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Pacific Region

Canadian Science Advisory Secretariat
Science Advisory Report 2019/030

CUMULATIVE EFFECTS ASSESSMENT FOR NORTHERN AND SOUTHERN RESIDENT KILLER WHALE (*ORCINUS ORCA*) POPULATIONS IN THE NORTHEAST PACIFIC

Resident Killer Whale.
Photo: © Jared Towers

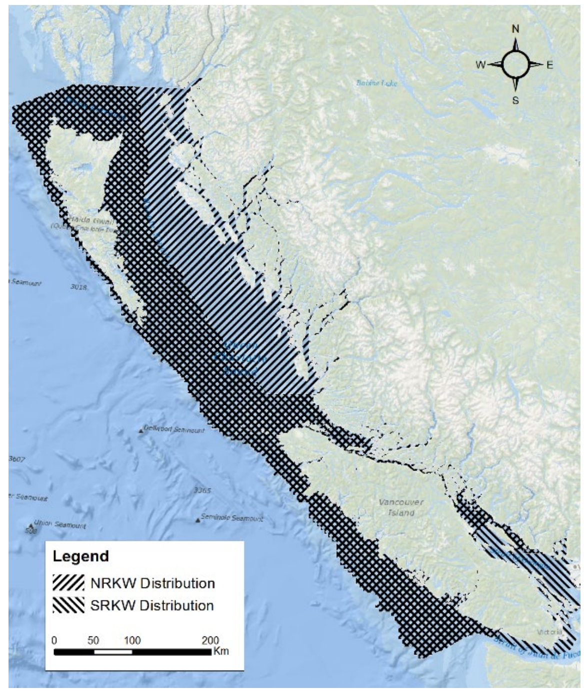

Figure 1: Distribution of Northern and Southern Resident Killer Whale (NRKW and SRKW) populations in Canadian waters

Context:

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated Southern Resident Killer Whales (SRKWs) as Endangered and Northern Resident Killer Whales (NRKWs) as Threatened in 2001, due to their small population sizes, low reproductive rates, declines in numbers, and the existence of a variety of anthropogenic threats. These designations became law when the two populations were listed under Schedule 1 of the Canadian Species at Risk Act (SARA) in 2003. The status of the SRKW and NRKW populations in Canada was reaffirmed by COSEWIC in 2008. A Recovery Strategy for Resident Killer Whales was published in 2008, with a goal to "ensure the long-term viability of Resident Killer Whale populations by achieving and maintaining demographic conditions that preserve their reproductive potential, genetic variation, and cultural continuity". The Recovery Strategy has been amended twice to date, in 2011 and 2018, to update the critical habitat section and include minor updates to the species information and background sections. An Action Plan was subsequently developed and published in 2017 which includes a high priority recovery measure (#11) to "Assess cumulative effects of potential anthropogenic impacts on Resident Killer Whales using an appropriate impact assessment framework for aquatic species". The Fisheries and Oceans Canada

(DFO) Species at Risk Program requested that DFO Science Branch undertake a cumulative effects assessment of threats to SRKWs and NRKWs. The science advice resulting from this assessment can be used to evaluate how such tools can be used to adaptively inform the survival and recovery of these populations.

