Drowned Out: How Marine Vessel Noise Impacts the Southern Resident Killer Whale Population in the Salish Sea

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Abstract:

The endangered Southern Resident killer whale (SRKW) population that consists of a total of 73 members, concentrates in the Salish Sea off the coast of British Columbia, Canada and Washington, USA during the summer. The Salish Sea is also an area of high human occupancy and activity, resulting in high amounts of marine vessel traffic. The noise created by vessel traffic can negatively affect SRKW life processes, which threatens the small population's survival. The purpose of this paper is to determine how marine vessel noise affects the SRKW population as well as how commercial and whale watching vessels specifically affect SRKW, as they are notable industries in the area. Another objective is to assess how affective current SRKW-specific legislation is.

An examination of published journal articles, theses, and other literature reveals that vessel noise originates from multiple characteristics of a vessel such as length, size, propeller cavitation, distance, and speed. Whale watching vessel noise is mainly due to certain practices such as leapfrogging which increases noise levels near pods, masking SRKW communication. Additionally, commercial shipping vessels increase background noise, masking SRKW calls, and interfering with echolocation. Vessel noise affects SRKW social behaviour including the reduction of SRKW communication space, vessel noise masking SRKW calls, SRKW decreased detection of calls, altering calls, and increased surface active behaviours. Vessel noise disrupts SRKW echolocation and navigation of prey, reduces the amount of resting and foraging time, causes avoidance behaviour, and decreases energy production. SRKW can also suffer from hearing loss due to the constant exposure of vessel noise. This constant exposure to vessel noise can also lead SRKW to permanently abandon their habitat.

Current Canadian and American SRKW legislation such as the Oceans Protection Plan and the Species at Risk Act establish protection zones, fines for violating SRKW critical habitat

zones, and voluntary vessel slowdowns but overall, legislation isn't properly addressing noise level effects on SRKW. Further, noise levels in critical habitat zones have been found to significantly affect SRKW communication. Findings have shown that voluntary regulations and boundaries established aren't effective and enforcement of regulations is minimal. Recommendations include developing SRKW education campaigns as well as creating clear channels of communication among researchers, policy-makers and the public to increase awareness of current legislation. Additionally, creating one universal piece of SRKW legislation for easier management of vessels and SRKW, altering shipping routes in the summer to avoid critical habitats, and making all voluntary measures for vessel slowdowns obligatory could aid in the survival of the SRKW population in the Salish Sea.

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Introduction:

Known as family to some, foe to others, and a fascinator to the rest, Southern Resident Killer Whales (SRKW) have become a subject of interest in recent years as their already small population dwindles due to modern anthropogenic pressures. Spending their summer months in the Salish Sea, their habitat overlaps with human settlements and activities. A number of historic events caused the SRKW population to plummet to its current number. These events included targeted hunting, which initially reduced SRKW population numbers due to the false assumption and resulting negative connotation of the SRKW threatening local salmon stocks. Further reductions occurred when whales were captured for marine parks and aquariums during the mid-1960s to early 1970s. These historical factors, along with modern anthropogenic factors, have reduced the population from its pre-twentieth century number of approximately 200 to a modern total of 73 members (Marine Mammal Commission, 2020).

Current anthropogenic pressures have further affected the already dwindling population in multiple ways. The population has struggled with poor physical health due to interactions with pollution and contamination in the ocean, such as persistent organic pollutants (POPs), including dichloro-diphenyl-trichloroethanes (DDTs) and polychlorinated biphenyls (PCBs), which affect SRKW endocrine and immune systems (Krahn et al., 2009). The combination of SRKW relying on a relatively exclusive diet of Chinook salmon (*Oncorhynchus tshawytscha*) and the current low levels of the Chinook salmon stocks affect SRKW nutrition uptake and therefore, reproduction rates (Wasser et al., 2017).

Other anthropogenic pressures include the high noise levels from a large amount of vessel traffic in the Salish Sea. With increasing development around the Salish Sea and recreational vessel presence, commercial whale watching, and the shipping industry have bloomed. This increase in vessel presence is especially concerning for the SRKW population as vessel effects are multifaceted. These effects range from masked communication calls, SRKW avoidance behaviour due to vessel presence, to permanent hearing loss. Though there are regulations on vessel noise and SRKW, because of the multiple ways in which vessels affect the population, there is always room for improvement with regards to current regulations and legislation.

