# Southern Resident Killer Whale (Orcinus orca) 2016-2021

## *Bibliography*

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## Background & Scope

This bibliography focuses on any relevant Southern Resident Killer Whale literature (peer-reviewed, technical reports, memos, biological opinions, International Whaling Commission (IWC) reports, etc.) since 2016. It is intended as a reference resource for staff of the NOAA Fisheries Office of Protected Resources when compiling and summarizing any relevant new (i.e. 2016-present) information for this cetacean species. It is organized into eight sections: Distribution and Habitat, Population Dynamics and Ecology, Genetics, Prey, Contaminants and Health, Energetics, Vessel Interaction and Noise, and Recovery.

### Section I – Distribution and Habitat

This section contains research related to SRKW geographic distribution, sighting and tracking data, and information related to habitat preferences or current state or quality of habitat (excluding prey-related habitat research).

### Section II – Population Dynamics and Ecology

This section contains research related to SRKW population abundance and trends or projections, demography, and population size estimates. This section also includes papers on SRKW ecology including social structure and dynamics, fitness (survival or reproduction), or climate change impacts.

### Section III – Genetics

This section contains research related to SRKW genetics, including evolutionary studies within and across killer whale ecotypes, genome sequencing, cultural evolution, and phylogenetic studies.

### Section IV – Prey

This section contains research related to prey as observed in the SRKW diet, or other salmonid research related to SRKW such as prey abundance, quality, distribution, seasonality, or temporal trends. This section may also include fishery- and hatchery-related publications.

### Section V – Contaminants and Health

This section contains research related to contaminants found in, or may be a threat to, SRKW, impacts of contamination in killer whales, and emerging contaminants in the Puget Sound and WA coastal region. This section also includes any studies related to SRKW health, including data from strandings and necropsies, and related protocols.

### Section VI – Energetics

This section contains research related to killer whale metabolic rates, caloric intake requirements, sound production, measurements of energetic expenditure, and related impacts.

### Section VII – Vessel Interaction and Noise

This section contains research related to vessel impacts including physical interactions with SRKW, fishery entanglements, noise exposure and/or response, vessel traffic, exhaust emissions, and echolocation, foraging, and social impacts.

### Section VIII – Recovery

This section relates to publications that document recovery actions related to SRKW, that address a need for recovery actions, that assess the impact of actions on recovery, or that assess recovery progress.

## Sources Reviewed

Along with a web search for relevant grey literature materials the following databases were used to identify sources: Aquatic Science and Fisheries Abstracts, Dimensions, Lens.org, Clarivate Analytics' Web of Science: Science Citation Index Expanded, Wiley Online Library, ProQuest's Earth-Atmospheric & Aquatic Science Database, Science Direct, BioOne Complete, Google Scholar via Publish or Perish, and JSTOR. Only English language materials were considered.

## Section I: Distribution and Habitat

Canadian Science Advisory Secretariat. (2017). *Identification of Habitats of Special Importance to Resident Killer Whales (Orcinus Orca) Off the West Coast of Canada.* Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40600385.pdf

In 2001, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listed Southern Resident Killer Whales (SRKWs) as Endangered and Northern Resident Killer Whales (NRKWs) as Threatened due to their small population sizes, low reproductive rates, recent unexplained declines in numbers, and the existence of a variety of anthropogenic threats (COSEWIC 2001). These listings became law 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 2011, 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 included partial identification of critical habitat and a schedule of studies to identify further areas that would be considered essential for the recovery of both SRKWs and NRKWs. The DFO Species at Risk Program has requested that DFO Science undertake an assessment of important habitats for SRKWs and NRKWs. Advice based on this assessment will be considered (by the relevant recovery teams and Species at Risk Program at DFO) in the identification of additional critical habitat for the action plans for these populations.

Drackett, L., & Dragicevic, S. (2021). Suitability Analysis of Acoustic Refugia for Endangered Killer Whales (Orcinus Orca) Using the Gis-Based Logic Scoring of Preference Method. *Environmental management*, https://doi.org/10.1007/s00267-021-01481-y

An emerging priority in marine noise pollution research is identifying marine "acoustic refugia" where noise levels are relatively low and good-quality habitat is available to acoustically sensitive species. The endangered Southern Resident population of killer whales (Orcinus orca) that inhabits the transboundary Salish Sea in Canada and the USA are affected by noise pollution. Geographic Information Systems (GIS) and spatial multicriteria evaluation (MCE) methods have been used to operationalize suitability analysis in ecology and conservation for site selection problems. However, commonly used methods lack the ability to represent complex logical relationships between input criteria. Therefore, the objective of this study is to apply a more advanced MCE method, known as Logic Scoring of Preference (LSP), to identify acoustic refugia for killer whales in the Salish Sea. This GIS-based LSP-MCE approach considers multiple input criteria by combining input data representing killer whale habitat requirements with noise pollution and other factors to identify suitable acoustic refugia. The results indicate the locations of suitable acoustic refugia and how they are affected by noise pollution from marine vessels in three scenarios developed to represent different levels of vessel traffic. Identifying acoustic refugia can contribute to efforts to reduce the effect of marine noise pollution on killer whale populations by highlighting high-priority areas in which to implement policies such as traffic-limiting measures or marine protected areas. Moreover, the proposed LSP-MCE procedure combines criteria in a stepwise manner that can support environmental management decision-making processes and can be applied to other marine suitability analysis contexts.

Emmons, C. K., Hanson, M. B., & Lammers, M. O. (2021). Passive Acoustic Monitoring Reveals Spatiotemporal Segregation of Two Fish-Eating Killer Whale Orcinus Orca Populations in Proposed Critical Habitat. *Endangered Species Research, 44*, https://doi.org/10.3354/esr01099

Competition for prey resources among ecologically similar populations that occur in sympatry can be reduced by spatiotemporal resource partitioning. Understanding patterns of habitat use of cetaceans can be difficult since they are highly mobile and can have large home ranges. We used passive acoustic monitoring at 15 sites along the coast of Washington State, USA, to assess habitat use patterns of 2 sympatric populations of fish-eating killer whales Orcinus orca: northern residents (NRKW) and southern residents (SRKW). This area is part of the ocean distributions of a number of important runs of Chinook salmon Oncorhyncus tshawytscha, the preferred prey of both populations, and is proposed critical habitat for SRKW. We compared monthly occurrence of both populations at recorder locations grouped by their proximity to the Strait of Juan de Fuca to the north and the Columbia River to the south in one analysis and by their distance from shore in a second analysis. NRKW and SRKW were detected throughout the year with spring and fall peaks in occurrence. The northernmost sites accounted for 93% of NRKW detections, while less than half of SRKW detections were at these sites. SRKW were most frequently detected at nearshore sites (83% of detections), while the majority of NRKW detections were at mid-shelf and deep sites (94% of detections). This study provides further information about the habitat use of these resident killer whale populations with implications for their management and conservation.

Ford, J. K. B., Pilkington, J. F., Reira, A., Otsuki, M., Gisborne, B., Abernethy, R. M., . . . Ellis, G. M. (2017). *Habitats of Special Importance to Resident Killer Whales (Orcinus Orca) Off the West Coast of Canada.* Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40613586.pdf

Two populations of fish-eating Killer Whales, Northern Resident and Southern Resident, inhabit waters off Canada's west coast. The populations were listed under the Species at Risk Act (SARA) as Threatened and Endangered, respectively, in 2003. As required by the SARA, efforts have since been underway to identify critical habitat for these populations. Partial critical habitat was identified for each of the two populations in the 2011 Resident Killer Whale Recovery Strategy, which included a schedule of future studies to identify additional areas of critical habitat. In this report, we identify two new areas of special importance to Resident Killer Whales that potentially meet the criteria for designation as critical habitat under the SARA. One area includes waters on the continental shelf off southwestern Vancouver Island, including Swiftsure and La Perouse Banks. The other area includes waters of west Dixon Entrance, along the north coast of Graham Island from Langara Island to Rose Spit. Long-term vesselbased field studies and remote passive underwater acoustic monitoring show that both areas are important year-round habitat for Resident Killer Whales, especially for feeding on the whales' primary prey, Chinook Salmon. The biophysical functions, features and attributes of these habitats of special importance are described, and examples of activities likely to result in the destruction of these components of critical habitat are summarized

Murray, C. C., Hannah, L. C., Doniol-Valcroze, T., Stredulinsky, E., Wright, B., Locke, A., & Lacy, R. (2019). *Cumulative Effects Assessment for Northern and Southern Resident Killer Whale Populations in the Northeast Pacific.* Fisheries and Oceans Canada Ottawa. Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40805323.pdf

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). The SARA recovery plan developed for these populations identified the assessment of the cumulative effects of anthropogenic threats impacting these populations as a high priority. To address this, a cumulative effects assessment framework was developed and applied comprising two components: a Pathways of Effects (PoE) conceptual model and a subsequent Population Viability Analysis (PVA) model. The findings of this cumulative effects assessment highlight the importance of considering threats collectively. Specifically, within the cumulative effects PVA assessment, Chinook salmon abundance and its interactions with vessel noise/presence and PCBs strongly influenced modelled killer whale population dynamics. The cumulative effects PVA model was also used to project population trajectories for NRKW and SKRW into the future. The model outputs indicate that the mean modelled NRKW population trajectory increased to the carrying capacity set in the model within 25 years. In contrast, the mean 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 86 (~c11) years. The cumulative effects assessment 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.

Noren, D. P., & Hauser, D. D. W. (2016). Surface-Based Observations Can Be Used to Assess Behavior and Fine-Scale Habitat Use by an Endangered Killer Whale (Orcinus Orca) Population. *Aquatic Mammals, 42*(2), https://doi.org/10.1578/am.42.2.2016.168

Behavioral observations can provide insight into the ecology and habitat use of marine species. Studies have shown that movement patterns are influenced by prey availability and that the presence of vessels can reduce foraging, resting, and/or social behaviors in delphinids, including killer whales (Orcinus orca). Southern resident killer whales are listed as "Endangered" in both the United States and Canada. Reduced prey availability and vessel disturbance are risk factors for this population. Surface observations were conducted to understand southern resident killer whale behavior and habitat use in their Endangered Species Act-designated core summer critical habitat. The activity budget comprised 70.4% travel, 21.0% forage, 6.8% rest, and 1.8% social behavior. Dive duration, surface duration, and swim speed varied significantly among activity states and validated the activity state classifications. For example, traveling killer whales swam the fastest and had the lowest surface to dive duration ratios, which presumably minimizes energetic costs while maximizing distance traveled. Movement patterns, spatial arrangements, and configurations of killer whales also varied significantly among activity states and, to some extent, varied by geographic location. We found that killer whale spatial arrangement and configuration patterns were strikingly different in two adjacent areas, indicating that these may change abruptly. This may be informative for vessel operators who are required to maintain a 182.9-m distance from killer whales. Killer whales engaged in most activity states throughout the area, but foraging and resting predominantly occurred in some localized regions. Activity budgets reported in the present and other contemporary studies differ from those reported 20 to 30 y ago. The proportion of forage in the activity budget has decreased in recent years, yet the main foraging area has persisted for several decades. These findings are important for understanding key risk factors for southern resident killer whales and may aid in formulating mitigation measures to protect them from vessel traffic and other human activities.

Olsen, D. W. (2017). *Hotspots and Behavioral Patterns of Southern Alaska Resident Killer Whales (Orcinus Orca).* (MS), University of Alaska Fairbanks, Retrieved from https://scholarworks.alaska.edu/handle/11122/7630

The resident killer whale (Orcinus orca) is a genetically and behaviorally distinct ecotype of killer whale that feeds primarily on Pacific salmon (Oncorhynchus spp.). Long-term monitoring over 30 years of study has enabled detailed investigation into pod-specific, seasonal, and compositional differences in space use and behavior. To investigate use of habitat, 33 resident killer whales representing 14 pods in the northern Gulf of Alaska were tagged with satellite transmitters during all years from 2006 to 2014, and transmissions were received during the months of June to January. Core use areas were identified through utilization distributions using a biased Brownian Bridge movement model. Tagging results indicate different core use areas between pods, which could be due to cultural transmission within matrilineal groups. To investigate differences in behavior, 1337 hours of behavioral data were collected from 2006 to 2015. For these observations, chi squared tests were used to determine significant differences in behavior budgets between seasons, regions, haplotypes, and numbers of pods. The presence of 'rarely sighted' pods (sighted in less than 5% of encounters) had a large influence on the frequency of social behavior, which increased from 18.5% without their presence to 31.4% with it ($X2 = 17.3$, $d f = 1$, $P < 0.001$). Frequency of social behavior was also significantly affected by the number of pods present ($X2 = 72.8$, $d f = 3$, $P < 0.001$), and increased from 4.7% to 31.2% with one pod to more than four pods present. Strong seasonal and pod-specific differences were found in core use areas, possibly driven by the availability of seasonal salmon migration. Social behavior, and to some extent foraging and resting behaviors, appear to be driven by group composition and numbers of pods throughout the spring to fall seasons. Overall, these findings help clarify spatial and behavioral patterns observed for resident killer whales.

Olson, J. K. (2018). *Southern Resident Killer Whale Sighting Compilation 1948-2017.* T. W. Museum Retrieved from https://whalemuseum.org/pages/conservation-research

The primary goal of the Southern Resident Killer Whale (SRKW) Sighting Compilation 14th Edition is to update and re-integrate available sighting data from the inland marine waters of Washington State and Southern British Columbia on the Southern Resident population of killer whales from 1948 through 2017. This 14th edition includes the addition of 2,468 new sightings. Of these sightings, 2,113 are new entries from the 2017 calendar year. An additional 355 SRKW sightings from the B. C. Cetaceans Sightings Network (BCCSN) that occurred during 2016 but were not added to their database until the 2017 season. Information processed for this database comes from identified killer whale sighting sources that have been systematically evaluated for accuracy, entered and integrated into a single uniform dataset in MS Access with normalized spatial locations that have been translated into latitude and longitude, UTM coordinates, and WDFW/DFO Fisheries reporting areas. The six primary data sources for this database are: 1) The Whale Museum’s sighting archives (which includes sightings from Museum affiliated researchers, naturalists, and whale watch companies; Orca Network sightings posted on the internet; and sightings via the Museum’s Whale Hotline); 2) Commercial whale watch pager system reports; 3) Soundwatch Boater Education program data; 4) a longitudinal dataset from Lime Kiln Point State Park; 5) SPOT recorder data; and 6) BCCSN data. This database is updated on an annual basis by staff and affiliated researchers. Included with this report are compact discs (CDs) of the entire 105,344 records in the sightings database in both MS Access and MS Excel. This project was funded with resources from NOAA Contract #RA133F-12CQ-0057 and The Whale Museum.

Olson, J. K., Wood, J., Osborne, R. W., Barrett-Lennard, L., & Larson, S. (2018). Sightings of Southern Resident Killer Whales in the Salish Sea 1976-2014: The Importance of a Long-Term Opportunistic Dataset. *Endangered Species Research, 37*, https://doi.org/10.3354/esr00918

Southern resident killer whales (SRKWs) Orcinus orca may be present year round in the Salish Sea, i.e. the inland waterways of Washington State (USA) and southern British Columbia (Canada). SRKWs were listed as endangered in 2005 under the US Endangered Species Act. The Whale Museum (Washington, USA) has been collecting opportunistic sightings reports on SRKWs since 1976 with a goal of providing managers and regulatory agencies with reliable spatial and temporal data on this population.

Information in this dataset comes from 5 classes of killer whale sighting sources and is systematically evaluated for accuracy before integration into the dataset. From 1976 to 2014, The Whale Museum's Orca Master dataset documented a total of 82 447 SRKW sightings in the Salish Sea. Sightings were concentrated in a few key hot spots, with an overall pattern of consistent presence in the Central Salish Sea during the summer months and a presence in Puget Sound proper during the fall and early winter months. A shift in SRKW presence in Puget Sound was documented in the late 1990s, possibly driven by increased foraging on fall chum salmon Oncorhynchus keta by 2 pods ('K' and 'L'), and is consistent with the hypothesis that the movement patterns of these whales may be driven by prey availability. The Whale Museum's dataset highlights the importance of long-term monitoring to document shifts that may take decades, and shows how opportunistic datasets can be valuable tools for illuminating spatial and temporal trends.

Olsen, D. W., Matkin, C. O., Andrews, R. D., & Atkinson, S. (2018). Seasonal and Pod-Specific Differences in Core Use Areas by Resident Killer Whales in the Northern Gulf of Alaska. *147*(NA), https://doi.org/10.1016/j.dsr2.2017.10.009

The resident killer whale is a genetically and behaviorally distinct ecotype of killer whale (Orcinus orca) found in the North Pacific that feeds primarily on Pacific salmon (Oncorhynchus spp .). Details regarding core use areas have been inferred by boat surveys, but are subject to effort bias and weather limitations. To investigate core use areas, 37 satellite tags were deployed from 2006 to 2014 on resident killer whales representing 12 pods in the Northern Gulf of Alaska, and transmissions were received during the months of June to January. Core use areas were identified through utilization distributions using a biased Brownian Bridge movement model. Distinct differences in these core use areas were revealed, and were highly specific to season and pod. In June, July, and August, the waters of Hinchinbrook Entrance and west of Kayak Island were primary areas used, mainly by 3 separate pods. These same pods shifted their focus to Montague Strait in August, September, and October. Port Gravina was a focal area for 2 other pods in June, July, and August, but this was not the case in later months. These pods were responsible for seven of eight documented trips into the deeper fjords of Prince William Sound, yet these fjords were not a focus for most groups of killer whales. The seasonal differences in core use may be a response to the seasonal returns of salmon, though details on specific migration routes and timing for the salmon are limited. We found strong seasonal and pod-specific shifts in patterns between core use areas. Future research should investigate pod differences in diet composition and relationships between core area use and bathymetry.

Pacific Salmon Foundation. (2019). Marine Traffic and Resident Killer Whale Critical Habitat in British Columbia. Retrieved from https://maps.sogdatacentre.ca/apps/6f0b5006a40347d3ad862219cebfa08a/explore

Web Mapping Application - This map allows you to compare large marine vessel activities with Resident Killer Whale critical habitat in British Columbia.

Rice, A., Deecke, V. B., Ford, J. K. B., Pilkington, J. F., Oleson, E. M., Hildebrand, J. A., & Sirovic, A. (2017). Spatial and Temporal Occurrence of Killer Whale Ecotypes Off the Outer Coast of Washington State, USA. *Marine Ecology Progress Series, 572*, https://doi.org/10.3354/meps12158

Three killer whale Orcinus orca ecotypes inhabit the northeastern Pacific: residents, transients, and offshores. To investigate intraspecific differences in spatial and temporal occur rence off the outer coast of Washington State, USA, 2 long-term acoustic recorders were deployed from July 2004 to August

2013: one off the continental shelf in Quinault Canyon (QC) and the other on the shelf, off Cape Elizabeth (CE). Acoustic encounters containing pulsed calls were analyzed for call types attributable to specific ecotypes, as no calls are shared between ecotypes. Both sites showed killer whale presence year-round, although site CE had a higher number of days with encounters overall. Transients were the most common ecotype at both sites and were encountered mainly during the spring and early summer. Residents were encountered primarily at site CE and showed potential seasonal segregation between the 2 resident communities, with northern residents present mainly during summer and early fall when southern residents were not encountered. Offshore encounters were higher at site QC, with little evidence for seasonality. Spatial and temporal variability of residents and transients matches the distribution of their prey and can potentially be used for further inferences about prey preferences for different transient groups.

Riera, A., Pilkington, J. F., Ford, J. K. B., Stredulinsky, E. H., & Chapman, N. R. (2019). Passive Acoustic Monitoring Off Vancouver Island Reveals Extensive Use by at-Risk Resident Killer Whale (Orcinus Orca) Populations. *Endangered Species Research, 39*, https://doi.org/10.3354/esr00966

Two sympatric populations of fish-eating Resident killer whales inhabit the coastal waters of British Columbia, Canada: Southern and Northern Resident killer whales. These populations are listed under Canada's Species at Risk Act (SARA) as 'endangered' and 'threatened', respectively. Relatively little is known about their habitat use outside of the sheltered waters along the east coast of Vancouver Island, especially during the winter. SARA requires the identification of critical habitat for these populations. High densities of Chinook salmon-their primary prey- are found around Swiftsure Bank, an area identified as potential critical habitat for Southern Residents. However, it is a difficult area to survey for whales using conventional small-boat approaches. Here, we used 2 yr of data collected from an autonomous acoustic recorder deployed at Swiftsure Bank from 2009-2011 to assess the year-round habitat use of this area by Resident killer whales. Overall, Resident killer whales were detected on 244 of 680 monitored days (36%). Southern Residents were heard in all months, with activity peaking during the summer. Northern Residents were also heard throughout the year, but were mostly detected in the spring and fall, which indicates the 2 populations may differ in their strategies for using this common foraging area. High levels of use by both of these populations highlights the importance of Swiftsure Bank to both, supporting the expansion of Resident killer whale critical habitat to include this site.

Shields, M. W., Lindell, J., & Woodruff, J. (2018). Declining Spring Usage of Core Habitat by Endangered Fish-Eating Killer Whales Reflects Decreased Availability of Their Primary Prey. *Pacific Conservation Biology, 24*(2), https://doi.org/10.1071/pc17041

The salmon-eating Southern Resident killer whales (Orcinus orca) of the north-eastern Pacific Ocean are listed as endangered both in the United States and Canada. Their critical habitat has been defined as the region ofthe inland waters of Washington State and British Columbia known as the Salish Sea, where they have traditionally spent much of their time from spring through fall. Using reports from experienced observers to sightings networks, we tracked the daily presence of the Southern Residents in these waters from 1 April to 30 June from 1994 through 2016. We found that the escapement estimates of spring Chinook salmon (Oncorhynchus tshawytscha) on the Fraser River in British Columbia were a significant predictor ofthe cumulative presence/absence ofthe whales throughout the spring season. There was also a difference in both whale presence and salmon abundance before and after 2005, suggesting that the crash in Chinook salmon numbers has fallen below threshold where it is worthwhile for the whales to spend as much time in the Salish Sea. The use of the Salish Sea by the Southern Residents has declined in the spring months as they are either foraging for Chinook salmon elsewhere or are shifting to another prey species. In order to continue providing necessary protections to this endangered species, critical habitat designations must be re-evaluated as this population ofkiller whales shifts its range in response to prey availability.

Theriault, J. A., Yurk, H., & Moors-Murphy, H. B. (2020). *Workshop Report: Review of near-Real Time Whale Detection Technologies.* Retrieved from https://publications.gc.ca/collections/collection_2020/mpo-dfo/Fs97-6-3410-eng.pdf
Vessel strikes are one of the threats negatively affecting the recovery of two of Canada's endangered whale species: North Atlantic Right Whales (NARWs) and Southern Resident Killer Whales (SRKWs). A component of Canada's Ocean Protection Plan (OPP), referred to as the Whale Detection and Collison Avoidance (WDCA) initiative, involves investigating technologies that will enable detection of whales in and around areas where vessel activities occur in support of the development of a near real-time alert system for reducing the threat of vessel strikes. This paper reviews technologies that could be used to provide information on the presence of NARWs and SRKWs in near real-time. The goal is to identify existing or emerging technologies or systems that could be useful for detecting whales, and specifically to evaluate their suitability and likely effectiveness for detecting NARWs and SRKWs in near real-time in Canadian waters. Above water sensing systems such as basic light cameras, thermal imaging detection via infrared (IR) cameras, radio detection and ranging (RADAR), and satellite-based multispectral optical technologies; and underwater sensing systems including passive acoustic monitoring (PAM) and active Sound Navigation and ranging (SONAR) technologies are considered. Visual detection and PAM systems are currently the primary and most accurate marine mammal detection modalities being used, and substantial developments in both PAM and IR camera systems in recent years make them the most promising technologies on which to focus efforts under the OPP WDCA initiative. PAM and IR camera technologies will be tested in near shore areas off eastern and western Canada, the results of which are expected to provide insights into future development of a near real-time alert system to reduce potential NARW and SRKW vessel strikes.

Williams, R., Ashe, E., Broadhurst, G., Jasny, M., Tuytel, D., Venton, M., & Ragen, T. (2021). Destroying and Restoring Critical Habitats of Endangered Killer Whales. *BioScience*, https://doi.org/10.1093/biosci/biab085
Endangered species legislation in the United States and Canada aims to prevent extinction of species, in part by designating and protecting critical habitats essential to ensure survival and recovery. These strict laws prohibit adverse modification or destruction of critical habitat, respectively. Defining thresholds for such effects is challenging, especially for wholly aquatic taxa. Destruction of critical habitat (e.g., prey reduction and ocean noise) threatens the survival and recovery of the 75 members of the endangered southern resident killer whale population found in transboundary (Canada–United States) Pacific waters. The population's dynamics are now driven largely by the cumulative effects of prey limitation (e.g., the endangered Chinook salmon), anthropogenic noise and disturbance (e.g., reducing prey accessibility), and toxic contaminants, which are all forms of habitat degradation. It is difficult to define a single threshold beyond which habitat degradation becomes destruction, but multiple lines of evidence suggest that line may have been crossed already.

## Section II: Population Dynamics and Ecology

Bubac, C. M., Johnson, A. C., & Otis, R. (2021). Surface Behaviors Correlate with Prey Abundance and Vessels in an Endangered Killer Whale (Orcinus Orca) Population. *Marine Ecology-an Evolutionary Perspective, 42*(1), https://doi.org/10.1111/maec.12626

Southern Resident killer whales (SRKWs) (Orcinus orca) are an endangered population in the United States and Canada, partly due to declines of their primary prey species, Chinook salmon. Prey availability influences various aspects of SRKW behavior, including distribution patterns and social structure. Yet, it is unclear to what extent a limited prey source influences the frequency of surface-active behaviors (SABs), behaviors with important ecological implications. Here, we used long-term datasets (1996-2019) to examine the relationships between the abundance of Chinook salmon, vessel presence, and the frequency with which SRKWs perform SABs. Salmon abundance was a significant predictor of SAB frequency, with fewer SABs performed in times of lower salmon abundance. SRKWs displayed more SABs when more whale watching vessels were present, and the whales spent a greater amount of time in the study area, performing more milling as opposed to traveling behavior, when vessel numbers were higher. Lastly, we found pod-specific differences, such that K pod displayed significantly fewer SABs than either J or L pods. The observed relationships between SRKW behavior and both salmon abundance and vessel presence have implications for social network cohesion and foraging success. Our study adds to a growing body of literature highlighting factors affecting SRKW behavior as they experience increased threats from decreased prey availability, habitat loss, and anthropogenic disturbance, with implications for trans-boundary management and conservation efforts.

Busson, M., Authier, M., Barbraud, C., Tixier, P., Reisinger, R. R., Janc, A., & Guinet, C. (2019). Role of Sociality in the Response of Killer Whales to an Additive Mortality Event. *Proceedings of the National Academy of Sciences of the United States of America, 116*(24), https://doi.org/10.1073/pnas.1817174116

In highly social top predators, group living is an ecological strategy that enhances individual fitness, primarily through increased foraging success. Additive mortality events across multiple social groups in populations may affect the social structure, and therefore the fitness, of surviving individuals. This hypothesis was examined in a killer whale (Orcinus orca) population that experienced a 7-y period of severe additive mortality due to lethal interactions with illegal fishing vessels. Using both social and demographic analyses conducted on a unique long-term dataset encompassing periods before, during, and after this event, results indicated a decrease in both the number and the mean strength of associations of surviving individuals during the additive mortality period. A positive significant correlation between association strength and apparent survival suggested that the fitness of surviving individuals was impacted by the additive mortality event. After this event, individuals responded to the loss of relatives in their social groups by associating with a greater number of other social groups, likely to maintain a functional group size that maximized their foraging success. However, these associations were loose; individuals did not reassociate in highly stable social groups, and their survival remained low years after the mortality event. These findings demonstrate how the disruption of social structure in killer whales may lead to prolonged negative effects of demographic stress beyond an additive mortality event. More importantly, this study shows that sociality has a key role in the resilience of populations to human-induced mortality; this has major implications for the conservation of highly social and long-lived species.

Carretta, J. V., Forney, K. A., Oleson, E. M., Weller, D. W., Lang, A. e. R., Baker, J. D., . . . Brownell, R. L. (2019). *U.S. Pacific Marine Mammal Stock Assessments: 2018*. La Jolla, CA https://doi.org/10.25923/x17q-2p43

Pacific region stock assessments include those studied by the Southwest Fisheries Science Center (SWFSC, La Jolla, CA), the Pacific Islands Fisheries Science Center (PIFSC, Honolulu, HI), the National Marine Mammal Laboratory (NMML, Seattle, WA), and the Northwest Fisheries Science Center (NWFSC, Seattle, WA). The 2018 Pacific marine mammal stock assessments include revised reports for 16 Pacific marine mammal stocks under NMFS jurisdiction, including 7 "strategic" stocks: Hawaiian monk seal, Eastern North Pacific blue whale, Western North Pacific gray whale, California/Oregon/Washington humpback whale, California/Oregon/Washington fin whale, Eastern North Pacific sei whale and Southern Resident killer whale. New abundance estimates are available for 8 stocks: California sea lions, Hawaiian monk seals, Eastern North Pacific Offshore killer whales, Southern Resident killer whales, Eastern North Pacific gray whales, Western North Pacific gray whales, California/Oregon/Washington humpback whales, and Hawaii Island spinner dolphins. Information on sea otters, manatees, walrus, and polar bears are published separately by the US Fish and Wildlife Service.

Carretta, J. V., Forney, K. A., Oleson, E. M., Weller, D. W., Lang, A. R., Baker, J., . . . Brownell, R. L. (2020). *U.S. Pacific Marine Mammal Stock Assessments: 2019*. La Jolla, CA https://doi.org/10.25923/trxr-z635

Pacific region stock assessments include those studied by the Southwest Fisheries Science Center (SWFSC, La Jolla, CA), the Pacific Islands Fisheries Science Center (PIFSC, Honolulu, HI), the National Marine Mammal Laboratory (NMML, Seattle, WA), and the Northwest Fisheries Science Center (NWFSC, Seattle, WA). The 2019 Pacific marine mammal stock assessments include revised reports for 10 Pacific marine mammal stocks under NMFS jurisdiction, including 6 "strategic" stocks: Guadalupe fur seal, Hawaiian monk seal, Eastern North Pacific blue whale, California/Oregon/Washington humpback whale, California/Oregon/Washington sperm whaleand Southern Resident killer whale. New abundance estimates are available for 8 stocks: Guadalupe fur seal, Hawaiian monk seal, four stocks of U.S. West Coast harbor porpoise, Southern Resident killer whale, Eastern North Pacific blue whale. Information on sea otters, manatees, walrus, and polar bears are published separately by the US Fish and Wildlife Service. New information on human-caused sources of mortality and serious injury is included for those stocks where new data are available or resulted in a significant change compared with previously-documented levels of anthropogenic mortality and injury.