This Science Advisory Report is from the March 12-13, 2019 Cumulative effects assessment for Northern and Southern Resident Killer Whale populations in the Northeast Pacific. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- Southern Resident (SRKW) and Northern Resident Killer Whales (NRKW) were listed as Endangered and Threatened, respectively, in 2003 under the *Species at Risk Act* (SARA). A Recovery Strategy for these populations was completed in 2008 (most recently amended in 2018; DFO 2018) and an Action Plan was completed in 2017 (DFO 2017a).
- The Species at Risk Act (SARA) Recovery Strategy (amended) identifies three principal threats to Resident Killer Whales – reduced prey availability, acoustic and physical disturbance, and environmental contaminants (DFO 2018).
- The current work aims to address the high priority recovery measure (RM #11) in the Action Plan which identifies the need to “Assess cumulative effects of potential anthropogenic impacts on Resident Killer Whales using an appropriate impact assessment framework for aquatic species”.
- In the current analysis, potential mitigation measures and management actions have not been addressed. Future changes in anthropogenic activities have not been included. The population level effects of low probability-high impact events, such as catastrophic oil spills, were out of scope for this assessment.
- The cumulative effects assessment framework developed consisted of two phases, the first being a Pathways of Effects (PoE) conceptual model that described the linkage pathways between threats and Resident Killer Whale mortality and birth rates, including potential interactions between threats.
- The second phase of the cumulative effects assessment framework was a Population Viability Analysis (PVA) model that quantitatively assessed the effects of the priority threats on the population trajectories of Resident Killer Whales.
- Seven of the 13 linkage pathways identified in the PoE could be quantified in the second phase of the assessment framework (PVA model) based on current data and knowledge.
- A number of key assumptions were made in the PVA modeling. The consequence of exposure to threats is assumed to be the same for both populations while the exposure to the threats is assumed to be population-specific. Quantification of linkage pathways to mortality rate and birth rate was based on information mostly obtained in the Salish Sea area in the summer/fall period but was assumed to represent threat conditions throughout the range and throughout the year. Chinook salmon abundance, irrespective of size selectivity by killer whales, was assumed to represent preferred prey available to Resident Killer Whales.
- Population models were constructed using demographic and genealogy data from DFO and Center for Whale Research, and a previously published population model for SRKW (Lacy et al. 2017).

- The impacts of individual and cumulative threat scenarios on modelled SRKW and NRKW populations were compared to the observed population trajectories (2000-2017) in order to define a model that best captured the real-world dynamics of the two populations. Individual and cumulative threat scenarios were each tested by running 10,000 model simulations.
- Individual threat scenarios used both updated and newly available parameters for Chinook salmon abundance, vessel noise/physical presence, vessel strike, and polychlorinated biphenyl (PCB) contamination. Taken one at a time, the modeled effects of individual threats did not replicate the observed population trajectories for NRKW and SRKW populations, suggesting that a cumulative model could better replicate the trends in Resident Killer Whale populations.
- When the threats are considered together (Chinook salmon abundance, vessel noise/physical presence, vessel strike and PCB contamination), the output of the PVA model closely replicated the observed population trajectories for the two populations, suggesting it is a useful model for the assessment of cumulative effects.
- The cumulative effects PVA model was then used to project population trajectories for NRKW and SRKW 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 indicate that the average modelled NRKW population trajectory increases to the carrying capacity set in the model within 25 years. In contrast, the average modelled SRKW population trajectory declines, 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.
- The model highlights the importance of considering threats collectively. Specifically, within the cumulative effects PVA assessment, Chinook salmon abundance and its interactions with vessel noise and PCBs strongly influenced modelled killer whale population dynamics.
- The cumulative effects framework developed, that combines a PoE with a PVA model, is a novel approach that explicitly identifies and quantifies threat linkage pathways, and associated uncertainties, and this approach has the potential for use in other populations and species.

BACKGROUND

Three genetically and acoustically distinct killer whale (*Orcinus orca*) ecotypes inhabit the waters of the Northeast Pacific coast of North America: Offshore; Transient (or Bigg's); and Residents (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). Though all three 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 2017b).

Long-term photo-identification census surveys for both NRKW and SRKW populations were initiated by Michael Bigg in the 1970s and continue to the present day (DFO Cetacean Research Program; Center for Whale Research). Population trends based on the census data indicate that the SRKW population has experienced an overall negative population growth rate (-0.2%; 1979-2017), with particularly sharp declines between 1995 and 2001. Since then, the population has shown little recovery, having 74 members in 2018. In contrast, the NRKW population has experienced a steady increase over the census period (population growth rate = 2%; 1979-2017), except for a decline between 1997 and 2001. The population has since increased from 219 members in 2004, to approximately 309 members in 2017 (DFO 2018).

The Southern and Northern Resident populations were listed as Endangered and Threatened, respectively, under the SARA in 2003. The three primary threats to NRKW and SRKW are: reduced prey availability, acoustic and physical disturbance, and environmental contaminants (DFO 2011; DFO 2017a; DFO 2018). The SARA Action Plan for NRKW and SRKW (DFO 2017a) contains 98 Recovery Measures (RMs); one high priority recovery measure (RM #11) identifies the need to "*Assess cumulative effects of potential anthropogenic impacts on Resident Killer Whales using an appropriate impact assessment framework for aquatic species*". To date, most research on threats to Resident Killer Whales has studied these threats in isolation. Assessment of cumulative effects, however, involves examining the combined, incremental impacts that threats from multiple human activities can have on individuals, populations, communities and ecosystems through space and time. Cumulative effects assessments evaluate the effects of multiple threats by converting impacts into a single currency or metric, thereby allowing for comparisons among threats and their combined long-term impact.