Purpose:

The purpose of this paper is to examine and investigate the impacts of marine vessel noise on the endangered SRKW population in the Salish Sea. Additional questions to be addressed include how commercial shipping and whale-watching vessels contribute to noise levels and specifically affect SRKW. Another objective is to determine the efficacy of the current legislation and make recommendations regarding the SRKW population and vessel effects in the Salish Sea.

Overview:

This paper will begin by introducing the SRKW species of the Northeastern Pacific Ocean. The structure, characteristics, and historical factors that led to the current situation of the SRKW population will be reviewed. The Salish Sea ecosystem and anthropogenic activities will be discussed. The paper will then examine the characteristics of marine vessel noise and how marine vessel noise affects the SRKW population, focussing specifically on commercial shipping vessels and whale watching vessels. A review of the strengths and weaknesses of the literature and research on the population will also be addressed. The paper will finish with a discussion of the current legislation that addresses the SRKW population, further recommendations to improve it, concluding thoughts, and a summary of the main points of the thesis.

Beyond the Scope:

Due to length limitations, this paper will not address other effects of vessel traffic, including chemicals originating from vessel engines and oil spills, as well as the effects of the Trans Mountain Pipeline expansion on vessel traffic. Broader issues, including the impact of industrial pollution and prey availability on the SRKW population, will also not be included in this paper. Vessel noise is the focus of this paper as it affects multiple SRKW life processes and is an anthropogenic effect that is easier addressed than the subjects discussed above. This is due to the characteristics of the creation of underwater noise being relatively straightforward to address compared to other anthropogenic pressures. These pressures require time and resource-intensive measures like pollution cleanup and reduction.

Methods:

The research in this paper consists of a literature review of published papers and theses. Publications were collected from search engines, including Google Scholar, as well as peer-reviewed journals and articles. Research and data from NGOs were incorporated as well as government organization reports and legislation from Canada and the United States. Due to the SRKW population's endangered status and constraints to technology, specific literature on research regarding the SRKW population was limited. Therefore, there wasn't a restriction regarding publication dates, so both recent papers and frequently cited literature from earlier time periods were incorporated. Literature regarding the Northern Resident Killer Whale (NRKW) population, located further North off the British Columbian and Alaskan coast, was included to supplement this literature. It is acknowledged that there are differences between the two populations of killer whales.

Meet the Family

Northeastern Pacific Killer Whales

Three types of killer whale ecotypes inhabit the Northeastern Pacific Ocean, including Offshore killer whales, Transient killer whales, and Resident killer whales. The three ecotypes do not interbreed and are, therefore, genetically distinct. Transients feed on pinnipeds such as harbour seals, Residents feed on salmon species, primarily Chinook, and Offshores focus on fish and shark species (Baird, Abrams, & Dill, 1992). Each ecotype is made up of clans whose calls have particular dialects. Clans consist of pods which are further made up of matrilines comprising of a matriarch, the eldest female, and her descendants (Bigg, 1990). The Transient population numbers at 250 members and the Offshore population numbers at 300 members. The Resident killer whale population consists of approximately 382 members, of which 73 are identified as SRKW (Fisheries and Oceans Canada, 2007; Fisheries and Oceans Canada, 2018a; Fisheries and Oceans Canada, 2018b; Marine Mammal Commission, 2020).

Habitat

The habitat of Offshore killer whales ranges from Southern California to the Bering Sea, whereas Transients remain off the coast of British Columbia as they are non-migratory. Resident killer whales are separated into two subgroups known as Northern Resident killer whales and Southern Resident killer whales. Northern Residents range from Southern Alaska to Northern Vancouver Island. Southern Residents range from Southern Alaska to central California, occupying the waters of the Salish Sea in British Columbia and Washington State in the summer months (Figure 1) (Fisheries and Oceans Canada, 2020).