Carretta, J. V., Oleson, E. M., Baker, J. D., Weller, D. W., Lang, A. e. R., Forney, K. A., . . . Brownell, R. L. (2016). *U.S. Pacific Marine Mammal Stock Assessments: 2015*. https://doi.org/10.7289/V5/TM-SWFSC-561

The 2015 Pacific marine mammal stock assessments include revised reports for eight Pacific marine mammal stocks under NMFS jurisdiction, including five "strategic" stocks: Hawaiian monk seal, Southern Resident killer whale, Eastern North Pacific blue whale, Main Hawaiian Islands Insular false killer whale, and Hawaii Pelagic false killer whale. New abundance estimates are available for three stocks in the Pacific Islands region (Hawaiian monk seal, Hawaii Pelagic and Northwestern Hawaiian Islands false killer whales) and two U.S. west coast stocks (Southern Resident killer whale and California northern fur seal). The stock range and boundaries of the three Hawaiian stocks of false killer whales, which have overlapping ranges, were recently reevaluated based on new information on the occurrence and movements of each stock (Bradford et al. 2015). New information on fisheryrelated serious injury and mortality of false killer whales has also been updated. A stock assessment report for the Eastern Tropical

Pacific stock of Bryde's whale has been reinstated into the Pacific reports in response to a regular and increasing presence of this species in southern California waters (Kerosky et al. 2012, Smultea et al. 2012). The Eastern Tropical Pacific Bryde's whale report last appeared in the Pacific stock assessments in 2007. The genus of Hawaiian monk seal has been updated from Monachus to Neomonachus to reflect recent genetic and skull morphology data (Scheel et al. 2014). The report for Eastern North Pacific blue whales includes significant new information on historic whaling removals, the population's status relative to carrying capacity, and risk of ship strikes to the population (Monnahan et al. 2014, 2015). This is a working document and individual stock assessment reports will be updated as new information on marine mammal stocks and fisheries becomes available. Background information and guidelines for preparing stock assessment reports are reviewed in Wade and Angliss (1997). The authors solicit any new information or comments which would improve future stock assessment reports

Carretta, J. V., Oleson, E. M., Forney, K. A., Lang, A. e. R., Weller, D. W., Baker, J. D., . . . Brownell, R. L. (2018). *U.S. Pacific Marine Mammal Stock Assessments: 2017*. https://doi.org/10.7289/v5/tm-swfsc-602

Pacific region stock assessments include those studied by the Southwest Fisheries Science Center (SWFSC, La Jolla, CA), the Pacific Islands Fisheries Science Center (PIFSC, Honolulu, HI), the National Marine Mammal Laboratory (NMML, Seattle, WA), and the Northwest Fisheries Science Center (NWFSC, Seattle, WA). The 2017 Pacific marine mammal stock assessments include revised reports for 35 Pacific marine mammal stocks under NMFS jurisdiction, including 9 “strategic” stocks: Hawaiian monk seal, Eastern North Pacific blue whale, Southern Resident killer whale, California/Oregon/Washington humpback whale, Hawaii sperm whale, Central North Pacific blue whale, Hawaii fin whale, Hawaii sei whale, and Main Hawaiian Islands Insular false killer whale. The status of Hawaii Pelagic false killer whale has changed from strategic to non-strategic because the 5-year annual mean human-caused serious injury and mortality is currently below PBR. New abundance estimates are available for 4 U.S. west coast stocks: Cuvier’s beaked whale, Mesoplodont beaked whales, Baird’s beaked whale, and Southern Resident killer whales. New information on fishery-related serious injury and mortality has been updated for those stocks where possible. Updated estimates of stock abundance are also available for many Pacific Islands region stocks, based on a new analysis of a 2010 pelagic line-transect survey in the region (Bradford et al. 2017a), a markrecapture photo-ID analysis of Hawaii Insular false killer whales (Bradford et al. 2017b) and completed 2015 field studies of Hawaiian monk seals (Johanos 2017a). Updated estimates of abundance are available for the following Pacific Islands stocks: Hawaiian monk seal, Hawaii rough-toothed dolphin, Hawaii Risso’s dolphin, Hawaii Pelagic bottlenose dolphin, Hawaii Pelagic pantropical spotted dolphin, Hawaii Pelagic striped dolphin, Hawaii Fraser’s dolphin, Hawaiian Islands melon-headed whale, Hawaii pygmy killer whale, Main Hawaiian Islands Insular false killer whale, Hawaii killer whale, Hawaii short-finned pilot whale, Hawaii Pelagic Blainville’s beaked whale, Hawaii Longman’s beaked whale, Hawaii Pelagic Cuvier’s beaked whale, Hawaii sperm whale, Central North Pacific blue whale, Hawaii fin whale, and Hawaii sei whale. Updated estimates of abundance are available for California Current beaked whales, based on a recent trend-based analysis (Moore and Barlow 2017). New
information on human-caused serious injury and mortality is included for California/Oregon/Washington stocks of humpback whale and the Eastern North Pacific stock of blue whale.

Carretta, J. V., Oleson, E. M., Lang, A. e. R., Weller, D. W., Baker, J. D., Muto, M., . . . Brownell, R. L. (2017). *U.S. Pacific Marine Mammal Stock Assessments: 2016*. https://doi.org/10.7289/V5/TM-SWFSC-577

Pacific region stock assessments include those studied by the Southwest Fisheries Science Center (SWFSC, La Jolla, CA), the Pacific Islands Fisheries Science Center (PIFSC, Honolulu, HI), the National Marine Mammal Laboratory (NMML, Seattle, WA), and the Northwest Fisheries Science Center (NWFSC, Seattle, WA). The 2016 Pacific marine mammal stock assessments include revised reports for 23 Pacific marine mammal stocks under NMFS jurisdiction, including eight "strategic" stocks: Hawaiian monk seal, Guadalupe fur seal, Southern Resident killer whale, California/Oregon/Washington humpback whale, California/Oregon/Washington fin whale, Eastern North Pacific sei whale, Main Hawaiian Islands Insular false killer whale, and Hawaii Pelagic false killer whale. New abundance estimates are available for 16 U.S. west coast stocks: Guadalupe fur seal, Washington Inland Waters harbor porpoise, California/Oregon/Washington stocks of Dall's porpoise, Pacific white-sided dolphin, Risso's dolphin, coastal and offshore stocks of common bottlenose dolphin, striped dolphin, short- and long-beaked common dolphin, northern right whale dolphin, short-finned pilot whale, pygmy sperm whale, fin whale, Eastern North Pacific sei whale and Southern Resident killer whales. New information on fishery-related serious injury and mortality has been updated for those stocks where possible. Updated estimates of stock abundance are also available for the Hawaiian monk seal

Croft, D. P., Johnstone, R. A., Ellis, S., Nattrass, S., Franks, D. W., Brent, L. J. N., . . . Cant, M. A. (2017). Reproductive Conflict and the Evolution of Menopause in Killer Whales. *Current Biology 27*(2), https://doi.org/10.1016/j.cub.2016.12.015

Summary Why females of some species cease ovulation prior to the end of their natural lifespan is a long-standing evolutionary puzzle [1–4]. The fitness benefits of post-reproductive helping could in principle select for menopause [1, 2, 5], but the magnitude of these benefits appears insufficient to explain the timing of menopause [6–8]. Recent theory suggests that the cost of inter-generational reproductive conflict between younger and older females of the same social unit is a critical missing term in classical inclusive fitness calculations (the \"reproductive conflict hypothesis\" [6, 9]). Using a unique long-term dataset on wild resident killer whales, where females can live decades after their final parturition, we provide the first test of this hypothesis in a non-human animal. First, we confirm previous theoretical predictions that local relatedness increases with female age up to the end of reproduction. Second, we construct a new evolutionary model and show that given these kinship dynamics, selection will favor younger females that invest more in competition, and thus have greater reproductive success, than older females (their mothers) when breeding at the same time. Third, we test this prediction using 43 years of individual-based demographic data in resident killer whales and show that when mothers and daughters co-breed, the mortality hazard of calves from older-generation females is 1.7 times that of calves from younger-generation females. Intergenerational conflict combined with the known benefits conveyed to kin by post-reproductive females can explain why killer whales have evolved the longest post-reproductive lifespan of all non-human animals.

Duffield, D., Gaydos, J. K., Raverty, S. A., Wilkinson, K. M., Norberg, B., Barre, L. M., . . . Brubaker, H. W. (2016). *Wild Animal Mortality Investigation : Southern Resident Killer Whale L-112 : Final Report*. https://doi.org/10.7289/V5/TM-NWFSC-133

The Northern Oregon/Southern Washington Marine Mammal Stranding Network received a report of a stranded female juvenile killer whale (Orcinus orca) at 07:00 on 11 February 2012, 0.9 miles (1.4 km) north of Cranberry Road, Long Beach, Washington (lat 46.41°N, long 124.06°W). Keith Chandler of Seaside Aquarium, Seaside, Oregon, responded and collected Level A data, including photographs (Figures 1 and 2). He also had the animal moved (Figure 3) to a secure area in Cape Disappointment State Park, both to protect the carcass from vandalism and to provide a suitable site for the necropsy.

The whale was subsequently identified as Southern Resident killer whale L-112, based on photographs of the dorsal fin and saddle patch that biologists from the National Marine Fisheries Service (Seattle, Washington) and the Center for Whale Research (Friday Harbor, Washington) matched to catalogs of known killer whales. To fully investigate the stranding of L-112, a member of the endangered Southern Resident killer whale population, a multidisciplinary team conducted a gross examination and full necropsy, including a suite of diagnostic tests. In addition, the team evaluated information on the sighting history of L-112 and environmental factors prior to the time of the stranding, to identify the geographic area and timing of mortality. This report compiles all available information on L-112, the gross and histopathologic findings, and additional test results, to inform our assessment of pathologic factors contributing to the whale's death. We also examine the context of the stranding, including both environmental factors and human activities, to assess the potential cause of death

Ellis, S., Franks, D. W., Weiss, M. N., Cant, M. A., Domenici, P., Balcomb, K. C., . . . Croft, D. P. (2021). Mixture Models as a Method for Comparative Sociality: Social Networks and Demographic Change in Resident Killer Whales. *Behavioral Ecology and Sociobiology, 75*(4), https://doi.org/10.1007/s00265-021-03006-3

In studies of social behaviour, social bonds are usually inferred from rates of interaction or association. This approach has revealed many important insights into the proximate formation and ultimate function of animal social structures. However, it remains challenging to compare social structure between systems or time-points because extrinsic factors, such as sampling methodology, can also influence the observed rate of association. As a consequence of these methodological challenges, it is difficult to analyse how patterns of social association change with demographic processes, such as the death of key social partners. Here we develop and illustrate the use of binomial mixture models to quantitatively compare patterns of social association between networks. We then use this method to investigate how patterns of social preferences in killer whales respond to demographic change. Resident killer whales are bisexually philopatric, and both sexes stay in close association with their mother in adulthood. We show that mothers and daughters show reduced social association after the birth of the daughter's first offspring, but not after the birth of an offspring to the mother. We also show that whales whose mother is dead associate more with their opposite sex siblings and with their grandmother than whales whose mother is alive. Our work demonstrates the utility of using mixture models to compare social preferences between networks and between species. We also highlight other potential uses of this method such as to identify strong social bonds in animal populations. Significance statement Comparing patters of social associations between systems, or between the same systems at different times, is challenging due to the confounding effects of sampling and methodological differences. Here we present a method to allow social associations to be robustly classified and then compared between networks using binomial mixture models. We illustrate this method by showing how killer whales change their patterns of social association in response to the birth of calves and the death of their mother. We show that after the birth of her calf, females associate less with their mother. We also show that whales' whose mother is dead associate more with their opposite sex siblings and grandmothers than whales' whose mother is alive. This clearly demonstrates how this method can be used to examine fine scale temporal processes in animal social systems.

Fisheries and Oceans Canada. (2019). *Population Status Update for the Northern Resident Killer Whale (Orcinus Orca) in 2018*. Ottawa: Fisheries and Oceans Canada Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/4080771x.pdf

Northern Resident Killer Whales (NRKW) are currently designated as 'Threatened' in Canada under the Species at Risk Act, due to their small population size, low reproductive rate, and the existence of several anthropogenic threats that are likely to impede their on-going population recovery or cause future population declines (DFO 2018). Population censusing by photoidentification is a key research activity outlined in the Species at Risk Act Action Plan for Resident Killer Whales (DFO 2017) and has been conducted on the NRKW population each year since 1973, making it one of the longest-running, continuous time series of data for a cetacean population. This report presents updated population information for NRKW in 2018 and supplements existing publications, particularly between releases of NRKW photo-identification catalogues. Please cite this document according to the citation provided at the end of this report. The demographic data presented here are not intended to be analyzed for further studies without permission of Fisheries and Oceans Canada's (DFO) Cetacean Research Program. Please contact the Cetacean Research Program for data use requests relating to this report. This Science Response Report results from the Science Response Process of February 2019 on the 2018 Report on the Northern Resident Killer Whale annual census.

Jensen, R., Young, J. K., & Otis, R. E. (2020). Age, Sex Class, and Prey Abundance Influence the Frequency and Type of Percussive Behavior in the Southern Resident Killer Whale (Orcinus Orca) Population at Lime Kiln Point State Park. *Northwestern Naturalist, 101*(2), https://doi.org/10.1898/1051-1733-101.2.65

The endangered Southern Resident Killer Whale (Orcinus orca, SRKW) is an iconic species in the Pacific Northwest. Although many ecological aspects of this population have been studied, why SRKW perform above-surface percussive behavior such as breaching, cartwheeling, pectoral-fin slapping, tail lobbing, and dorsal-fin slapping remains unclear. In the present study, we observed SRKW in Haro Strait, Washington, to evaluate trends in percussive behavior by age and sex class during the summer of 2016, and used long-term data (19962016) to compare the relationship between the seasonal frequency of percussive behaviors and the abundance of Chinook Salmon (Oncorhynchus tshawytscha) the primary food source of SRKW. Over the summer season in 2016, we documented 24 encounters involving percussive behavior. We found a significant difference between ages and sexes in the rate of percussive behaviors performed, with adult females performing the most behaviors among these groups, and tail slaps comprising the most frequent behavior performed. We also found a significant positive relationship between the rate of percussive behaviors and Chinook Salmon abundance in the Salish Sea over the past 2 decades. These findings present a preliminary investigation into the potential for behavioral observations to serve as indicators of population-level health or behavioral trends, which could be important for this population's conservation.

Knight, K. (2019). Male Killer Whales Unexpectedly Hunt More Than Females. *Journal of Experimental Biology, 222*(3), https://doi.org/10.1242/jeb.197798

The article focuses on the condition of the imperilled killer whales with the southern resident killer whale population announced as endangered species. It discusses how the probable cause may have been the lack of Chinook salmon in the Pacific Northwest as per Jennifer Tennessen from the National Oceanic and Atmospheric Administration (NOAA).

Murray, C. C., Hannah, L. C., Doniol-Valcroze, T., Wright, B. M., Stredulinsky, E. H., Nelson, J. C., . . . Lacy, R. C. (2021). A Cumulative Effects Model for Population Trajectories of Resident Killer Whales in

the Northeast Pacific. *Biological Conservation, 257*, https://doi.org/10.1016/j.biocon.2021.109124
Like numerous species at risk, the resident killer whale populations of the Northeast Pacific are vulnerable to the cumulative effects of anthropogenic threats. A Pathways of Effects conceptual model summarised the current understanding of each threat (prey availability, acoustic and physical disturbance, and contaminants), threat interactions, and potential impacts to fecundity and mortality. A Population Viability Analysis utilised the most recent available data to quantify impacts of threats on population parameters. The impacts of individual and cumulative threat scenarios on modelled Southern and Northern Resident Killer Whale populations were compared to the observed population demographics to define a model that best captured the real world dynamics. Of the individual and combined threat models tested, the cumulative model incorporating all threats predicted demographic rates closest to those observed for both populations. Recent low Chinook salmon abundance and its interactions with vessel disturbance and contamination strongly influenced modelled killer whale population dynamics. The cumulative effects population viability analysis model projected a mean increase in the modelled Northern Resident Killer Whale population to the carrying capacity within 25 years. In contrast, the mean modelled Southern Resident Killer Whale population trajectory was projected to decline under current conditions, with a 26% probability of population extinction, and in those projections, extinction was estimated to occur after 86 (± 11) years. Our results highlight the importance of considering the collective impact of multiple threats to imperilled species and the necessity of testing management and mitigation measures aimed at recovery using a holistic, validated model.

Ogilvie, M. K. H. (2019). *Phenological Effects on Southern Resident Killer Whale Population Dynamics.* (MSc Environment and Management), Royal Roads Univsersity, https://doi.org/10.25316/IR-14033
Southern resident killer whale survival is threatened by a variety of known risk factors, but more likely exist. As this population lives entirely within the coastal Pacific waters of North America, the ocean environment may play a role in their survival. Killer whale life history population dynamics, reproductive success and neonate survival were evaluated for links to five physical oceanographic parameters: salinity, sea surface temperature, air pressure, wave height and wave period. This phenological study was conducted within the Canadian waters of the Salish Sea in the federally identified critical habitat. The timings of physical changes were analysed annually and seasonally over temporal periods of positive and negative population trajectories. Significant relationships were found in all cases, most notably with ocean salinity and air pressure. These findings shed light on the biophysical phenological relationships in killer whale survival and should be incorporated into future recovery actions.

Olsen, D. W., Matkin, C. O., Andrews, R. D., & Atkinson, S. (2018). Seasonal and Pod-Specific Differences in Core Use Areas by Resident Killer Whales in the Northern Gulf of Alaska. *Deap-Sea Research Part II 147*, https://doi.org/10.1016/j.dsr2.2017.10.009
The resident killer whale is a genetically and behaviorally distinct ecotype of killer whale (Orcinus orca) found in the North Pacific that feeds primarily on Pacific salmon (Oncorhynchus spp .). Details regarding core use areas have been inferred by boat surveys, but are subject to effort bias and weather limitations. To investigate core use areas, 37 satellite tags were deployed from 2006 to 2014 on resident killer whales representing 12 pods in the Northern Gulf of Alaska, and transmissions were received during the months of June to January. Core use areas were identified through utilization distributions

using a biased Brownian Bridge movement model. Distinct differences in these core use areas were revealed, and were highly specific to season and pod. In June, July, and August, the waters of Hinchinbrook Entrance and west of Kayak Island were primary areas used, mainly by 3 separate pods. These same pods shifted their focus to Montague Strait in August, September, and October. Port Gravina was a focal area for 2 other pods in June, July, and August, but this was not the case in later months. These pods were responsible for seven of eight documented trips into the deeper fjords of Prince William Sound, yet these fjords were not a focus for most groups of killer whales. The seasonal differences in core use may be a response to the seasonal returns of salmon, though details on specific migration routes and timing for the salmon are limited. We found strong seasonal and pod-specific shifts in patterns between core use areas. Future research should investigate pod differences in diet composition and relationships between core area use and bathymetry.

Olsen, D. W., Matkin, C. O., Mueter, F. J., & Atkinson, S. (2020). Social Behavior Increases in Multipod Aggregations of Southern Alaska Resident Killer Whales (Orcinus Orca). *Marine Mammal Scince 36*(4), https://doi.org/10.1111/mms.12715

Killer whales (Orcinus orca) are highly social and occasionally gather in large aggregations that reach 150 individuals. During 338 encounters with Southern Alaska resident killer whales, we collected 1,352 hr of behavioral data to assess the probability of various behaviors based on season, number of pods present, presence of rarely sighted pods, and number of mitochondrial DNA haplotypes present. A binomial generalized linear model was used to estimate the role of these factors in the probability of four behaviors, foraging, resting, socializing, and traveling. The presence of “rarely sighted” pods (sighted in <5% of encounters) significantly increased probability of social behavior, and significantly decreased probability of resting. The number of pods present also significantly increased probability of increased social behavior. The presence of rarely sighted pods and the number of pods present did not have a significant interaction. Ordinal day and number of mitochondrial DNA haplotypes appears to not have changed the probability of any behavior. Foraging remained the predominant behavior throughout all factors. The concurrent increase in social behavior and decrease in resting behavior with rarely sighted pods present implies an unusually high importance of social behavior in the lives of resident killer whales.

Robeck, T. R., Willis, K., Carpuzzi, M. R. S., & O'Brien, J. K. (2016). Survivorship Pattern Inaccuracies and Inappropriate Anthropomorphism in Scholarly Pursuits of Killer Whale (Orcinus Orca) Life History: A Response to Franks Et Al. (2016). *Journal of Mammalogy, 97*(3), https://doi.org/10.1093/jmammal/gyw023

Franks et al. (2016) consider that the degree of error in estimated ages used to define survivorship patterns of northern and southern resident killer whale (Orcinus orca) populations is of insignificant impact to estimates of the species' postreproductive lifespan (PRLS). We provide evidence that survival probabilities for killer whales using a dataset comprising estimated age animals differ significantly from that determined using data collected from known-age animals in the Pacific Northwest over the past 40 years. Consequently, our findings indicate that the degree of error in age estimates and ensuing survivorship patterns do not support the notion by Franks et al. (2016) of a prolonged PRLS in the female killer whale that is comparable to the PRLS observed in humans.

Ruggerone, G. T., Springer, A. M., Shaul, L. D., & van Vliet, G. B. (2019). Unprecedented Biennial Pattern of Birth and Mortality in an Endangered Apex Predator, the Southern Resident Killer Whale, in the Eastern North Pacific Ocean. *Marine Ecology Progress Series, 608*, https://doi.org/10.3354/meps12835

We report on an unprecedented, synchronized biennial pattern of birth and mortality in an apex predator inhabiting the eastern North Pacific Ocean-the critically endangered southern resident killer whale Orcinus orca. From 1998-2017, mortality of newborn and older whales was 3.6 times higher (61 versus 17 whales) and successful births 50% lower (16 versus 32 whales) in even years than in odd years as the population decreased from 92 to only 76 whales. Percent mortality was 3.1 times higher in even years during the recent 20 yr period of population decline than during an earlier 22 yr period (1976-1997) of population increase and relative high abundance, whereas mortality in recent odd years was 43% lower. Recognized potential mechanisms of decline (low abundance of a key prey species, Chinook salmon Oncorhynchus tshawytscha, toxic contaminants, and ship noise) cannot explain this biennial pattern. We present evidence that the causal mechanism is indirectly linked to pink salmon (O. gorbuscha), which exhibit a unique and extreme biennial pattern of abundance and interact strongly with other species in marine ecosystems in the North Pacific. Further investigation of this unique biennial pattern in southern resident killer whales is needed to inform recovery efforts for the population.

Shedd, T. (2018). *Characterization of Surface Foraging Behaviors of Southern Resident Killer Whales from Aerial Photographs.* Scripps Institution of Oceanography, UC San Diego Retrieved from https://escholarship.org/uc/item/0hb1w3pz

The endangered Southern Resident Killer Whale (SRKW) population is an icon of the Pacific Northeast. The population has experienced a 10 percent decline in population since 2005 and now number only 76 individuals, the lowest abundance in more than 30 years. The SRKWs have been shown to be food-limited with declines in survival and reproduction in years following low salmon availability. Diet studies conducted on the SRKWs have shown a strong prey preference for Chinook salmon (Oncorhynchus tshawytscha) in the summer, yet uncertainty remains about prey preferences and foraging behavior. To help fill this data gap, I used high-resolution aerial images to quantify and describe foraging behavior from a new perspective. Specifically, I reviewed images collected by a small unmanned hexacopter during five individual month-long field efforts between 2015 and 2017. From this collection 29 distinct foraging events were documented in 2,384 images that allowed for photogrammetry measurements of fish size, and species identification of fish preyed upon. The data show that there is a clear difference in the size of fish chased versus the size of fish confirmed to be captured and shared with other members of the pod, suggesting that the whales may be selectively targeting certain size or age classes of fish. Most of the fish observed within the study were determined to be Chinook salmon with the possibility of other salmonid species also being preyed upon. Of the 18 successful foraging events, prey-sharing occurred 88% of the time, with 62.5% of prey-sharing behavior occurring between mothers and calves. This knowledge is important to the successful management and protection of this unique and critically endangered population. Knowing targeted species and size classes of fish can allow for better fishing and recovery strategies, which may lead to increased foraging success of the SRKWs.

Shedd, T., Northey, A., & Larson, S. (2020). Epimeletic Behaviour in a Southern Resident Killer Whale (Orcinus Orca). *Canadian Field-Naturalist, 134*(4), https://doi.org/10.22621/cfn.v134i4.2555

Southern Resident Killer Whale (SRKW, Orcinus orca) may be found year round in the Salish Sea. These orcas comprise three matrilineal pods (J, K, and L) and were listed as Endangered under the Canadian

Species at Risk Act in 2003 and under the United States Endangered Species Act in 2005 because of prey scarcity, vessel noise and disturbance, small population size, and exposure to toxins. Since 1993, the Whale Museum has been operating Soundwatch, a boater education program for vessels. Soundwatch personnel are on the water in the central Salish Sea throughout the summer educating boaters on how to maneuver near marine mammals legally and documenting vessel regulation violations and marine mammal presence and behaviour. Starting on 24 July 2018, Soundwatch documented an adult female SRKW of J pod (J35) carrying a dead neonate calf. J35 continued to carry her dead calf for 17 consecutive days covering ~1600 km. Her story riveted the attention of the people of the Salish Sea as well as people around the world, evoking empathy for J35 and her loss as well as the plight of the Endangered SRKW population. Here, we tell her story and evaluate whether the behaviour J35 displayed toward her dead calf was an example of epimeletic behaviour, animal grief.

Shields, M. W., Hysong-Shimazu, S., Shields, J. C., & Woodruff, J. (2018). Increased Presence of Mammal-Eating Killer Whales in the Salish Sea with Implications for Predator-Prey Dynamics. *Peerj, 6*, https://doi.org/10.7717/peerj.6062

The inland waters of Washington State and southern British Columbia, collectively known as the Salish Sea, comprise key habitat for two regional populations of killer whales (Orcinus orca): the mammal-eating West Coast Transients and the endangered fish-eating Southern Residents. These two populations are genetically distinct and may avoid each other. Transient killer whale usage of the Salish Sea has been previously assessed over two seven-year time periods, showing an increase from 1987 to 2010. We documented a continued significant increase in mammal-eating killer whale presence in the Salish Sea from 2011 to 2017, with intra- and inter-annual variability and with record sightings in 2017. This continued increase, likely in response to abundant marine mammal prey, is related to both a growing population and an increase in the number of West Coast Transients visiting the area. Additionally, a negative binomial regression shows that absence of Southern Residents is correlated to transient presence. Finally, both populations of killer whales have been linked to regional harbor seal populations; harbor seals are salmonid-eating competitors of the Southern Residents and are prey for the mammal-eating transients. With Southern Residents listed as endangered, culling harbor seals has been proposed as a measure to help in their recovery. With this in mind, we developed an energetic model to assess the minimum number of harbor seals consumed by transient killer whales. Using the actual number of whales present in each age-sex class for each day of the year, we estimate that, at a minimum, transients in the Salish Sea consumed 1090 seals in 2017. This is more than 2% of the 2014 estimated harbor seal population the Salish Sea. The population controlling effects of transient killer whale predation on harbor seals should be considered when evaluating any pinniped management actions in the Salish Sea.

Souhaut, M., & Shields, M. W. (2021). Stereotyped Whistles in Southern Resident Killer Whales. *PeerJ, 9*, https://doi.org/10.7717/peerj.12085

The endangered Southern Resident killer whales (Orcinus orca) of the northeast Pacificregion use two main types of vocal signals to communicate: discrete calls and whistles.Despite being one of the most-studied cetacean populations in the world, whistleshave not been as heavily analyzed due to their relatively low occurrence comparedto discrete calls. The aim of the current study is to further investigate the whistlerepertoire and characteristics of the Southern Resident killer whale population. Acousticdata were collected between 2006–2007 and 2015–2017 in the waters around San JuanIsland, Washington State, USA from boats and from shore. A total of 228 whistleswere extracted and analyzed with 53.5% of them found to be stereotyped. Three ofthe four stereotyped whistles identified by a previous study using recordings from1979–1982 were still occurring, demonstrating that whistles are stable vocalizationsfor a period of more than 35 years. The presence of three new stereotyped whistleswas also documented. These results demonstrate that whistles share the longevity andvocal tradition of discrete calls, and warrant further study as a key element of SouthernResident killer whale communication and cultural transmission

Stewart, J. D., Durban, J. W., Fearnbach, H., Barrett-Lennard, L. G., Casler, P. K., Ward, E. J., & Dapp, D. R. (2021). Survival of the Fattest: Linking Body Condition to Prey Availability and Survivorship of Killer Whales. *ECOSPHERE, 12*(8), https://doi.org/10.1002/ecs2.3660

Recovering small, endangered populations is challenging, especially if the drivers of declines are not well understood. While infrequent births and deaths may be important to the outlook of endangered populations, small sample sizes confound studies seeking the mechanisms underlying demographic fluctuations. Individual metrics of health, such as nutritive condition, can provide a rich data source on population status and may translate into population trends. We examined interannual changes in body condition metrics of endangered Southern Resident killer whales (SRKW) collected using helicopters and remotely operated drones. We imaged and measured the condition of the majority of all three social pods (J, K, and L) in each of seven years between 2008 and 2019. We used Bayesian multi-state transition models to identify relationships between body condition changes and both tributary-specific and area-based indices of Chinook salmon abundance, and K-fold cross-validation to compare the predictive power of candidate salmon covariates. We found that Fraser River (tributary-specific) and Salish Sea (area-based) Chinook salmon abundances had the greatest predictive power for J Pod body condition changes, as well as the strongest relationships between any salmon covariates and SRKW condition across pods. Puget Sound (tributary-specific) Chinook salmon abundance had the greatest predictive power for L Pod body condition changes, but a weaker relationship than Fraser River or Salish Sea abundance had with J Pod body condition. The best-fit model for K Pod included no Chinook covariates. In addition, we found elevated mortality probabilities in SRKW exhibiting poor body condition (reflecting depleted fat reserves), 2-3 times higher than whales in more robust condition. Collectively, these findings demonstrate that (1) fluctuations in SRKW body condition can in some cases be linked to Chinook salmon abundance; (2) the three SRKW pods appear to have distinct patterns of body condition fluctuations, suggesting different foraging patterns; and (3) aerial photogrammetry is a useful early-warning system that can identify SRKW at higher risk of mortality in the near future.

Tennessen, J., Holt, M. M., Hanson, B., Emmons, C. K., Giles, D. A., & Hogan, J. (2018). *Multi-Sensor Archival Tags on Southern Resident Killer Whales Reveal Patterns in Kinematic Behavior During Subsurface Foraging in the Salish Sea*. Paper presented at the Salish Sea Ecosystem Conference, Seattle, WA. Oral Retrieved from https://cedar.wwu.edu/ssec/2018ssec/allsessions/478/

Accumulating evidence suggests that Endangered southern resident killer whales may not be meeting their energetic requirements for body maintenance and growth, which can negatively affect survival and reproduction. A variety of factors are likely contributing to the decline in body condition and population size of southern residents, including disturbance from vessels and noise, which is known to interfere with foraging behavior. Between 2010-2014 we deployed 28 suction cup-attached digital acoustic recording tags (“DTAGs”) equipped with hydrophones, pressure sensors, and tri-axial accelerometers and magnetometers on southern residents as part of a study to investigate how underwater vessel noise impacts foraging behavior. Here, we present a fine-scale analysis of the kinematic behavior associated with subsurface foraging, which is a necessary precursor to understanding how vessel noise may be

impairing successful foraging. First, we describe a method to identify subsurface prey capture events using kinematic data, and characterize the kinematic behavior associated with prey capture dives. Next, we show how foraging behavior differs between sexes. Finally, we discuss next steps to relate these findings to vessel noise impacts and implications for population recovery.