ASSESSMENT

Methods

The cumulative effects assessment framework developed to address this request consisted of two phases (Figure 2). In the first phase, a Pathways of Effects (PoE) conceptual model was developed to describe the threats and their impacts on Resident Killer Whale mortality and birth rates. The interactions between stressors were incorporated in the PoE to more accurately represent the natural system, as threats can interact over space and time, altering their respective intensities and consequent effects on individuals and populations. The outputs of the PoE conceptual model were used to design and refine the Population Viability Assessment (PVA) model in the second phase.

The second phase of the cumulative effects assessment framework uses PVA model to quantitatively assess the individual and cumulative effects of the priority threats on the population trajectories of the two Resident Killer Whale populations, building upon the methods and results of previous work (Ward et al. 2009; Ford et al. 2010; Vélez-Espino et al. 2014; Lacy et al. 2017). Existing literature and data were used to parameterise the impact of each threat on Resident Killer Whale vital rates (mortality and birth rates) and previously published relationships were updated with recent data and re-analysed. The model structure builds upon an existing PVA model developed for SRKW by Lacy et al. (2017).

Population models were constructed for each of the SRKW and NRKW populations separately using census data collected between 1979-2017 (DFO Cetacean Research Program (NRKW); Center for Whale Research (SRKW)). Baseline mortality and birth rates for both SRKW and NRKW were assumed to be those of the Southern Alaskan Resident Killer Whale population, as a reference population of fish-eating killer whales (Matkin et al. 2014). Threats were then added as modifiers of the baseline vital rates. The population data were partitioned to evaluate the ability of the model scenarios to produce outputs that were representative of the observed data. Threat modelling began in the year 2000, was projected forward to the present and the modelling results were then compared to the observed population dynamics until 2017. Threats were tested individually and cumulatively based on the assumption that appropriate models would replicate the observed population dynamics for both the SRKW and NRKW populations.

