analysis will be reviewed, as recommended in DFO 2012 and undertaken in DFO 2014, and DFO 2017b.

Murray, C., Hannah, L., Locke A. et al. Cumulative Effects Assessment for Northern and Southern Resident Killer Whale Populations in the Northeast Pacific*. CSAP Working Paper 2017SAR01*

The specific objectives of this review are to:

4. Review the individual components of the quantitative analysis for the NRKW and SRKW cumulative effects assessment, namely;
   a. pathways of effects (PoE) conceptual model, and
   b. quantitative population viability analysis (PVA); and
   c. assess the biological relevance and the applicability of each component to adequately reflect current best knowledge regarding threats and the interaction of the three priority threats outlined in the recovery plan.
5. Review the resultant cumulative effects assessment for resident killer whales and provide guidance regarding the utility and applicability of the approach for future applications, including limitations (if any) in its use for other populations and species where there may be data deficiencies.
6. Examine and identify uncertainties in the data and methods and highlight knowledge gaps for future research.

Expected Publications

- Science Advisory Report
- Proceedings
- Research Document

Expected Participation

- Fisheries and Oceans Canada (Species At Risk, Fisheries Protection Program, Oceans, Ecosystems and Oceans Science, and Ecosystems and Fisheries Management)
- Federal Government (Environment and Climate Change Canada, Transport Canada)
- First Nations
- Province of British Columbia
- Academia
- Industry representatives (Shipping industry, Fishing industry, Whale watching industry)
- Environmental non-government organizations

References

DFO. 2012. Risk-based Assessment Framework to Identify Priorities for Ecosystem-based Oceans Management in the Pacific Region. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/044.

DFO. 2014. Pilot application of an ecological risk assessment framework to inform ecosystem-based management in the Pacific North Coast Integrated Management Area. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2014/026.

DFO. 2017a. Action Plan for the Northern and Southern Resident Killer Whale (*Orcinus orca*) in Canada. *Species at Risk Act* Action Plan Series. Fisheries and Oceans Canada, Ottawa. v + 33 pp.

DFO. 2017b. A framework for assessing vulnerability of biological components to ship-source oil spills. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep 2017/032.

DFO 2019. Protecting Canada's Endangered Whales. Last accessed January 14, 2019.

Gobas, F., and Ross, P.S. 2017. Health risk-based evaluation of emerging pollutants in Killer whales (Orcinus orca): priority setting in support of recovery. Unpublished research report.

Hall, A.J., McConnell, B.J., Schwacke, L.H., Ylitalo, G.M., Williams, R., and Rowles, T.K., 2018. Predicting the effects of polychlorinated biphenyls on cetacean populations through impacts on immunity and calf survival. Environmental Pollution 233: 407-418.

Lacy, R.C., Williams, R., Ashe, E., Balcomb III, K.C., Brent, L.J.N., Clark, C.W., Croft, D.P., Giles, D.A., MacDuffee, M., and P.C. Paquet. 2017. Evaluating anthropogenic threats to endangered killer whales to inform effective recovery plans. Scientific Reports 7: 14119(1): 2045-2322pp.

Taylor, M.F.J. and B. Plater. 2001. Population viability analysis for the southern resident population of the killer whale (*Orcinus orca*). Center for Biological Diversity Electronic Resource.

Vélez-Espino, L.A., Ford, J.K., Araujo, H.A., Ellis, G., Parken, C.K. and Sharma, R., 2015. Relative importance of Chinook salmon abundance on resident killer whale population growth and viability. Aquatic Conservation: Marine and Freshwater Ecosystems, 25(6), pp.756-780.

Ward, E.J., Holmes, E.E. and Balcomb, K.C., 2009. Quantifying the effects of prey abundance on killer whale reproduction. Journal of Applied Ecology, 46(3), pp.632-640.

Williams, R., Lacy, R.C., Ashe, E., Hall, A., Lehoux, C., Lesage, V., McQuinn, I. and Pourde, S., 2017. Predicting Responses of St. Lawrence Beluga to Environmental Change and Anthropogenic Threats to Orient Effective Management Actions. Canadian Science Advisory Secretariat.