Towers, J. R., Pilkington, J. F., Gisborne, B., Wright, B. M., Ellis, G. M., Ford, J. K. B., & Doniol-Valcroze, T. (2020). Photo-Identification Catalogue and Status of the Northern Resident Killer Whale Population in 2019. Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40877012.pdf

Censuses of the northern resident killer whale population using photoidentification have been conducted annually since 1973. These studies are based on photographic recapture of permanent natural markings on every individual within the population. In this report, we summarize northern resident killer whale population trends over the time series of this study and provide a photo-identification catalogue of all individuals considered to be alive in 2019. This population has grown at a mean annual rate of 2.2% since 1973 and in 2019 contained a minimum of 310 individuals. Continued annual photo-identification censusing is a key strategy to accurately document the abundance, genealogy, sociality, demographics, and health of this threatened population.

Ward, E. J., Dahlheim, M. E., Waite, J. M., Emmons, C. K., Marshall, K. N., Chasco, B. E., & Balcomb, K. C., III. (2016). Long-Distance Migration of Prey Synchronizes Demographic Rates of Top Predators across Broad Spatial Scales. *Ecosphere, 7*(2), https://doi.org/10.1002/ecs2.1276

Reproductively and geographically isolated populations of predators may be synchronized by a phenomenon known as the Moran effect-specifically if they exhibit common responses to external processes, such as climate, density dependence (parasites, disease), or prey. Prey has the ability to synchronize predators if geographically isolated predator populations target the same prey species, or if the migration and range of the prey species occurs over a large enough scale to be available to multiple predator populations. The objective of our study was to investigate evidence for correlations of demographic rates between geographically isolated populations of piscivorous killer whales in the Northeast Pacific; using long-term mark-recapture datasets collected over the last 30+ yrs, we constructed a hierarchical occupancy model, linking models of survival and fecundity in a single framework. We found strong support for synchronized demographic rates in Southeast Alaska and Southern Resident killer whales, which are geographically and reproductively isolated. Despite their isolation, they experience extremely correlated dynamics-the correlation in fecundity rates between populations exceeds 0.9. The correlation in demographic rates across these populations of killer whales in different regions of the Northeast Pacific Ocean suggests a common environmental driver. Both killer whale populations are known to prey on Chinook salmon, which have a long-distance coastal migration larger than the habitat range of killer whales. Many of these Chinook salmon are also of the same origin (southern stocks), suggesting that these populations not only consume the same prey species but the same prey populations.

Wasser, S. K., Lundin, J. I., Ayres, K., Seely, E., Giles, D., Balcomb, K., . . . Booth, R. (2017). Population Growth Is Limited by Nutritional Impacts on Pregnancy Success in Endangered Southern Resident Killer Whales (Orcinus Orca). *Plos One, 12*(6), https://doi.org/10.1371/journal.pone.0179824

The Southern Resident killer whale population (Orcinus orca) was listed as endangered in 2005 and shows little sign of recovery. These fish eating whales feed primarily on endangered Chinook salmon.

Population growth is constrained by low offspring production for the number of reproductive females in the population. Lack of prey, increased toxins and vessel disturbance have been listed as potential causes of the whale's decline, but partitioning these pressures has been difficult. We validated and applied temporal measures of progesterone and testosterone metabolites to assess occurrence, stage and health of pregnancy from genotyped killer whale feces collected using detection dogs. Thyroid and glucocorticoid hormone metabolites were measured from these same samples to assess physiological stress. These methods enabled us to assess pregnancy occurrence and failure as well as how pregnancy success was temporally impacted by nutritional and other stressors, between 2008 and 2014. Up to 69% of all detectable pregnancies were unsuccessful; of these, up to 33% failed relatively late in gestation or immediately post-partum, when the cost is especially high. Low availability of Chinook salmon appears to be an important stressor among these fish-eating whales as well as a significant cause of late pregnancy failure, including unobserved perinatal loss. However, release of lipophilic toxicants during fat metabolism in the nutritionally deprived animals may also provide a contributor to these cumulative effects. Results point to the importance of promoting Chinook salmon recovery to enhance population growth of Southern Resident killer whales. The physiological measures used in this study can also be used to monitor the success of actions aimed at promoting adaptive management of this important apex predator to the Pacific Northwest.

Weiss, M. N., Franks, D. W., Giles, D. A., Youngstrom, S., Wasser, S. K., Balcomb, K. C., . . . Croft, D. P. (2021). Age and Sex Influence Social Interactions, but Not Associations, within a Killer Whale Pod. *Proceedings of the Royal Society B: Biological Sciences, 288*(1953), https://doi.org/10.1098/rspb.2021.0617

Social structure is a fundamental aspect of animal populations. In order to understand the function and evolution of animal societies, it is important to quantify how individual attributes, such as age and sex, shape social relationships. Detecting these influences in wild populations under natural conditions can be challenging, especially when social interactions are difficult to observe and broad-scale measures of association are used as a proxy. In this study, we use unoccupied aerial systems to observe association, synchronous surfacing, and physical contact within a pod of southern resident killer whales (Orcinus orca). We show that interactions do not occur randomly between associated individuals, and that interaction types are not interchangeable. While age and sex did not detectably influence association network structure, both interaction networks showed significant social homophily by age and sex, and centrality within the contact network was higher among females and young individuals. These results suggest killer whales exhibit interesting parallels in social bond formation and social life histories with primates and other terrestrial social mammals, and demonstrate how important patterns can be missed when using associations as a proxy for interactions in animal social network studies.

Wright, B. M., Stredulinsky, E. H., Ellis, G. M., & Ford, J. K. B. (2016). Kin-Directed Food Sharing Promotes Lifetime Natal Philopatry of Both Sexes in a Population of Fish-Eating Killer Whales, Orcinus Orca. *Animal Behaviour, 115*, https://doi.org/10.1016/j.anbehav.2016.02.025

The vast majority of social animals exhibit sex-biased dispersal as a strategy to reduce kin competition and avoid inbreeding. Piscivorous ‘resident’ killer whales, Orcinus orca, of the eastern North Pacific, however, are unusual in that both sexes remain philopatric throughout life, forming highly stable, multigeneration matrilines that are closed to immigration. We conducted a 12-year study documenting extensive cooperative prey sharing within these matrilines, and hypothesized that extreme natal philopatry in resident killer whales arose due to inclusive fitness benefits gained by provisioning maternal kin. We found that prey sharing was nonreciprocal, and even though whales routinely foraged in mixed associations containing multiple matrilines, prey sharing among individuals belonging to different matrilines was very infrequent. Furthermore, maternal relatedness was a significant predictor of the frequency of prey sharing between individuals, with close maternal kin sharing more often than distant relatives or nonkin. Adult females were much more likely to share prey than adult males or subadults, probably because they mainly provisioned their offspring. However, food sharing was not limited solely to maternal care; all ageesex classes engaged in this behaviour by sharing with close maternal relatives, such as siblings and mothers. We also investigated the frequency of prey sharing between mothers and their offspring as a function of offspring sex and age, and found that maternal food sharing with daughters declined after daughters reached reproductive maturity, which could help to explain matriline fission events. The evolution of kin-directed food sharing requires the ability to reliably discriminate kin, which resident killer whales likely achieve through social familiarity and vocal dialect recognition. We propose that lifetime philopatry of both sexes has been selectively favoured in this population due to the inclusive fitness benefits of kin-directed food sharing, a cooperative behaviour that may also inhibit dispersal by reducing resource competition among kin.

Workgroup, S. R. K. W. (2020). *Pacific Fishery Management Council Salmon Fishery Management Plan Impacts to Southern Resident Killer Whales: Risk Assessment.* Retrieved from https://www.pcouncil.org/june-2020-briefing-book/

This report is a product of PFMC's ad-hoc SRKW Workgroup which was tasked with reassessing the effects of Council-area ocean salmon fisheries on SRKW. We first provide a brief overview of the background context, workshop process, and the role of the SRKW Workgroup. Then we assess the current status of the SRKWs, followed by describing the interactions known to occur between SRKW and salmon fisheries, leading to a general description of the Pacific Coast Salmon Fishery Management Plan (FMP). Lastly, we attempt to assess how reductions in prey through implementing the FMP may affect SRKW demographics.

## Section III: Genetics

Baker, C. S., Steel, D., Nieukirk, S., & Klinck, H. (2018). Environmental DNA (Edna) from the Wake of the Whales: Droplet Digital Pcr for Detection and Species Identification. *Frontiers in Marine Science, 5*, https://doi.org/10.3389/fmars.2018.00133

Genetic sampling for identification of species, subspecies or stock of whales, dolphins and porpoises at sea remains challenging. Most samples have been collected with some form of a biopsy dart requiring a close approach of a vessel while the individual is at the surface. Here we have adopted droplet digital (dd)PCR technology for detection and species identification of cetaceans using environmental (e)DNA collected from seawater. We conducted a series of eDNA sampling experiments during 25 encounters with killer whales, Orcinus orca, in Puget Sound (the Salish Sea). The regular habits of killer whales in these inshore waters allowed us to locate pods and collect seawater, at an initial distance of 200 m and at 15-min intervals, for up to 2 h after the passage of the whales. To optimize detection, we designed a set of oligonucleotide primers and probes to target short fragments of the mitochondrial (mt)DNA control region, with a focus on identification of known killer whale ecotypes. We confirmed the potential to detect eDNA in the wake of the whales for up to 2 h, despite movement of the water mass by several kilometers due to tidal currents. Re-amplification and sequencing of the eDNA barcode confirmed that the ddPCR detection included the "southern resident community" of killer whales, consistent with the calls from hydrophone recordings and visual observations.

Crossman, C. A., Barrett-Lennard, L. G., & Frasier, T. R. (2021). An Example of DNA Methylation as a Means to Quantify Stress in Wildlife Using Killer Whales. *Scientific Reports, 11*(1), https://doi.org/10.1038/s41598-021-96255-1

The cumulative effects of non-lethal stressors on the health of biodiversity are a primary concern for conservation, yet difficulties remain regarding their quantification. In mammals, many stressors are processed through a common stress-response pathway, and therefore epigenetic changes in genes of this pathway may provide a powerful tool for quantifying cumulative effects. As a preliminary assessment of this approach, we investigated epigenetic manifestations of stress in two killer whale populations with different levels of exposure to anthropogenic stressors. We used bisulfite amplicon sequencing to compare patterns of DNA methylation at 25 CpG sites found in three genes involved in stress response and identified large differences in the level of methylation at two sites consistent with differential stress exposure between Northern and Southern Resident killer whale populations. DNA methylation patterns could therefore represent a useful method to assess the cumulative effects of non-lethal stressors in wildlife.

Emmons, C. K., Hard, J. J., Dahlheim, M. E., & Waite, J. M. (2019). Quantifying Variation in Killer Whale Orcinus Orca Morphology Using Elliptical Fourier Analysis. *Marine Mammal Science, 35*(1), https://doi.org/10.1111/mms.12505

In the northeastern Pacific Ocean, there are three “ecotypes” of killer whales that differ in diet, ecology, behavior, acoustics, genetics, and morphology. Previous attempts to describe the morphological differences among populations of killer whales (Orcinus orca) have been limited to descriptive accounts or categorical studies. We used elliptical Fourier analysis (EFA) to quantify shape differences of dorsal fins and pigmentation patterns among the ecotypes from photo-identification data of more than 500 individuals. Variation in shapes of the dorsal fin, saddle patch, and eye patch were successfully quantified using EFA, and there were highly significant ($P < 0.01$) differences among the ecotypes in all three morphological traits. The ability of EFA to discriminate ecotypes based on dorsal fin and eye patch shapes was substantial, while it did not perform as well for saddle patches. Visualization of the shape variation along principal component axes mirrored previous descriptions of the differences among ecotypes. Although the degree of inheritance of morphology in killer whales has not been determined, these results are consistent with previous inference of reduced gene flow between the ecotypes, and introduces elliptical Fourier analysis to the study of cetacean morphometrics.

Filatova, O., Borisova, E. A., Meschersky, I. G., Logacheva, M. D., Kuzkina, N. V., Shpak, O. V., . . . Hoyt, E. (2018). Colonizing the Wild West: Low Diversity of Complete Mitochondrial Genomes in Western North Pacific Killer Whales Suggests a Founder Effect. *Journal of Heredity 109*(7), https://doi.org/10.1093/jhered/esy037

In the North Pacific, fish-eating R-type \"resident\" and mammal-eating T-type \"transient\" killer whales do not interbreed and differ in ecology and behavior. Full-length mitochondrial genomes (about 16.4 kbp) were sequenced and assembled for 12 R-type and 14 T-type killer whale samples from different areas of the western North Pacific. All R-type individuals had the same haplotype, previously described for R-type killer whales from both eastern and western North Pacific. However, haplotype diversity of R-type killer whales was much lower in the western North Pacific than in the Aleutian Islands and the eastern North Pacific. T-type whales had 3 different haplotypes, including one previously undescribed. Haplotype diversity of T-type killer whales in the Okhotsk Sea was also much lower than in the Aleutian Islands and the eastern North Pacific. The highest haplotype diversity for both R- and T-type killer whales was observed in the Aleutian Islands. We discuss how the environmental conditions during the last glacial period might have shaped the history of killer whale populations in the North Pacific. Our results suggest the recent colonization or re-colonization of the western North Pacific by small groups of killer whales originating from the central or eastern North Pacific, possibly due to favorable environmental changes after the Last Glacial Maximum.

Ford, M. J., Parsons, K. M., Ward, E. J., Hempelmann, J. A., Emmons, C. K., Hanson, M. B., . . . Park, L. K. (2018). Inbreeding in an Endangered Killer Whale Population. *Animal Conservation, 21*(5), https://doi.org/10.1111/acv.12413
There are genetic risks associated with small population sizes, including loss of genetic diversity and inbreeding depression. The southern resident killer whale Orcinus orca population is a group of similar to 80 whales listed as 'endangered' under the U.S. Endangered Species Act. Recovery efforts are focused on increasing prey and reducing impacts from environmental disturbance, but the population's small size and insularity suggest that inbreeding depression could also be important. We analyzed genotypes at 68-94 nuclear loci from 105 individuals to refine a population pedigree to evaluate inbreeding and the relationship between multi-locus heterozygosity and fitness. Our results expand upon an earlier study and shed new light on both inbreeding within this population and the mating patterns of killer whales. We found that only two adult males sired 52% of the sampled progeny born since 1990. Confirming earlier results, we found male reproductive success increased with age. Based on the pedigree, four sampled offspring were the result of inbred mating - two between a parent and offspring, one between paternal half-siblings, and one between uncle and half-niece. There is no evidence to date that the survival or fecundity of these individuals is lower than normal. There was some evidence for inbreeding depression in the form of a weakly supported relationship between multi-locus heterozygosity and annual survival probability, but the power of our data to quantify this effect was low. We found no evidence of inbreeding avoidance in the population, but a late age of breeding success for males may indirectly limit the frequency of parent/offspring mating. The effective number of breeders in the population is currently similar to 26, and was estimated to have ranged from 12-53 over the past 40 years. The population that produced the oldest (pre-1970) sampled individuals was estimated to have 24 effective breeders. Overall, our results indicate that inbreeding is likely common in the population, but the fitness effects continue to be uncertain.

Nielsen, M. L. K., Ellis, S., Towers, J. R., Doniol-Valcroze, T., Franks, D. W., Cant, M. A., . . . Croft, D. P. (2021). A Long Postreproductive Life Span Is a Shared Trait among Genetically Distinct Killer Whale Populations. *Ecology and Evolution 11*(13), https://doi.org/10.1002/ece3.7756
The extended female postreproductive life span found in humans and some toothed whales remains an evolutionary puzzle. Theory predicts demographic patterns resulting in increased female relatedness with age (kinship dynamics) can select for a prolonged postreproductive life span due to the combined costs of intergenerational reproductive conflict and benefits of late-life helping. Here, we test this prediction using >40 years of longitudinal demographic data from the sympatric yet genetically distinct killer whale ecotypes: resident and Bigg's killer whales. The female relatedness with age is predicted to increase in both ecotypes, but with a less steep increase in Bigg's due to their different social structure. Here, we show that there is a significant postreproductive life span in both ecotypes with >30% of adult female years being lived as postreproductive, supporting the general prediction that an increase in local relatedness with age predisposes the evolution of a postreproductive life span. Differences in the magnitude of kinship dynamics however did not influence the timing or duration of the

postreproductive life span with females in both ecotypes terminating reproduction before their mid-40s followed by an expected postreproductive period of about 20 years. Our results highlight the important role of kinship dynamics in the evolution of a long postreproductive life span in long-lived mammals, while further implying that the timing of menopause may be a robust trait that is persistent despite substantial variation in demographic patterns among populations.

## Section IV: Prey

Adams, J., Kaplan, I. C., Chasco, B., Marshall, K. N., Acevedo-Gutiérrez, A., & Ward, E. J. (2016). A Century of Chinook Salmon Consumption by Marine Mammal Predators in the Northeast Pacific Ocean. *Ecological Informatics, 34*, https://doi.org/10.1016/j.ecoinf.2016.04.010

As many marine mammal populations have increased following bans on their harvest, there has been a growing need to understand potential impacts of these population changes on coastal marine ecosystems. Quantifying consumption of prey species, such as fish, is particularly important when those same prey are also targeted by commercial fisheries. Estimating the impact of marine mammal predators on prey fish depends upon knowledge of marine mammal diet composition; scientific advances over the last century have improved understanding of diets but have also led to inconsistent methods that challenge attempts at synthesis and comparison. Meta-analysis techniques offer the opportunity to overcome such challenges, yet have not been widely applied to synthesize marine mammal diets over space and time. As a case study, we focus on synthesizing diet studies of Chinook (king) salmon (Oncorhynchus tshawytscha) by four species of marine mammal predators in the Northeast Pacific Ocean: Steller sea lions (Eumetopias jubatus), California sea lions (Zalophus californianus), harbor seals (Phoca vitulina), and killer whales (Orcinus orca). We also highlight several simple meta-analyses for which these types of diet databases may be employed. Our assembled database consists of > 330 records, spanning more than 100 years. Results indicate that the frequency of occurrence of Chinook salmon in killer whale studies is high (63%) relative to pinniped studies (< 10%). They also suggest a strong increasing ability to discriminate Chinook salmon from other salmonids, which we attribute to switches in diet studies from lethal or observational sampling toward molecular methods (DNA, fatty acids). Our database and analysis code are published as supplementary material, which we hope will be useful for other researchers and will inspire more of these syntheses.

Chasco, B., Kaplan, I. C., Thomas, A., Acevedo-Gutiérrez, A., Noren, D., Ford, M. J., . . . Ward, E. J. (2017). Estimates of Chinook Salmon Consumption in Washington State Inland Waters by Four Marine Mammal Predators from 1970 to 2015. *Canadian Journal of Fisheries and Aquatic Sciences, 74*(8), https://doi.org/10.1139/cjfas-2016-0203

Conflicts can arise when the recovery of one protected species limits the recovery of another through competition or predation. The recovery of many marine mammal populations on the west coast of the United States has been viewed as a success; however, within Puget Sound in Washington State, the increased abundance of three protected pinniped species may be adversely affecting the recovery of threatened Chinook salmon (Oncorhynchus tshawytscha) and endangered killer whales (Orcinus orca) within the region. Between 1970 and 2015, we estimate that the annual biomass of Chinook salmon consumed by pinnipeds has increased from 68 to 625 metric tons. Converting juvenile Chinook salmon into adult equivalents, we found that by 2015, pinnipeds consumed double that of resident killer whales and six times greater than the combined commercial and recreational catches. We demonstrate the importance of interspecific interactions when evaluating species recovery. As more protected species respond positively to recovery efforts, managers should attempt to evaluate tradeoffs between these recovery efforts and the unintended ecosystem consequences of predation and competition on other protected species.

Chasco, B. E., Kaplan, I. C., Thomas, A. C., Acevedo-Gutierrez, A., Noren, D. P., Ford, M. J., . . . Ward, E. J. (2017). Competing Tradeoffs between Increasing Marine Mammal Predation and Fisheries Harvest of Chinook Salmon. *Scientific Reports, 7*(1), https://doi.org/10.1038/s41598-017-14984-8

Many marine mammal predators, particularly pinnipeds, have increased in abundance in recent decades, generating new challenges for balancing human uses with recovery goals via ecosystem-based management. We used a spatio-temporal bioenergetics model of the Northeast Pacific Ocean to quantify how predation by three species of pinnipeds and killer whales (Orcinus orca) on Chinook salmon (Oncorhynchus tshawytscha) has changed since the 1970s along the west coast of North America, and compare these estimates to salmon fisheries. We find that from 1975 to 2015, biomass of Chinook salmon consumed by pinnipeds and killer whales increased from 6,100 to 15,200 metric tons (from 5 to 31.5 million individual salmon). Though there is variation across the regions in our model, overall, killer whales consume the largest biomass of Chinook salmon, but harbor seals (Phoca vitulina) consume the largest number of individuals. The decrease in adult Chinook salmon harvest from 1975-2015 was 16,400 to 9,600 metric tons. Thus, Chinook salmon removals (harvest + consumption) increased in the past 40 years despite catch reductions by fisheries, due to consumption by recovering pinnipeds and endangered killer whales. Long-term management strategies for Chinook salmon will need to consider potential conflicts between rebounding predators or endangered predators and prey.

Ford, M. J., Hempelmann, J., Hanson, M. B., Ayres, K. L., Baird, R. W., Emmons, C. K., . . . Park, L. K. (2016). Estimation of a Killer Whale (Orcinus Orca) Population's Diet Using Sequencing Analysis of DNA from Feces. *Plos One, 11*(1), https://doi.org/10.1371/journal.pone.0144956

Estimating diet composition is important for understanding interactions between predators and prey and thus illuminating ecosystem function. The diet of many species, however, is difficult to observe directly. Genetic analysis of fecal material collected in the field is therefore a useful tool for gaining insight into wild animal diets. In this study, we used high-throughput DNA sequencing to quantitatively estimate the diet composition of an endangered population of wild killer whales (Orcinus orca) in their summer range in the Salish Sea. We combined 175 fecal samples collected between May and September from five years between 2006 and 2011 into 13 sample groups. Two known DNA composition control groups were also created. Each group was sequenced at a ~330bp segment of the 16s gene in the mitochondrial genome using an Illumina MiSeq sequencing system. After several quality controls steps, 4,987,107 individual sequences were aligned to a custom sequence database containing 19 potential fish prey species and the most likely species of each fecal-derived sequence was determined. Based on these alignments, salmonids made up >98.6% of the total sequences and thus of the inferred diet. Of the six salmonid species, Chinook salmon made up 79.5% of the sequences, followed by coho salmon (15%). Over all years, a clear pattern emerged with Chinook salmon dominating the estimated diet early in the summer, and coho salmon contributing an average of >40% of the diet in late summer. Sockeye salmon appeared to be occasionally important, at >18% in some sample groups. Non-salmonids were rarely observed. Our results are consistent with earlier results based on surface prey remains, and confirm the importance of Chinook salmon in this population's summer diet.

Hanson, M. B., Emmons, C. K., Ford, M. J., Everett, M., Parsons, K., Park, L. K., . . . Barre, L. (2021). Endangered Predators and Endangered Prey: Seasonal Diet of Southern Resident Killer Whales. *Plos One, 16*(3), https://doi.org/10.1371/journal.pone.0247031

Understanding diet is critical for conservation of endangered predators. Southern Resident killer whales (SRKW) (Orcinus orca) are an endangered population occurring primarily along the outer coast and inland waters of Washington and British Columbia. Insufficient prey has been identified as a factor limiting their recovery, so a clear understanding of their seasonal diet is a high conservation priority. Previous studies have shown that their summer diet in inland waters consists primarily of Chinook salmon (Oncorhynchus tshawytscha), despite that species' rarity compared to some other salmonids. During other times of the year, when occurrence patterns include other portions of their range, their diet remains largely unknown. To address this data gap, we collected feces and prey remains from October to May 2004-2017 in both the Salish Sea and outer coast waters. Using visual and genetic species identification for prey remains and genetic approaches for fecal samples, we characterized the diet of the SRKWs in fall, winter, and spring. Chinook salmon were identified as an important prey item year-round, averaging similar to 50% of their diet in the fall, increasing to 70-80% in the mid-winter/early spring, and increasing to nearly 100% in the spring. Other salmon species and non-salmonid fishes, also made substantial dietary contributions. The relatively high species diversity in winter suggested a possible lack of Chinook salmon, probably due to seasonally lower densities, based on SRKW's proclivity to selectively consume this species in other seasons. A wide diversity of Chinook salmon stocks were consumed, many of which are also at risk. Although outer coast Chinook samples included 14 stocks, four rivers systems accounted for over 90% of samples, predominantly the Columbia River. Increasing the abundance of Chinook salmon stocks that inhabit the whales' winter range may be an effective conservation strategy for this population.

Kendall, N. W., Nelson, B. W., & Losee, J. (2020). Density-Dependent Marine Survival of Hatchery-Origin Chinook Salmon May Be Associated with Pink Salmon. *Ecosphere, 11*(4), https://doi.org/10.1002/ecs2.3061

Understanding how protected species influence the population dynamics of each other is an essential part of ecosystem-based management. Chinook salmon (Oncorhynchus tshawytscha) are critical prey for endangered southern resident killer whales (SRKWs; Orcinus orca), and increasing releases of hatchery Chinook salmon has been proposed to aid SRKW recovery. We analyzed 30 yr of data and found that density-dependent survival of hatchery Chinook salmon released into the central and southern parts of the Salish Sea (Washington, USA; and British Columbia, Canada) may be associated with the presence of naturally produced pink salmon (O. gorbuscha), which are highly abundant as juveniles only in even-numbered years. We first modeled hatchery Chinook salmon marine survival as a function of the numbers of juvenile Chinook released and the presence of emigrating juvenile pink salmon between 1983 and 2012. Then, we related reconstructed numbers of hatchery Chinook salmon returning to Puget Sound to the abundance of juvenile Chinook released in even (pink emigration) and odd (non-pink emigration) years from 1980 to 2010. We found that in some regions of the Salish Sea, both hatchery Chinook salmon marine survival and adult Chinook returns varied depending on the number of hatchery Chinook released and the presence of juvenile pink salmon. Specifically, in some regions survival of hatchery Chinook salmon decreased when greater numbers of juveniles were released into the Salish Sea in even years, when large numbers of pink salmon were present, but increased or remained stable when pink salmon were not present in large numbers (in odd years). This suggests lower, density-dependent survival of juvenile Salish Sea Chinook salmon during even outmigration years. Our analyses suggest that scientists and managers should further investigate potential mechanisms for density-dependent survival of hatchery Chinook salmon from Salish Sea hatcheries when designing strategies to maximize adult returns.

Manishin, K. A., Cunningham, C. J., Westley, P. A. H., & Seitz, A. C. (2021). Can Late Stage Marine Mortality Explain Observed Shifts in Age Structure of Chinook Salmon? *Plos One, 16*(2), https://doi.org/10.1371/journal.pone.0247370
Chinook salmon (Oncorhynchus tshawytscha) populations have experienced widespread declines in abundance and abrupt shifts toward younger and smaller adults returning to spawn in rivers. The causal agents underpinning these shifts are largely unknown. Here we investigate the potential role of late-stage marine mortality, defined as occurring after the first winter at sea, in driving this species' changing age structure. Simulations using a stage-based life cycle model that included additional mortality during after the first winter at sea better reflected observed changes in the age structure of a well-studied and representative population of Chinook salmon from the Yukon River drainage, compared with a model estimating environmentally-driven variation in age-specific survival alone. Although the specific agents of late-stage mortality are not known, our finding is consistent with work reporting predation by salmon sharks (Lamna ditropis) and marine mammals including killer whales (Orcinus orca). Taken as a whole, this work suggests that Pacific salmon mortality after the first winter at sea is likely to be higher than previously thought and highlights the need to investigate selective sources of mortality, such as predation, as major contributors to rapidly changing age structure of spawning adult Chinook salmon.

Miler, O., Johnson, G., & James, C. (2019, //). *Spatial Mismatch of Chinook Salmon (Oncorhynchus Tshawytscha) Fisheries and Southern Resident Killer Whale (Orcinus Orca) Distribution in the Salish Sea.* Paper presented at the American Fisheries Society …. Retrieved from https://afs.confex.com/afs/2019/meetingapp.cgi/Paper/39143
Southern Resident Killer Whales (SRKW) forage in the Salish Sea between British Columbia and Washington State during the summer. Their main food source are Chinook salmon due to their high lipid content. SRKW abundances have been decreasing in the last 10 years, down to currently 75 individuals. Recent suggestions to increase SRKW abundances include the decrease of salmon harvest, noise pollution by boats and toxic contaminants, especially around the San Juan Islands (Washington State fishing area 7), where SRKW mainly forage from May to September. The Fishery Regulation Assessment Model (FRAM) is used to manage Chinook fisheries in Washington State and provides pre- and postseason Chinook mortalities by stock, fishery and time step. In the summer time step from July to September, Chinook harvest and fishing effort (number of fishing vessels per day) showed little spatial overlap with the observed high abundances of SRKW in fishing area 7. Chinook harvest by tribal fisheries showed even less spatial overlap with SRKW abundances than Washington state commercial and sport fisheries. Our results suggest that restricting salmon harvest in the Salish sea will have little impact on SRKW prey availability and alternative measures i.e. the restoration of stream habitats, should instead be pursued.

Mordecai, G. J., Miller, K. M., Bass, A. L., Bateman, A. W., Teffer, A. K., Caleta, J. M., . . . Joy, J. B. (2021). Aquaculture Mediates Global Transmission of a Viral Pathogen to Wild Salmon. *SCIENCE ADVANCES, 7*(22), https://doi.org/10.1126/sciadv.abe2592

Global expansion of aquaculture and agriculture facilitates disease emergence and catalyzes transmission to sympatric wildlife populations. The health of wild salmon stocks critically concerns Indigenous peoples, commercial and recreational fishers, and the general public. Despite potential impact of viral pathogens such as Piscine orthoreovirus-1 (PRV-1) on endangered wild salmon populations, their epidemiology in wild fish populations remains obscure, as does the role of aquaculture in global and local spread. Our phylogeographic analyses of PRV-1 suggest that development of Atlantic salmon aquaculture facilitated spread from Europe to the North and South East Pacific. Phylogenetic analysis and reverse transcription polymerase chain reaction surveillance further illuminate the circumstances of emergence of PRV-1 in the North East Pacific and provide strong evidence for Atlantic salmon aquaculture as a source of infection in wild Pacific salmon. PRV-1 is now an important infectious agent in critically endangered wild Pacific salmon populations, fueled by aquacultural transmission.

National Marine Fisheries Service. (2020). *Endangered Species Act (Esa) Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat (Efh) Consultation Wells Summer Chinook Hatchery Program for Southern Resident Killer Whales*. https://doi.org/10.25923/mrs5-3z42

The objective of this opinion is to determine the likely effects on ESA-listed salmon and steelhead and their designated critical habitat resulting from operation of the proposed hatchery program in the Upper Columbia River. The applicants propose to wholly carry out all activities described in the Wells Summer Chinook for Southern Resident Killer Whales (SRKW) HGMP (WDFW 2019).There is one federal Proposed Action we are considering in this opinion:

The Proposed Action for National Marine Fisheries Service (NMFS) is the approval of the Columbia River summer Chinook salmon hatchery program (Table 1) HGMP under 4(d) of the Endangered Species Act (ESA). The objective of this opinion is to determine the likely effects on ESA-listed salmon and steelhead and their designated critical habitat resulting from this Federal action. The effects of this action, as well as the WDFWs' funding of the program, is subsumed within the operation of the hatchery program. Therefore, this Opinion will determine if the actions proposed by the operators comply with the provisions of sections 7 and 10(a)(1)(B) of the ESA. The duration of the Proposed Action is unlimited from the date of Opinion completion. The proposed hatchery program produces subyearling summer Chinook salmon with the primary intent for Southern Resident Orca recovery and sustainability. The approval of this HGMP would authorize take of listed species incidental to the implementation of the proposed summer Chinook salmon artificial propagation program in the UCR region. Below is a description of the proposed activities.

