The Impact of Vessel Presence and Noise on Foraging Behaviors in Southern Resident Killer Whale Populations: A Literature Review (2017-2024)

By

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List of Acronyms

PNW	Pacific Northwest
SRKWs	Southern Resident Killer Whales
NRKWs	Northern Resident Killer Whales
SARA	Canadian Species at Risk Act
AIS	Automatic Identification System
BC	British Columbia
MEOPAR	Marine Environmental Observation Prediction and Response Network
NEMES	Marine Environment from Ships
BRs	Behavioral Responses
NOAA	National Oceanic Atmospheric Administration’s (NOAA)
D TAGS	Digital Acoustic Recording Tags
SPL	Sound Pressure Level
SABs	Surface Active Behaviors
ECHO	Enhancing Cetacean Habitat and Observation

1. Introduction

In the Pacific Northwest (PNW) of the United States, and the Canadian Pacific of Canada, the world's most researched group of killer whales (Orcinus orca) have existed for a millennium: the Southern Resident Killer Whales (SRKWs). 'Southern' identifies which area they occupy, as they have 'Northern' counterparts; 'Resident' identifies their hunting capabilities for fish in coastal areas; and 'Killer Whale' refers to an alternative name for 'Orca' that was previously used due to some ecotype's ability to hunt whales and sharks. The Southern Resident Killer Whale population has been listed as 'endangered' under the Canadian Species at Risk Act (SARA) and the United State's Endangered Species Act since 2003, and 2005, respectively. Historically, the SRKW's population hovered around 200 individuals, but today, there are only 75 remaining[1].

In the past, SRKWs have been the target of several live capture missions for the live animal entertainment industry. From the years of 1962-1977, live captures removed 48 individuals from SRKW populations. In total, 26 individuals were males and 18 were females. Of the 48 individuals removed, 30 were deemed to be physically immature. Furthermore, 71% of captures across several ecotypes and pods during this time were sourced from the SRKWs populations due to their costal accessibility. The individuals were sold to marine parks internationally for live entertainment. In 1977 live captures ended in Canada and the last live capture permit was issued from the U.S. in 1989[1]. After almost 25 years of live capture, in 1980 the population experienced an 11% population reduction assumably from the removal of juveniles leading to a skewed population structure[1].

The SRKW's have a large territory that expands from the waters of southern Alaska to Monterey Bay, California. Historically, all three groups of orca (J, K, and L), also known as 'pods,' are known to inhabit the area between the San Juan Islands and Vancouver Island, known as the Salish Sea. between the fall and summer months due to prey access from the local 'chum runs.' During the Winter and spring seasons, the pods tend to inhabit the open coastline of the pacific. Their time in the Salish Sea is thought to be specifically chosen for the historically prime hunting and feeding grounds. The Salish Sea extends from Olympia, Washington, U.S.A. north towards the South to Campbell River, B.C., CA. It covers a total area of just under 17,000 km^2 and includes about 7,500 km of coastline. Overall, all three pods face three detrimental factors limiting their

ecotype's biological success in the Salish Sea. Exposure to contaminated waterways, lack of food, and vessel disturbance all bring major threats to the endangered pods. In this review, vessel disturbance to SRKWs foraging behavior will be examined. Seventeen documents were reviewed between the years of 2017-2024 to provide the most comprehensive, and up to date research on the population's foraging behaviors.[1]

1.1. Objective

This thesis aims to review current literature between the years of 2017-2024 around the impact that vessel presence and noise has on the foraging behavior of Southern Resident Killer Whales (SRKWs) (*Orcinus orca).*

1.2. Study Area

The Salish Sea, a deep inland body of water in the North Pacific, comprises Juan de Fuca Strait, Georgia Strait, Puget Sound, and their connecting channels and coastal fjords. The border between Canada and the United States bisects both the Strait of Juan de Fuca and Haro Strait, which separates the San Juan Islands from the Gulf Islands of Canada. The Salish Sea, specifically the Haro Strait, is a crucial habitat for the Southern Resident Killer Whale population, as designated by Fisheries and Oceans Canada. The Haro Strait, a core summer feeding ground for the pods, is also a major shipping lane that connects the Juan de Fuca and Straits of Georgia together[1] (***Figure 1***.).