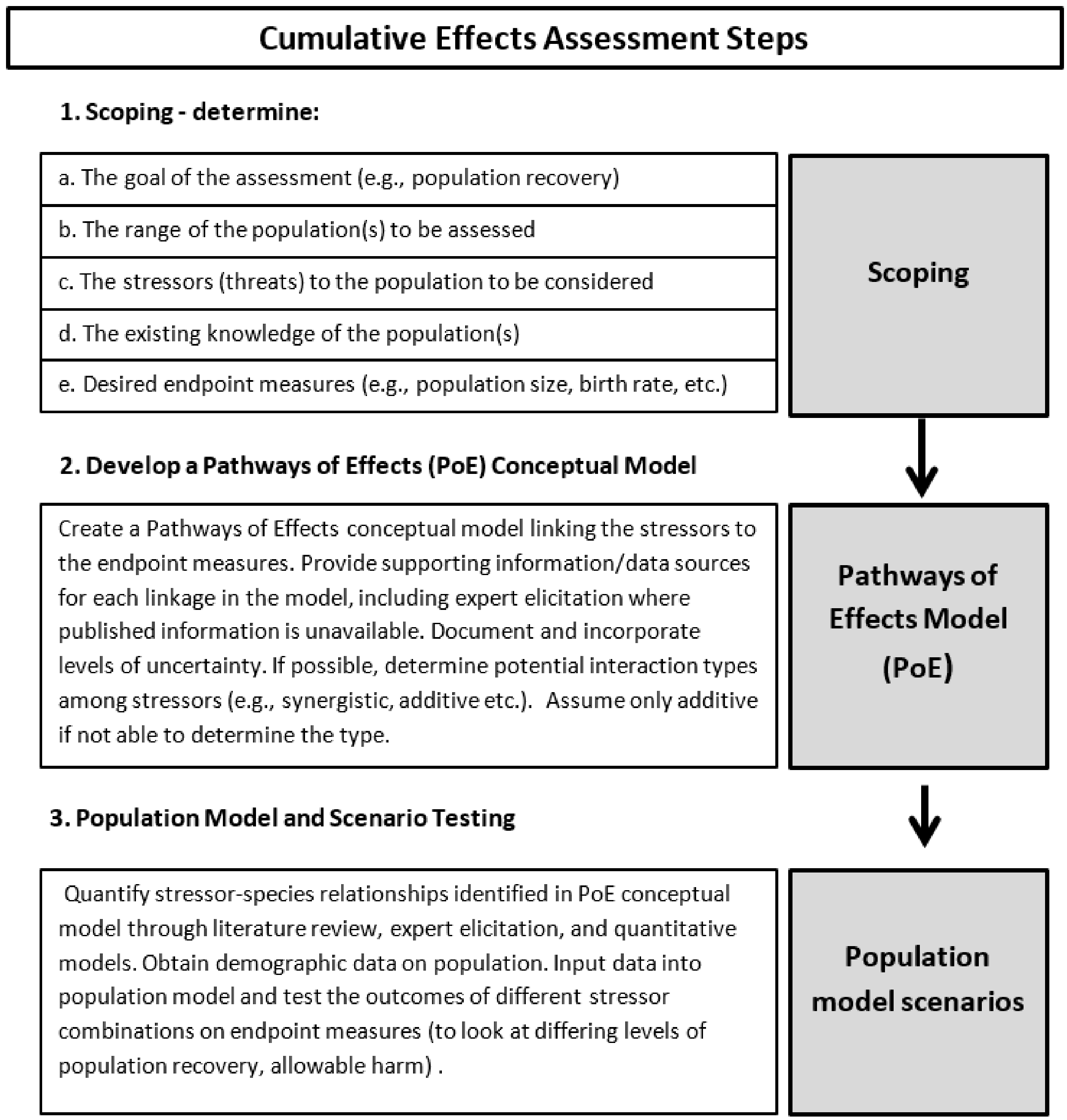

Figure 2: Diagram of the steps in the current cumulative effects assessment.

Results

Pathways of Effects conceptual models provide a visual representation of the structure of the system under investigation with supporting evidence provided for each linkage pathway identified. This structure forms the basis for the population viability analysis modelling in the subsequent phase of the assessment. In the PoE model for Resident Killer Whales (Figure 3), prey availability is a central node, with two direct linkage pathways to mortality rate and birth rate and two interactions with other threats (Prey-Disturbance and Prey-Contaminants) that each have two linkage pathways to mortality and birth rate (six linkage pathways in total). The incorporation of threat interactions make the assessment of impacts more difficult, as they imply that impacts are not additive and may have non-linear or threshold effects. The threats identified by SARA (reduced prey availability, acoustic and physical disturbance and environmental contaminants) that were quantified in the PVA model were represented by Chinook salmon abundance, vessel noise and vessel physical presence, vessel strikes, and PCB contamination (Figure 4). Additional threats to Resident Killer Whale populations were identified in the SARA Recovery Strategy (amended) (DFO 2018) that were not included in the current model; including incidental mortality in fisheries, oil spills, disease, harmful algal blooms, as well as seismic exploration and other high-intensity sounds.