National Marine Fisheries Service. (2020). *Supplemental Environmental Assessment of the Wells Summer Chinook Hatchery and Genetic Management Plan*. Retrieved from https://repository.library.noaa.gov/view/noaa/25248

This Supplemental Environmental Assessment (Supplemental EA) supplements the 2019 Environmental Assessment for Endangered Species Act Section 4(d) Approval and Section 10(a)(1)(A) Permit Issuance for Steelhead Hatchery Programs and Section 10(a)(1)(B) Permit Issuance for Summer/Fall and Fall Chinook Salmon Hatchery Programs in Upper Columbia River (2019 EA) (NMFS 2019). NMFS is proposing to approve an additional 1,000,000 subyearling summer Chinook salmon from the Wells Hatchery under limit 5 of the 4(d) Rule of the Endangered Species Act (ESA). The Washington Department of Fish and Wildlife and Douglas County Public Utility District have submitted a Hatchery and Genetic Management Plan (HGMP) that outlines the supportive breeding, rearing, releasing, and associated monitoring and evaluation actions for the proposed hatchery program (WDFW 2019). The primary purpose of the proposed hatchery program is to augment the prey base of Southern Resident killer whale (SRKW). This Supplemental EA expands upon the range of alternatives analyzed and may be used in future years. This Supplemental EA relies largely on the background information and analysis contained in the 2019 EA as no significant changes have occurred in the status of the Water Quantity, Water Quality, Salmon and Steelhead, Other Fish Species, Wildlife, Socioeconomics, Cultural Resources, Environmental Justice, and Human Health and Safety (i.e., the affected environment and baseline conditions remain the same). The 2019 EA analyzed a full range of alternatives, including different hatchery production levels. Although the 4(d) approval of the Wells Hatchery program was within the alternatives analyzed, the additional 1,000,000 production was not. The total overall Chinook and steelhead releases covered in the 2019 EA totaled 7,184,135. According to the Mitchell Act FEIS Table 3-11, the Columbia River basin releases total 140,593,000; the Interior Columbia releases total 61,392,000; and the Interior Columbia Chinook releases total 46,174,000 (NMFS 2014).

National Marine Fisheries Service. (2021). *Endangered Species Act (Esa) Section 7(a)(2) Biological Opinion and Conference Opinion Biological Opinion on the Authorization of the West Coast Ocean Salmon Fisheries through Approval of the Pacific Salmon Fishery Management Plan Including Amendment 21 and Promulgation of Regulations Implementing the Plan for Southern Resident Killer Whales and Their Current and Proposed Critical Habitat*. https://doi.org/10.25923/ztk9-1x74

In 2019, NMFS consulted on impacts to ESA-listed species from several U.S. domestic actions associated with the 2019 -2028 PST Agreement (NMFS 2019e) including federal funding of a conservation program for critical Puget Sound salmon stocks and SRKW prey enhancement. The 2019 opinion (NMFS 2019e) included a programmatic consultation on the PST funding initiative, which is an important element of the environmental baseline in this opinion. In Fiscal Year 2020 Congress appropriated $35.1 million dollars for implementation of U.S. domestic activities associated with implementation of the new PST agreement, of which $5.6 million is being used for increased hatchery production to support prey abundance for SRKWs and $13.5 million is being used in support of Puget Sound Critical Stock Conservation and Habitat Restoration and Protection, consistent with the funding initiative. The beneficial effects of these activities (i.e.,increases in the abundance of Chinook salmon available as prey to SRKWs, hatchery conservation programs to support critical Puget Sound Chinook populations, and improved habitat conditions for those populations) are expected to begin in 3 –5 years following implementation.Subsequent specific actions (i.e., hatchery production programs) will undergo separate consultations, tiered from the programmatic consultations (NMFS 2019e) to assess effects for site-specific actions.  The harvest management provisions of the 2019 –2028 Agreement and the appropriations to initiate the conservation activities are in place now and will be taken into account in this biological opinion. The effects of the conservation activities will be important to the analysis of the impacts of PFMC salmon fisheries over the long term to SRKWs. Additional detail on the activities associated with the PST funding initiative are described in more detail in the Environmental Baseline.

Ohlberger, J., Schindler, D. E., Ward, E. J., Walsworth, T. E., & Essington, T. E. (2019). Resurgence of an Apex Marine Predator and the Decline in Prey Body Size. *Proceedings of the National Academy of Sciecnes U S A*, https://doi.org/10.1073/pnas.1910930116

In light of recent recoveries of marine mammal populations worldwide and heightened concern about their impacts on marine food webs and global fisheries, it has become increasingly important to understand the potential impacts of large marine mammal predators on prey populations and their life-history traits. In coastal waters of the northeast Pacific Ocean, marine mammals have increased in abundance over the past 40 to 50 y, including fish-eating killer whales that feed primarily on Chinook salmon. Chinook salmon, a species of high cultural and economic value, have exhibited marked declines in average size and age throughout most of their North American range. This raises the question of whether size-selective predation by marine mammals is generating these trends in life-history characteristics. Here we show that increased predation since the 1970s, but not fishery selection alone, can explain the changes in age and size structure observed for Chinook salmon populations along the west coast of North America. Simulations suggest that the decline in mean size results from the selective removal of large fish and an evolutionary shift toward faster growth and earlier maturation caused by selection. Our conclusion that intensifying predation by fish-eating killer whales contributes to the continuing decline in Chinook salmon body size points to conflicting management and conservation objectives for these two iconic species.

Pacific Fishery Management Council. (2020). *Pacific Fishery Management Council Salmon Fishery Management Plan Impacts to Southern Resident Killer Whales: Risk Assessment.* Retrieved from https://www.pcouncil.org/june-2020-briefing-book/

This report is a product of PFMC's ad-hoc SRKW Workgroup which was tasked with reassessing the effects of Council-area ocean salmon fisheries on SRKW. We first provide a brief overview of the background context, workshop process, and the role of the SRKW Workgroup. Then we assess the current status of the SRKWs, followed by describing the interactions known to occur between SRKW and salmon fisheries, leading to a general description of the Pacific Coast Salmon Fishery Management Plan (FMP). Lastly, we attempt to assess how reductions in prey through implementing the FMP may affect SRKW demographics.

Satterthwaite, W. H., Andrews, K. S., Burke, B. J., Gosselin, J. L., Greene, C. M., Harvey, C. J., . . . Sobocinski, K. L. (2020). Ecological Thresholds in Forecast Performance for Key United States West Coast Chinook Salmon Stocks. *Ices Journal of Marine Science, 77*(4), https://doi.org/10.1093/icesjms/fsz189

Preseason abundance forecasts drive management of US West Coast salmon fisheries, yet little is known about how environmental variability influences forecast performance. We compared forecasts of Chinook salmon (Oncorhynchus tshawytscha) against returns for (i) key California-Oregon ocean fishery stocks and (ii) high priority prey stocks for endangered Southern Resident Killer Whales (Orcinus orca) in Puget Sound, Washington. We explored how well environmental indices (at multiple locations and time lags) explained performance of forecasts based on different methods (i.e. sibling-based, production-based, environment-based, or recent averages), testing for nonlinear threshold dynamics. For the California stocks, no index tested explained >50% of the variation in forecast performance, but spring Pacific Decadal Oscillation and winter North Pacific Index during the year of return explained >40% of the variation for the sibling-based Sacramento Fall Chinook forecast, with nonlinearity and apparent thresholds. This suggests that oceanic conditions experienced by adults (after younger siblings returned) have the most impact on sibling-based forecasts. For Puget Sound stocks, we detected nonlinear/threshold relationships explaining >50% of the variation with multiple indices and lags. Environmental influences on preseason forecasts may create biases that render salmon fisheries management more or less conservative, and therefore could motivate the development of ecosystem-based risk assessments.

Smith, K. (2019, //). *Cascadia Collapse?-Saving Endangered Wild Chinook and the Southern Resident Killer Whale in the Face of Climate Change.* Paper presented at the 18th Annual Stream Restoration Symposium. Retrieved from https://rrnw.confex.com/rrnw/2019/meetingapp.cgi/Paper/2023

Has the Cascadia ecosystem reached a tipping point of ecological collapse, despite our diligence in decades of riparian tree planting, log jam placement, flow restoration and barrier removals? Can we alter the declining trajectory of the endangered Southern Resident killer whales starving due to the lack of their primary prey - the equally endangered large, wild Chinook salmon of the Fraser, Columbia, Klamath, and every salmon river in between? As river managers, are we capable of coordinating our efforts on a Cascadia scale, and understanding how marine conditions and fisheries management may thwart our efforts to bring Chinook salmon back to their home waters to rejuvenate beleaguered populations? And are we willing to stand up and demand optimal levels of wild fish escapement to utilize the riverine habitats we have available in our watersheds? This presentation explores the above questions by sharing a summary of existing Cascadia scale research and data, and challenges practitioners to think beyond their single project or watershed. It will share an approach to assessing the cumulative benefits and limiting factors of the river restoration playing out across the landscape, to spark discussion of how to best maintain resiliency in the face of a changing climate. The Southern Resident killer whale and Chinook salmon are our canaries in the coal mine. How these endangered species fare in the next 3-5 years, and the possible redirection of federal and state funding to support their survival, impacts almost everyone in this field. There are many species on the pathway towards extinction in Cascadia, but none are more iconic than the Southern Resident killer whale and Chinook salmon. They are culturally, ecologically and economically critical to the Pacific Northwest. Finding new, more strategic and rapid approaches to triage our rivers and watersheds to help support wild Chinook recovery, and buffer against years of low marine survival, may help prevent a co-extinction. There is no time to waste. The implication for river restoration is understanding that to remain relevant and effective in the work, there has to be a higher cause that the public can relate to. After decades of well-meaning community-based efforts, watershed restoration and salmon recovery have not turned the tide on species decline. The co-extinction will be on our watch if we don't re-evaluate the scale, pace and cost of our collective efforts to make them more effective. The Southern Resident J35 carried her dead calf through the Salish Sea for an unprecedented 17 days this summer, garnering international attention to the plight of their struggle to survive. River practitioners hold some power to deliver the whales and all the other species that depend on salmon, the prey they need. Will we step up to this higher cause?

Strange, E. L. (2016). *Assessing Southern Resident Killer Whale (Orcinus Orca) Prey Abundance: The Effects of Chinook Salmon (Oncorhynchus Tshawystcha) Ocean Fishery Reductions and Related Hatchery Production.* (M.S., Biological Sciences ), California State University, Sacramento, Retrieved from http://hdl.handle.net/10211.3/171230

Predator-prey dynamics and their ecological drivers have absorbed the interest of population ecologists since models were first developed describing the cyclical nature of predator-prey populations in a static framework. Empirical data has demonstrated that species life histories evolve over ecological timescales in response to changes in broad ecological processes or specific changes in population densities and/or spatial distributions. Anthropomorphic environmental impacts have influenced ecological processes on a broad scale and in many cases impacted predator-prey relationships. Southern Resident killer whale, Orcinus orca, and its preferred prey, Chinook salmon, Oncorhynchus tshawystcha, provide an opportunity to evaluate human impacts from Chinook salmon ocean harvest and hatchery production to the predator-prey dynamic between these co-evolved species. This is particularly important when considering the management of ocean fisheries and hatcheries that support those fisheries relative to the recovery of the Southern Resident killer whale population, a federally-endangered marine mammal species. The purpose of this study was to: 1) investigate the impacts of modifications in Chinook salmon ocean harvest and hatchery production inputs on their abundance as a prey species for Southern Resident killer whale; and 2) evaluate how the Southern Resident killer whale population responds to the subsequent prey availability. Time-series (1984-2011) Chinook salmon terminal run (freshwater harvest plus spawning population) and ocean fishery harvest data from British Columbia, Washington, Oregon and California, were analyzed under twelve scenarios involving different combinations of ocean fishery harvest and hatchery production. Chinook salmon terminal run results were used as input to the Southern Resident killer whale population dynamics model to evaluate the whale population response to varying levels of prey availability. Two covariates were chosen for the Chinook salmon time-series analysis: reduction in ocean fishery harvest and reduction in hatchery production. The primary response variable chosen for this analysis was Chinook salmon terminal run, although ocean fishery harvest and Chinook salmon total abundance were also evaluated. Linear regression was used to evaluate the influence that reductions in ocean harvest and hatchery production have on the relative absolute change in Chinook salmon terminal run, fishery harvest, and total abundance between the status quo and each scenario. A Mann-Whitney Test was used to determine trends between early and late periods in the Chinook salmon time-series. Results of this study indicate significant interactions between covariate and response variables, revealing that reduction in ocean fishery harvest explains the amount of Chinook salmon in the terminal run to a weak degree, while the reduction in hatchery production explains the amount of Chinook salmon in the terminal run to a moderate degree. Although percent reduction calculations showed decreasing ocean harvest as hatchery production decreased, the linear regression showed that percent reduction in hatchery production does not explain the amount of Chinook salmon ocean fishery harvest. The ocean fishery harvest reduction percentage weakly explains the Chinook salmon fishery harvest. In addition, reduction in hatchery production explains the total abundance of Chinook salmon in the ocean to a weak degree, while ocean harvest reduction explains the total abundance of Chinook salmon in the ocean to a moderate degree. Results also indicate a significant decrease in fishery impacts from an early time period (1984-1997) to a late time period (1998-2011), while no significant difference was demonstrated between the two timeframes for terminal run and total abundance. Southern Resident killer whale modeling results revealed that all of the Chinook salmon scenarios (terminal run data) resulted in a positive Southern Resident killer whale population growth response. However, statistical analysis between scenarios indicated no significant difference in the Southern Resident killer whale population growth over a 10-year projection. These results have value to fishery managers with regard to potential modifications to Chinook salmon ocean fishing harvest and hatchery production that may result in a greater prey base for the Southern resident killer whale population. Identification of the Chinook salmon populations most important as prey to Southern resident killer whale could focus natural/wild Chinook salmon population restoration and hatchery reform efforts with the target of increasing the numbers of Chinook salmon produced in those important watersheds. Chinook salmon management decisions directed at changing the focus of hatchery operations to support naturally spawning populations and improving freshwater habitats to support natural/wild spawning Chinook salmon populations may provide more prey over the long-term for Southern resident killer whale than management actions directed at further restrictions on the commercial ocean Chinook salmon fishery. However, based on prior research (Ward et al. 2013) and the results of this study, Chinook salmon management practice involving a complete closure of the ocean fishery while maintaining current levels of hatchery production may produce a higher likelihood that the Southern Resident killer whale population would reach their recovery target.

Ward, E. J., Dahlheim, M. E., Waite, J. M., Emmons, C. K., Marshall, K. N., Chasco, B. E., & Balcomb, K. C. (2016). Long-Distance Migration of Prey Synchronizes Demographic Rates of Top Predators across Broad Spatial Scales. *7*(2), https://doi.org/10.1002/ecs2.1276
Reproductively and geographically isolated populations of predators may be synchronized by a phenomenon known as the Moran effect—specifically if they exhibit common responses to external processes, such as climate, density dependence (parasites, disease), or prey. Prey has the ability to synchronize predators if geographically isolated predator populations target the same prey species, or if the migration and range of the prey species occurs over a large enough scale to be available to multiple predator populations. The objective of our study was to investigate evidence for correlations of demographic rates between geographically isolated populations of piscivorous killer whales in the Northeast Pacific; using long-term mark-recapture datasets collected over the last 30+ yrs, we constructed a hierarchical occupancy model, linking models of survival and fecundity in a single framework. We found strong support for synchronized demographic rates in Southeast Alaska and Southern Resident killer whales, which are geographically and reproductively isolated. Despite their isolation, they experience extremely correlated dynamics—the correlation in fecundity rates between populations exceeds 0.9. The correlation in demographic rates across these populations of killer whales in different regions of the Northeast Pacific Ocean suggests a common environmental driver. Both killer whale populations are known to prey on Chinook salmon, which have a long-distance coastal migration larger than the habitat range of killer whales. Many of these Chinook salmon are also of the same origin (southern stocks), suggesting that these populations not only consume the same prey species but the same prey populations.

Warlick, A. J., Ylitalo, G. M., O'Neill, S. M., Hanson, M. B., Emmons, C., & Ward, E. J. (2020). Using Bayesian Stable Isotope Mixing Models and Generalized Additive Models to Resolve Diet Changes for Fish-Eating Killer Whales Orcinus Orca. *Marine Ecology Progress Series, 649*, https://doi.org/10.3354/meps13452
Understanding diet composition is fundamental to making conservation and management decisions about depleted species, particularly when nutritional stress is a potential threat hindering recovery. Diet in free-ranging marine mammals is challenging to study, but stable isotope mixing models are a powerful means of estimating the contribution of prey species to diet and can improve precision by leveraging information from multiple data sources. We evaluated diet composition of a fish-eating killer whale population (Southern Resident killer whales, Orcinus orca) using 2 approaches. First, we fit generalized additive models to evaluate seasonal and inter-annual patterns in isotopic values across age, sex, and pod, which revealed seasonal carbon enrichment for certain pods and a recent increased nitrogen enrichment that could suggest increased Chinook salmon consumption, changing isotopic values of prey, or nutritional stress. Second, we developed a Bayesian stable isotope mixing model that accounts for the different integration times represented by bulk stable isotopes and fecal samples. Results showed that estimated prey contributions are similar between prey data sources, though the precision of estimates from periods with smaller sample sizes was improved by using an informative prior to account for the different consumption windows of the data. This study illustrates the importance of improving our understanding of how killer whale diets vary over time (both seasonally and across years) and uses a novel approach to resolve 2 sources of diet information (stable isotope, fecal samples) with different consumption windows.

Wright, B. M., Ford, J. K. B., Ellis, G. M., Deecke, V. B., Shapiro, A. D., Battaile, B. C., & Trites, A. W. (2017). Fine-Scale Foraging Movements by Fish-Eating Killer Whales (Orcinus Orca) Relate to the Vertical Distributions and Escape Responses of Salmonid Prey (Oncorhynchus Spp.). *Movement Ecology, 5*, https://doi.org/10.1186/s40462-017-0094-0

We sought to quantitatively describe the fine-scale foraging behavior of northern resident killer whales (Orcinus orca), a population of fish-eating killer whales that feeds almost exclusively on Pacific salmon (Oncorhynchus spp.). To reconstruct the underwater movements of these specialist predators, we deployed 34 biologging Dtags on 32 individuals and collected high-resolution, three-dimensional accelerometry and acoustic data. We used the resulting dive paths to compare killer whale foraging behavior to the distributions of different salmonid prey species. Understanding the foraging movements of these threatened predators is important from a conservation standpoint, since prey availability has been identified as a limiting factor in their population dynamics and recovery. RESULTS: Three-dimensional dive tracks indicated that foraging (N = 701) and non-foraging dives (N = 10,618) were kinematically distinct (Wilks' lambda: lambda16 = 0.321, P < 0.001). While foraging, killer whales dove deeper, remained submerged longer, swam faster, increased their dive path tortuosity, and rolled their bodies to a greater extent than during other activities. Maximum foraging dive depths reflected the deeper vertical distribution of Chinook (compared to other salmonids) and the tendency of Pacific salmon to evade predators by diving steeply. Kinematic characteristics of prey pursuit by resident killer whales also revealed several other escape strategies employed by salmon attempting to avoid predation, including increased swimming speeds and evasive maneuvering. CONCLUSIONS: High-resolution dive tracks reconstructed using data collected by multi-sensor accelerometer tags found that movements by resident killer whales relate significantly to the vertical distributions and escape responses of their primary prey, Pacific salmon.

## Section V: Contaminants and Health

Alava, J. J. (2020). Modeling the Bioaccumulation and Biomagnification Potential of Microplastics in a Cetacean Foodweb of the Northeastern Pacific: A Prospective Tool to Assess the Risk Exposure to Plastic Particles. *Frontiers in Marine Science, 7*, https://doi.org/10.3389/fmars.2020.566101

Microplastics (MPs) can readily be ingested by marine organisms. Direct ingestion and trophic transfer are likely to be the main pathway for microplastics to bioaccumulate in upper trophic level organisms. Bioaccumulation potential of MPs in marine mammalian foodwebs is scarcely known. To understand whether microplastics bioaccumulate in marine mammals, a bioaccumulation model for MPs was developed for the filter-feeding humpback whale and fish-eating resident killer whale foodwebs of the Northeastern Pacific. Applying three concentration scenarios for MPs by entering observed water and sediment concentrations as input data (low, high and moderate scenarios), and tested under two different elimination rates (kE) for zooplankton, the model predicted species-specific and foodweb-specific bioaccumulation potential. The predator-prey biomagnification factor (BMFTL, used to assess the ratio of the MP concentration in predator to that in prey adjusted to the difference of trophic levels), involving cetaceans, appeared to be not only lower than one or equal to one (BMFTL ≤ 1 as in resident killer whale/Chinook salmon), but also BMFTL > 1 in some predator-prey relationships (humpback whale/zooplankton). Depending on the magnitude of abiotic concentrations used in the modelling, the trophic magnification factor (TMF) regression analyses over time showed lack of evidence for trophic magnification as the magnification was independent of the trophic level, indicating no

changes (TMF = 1; p>0.05), and trophic dilution (TMF<1; p<0.05) due to the decrease in MP concentrations as the trophic level increased. Projected biomagnification in simplified foodwebs revealed no significant increase in concentrations as the trophic level increased (TMF=1; p>0.05), following 100-365 days. Compared to the high biomagnification behaviour of persistent organic pollutants in marine foodwebs, scarce biomagnification capacity of microplastic was predicted in the cetacean foodwebs. Notwithstanding, the moderate to high microplastic bioaccumulation predicted in some lower trophic level marine organisms highlights the health risks of toxic exposure to marine fauna and coastal communities relying strongly on seafood. This modelling work provides a tool to assess the bioaccumulation potential and impact of microplastics in the marine environment to support risk assessment and inform plastic waste management.

Alava, J. J., Cisneros-Montemayor, A. M., Sumaila, U. R., & Cheung, W. W. L. (2018). Projected Amplification of Food Web Bioaccumulation of Mehg and Pcbs under Climate Change in the Northeastern Pacific. *Scientific Reports, 8*(1), https://doi.org/10.1038/s41598-018-31824-5

Climate change increases exposure and bioaccumulation of pollutants in marine organisms, posing substantial ecophysiological and ecotoxicological risks. Here, we applied a trophodynamic ecosystem model to examine the bioaccumulation of organic mercury (MeHg) and polychlorinated biphenyls (PCBs) in a Northeastern Pacific marine food web under climate change. We found largely heterogeneous sensitivity in climate-pollution impacts between chemicals and trophic groups. Concentration of MeHg and PCBs in top predators, including resident killer whales, is projected to be amplified by 8 and 3%, respectively, by 2100 under a high carbon emission scenario (Representative Concentration Pathway 8.5) relative to a no-climate change control scenario. However, the level of amplification increases with higher carbon emission scenario for MeHg, but decreases for PCBs. Such idiosyncratic responses are shaped by the differences in bioaccumulation pathways between MeHg and PCBs, and the modifications of food web dynamics between different levels of climate change. Climate-induced pollutant amplification in mid-trophic level predators (Chinook salmon) are projected to be higher (~10%) than killer whales. Overall, the predicted trophic magnification factor is ten-fold higher in MeHg than in PCBs under high CO2 emissions. This contribution highlights the importance of understanding the interactions with anthropogenic organic pollutants in assessing climate risks on marine ecosystems.

Alava, J. J., & Gobas, F. A. (2016). Modeling (137)Cs Bioaccumulation in the Salmon-Resident Killer Whale Food Web of the Northeastern Pacific Following the Fukushima Nuclear Accident. *Science of the Total Environment, 544*, https://doi.org/10.1016/j.scitotenv.2015.11.097

To track the long term bioaccumulation of (137)Cs in marine organisms off the Pacific Northwest coast of Canada, we developed a time dependent bioaccumulation model for (137)Cs in a marine mammalian food web that included fish-eating resident killer whales. The model outcomes show that (137)Cs can be expected to gradually bioaccumulate in the food web over time as demonstrated by the increase of the apparent trophic magnification factor of (137)Cs, ranging from 0.76 after 1 month of exposure to 2.0 following 30 years of exposure. (137)Cs bioaccumulation is driven by relatively rapid dietary uptake rates, moderate depuration rates in lower trophic level organisms and slow elimination rates in high trophic level organisms. Model estimates of the (137)Cs activity in species of the food web, based on current measurements and forecasts of (137)Cs activities in oceanic waters and sediments off the Canadian Pacific Northwest, indicate that the long term (137)Cs activities in fish species including Pacific herring, wild Pacific salmon, sablefish and halibut will remain well below the current (137)Cs-Canada Action Level for consumption (1000 Bq/kg) following a nuclear emergency. Killer whales and Pacific salmon are expected to exhibit the largest long term (137)Cs activities and may be good sentinels for monitoring (137)Cs in the region. Assessment of the long term consequences of (137)Cs releases from the Fukushima aftermath should consider the extent of ecological magnification in addition to ocean dilution.

Alava, J. J., Ross, P. S., & Gobas, F. A. P. C. (2016). Food Web Bioaccumulation Model for Resident Killer Whales from the Northeastern Pacific Ocean as a Tool for the Derivation of Pbde-Sediment Quality Guidelines. *Archives of Environmental Contamination and Toxicology, 70*(1), https://doi.org/10.1007/s00244-015-0215-y

Resident killer whale populations in the NE Pacific Ocean are at risk due to the accumulation of pollutants, including polybrominated diphenyl ethers (PBDEs). To assess the impact of PBDEs in water and sediments in killer whale critical habitat, we developed a food web bioaccumulation model. The model was designed to estimate PBDE concentrations in killer whales based on PBDE concentrations in sediments and the water column throughout a lifetime of exposure. Calculated and observed PBDE concentrations exceeded the only toxicity reference value available for PBDEs in marine mammals (1500 mu g/kg lipid) in southern resident killer whales but not in northern resident killer whales. Temporal trends (1993-2006) for PBDEs observed in southern resident killer whales showed a doubling time of a parts per thousand 5 years. If current sediment quality guidelines available in Canada for polychlorinated biphenyls are applied to PBDEs, it can be expected that PBDE concentrations in killer whales will exceed available toxicity reference values by a large margin. Model calculations suggest that a PBDE concentration in sediments of approximately 1.0 mu g/kg dw produces PBDE concentrations in resident killer whales that are below the current toxicity reference value for 95 % of the population, with this value serving as a precautionary benchmark for a management-based approach to reducing PBDE health risks to killer whales. The food web bioaccumulation model may be a useful risk management tool in support of regulatory protection for killer whales.

Desforges, J.-P., Hall, A., McConnell, B., Rosing-Asvid, A., Barber, J. L., Brownlow, A., . . . Dietz, R. (2018). Predicting Global Killer Whale Population Collapse from PCB Pollution. *Science, 361*(6409), https://doi.org/10.1126/science.aat1953

Until they were recognized as highly toxic and carcinogenic, polychlorinated biphenyls (PCBs) were once used widely. Their production was banned in the United States in 1978, though they are still produced globally and persist in the environment. Persistent organic compounds, like PCBs, magnify across trophic levels, and thus apex predators are particularly susceptible to their ill effects. Desforges et al. looked at the continuing impact of PCBs on one of the largest marine predators, the killer whale. Using globally available data, the authors found high concentrations of PCBs within killer whale tissues. These are likely to precipitate declines across killer whale populations, particularly those that feed at high trophic levels and are the closest to industrialized areas.Science, this issue p. 1373Killer whales (Orcinus orca) are among the most highly polychlorinated biphenyl (PCB)–contaminated mammals in the world, raising concern about the health consequences of current PCB exposures. Using an individual-based model framework and globally available data on PCB concentrations in killer whale tissues, we show that PCB-mediated effects on reproduction and immune function threaten the long-term viability of >50% of the world's killer whale populations. PCB-mediated effects over the coming 100 years predicted that killer whale populations near industrialized regions, and those feeding at high trophic levels regardless of location, are at high risk of population collapse. Despite a near-global ban of PCBs more than 30 years ago, the world's killer whales illustrate the troubling persistence of this chemical class.

Fearnbach, H., Durban, J. W., Ellifrit, D. K., & Balcomb, K. C. (2018). Using Aerial Photogrammetry to Detect Changes in Body Condition of Endangered Southern Resident Killer Whales. *Endangered Species Research, 35*, https://doi.org/10.3354/esr00883

The endangered population of southern resident killer whales Orcinus orca is hypothesized to be food-limited, but uncertainty remains over if and when the availability of their primary prey, Chinook salmon Oncorhynchus tshawytscha, is low enough to cause nutritional stress. To measure changes in body condition, we collected 1635 measurable images from a helicopter hovering 230-460 m above whales, and linked these to individuals with distinctive natural markings. Head width (HW), measured at 15% of the distance between the blowhole and the dorsal fin (BHDF), was measured from images of 59 individuals in 2008 (from a population of 84) and 66/81 individuals in 2013, enabling assessment of between-year changes for 44 individuals (26 females, 18 males). Of these, 11 had significant declines in the ratio of HW/BHDF compared to 5 with significant increases. Two whales with declines died shortly after being photographed, suggesting a link between body condition and mortality. Most (8/11) of the significant declines in condition were from 1 social pod (J-pod), and all the whales that increased in condition were from one of the other 2 pods, K-pod (n = 3) and L-pod (n = 2). Notably, 11/16 whales that changed condition were re productive-aged females and there were no adult males with significant changes. This likely reflects the increased energetic costs of lactation to reproductive females, and the nutritional help provided to adult males through prey sharing. These data demonstrate the utility of aerial photo-grammetry as a non-invasive approach for providing quantitative data on body condition, and support monitoring the condition of reproductive females as key indicators of nutritional stress.

Harlacher, J. *Whale, What Do We Have Here? Evidence of Microplastics in Top Predators: Analysis of Two Populations of Resident Killer Whale Fecal Samples.*, Retrieved from http://hdl.handle.net/1773/46085

Environmental microplastics (plastic particles less than 5 mm in size) are a growing ecological issue and are widely documented in marine life. The consequences of microplastic ingestion in top predators are poorly understood but may include physiological and toxicological effects, and the potential for bioaccumulation in apex predators has been suggested. Here, I investigate the presence of microplastics in two populations of North Pacific Resident killer whales and determine if there is a significant difference in the number of microplastics between the populations. This study examined 33 feces samples, 18 from the Southern Resident population, and 15 from the Alaskan Resident population. We implemented multiple contamination-control measures to reduce sample contamination from synthetic clothing and plastic equipment. Microplastics were found in every fecal sample except one, with an average and standard deviation of 82.5 (173) per sample. I observed no significant difference in the number of microplastics between the two populations (p-value = 0.799). Preliminary Raman microspectroscopy revealed three plastic polymer types that included polyethylene, nylon, and polyamide. Verified microplastics were found in fecal samples from both populations of resident killer whales, validating the occurrence of microplastic pollution in upper-trophic marine predators. This study is another example of the pervasiveness of microparticles in the marine environment, and the need for a better understanding of the potential effects on apex predators.