APPENDIX B: ABSTRACT OF WORKING PAPER

The Northern and Southern Resident Killer Whale populations (NRKW and SRKW) that inhabit the waters of the Canadian Pacific coast are listed as Threatened (NRKW) and Endangered (SRKW) under the Species at Risk Act (SARA). Multiple anthropogenic threats impact these populations and the SARA recovery plan developed for these populations has identified that the assessment of the cumulative effects of these threats is a high priority. The cumulative effects assessment (CEA) comprises two components: a Pathways of Effects (PoE) conceptual model which informs the subsequent Population Viability Model (PVA). The PoE model summarises the current understanding of each priority threat (prey availability, disturbance and contaminants) and describes the structure of the threats in the assessment, including threat interactions and potential impacts to the population parameters (birth and mortality rates). The population viability model utilises the most recent available threat data to quantify the way threats impact population parameters and together with demographic data explore patterns of population growth and decline in different threat scenarios. Individual and cumulative threat scenarios were constructed and tested by comparing their predicted population growth to the observed population growth from 2000 to 2017. Of the various individual and combined threat models tested, the cumulative threats model, which incorporated all priority threats (prey availability, acoustic disturbance, vessel strike, and PCB contamination), predicted demographic rates closest to that observed for both populations. The model predictions closely followed the observed demographics for NRKW and was the closest model to the observed population size for SRKW, but did not include the observed values within the bounds of uncertainty. When historical chinook model data was included in the model prediction, rather than a randomly chosen Chinook index value, the fit improved for SRKW and the uncertainty bounds of both models included the observed values suggesting that the cumulative model is a valid representation of the system. The findings of this cumulative effects assessment strongly support the significant role of prey availability in the population trajectory of these populations. The method outlined in this work illustrates a potentially useful tool for managers and scientists that has been refined and tested with the latest threat information for these populations. It has the potential to be a valuable way for managers to explore potential impacts to population demography under different proposed scenarios of mitigation and management. It is cautioned that as model outputs are only as good as the model inputs, changes in exposure to natural and anthropogenic threats can affect the model’s accuracy. An iterative approach should be used so that model inputs and structure are regularly reviewed and updated to include new information about existing threats and the addition of new threats as knowledge is increased on these populations.

APPENDIX C: AGENDA

Regional Peer Review Meeting (RPR)

Cumulative Effects Assessment for Northern and Southern Resident Killer Whale Populations in the Northeast Pacific

March 12-14, 2019[1]

Nanaimo, BC

Chair: Gilles Olivier

DAY 1 – Tuesday, March 12th

Time	Subject	Presenter
0900	Introductions Review Agenda & Housekeeping CSAS Overview and Procedures	Chair
0915	Review Terms of Reference	Chair
0930	Presentation of Working Paper – Overview	Authors
1000	Overview Written Reviews (if needed)	Chair + Reviewers & Authors
1030	***Break***	
1045	Presentation of Working Paper – Pathways of Effects	Authors
1130	Overview Written Reviews – Pathways of Effects	Chair + Reviewers & Authors
1200	***Lunch Break***	
1300	Presentation of Working Paper – Population Viability Analysis	Authors
1400	Overview Written Reviews – Population Viability Analysis	Chair + Reviewers & Authors
1430	Identification of Key Issues for Group Discussion	RPR Participants
1445	***Break***	
1500	Identification of Key Issues for Group Discussion, cont'd	RPR Participants

[1]This regional peer review was scheduled for three days but concluded in two days. The agenda was followed but the timelines were compressed.

Time	Subject	Presenter
1630	Adjourn for the Day	

DAY 2 – Wednesday, March 13th

Time	Subject	Presenter
0900	Review Agenda & Housekeeping Review Status of Day 1 (*As Necessary)*	Chair
0915	Identification of Key Issues for Group Discussion cont'd	RPR Participants
1030	***Break***	
1045	Identification of Key Issues for Group Discussion cont'd	RPR Participants
12:00	***Lunch Break***	
1300	Discussion & Resolution of Results & Conclusions	RPR Participants
1445	***Break***	
1500	Develop Consensus on Paper Acceptability & Agreed-upon Revisions (TOR objectives)	RPR Participants
1630	Adjourn for the Day	

DAY 3 - Thursday, March 14th

Time	Subject	Presenter
0900	Review Agenda & Housekeeping Review Status of Day 2 (*As Necessary*)	Chair
0915	*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
1030	***Break***	

Time	Subject	Presenter
1045	*Science Advisory Report (SAR) cont'd*	RPR Participants
1200	***Lunch Break***	
1300	Next Steps – Chair to review • SAR review/approval process and timelines • Research Document & Proceedings timelines Other business (*as necessary)*	Chair & Participants
1430	***Adjourn meeting***	

APPENDIX D: WORKING PAPER REVIEWS

REVIEWER: MIRIAM O, FISHERIES AND OCEANS CANADA

General comments

The authors have done a great job with this document. The approach is well researched and thought out, building on existing cumulative effects assessments, and providing good justifications for the approach used. The approach is sound; the paper is thorough, clear and well written and is well supported with citations and justifications.

I focussed on reviewing the overall approach/framework proposed, due to my experience with similar frameworks and pathways of effects development. I do not have expertise on specific methods/models for Population Viability Analysis or the accuracy of population inputs used in these models for Southern and Northern Resident Killer Whales. However, I believe the authors provided a clear description of the PVA methods used in this assessment, and clear justifications for the method and inputs used.

Based on the planned agenda, I have divided my comments into general comments, followed by more specific points on the Pathways of Effects and PVA sections.