Figure 1: A map of the Critical Habitat of SRKWs within the Salish Sea with labeled waterways. At the time of this review, Critical Habitats expand through California, Oregon, Washington, and British Columbia (BC). Map created by ClearSeas (2024)[2].

2. Methods

Thirteen sources have been chosen for this review to represent the most accurate information on the effect of vessels and vessel noise on the foraging behavior and success of the ecotype.

2.1. PRISMA

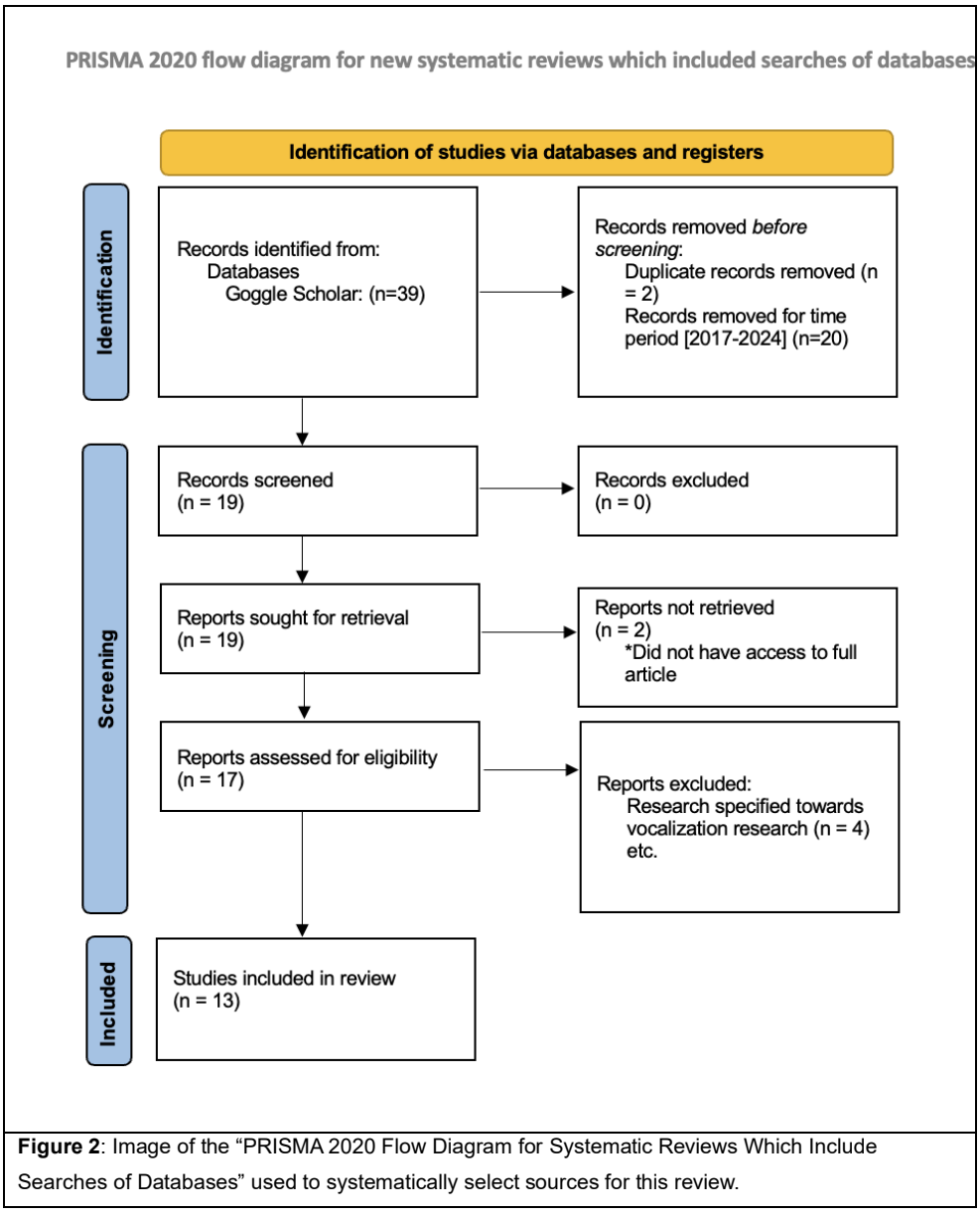

Figure 2: Image of the "PRISMA 2020 Flow Diagram for Systematic Reviews Which Include Searches of Databases" used to systematically select sources for this review.