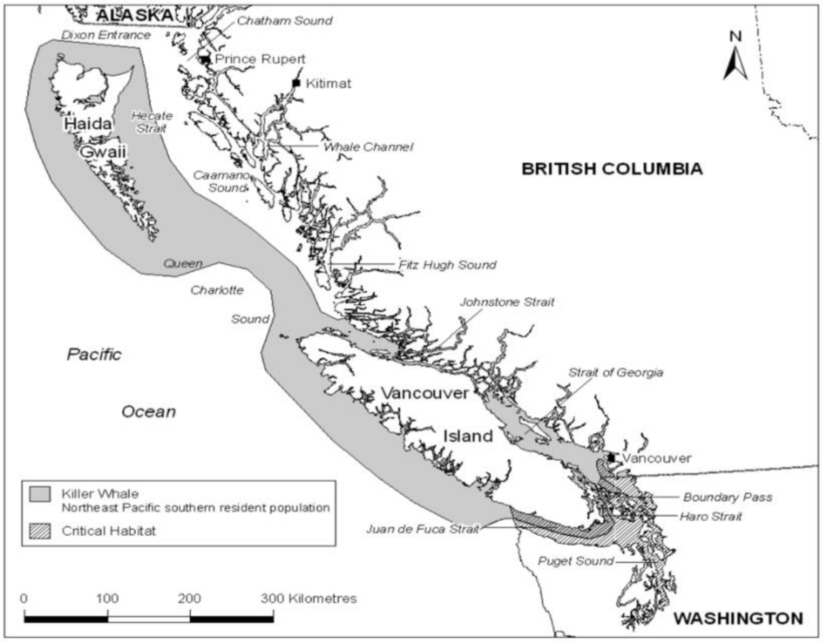

Figure 1. SRKW range in Canadian waters. Diagonal lines indicate summer and fall habitat of the SRKW and are designated as Critical Habitat. Shaded area indicates the winter and spring habitat ranging from Haida Gwaii to California. Adapted from "COSEWIC Assessment and Update Status Report on the Killer Whale in Canada" (p.11) (COSEWIC, 2008).

Southern Resident Killer Whales

Due to their proximity to human settlements and activities in the Salish Sea, the SRKW population frequently crosses paths with human activities. SRKW spend the majority of their time foraging for Chinook salmon but have been observed to consume Sockeye salmon (*Oncorhynchus nerka*), Coho salmon (*Oncorhynchus kisutch*), Steelhead trout (*Oncorhynchus mykiss*), Chum salmon (*Oncorhynchus keta*), and other fish species to a smaller extent (Hanson et al., 2010).

Physiology:

SRKW rely on echolocation to navigate their way through their habitat and for hunting purposes, such as locating their prey (Ford, 1989). SRKW echolocation clicks last between 0.1-25 milliseconds and are repeated up to 300 clicks per second (Ford, 1989). SRKW also rely on sound to communicate with one another by producing variable, discrete, and aberrant calls that preserve social relationships between whales and better facilitate foraging among pods (Ford, 1989). Discrete calls are repetitive in nature and are characterized by pulsed sounds. Alternatively, variable calls are not repetitive and do not have structural properties, like trills and squeaks, that vary in length. Aberrant calls are similar to discrete calls but are altered and infrequent (Ford, 1989). Whistles are another form of communication that can last up to 12 seconds. The characteristics and dialects of these calls are unique to the SRKW population (Smith, 2014).

SRKW Frequencies

Key characteristics of killer whale sounds include dialects, which are sound variances among killer whale populations as well as within the same populations. For example, SRKW J Pod, K Pod, and L Pod calls all have different dialects (Erbe, 2011). SRKW calls have frequencies ranging from 100-6000 Hz and harmonics that reach 30 000 Hz (Ford, 1987). Whistles range between 2000-16 000 Hz (Riesch, Ford & Thomsen, 2006), and echolocation click frequency is around 40 000 Hz (Au et al., 2004).

SRKW Hearing

The auditory sensitivity of SRKWs ranges from 600 Hz to 100 000 Hz (Heise et al., 2017). With lower frequencies, SRKW auditory sensitivity, the range of frequencies that SRKW have the ability to perceive, improves and high frequencies sensitivity decreases (Erbe, 2011). Many odontocetes, toothed whales, have ultrasonic hearing reaching up to 200 kHz as well (National Research Council, 2003).