Huggins, J. L., Garner, M. M., Raverty, S. A., Lambourn, D. M., Norman, S. A., Rhodes, L. D., . . . Hanson, M. B. (2020). The Emergence of Mucormycosis in Free-Ranging Marine Mammals of the Pacific Northwest. *Frontiers in Marine Science, 7*, https://doi.org/10.3389/fmars.2020.00555

Primary fungal diseases in marine mammals are rare. Mucormycosis, a disease caused by fungi of the order Mucorales, has been documented in few cetaceans and pinnipeds. In 2012, the first case of mucormycosis in the Pacific Northwest was documented in a dead stranded harbor porpoise (Phocoena phocoena) in Washington state. Since then, mucormycosis has been detected in a total of 21 marine mammals; fifteen harbor porpoises, five harbor seals (Phoca vitulina), and one southern resident killer whale (Orcinus orca). Infected animals were predominately found in the inland waters of Washington and British Columbia, and one harbor seal was recovered in northern Oregon. Fungal hyphae were detected histologically in a variety of tissues, including brain, lung, spleen, pancreas, kidneys, muscle, lymph nodes, and skin. Three fungal species were identified from seven cases by PCR screening or fungal culture;Rhizomucor pusillus(four cases), Lichtheimia corymbifera(two cases), andCunninghamella bertholletiae.Underlying conditions such as emaciation, current or recent pregnancy, multisystemic parasitism, protozoal infection, and herpesvirus were found in several affected animals. Reasons for the appearance and subsequent increase of these fungal infections in marine mammals are unknown. The emergence of this disease as a source of marine mammal mortality in the Pacific Northwest is of particular concern for endangered southern resident killer whales that spend time in this region. Current population-level stressors such as insufficient prey, high levels of contaminants, and noise pollution, could predispose them to these fatal infections.

Lawson, T. M., Ylitalo, G. M., O'Neill, S. M., Dahlheim, M. E., Wade, P. R., Matkin, C. O., . . . Boyd, D. T. (2020). Concentrations and Profiles of Organochlorine Contaminants in North Pacific Resident and Transient Killer Whale (Orcinus Orca) Populations. *Science of the Total Environment, 722*, https://doi.org/10.1016/j.scitotenv.2020.137776

Organochlorine (OC) profiles have been used as chemical "fingerprints" to infer an animal's foraging area. North Pacific killer whale (Orcinus orca) populations are exposed to different levels and patterns of OCs based on their prey, distribution, and amount of time spent in a particular area. To characterize concentrations and profiles of OCs found in various populations of North Pacific killer whales, polychlorinated biphenyls (PCBs), including dioxin-like congeners, DDTs, and hexachlorobenzene (HCB), were measured in biopsy blubber samples of photo-identified resident (fish-eating) and transient (mammal-eating) killer whales collected from 1994 through 2002 from Russian Far East waters to the waters of the west coast of the United States, representing 10 populations. We compared blubber OC concentrations based on ecotype (resident vs. transient), sex and reproductive maturity, and geographic area. We also examined OC mixtures to determine if we could detect segregated geographical areas (foraging areas) among the six populations with sufficient sample sizes. Transients had significantly higher OC concentrations than residents and adult male whales had consistently higher OC levels compared to adult females, regardless of ecotype. Our OC profile findings indicate segregated foraging areas for the North Pacific killer whales, consistent with observations of their geographic distributions. Several potential health risks have also been associated with exposure to high levels of contaminants in top-level predators including reproductive impairment, immune suppression, skeletal deformities, and carcinoma. The results of this baseline study provide information on the geographic distribution of OCs found in North Pacific killer whales, results which are crucial for assessing the potential health risks associated with OC exposure in this species.

Lundin, J., Ylitalo, G., Giles, D., Seely, E., Parsons, K., Hempelmann, J., . . . Wasser, S. (2018). *The Threat of Toxic Contaminants to Southern Resident Killer Whales: Monitoring Pops and Pahs in Scat Samples*. Paper presented at the Salish Sea Ecosystem Conference, Seattle, WA. Oral Retrieved from https://cedar.wwu.edu/ssec/2018ssec/allsessions/39/

The Southern Resident killer whale population (SRKW; Orcinus orca) feed primarily on Chinook salmon, which is currently their primary source of exposure to toxics. We measured lipophilic persistent organic

pollutants (POPs: PBDEs, PCBs, and DDTs) in SRKW scat (fecal) samples to quantify variations in toxicant levels by pod, sex, and reproductive class, as well as prey availability. We also measured polycyclic aromatic hydrocarbons (PAHs), which do not generally bioaccumulate and would reflect recent exposure to oil, engine (combustion) exhaust, among other potential exposure sources. Samples were collected using detection dogs that use scent to locate fresh SRKW scat on the water's surface. We collected 267 samples during four 5-month study periods between 2010 and 2013. POP levels in scat had expected trends, such as increasing with age and decreasing by number of calves (for adult females). POPs were also highest when the whales primary prey source was at low seasonal abundance, presumably due to metabolizing endogenous lipid stores. By contrast, overall measures of PAHs were low (<5 ppb, wet weight), as expected. However, PAHs indicative of motor exhaust versus oil exposure were relatively high prior to implementation of guidelines aimed at increasing vessel distances to the whales. Results point to the value of monitoring POPs by age, sex and reproductive class and in relation to changes in prey abundance to help identify what reproductive classes are most at risk to high toxic loads, what season the liability is greatest, and whether prey recovery and clean up efforts are working. The PAH exposure data will be available as baseline in SRKW feces in relation to environmental events over time, such as the circumstance of an oil spill in the Salish Sea. Addressing toxics and other vulnerabilities is important for SRKW recovery.

Lundin, J. I., Dills, R. L., Ylitalo, G. M., Hanson, M. B., Emmons, C. K., Schorr, G. S., . . . Wasser, S. K. (2016). Persistent Organic Pollutant Determination in Killer Whale Scat Samples: Optimization of a Gas Chromatography/Mass Spectrometry Method and Application to Field Samples. *Archives of Environmental Contamination and Toxicology, 70*(1), https://doi.org/10.1007/s00244-015-0218-8
Biologic sample collection in wild cetacean populations is challenging. Most information on toxicant levels is obtained from blubber biopsy samples; however, sample collection is invasive and strictly regulated under permit, thus limiting sample numbers. Methods are needed to monitor toxicant levels that increase temporal and repeat sampling of individuals for population health and recovery models. The objective of this study was to optimize measuring trace levels (parts per billion) of persistent organic pollutants (POPs), namely polychlorinated-biphenyls (PCBs), polybrominated-diphenyl-ethers (PBDEs), dichlorodiphenyl-trichloroethanes (DDTs), and hexachlorocyclobenzene, in killer whale scat (fecal) samples. Archival scat samples, initially collected, lyophilized, and extracted with 70 % ethanol for hormone analyses, were used to analyze POP concentrations. The residual pellet was extracted and analyzed using gas chromatography coupled with mass spectrometry. Method detection limits ranged from 11 to 125 ng/g dry weight. The described method is suitable for p,p'-DDE, PCBs-138, 153, 180, and 187, and PBDEs-47 and 100; other POPs were below the limit of detection. We applied this method to 126 scat samples collected from Southern Resident killer whales. Scat samples from 22 adult whales also had known POP concentrations in blubber and demonstrated significant correlations ($p < 0.01$) between matrices across target analytes. Overall, the scat toxicant measures matched previously reported patterns from blubber samples of decreased levels in reproductive-age females and a decreased p,p'-DDE/Sigma PCB ratio in J-pod. Measuring toxicants in scat samples provides an unprecedented opportunity to noninvasively evaluate contaminant levels in wild cetacean populations; these data have the prospect to provide meaningful information for vital management decisions.

Lundin, J. I., Ylitalo, G. M., Booth, R. K., Anulacion, B., Hempelmann, J. A., Parsons, K. M., . . . Wasser, S. K. (2016). Modulation in Persistent Organic Pollutant Concentration and Profile by Prey

Availability and Reproductive Status in Southern Resident Killer Whale Scat Samples. *Environmental Science & Technology, 50*(12), https://doi.org/10.1021/acs.est.6b00825
Persistent organic pollutants (POPs), specifically PCBs, PBDEs, and DDTs, in the marine environment are well documented, however accumulation and mobilization patterns at the top of the food-web are poorly understood. This study broadens the understanding of POPs in the endangered Southern Resident killer whale population by addressing modulation by prey availability and reproductive status, along with endocrine disrupting effects. A total of 140 killer whale scat samples collected from 54 unique whales across a 4 year sampling period (2010-2013) were analyzed for concentrations of POPs. Toxicant measures were linked to pod, age, and birth order in genotyped individuals, prey abundance using open-source test fishery data, and pregnancy status based on hormone indices from the same sample. Toxicant concentrations were highest and had the greatest potential for toxicity when prey abundance was the lowest. In addition, these toxicants were likely from endogenous lipid stores. Bioaccumulation of POPs increased with age, with the exception of presumed nulliparous females. The exceptional pattern may be explained by females experiencing unobserved neonatal loss. Transfer of POPs through mobilization of endogenous lipid stores during lactation was highest for first-borns with diminished transfer to subsequent calves. Contrary to expectation, POP concentrations did not demonstrate an associated disruption of thyroid hormone, although this association may have been masked by impacts of prey abundance on thyroid hormone concentrations. The noninvasive method for measuring POP concentrations in killer whales through scat employed in this study may improve toxicant monitoring in the marine environment and promote conservation efforts.

Lundin, J. I., Ylitalo, G. M., Giles, D. A., Seely, E. A., Anulacion, B. F., Boyd, D. T., . . . Wasser, S. K. (2018). Pre-Oil Spill Baseline Profiling for Contaminants in Southern Resident Killer Whale Fecal Sample Indicates Possible Exposure to Vessel Exhaust. *Marine Pollution Bulletin, 136*, https://doi.org/10.1016/j.marpolbul.2018.09.015
The Southern Resident killer whale population (Orcinus orca) was listed as endangered in 2005 and shows little sign of recovery. Exposure to contaminants and risk of an oil spill are identified threats. Previous studies on contaminants have largely focused on legacy pollutants. Here we measure polycyclic aromatic hydrocarbons (PAHs) in whale fecal (scat) samples. PAHs are a diverse group of hazardous compounds (e.g., carcinogenic, mutagenic), and are a component of crude and refined oil as well as motor exhaust. The central finding from this study indicates low concentrations of the measured PAHs (< 10 ppb, wet weight), as expected; however, PAHs were as high as 104 ppb prior to implementation of guidelines mandating increased distance between vessels and whales. While causality is unclear, the potential PAN exposure from vessels warrants continued monitoring. Historical precedent similarly emphasizes the importance of having pre-oil spill exposure data available as baseline to guide remediation goals.

Matkin, C. O., Moore, M. J., & Gulland, F. M. D. (2017). *Review of Recent Research on Southern Resident Killer Whales to Detect Evidence of Poor Body Condition in the Population.* Independent Science Panel https://doi.org/10.1575/1912/8803
This review was commissioned by the SeaDoc Society in light of major concern for the population trajectory of the SRKW population. The review focuses on identifying evidence for poor body condition in the SRKW population from information presented in Seattle, March 6 2017 (see Appendix 1 Agenda). Body condition can be influenced by food availability (quantity and quality), energy balance, disease, toxin exposure, physiological status, genetics and stress from noise and vessel traffic, amongst other factors, although food availability is the most common cause in wild mammalian populations. For SRKW,

food availability to individuals is determined by both prey availability and time to find, catch, share and consume prey. Anthropogenic disturbance will reduce food consumption and thus influence body condition. The small population size and complex social structure of SRKW complicate detection of associations between measures of body condition and population dynamics. Stochastic events can skew population-wide trends substantially. Therefore, individual cases must be considered rather than analyses of trends and correlations on limited-sample-sizes. The small sample size problem hinders many analyses of this population's ecology. A recent shift in distribution of Northern Resident Killer Whales (NRKW) into offshore SRKW range complicates choice of a control population. NRKW could compete for space and prey, and may be influenced by environmental variables that influence SRKW. Thus when using a case control approach, and comparing parameters between SRKW and a reference population, care should be taken when using the NRKW, and another population should be used such as the southern Alaskan residents.

Matkin, C. O., Moore, M. J., & Gulland, F. M. D. (2017). *Review of Recent Research on Southern Resident Killer Whales to Detect Evidence of Poor Body Condition in the Population - Review of Recent Research on Southern Resident Killer Whales to Detect Evidence of Poor Body Condition in the Population.* https://doi.org/10.1575/1912/8803
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Melendez, D., Roberts, M. C., Greninger, A. L., Weissman, S., No, D., Rabinowitz, P., & Wasser, S. (2019). Whole-Genome Analysis of Extraintestinal Pathogenic Escherichia Coli (Expec) Mdr St73 and St127 Isolated from Endangered Southern Resident Killer Whales (Orcinus Orca). *Journal of Antimicrobial Chemotherapy, 74*(8), https://doi.org/10.1093/jac/dkz159
Background: Limited studies have investigated the microbial diversity of wild marine mammals. Objectives: This study characterized Escherichia coli isolates collected from fresh faecal samples of endangered southern resident killer whales (Orcinus orca) located by detection dogs. Methods: WGS of each strain was done to determine ST (using MLST), clonotype (C:H), antimicrobial resistance and virulence profile. Conjugation experiments were done to determine the mobility of the tet(B) tetracycline resistance gene. Results: All isolates belonged to extraintestinal pathogenic E. coli (ExPEC) clonal lineages ST73 (8/9) and ST127 (1/9), often associated with human community-acquired urinary

tract disease. Clonotyping using fumC and fimH alleles showed divergence in clonal lineages, with ST73 isolates belonging to the C24:H10 clade and the ST127 isolate belonging to C14:H2. The eight ST73 isolates carried multiple acquired antibiotic resistance genes, including aadA1, sul1 and tet(B), encoding aminoglycoside, sulphonamide and tetracycline resistance, respectively. Conjugative transfer of the resistance gene tet(B) was observed for three of the eight isolates. ST127 did not carry any of these acquired resistance genes. Virulence-associated genes identified included those encoding adhesins (iha, papC, sfaS), toxins (sat, vat, pic, hlyA, cnf1), siderophores (iutA, fyuA, iroN, ireA), serum survival/protectins (iss, ompT), capsule (kpsM) and pathogenicity island marker (malX). Conclusions: Orca whales can carry antibiotic-resistant potentially pathogenic strains of E. coli. Possible sources include contamination of the whale's environment and/or food. It is unknown whether these isolates cause disease in southern resident killer whales, which could contribute to the ongoing decline of this critically endangered population.

Mongillo, T. M., Ylitalo, G. M., Rhodes, L. D., O'Neill, S. M., Noren, D. P., & Hanson, M. B. (2016). *Exposure to a Mixture of Toxic Chemicals : Implications for the Health of Endangered Southern Resident Killer Whales.* https://doi.org/10.7289/V5/TM-NWFSC-135

The distinct population segment (DPS) of Southern Resident killer whales (Orcinus orca) was listed as endangered under the Endangered Species Act (ESA) on 18 November 2005. The Southern Residents regularly occur in the inland waters of Washington and British Columbia during late spring, summer, and early fall. Less is known about their movements in the winter, but they occur in coastal waters from California to southeast Alaska. Many studies have indicated that they primarily consume Chinook salmon (Oncorhynchus tshawytscha). Several major threats were identified--both in the final determination to list the Southern Resident killer whale DPS as endangered, and in the Southern Resident killer whale recovery plan--one of which was exposure to high levels of organochlorine contaminants and increasing levels of emerging contaminants. The primary objectives of this Technical Memorandum are to review the contaminants that may pose a risk to the Southern Resident killer whales and to discuss the health implications of exposure to these contaminants. In this report, we focus on three persistent organic pollutants (POPs): polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and dichlorodiphenyltrichloroethane (DDT) and its metabolites. We focus on these three POPs because they are found at relatively high levels in the whales and may cause adverse health effects. We also describe what is currently known about the whales' geographic distribution and diet, as well as contaminant levels measured in their prey. We review the factors that influence contaminant bioaccumulation and the development of biomarkers for exposure and toxicity. Lastly, we highlight data gaps and make recommendations for future studies

Noel, M., & Brown, T. M. (2021). Contaminants as a Conservation Threat to Marine Mammals (Vol. NA, pp. 401-420) https://doi.org/10.1007/978-3-030-64682-0_15

Persistent Organic Pollutants (POPs) and inorganic elements like mercury (Hg) are ubiquitous environmental pollutants. Their physico-chemical properties allow them to be transported over great distances, deposited, and incorporated into aquatic food webs. As long-lived species, many high trophic level marine mammals bioaccumulate high levels of certain contaminants, and a variety of contaminant-related health effects have been reported in populations around the world. Contaminants have been identified as one of the top threats to over 80% of the marine mammal populations globally, including two of Canada’s most endangered cetacean populations, Southern Resident killer whales (orcinus orca) from the northeastern Pacific, and St Lawrence Estuary beluga whales (Delphinapterus leucas). It is therefore critical that we continue to improve upon our understanding of contaminant sources, their fate, and effects in order to better inform on marine mammal conservation measures. The collection of samples from marine mammals poses a number of challenges, however, over the past few decades novel approaches have been developed that allow for minimally invasive collection of samples (e.g., fecal). As well, the development and use of new laboratory techniques (e.g., omics) has allowed for the assessment of contaminant-related impacts at different levels of biological organization. Despite these advances, there is much to be learned about contaminant-mediated effects in marine mammals at both the individual and population levels. There is a need for long-term monitoring programmes that use multidisciplinary approaches to assess regional contaminant trends and effects in marine mammals in the context of other environmental stressors, including climate change.

Noel, M., Ylitalo, G., Hanson, B., Towers, J., & Ross, P. (2018). *PCB and PBDE Levels in Southern and Northern Resident Killer Whales: Update on Contaminant Levels and Related Health Effects*. Paper presented at the Salish Sea Ecosystem Conference, Seattle, WA. Oral Retrieved from https://cedar.wwu.edu/ssec/2018ssec/allsessions/30/

Salish Sea's killer whale populations are among the most contaminated marine mammals in the world and face risks related to the effects of polychlorinated biphenyls (PCBs) and related contaminants such as polybrominated diphenylethers (PBDEs). While PCBs have long been banned, they continue to present toxic risks to marine mammals, along with a number of other, emerging persistent, bioaccumulative and toxic (PBT) contaminants. Since PBTs have been identified as a threat to the recovery of resident killer whale populations under the auspices of the US Endangered Species Act and the Canadian Species at Risk Act (SARA), documenting the presence, trends and health effects of emerging PBT contaminants represents an important line of research. In the summer of 2016 and 2017, we collected blubber biopsies from 10 southern resident and nine northern resident killer whales. PCB and PBDE analyses were conducted using high resolution gas chromatography/high resolution mass spectrometry. Given the likelihood of significant temporal changes in the concentrations of these contaminants, this study will provide updated contaminant concentration data and strengthen our ability to prioritize contaminants of concern in resident killer whales. In addition, stable isotope and fatty acid analyses will provide important information on diet and nutritional status. Together with analyses of the expression of essential genes involved in immune response, hormone regulation and lipid metabolism, this study provides new essential information on the health status of resident killer whales as it relates to contaminant exposure and will help inform the development and application of recovery action plans.

Pearce, R. (2018). *Bioaccumulation of Pcbs in Southern Resident Killer Whales in the Salish Sea.* (Master of Resource and Environmental Management), Simon Fraser University, Retrieved from https://summit.sfu.ca/item/19543

Chemical contaminants are a threat to Southern Resident Killer Whales (SRKW). The contribution of polychlorinated biphenyls (PCBs) in local sediments to the bioaccumulation of PCBs in SRKW was investigated. The temporal and spatial trends of concentrations of PCBs in sediment, Chinook salmon and SRKW were assessed. The half – lives of PCBs were estimated using a food web bioaccumulation model and the concentrations of PCBs in Chinook salmon and SRKW were estimated using Biota Sediment Accumulation Factors. There were no significant temporal declines in the concentrations of PCBs in sediment, Chinook salmon or SRKW as would be expected given the half – lives. The concentrations of PCBs in sediment could bioaccumulate to the levels observed in SRKW. Some similarities in the PCB congener composition were observed in sediment, salmon and SRKW. The results suggest that local environmental sources of PCBs in the Salish Sea could contribute to the PCBs observed in SRKW.

Raverty, S., St Leger, J., Noren, D. P., Burek Huntington, K., Rotstein, D. S., Gulland, F. M. D., . . . Gaydos, J. K. (2020). Pathology Findings and Correlation with Body Condition Index in Stranded Killer Whales (Orcinus Orca) in the Northeastern Pacific and Hawaii from 2004 to 2013. *Plos One, 15*(12), https://doi.org/10.1371/journal.pone.0242505

Understanding health and mortality in killer whales (Orcinus orca) is crucial for management and conservation actions. We reviewed pathology reports from 53 animals that stranded in the eastern Pacific Ocean and Hawaii between 2004 and 2013 and used data from 35 animals that stranded from 2001 to 2017 to assess association with morphometrics, blubber thickness, body condition and cause of death. Of the 53 cases, cause of death was determined for 22 (42%) and nine additional animals demonstrated findings of significant importance for population health. Causes of calf mortalities included infectious disease, nutritional, and congenital malformations. Mortalities in sub-adults were due to trauma, malnutrition, and infectious disease and in adults due to bacterial infections, emaciation and blunt force trauma. Death related to human interaction was found in every age class. Important incidental findings included concurrent sarcocystosis and toxoplasmosis, uterine leiomyoma, vertebral periosteal proliferations, cookiecutter shark (Isistius sp.) bite wounds, excessive tooth wear and an ingested fish hook. Blubber thickness increased significantly with body length (all $p < 0.001$). In contrast, there was no relationship between body length and an index of body condition (BCI). BCI was higher in animals that died from trauma. This study establishes a baseline for understanding health, nutritional status and causes of mortality in stranded killer whales. Given the evidence of direct human interactions on all age classes, in order to be most successful recovery efforts should address the threat of human interactions, especially for small endangered groups of killer whales that occur in close proximity to large human populations, interact with recreational and commercial fishers and transit established shipping lanes.

Raverty, S. A., Rhodes, L. D., Zabek, E., Eshghi, A., Cameron, C. E., Hanson, M. B., & Schroeder, J. P. (2017). Respiratory Microbiome of Endangered Southern Resident Killer Whales and Microbiota of Surrounding Sea Surface Microlayer in the Eastern North Pacific. *Scientific Reports, 7*, https://doi.org/10.1038/s41598-017-00457-5

In the Salish Sea, the endangered Southern Resident Killer Whale (SRKW) is a high trophic indicator of ecosystem health. Three major threats have been identified for this population: reduced prey availability, anthropogenic contaminants, and marine vessel disturbances. These perturbations can culminate in significant morbidity and mortality, usually associated with secondary infections that have a predilection to the respiratory system. To characterize the composition of the respiratory microbiota and identify recognized pathogens of SRKW, exhaled breath samples were collected between 20062009 and analyzed for bacteria, fungi and viruses using (1) culture-dependent, targeted PCR- based methodologies and (2) taxonomically broad, non-culture dependent PCR-based methodologies. Results were compared with sea surface microlayer (SML) samples to characterize the respective microbial constituents. An array of bacteria and fungi in breath and SML samples were identified, as well as microorganisms that exhibited resistance to multiple antimicrobial agents. The SML microbes and respiratory microbiota carry a pathogenic risk which we propose as an additional, fourth putative stressor (pathogens), which may adversely impact the endangered SRKW population.

Rosenberger, A. L. J., MacDuffee, M., Rosenberger, A. G. J., & Ross, P. S. (2017). Oil Spills and Marine Mammals in British Columbia, Canada: Development and Application of a Risk-Based Conceptual Framework. *Archives of Environmental Contamination and Toxicology, 73*(1), https://doi.org/10.1007/s00244-017-0408-7

Marine mammals are inherently vulnerable to oil spills. We developed a conceptual framework to evaluate the impacts of potential oil exposure on marine mammals and applied it to 21 species inhabiting coastal British Columbia (BC), Canada. Oil spill vulnerability was determined by examining both the likelihood of species-specific (individual) oil exposure and the consequent likelihood of population-level effects. Oil exposure pathways, ecology, and physiological characteristics were first used to assign species-specific vulnerability rankings. Baleen whales were found to be highly vulnerable due to blowhole breathing, surface filter feeding, and invertebrate prey. Sea otters (Enhydra lutris) were ranked as highly vulnerable due to their time spent at the ocean surface, dense pelage, and benthic feeding techniques. Species-specific vulnerabilities were considered to estimate the likelihood of population-level effects occurring after oil exposure. Killer whale (Orcinus orca) populations were deemed at highest risk due to small population sizes, complex social structure, long lives, slow reproductive turnover, and dietary specialization. Finally, we related the species-specific and population-level vulnerabilities. In BC, vulnerability was deemed highest for Northern and Southern Resident killer whales and sea otters, followed by Bigg's killer whales and Steller sea lions (Eumetopias jubatus). Our findings challenge the typical "indicator species" approach routinely used and underscore the need to examine marine mammals at a species and population level for risk-based oil spill predictions. This conceptual framework can be combined with spill probabilities and volumes to develop more robust risk assessments and may be applied elsewhere to identify vulnerability themes for marine mammals.

Weiss, M. N., Franks, D. W., Balcomb, K. C., Ellifrit, D. K., Silk, M. J., Cant, M. A., & Croft, D. P. (2020). Modelling Cetacean Morbillivirus Outbreaks in an Endangered Killer Whale Population. *Biological Conservation, 242*, https://doi.org/10.1016/j.biocon.2019.108398

The emergence of novel diseases represents a major hurdle for the recovery of endangered populations, and in some cases may even present the threat of extinction. In recent years, epizootics of infectious diseases have emerged as a major threat to marine mammal populations, particularly group-living odontocetes. However, little research has explored the potential consequences of novel pathogens in endangered cetacean populations. Here, we present the first study predicting the spread of infectious disease over the social network of an entire free-ranging cetacean population, the southern resident killer whale community (SRKW). Utilizing 5 years of detailed data on close contacts between individuals, we build a fine-scale social network describing potential transmission pathways in this population. We then simulate the spread of cetacean morbillivirus (CeMV) over this network. Our analysis suggests that the SRKW population is highly vulnerable to CeMV. The majority of simulations resulted in unusual mortality events (UMEs), with mortality rates predicted to be at least twice the recorded maximum annual mortality. We find only limited evidence that this population's social structure inhibits disease spread. Vaccination is not likely to be an efficient strategy for reducing the likelihood of UMEs, with over 40 vaccinated individuals (> 50% of the population) required to reduce the likelihood of UMEs below 5%. This analysis highlights the importance of modelling efforts in designing strategies to mitigate disease, and suggests that populations with strong social preferences and distinct social units may still be highly vulnerable to disease outbreaks.

## **Section VI:** Energetics

Groskreutz, M. J., Durban, J. W., Fearnbach, H., Barrett-Lennard, L. G., Towers, J. R., & Ford, J. K. B. (2019). Decadal Changes in Adult Size of Salmon-Eating Killer Whales in the Eastern North Pacific. *Endangered Species Research, 40*, https://doi.org/10.3354/esr00993

Two populations of killer whales aggregate around Vancouver Island to feed primarily on Chinook salmon. Aerial photogrammetry of endangered southern residents has documented some adults growing to smaller lengths in recent decades, suggesting that early growth may have been constrained by low Chinook availability in the 1990s. We investigated whether growth and adult length were also constrained in the more abundant northern residents. Photographs were collected from an unmanned hexacopter at altitudes of 30 to 37 m over 4 yr, 2014 to 2017. Images were linked to 78 individuals of known age and sex based on distinctive saddle patch pigmentation. The length of each whale was estimated by measuring pixel dimensions between both the snout and dorsal fin and the dorsal fin and fluke; these were scaled to real size using camera lens focal length and altitude, determined by a laser or pressure altimeter. Total length, derived by summing the longest (flattest) of each measure, ranged from 2.42 m for a first-year calf to 7.45 m for the largest adult male. A Bayesian change point analysis revealed that adult whales < 40 yr old were on average shorter by 0.44 m than older adults, which grew to typical lengths of 6.28 and 7.14 m for females and males, respectively. This mirrors the growth trends reported for southern residents, supporting demographic evidence of correlated prey limitation in both populations. The growth data suggest that the effects of nutritional stress are not only acutely lethal but also have long-term consequences for the condition of whales in both populations.

Roos, M. M., Wu, G. M., & Miller, P. J. (2016). The Significance of Respiration Timing in the Energetics Estimates of Free-Ranging Killer Whales (Orcinus Orca). *Journal of Experimental Biology, 219*(Pt 13), https://doi.org/10.1242/jeb.137513

Respiration rate has been used as an indicator of metabolic rate and associated cost of transport (COT) of free-ranging cetaceans, discounting potential respiration-by-respiration variation in O2 uptake. To investigate the influence of respiration timing on O2 uptake, we developed a dynamic model of O2 exchange and storage. Individual respiration events were revealed from kinematic data from 10 adult Norwegian herring-feeding killer whales (Orcinus orca) recorded with high-resolution tags (DTAGs). We compared fixed O2 uptake per respiration models with O2 uptake per respiration estimated through a simple 'broken-stick' O2-uptake function, in which O2 uptake was assumed to be the maximum possible O2 uptake when stores are depleted or maximum total body O2 store minus existing O2 store when stores are close to saturated. In contrast to findings assuming fixed O2 uptake per respiration, uptake from the broken-stick model yielded a high correlation (r(2)>0.9) between O2 uptake and activity level. Moreover, we found that respiration intervals increased and became less variable at higher swimming speeds, possibly to increase O2 uptake efficiency per respiration. As found in previous studies, COT decreased monotonically versus speed using the fixed O2 uptake per respiration models. However, the broken-stick uptake model yielded a curvilinear COT curve with a clear minimum at typical swimming speeds of 1.7-2.4 m s(-1) Our results showed that respiration-by-respiration variation in O2 uptake is expected to be significant. And though O2 consumption measurements of COT for free-ranging cetaceans remain impractical, accounting for the influence of respiration timing on O2 uptake will lead to more consistent predictions of field metabolic rates than using respiration rate alone.

Tennessen, J. B., Holt, M. M., Hanson, M. B., Emmons, C. K., Giles, D. A., & Hogan, J. T. (2019). Kinematic Signatures of Prey Capture from Archival Tags Reveal Sex Differences in Killer Whale Foraging Activity. *Journal of Experimental Biology, 222*(3), https://doi.org/10.1242/jeb.191874

Studies of odontocete foraging ecology have been limited by the challenges of observing prey capture events and outcomes underwater. We sought to determine whether subsurface movement behavior recorded from archival tags could accurately identify foraging events by fish-eating killer whales. We used multisensor bio-logging tags attached by suction cups to Southern Resident killer whales (Orcinus orca) to: (1) identify a stereotyped movement signature that co-occurred with visually confirmed prey capture dives; (2) construct a prey capture dive detector and validate it against acoustically confirmed prey capture dives; and (3) demonstrate the utility of the detector by testing hypotheses about foraging ecology. Predation events were significantly predicted by peaks in the rate of change of acceleration ('jerk peak'), roll angle and heading variance. Detection of prey capture dives by movement signatures enabled substantially more dives to be included in subsequent analyses compared with previous surface or acoustic detection methods. Males made significantly more prey capture dives than females and more dives to the depth of their preferred prey, Chinook salmon. Additionally, only half of the tag deployments on females (5 out of 10) included a prey capture dive, whereas all tag deployments on males exhibited at least one prey capture dive (12 out of 12). This dual approach of kinematic detection of prey capture coupled with hypothesis testing can be applied across odontocetes and other marine predators to investigate the impacts of social, environmental and anthropogenic factors on foraging ecology.