Search terms were inputted to Google Scholar and included the following format: "'Southern Resident Killer Whale', vessel presence, foraging behavior, noise, sound." The beginning of the search process yielded a total of 39 sources. Two of those sources were

removed due to a duplication between publications, and twenty more were removed using the “Custom Range” filter that was set to only include publications between the years of 2017-2024. These filters resulted in a total of 19 records that were screened. Unfortunately, two of the sources were ineligible for access through the Colorado State University databases and therefore were forcibly excluded from the pool of publications. From here, 17 articles were reviewed for applicability to the aim of this literature review and all except 1 was accepted. The single article was denied due to its focus on acoustical analysis of the pods which was outside the scope of this review (***Figure 2***.).

3. Behavioral Analysis

3.1. Foraging

To understand the basics of foraging, three studies were employed to provide information on food source, food preference, hunting and social strategies, and geographic location of hunts. The latter two studies that investigate the typical foraging and communicative surface behavior strategies are both done in non-invasive ways to reduce the interference of humans on the pods’ natural behaviors.

Historically, it has been thought that SRKW population decline was most entirely due to a decline in their preferred food source, Chinook Salmon (Oncorhynchus tshawytscha). A recent study performed by the Canadian Marine Mammal Research Institute on the density of prey between SRKWs and their northern counterparts, which still exist in their historic population numbers, challenged the idea that the lack of the SRKWs preferred food source was the main cause of their population decline. By using ship-based echosounders to measure fish distribution and density, and midwater trawling to assess species composition based on the acoustical readings, the team was able to find that the most common type of fish caught during the trawl were Chinook Salmon. The researchers also determined that the density of fish was anywhere between 4-6 times higher in the SRKW habitat (Juan de Fuca Straight) than in the Northern Resident Killer Whale (NRKW) population. The NRKWs are oftentimes used as a control group to compare SRKWs data against due to their biological similarities and thriving population. This study outlined the difference between prey abundance and prey value where the latter being the amount of food available and the former being the ability of the predators to find the food. The researchers expect that other factors could be influencing the pods’

ability to hunt the food that is available rather than the amount of food that's available to be causing a potentially greater impact to the pods[3].

In another study performed by a University of California, San Diego research group, high resolution areal images were taken of SRKWs to understand their foraging behaviors when near the surface. From the photos, the species of fish and fish size were assigned. The average size of fish observed was 0.668 meters (26.30 inches), and the about 60% of the fish identified were Chinook Salmon which corresponds to the prior study which spoke to the density and theoretical availability of Chinook Salmon to SRKWs. The study found that there was no correlation on the time of foraging events and the time of day.

From the arial photography, 29 individual foraging events were recorded containing 33 individual whales. Of the 29 events, only 6 events had just 1 whale individually foraging. This frequent pairs or group hunting represents the characteristic, strong social connection that the species shares. Overall, 96% of all recorded foraging events occurred from members of the same pod which outlines the lack of co-habitation between pods. Of the 88% of prey-sharing recorded from all kills, 62.5% of all prey sharing events occurred between mothers and their calves of varying ages.

This study also stated that due to the current adjustments to Chinook Salmon supplied from the Fraser River, the SRKWs were seen to be using their habitat in new ways and not returning to their traditional core habitat for the spring salmon runs[4].