SRKW J Clan

Three pods make up the SRKW J Clan, the J Pod, K Pod, and L Pod, which generally inhabit different areas of the Salish Sea, with each containing multiple matrilines as depicted in Figure 2. Pods may group together at certain times as their habitats overlap in some regions (Hauser et al., 2007). They are the smallest population of Resident killer whales in the Pacific Ocean, with a total population of around 73 whales (Marine Mammal Commission, 2020). The SRKW population is listed as *Endangered* under Canada's Species at Risk Act (Fisheries and Oceans Canada, 2020), *Endangered* under the United States' Endangered Species Act (NOAA, 2019a), *Endangered* by COSEWIC (Southern Resident Killer Whale Imminent Threat Assessment, 2018), and *Depleted* under the Marine Mammal Protection Act (NOAA, 2019b).

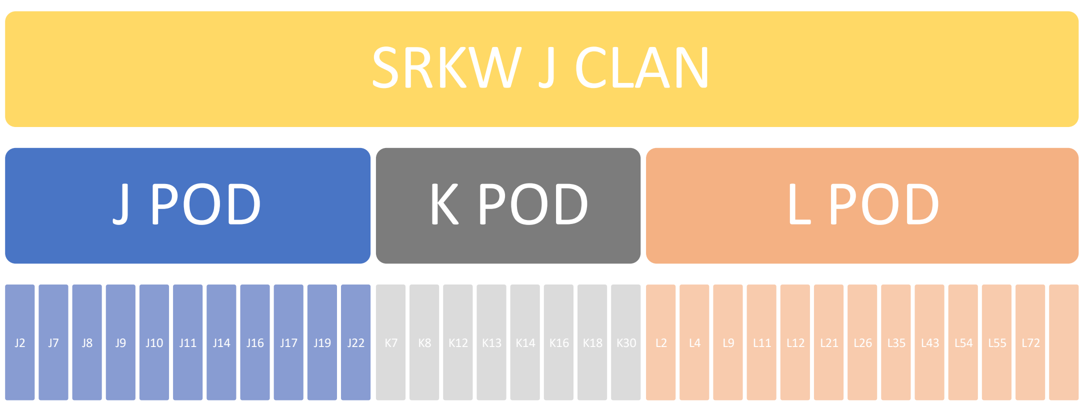

Figure 2. SRKW J Clan matriarchs. Depicted is the SRKW J Clan with its three pods, J Pod, K Pod, and L Pod. Within each pod, the surviving matriarchs are labelled, representing each matriline within the pod. Information adapted from https://www.whaleresearch.com/orcasurvey.

Historic Pressures on the SRKW Population:

Before the twentieth century, the SRKW population was estimated to be around 200 whales. With the arrival of colonisers on the west coast of British Columbia and Washington, a negative connotation was assigned to the whales as fishermen believed that the species was depleting the salmon stock that humans relied on. To prevent their presumed adversary from threatening their survival, fishermen were encouraged to shoot and kill any killer whale they encountered. By the 1960s, advances in science and knowledge of the species changed opinions towards killer whales. This shift resulted in large-scale captures of SRKW for aquariums and marine parks, which occurred from 1967-1971. Because of their proximity to human settlements in the Salish Sea, the SRKW population was the easiest to capture, resulting in a significant reduction in population size. This led to approximately 47 Southern Residents being captured, 35 transported to marine parks, and at least 12 or more killed in the process. By 1976, public opinion about the live-capture process shifted again, live captures were banned in Canada, and population surveys were implemented. These surveys revealed that the live captures had left the SRKW population with 71 remaining members. Since the 1970s, the SRKW population has fluctuated between member numbers in the 70s with a high in the mid-1990s of 98 members but their abundance has decreased to a current total of 73 (Giles et al., 2012; Marine Mammal Commission, 2020).

Modern Anthropogenic Pressures on the SRKW Population

Today multiple modern anthropogenic pressures impact the population. The three main threats to the population's survival are:

- Contaminants and pollution
- Reduction in prey availability
- Impacts of marine vessel traffic noise

Contaminants such as POPs including, PCBs, DDTs, and HCBs are biomagnified in SRKW prey. This means that SRKW members consume high concentrations of these chemicals leading to biological effects such as immune system and endocrine system disruption (O'Hara and O'Shea, 2001). These pollutants can be passed on from mothers to SRKW calves at higher concentrations potentially through nursing (Haenel, 1986), causing similar issues and making it difficult for the calves to survive (Krahn et al., 2007).