## Section VII: Vessel Interaction and Noise

Burnham, R. (2018). *The Impacts of Noise on Southern Resident Killer Whales: A Literature Review*. Retrieved from https://apps.neb-one.gc.ca/REGDOCS/File/Download/3718207

In October 2018, I was asked by the Province of British Columbia to conduct a literature review and prepare a high-level summary of the impacts of underwater noise on southern resident killer whales (SRKWs). In order to do so, I reviewed peer-reviewed scientific literature, with a focus on the most recently published material. I also focused as much as possible on the literature that related directly to SRKWs in the Salish Sea and surrounding waters. Other sources have been included to set the salient points into context.

Burnham, R. E., Vagle, S., O'Neill, C., & Trounce, K. (2021). The Efficacy of Management Measures to Reduce Vessel Noise in Critical Habitat of Southern Resident Killer Whales in the Salish Sea. *Frontiers in Marine Science, 8*, https://doi.org/10.3389/fmars.2021.664691

The inland waters around southern Vancouver Island and northern Washington State, known as the Salish Sea, host critical habitat for endangered southern resident killer whales (SRKW). This is, however, a highly traversed area, with approaches to industrial ports and coastal cities, international shipping lanes, ferry routes, and considerable recreational vessel traffic. Vessel noise is a key threat to SRKW prosperity, and so conservation measures directed to mitigate its effects have been explored annually since 2017. Here, we describe trials undertaken in 2020, which included spatially limited slowdown zones, exclusion areas as Interim whale Sanctuary Zones (ISZs), and a lateral displacement of tug transits to increase the distance between their route and SRKW foraging areas. To assess each of the measures we first considered the level of mariner participation using data from the Automated Identification Systems (AIS), mandatory for commercial vessels. Knowing this, the changes in soundscape were examined, focused on impacts on broadband (10 Hz to 100 kHz) ambient noise and the frequencies used by SRKW for communication (500 Hz to 15 kHz) and echolocation (15 to 100 kHz). A control period of two-months prior to trial initiation was used to quantify the changes. High levels (> 80%) of compliance were found for each measure, except ISZs, where observance was low. Median reduction in speeds ranged from 0.2-3.5 knots. Resulting sound reductions were most notable in the lower frequencies, although reductions were also recorded in SRKW pertinent ranges. Tug displacement also reduced ambient noise in these frequencies, despite making up a small portion of the overall traffic. The management trials were effective in reducing potential impacts singularly and in concert. Greater awareness and stakeholder engagement may increase compliance and, therefore, the efficacy of measures in the future.

Cominelli, S. (2018). *A Framework to Estimate the Risk of Noise Exposure from Vessels for Endangered Cetacean Species.* (Master of Science, Geography Department, Faculty of Humanities and Social Sciences), Memorial University of Newfoundland, Retrieved from https://research.library.mun.ca/13614/

This thesis proposes a framework for assessing and visualizing exposure of the Southern Resident Killer Whale (SRKW) population to vessels' noise. First, SRKW distribution was mapped and the risk for this population to be exposed to vessel-noise was estimated. The study identified six vessel classes as being the main contributors to noise exposure for SRKW. Building on this result, the second study presents an analytical framework focused on exposure hotspot mapping, the computation of probabilistic levels of exposure, and the identification of shipping routes minimizing exposure for SRKW. The framework was tested in the Salish Sea, leading to the identification of four hotspots of exposure for SRKW. Small spatial changes in the current shipping lanes could lead to a large reduction of the overlap between vessel traffic and sensitive areas for SRKW. The results highlight how effectively addressing vessel noise requires the implementation of adaptive management strategies.

Cominelli, S., Devillers, R., Yurk, H., MacGillivray, A., McWhinnie, L., & Canessa, R. (2018). Noise Exposure from Commercial Shipping for the Southern Resident Killer Whale Population. *Marine Pollution Bulletin, 136*, https://doi.org/10.1016/j.marpolbul.2018.08.050

This study assesses vessel-noise exposure levels for Southern Resident Killer Whales (SRKW) in the Salish Sea. Kernel Density Estimation (KDE) was used to delineate SRKW summer core areas. Those areas were combined with the output of a regional cumulative noise model describing sound level variations generated by commercial vessels (1/3-octave-bands from 10 Hz to 63.1 kHz). Cumulative distribution functions were used to evaluate SRKW's noise exposure from 15 vessel categories over three zones located within the KDE. Median cumulative noise values were used to group categories based on the associated exposure levels. Ferries, Tugboats, Vehicle Carriers, Recreational Vessels, Containers, and Bulkers showed high levels of exposure (Leq-50th > 90 dB re 1 mu Pa) within SRKW core areas. Management actions aiming at reducing SRKW noise exposure during the summer should target the abovementioned categories and take into consideration the spatial distribution of their levels of exposure, their mechanical and their operational characteristics.

Cominelli, S., Leahy, M., Devillers, R., & Hall, G. B. (2019). Geovisualization Tools to Inform the Management of Vessel Noise in Support of Species' Conservation. *Ocean & Coastal Management, 169*, https://doi.org/10.1016/j.ocecoaman.2018.11.009
The growth of global ocean noise recorded over the past decades is increasingly affecting marine species and requires assessment on the part of marine managers. We present a framework for the analysis of species' exposure to noise from shipping. Integrated into a set of geovisualization tools, our approach focuses on exposure hotspot mapping, on the computation of probabilistic levels of exposure, and on the identification of shipping routes that minimize exposure levels for Cetacean species. The framework was applied to estimate noise exposure for the Southern Resident Killer Whale (SRKW) population, and for the exploration of possible ship traffic displacement scenarios in the Salish Sea, British Columbia. Four noise exposure hotspots were identified within the SRKW's core habitat. Exposure over these areas was mainly produced by six vessel classes, namely Ferries, Tugboats, Recreational Vessels, Vehicle Carriers, Containers, and Bulkers. Exposure levels showed variability across hotspots suggesting that a fine-scale spatial dimension should be included in the design of noise pollution mitigation strategies for the Salish Sea. The scenarios suggest that small changes in the current shipping lanes (3.4% increase in traveled distance) can lead to a 56% reduction of the overlap between vessel traffic and sensitive areas for SRKW.

Ferrara, G. A., Mongillo, T. M., & Barre, L. M. (2017). *Reducing Disturbance from Vessels to Southern Resident Killer Whales : Assessing the Effectiveness of the 2011 Federal Regulations in Advancing Recovery Goals.* Retrieved from https://repository.library.noaa.gov/view/noaa/17432
In 2008, NMFS issued the final recovery plan for Southern Residents to identify actions to address factors that may be limiting recovery, including quantity and quality of prey, toxic chemicals that accumulate in top predators, and disturbance from vessels and sound (NMFS 2008). Oil spills and disease were also identified as potential risk factors. Despite efforts to study these whales over the last 40 years, we are unsure which threats are most significant to the survival and recovery of the species. It is likely that these threats are acting together to threaten the killer whales. Below are very brief descriptions of the primary threats. More detailed information is provided in the recovery plan (NMFS 2008) with additional updates provided in the most recent ESA 5-year review (NMFS 2016a).

Fisheries and Oceans Canada. (2017). *Evaluation of the Scientific Evidence to Inform the Probability of Effectiveness of Mitigation Measures in Reducing Shipping-Related Noise Levels Received by Southern Resident Killer Whales.* Fisheries and Oceans Canada Ottawa. Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/40646713.pdf
Ambient underwater noise levels have increased significantly over the past half century, largely as a result of increasing human activities in the marine environment. Marine shipping and vessel navigation activities of all types have been identified as important contributors. However, the extent of this contribution, and its associated impacts on marine species, is not well understood, and is complex to assess. There have been growing demands for government action to address this issue domestically and internationally in order to protect the marine ecosystem, and more specifically, species at risk. In Canada, concerns are growing over the effects of underwater noise on marine mammals particularly in the south coast of British Columbia, the Estuary and Gulf of St. Lawrence, and the Bay of Fundy. Most recently, in its review of the Trans Mountain Expansion (TMX) Project, the National Energy Board (NEB) found that the increase in marine vessels associated with the Project would further contribute to cumulative effects that are already jeopardizing the recovery of the Southern Resident Killer Whale (SRKW). Consequently, the Board concluded that the operation of Project-related marine vessels is likely

to result in significant adverse effects to the SRKW population. The NEB encouraged regulatory authorities who have jurisdiction, notably Transport Canada (TC) and Fisheries and Oceans Canada (DFO), to explore initiatives that would reduce the potential effects of marine vessels on the SRKW population. In approving TMX, the Government of Canada committed to more than mitigate the impact of additional TMX traffic on the SRKW before any shipping associated with the Project begins. DFO's Fisheries Protection Program (FPP) has asked DFO Science to provide science advice on the effectiveness of various mitigation measures (or a combination of these) for reducing shipping-related noise levels received by SRKW.

Fisheries and Oceans Canada. (2017). Technical Review of Roberts Bank Terminal 2 Environmental Impact Statement and Marine Shipping Supplemental Report : Effects on Marine Mammals. In (pp. 31). Ottawa: Peches et Oceans Canada. Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/40621418.pdf

DFO's Pacific Region Fisheries Protection Program (FPP) has requested DFO Science Branch provide an evaluation of the Proponent's characterization of effects of project construction and operation, and Project-related increase in marine vessel traffic on marine mammals and marine mammal habitat. The assessment and advice arising from this Science Response (SR) will be used to assist in the development of DFO's submission to the Review Panel during its review of the Roberts Bank Terminal 2 Project. With respect to the Project's potential effects on marine mammals and marine mammal habitat, this Science Response will address the following objectives: 1. Assess the adequacy of the data, and the technical acceptability of the methods and models used to characterize the potential effects of underwater noise from: a) pile driving during project construction; b) increased local vessel activity within the Vancouver Fraser Port Authority's jurisdiction; and, c) increased vessel traffic outside of the Vancouver Fraser Port Authority's jurisdiction to the 12 nautical mile limit of Canada's territorial sea. 2. Determine if the conclusions related to potential effects of underwater noise are adequately supported by the data, methods and models and identify key information gaps and uncertainty. 3. Determine if the rationale and conclusions related to potential effects of ship strikes are reasonable, and identify key information gaps and uncertainty. 4. In relation to availability of prey for Southern Resident Killer Whale, provide advice regarding the validity of the conclusion that the Project would have a negligible effect on the combined productive potential of juvenile and adult Chinook and Chum Salmon, and identify key information gaps and uncertainty. 5. Provide advice regarding effectiveness of measures proposed by the Proponent to mitigate effects of underwater noise on Southern Resident Killer Whale, identify key information gaps and uncertainty related to these measures, and provide additional recommendations for mitigation, where possible.

Fisheries and Oceans Canada. (2018). Technical Review: Potential Effectiveness of Mitigation Measures to Reduce Impacts from Project-Related Marine Vessels on Southern Resident Killer Whale. In (pp. 23). Ottawa: Fisheries and Oceans Canada. Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/4073982x.pdf

Trans Mountain Pipeline ULC (Trans Mountain) is proposing an expansion of its current 1,150 km pipeline system between Edmonton, Alberta (AB) and Burnaby, British Columbia (BC), along with an expansion of the Westridge Marine Terminal in Burrard Inlet, to accommodate increased marine vessel traffic. On November 29, 2016, the Government of Canada granted approval for the Project, following a 29-month environmental assessment review by the National Energy Board (NEB), which concluded that the Project is in the Canadian public interest and recommended that the federal Governor in Council (GiC) approve the expansion. On August 30, 2018, the Federal Court of Appeal (FCA) released its

decision with respect to judicial review applications challenging the federal approval of the Project. The Court ordered that the Order in Council (OIC) approving the Project be set aside. On September 20, 2018, the GiC sent the NEB's Recommendation Report back to the NEB for reconsideration to address the issues specified by the FCA ruling and gave the NEB 155 days to complete its Reconsideration. Therefore, the Board must complete the Reconsideration process and issue its Reconsideration report no later than February 22, 2019. On October 12, 2018, the NEB released Hearing Order MH-052-2018, announcing that it will hold a public hearing and set out the timelines and process for the Reconsideration. On the same day, the NEB sent a letter to federal authorities (including Fisheries and Oceans Canada [DFO]) requesting specialist or expert information to support the Reconsideration. Specifically, the NEB has requested information in regard to the effectiveness of mitigation measures aimed at avoiding or reducing impacts from Project-related marine vessels on the Southern Resident Killer Whale (SRKW). Existing and proposed Project-related marine vessel traffic are expected to use the established in-bound and out-bound marine shipping lanes in the Marine Regional Study Area (Marine RSA), which intersect critical habitat for SRKW (Figure 1). As an intervenor in the Reconsideration hearing process for the Trans Mountain Expansion Project, Fisheries and Oceans Canada (DFO) will be presenting written evidence and responding to information requests from the NEB and other Intervenors in relation to its expertise on the effects of the Project on marine fish and fish habitat and marine mammals (including aquatic species at risk), the efficacy and adequacy of mitigation measures, and monitoring and follow-up programs that were not considered in the last NEB Hearing (OH-001-2014).

Fraser, M. D., McWhinnie, L. H., Canessa, R. R., & Darimont, C. T. (2020). Compliance of Small Vessels to Minimum Distance Regulations for Humpback and Killer Whales in the Salish Sea. *Marine Policy, 121*, https://doi.org/10.1016/j.marpol.2020.104171

To support optimal monitoring and enforcement investment, management aimed at minimizing disturbance to wildlife requires an understanding of how regulatory compliance might vary spatially as well as across species and human-user groups. In the Salish Sea, humpback whales (Megaptera novaeangliae) and two ecotypes (southern resident and Bigg's) of killer whales (Orcinus orca) now interact with a large and growing number of small commercial and recreational vessels that partake in whale watching. Those vessels often approach close to cetaceans and thus pose risk via collision, marine noise and pollution, exposure to which may result in disturbance, injury and death. The primary management tool for mitigating impacts is minimum distance regulations. Compliance, however, is poorly understood. We examined commercial and recreational small vessel compliance with viewing distances across two seasons (June-September 2018 and 2019) in over approximate to 404 h of on-water observation. Overall vessel compliance was nearly 80%, but several distinct patterns emerged. Recreational boats were significantly more likely to violate distance regulations and boaters were more likely to be noncompliant around killer whales. Compliance did not vary with day of week or time of day. Spatially, noncompliance was concentrated in waters closer to coastal communities. Collectively, these patterns suggest that optimal enforcement could be targeted to identify areas of high non-compliance, especially for killer whales, with effort spread across days and times. Finally, we discuss how investments in education could target recreational boaters at a time when multiple and interacting stressors are accumulating in the Salish Sea.

Green Marine Management Corporation. (2017). Understanding Anthropogenic Underwater Noise. Retrieved from https://www.ceaa-acee.gc.ca/050/documents/p80054/123654E.pdf

Sources of anthropogenic (human-caused) unde.rwater noise have increased significantly over the past fifty years, largely as a result of increases in seismic exploration, military and commercial sonars, and maritime transportation. Commercial shipping is one of the main contributors to anthropogenic noise and is mainly generated by propeller cavitation and onboard machinery. Tt1e low-frequency sounds that ships generate propagate efficiently and travel vast distances in deep water marine environments. This has sparked concerns about the impacts of underwater noise on marine life, which use sound to communicate, navigate, feed and reproduce. As the agency responsible for regulating shipping in Canada, Transport Canada (TC) considered it essential to better understand the problem of underwater noise within Canadian waters. This report assembles some of the technical knowledge about anthropogenic underwater noise and its potential impacts in a marine environment. It details· information about how, based on the current state of knowledge, the maritime industry contributes to ambient underwater noise and should facilitate understanding on how noise can pose a threat to the conservation of marine animals and to the recovery of species at risk.

Heise, K., Barrett-Lennard, L., Chapman, R., Dakin, T., Erbe, C., Hannay, D., . . . Yurk, H. (2017). *Proposed Metrics for the Management of Underwater Noise for Southern Resident Killer Whales.* C. O. R. Institute https://doi.org/10.25317/CORI20172

The endangered transboundary Southern Resident Killer Whale population (SRKW) is a distinct, reproductively- and demographically-isolated population of salmon-eating killer whales that is most often found in the waters of the western coast of North America. It numbers only 78 individuals at present and has shown no net increase in numbers in four decades (Centre for Whale Researchwhaleresearch.com). Its inherently low reproductive rate gives it very limited capacity to sustain elevated mortality rates. Its scientifically-identified and legally-designated critical habitat includes most of the network of waterways in southern British Columbia and northern Washington State known as the Salish Sea (DFO 2011). Other important areas include the north side of the Strait of Juan de Fuca and Swiftsure Bank (James Pilkington, pers. comm. this workshop. Ford et al. 2017). Ship traffic is heavy throughout all of these areas.

Holt, M. M., Hanson, M. B., Emmons, C. K., Haas, D. K., Giles, D. A., & Hogan, J. T. (2019). Sounds Associated with Foraging and Prey Capture in Individual Fish-Eating Killer Whales, Orcinus Orca. *Journal of the Acoustical Society of America, 146*(5), https://doi.org/10.1121/1.5133388

Foraging behavior in odontocetes is fundamentally tied to the use of sound. Resident-type killer whales use echolocation to locate and capture elusive salmonid prey. In this investigation, acoustic recording tags were suction cup-attached to endangered Southern Resident killer whales to describe their acoustic behavior during different phases of foraging that, along with detections of prey handling sounds (e.g., crunches) and observed predation events, allow confirmation of prey capture. Echolocation click trains were categorized based on the inter-click interval (ICI) according to hypothesized foraging function. Whales produced slow click trains (ICI >100 ms) at shallowest depths but over the largest change of depth, fast click trains (10 ms < ICI <= 100 ms) at intermediate depths, and buzz trains (ICI <= 10 ms) at deepest depths over the smallest depth change. These results align with hypotheses regarding biosonar use to search, pursue and capture prey. Males exhibited a higher probability of producing slow click trains, buzzes and prey handling sounds, indicating higher levels of prey searching and capture to support the energy requirement of their larger body size. These findings identify relevant acoustic indicators of subsurface foraging behaviors of killer whales, enabling investigations of human impacts on sound use and foraging.

Holt, M. M., Hanson, M. B., Giles, D. A., Emmons, C. K., & Hogan, J. T. (2017). Noise Levels Received by Endangered Killer Whales Orcinus Orca before and after Implementation of Vessel Regulations. *Endangered Species Research, 34*, https://doi.org/10.3354/esr00841

Whale watching is often conducted from motorized vessels, which contribute to underwater noise pollution and can disturb marine mammals. Protective measures can ameliorate some effects of disturbance, but it is crucial to empirically assess the effectiveness of such measures, particularly for endangered species. We quantitatively compared noise exposure to endangered southern resident killer whales before and after US federal vessel regulations were established to protect this population from disturbance by vessels and sound. We expected to see a reduction in noise exposure to this population from vessel sound propagation loss due to a doubling of the minimum viewing distance relative to a prior state law. Noise levels were empirically measured from digital acoustic recording tags (DTAGs) suction-cup attached to killer whales in transboundary critical habitat. We collected concurrent vessel data during DTAG deployments to relate to received noise levels at the animal. Results of a linear mixed model analysis that included 10 explanatory variables in candidate models revealed that noise was best predicted by animal ID, vessel count, vessel speed category, and year. Vessel count and speed category were positive predictors of noise levels. Vessel regulations (before vs. after implementation), country, and average vessel distance were not significant predictors of noise levels, although only 1 yr of baseline data limited assessment. These findings inform managers about the effectiveness of current regulations for viewing killer whales and are applicable to other cetacean species that are exposed to vessel noise from whale-watching activities.

Holt, M. M., Tennessen, J. B., Hanson, M. B., Emmons, C. K., Giles, D. A., Hogan, J. T., & Ford, M. J. (2021). Vessels and Their Sounds Reduce Prey Capture Effort by Endangered Killer Whales (Orcinus Orca). *Mar Environ Res, 170*, https://doi.org/10.1016/j.marenvres.2021.105429

Vessel traffic is prevalent throughout marine environments. However, we often have a limited understanding of vessel impacts on marine wildlife, particularly cetaceans, due to challenges of studying fully-aquatic species. To investigate vessel and acoustic effects on cetacean foraging behavior, we attached suction-cup sound and movement tags to endangered Southern Resident killer whales in their summer habitat while collecting geo-referenced proximate vessel data. We identified prey capture dives using whale kinematic signatures and found that the probability of capturing prey increased as salmon abundance increased, but decreased as vessel speed increased. When vessels emitted navigational sonar, whales made longer dives to capture prey and descended more slowly when they initiated these dives. Finally, whales descended more quickly when noise levels were higher and vessel approaches were closer. These findings advance a growing understanding of vessel and sound impacts on marine wildlife and inform efforts to manage vessel impacts on endangered populations.

Holt, M. M., Tennessen, J. B., Ward, E. J., Hanson, M. B., Emmons, C. K., Giles, D. A., & Hogan, J. T. (2021). Effects of Vessel Distance and Sex on the Behavior of Endangered Killer Whales. *Frontiers in Marine Science, 7*, https://doi.org/10.3389/fmars.2020.582182

Accurate knowledge of behavior is necessary to effectively manage the effects of human activities on wildlife, including vessel-based whale-watching. Yet, the wholly aquatic nature of cetaceans makes understanding their basic behavioral ecology quite challenging. An endangered population of killer whales faces several identified threats including prey availability and disturbance from vessels and sound. We used biologging tags that were temporally attached to individuals of the endangered Southern Resident killer whale population to more fully understand their subsurface behavior and to investigate vessel effects on behavior, including foraging behavior involving prey capture. We collected tag data over three field seasons in the waters surrounding the San Juan Islands, WA, United States, corresponding to the core summer area of the critical habitat of the population. Here, we used hidden Markov models to identify latent behavioral states that include characterization of different foraging states from sound and movement variables recorded by the multi-sensor tags. We tested a number of vessel variables (e.g., vessel counts, distance, and speed) on state transition probabilities, state occurrence and time spent within each behavioral state. Whales made fewer dives involving prey capture and spent less time in these dives when vessels had an average distance less than 400 yd (366 m). Additionally, we found both a sex and vessel distance effect on the state transition probabilities, suggesting that females and males respond differently to nearby vessels. Specifically, females were more likely to transition to a non-foraging state when vessels had an average distance less than 400 yd (366 m). A female's decision to forego foraging states due to the close proximity of vessels could have cascading effects on the ability to meet energetic requirements to support reproductive efforts. This is particularly concerning in an endangered population that is in decline. Our findings, suggesting that female killer whales are at greater risk to close approaches by vessels, highlight the importance of understanding sex-specific responses to disturbance. These findings can inform future management decisions seeking to preserve foraging opportunities and enhance recovery efforts relevant to many cetacean species, including vulnerable and endangered populations.

Joy, R., Tollit, D., Wood, J., MacGillivray, A., Li, Z., Trounce, K., & Robinson, O. (2019). Potential Benefits of Vessel Slowdowns on Endangered Southern Resident Killer Whales. *Frontiers in Marine Science, 6*, https://doi.org/10.3389/fmars.2019.00344

A voluntary commercial vessel slowdown trial was conducted through 16 nm of shipping lanes overlapping critical habitat of at-risk southern resident killer whales (SRKVV) in the Salish Sea. From August 7 to October 6, 2017, the trial requested piloted vessels to slow to 11 knots speed-through-water. Analysis of AIS vessel tracking data showed that 350 of 951 (37%) piloted transits achieved this target speed, 421 of 951 (44%) transits achieved speeds within one knot of this target (i.e., <= 12 knots), and 55% achieved speeds <= 13 knots. Slowdown results were compared to 'Baseline' noise of the same region, matched across lunar months. A local hydrophone listening station in Lime Kiln State Park, 2.3 km from the shipping lane, recorded 1.2 dB reductions in median broadband noise (10-100,000 Hz, rms) compared to the Baseline period, despite longer transit. The median reduction was 2.5 dB when filtering only for periods when commercial vessels were within 6 km radius of Lime Kiln. The reductions were highest in the 1st decade band (-3.1 dB, 10-100 Hz) and lowest in the 4th decade band (-0.3 dB reduction, 10-100 kHz). A regional vessel noise model predicted noise for a range of traffic volume and vessel speed scenarios for a 1133 km(2) 'Slowdown region' containing the 16 nm of shipping lanes. A temporally and spatially explicit simulation model evaluated the changes in traffic volume and speed on SRKW in their foraging habitat within this Slowdown region. The model tracked the number and magnitude of noise-exposure events that impacted each of 78 (simulated) SRKW across different traffic scenarios. These disturbance metrics were simplified to a cumulative effect termed 'potential lost foraging time' that corresponded to the sum of disturbance events described by assumptions of time that whales could not forage due to noise disturbance. The model predicted that the voluntary Slowdown trial achieved 22% reduction in 'potential lost foraging time' for SRKW, with 40% reductions under 100% 11-knot participation. Slower vessel speeds reduced underwater noise in the Slowdown area despite longer passage times and therefore suggest this is an effective way to benefit SRKW habitat function in the vicinity of shipping lanes.

Joy, R., Wood, J., Miller, B., MacGillivray, A., & Meier, S. (2016). *Development of a Simulation Model for Estimating Behavioural Responses to Vessel Noise: A Case Study with the Southern Resident Killer Whale*. Retrieved from https://cedar.wwu.edu/ssec/2016ssec/species_food_webs/52/
In the marine environment, underwater noise is introduced through a diverse set of industrial activities, including vessel traffic. Endangered Southern Resident killer whales (SRKW), as well as their critical habitat, are federally protected in Canada by the Species at Risk Act. Fisheries and Oceans Canada states in the SRKW recovery strategy that this population of killer whales is potentially vulnerable to underwater noise through loss of echolocation efficiency (masking) and/or behavioural responses. To date, many assessments of the potential effects of underwater noise on marine mammals have used static estimates of noise and animal density (e.g. long-term averages). However, behavioural responses and masking are driven by the short-term confluence of noise and animal density. We therefore developed a simulation model that incorporates short-term estimates of underwater noise and animal density in order to estimate the number of behavioural responses and masking that might occur for each individual SRKW during a year. The simulation inputs included predicted underwater noise levels from vessel traffic at five-minute intervals, and spatiotemporally-informed probabilities of occurrence of three pods of SRKW. Inputs were based on the statistical properties of the source data and varied based on location and time of year. The model was run for 365 days and repeated 1,000 times to generate estimates of the number and the severity of behavioural responses to vessel noise, as well as provide estimates of variability. This simulation model provides a potential management and decision support tool for assessing the likelihood of behavioural responses and masking in SRKW in response to different underwater noise scenarios.

Jurado Fuentes, A., Suchy, M., Beltran Palomo, P., & Ieee. (2019). *The Greatest Challenge for Urn Reduction in the Oceans by Means of Engineering.* Paper presented at the Oceans 2019 MTS/IEEE Retrieved from https://ieeexplore.ieee.org/document/8962779
The Underwater Radiated Noise (URN) of the oceans due to shipping activity has increased during the last decades. This significant increment of URN can be explained by the remarkable growth of maritime traffic in recent years and the greater number of seismic explorations in the oceans. In relation to this issue, the current elevated level of underwater radiated noise in the oceans is producing a negative impact on marine fauna as it is happening with the Southern Resident Killer Whale (SRKW) in the Salish Sea in the west border between Canada and the USA. In the short-term, these high levels of URN block animal's ability to communicate, navigate, reproduce or hunt; while in the long-term, it may cause hearing loss in them. Hence, it is urgent to control the elevated level of URN in the oceans to protect the marine fauna and ensuring the sustainability of the sea environment. The majority of the underwater radiated noise produced by ships in the oceans originates from propellers, engines and auxiliary machinery. The International Council for the Exploration of the Sea (ICES) Report N-o 209 was created with the aim to establish certain limit values on the URN generated by ships. The main purpose of this analysis is to avoid the negative effects of the URN on the sea environment and protect to the marine fauna of the vessel echosounders interferences focusing on the design and build of silent ships by means of a noise and vibration comprehensive management methodology. The scientific community has demonstrated that the anthropogenic noise produced by the shipping sector is the main responsible for the relevant growth of the URN in the oceans which causes negative effects on marine life [2]. As a result, a benchmarking study has been addressed by Canada to inform about the negative impacts of URN in the marine environment and propose the creation of new regulatory policies on URN reduction. This exploratory study has been carried out by a specialized steering committee which is composed of a

network of organizations with a proven record in R&D and innovation activities in shipping URN. This technical study is in line with IMO conclusions for the reduction of URN from commercial shipping to address adverse impacts on marine life (MEPC.1/Circ.833; MEPC 74/17/2; MEPC 74/INF.36) representing the greatest challenge for the protection of the marine fauna in the oceans. To deal with the challenge of URN reduction in the oceans, the technological experiences accumulated over the years in the dynamic and acoustical design of modern Fishing Research Vessels (FRV) and Oceanographic Research Vessels (ORV) can be extrapolated to the rest of marine sectors. The main objective of this study is to identify which type of actions can be potentially used to manage and minimize URN generated by ships in the oceans without affecting the marine traffic and the transport of goods. The main idea is to design a new generation of "Silent Ships" in compliance not only with the strictest Comfort Class Notation requirements but also with the most restrictive URN requirements such as ICES N-o 209. The overall URN level of a ship at certain operational speed is the combination of the noise spectral component generated by different URN sources such as the main engine and the propeller. Consequently, the reduction of the overall URN level will imply preventive actions for each one of the dominant URN sources. In summary, it can be concluded that a drastic reduction of the underwater radiated noise in the oceans is of vital importance to guarantee the sustainability of the sea environment and protect marine life. Thus, it is necessary to promote the design of a new generation of silent vessels using the most advanced engineering technology developed for the minimization of URN.

Kuehne, L. M., Erbe, C., Ashe, E., Bogaard, L. T., Salerno Collins, M., & Williams, R. (2020). Above and Below: Military Aircraft Noise in Air and under Water at Whidbey Island, Washington. *Journal of Marine Science and Engineering, 8*(11), https://doi.org/10.3390/jmse8110923
Military operations may result in noise impacts on surrounding communities and wildlife. A recent transition to more powerful military aircraft and a national consolidation of training operations to Whidbey Island, WA, USA, provided a unique opportunity to measure and assess both in-air and underwater noise associated with military aircraft. In-air noise levels (110 +/- 4 dB re 20 mu Pa rms and 107 +/- 5 dBA) exceeded known thresholds of behavioral and physiological impacts for humans, as well as terrestrial birds and mammals. Importantly, we demonstrate that the number and cumulative duration of daily overflights exceed those in a majority of studies that have evaluated impacts of noise from military aircraft worldwide. Using a hydrophone deployed near one runway, we also detected sound signatures of aircraft at a depth of 30 m below the sea surface, with noise levels (134 +/- 3 dB re 1 mu Pa rms) exceeding thresholds known to trigger behavioral changes in fish, seabirds, and marine mammals, including Endangered Southern Resident killer whales. Our study highlights challenges and problems in evaluating the implications of increased noise pollution from military operations, and knowledge gaps that should be prioritized with respect to understanding impacts on people and sensitive wildlife.