Overview

- The authors clearly state the background and purpose of this assessment. It would be helpful to provide information on how this assessment will be used in the management decision making process. However, it isn't clear whether a structured decision making model exists. If one does, inclusion of a description or framework diagram/figure would be very helpful. If a process does not exist, then I highly recommend that one be developed (by both managers and science) so it is clear where this scientific assessment will be used versus other important considerations (i.e. cultural, social, economic) or input from stakeholders. From my experience with providing science advice to management, this a critical step to the success of any departmental initiative or decision requiring integration of input from various groups. Not only does it clearly lay out where roles and responsibilities lie, but it also highlights where different inputs are needed for decision-making (i.e. scientific, socio-cultural, economic), making it much easier to identify and communicate gaps in knowledge and understanding both internally and externally.
- Table 1 on page 3 provides very clear direction from the SARA action plan. Athough this document only deals with RM 11, the other two recovery measures are not independent of RM 11 or each other. I think additional text could be added to this section to discuss the how these RMs may be linked, albeit the focus being on RM 11 (i.e Can proposed approach for RM11 be used to inform the management of fisheries (RM6) and/or be used to assess project impacts?). My recommendation for a structured decision-making model would help address questions around who is addressing Recovery Measures 6 and 17, are there existing processes for how these RMs will be addressed, and what science advice is needed (if any) in order to do so.
- The framework proposed does a great job of assessing cumulative effects given the specific purpose and context – multiple stressors on two populations of one species, for which a lot is known (relatively speaking for marine species) about life history parameters and population trends/census, as well as impacts from natural and human induced stressors. It is an excellent addition to the growing cumulative assessment 'toolbox'. Quite often a 'one size fits all' method is requested for cumulative assessment when this is an impossible task. Different methods are needed for different purposes (eg. Area-based vs species/population based), at different spatial/temporal scales and under different states of data/knowledge. I

recommend that next steps would include a best practices workbook for which existing models/methods are proposed for cumulative assessments under different circumstances (eg. Available data/knowledge) and for different purposes (eg. Spatial/species). I believe the authors have already made great strides with respect to outlining different types of cumulative assessments so best practices would be a logical next step.

- The quality of this assessment and usefulness of the outputs reflects the hard work of the authors but also the importance of a clear purpose – it highlights the importance of clear objectives and requests from managers, in this case provided by the SARA action plan RMs.
- Kudos to the authors for building upon (and giving credit to) existing work of others in the field of risk/cumulative assessment as well as specific species/population expertise, instead of re-inventing the wheel. They have couched their methods within other assessments and have modified methods/approaches where appropriate, providing clear justifications for doing so.
- A discussion on next steps and applicability of this approach for other purposes would be very helpful. This section could address questions on general expandability of approach to other species/groups of species (eg. Janelle Curtis's PVA work for salmon or VMEs), or whether the population-specific PVA model could be expanded or replaced by community/ecosystem models to look at impacts on broader systems (eg. Caihong Fu's OSMOSE ecosystem model). If not in the research document, then in the SAR.

Specific Comments

Background

1.1.1 Population Trends

- Could the steady increase in population size shown in Figure 2 be due to increased monitoring effort, particularly after 2001 when DFO's marine mammal research group was formed? If so, this should be mentioned as a possible reason for the increase.

1.1.4 Goal of the Assessment

- Main comments are in the overview section above. Table 1 on page 3 provides very clear direction from the SARA action plan. Although this document only deals with RM 11, the other two recovery measures are not independent of RM 11 or each other. I think additional text could be added to this section to discuss the how these RMs may be linked, albeit the focus being on RM 11 (i.e Can proposed approach for RM11 be used to inform the management of fisheries (RM6) and/or be used to assess project impacts?).
- Is the terminology 'acute' and 'chronic' used as shown in RM6? If so, these terms are used in a very different context than their standard definitions. I find it confusing and distracting to have the text shown as is without mention of it in this document.

Figure 4

- This is a very clear and useful figure which outlines the steps in the assessment undertaken.
- The text in the 2nd box (PoEs) seems to be cut off

1.4 Objectives

- The objectives for this working paper are clear and quite specific
- One additional objective that I think could be very useful would have been to provide guidance on how this assessment could inform or be used by managers – I think this

document provides some preliminary guidance on this in the conclusions section that could be elaborated.

2 Pathways of Effects Conceptual Model

- The definition, structure and outputs section does an excellent job of explaining the type of PoE used for this assessment, what it does, and how this information is fed into the cumulative effects assessment
- The authors point out the first step of developing a PoE as scoping the stressors and endpoints, which in this case were determined previously by recovery actions and recovery strategy documents
- Determining the appropriate endpoints measures linked to the goal/objectives of the assessment (step E in the Scoping phase in Figure 4) is key to developing useful PoE models. It's not always as simple as it sounds, particularly when objectives are broad or not clearly defined, such as determine measures for a 'healthy' population, species or ecosystem.
- I believe including interaction types among stressors is novel to PoEs, at least those previously developed within the department. This is a very helpful addition since this information is needed in the next phase of assessment, be it a PVA or a risk assessment model.
- Separate PoEs were developed for direct and interaction effects to simplify interpretation and I understand the need for this. However, having 2 separate PoEs has the potential to misrepresent the total number of effects and the various pathways stemming from the 4 main stressors. I'm sure the authors tried developing one large PoE including both effects. It would be interesting to hear their thoughts on this.
- The paragraph following Figure 6 on page 9 provides key information and an important clarification missing from many PoE descriptions. It states the assumptions of the model(s), and explains that the details and quantification of the linkages are explored in the next step in the assessment, which in this case is a PVA. In my experience, PoEs have often been mistaken as a risk assessment on their own when in fact they provide the supporting information and data sources for each link in the model, on which a more quantitative assessment is based.
- Each linkage shown in the visual representation of the PoE model is supported with a well written justification including citations, data sources or expert elicitation where necessary.
- Tollit et al 2017 needs to be added to the reference list