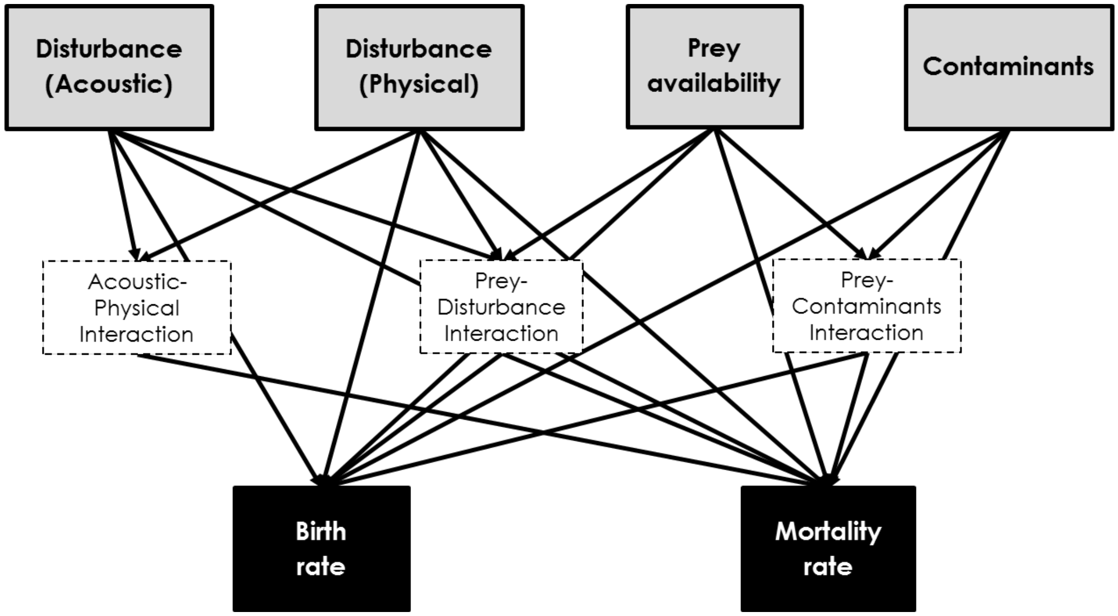

Figure 3: Pathways of effects conceptual model defined for Resident Killer Whale populations, including the priority threats, interactions, and their impacts on Resident Killer Whale mortality rates and birth rates.

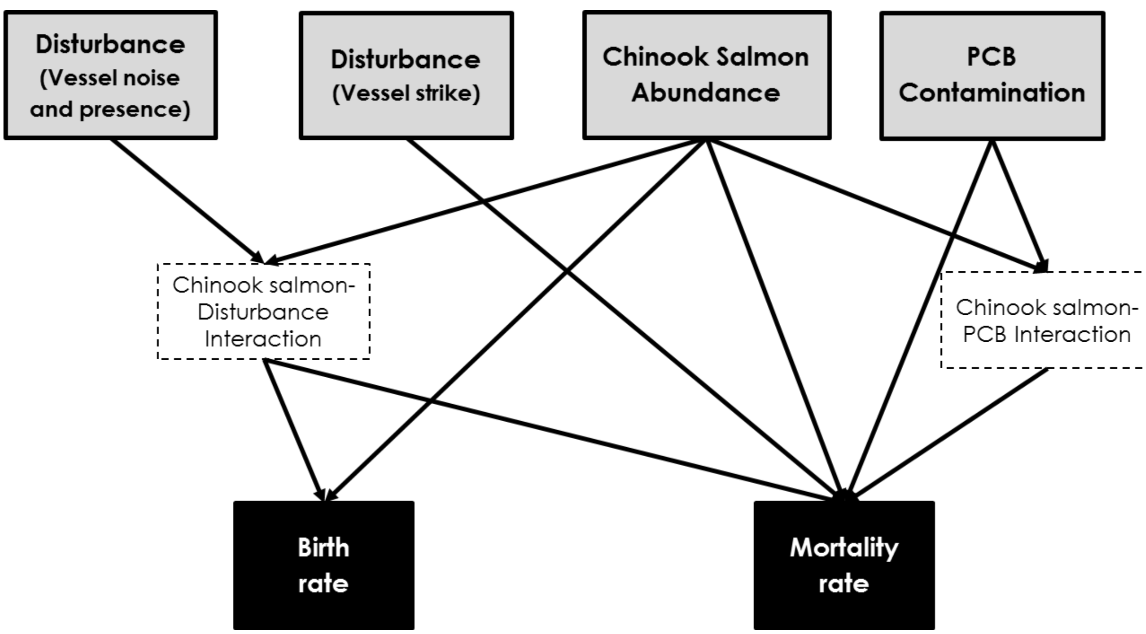

Figure 4: Simplified pathways of effects conceptual model defined for the Population Viability Analysis (PVA) of Resident Killer Whale populations.

Updated and/or new inputs for all of the threats that were considered in this cumulative effects assessment were incorporated into the model scenarios. The prey availability scenarios used updated Chinook salmon ocean abundance model data, extending the time series from 1979 to 2017 from that used in previous studies (2008: Lacy et al. 2017, and 2011: Vélez-Espino et al. 2014b). Statistical and model selection analyses were performed on these data to update the relationships between Chinook salmon indices and Resident Killer Whale mortality and birth rate. Vessel disturbance scenarios applied a proportional loss of foraging time due to vessel noise from a new study (Tollit et al. 2017), and the incorporation of relative vessel density for both populations was estimated using an analysis of the number of ship transits and the presence of marinas. The risk of vessel strike was estimated based on collation of reports of presumed strikes. PCB contamination used measured PCB concentration data summarised from a number of new sources (Guy 2018; Gobas and Ross 2017 unpubl.[1]).