Processes like habitat destruction and climate change reduce prey availability of the SRKW population's main food source, Chinook salmon. This makes it difficult for SRKW to sustain themselves and risk starvation (Muñoz et al., 2015; Ruff et al., 2017).

Vessel noise can cause a multitude of effects on SRKW, including hearing loss, interference with communication between members, and interfering with foraging due to vessel noise masking their calls and echolocation clicks. The extra energy exerted to avoid vessel noise leaves SRKW unable to perform other processes like hunting or travelling, affecting the amount of nutrients they obtain (Lusseau et al., 2009). Long term stress associated with this disturbance leads to hormonal and reproductive issues (New et al., 2015). The resulting effects of vessel noise can cause a domino effect when it comes to SRKW life processes; therefore, it is essential to reduce unnecessary underwater noise.

The Salish Sea

The Salish Sea is located on the west coast of British Columbia, Canada and Washington State, USA. The Salish Sea consists of waterways such as the Strait of Georgia, Juan de Fuca Strait, and Puget Sound. Ranging from Campbell River, British Columbia to Olympia, Washington State, the Salish Sea is high in marine biodiversity and is SRKW summer habitat (Barrie et al., 2014; Cominelli et al., 2018).

The coastlines and islands of the Salish Sea contain a human population of 7 million (Environmental Protection Agency, 2018). The high human population and rich resources of the Salish Sea have led to increased coastal development and activity in the area. The Salish Sea is dominated by both commercial and recreational vessels, fishing vessels, ferries, and whale watching vessels whose activity increases in the summer months, both coinciding and intentionally increasing with the Southern Resident Killer Whale's occupation (Cominelli et al., 2018). Many of the Salish Sea's channels are continually used as commercial shipping and ferry routes, boosting the local economy and accessibility for humans in the region. As of 2014, around 12 400 shipping vessels were present in the Salish Sea. Further, there were over 300 000 recreational vessels registered in the Salish Sea and over 50 ferries in operation (Gillespie, 2016; Friends of the San Juans, 2015) with Washington State ferries accounting for 170 000 transits in the Salish Sea alone (Washington State Department of Ecology, 2019). As of 2015, whale-watching in the Salish Sea was an industry worth approximately $40-50 million (San Juan Tourism Bureau, 2015; Seely, Osborne, Koski & Larson, 2017).

Because of the high human population in the Salish Sea, overlap occurs between the core areas of the SRKW pods (J, K, L) and human activities. As seen in Figure 3, L Pod's core area is located among the Southern Gulf Islands, which also hosts ferry, fishing, and recreational routes. Additionally, J Pod's core area is located in Haro Strait, which is an area that experiences high-intensity commercial traffic. K Pod's core area in Boundary Pass hosts high-intensity commercial traffic as well (Cominelli, 2018, p. 184).