Effects of Removals

- I was glad to see this 'historical threat' acknowledged and taken into consideration here. It is important to set the context, particularly given the small size of the SRKW population and the longterm effect that these removals have had on the population structure of such a long-lived species.

PoE Discussion

- "The development of the Pathways of Effects conceptual model provides an illustration and summary of the evidence for the conceptual structure of the system under investigation. This structure forms the basis for the population viability analysis modelling in the subsequent section of the paper."
    - This is an excellent description of the purpose of a PoE conceptual model and how its outputs are used in the next step of the assessment, in this case a PVA.

- The authors show the resulting PoE model in section 2.9, modified to represent only the portions that could be parameterized in the PVA (based on evidence provided). This is the first time I have seen this done and I think it's quite helpful in that they show how the assumed stressors/impacts are refined or removed due to lack of evidence. Usually only the final PoE model is shown, with all linkages present and dotted lines used for linkages that are uncertain. Not only have linkages changed, but direct and interaction impact pathways are now shown all in one conceptual PoE model. The stressors have now been refined/specific based on information gained in the process of gathering evidence for the supporting justification text.

Population Viability Analysis

- I am not an expert in PVA models so I will restrict my comments to the author's description and justification of methods and results in the text rather than if they are adequate to support the stated conclusions.
- The authors clearly explain methods and parameters used in the population models for both SRKWs and NRKWs.
- As described, the methods seem appropriate for this assessment and the results support the author's conclusions. However, I am not familiar with many PVA models and cannot speak to whether other models or parameters would be more appropriate given the goals of this assessment or the given circumstances.
- Pg 29, max age of reproduction is stated mistakenly as 90yr for males in the text but should be 70 if based on Table 8.
- Sections on model verification and validation, as well as the various individual and cumulative threat scenarios are well written and supported by data and citations.

Discussion

- Overall, I found the data and methods in this document explained in sufficient detail to properly evaluate the conclusions
- On page 58, the authors state "*The systematic assessment of both individual and combined threats in the model scenarios allows examination of which threats (or combination of threats) best explain the observed population growth and in turn may have a greater influence on the population trajectories and demographics of these killer whale populations."* The reader should be guided to section 5.2 (Comparing individual threats) for discussion on which threats seem to be driving the population trajectories or demographics.
- Likewise, the authors mention that there are broader uses for this cumulative assessment method but do not elaborate further – I would like to see some suggestions included in the text on how this method could be useful as a tool for managers and scientists.
- Section 5.2 states "*The findings of this cumulative effects assessment strongly support the significant role of prey availability in determining the population trajectory of these populations, and are consistent with previous work* (Lacy et al. 2017, Vélez-Espino et al. 2014b; Ford et al. 2009; 2010; Ward et al. 2009)." However, on pg 13 (section 2.4) it states that the Vélez-Espino and Ward studies did not find any statistical evidence for a relationship between chum and other salmon species stocks and RKW mortality or fecundity. In light of this, should these studies be referenced here?

Assumptions and Uncertainties

- Uncertainties linked to model fit and population and threat parameters are well described in this section, as are PoE and PVA assumptions.

- The authors address the difficulty in including low probability, high consequence threats into simulation modeling and suggest reducing the population by 50-75% to test if the model population would be resilient enough to recover from a catastrophe such as an oil spill or disease epidemic. I think this could be a very useful way to evaluate this risk and any proposed mitigation measures.

Conclusions

- I agree with the authors that this cumulative effects population viability model could be used as a decision-support tool – to prioritize threats (by most impact on long-term population persistence) or to evaluate how changes in any of the parameters or threats (existing or additional) will impact the viability of a population. One could simulate the impacts of different management measures/scenarios for individual threats.
- I think this section would benefit from a discussion on potential applications of this approach for other purposes – eg. general expandability of approach to other species, groups of species, communities, or ecosystems to look at impacts on broader systems

REVIEWERS: MISTY MACDUFFEE, RAINCOAST CONSERVATION FOUNDATION AND PAUL PAQUET, UNIVERSITY OF VICTORIA AND RAINCOAST CONSERVATION FOUNDATION

Overview

Well-conceived, well written, and technically sound, the manuscript (a progress report on ongoing investigations) assesses the cumulative effects of threats to British Columbia's Northern and Southern resident killer whales, which are currently exposed to varying degrees of anthropogenic influence. The cumulative effects assessment (CEA) comprises two components: a Pathways of Effects (PoE) conceptual model which then informs a Population Viability Model (PVA).