MacGillivray, A. O., & Li, Z. (2018). *Reductions in Underwater Radiated Noise from Shipping During the 2017 Haro Strait Vessel Slowdown Trial*. Paper presented at the Journal of the Acoustical Society of America. https://asa.scitation.org/doi/abs/10.1121/1.5067678
During 2017, the Vancouver Fraser Port Authority's Enhancing Cetacean Habitat and Observation (ECHO) program carried out a voluntary slowdown trial in Haro Strait (British Columbia) to investigate whether limiting vessel speeds to 11 knots would decrease noise in Southern Resident Killer Whale habitat. During the trial, JASCO collected source levels measurements on two underwater listening stations situated adjacent to the Haro Strait traffic lanes, while a third listening station in Georgia Strait measured noise from vessels outside the slowdown zone. Acoustic data from these three listening

stations were analyzed using JASCO's PortListen® system, which tracks vessels using the Automated Identification System (AIS) and automatically measures the source levels of passing vessels, according to the ANSI standard for ship noise measurement (12.64-2009 R2014). The effects of voluntary slowdowns on vessel noise emissions were investigated, on a per-class basis, by comparing measurements of participating vessels with measurements obtained during control periods before and after the trial. Analysis of the trial data showed that speed reductions were an effective method for reducing broadband source levels for five categories of piloted commercial vessels: containerships, cruise vessels, vehicle carriers, tankers, and bulk carriers.

MacGillivray, A. O., Li, Z., Hannay, D. E., Trounce, K. B., & Robinson, O. M. (2019). Slowing Deep-Sea Commercial Vessels Reduces Underwater Radiated Noise. *Journal of the Acoustical Society of America, 146*(1), https://doi.org/10.1121/1.5116140
During 2017, the Vancouver Fraser Port Authority's Enhancing Cetacean Habitat and Observation program carried out a two-month voluntary vessel slowdown trial to determine whether slowing to 11 knots was an effective method for reducing underwater radiated vessel noise. The trial was carried out in Haro Strait, British Columbia, in critical habitat of endangered southern resident killer whales. During the trial, vessel noise measurements were collected next to shipping lanes on two hydrophones inside the Haro Strait slowdown zone, while a third hydrophone in Strait of Georgia measured vessels noise outside the slowdown zone. Vessel movements were tracked using the automated identification system (AIS), and vessel pilots logged slowdown participation information for each transit. An automated data processing system analyzed acoustical and AIS data from the three hydrophone stations to calculate radiated noise levels and monopole source levels (SLs) of passing vessels. Comparing measurements of vessels participating in the trial with measurements from control periods before and after the trial showed that slowing down was an effective method for reducing mean broadband SLs for five categories of piloted commercial vessels: containerships (11.5 dB), cruise vessels (10.5 dB), vehicle carriers (9.3 dB), tankers (6.1 dB), and bulkers (5.9 dB).

Matthews, M. N., Alavizadeh, Z., O'Reilly, J., & Fyfe, A. (2019). *Assessment of Vessel Noise within the Southern Resident Killer Whale Critical Habitat.* trid.trb.org Query date: 2021-09-10 13:23:10. Retrieved from https://trid.trb.org/view/1572483
This study applied specialized computer models to examine shipping noise levels over four subregions of the southern Salish Sea in SRKW critical habitat that the major shipping lanes leading to Vancouver pass though: Strait of Georgia, Haro Strait, Juan de Fuca Strait, and Swiftsure Bank. Baseline (present case) noise levels were established by modelling the noise emissions of existing shipping traffic, represented by all tracked vessel transits from July 2015. A future case scenario was developed to represent vessel traffic conditions in 2020 or later; it assumes that new oil tanker and tug traffic associated the expected expansion of the Trans Mountain Pipeline Project will increase the baseline traffic. The study also examines and compares noise levels of the future traffic under several possible vessel noise mitigation options. These mitigation options are: Vessel speed reductions: Noise emissions of most vessel classes are known to decrease with reduced speed, as has been confirmed recently by measurements performed under Vancouver Fraser Port Authority's ECHO program. A mitigation option was tested by slowing vessels to either 15 knots or 11 knots, depending on vessel class and location. Grouping vessels into convoys: This mitigation is intended to produce longer quiet times between vessel convoys, which could allow animals longer periods of quiet for more effective use of sound for echolocation foraging and communicating. Convoys spaced at 4 hours in Haro Strait and Juan de Fuca Strait, and an additional 2 hour spacing in Haro Strait were investigated. Re-routing the traffic lanes away from SRKW habitat: In

one scenario, the traffic lanes in southern Haro Strait were moved west, away from known SRKW feeding grounds on Salmon Bank off San Juan Island. In a second scenario, large vessel traffic was shifted to the southern side of the outbound lane in Juan de Fuca Strait and tug traffic was moved to its centre, away from the higher SRKW density area along the southwestern coast of Vancouver Island. Restricting traffic during a specific time of day (no-go period) in Haro Strait: Vessel traffic was restricted from passing through the strait from 0:00 to 04:00 each day. The restricted vessels were distributed through other times of the day. Replacing 10% of the noisiest vessels with quieter vessels: The selection of the noisiest 10% of vessels was performed after ranking them using two approaches: first using unweighted noise emission levels and second, using SRKW audiogram-weighting to account for killer whales' more acute hearing sensitivity to high-frequency sounds. Results differed between these two approaches. Reducing noise emissions (source levels) of specific vessel classes by 3 and 6 decibels: This evaluation considered the outcomes of the method in terms of the change in noise levels in SRKW habitat, but it did not suggest how the reductions in noise emission levels would be achieved

McWhinnie, L. H., O'Hara, P. D., Hilliard, C., Le Baron, N., Smallshaw, L., Pelot, R., & Canessa, R. (2021). Assessing Vessel Traffic in the Salish Sea Using Satellite Ais: An Important Contribution for Planning, Management and Conservation in Southern Resident Killer Whale Critical Habitat. *Ocean & Coastal Management, 200*, https://doi.org/10.1016/j.ocecoaman.2020.105479

In the Salish Sea, a body of water spanning British Columbia, Canada, and Washington State, USA, increasing vessel traffic has the potential to cause many direct and indirect impacts on an endangered population of cetaceans; Southern Resident Killer Whales (SRKW) (Orcinus orca). This study uses satellite Automatic Identification System (AIS) data to provide a detailed description of the volume, distribution and type of vessels within SRKW critical habitat and emphasises the heterogeneity of their movement and presence throughout this area. Further statistical analysis of vessel data within two physically restricted regions (Active Pass and Boundary Pass) showed a particularly strong seasonal influence on vessel presence in Active Pass. This could largely be attributed to the dominance of ferry traffic during summer months in comparison to winter. In Boundary Pass, cargo ships were the predominant type of vessel each year, with their presence increasing over the four-year period analysed. Such information indicates that there is potential for considering seasonal management measures aimed at mitigating threats associated with vessel activity and reducing the risk of impact on SRKW particularly during summer months. Vessel speed was found to vary inconsistently with year, between regions and among vessel groups. However, there was a strong seasonal effect in both regions with vessels generally transiting slower in the winter than summer. This is another important consideration as vessel speed has been directly correlated to strike risk and noise emissions and therefore seasonal speed restrictions could also be explored if the area is navigationally suitable. The data presented here provides specific information related to vessel movement within areas that potentially pose a 'higher risk' from vessel related impacts, (e. g. noise pollution, strikes, spills etc.). Furthermore, this study considers the potential for vessel management measures to help mitigate these impacts and makes recommendations for future measures to be targeted at specific areas and vessel types. This sort of information can be used to help inform regional marine spatial planning frameworks, species recovery measures and management plans as well as any other future conservation designations and management schemes both within the Salish Sea but also globally.

Moulton, J. V. (2021). The Matter of Mapping Multispecies Entanglements of Mourning—a Manifesto's Shout, an Orca's Tour of Grief. *Matter: Journal of New Materialist Research, 2*(1), https://doi.org/10.1344/jnmr.v2i1.33376

Mapping entanglements is work—work of care, maintenance, and mourning. This project utilises a new materialist methodology inherited from the work of Gilles Deleuze and Félix Guattari, who follow lines of becoming to track compositions which compose worlds. To map (non-linear, temporal, and situated) lines of loss across multispecies landscapes is material work of more-than-human mourning. The New York City-based performance artist Mierle Laderman Ukeles—alongside scholars such as María Puig de la Bellacasa and Donna J. Haraway—reorient configurations of work and care, which enable these lines to be followed into more-than-human worlds. Mapping lines of mourning into multispecies worlds is material work of the aesthetic-ethical response within shared and troubled landscapes. The key storytellers within the narrative of mourning and joy woven into this paper are the Salish Sea, the Lummi Nation, the Chinook Salmon, and the Southern Resident killer whale; the voices and cries to which this project, in work and care, is dedicated.

Secretariat, C. S. A. (2018). *Technical Review: Potential Effectiveness of Mitigation Measures to Reduce Impacts from Project-Related Marine Vessels on Southern Resident Killer Whales.* Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/4073982x.pdf

DFO's Pacific Region Fisheries Protection Program (FPP) is responsible for reviewing potential effects of the marine terminal and shipping components of the Project on fish, fish habitat and marine mammals. In 2015, on the request from FPP, DFO Science Branch conducted a sufficiency and technical review of the information on the effects of marine shipping on marine mammals in the Facilities Application for the Project (DFO 2015a and DFO2015b). FPP is now seeking DFO Science Branch support in responding to information requests from the NEB regarding the effectiveness of mitigation measures for impacts to SRKW from Project-related marine shipping. This CSAS Science Response (SR) is anticipated to be a review of existing peer-reviewed information and research from DFO and other published scientific literature and proceedings. The objective of this SR is to provide advice on the following questions: 1. Provide any information or knowledge concerning the potential effectiveness of the following potential mitigation measures: o altering shipping lanes to reduce adverse effects on SRKW, such as shifting lanes away from marine mammal congregation areas; o speed restrictions and altered shipping patterns, such as convoys, in order to reduce potential adverse effects such as underwater noise or the potential for ship strikes; o vessel design (including hull and propeller) and maintenance measures for reducing adverse effects such as underwater noise from Project-related marine vessels; o use of marine mammal on-board observers on Project-related marine vessels, and what actions need to be taken if SRKW are observed; o measures to increase abundance of prey to offset adverse effects from Project-related marine shipping; o any other measure that could avoid, reduce, and/or offset the adverse effects of Projectrelated marine shipping on SRKW; and o measures that could avoid or reduce cumulative adverse effects on SKRW. 2. Provide any information or knowledge concerning the relationship between a vessel's speed and tonnage (including the different types of Project-related marine vessels under both loaded and unloaded conditions) and how much underwater noise the vessel creates. This Science Response Report results from the Science Response Process of October 2018 on a review of the effectiveness of potential mitigation measures to address impacts from projectrelated marine vessel traffic on the Southern Resident Killer Whale.

Seely, E., Osborne, R. W., Koski, K., & Larson, S. (2017). Soundwatch: Eighteen Years of Monitoring Whale Watch Vessel Activities in the Salish Sea. *Plos One, 12*(12), https://doi.org/10.1371/journal.pone.0189764

The Soundwatch Boater Education Program is a vessel monitoring and public education outreach program. Soundwatch has been run by The Whale Museum (TWM) during the whale watch season (May through September) in the Haro Strait Region of the Central Salish Sea since 1993. Data collection has been in a consistent manner since 1998 and is presented here. The program compiles data on vessel types and vessel interactions with marine mammals with a focus on the Southern Resident killer whale (SRKW), Orcinas orca, which was listed as endangered under the U.S. Endangered Species Act (ESA) in 2005. The primary goal of the Soundwatch program is to reduce vessel disturbance to SRKWs and other marine wildlife through the education of boaters on regional, local and federal guidelines and regulations and the systematic monitoring of vessel activities around cetaceans. Since 1998, the number of active commercial whale watching vessels has increased over time; ranging from a low of 63 in 1999, to a high of 96 in 2015. In addition, the number of vessel incidents or violation of regulations and guidelines has also increased; ranging from a low of 398 in 1998 to a high of 2621 in 2012. Soundwatch collected data on 23 incident types, some remaining the same over the 18-year data set and some changing over time. The most common incidents over the 18 years were "Within 880 m of Lime Kiln" and "Crossing the path of whales". The numbers of people kayaking near whales also significantly increased since 2004 with the incident "kayaks spread out" with a significantly increasing trend making it difficult for whales to avoid vessels. These results suggest a need for further outreach for effective education and enforcement of whale watching guidelines and regulations in the Central Salish Sea.

Vagle, S. (2020). *Evaluation of the Efficacy of the Juan De Fuca Lateral Displacement Trial and Swiftsure Bank Plus Swanson Channel Interim Sanctuary Zones, 2019*. (07116764). Ottawa: Department of Fisheries & Oceans, Communications Directorate Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40869696.pdf

In 2019, the ECHO Program coordinated the implementation of a voluntary inshore lateral displacement trial in the Strait of Juan de Fuca, with support from Transport Canada, Canadian and U.S. coast guards, Fisheries and Oceans Canada, and Canadian and U.S. marine transportation industries. The overall purpose of the trial was to reduce underwater noise from tugs in a known southern resident killer whales feeding area. This lateral displacement of vessel traffic was in place between June 17 and October 31, 2019. By shifting their routes southward individual tugs were observed to decrease their noise impact on the Jordan River SRKW feeding area by between 6 and 11 dB, depending on the frequency band being considered. By moving their routes to more than 3 km from the feeding areas most of the tugs will contribute minimally to the over all soundscape in these areas. However, since tugs make up a small proportion of the vessel traffic in the Strait of Juan de Fuca, this cannot account for the observed overall reduction in broad-band (10-100,000 Hz) noise of 3.6 dB in the feeding area. Rather, analysis of the ship transit data indicates that the reduction was due to a reduction in overall ship traffic during the period of the study. A second mitigation measure was to implement interim whale sanctuary zones in key foraging areas on Swiftsure Bank and in Swanson Channel, off North Pender Island between June 1 and October 31, 2019. At the Swiftsure Bank mooring, which was just south of the interim sanctuary zone, the broadband (10-100,000 Hz) noise reduction was 1.1 dB, while no such reduction was observed in Swanson Channel. As with the results in the Strait of Juan de Fuca the noise reduction on Swiftsure Bank is attributed to a decline in ship traffic during the study. Analysis of available vessel track data indicated that in both sanctuary zones there was poor compliance with the request to avoid these areas.

Vagle, S., & Neves, M. (2019). *Evaluation of the Effects on Underwater Noise Levels from Shifting Vessel Traffic Away from Southern Resident Killer Whale Foraging Areas in the Strait of Juan De Fuca in 2018*. (07116764). Ottawa: Department of Fisheries & Oceans, Communications Directorate Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40812431.pdf

Between August 20 and October 31, 2018 the Vancouver Fraser Port Authority and Transport Canada led a voluntary program where all outbound deep sea vessels and inshore vessels (tugs) in a portion of the Strait of Juan de Fuca were requested to shift their outbound tracks southwards, and further away from areas of critical importance to the endangered Southern Resident Killer Whale (SRKW) population. The main goal of this study was to investigate the efficacy of lateral vessel displacement to reduce the impact of underwater vessel noise on SRKW at three locations off Port Renfrew, Jordan River and Sooke. The mean distance between the monitoring location off Jordan River and the outbound deep sea vessels increased by 632 m (from 5256 m to 5888 m) during the study and resulted in a broad-band (10-100,000 Hz) noise reduction varying between 0.6 and 1.0 dB, dependent on vessel type. These are small reductions when compared to vessel-to-vessel noise output and acoustic propagation variabilities. However, the mean lateral displacement of tugs increased by 1896 m (from 2010 m to 3906 m), which resulted in a significant broad-band noise reduction of 4.3 dB.

Vagle, S., O'Neill, C., Thornton, S., & Yurk, H. (2018). *Soundscape Characteristics in Southern Resident Killer Whale Critical Habitats*. Paper presented at the Journal of the Acoustical Society of America. https://asa.scitation.org/doi/abs/10.1121/1.5068130

The Southern Resident Killer whales (Orcinus orca) (SRKW) are an endangered group of orcas with current range of Pacific North East from California to Northern British Columbia and spend most of the summer months in and around the Salish Sea. This group of mammals feed primarily on fish, are very local, and live in tight-knit family units called pods. July 1 2017 census reported 77 animals; which now has been reduced to 76 by a more recent death. Anthropogenic underwater noise, primarily from commercial and recreational vessels is suspected to have detrimental effects on these whales. Here, we present results from a seven month, continuous sound recording (125 kHz acoustic bandwidth), whale centered study to monitor and interpret different soundscapes in SRKW critical habitats. The six different locations studied have significantly different acoustic transmission characteristics and cover open ocean areas, where natural sound spectral levels are high, to areas where anthropogenic noise-sources dominate. Possible implications of these different characteristics on the ability of the orcas to communicate and find prey are discussed.

Vakili, S., Oalcer, A. I., & Ballini, F. (2019). The Trade-Off Analysis for the Mitigation of Underwater Noise Pollution from Commercial Vessels: Case Study - Trans Mountain Project, Port of Vancouver, Canada. *Proceedings of the Institution of Mechanical Engineers Part M-Journal of Engineering for the Maritime Environment, 234*(2), https://doi.org/10.1177/1475090219886397

Although shipping has significant positive effect on human civilization, it introduced negative environmental impacts such as oil, air, and plastic pollutions. Many negative externalities through international and local regulations have been in place, and preventive actions have been taken to monitor and control. However, underwater noise pollution as an emerging negative shipping impact has not been well introduced to society nor appropriately regulated in international scale. Because of traffic density and the presence of sensitive marine species in some parts of the world, the negative social and environmental impacts of underwater noise pollution become more critical. Haro Strait due to high shipping traffic and presence of vulnerable marine species such as Southern Resident Killer Whale is a good example. The majority of ocean-going vessels transiting to Vancouver and vice versa pass through the corridor which includes Haro Strait. Tankers currently represent about 2% of total ship traffic visiting the Port of Vancouver; however, regarding the Trans Mountain Pipeline Expansion Project, the traffic density will grow by 11%, which will enhance the adverse impacts of underwater noise pollution on marine mammals. This study, by considering the features and characteristics of the area and the project, proposed four scenarios and modelling. The article by developing simulations and utilizing the Multiple Criteria Decision Making (Multiple Attribute Decision Making) algorithms and Technique for Order of Preference by Similarity to Ideal Solution techniques strives to trade-off between the environmental (noise and CO2 emission) and economical (fuel cost) aspects of the project to enhance the Decision Support System to promote sustainable development. This will help the decision makers to have a multi-dimensional thinking instead of the single-dimensional thinking in addressing and tackling the negative externalities of the Trans Mountain project in the area. Moreover, at the end of each scenario, a sensitivity analysis will be conducted to provide a clean environment for decision makers.

Veirs, S., Veirs, V., & Wood, J. D. (2016). Ship Noise Extends to Frequencies Used for Echolocation by Endangered Killer Whales. *Peerj, 4*, https://doi.org/10.7717/peerj.1657
Combining calibrated hydrophone measurements with vessel location data from the Automatic Identification System, we estimate underwater sound pressure levels for 1,582 unique ships that transited the core critical habitat of the endangered Southern Resident killer whales during 28 months between march, 2011, and octoher, 2011 Median received spectrum levels of noise from 2,809 isolated transits are elevated relative to median background levels not only at low frequencies (20-30 dB re 1 mu Pa-2/Hz from 100 to 1,000 Hz), but also at high frequencies (5-13 dB from 10 000 t 96,000 Hz) frequencies used by odontocetes. Broadband received levels (11.5-40,000 Hz) near the shoreline in Haro Strait (WA, USA) for the entire ship population were 110 +/- 7 dB mu Pa-2 on average. Assuming near-spberieal spreading based on a tranSm1SS1On loss expenment we compute mean broadband source levels for the ship population of 173 + 7 dB re 1 tiPa 1 m without accounting for frequency-dependent absorption. Mean ship speed was 73 + m/s 14.1 + 3.9 knots). Most ship classes show a linear relationship between source level and speed with a slope near +2 dB per m/s (+1 dB/knot). Spectrum, 1/12-octave, and 1/3-octave source levels for the whole population have median values that are comparable to previous measurements and models at most frequencies, but for select studies may be relatively low below 200 Hz and high above 20,000 Hz. Median source spectrum levels peak near 50 Hz for all 12 ship classes, have a maximum of 159 dB re 1 it mu Pa-2/Hz @ 1 m for container ships, and vary between classes. Below 200 Hz, the class-specific median spectrum levels bifurcate with large commercial ships grouping as higher power noise sources. Within all ship classes spectrum levels vary more at low frequencies than at high frequencies, and the degree of variability is almost halved for classes that have smaller speed standard deviations. This is the first study to present source spectra for populations of different ship classes operating in coastal habitats, including at higher frequencies used by killer whales for both communication and echolocation.

Washington State Academy of Sciences. (2020). *Summary of Key Research Findings About Underwater Noise and Vessel Disturbance.* Retrieved from https://wdfw.wa.gov/sites/default/files/2020-09/reportwsas_srkw_summary.pdf
A summary of the Relevant Scientific Findings is as follows: 1. Close approaches by vessels can cause significant direct effects on foraging. 2. Close approaches of boats can cause indirect negative effects including masking (elevated noise levels that interfere with communication and foraging), even with slow-moving vessels. 3. Behavioral responses to noise and disturbance, such as increased surface-active behaviors or changes in vocalizations, can increase energy expenditure. 4. Reduced individual foraging success due to vessels may in turn result in reduced survival and fecundity that may result in population-level effects. 5. Chinook prey abundance has a greater effect on SRKW population growth rates than vessel noise and disturbance, according to recent population viability analysis models. 6. Strike risk is

not zero, and the risk of injury and or mortality increases with vessel speed. 7. Data gaps include an understanding of the chronic effects of whale watching activities on SRKW foraging success under current management, and of the extent that reduced foraging success translates into the growth or decline for the SRKW population. Additional findings specifically pertaining to Mitigation and Management are as follows: 8. While the presence of SRKW in inshore waters over recent years has been lower than historically observed, the evidence does not suggest basing management solely on recent levels of inshore habitat use. 9. Observed habitat of SRKW suggests extending management actions to the entire SRKW home range, including the Salish Sea and outer coasts of Washington and southern Vancouver Island. 10. There is insufficient evidence for a positive "sentinel" effect of commercial whale watching; this topic needs further study.

Williams, R., Veirs, S., Veirs, V., Ashe, E., & Mastick, N. (2019). Approaches to Reduce Noise from Ships Operating in Important Killer Whale Habitats. *Marine Pollution Bulletin, 139*, https://doi.org/10.1016/j.marpolbul.2018.05.015

Shipping is key to global trade, but is also a dominant source of anthropogenic noise in the ocean. Chronic noise from ships can affect acoustic quality of important whale habitats. Noise from ships has been identified as one of three main stressors-in addition to contaminants, and lack of Chinook salmon prey-in the recovery of the endangered southern resident killer whale (SRKW) population. Managers recognize existing noise levels as a threat to the acoustical integrity of SRKW critical habitat. There is an urgent need to identify practical ways to reduce ocean noise given projected increases in shipping in the SRKW's summertime critical habitat in the Salish Sea. We reviewed the literature to provide a qualitative description of mitigation approaches. We use an existing ship source level dataset to quantify how some mitigation approaches could readily reduce noise levels by 3-10 dB.

Williams, R., Ashe, E., Yruretagoyena, L., Mastick, N., Siple, M., Wood, J., . . . Finne, E. (2021). Reducing Vessel Noise Increases Foraging in Endangered Killer Whales. *Marine Pollution Bulletin, 173*, https://doi.org/10.1016/j.marpolbul.2021.112976

Disturbance from underwater noise is one of the primary threats to the critically endangered southern resident killer whales (SRKWs). Previous studies have demonstrated that SRKWs spend less time feeding when vessels are present. In 2018, we measured the effects of a voluntary vessel slowdown action in SRKW critical habitat to assess whether ship speed (and related source level) affects foraging behaviour. Observations of SRKWs and ships were collected from land-based sites on San Juan Island, WA, USA, overlooking the Haro Strait slow-down area. Exploratory analyses found little support for a linear relationship between ship speed and SRKW behaviour, but strong support between received noise level from ships and the probability of SRKWs engaging in foraging activity. Reducing ship speed, and therefore ship noise amplitude will help decrease the probability of ship noise disrupting SRKW foraging activity and may help to increase the proportion of accessible salmon.

Wladichuk, J. L., Hannay, D. E., MacGillivray, A. O., Zizheng, L., & Thornton, S. J. (2019). Systematic Source Level Measurements of Whale Watching Vessels and Other Small Boats. *Journal of Ocean Technology, 14*(3) Retrieved from https://www.thejot.net/article-preview/?show_article_preview=1091

Marine mammals rely heavily on sound for foraging, communicating, and navigating. As noise in the ocean increases, their ability to perform these important life functions can be affected. In the past decade, numerous studies have expanded our awareness of the effects of anthropogenic noise on marine life. Improving our knowledge of how sound impacts marine mammals is particularly important

in coastal waters where the spatial distributions of vessels and marine mammals overlap, as exemplified by the critical habitat for the endangered Southern Resident killer whale (Orcinus orca). The impacts of small vessel traffic (including the commercial and recreational whale watching that is directed on this population) has been difficult to assess as there is a data gap for small vessel noise emissions. In this study, two autonomous marine acoustic recorders were deployed in transboundary Haro Strait (British Columbia, Canada, and Washington State, USA) from July to October 2017 to measure sound levels produced by whale watching vessels and other small boats. During this period, 20 different volunteer vessels were assessed operating at a range of speeds - nominally 5 knots, 9 knots, and cruising speed (generally 20-30 knots) to represent whale watching, approach, and transit speeds, respectively. The vessels were categorized into six types: rigid-hulled inflatable boats (RHIBs), monohulls, catamarans, sailboats, landing crafts, and a small boat with a 9.9 horsepower outboard engine. Acoustic data were analyzed according to the ANSI S12.64 (2009) standard for measuring ship noise using JASCO Applied Sciences' PortListen® software system, which automatically calculates source levels from calibrated hydrophone data and vessel position logs. For all vessels, we observed positive correlations between source levels and speed; however, the rate of increase of source levels with speed were not as strong as those measured previously for large commercial vessel speed trends. Mean source levels (SLs) were computed for each vessel type in the broadband frequency range (0.05-64 kHz), the Southern Resident killer whale (SRKW) communication band (0.5-15 kHz), and the SRKW echolocation band (15-64 kHz) for each of the speed groups. In general, landing crafts produced the highest source levels (overall mean = 166 ± 5 dB re 1 μPa m), followed by catamarans (160 ± 10 dB re 1 μPa m), then RHIBs (158 ± 11 dB re 1 μPa m), monohulls (157 ± 12 dB re 1 μPa m), sailboats (153 ± 9 dB re 1 μPa m), and the small vessel with a 9.9 HP outboard engine was the quietest across speeds and frequency bands measured (150 ± 10 dB re 1 μPa m). However, it should be taken into account that the sailboats and the vessel with the 9.9 HP outboard engine did not perform any high speed passes. A comparison of the 1/3 octave band levels for six of the vessels that had inboard diesel engines suggests that Arneson drive propulsion (a surface-piercing propeller) produces lower sound levels than traditional propellers. However, this is based on a small sample size and more research into acoustic emissions from different propulsion types (e.g., jet, electric, Arneson drive) is needed. Finally, depth sounders were observed to create a peak in acoustic energy at approximately 50 kHz, which is well within the most sensitive hearing range of killer whales [Branstetter et al., 2017]. Therefore, it is recommended that sounders are turned off when not needed in proximity to killer whales and other cetaceans that use high-frequency sound (e.g., harbour porpoises, Phocoena phocoena, Dall's porpoises, Phocoenoides dalli, Pacific white-sided dolphins, Lagenorhynchus obliquidens).

Wood, J., Tollit, D., & Joy, R. (2018). *Ship Speed Reduction Is an Effective Mitigation for Underwater Noise Effects*. Paper presented at the Journal of the Acoustical Society of America. https://asa.scitation.org/doi/abs/10.1121/1.5067689

The Vancouver Fraser Port Authority's ECHO Program led a voluntary 2-month ship slowdown trial during which 56% of piloted ships slowed down to <13 knots in a 16 nautical mile corridor. The goal was to determine if a slowdown could be used as a mitigation measure to reduce ship related underwater noise effects in core Southern Resident killer whale habitat. A calibrated hydrophone system was used to measure ambient noise levels from 10 Hz to 100 kHz during the trial and a representative 2-month baseline period. The hydrophone was located 2.3 (inbound) and 5 km (outbound) from the center of the shipping lanes at 23 m depth. Analyses of data with ships present showed a median broadband noise reduction of 2.5 dB. This reduction was highest in the 10–100 Hz decade band (3.1 dB) and lowest in the 10,000–100,000 Hz band (0.3 dB). A statistical model found that received noise levels were best described by the distance to ships, the presence of small boats, water velocity, slowdown period, ship speed through water, and wind speed. This highlights that appropriate temporal scales and the inclusion of covariate data are needed to adequately measure ship related changes in underwater ambient noise levels.

Wright, B. M., Deecke, V. B., Ellis, G. M., Trites, A. W., & Ford, J. K. B. (2021). Behavioral Context of Echolocation and Prey-Handling Sounds Produced by Killer Whales (Orcinus Orca) During Pursuit and Capture of Pacific Salmon (Oncorhynchus Spp.). *Marine Mammal Science*, https://doi.org/10.1111/mms.12836

Availability of preferred salmonid prey and a sufficiently quiet acoustic environment in which to forage are critical to the survival of resident killer whales (Orcinus orca)in the northeastern Pacific. Although piscivorous killer whales rely on echolocation to locate and track prey, the relationship between echolocation, movement, and prey capture during foraging by wild individuals is poorly understood. We used acoustic biologging tags to relate echolocation behavior to prey pursuit and capture during successful feeding dives by fish-eating killer whales in coastal British Columbia, Canada. The significantly higher incidence and rate of echolocation prior to fish captures compared to afterward confirms its importance in prey detection and tracking. Extremely rapid click sequences (buzzes) were produced before or concurrent with captures of salmon at depths typically exceeding 50 m, and were likely used by killer whales for close-range prey targeting, as in other odontocetes. Distinctive crunching and tearing sounds indicative of prey-handling behavior occurred at relatively shallow depths following fish captures, matching concurrent observations that whales surfaced with fish prior to consumption and often shared prey. Buzzes and prey-handling sounds are potentially useful acoustic signals for estimating foraging efficiency and determining if resident killer whales are meeting their energetic requirements.

## Section VIII: Recovery

Fisheries and Oceans Canada. *Southern Resident Killer Whale: A Science Based Review of Recovery Actions for Three at-Risk Whale Populations*. Retrieved from http://waves-vagues.dfo-mpo.gc.ca/Library/40680071.pdf

The Recovery Strategy for the Northern and Southern Resident Killer Whales (Orcinus orca) in Canada (DFO 2011) states the following goal (population and distribution objective) for the SRKW population: 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 continuity1 (DFO 2011). The associated Action Plan for the Northern and Southern Resident Killer Whale (Orcinus orca) in Canada (DFO 2017) outlines Broad Strategies for recovery, and identifies 98 specific Recovery Measures to achieving them. This review will provide a summary of the achievements to date on addressing the Recovery Measures and will provide an assessment of their overall effectiveness in terms of their ability to abate threats to recovery of the population. Research-based measures, while they do not directly abate threats, are also acknowledged for their role in addressing knowledge gaps in order to clarify the mechanism by which a threat impacts the population. This document also aims to identify how recovery can be better achieved by accelerating implementation of Recovery Measures not yet underway, by identifying new measures if needed, and by providing guidance on the relative priority of Recovery Measures required to promote recovery.