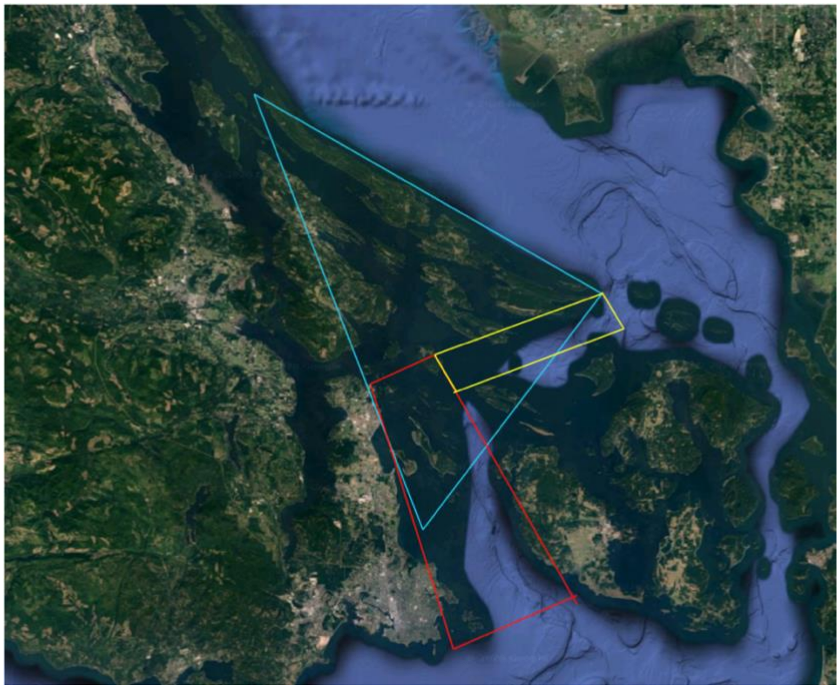

Figure 3. SRKW pod core areas in Salish Sea. The blue area represents the L Pod core area, the red area represents the J Pod core area, and the yellow area represents the K Pod core area. Image adapted from Google Maps (2020). Information adapted from “Noise exposure from commercial shipping for the Southern Resident killer whale population” by Cominelli et al., 2014.

Characteristics of Vessel Noise

How Noise Travels Underwater

Sound consists of longitudinal pressure waves that move through a medium, in this case ocean water. A sound’s frequency is the wave’s rate of oscillation, which consists of the number of cycles (sound vibrations) every second. Frequency is measured in Hertz (Hz) with 1 Hz=1 cycle per second. A decibel (dB) is a measure of the amplitude of a sound wave and is a unit that characterizes the intensity or level of sound (Clason, 2018).

Some characteristics of sound moving through the ocean are as follows: Spherical spreading in water occurs when energy from a sound source propagates equally in a spherical shape in all directions. Spherical spreading loss occurs because the energy intensity is reduced in proportion to the sphere's area. Cylindrical spreading occurs in shallow water where rather than sound moving as a spherical wave, it must move as a cylindrical wave between the ocean floor and the surface. Cylindrical spreading loss occurs uniformly in proportion to a cylindrical area (University of Rhode Island & Inner Space Center, 2018a).

Further, with combined spreading, a sound wave will move spherically near its source, but then at some point in its range, the wave will make contact with the ocean floor and turn into a cylindrical wave from then on. Combined spreading loss occurs both spherically and cylindrically, as noted above. A sound level is reduced due to multiple processes, including absorption loss, where the sound is reduced due to materials and characteristics in water. Further losses include the scattering of the sound waves off particles and bubbles, scattering at the ocean floor and surface, as well as loss to the ocean floor. Reverberation also affects sound propagation, as other sound waves echoing and scattering off surfaces from other sources can modify the sound waves (Erbe, 2011). For example, in the open ocean at a considerable distance from shipping lanes, high frequency noise from shipping vessels will be absorbed within 10 km (Erbe & Farmer, 2000). In the Salish Sea, noise concentrates due to the combined waterways' physical geographies. Additionally, SRKW can consistently be within 1-10 km of a ship, meaning that SRKW can be exposed to high noise levels (Veirs, Veirs & Wood, 2016).

Noise Characteristics of Vessels

Underwater vessel noise can originate from many different parts of a ship and vary in frequency. Vessel noise can come from engines and gears (low frequency), propeller cavitation (high and low frequency), hydrodynamic noise-consisting of the sound of water flowing past a vessel's hull (low frequency), and propeller singing (high and low frequency) (Veirs et al., 2016). The frequency of these overlaps with many forms of SRKW communication calls and echolocation clicks, is demonstrated in Table 1. Vessel noise frequencies overlapping with SRKW sensitivity and calls make it difficult for SRKW members to forage or hear and understand calls from other members (Veirs et al., 2016).

Table 1

SRKW communication frequencies compared to vessel noise frequencies

SRKW Communication	Frequency (Hz)	Vessel Noise	Frequency (Hz)
Auditory Sensitivity	600-100 000 (Heise et al., 2017)	Propeller Cavitation	50-100 000 (Ross & Kuperman, 1989)
Calls	100-6000 (Ford, 1987)	Propeller Singing	100-1000 (Richardson et al., 1995)
Echolocation click	50 000 (Au et al., 2004)	Engines/Gears	50 (Richardson et al., 1995)

Note. Information adapted from "Ship noise extends to frequencies used for echolocation by endangered killer whales," by Veirs, S., Veirs, V., & Wood, J. (2016).