The development of the Pathways of Effects conceptual model provides an illustration and summary of the evidence for the conceptual structure of the system under investigation. The PoE model summarises the current understanding of all SARA priority threats, which are identified as availability of prey, disturbance, and contaminants. The structure of these threats is theoretically described in the assessment, including the linkages to threats and their potential influence and interactions on birth and mortality rates. In previous studies, linkages between priority threats and the PVA were implied conceptually but not explicitly, so this is a significant advancement.

The population viability model is the most comprehensive to date for SRKWs and the first for NRKWs. It combines empirically derived threat data with demographic data to quantify how threats might affect the population persistence of killer whales by elucidating patterns of population growth and decline in different threat scenarios. Iterative testing and sensitivity analyses help characterize the contributions of different threats to population dynamics, both singularly and interactively, revealing the limitations or weakness of the model structure and data used to parameterize the model.

This is the first cumulative effects assessment (peer reviewed and gray literature) that we are aware of that examines both the Northern Resident (NRKW) and Southern Resident (SRKW) populations, and as such, marks an important contribution to our understanding of threat interactions. As noted by the authors, the systematic assessment of individual and potentially interacting combined threats in the model scenarios allowed consideration of which threats (or combination of threats) best explain the observed population growth, and in turn, might have a greater influence on the population trajectories and demographics of these killer whale populations.

Of the different individual and combined cumulative threat models tested, the model that incorporated all known priority threats (prey availability, acoustic disturbance, vessel strike, and PCB contamination), aligned most closely with historic rates of growth observed for both populations. The model predictions closely followed the observed size, structure, and temporal changes in response to birth, migration, aging, and death for NRKW. Although failing to include the observed values within the bounds of uncertainty, the model predictions were also closest to the historic population rate of growth and age/sex structure documented for the SRKW. Notably, however, when historical Chinook model data were included in the model prediction, rather than a randomly chosen Chinook index value, the fit improved for SRKW. Therefore, the uncertainty bounds of both models included the historic annual observed vital rates for (births and deaths) mortality and fecundity. This implies that the cumulative effects models reflect the actual ecological systems being described for both NRKW and SRKW.

A major finding of this cumulative effects assessment is that it strongly supports the important influence of prey availability in the population trajectory of these populations.

The *Abstract and Introduction* clearly identify the need for this research, and its relevance. Explicitly outlining the background and current state of knowledge of priority threats, interactions and impacts, and in particular, the uncertainties and limitations provided a strong evidence-based pathways of effects conceptual model, creating the foundation for the assessment.

The *Data and Methods* appropriately target the main questions, are technically sound, and explained in sufficient detail to properly evaluate the conclusions. With some exceptions and improvements, the methods largely follow or build upon other studies that have been peer reviewed and published. Two notable changes and significant methodological improvements from previous PVAs are:

- The use of baseline vital rates derived from the comparatively undisturbed Southern Alaska Resident killer whale population, and
- Threats were added to the model as modifiers of these rates.

This approach differs from Lacy et al. (2017) for SRKW, where the “baseline” was defined with the mean demographic rates observed recently (i.e., including current threats to the population), and threat levels then varied to assess the affect on population dynamics. The use of vital rates derived from the relatively undisturbed Alaska Residents Killer whales as a baseline is a considerable advancement over previous work.

The *Results* are presented clearly and logically, and are justified by the data provided. Notably, individual threat models did not closely align with the observed population dynamics. However, of all individual and combined threat models tested the cumulative threats model, which incorporated all priority threats (Chinook availability, acoustic disturbance, physical disturbance, and contaminants), predicted population growth closest to rates observed historically for both populations. The cumulative effects model scenario results matched the observed data more closely for NRKW than for SRKW. Nevertheless, we think it would be useful for the authors to note that the original causes of the Resident Whale’s endangerment might differ from the current threats, and are not captured in the model. Therefore, population viability assessments that use current threats might not reflect historical conditions.

Of particular note, assessing the enduring effect of aquarium removals is an important consideration for the SRKW population, because many more individuals were removed from the SRKW population than the NRKW. The PVA model was used to examine the SRKW population trajectory had these individuals remained in the population. The conclusion was that although the population might not have grown over the last four decades, the population size would likely be stable at much higher and more robust numbers.

The *Conclusions* justifiably respond to the main questions posed by the author(s) in the Introduction and are fully supported by the results of the analyses. Assumptions are explicitly acknowledged and accounted for, reflecting the uncertainty in the data and analyses. The interpretation of results is appropriately discussed in the context of previous literature. We note that the conclusions are informative and not prescriptive regarding recommendations for decision makers (there are none).

The Tables and Figures are described clearly and fully, but some would be more instructive with inclusion of dates and locations and better legend descriptors. Many readers will only look at tables and figures without reading the main text of the manuscript. Therefore, ensuring that the tables and figures can stand-alone from the text and communicate clearly the most significant results might be sensible.