To fully understand the foraging behavior without the presence of boats, a third study was enrolled in this review. This study, performed by Utah State University, investigated the correlation between age, sex, and percussive surface behavior. 'Percussive' referring to the sound that a body part of an orca makes when contacting the water's surface. The data was observationally collected from the shore of Lime Kiln State Park off of the Haro Straight where no boats were used by the team to follow, search for, or interfere with the SRKWs in any way. The study spanned 83 days from the hours of 9:00A.M. to 5:00P.M. PST and collected information on 34 pass-by's, 24 of which displayed several types of percussive behavior (***Figure 3***.). Following the analysis of the data, it was revealed that adult females (x>11 years old) had very high numbers of percussive behaviors (breach, n=1.5 per pass by) compared to adult males (x>20 years old) had very low numbers of percussive behaviors (breach, n= x<1 per pass by), and the juvenile males (x= 2-10 years old) had a moderate amount of participation in percussive behavior (breach, n=1.75). From this data, it is inferred that adult females, presumably

mothers, are role-modeling proper interactions for the offspring of their pod. Another correlation was seen also between the timing of percussive behavior and the presence of Chinook Salmon hunting attempts indicating that percussive surface behavior is directly correlated to the presence and subsequent hunting of prey. Juveniles were inferred to have relatively high amounts of percussive behavior due to their social learning, and desire for play. Furthermore, tail slaps were seen most often which is likely due to their low energy inputs when compared to something more energy intensive such as breaching[5].

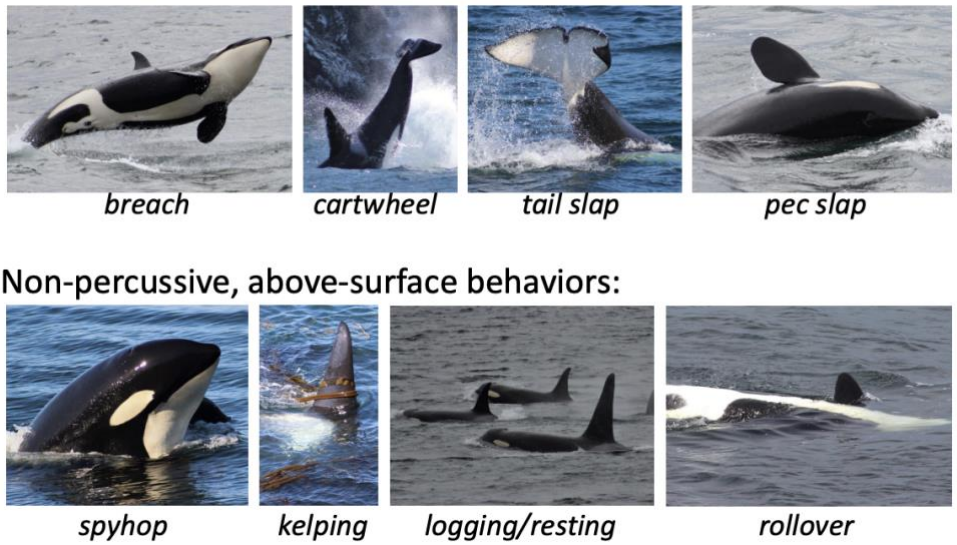

Figure 3. Several types of percussive behavior displayed. In the study on percussive behavior, only 'tail slap,' 'breach,' 'cartwheel,' 'pec slap,' and 'dorsal slap' were observed[5].

3.2. Measured Noise in SRKW Habitat

Aforementioned research has understood the presence of food, the activities of foraging and the communication seen within pods during foraging sessions, one can move towards understanding the current noise levels of the Salish Sea. Considering that there is ample prey during certain seasons and in certain areas available to the SRKWs, it is realistic to consider other factors that could impact the declining numbers of SRKWs. To understand the potential drive behind the decreasing population levels, several sources investigating the current noise levels in the Salish Sea have also been chosen for review. One research-backed perspective on the cause for the decline in numbers has been attributed to vessel noise. Vessel noise is thought to make the oceans more noisy

and therefore harder for individuals within a pod to communicate with one another through their group hunting strategies which were previously outlined[6].