The individual threat models (i.e., considering one threat at a time) did not closely align with the observed population dynamics. Out of all individual and combined threat scenarios tested, the cumulative threats model that incorporated all priority threats (Chinook salmon abundance, vessel noise/physical presence, vessel strikes, and PCB contamination), predicted population growth closest to the observed rates for both populations. The cumulative effects model scenario results matched the observed data more closely for NRKW than for SRKW. Holding all other threats at the same values, using the historical Chinook salmon index values (instead of random values representing the range of salmon indices for the full time period) proved key to obtain a good match between the SRKW model and the observed SRKW data (Figure 5).The sensitivity of model scenario parameters were tested to distinguish which threats have the highest impact on modeled long-term population dynamics. Chinook salmon abundance was the most sensitive model parameter and therefore prey availability and its interactions with vessel noise and vessel physical presence and PCB contamination strongly influenced modelled Resident Killer Whale population dynamics for both NRKW and SRKW.

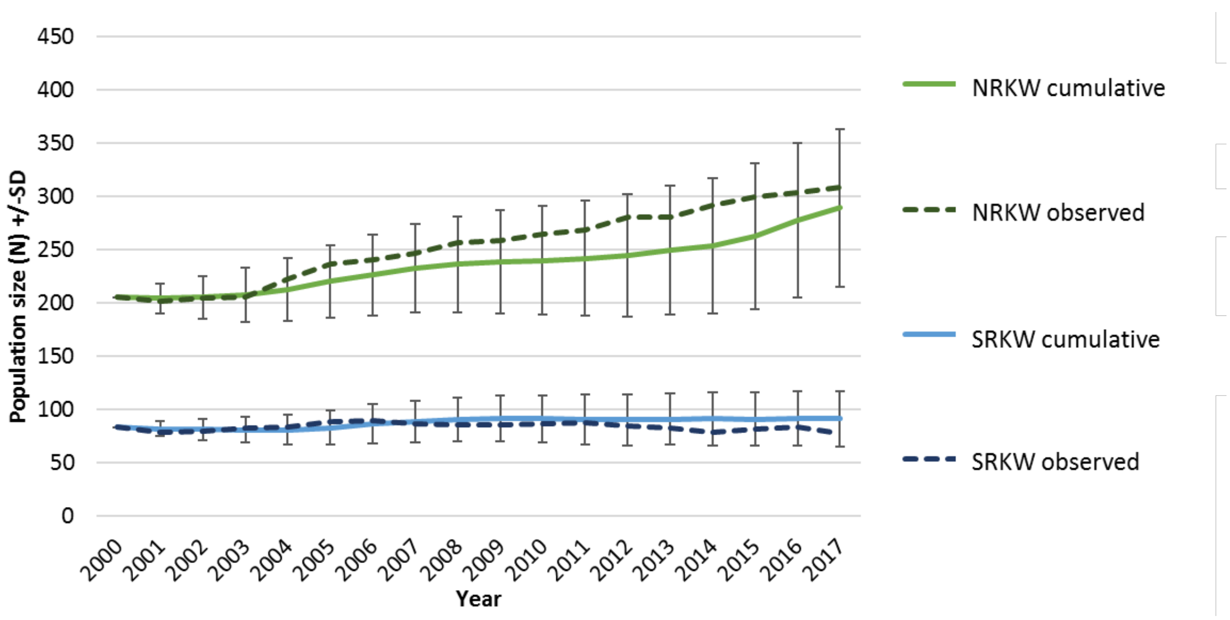

Figure 5: Average cumulative effects model results (over 10,000 model scenarios) for NRKW (green) and SRKW (blue) model scenarios (solid lines) using historical Chinook salmon index values, and observed population size (dashed lines), with ±1 standard deviation error bars.