Summary of important contributions

1. Consideration and elucidation of the effects of aquariums captures on RKW population structure and dynamics
2. Use of SARKW baseline vital rates to examine reproductive potential
3. Reanalysis of the role of Chinook abundance with data updates including
   - ocean Chinook abundance data used by Velez-Espino et al. 2014
   - logistic regression analysis done on fecundity by Ward et al. 2009
   - re-interpretation of coast wide Chinook abundance indices from Ford et al. 2009
4. Comparative characterizations between SRKW and NRKWs on vessel exposure (i.e. SRKW are exposed to 5 times commercial vessel traffic, with NRKW disturbance distributed over a much larger area, suggesting that NRKWs spend comparably little time in the presence of vessels)
5. Comparative characterizations between SRKW and NRKWs on PCB burdens
   - (i.e. SRKW Females 17.46 mg/kg; Males 40.74 mg/kg; Accumulation rate 2 mg/kg/y; Depuration rate 0.77;
   - NRKW Females 4.97 mg/kg; Males 10.09 mg/kg; Accumulation rate 1 mg/kg/y; Depuration rate 0.77;
6. Application of noise effects thresholds under given levels of Chinook abundance
7. Application of an additive model to consider prey availability with PCB accumulation, including thresholds.

Specific PVA insights

1. Support for role of prey availability as a primary driver of killer whale dynamics;
2. Identifying potential population growth rates in the absence of primary threats, including the potential role of live captures on SRKW trend;
3. The power of cumulative threats to enhance explanation of population trends.

Section specific questions

Section 1.2. Should the purpose of a cumulative effects paper be stated in section 1.2 (i.e. to better inform management decisions and actions, etc)

Fig 5. Pg. 8. Why does physical disturbance impact mortality, but not growth rate? Is it just vessel strike avoidance or is it also interference with prey pursuit?

Table 5 pg 19. Death of L112. Should this young female also be included or is her death inconclusive?

3.14. SARKW are described as “not pristine” in 3.14, but the term “pristine’ is used in the PVA. Perhaps “comparatively undisturbed” would be more appropriate in later use.

Concepts and definitions that *need* to be addressed

Two important concepts, ecotypes and culture, are introduced in the Background but were not defined and their relevance is not addressed in the report. They may warrant further attention. Specifically:

Ecotypes (page 11)

> *"Three genetically and acoustically distinct killer whale (Orcinus orca)* ***ecotypes*** *inhabit the waters of the Northeast Pacific coast of North America: offshore (shark eaters); Bigg's (or transient); (marine mammal eaters); and residents (fish eaters) (Ford et al. 1998). The resident fish-eating ecotype is further divided into the Northern and Southern Resident Killer Whale (NRKW and SRKW) and the Southern Alaskan Resident Killer Whale populations (SARKW) (Ford et al. 2000; Matkin et al. 1999; 2014)."*

We note that the complex nature of ecotypes has spurred some confusion and inconsistencies in how it is defined, limiting practical application. Ecotypes are generally considered variants of a species adapted to a specific environment. Le Moan et al. (2016) provide the following definition of ecotype focused on heritable differences while considering a diverse set of traits: "Ecotypes are defined as populations of the same species which have evolved heritable physiological, morphological, behavioural or life history differences that are closely associated with environmental variation". Riesch et al. (2012) and Baird and Whitehead (2000) have described ecologically distinct communities of killer whales in the NE Pacific (Residents, Biggs, Offshores) that are recognized based on their prey specializations and social structure.

Le Moan A, Gagnaire P-A, Bonhomme F. 2016. Parallel genetic divergence among coastal–marine ecotype pairs of European anchovy explained by differential introgression after secondary contact. Molecular Ecology 25: 3187-3202.

Culture (page 11)

> *"Though all populations of resident killer whales are fish-eating cetaceans, feeding primarily on Chinook (Oncorhynchus tshawytscha) and Chum salmon (O. keta), and overlap to some extent in habitat and diet, they do not interact with one another socially and are distinct in terms of* ***their culture****, acoustics and genetics (DFO 2017a)."*

We note that animal culture (defined as "information or behavior—shared within a community—which is acquired from conspecifics through some form of social learning") in killer whales includes food sharing (Ford & Ellis 2006; Wright et al. 2017), the transmission of knowledge on when and where to find salmon (Brent et al. 2015, Croft et al. 2017) and other potential fitness benefits that accrue from kinship (see Brakes et al. 2019). Aspects of this culture may be unique within killer whale clans (i.e. J clan, SRKWs; A, R and G clans in NRKWs).

Conservation strategies and policies have focused primarily on broad demographic responses and the preservation of genetically defined, evolutionarily significant units. However, a growing body of evidence confirming social learning and culture in cetaceans has raised important questions about how best to conserve these animals, especially because human activity may be contributing to the loss of cultural behaviours. This can have important consequences for the survival and reproduction of individuals, social groups, and potentially, entire populations.