The first study that was considered in this review was titled, “Noise exposure from commercial shipping for the southern resident killer whale population[7].” This study, performed by the Marine Environmental Observation Prediction and Response Network (MEOPAR) and its funded noise exposure to the Marine Environment from Ships (NEMES) project, tracked commercial vessels equipped with Automatic Identification Systems (AIS) during summer months in the Salish Sea. AIS is a required commercial vessel system responsible for tracking the vessel’s speed, build, position, course, and navigation status. The researchers from the two organizations used the AIS data to map different octave bands calculated from the speed of commercial vessels and overlayed this information to high density SRKW population maps and confirmed sightings. From this information, the researchers found that median cumulative noise values exceeded 90 dB re 1 µPa within the SRKWs most used areas. In general, µPa is used as a reference value for underwater acoustics. This trend was particularly prevalent in areas with high commercial shipping traffic. Areas with concentrated ferry traffic and those overlapping with commercial shipping lanes experienced the highest noise levels. When re-considering the AIS data, vessel type was considered to better understand the high noise exposure. It was found that ferries, boats, vehicle carriers, recreational vessels, container ships, and bulk carriers contributed the most noise to these high noise areas.

Another study that was employed for this review was performed by the Canada Energy Regulator in conjunction with the Canadian government to produce a simulation model to predict the number of noise-related behavioral responses (BRs) as well as the extent of high-frequency echolocation click masking. BRs ranged from anywhere between low, moderate, and severe rankings. ‘Low’ behavioral response was identified as a slight change in swimming direction, increased vigilance, looking around more frequently, brief vocalizations, and or moving slightly further away from the disturbance. ‘Moderate’ behavioral responses were characterized by a noticeable change in travel path, more frequent vocalizations, increased speed or rapid acceleration, and or temporary cessation of foraging behavior. Finally, ‘Severe’ behavioral responses were characterized by an abrupt change in direction, erratic movements, leaving the area quickly, prolonged vocalizations, possibly distress calls, complete cessation of foraging, and or visible signs of stress like rapid breathing.

For this study, both commercial vessel and whale-watching boat noise were considered. When analyzing data from the commercial vessels, the increased noise was found to trigger 7.1 low severity BRs and 3.2 moderate severity BRs per day per whale. When computing this data to the simulation model, the disturbances lead to a 12.5% potential loss of foraging time due to BRs. From the model it was also found that there was a negligible reduction in echolocation click detection range. When investigating the impact of whale-watching boats on SRKW behavior, it was computed that an increase in low (16%) and moderate (3%) BRs occurred. This disturbance was estimated to contribute to a 7% increase in potential lost foraging time due to BRs. Furthermore, the noise produced by whale-watching boats computed to reduce echolocation click detection range by 5-34%. The researchers were also able to gather data from instances where both vessel types were present (within a few hundred feet) of the whales which computed to a 12-37% reduction in click detection range. In total, potential lost foraging time due to BRs and masking is estimated to be 20-23% of each day the pods spend in the Salish Sea[7].

3.3. Differences in Observed Behavior Due to Vessel Presence

In a research study conducted by several government and university agencies including National Oceanic Atmospheric Administration's (NOAA) Ocean Acoustics Program and Fisheries and Oceans Canada Cetacean Research Program, attached Digital Acoustic Recording Tags ('D TAGS') via suction cup to both SRKWs and NRKWs. These tags transmit data on the whale's position, sound use, sound exposure, and behavior and were specifically used to better understand various steps of foraging including prey searching, pursuing, and capturing. From the data analysis, the three stages were characterized by different behavioral responses. Searching was characterized by the presence of 'slow clicks' (echolocation clicks with intervals greater than 100 ms). This phase involves the individual using echolocation to locate potential prey. The 'pursuit' phase was marked by the emission of 'buzzes' (rapid echolocation clicks with intervals less than 11 ms). Buzzes indicate that the whale is actively chasing prey. Finally, capture was identified by analyzing the tag's movement data, specifically looking for patterns of rapid acceleration and changes in roll and heading, which are typical of prey capture events[8].