Fisheries and Oceans Canada. (2016). *Report on the Progress of Recovery Strategy Implementation for the Northern and Southern Resident Killer Whales (Orcinus Orca) in Canada for the Period 2009 - 2014.* Fisheries and Oceans Canada Ottawa. Retrieved from https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/5yr-ResidentKillerWhale-v00-2016Sep28-Eng.pdf

This report documents the progress of Recovery Strategy implementation for the Northern and Southern Resident Killer Whales in Canada for the period 2009-2014. Progress to date includes: - continued monitoring of Northern and Southern Resident Killer Whales, through ongoing annual censuses of both populations; improved understanding of winter distribution of Resident Killer Whales, through several methods including cetacean surveys, sightings networks, and passive acoustics; further research into the prey requirements of Resident Killer Whales, through identification of prey species and stocks, energetic modeling, and assessing body condition using aerial photogrammetry; bilateral (Fisheries and Oceans Canada/National Oceanographic and Atmospheric Administration) workshops held to assess the effects of salmon fisheries on Southern Resident Killer Whale recovery; - ocean noise workshops and reviews of current mitigation measures for seismic activities, to better understand and mitigate the threat of acoustic disturbance to Resident Killer Whales; and - progress toward understanding some of the sources and health effects of PCBs and other pollutants for Resident Killer Whales.

Fisheries and Oceans Canada. (2017). *Action Plan for the Northern and Southern Resident Killer Whale (Orcinus Orca) in Canada.* Fisheries and Oceans Canada Ottawa. Retrieved from https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/plans/Ap-ResidentKillerWhale-v00-2017Mar-Eng.pdf

This Action Plan provides a description of the measures that provide the best chance of achieving the population and distribution objectives for the Northern and Southern Resident Killer Whale, including measures to be taken to address threats to the species and monitor its recovery, to guide not only activities to be undertaken by Fisheries and Oceans Canada and Environment and Climate Change Canada, but those for which other jurisdictions, organizations and individuals have a role to play. As new information becomes available, these measures and the priority of these measures may change. Fisheries and Oceans Canada strongly encourages all Canadians to participate in the conservation of the Northern and Southern Resident Killer Whale through undertaking measures outlined in this action plan. Principal among the anthropogenic threats to recovery are reductions in the availability or quality of prey, environmental contamination, and both physical and acoustic disturbance. As these threats are common to all three ecotypes, of the 98 measures identified to recover Resident Killer Whales, 63 (64%) are likely to benefit Transient (Bigg's) and Offshore Killer Whale populations that frequent Canadian Pacific waters.

Fisheries and Oceans Canada. (2018). *Recovery Strategy for the Northern and Southern Resident Killer Whales (Orcinus Orca) in Canada.* Fisheries & Oceans Canada Ottawa. Retrieved from https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/plans/Rs-ResidentKillerWhale-v00-2018dec-Eng.pdf

The goal of the Resident Killer Whale recovery strategy is 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 continuity1". In order to achieve this goal, four principal objectives have been identified. They are: Objective 1: ensure that Resident Killer Whales have an adequate and accessible food supply to allow recovery Objective 2: ensure that chemical and

biological pollutants do not prevent the recovery of Resident Killer Whale populations Objective 3: ensure that disturbance from human activities does not prevent the recovery of Resident Killer Whales Objective 4: protect critical habitat for Resident Killer Whales and identify additional areas for critical habitat designation and protection

Fisheries and Oceans Canada. (2019). *Cumulative Effects Assessment for Northern and Southern Resident Killer Whale (Orcinus Orca) Populations in the Northeast Pacific.* Fisheries and Oceans Canada Ottawa. Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40809389.pdf
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 longterm 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 (No.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.

Fisheries and Oceans Canada. (2019). *Proceedings of the Pacific Regional Peer Review on Cumulative Effects Assessment for Northern and Southern Resident Killer Whale Populations in the Northeast Pacific*. Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40855363.pdf
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.

Fuchs, G. *Orcas in Peril: A Structured Literature Review, Seeking Greater Understanding of Trajectories in the Population Decline of the Endangered "Southern Resident" Killer Whales.* (M.S. Marine Environmental Management), Retrieved from https://www.researchgate.net/publication/338699330_Orcas_in_peril_A_structured_literature_review_seeking_greater_understanding_of_trajectories_in_the_population_decline_of_the_endangered_Southern_Resident_killer_whales

Background: The endangered population of “Southern Resident” killer whales (SRKWs) is small, reproductively isolated, and occurs in the eastern North Pacific. Since the population underwent severe historical depletion in the 1960s and 1970s, increased knowledge about the animals and the ongoing effects of multiple human actions on them and their habitat has been gained. This has raised serious conservation concerns and the population is struggling to recover from more recent declines. Objective: I investigate how human actions, and one of the major identified threats (i.e. pollution & contaminants) in particular, have been affecting the SRKWs, to provide a basis for future research and management. Methods: I completed a literature search for peer-reviewed studies and key grey documents directly concerned with anthropogenic threats to the SRKWs. Titles, abstracts and full-texts were evaluated against a priori defined input criteria, and a systematic map for all relevant studies was created, categorizing them according to year of publication, study type or type of anthropogenic threat. Results: The searches resulted in 71 studies and 26 grey documents that were considered relevant and included in the systematic map. Most studies (22) focused on noise and disturbance associated to vessel traffic, followed by pollution and contaminants (18) and prey availability (12). Discussion: SRKWs are long-lived top predators, that are highly vulnerable to persistent organic pollutants (POPs), which bioaccumulate and biomagnify in marine food-webs. Several crucial studies I identified showed the SRKWs to be among the most contaminated marine mammals in the world, with POP levels far exceeding known thresholds for adverse health effects in other marine mammals. Investigating the systematic map and wider scientific literature, it becomes clear that SRKWs face significant toxicological risks and that high levels of pollutants, in combination with other threats which likely exacerbate each other, may be keeping the population from increasing at the rate required for recovery.

Gaydos, J. K., Haulena, M., Raverty, S., Lutmerding, B., Wilkinson, K., Barre, L., . . . Nollens, H. H. (2019). *Cross-Border Multi-Agency Veterinary Response for a Free-Ranging Chronically Ill Juvenile Southern Resident Killer Whale (Orcinus Orca) Iaaam 2019.* Paper presented at the beta.vin.com. Retrieved from https://beta.vin.com/apputil/content/defaultadv1.aspx?pId=23437&catId=129397&id=9048623&ind=13&objTypeID=17

Southern resident killer whales (SRKWs) are a small population of endangered salmon-eating killer whales numbering 74 individuals as of October 2018. This population resides on the west coast of North America (USA and Canada). In May and September 2017, aerial photogrammetry measurements1 made by NOAA Fisheries and SR3 documented declining condition in a 3-year-old female from this population, J50 (a.k.a. Scarlet), who had been measured to be small for her age since birth. When observed again in June 2018, scientists from NOAA Fisheries and the Center for Whale Research noted that she was now noticeably emaciated with prominent loss of nuchal fat. Biologists also noted a fetid smell to her breath on at least one approach. Follow-up photogrammetry confirmed a considerable loss in body condition compared to the previous year. Through consultations with veterinarians and experts, NOAA Fisheries in the U.S. and Department of Fisheries and Oceans (DFO) in Canada worked closely with many partners and authorized an emergency response, which resulted in the first-ever attempt to provide veterinary care for a free-ranging SRKW (Figure 1).

Guernsey, P. J., Keeler, K., & Julius, J. J. (2021). How the Lummi Nation Revealed the Limits of Species and Habitats as Conservation Values in the Endangered Species Act: Healing as Indigenous Conservation. *Ethics, Policy & Environment*, https://doi.org/10.1080/21550085.2021.1955605

In their recent efforts to protect the Southern Resident killer whale population in the Salish Sea and bring 'Lolita' home, the Lummi Nation exposed significant limitations to species and habitats as values in Western conservation models. Where Indigenous conservation falls outside this scope, it is often invisible to or actively suppressed by the settler state. The conservation practices of NOAA, in accordance with the federal policy of the ESA, have amounted to extractive colonial enterprises, treating the whales as educational, economic, and environmental possessions while degrading the relationship of the Lummi to the whales as relatives and attacking Lummi sovereignty.

Government of Canada. (2017). *What We Heard Report.* Paper presented at the Southern Resident Killer Whale Symposium, Vancouver, British Columbia.

The SRKW Symposium on October 11-12, 2017, in Vancouver, British Columbia, was a key milestone in contributing to the collective understanding of the threats facing the SRKW and the actions needed for their protection and recovery. The symposium was supported by technical sessions on the primary threats to the SRKW, held on October 10, 2017.

Government of Canada. (2018). *Southern Resident Killer Whale Imminent Threat Assessment.* Retrieved from https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/Ri-Ita-SthnResidentKillerWhale-v00-2018Jul-Eng.pdf

This threat assessment considers the population and distribution objectives set out in the final federal recovery strategy for the species. It takes into account information on the biology and ecology of the species, threats to its survival and recovery, and its population and habitat status and trends. An analysis of existing measures that protect the species against threats is also provided. The information used to develop this ITA has been drawn from DFO publications on SRKW including the Recovery Strategy for the Northern and Southern Resident Killer Whales (Orcinus orca) in Canada (DFO 2011), the COSEWIC Assessment and Update Status Report on the Killer Whale Orcinus orca in Canada (COSEWIC 2008), the Action Plan for the Northern and Southern Resident Killer Whale (Orcinus orca) in Canada (DFO 2017a), and the Review of the Effectiveness of Recovery Measures for Southern Resident Killer Whales (DFO 2017b). EcoJustice also provided supporting documentation in their letter to the competent ministers dated January 30, 2018. No new science advice was generated specifically to inform the assessment nor was the interpretation of the information or the conclusions reached in the assessment the subject of a scientific peer-review process. Socio-economic impacts were not considered in the assessment, as they are not relevant to determining whether or not a wildlife species is facing imminent threats. Socio-economic considerations would inform a GiC decision, further to a recommendation by the competent ministers. Indigenous consultation was not specifically done to support this ITA. However, from October 10 to 12, 2017, DFO held a Southern Resident Killer Whale symposium in Vancouver. Indigenous groups provided a review of the linkages between threats, and expressed that the complexity and importance of Killer Whales and their relationship to First Nations is fundamental to cultural traditions and teachings.

Government of Canada. (2021). *Southern Resident Killer Whale Accountability Framework.* Retrieved from https://waves-vagues.dfo-mpo.gc.ca/Library/40970188.pdf

This endangered population is facing low quality and availability of food, increased noise and disturbance in their habitat, and contaminants in their environment. To help Southern Resident Killer Whales recover, the Government of Canada has taken action to introduce comprehensive measures.

These measures are aimed at improving our scientific understanding of the population, reducing the threats that Southern Resident Killer Whales face, and increasing public awareness about what we can all do to help. But given the complex environment and number of different impacts, how do we know if these measures are working? That's where the Accountability Framework comes in. The Accountability Framework looks at data collected by the Government of Canada and its partners through three priority action categories, which each have indicators and performance measures. Together, the information collected about these categories describes an important piece of the puzzle and offers a snapshot of how the Government of Canada and its partners are doing in their support of Southern Resident Killer Whale recovery. They give us information about trends towards our goal, they highlight where we need to improve, and they provide information for discussions going forward.

Governments of Argentina, B., Gabon, South Africa and Urugua,. (2018). *The South Atlantic: A Sanctuary for Whales.* Paper presented at the Annual Meeting of the International Whaling Commission.

Jefferies, C. S. G., Adie, D., Bliss, Z., & Kent, S. (2021). Legal Options (and Obligations?) for Enhanced Canada–United States Cooperative Southern Resident Killer Whale Conservation. *Journal of International Wildlife Law & Policy, 24*(2), https://doi.org/10.1080/13880292.2021.1930334
The critically endangered Southern Resident killer whale (SRKW) population is at a conservation crossroads. The SRKW?s range extends from California to southern Alaska, but the core habitat of the species is the inland Salish Sea. The principal threats to the population are the decline in Chinook salmon abundance, physical and acoustic disturbance, and environmental contamination. Effective management must respond to the cumulative impact of these threats. The SRKW population has been protected as an endangered species in Canadian and U.S. waters for more than a decade, and emergency conservation measures have been produced in both jurisdictions. Unfortunately, these conservation measures have failed to stabilize the population or advance cooperative ecosystem-based conservation. The United Nations Convention on the Law of the Sea (UNCLOS) legally obligates states to cooperate in marine mammal conservation and, with respect to cetaceans, specifically requires states to work through an appropriate institution for their conservation and management. This article examines ongoing efforts by Canada and the United States to stabilize and recover the SRKW population in view of UNCLOS and the objective of long-term stewardship. This assessment includes ad hoc cooperative mechanisms and possible developments under existing cooperative forums. Although the base legal obligations created by UNCLOS are likely met, the objective of institutionalized cooperative cetacean conservation and management in UNCLOS is not met; moreover, existing cooperative forums are insufficient to effect SRKW recovery. Canada and the United States continue to approve projects without properly assessing the cumulative transboundary impact on the SRKW population or quantifying their contribution to important ecosystem-based thresholds, which reveals the true extent of management dissonance in the Salish Sea. This analysis concludes that enhanced bi-lateral cooperation and long-term co-existence with the SRKW population requires the creation of a new institutional forum, analogous to the International Joint Commission, that coordinates SRKW recovery measures and assesses future projects in view of cumulative effects management.

Knoth, J. M. (2019). *Anthrozoology, Anthropomorphism, and Marine Conservation: A Case Study of Southern Resident Killer Whale, Tahlequah, and Her Tour of Grief.* (Master of Marine Affairs), University of Washington, Retrieved from http://hdl.handle.net/1773/44355

Part I of this thesis presents the concepts of anthrozoology and anthropomorphism. Specifically, it discusses how anthrozoology and anthropomorphism affect conservation and the interactions between humans and cetaceans. These concepts provide the reader with the background tools necessary to analyze Part II of this thesis, the case study of Southern Resident Killer Whale, Tahlequah, and her deceased calf. Part II of this thesis introduces the reader to Southern Resident Killer Whales and the history of their status in the Salish Sea with threats and subsequent conservation action. The case study itself focuses on J-35, Tahlequah. In 2018 her calf died and she carried it for 16 days at the detriment to her own health. The case looks at how anthropomorphism of the situation (fueled by a global news frenzy) influenced immediate conservation action.

Lacy, R. C., Williams, R., Ashe, E., Balcomb, K. C., III, Brent, L. J. N., Clark, C. W., . . . Paquet, P. C. (2017). Evaluating Anthropogenic Threats to Endangered Killer Whales to Inform Effective Recovery Plans. *Scientific Reports, 7*, https://doi.org/10.1038/s41598-017-14471-0
Understanding cumulative effects of multiple threats is key to guiding effective management to conserve endangered species. The critically endangered, Southern Resident killer whale population of the northeastern Pacific Ocean provides a data-rich case to explore anthropogenic threats on population viability. Primary threats include: limitation of preferred prey, Chinook salmon; anthropogenic noise and disturbance, which reduce foraging efficiency; and high levels of stored contaminants, including PCBs. We constructed a population viability analysis to explore possible demographic trajectories and the relative importance of anthropogenic stressors. The population is fragile, with no growth projected under current conditions, and decline expected if new or increased threats are imposed. Improvements in fecundity and calf survival are needed to reach a conservation objective of 2.3% annual population growth. Prey limitation is the most important factor affecting population growth. However, to meet recovery targets through prey management alone, Chinook abundance would have to be sustained near the highest levels since the 1970s. The most optimistic mitigation of noise and contaminants would make the difference between a declining and increasing population, but would be insufficient to reach recovery targets. Reducing acoustic disturbance by 50% combined with increasing Chinook by 15% would allow the population to reach 2.3% growth.

Minister of Fisheries Oceans and the Canadian Coast Guard. (2019). *A Species at Risk Act Section 11 Conservation Agreement to Support the Recovery of the Souther Resident Killer Whale*. Retrieved from https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/Ca-SrkwErs-v00-2019May-Eng.pdf

National Marine Fisheries Service. (2016). *Noaa Fisheries Protected Resources Strategic Plan: 2016 - 2020.* Retrieved from https://repository.library.noaa.gov/view/noaa/18268
This plan provides national-level strategic goals for the protected species management programs across National Oceanic and Atmospheric Administration (NOAA) Fisheries (this includes Protected Resources Divisions in NOAA Fisheries' fve Regional Ofces), as well as strategic goals specifc to the NOAA Fisheries Headquarters Ofce of Protected Resources. We developed these priorities in consideration of the Ofce of Protected Resources' core mission in the context of current fscal conditions and NOAA Fisheries, NOAA, and Department of Commerce (DOC) strategic plans and priorities which are highlighted in Table 1 and further described in Appendix 1. Our priorities are driven by and focused on the needs of the species and stakeholders.

National Marine Fisheries Service. (2016). *Species in the Spotlight : Priority Actions, 2016-2020. Southern Resident Killer Whale Dps, Orcinus Orca.* Retrieved from https://repository.library.noaa.gov/view/noaa/10748
The Southern Resident killer whale DPS was listed as endangered under the Endangered Species Act (ESA) in 2005 following an almost 20% decline in the population. The Southern Residents were chosen as one of the eight most at-risk species because the population has relatively high mortality and low reproduction and they are currently well below the population growth goals identified in the Recovery Plan (NMFS 2008). Unlike other North Pacific killer whale populations, which have generally been increasing since federal protection was initiated in the 1970's, the Southern Resident population remains small and vulnerable and has not had a net increase in abundance since the mid-1980s. The comprehensive recovery program requires engagement from vital partners and long-term support over a large range from California to Alaska

National Marine Fisheries Service. (2020). *Endangered Species Act (Esa) Section 7(a)(2) Biological Opinion and Conference Opinion Consultation on Implementation of the Pacific Fishery Management Council Salmon Fishery Management Plan in 2020 for Southern Resident Killer Whales and Their Current and Proposed Critical Habitat*. https://doi.org/10.25923/asw8-0y28
The proposed action analyzed in this opinion is NMFS's approval and implementation of the annual management measures that the Council has recommended for ocean salmon fisheries in the year 2020 within the U.S. Pacific Coast Region Exclusive Economic Zone (EEZ) (i.e., 3-200 nautical miles off the West Coast states of California, Oregon, and Washington) (FIGURE 1). These fisheries are authorized under the provisions of the Magnuson-Stevens Fishery Conservation and Management Act (MSA) and include commercial, recreational, and treaty Indian fisheries. The fisheries primarily use hook and line gear, which target coho and Chinook salmon. Pink salmon are caught in odd-numbered years but at much lower numbers than Chinook and coho salmon. The management measures typically apply from May 1 of the current year through April 30 of the following year. The PFMC adopts management measures each year at its April meeting, and recommends these measures to the Secretary of Commerce (Secretary). NMFS, upon approving these measures to determine if they are consistent with the MSA, the ESA, the Pacific Salmon Treaty (PST), and exercise of Indian fishing rights, and other applicable law publishes them in a final rule. (See, e.g. 84 FR 19729, May 6, 2019). Because the Secretary, acting through NMFS, has the ultimate authority for the FMP and its implementation, NMFS is both the action agency and the consulting agency for this consultation on the effects of the fishery on Southern Resident Killer Whales and their proposed critical habitat.

Nicol, C., Bejder, L., Green, L., Johnson, C., Keeling, L., Noren, D., . . . Simmonds, M. (2020). Anthropogenic Threats to Wild Cetacean Welfare and a Tool to Inform Policy in This Area. *Frontiers in Veterinary Science, 7*, https://doi.org/10.3389/fvets.2020.00057
Human activities and anthropogenic environmental changes are having a profound effect on biodiversity and the sustainability and health of many populations and species of wild mammals. There has been less attention devoted to the impact of human activities on the welfare of individual wild mammals, although ethical reasoning suggests that the welfare of an individual is important regardless of species abundance or population health. There is growing interest in developing methodologies and frameworks that could be used to obtain an overview of anthropogenic threats to animal welfare. This paper shows the steps taken to develop a functional welfare assessment tool for wild cetaceans (WATWC) via an iterative process involving input from a wide range of experts and stakeholders. Animal welfare is a

multidimensional concept, and the WATWC presented made use of the Five Domains model of animal welfare to ensure that all areas of potential welfare impact were considered. A pilot version of the tool was tested and then refined to improve functionality. We demonstrated that the refined version of the WATWC was useful to assess real-world impacts of human activity on Southern Resident killer whales. There was close within-scenario agreement between assessors as well as between-scenario differentiation of overall welfare impact. The current article discusses the challenges raised by assessing welfare in scenarios where objective data on cetacean behavioral and physiological responses are sparse and proposes that the WATWC approach has value in identifying important information gaps and in contributing to policy decisions relating to human impacts on whales, dolphins, and porpoises.

Office of Protected Resources, N. M. F. S., National Oceanic and Atmospheric Administration, U.S. Department of Commerce. (2017). *Biological and Conference Opinion on the Issuance of Permit No. 20605 to Robin Baird, Cascadia Research Collective, and Permit No. 20043 to Whitlow Au, University of Hawaii, for Research on Cetaceans*. https://doi.org/10.7289/V5P26WBH
This document represents NMFS opinion on the effects of the proposed issuance of Permit Nos. 20605 and 20043 on beluga whales (Delphinapterus leucas, Cook Inlet Distinct Population Segment (DPS)), blue whales (Balaena musculus), bowhead whales (Balaena mysticetus), false killer whales (Pseudorca crassidens, Main Hawaiian Islands Insular DPS), fin whales (Balaena physalus), gray whales (Eschrichtius robustus, Western North Pacific population), Gulf of Mexico Bryde's whales (Balaenoptera edeni), humpback whales (Megaptera novaeangliae, Central America, Mexico, and Western North Pacific DPSs), killer whales (Orcinus orca, Southern Resident DPS), North Atlantic right whales (Eubalaena glacialis), North Pacific right whales (Eubalaena japonica), sei whales (Balaena borealis), sperm whales (Physeter macrocephalus), Hawaiian monk seals (Neomonachus schauinslandi), Guadalupe fur seals (Arctocephalus townsendi), Steller sea lions (Eumetopias jubatus, Western DPS), green turtles (Chelonia mydas, Central North Pacific, Central South Pacific, Central West Pacific, East Pacific, and North Atlantic DPSs), hawksbill turtles (Eretmochelys imbricata), Kemp's ridley turtles, leatherback turtles (Dermochelys coriacea), loggerhead turtles (Caretta caretta, North Pacific, Northwest Atlantic, and South Pacific DPSs), and olive ridley turtles (Lepidochelys olivacea, Mexico's Pacific Coast Breeding Colonies and all other areas).

Parks Canada Agency. (2017). *Multi-Species Action Plan for Pacific Rim National Park Reserve of Canada.* Parks Canada Agency Ottawa. Retrieved from https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/plans/Ap-PacificRimNpr-v00-2017Aug21-Eng.pdf
The geographic scope of this action plan includes all federally managed lands and waters administered by Pacific Rim NPR (Figure 1). This multi-species action plan has been written specifically for Pacific Rim NPR because the Parks Canada Agency (Parks Canada) is legally responsible for species at risk on Parks Canada lands and waters, has the ability to take direct conservation action, and deals with different threats, legislation, and management priorities than areas outside the park. This action plan addresses SARA-listed species that regularly occur in Pacific Rim NPR which require an action plan under SARA (s.47), as well as other species of conservation concern (Table 1). This approach both responds to the legislated requirements of the SARA and provides the Parks Canada Agency with a comprehensive plan for species conservation and recovery at the site. The plan will be amended as required to meet the SARA requirements for action planning.

Parks Canada Agency. (2018). *Multi-Species Action Plan for Gulf Islands National Park Reserve of Canada.* Parks Canada Agency Ottawa. Retrieved from https://wildlife-species.canada.ca/species-risk-registry/virtual_sara/files/plans/Ap-GulfIslandsNpr-v00-2018Jun-Eng.pdf

The geographic scope of this action plan includes all federally owned lands and waters managed by GINPR (Figure 1). In addition, GINPR owns various rights of way on adjacent land and this plan will include GINPR management of species at risk on these rights of way where applicable. This multi-species action plan has been written specifically for GINPR because the Parks Canada Agency (PCA) is legally responsible for species at risk on PCA lands and waters, has the ability to take direct conservation action, and deals with different threats, legislation, and management priorities compared to areas outside the park reserve. This action plan addresses SARA-listed species that regularly occur in GINPR which require an action plan under SARA (s.47), as well as other species of conservation concern (Table 1). This approach both responds to the legislated requirements of the SARA and provides the Parks Canada Agency with a comprehensive plan for species conservation and recovery at the site. The plan will be amended as required to meet the SARA requirements for action planning. Indigenous Peoples have a critical role to play in the assessment, restoration, and management of species at risk. W̱ SÁNEĆ and Hul’q’umi’num people have been actively managing and harvesting species for millennia in the lands and waters that now form GINPR and consequently have much to contribute. This plan has incorporated some of the knowledge and perspectives of local Coast Salish people regarding species at risk as well as those cultural species of concern.

Region, N. M. F. S. W. C. (2016). *Southern Resident Killer Whales (Orcinus Orca) 5-Year Review : Summary and Evaluation.* Seattle, WA. Retrieved from https://repository.library.noaa.gov/view/noaa/17031

The Southern Resident killer whale Distinct Population Segment (DPS) was listed as endangered under the Endangered Species Act (ESA) in 2005. In the listing, the National Marine Fisheries Service (NMFS) identified three main threats to their survival: 1) scarcity of prey, 2) high levels of contaminants from pollution, and 3) disturbance from vessels and sound. As of 1 July 2016 after the summer census, there were only 83 individuals left in the population (CWR 2016). Their small population size and social structure also puts them at risk for a catastrophic event, such as an oil spill, that could impact the entire population. Updates regarding research and management actions for the primary threats (prey, pollution and vessels) are included below and in discussions of whether the recovery criteria related to each of the threats have been met. This review fulfills our requirement under section 4(c)(2) of the ESA to conduct, at least once every five years, a review of listed species to ensure that the listing of these species remains accurate.

Rehberg-Besler, N., & Jefferies, C. S. G. (2019). The Case for a Southern Resident Killer Whale Emergency Protection Order under Canada's Species at Risk Act. *Journal of Environmental Law & Practice (11817534), 32*(2) Retrieved from https://search.ebscohost.com/login.aspx?direct=true&AuthType=shib&db=eih&AN=135817585&site=ehost-live&scope=site&custid=s7484184

Southern Resident Killer Whales inhabiting the coastal and near-coastal waters of southern British Columbia and northern Washington State are listed as endangered under the Canadian Species at Risk Act (SARA). Extensive research of these whales and other marine mammals indicates that a healthy underwater acoustic soundscape is a vitally important aspect of successful conservation. Unfortunately, the Southern Resident Killer Whale's critical habitat, as defined in a protection order pursuant to SARA, entirely overlaps with important shipping routes wherein vessels constantly emit significant underwater noise. The recently approved Trans Mountain Pipeline Expansion Project predicts a sevenfold increase in oil tanker traffic in the Southern Resident Killer Whale critical habitat, further threatening and eroding the underwater acoustic environment. Canada's federal government consistently encourages the protection and recovery of species at risk, but simultaneously approves projects that jeopardize and undermine conservation efforts and commitments. We review current issues associated with the Traits Mountain Project as they relate to Southern Resident Killer Whales, the underwater acoustic soundscape, and developing conservation efforts. By approving the Project before new vessel noise regulations are created or soundreducing technology is mandated, an Emergency Protection Order pursuant to Section SO of SARA may be warranted to protect the Southern Resident Killer Whales against the impact of acoustically degraded critical habitat.

Shaikh, S., Wong, C., Rylko, M., & Hass, T. (2018). *Cumulative Effects on Southern Resident Killer Whales (Orcinus Orca)*. Paper presented at the Salish Sea Ecosystem Conference.
A suite of anthropogenic threats threaten the survival and recovery of the Salish Sea's endangered Southern Resident Killer Whale population (SRKW). With their population level at a historic low (78 individuals as of 2018), this session focused on how to assess and manage the cumulative effects of the threats SRKW face.

State of Washington, & Southern Resident Orca Task Force. (2018). *Southern Resident Orca Task Force : Report and Recommendations.* Retrieved from https://digitalarchives.wa.gov/ViewRecordMedia.aspx?RID=D5E09144FD93B58A370EDFDFBA78C1CD
On March 14, 2018, Gov. Jay Inslee signed Executive Order 18-02: Southern Resident Killer Whale Recovery and Task Force. Through this executive order, the governor directed state agencies to implement nine immediate actions to benefit Southern Resident killer whales (hereafter in this report "Southern Resident orcas"). He also established the Southern Resident Orca Task Force to identify, prioritize and support the implementation of a long-term action plan for the recovery of Southern Resident orcas to ensure a healthy and sustained population for the future. The new task force had nearly 50 representatives from diverse sectors, including tribal, federal, local and other state governments, state agencies, the Washington State Legislature, the private sector, nonprofit organizations and the Government of Canada. The governor charged the task force with preparing this comprehensive report which identifies needed policies and programs, recommends priority actions to support recovery efforts, highlights budget needs and recommends legislation necessary to support the recovery of Southern Resident orcas. The task force will continue its work in 2019 and produce a second report by October that will outline progress made, lessons learned and outstanding needs.

State of Washington, & Southern Resident Orca Task Force. (2019). *Southern Resident Orca Task Force Final Report and Recommendations.* Retrieved from https://www.governor.wa.gov/sites/default/files/OrcaTaskForce_FinalReportandRecommendations_11.07.19.pdf
The following report is a summary of this team's extraordinary work over the past two years — as well as an urgent call to action: With only 73 individuals remaining, there is no time to waste — the road to sustained Southern Resident recovery is through swift, bold and impactful solutions. The loss of three adult orcas this year was a tragic reminder that the Southern Residents are struggling from a lack of Chinook salmon, compounded by the stresses from vessel noise and disturbance, contaminants in their

ecosystem and the long-term threats to their survival from climate change, ocean acidification and human population growth.

Veirs, S., Veirs, V., McWhinnie, L., O'Hara, P., & O'Hagan, G. (2018). *Orcasound Lab: A Soundscape Analysis Case Study in Killer Whale Habitat with Implications for Coastal Ocean Observatories*. Paper presented at the Journal of the Acoustical Society of America. https://asa.scitation.org/doi/abs/10.1121/1.5068556

Orcasound lab is a cabled hydrophone array located near the shoreline of Haro Strait, the core summertime habitat of the endangered southern resident killer whales (SRKWs). In 2016–2017, we began to record data continuously on local hard drives and in 2018 are archiving both lossy and lossless data 24/7 in an AWS/S3 bucket. We discuss our statistical characterization of the soundscape from these continuous audio recordings, contextualized with the AIS data (to quantify sources of ship noise) and image data (to quantify sources of non-AIS boat noise). Of particular interest to ocean observatories are our methods of establishing non-anthropogenic acoustic baselines and then ranking noise pollution sources relative to these baselines. We explore the statistical consequences of selecting different averaging times (from seconds to years) and frequency band widths (spectrum to broadband levels) when computing baselines and pollution metrics, including “delta” metrics that may be most-relevant to SRKWs. Finally, we explain how soundscape analysis (with attention to tidal, diurnal, seasonal, or decadal time variations) could be implemented with cloud-based data in near-real-time and be enriched by citizen scientists interacting with a time-stamped live audio stream and other environmental data.