Baird, R.W. and Whitehead, H., 2000. Social organization of mammal-eating killer whales: group stability and dispersal patterns. *Canadian Journal of Zoology*, *78*(12), pp.2096-2105

Brakes, P., S.R.X. Dall, L.M. Aplin, S. Bearhop, E.L. Carroll, P. Ciucci, V. Fishlock, J.K.B. Ford, E.C. Garland, S.A. Keith, P.K. McGregor, S.L. Mesnick, M. J. Noad, G.N. di Sciara, M.M. Robbins, M.P. Simmonds, F. Spina, A. Thornton, P.R. Wade, M.J. Whiting, J. Williams, L. Rendell, H. Whitehead, A. Whiten, and C. Rutz. 2019. Animal cultures matter for conservation. Science **363**:1032-1034.

Riesch, R., Barrett-Lennard, L.G., Ellis, G.M., Ford, J.K. and Deecke,V.B. 2012. Cultural traditions and the evolution of reproductive isolation: ecological speciation in killer whales? *Biological Journal of the Linnean Society*, *106*(1), pp.1-17.

Whitehead, H. and Rendell, L., 2014. *The cultural lives of whales and dolphins*. University of Chicago Press.

Whitehead, H., 2010. Conserving and managing animals that learn socially and share cultures. *Learning & Behavior*, *38*(3), pp.329-336.

Whitehead, H., Rendell, L., Osborne, R.W. and Würsig, B., 2004. Culture and conservation of non-humans with reference to whales and dolphins: review and new directions. *Biological Conservation*, *120*(3), pp.427-437.

Research That Could Address Knowledge Gaps

Understanding the "undisturbed norm"

We do not know the undisturbed norm for killer whales, i.e. population dynamics and behavioural ecology in the absence of anthropogenic disturbances. Yet, disturbance history is a critical concept in understanding behaviour of long-lived animals that learn through social transmission. A whale's age/sex class, experiences, and inherited tolerances affect how they respond to human disturbances.

Predator-prey relationships

Research on predator-prey relationships and behaviour in the context of threats and disturbances is lacking. For example,

- The density, quantity, and quality of prey needed to support Resident Killer Whale populations are unknown. In addition, although it is assumed that Chinook remain the primary prey species of Resident Killer Whales throughout the year, most prey samples of Resident Killer Whales have been collected during summer and fall, and their year-round diet is not well understood. It is therefore possible that additional important prey species will be identified in the future.
- Effects of competition in multi prey, multi predator system. There are complex predator-prey relationships that are not yet well understood. This is a multi-prey, multi-predator system where both prey and predator can be either prey or predator depending on their life stage, as well as competitors.
- Foraging theory and use of habitat. Predation involves a decision-making process that leads to observed patterns of spatio-temporal distribution of individuals. Changes in distribution or habitat use over time reflect prey distribution and availability. Whales search for prey by travelling to a food patch where they assess the likelihood of success. If no prey are not found, they begin a new search. If prey are found, the whales pursue them. If unsuccessful, they abandon the pursuit and return to searching. If prey are captured, they handle the prey and continue feeding.

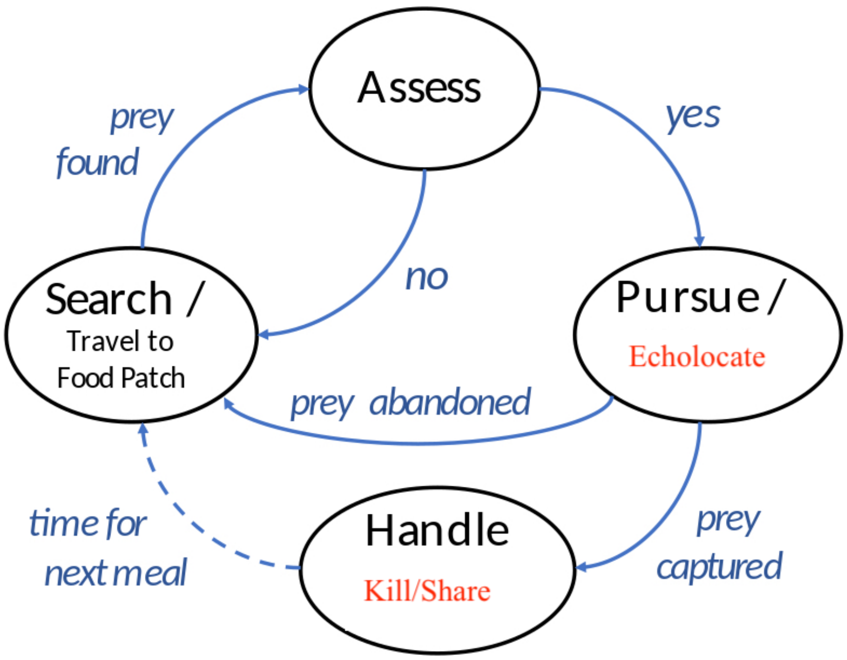

Figure 1. Patterns and outcomes of predator prey interactions

Ecosystem function and services of Resident Killer Whales

See the following recent publication:

Hammerschlag, N., Schmitz, O.J., Flecker, A.S., Lafferty, K.D., Sih, A., Atwood, T.B., Gallagher, A.J., Irschick, D.J., Skubel, R., and S.J. Cooke. 2019. Ecosystem Function and Services of Aquatic Predators in the Anthropocene *Trends in Ecology & Evolution,* ISSN 0169-5347, doi.org/10.1016/j.tree.2019.01.005.