When considering the capture of noise from the tag's, the researchers needed to quantify the base, ambient noise levels that are typical of the area without the presence of vessels. To do this, the researchers focused on sound recordings free of extra sounds from the tagged whale, other whales, or flow noise generated by the tag itself. They calculated the root-mean-square Sound Pressure Level (SPL) over 1-second intervals within these 'cleaned' recording sections. The study chose the SPL measurements in the 15–45 kHz frequency band (SPL15–45) as the area's optimal metric for ambient noise. This range effectively filtered out flow noise while still capturing anthropogenic noise, particularly from vessels.

From here, the team was able to begin understanding the impact of vessels on foraging behavior which was again split up into the three distinct groupings of searching, pursuing, and capture. For the searching category, it was found that for each 1 dB increase in the maximum noise level, there was a 4% increase in the odds of whales engaging in searching behavior[8]. The authors interpreted this finding as a response to auditory masking. This means that in the presence of increased vessel noise, the whales had to compensate for the difficulty of detecting echoes from their clicks and sounds by increasing their searching effort. For the 'pursuit' category, the team discovered that female whales were significantly less likely (58%) to pursue prey as the ambient noise increased, while, on the other hand, males showed no behavior change to the increased noise. The difference could be attributed to the possibility of different foraging strategies across the sexes. The researchers also pointed out that there is potential for females who are caring for calves to be more sensitive to noise. When it came to 'capture,' the probability of prey capture decreased with increasing noise levels for both sexes. Furthermore, almost all deep foraging attempts (those exceeding 75 m) made in high noise conditions (≥110 dB re 1 μPa) were unsuccessful. This finding suggests a strong link between vessel noise and reduced foraging success, particularly at greater depths where whales may be targeting larger, more energy-rich prey[8].

The researchers argued that the observed patterns are most consistent with an auditory masking mechanism. This is because the frequency range of vessel noise (20-70kHz) often overlaps with the frequencies used by killer whales for echolocation (low frequency, 20-30kHz, high frequency, 40-60kHz), making it harder for them to detect the faint echoes returning from prey or the environment[8].

When continuing to another study chosen for review, the Surface Active Behavior (SAB) with vessels present is investigated. This study researched how the amount of

Chinook salmon and the presence of vessels influenced the SABs of SRKWs. The research used a used land-based observations to collect 24-years of data (1996–2019) at Lime Kiln Point State Park in Washington. This study serves as a comparison from a formerly mentioned study that investigated SAB's over 87 days without vessels present in the same state park. The study revealed that SRKWs exhibited more SABs when a larger number of whale-watching vessels were present. Furthermore, the whales spent more time in the study area and engaged in more milling behavior, often associated with foraging, when vessel numbers were higher. This could be attributed to the challenge that vessels bring to the individuals' ability to forage and implications of auditory masking. These findings suggest that vessel presence can influence SRKWs behavior, and potentially disrupt their natural foraging patterns. Confirming the first study mentioned from Lime Kiln State Park, the pods were seen to reduce their SAB's when salmon numbers were lower and increase SAB's when salmon numbers were higher in the area. This is inferred to be linked with the SAB link to hunting as well as the need for energy conservation when food is not abundant[9].

The final study chosen to understand the impacts of vessel disturbances on SRKWs behavior, titled "Effects of vessel distance and Sex on the Behavior of Endangered Killer Whales" also used DTAGS which were used in a previously mentioned study. For this research, the DTAGS were used to understand how whales responded to different vessel distances in terms of their behavioral states as well as the transition between the behavioral states. To do this, 13 individuals were tagged with suction cup DTAGS during the summer months in the Salish Sea. The four behavioral states included State 1 characterized by traveling dives, shallow depths, minimal movement variation, and very little echolocation clicking. State 2 was characterized by deep foraging dives, state 3 was characterized by acoustic search dives, and state 4 was characterized by intermediate dives, of intermediate depth which were deeper than stage 3 dives[10].

Once the data was collected and analyzed, the team discovered that females exhibited stronger responses to vessel proximity than males. This was evidenced by females being more likely to switch from deep foraging (State 2) to other states, especially traveling (State 1), when vessels were close by. This suggests that females may be more sensitive to disturbance and may choose to abandon foraging attempts when vessels are nearby[10].