The cumulative effects PVA model was also used to project population trajectories for NRKW and SRKW into the future, based on best available knowledge and the assumption that no future mitigation will take place. The projected population growth was examined under two levels of Chinook salmon prey abundance – the long-term historical average abundance

[1] 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.

(1979-2017) and the recent abundance (2008-2017) (Figure 6). The model outputs show that the average NRKW population trajectory increased to the carrying capacity set in the model within 25 years, regardless of the prey abundance levels used in the projections (recent or long-term average). When prey levels were set to vary with the long-term average Chinook salmon index values, the average modeled SRKW population was projected to increase. When the recent Chinook salmon index values were used to set the variance in the model parameters, the average mean model SRKW population trajectory declined, with a 26% probability of extinction (defined in the model as only one sex remaining). In those 26% of model simulations (10,000 total), extinction was estimated to occur after 75-97 years.

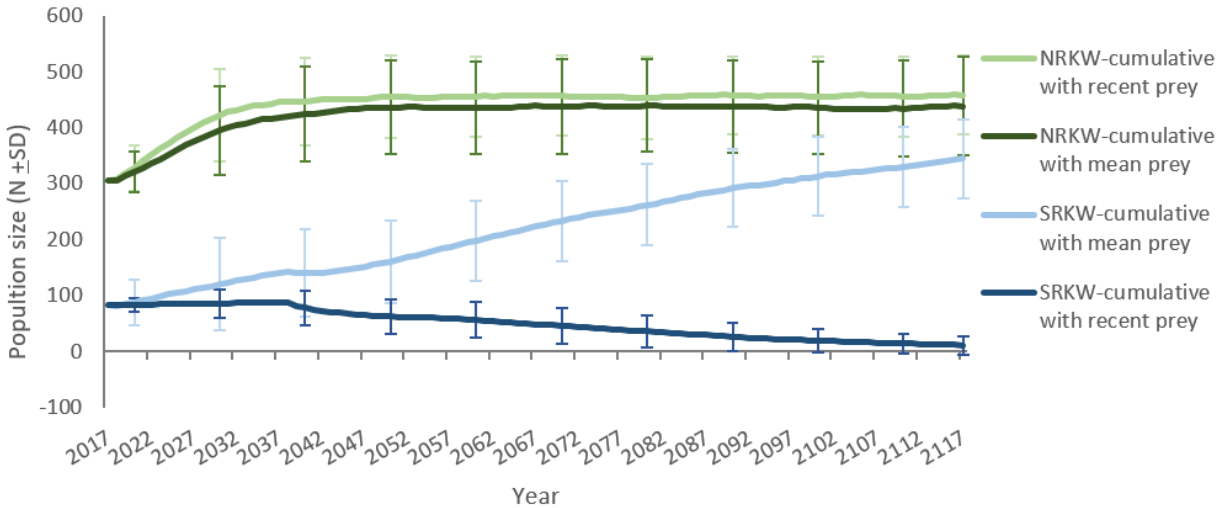

Figure 6: Average projected population size (±1 standard deviation error bars) of NRKW (green) and SRKW (blue) model (solid lines) 100 years into the future, using the cumulative effects model based on 10,000 simulations with either mean prey abundance (1979-2017) or recent prey abundance (2008-2017).

The findings of this cumulative effects assessment support the significant role that Chinook salmon abundance plays in the population trajectory of these populations. The cumulative effects framework that was developed, refined and tested with the latest threat information in this study, has the potential to be a useful tool for managers and scientists. This developing method combining Pathways of Effects conceptual modeling with Population Viability Analysis modeling could be a valuable way for managers to explore potential impacts to populations under different proposed scenarios of mitigation and management.

Sources of Uncertainty

- Sub-population level dynamics of Resident Killer Whales were not investigated and could become important if there are relevant differences (e.g. exposure to threats in space and time) occurring within populations (e.g., at the pod or clan level).
- Possible competition between NRKW and SRKW for prey was not included in the cumulative effects assessment, nor was potential competition with any other animals.
- Relationships between threats and Resident Killer Whale mortality and birth rates were based on information mostly obtained in the Salish Sea area in the summer/fall period but were assumed to represent threat conditions throughout the range of both populations and

throughout the year. Chinook salmon ocean abundance, irrespective of size selectivity by killer whales, was assumed to represent prey available to Resident Killer Whales.