Abstract: Arguments for the need to conserve aquatic predator (AP) populations often focus on the ecological and socioeconomic roles they play. Here, we summarize the diverse ecosystem functions and services connected to APs, including regulating food webs, cycling nutrients, engineering habitats, transmitting diseases/parasites, mediating ecological invasions, affecting climate, supporting fisheries, generating tourism, and providing bio inspiration. In some cases, human-driven declines and increases in AP populations have altered these ecosystem functions and services. We present a social ecological framework for supporting adaptive management decisions involving APs in response to social and environmental change. We also identify outstanding questions to guide future research on the ecological functions and ecosystem services of APs in a changing world.

Effects of prey biomass

Documenting the relationship of annual and seasonally partitioned changes in salmon biomass with Resident Killer Whale population dynamics could provide new insights. Changes in salmon biomass might be more useful and appropriate in explaining Resident Killer Whale population dynamics than changes in salmon abundance because biomass accounts for changes in the size of fish, whereas abundance does not. Having smaller fish as prey has consequential energetic and social implications for killer whales. A recent publication regarding prey biomass and the predator-prey power law has shown that the number and size of predators and their prey scale across a broad range of terrestrial and aquatic animal communities.

Hatton, I.A., McCann, K.S., Fryxell, J.M., Davies, T.J., Smerlak, M., Sinclair, A.R. and Loreau, M., 2015. The predator-prey power law: Biomass scaling across terrestrial and aquatic biomes. *Science*, *349*(6252), p.aac6284.

Pathway of Effects

- Role of other salmon species and interactions

The role and importance of other salmon species, including the consumption of chum salmon in the fall, coho in the winter, and interactions with dominant year pink and sockeye are areas warranting further research

- Effects of climate change

See, for example:

Climate change and its influence on Chinook salmon (Muñoz, N.J., Farrell, A.P., Heath, J.W. and Neff, B.D., 2015. Adaptive potential of a Pacific salmon challenged by climate change. *Nature Climate Change*, *5*(2), p.163.

Editorial Suggestions (edits are provided separately)

- Because this is a scholarly technical report similar to an academic publication, style guidelines would be useful for consistency and coherence.
- There is a mix Canadian and U.S. English spelling in the report should be modified for consistency.
- Use of kit (offspring), dam (mother) etc. Consider not using these terms.
- Chinook should be capitalized as a proper noun
- Subject and verb agreement where data are inconsistently plural and singular in the report.

APPENDIX E: MEETING PARTICIPANTS

Last Name	First Name	Affiliation
Balcomb	Ken	Centre for Whale Research
Bocking	Bob	Maa-nulth First Nations
Brekke	Heather	DFO Resource Management, Species at Risk
Brown	Tanya	DFO Science
Candy	John	DFO Centre for Science Advice Pacific
Christensen	Lisa	DFO Centre for Science Advice Pacific
Danelesko	Tessa	Georgia Strait Alliance (GSA)
Dangerfield	Neil	DFO Ocean Ecology & Biogeology
Demarchi	Mike	Maa-nulth First Nations
Doniol-Valcroze	Thomas	DFO Science, Marine Mammals
Grant	Paul	DFO Science, Species at Risk
Gregr	Edward	University of British Columbia
Hannah	Lucie	DFO Science, Ecosystem Stressors
Houston	Kim	DFO Science, Ocean Sciences Division Manager
Johnson	Larry	Maa-nulth First Nations
Jones	Lisa	DFO Resource Management, Species at Risk
Kling	Ashley	DFO Science, Marine Mammals
Lacy	Robert (Bob)	International Union for Conservation of Nature
Lawson	Jack	DFO Science, Newfoundland and Labrador
MacConnachie	Sean	DFO Science, Marine Mammals
McDuffee	Misty	Raincoast Conservation Foundation
Murray	Cathryn	DFO Science, Ecosystem Stressors
Nelson	Jocelyn	DFO Science
O	Miriam	DFO Science, Ecosystem Stressors
Olivier	Gilles	DFO Science, National Headquarters
Parken	Chuck	DFO Science
Serra-Sogas	Norma	University of Victoria
Shaikh	Sharlene	DFO Resource Management, Species at Risk
Stredulinsky	Eva	DFO Science, Marine Mammals
Vagle	Svein	DFO Science
Van Zandvoort	Alisha	Environment and Climate Change Canada (ECCC)
Wright	Brianna	DFO Science, Marine Mammals