3.4. Mitigation of Altered Behavior Due to Vessel Presence

To understand the requirements of mitigating altered behavior due to vessel presence, three studies were chosen. The first paper chosen, titled “Potential Benefits of Vessel Slowdowns on Endangered Southern Resident Killer Whales,” investigates the efficacy of the Vancouver Fraser Port Authority's Enhancing Cetacean Habitat and Observation (ECHO) Program’s voluntary vessel slowdown trial to assess the impact of reduced vessel speeds on noise and research the potential benefits to SRKWs. The trial focused on a 16 nautical mile section of shipping lanes overlapping a key SRKW foraging area in Haro Strait. During the two-month trial period, piloted vessels were requested to voluntarily reduce their speed to 11 knots[11].

Researchers then used AIS data to monitor vessel speeds and participation rates, deployed hydrophones to measure ambient noise levels, calculated vessel source levels to quantify noise emissions, and developed a regional vessel noise model to predict noise levels under different traffic scenarios. From the data collected, the findings indicated that the slowdown trial had a positive impact on reducing underwater noise levels which was evidenced by a reduction in median broadband noise levels at a hydrophone station located near a common SRKW foraging area. Noise reductions were particularly pronounced in lower frequency bands where commercial vessels are typically loudest and where SRKW’s produce their low frequency communication (20-30 kHz). The study also used a SRKW noise-exposure model to assess the potential effects of vessel noise on foraging behavior. This model, based on data and incorporating species-specific dose-response functions, estimated the "potential lost foraging time" experienced by whales due to noise disturbance. The model's results suggested that reducing vessel speeds can significantly decrease the amount of foraging time lost due to noise[11].

The next study chosen for review titled, “Reducing vessel noise increases foraging in endangered killer whales,” examined the effectiveness of speed reduction. While a linear relationship between ship speed and behavior of SRKWs was not produced by the data, the study emphasized that reducing ship speed, and consequently noise amplitude, can significantly reduce the disruption of SRKW foraging. The researchers also point out that while slowing ships reduces noise levels, it also increases the duration of exposure for the whales. This means that even though the noise is quieter, the whales are exposed to it for a longer period which could still impact auditory masking and foraging[12].

4. Conclusion

In conclusion, the Southern Resident Killer Whale (SRKW) population faces unique and multifaceted threats, including impacts from the dense population of shipping lanes and commercial vessel use in the Salish Sea. The pods' abilities to forage for their preferred prey choice, Chinook Salmon, is essential to their survival. Noise levels have been suggested to correlate to the success of foraging events, particularly when high noise levels hinder foraging efforts. Recent literature points to the greatest noise impacts stemming from ferries, vehicle carriers, recreational vessels, container ships, and bulk carriers significantly impacting SRKWs behavior and hunting successes.

In several studies, vessel noise was seen to disrupt the SRKW's ability to use echolocation to locate prey. Vessel proximity also brought on differences between the sex's choice to hunt which was seen in response to vessel proximity. The constant auditory stress of approximately 90-110 dB of ambient noise due to commercial vessels can lead to a reduction in foraging efficiency and successful feeding events. By slowing down in critical habitats, vessels can significantly reduce noise levels, creating a space that is more conducive towards accurate and precise foraging.

To ensure the long-term survival of the endangered SRKW ecotype, a continued conservation approach is essential. This approach should focus on implementing required speed limits under 11 knots for certain vessel types traveling through critical SRKW habitat. These approaches should also, where feasible, implement the re-routing traffic and shipping lanes away from known preferred foraging areas. Finally, the approaches should focus on limiting the number of vessels allowed to operate in sensitive areas to manage vessel density[6]. Based on the research presented, a decrease in the speed of commercial vessels will lead to increased foraging success which, in turn, will allow for a more productive environment for the Southern Resident Killer Whales.

4.1. Future Directions

Each source chosen for this literature review outlined the need for further research. Many sources emphasised similar future research endeavors. One of these future directions, one theme was common across all sources: the need for collaboration between industry, policymakers, and scientists to implement effective noise mitigation strategies that balance economic and environmental considerations.

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