- There are data limitations and uncertainties for each of the priority threats to Resident Killer Whales (prey availability, acoustic disturbance, physical disturbance, and contaminants) and their impacts on mortality and birth rates. An iterative, adaptive approach should be taken to update the cumulative effects model as new data become available and as data about other potential threats emerge.
- The current model used estimated Chinook salmon ocean abundance modeled by the Pacific Salmon Commission. Data that includes size and age could be used to better represent the prey requirements for Resident Killer Whales. Chinook salmon populations themselves are also affected by anthropogenic threats and predation by fish, birds and other marine mammals.
- The current model incorporates the impact of acoustic disturbance only as a direct impact on prey availability. The non-foraging impacts of acoustic disturbance on mortality and fecundity and the distinction between impacts from vessel presence and vessel noise were not included. The effects of noise and vessel presence on stress levels and susceptibility to disease or vessel strikes were also not included. Improvements in the characterisation of noise, including spatial and temporal variability in the natural soundscape should be included in subsequent versions of the cumulative effects model when knowledge and data become available.
- The documented occurrences of vessel strikes for these populations suggest that they are very rare (less than 10%), however attributing cause of death in killer whales is difficult. In many cases, carcasses are never recovered, meaning that only a small proportion are recovered for necropsy examination.
- The inclusion of the impacts of contaminants on Resident Killer Whales was limited to PCBs and their inferred impact on calf mortality, because of a lack of knowledge on other contaminants and possible impacts. Other impacts of PCBs on birth rate and the impacts of other priority contaminants for Resident Killer Whales should be included when knowledge and data become available.
- Projection of the cumulative effects model assumes that the modeled threat conditions remain at current levels, with no future changes in anthropogenic activities and no mitigation or management actions (beyond those in place in 2017). The inclusion of the latest management measures and testing of potential future actions can be used to further advance the model results.
- Additional threats to Resident Killer Whale populations that were identified in the SARA Recovery Strategy (amended) (DFO 2018) were not included in the current model; including incidental mortality in fisheries, oil spills, disease, harmful algal blooms, as well as seismic exploration and other high-intensity temporary sounds.

CONCLUSIONS

- This cumulative effects assessment framework further advances the field by combining a detailed Pathways of Effects conceptual model and a specific Population Viability Analysis to evaluate how the current state of human activities can affect the future persistence of SRKW and NRKW.

- The ongoing research being conducted under initiatives such as Oceans Protection Plan and the Whales Initiative can be used to refine the model and test possible mitigation and management actions and the impact on the long-term survival and recovery of the threatened and endangered Northern and Southern Resident Killer Whale populations.
- Information from ongoing and/or future research on Resident Killer Whales such as prey competition with other species in key foraging areas, foraging efficiency, diet composition, prey field analysis, underwater acoustic monitoring and modeling, contaminant sources and levels, will all help to inform future iterations of the cumulative effects model.
- The cumulative effects model for Resident Killer Whales, and refined future versions, can help to adaptively inform the recovery planning and implementation process for Resident Killer Whales. Possible contributions of this tool to the implementation of recovery measures from the Action Plan for the Northern and Southern Resident Killer Whale (Orcinus orca) in Canada include investigating the benefits of management actions to protect important areas, evaluating potential impacts of disturbance and prey competition from fisheries, assessing the potential impact of salmon recovery on Resident Killer Whales, and assessing project impacts on Resident Killer Whales and their habitat to provide advice on avoidance and mitigation measures as required.
- The Resident Killer Whale cumulative effects assessment components (Pathways of Effects and cumulative effects Population Viability Analysis models) should be reviewed and updated as new data and knowledge become available. In particular, Chinook salmon terminal run reconstruction data should be updated to use in future iterations in place of Chinook ocean abundance data.

OTHER CONSIDERATIONS

Climate change impacts and future changes in the threats, their impact on Resident Killer Whale populations, prey populations, and the ecosystem should be considered in any future modeling efforts.

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SOURCES OF INFORMATION

This Science Advisory Report is from the March 12-13, 2019 Cumulative effects assessment for Northern and Southern Resident Killer Whale populations in the Northeast Pacific. Additional publications from this meeting will be posted on the [Fisheries and Oceans Canada (DFO) Science Advisory Schedule] as they become available.

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