Vessel noise increases with the speed, load, size, power, length, and distance of a vessel, as well as propeller number (Holt, 2008; Houghton et al., 2015). Further, machinery working onboard the vessel radiates sound through the hull (Holt, 2008). The type of engines on vessels also impact the noise produced as vessels with propellers will produce more sound than jet-propelled vessels. Alternatively, smaller propellers found on smaller vessels work at higher speeds, which creates higher frequency tones. (Holt, 2008; Erbe, 2011).

As noted previously, the size of a vessel influences the frequency that is emitted from the vessel. Larger vessels can emit noise at high frequencies as well as low frequencies (Cominelli et al., 2018; Dyndo et al., 2015), and low frequency noise from vessels is a major source of background or ambient noise in the ocean (Wenz, 1962). A study of Haro Strait revealed that shipping vessel noise increased background noise or ambient noise by 91 dB (Cominelli et al., 2018). For a frame of reference, 100 dB is characterized by a nearby train approaching or a car horn honking, from 5 m away (Centers for Disease Control and Prevention, 2019).

Additionally, different classes of vessels emit different levels of noise. Cominelli et al. (2018) measured the noise exposure experienced by SRKW by comparing the broadband source levels (the intensity of noise produced over a range of frequencies at a distance of one metre from a source (University of Rhode Island & Inner Space Center, 2018b)) of underwater noise originating from a variety of vessels in the Salish Sea. This was done through combining the broadband source levels with the total sound energy from vessels over certain time periods (O'Neill et al., 2017). To verify source levels that were determined by the cumulative noise model, hydrophones were used to measure sound levels. The vessels that had the highest broadband source levels in the Salish Sea were container ships further than and within 200m of the hydrophones, which produced 178.6 dB re 1 μPa (dB re 1 μPa is the sound pressure level at one micropascal). In contrast, smaller vessels like recreational vessels had lower broadband source levels, producing 144.3 dB re 1 μPa (Cominelli et al., 2018, p. 182).

Noise levels from vessels in the Salish Sea are highest near the Port of Vancouver and Port of Seattle (Erbe, Macgillivray & Williams, 2012). This is due to vessel noise concentrating in coastal areas because the ports host many active vessels in the area (Holt et al., 2009). Additionally, these high frequency noise areas often overlap with SRKW critical habitat (Erbe et al., 2012). In terms of diurnal variation in vessel noise in the Salish Sea, the sound pressure levels produced by vessels are higher during the day, both in summer and winter seasons. Additionally, background noise levels are higher in summer months (maximum 117.5 dB) compared to winter months (<115.5 dB) (Veirs & Veirs, 2005).

Commercial Shipping Vessel Noise

Commercial shipping vessel noise ranges from 20-200 Hz, which is considered low frequency as it is less than 1000 Hz. These low frequencies are due to shipping vessels being high in power, with slower turning propellers and engines (Richardson et al., 1995). In SRKW core areas, ferries, vehicle carriers, large commercial shipping vessels, and tugboats create the greatest levels of sound exposure (Cominelli et al., 2018). These classes of vessels make up the majority of sound energy input in the Salish Sea with container ships being the loudest, producing 178 dB of sound (MacGillivray et al., 2017; Veirs et al., 2016). Further, the average source level of all shipping vessels passing through Haro Straight combined was found in a study by Veirs et al. (2016) to be 173 dB ± 7 dB re 1 μPa @ 1m. The average speed of these vessels was 14.4± 3.9 kn and an increase of each knot correlated to an increase of 0.93 dB.

Shipping vessel noise contributes to background noise levels, creating chronic ocean noise, defined as long term ongoing noise that is low in intensity and frequency (Williams, Clark, Ponirakis & Ashe, 2014). Due to these characteristics of shipping vessel noise, it can travel hundreds of kilometres in the ocean (Joy et al., 2019). The mean background noise level in the Salish Sea is estimated to be 91 ± 4 dB, with shipping vessels elevating background noise levels at low frequencies (20-30 dB at 100-1000 Hz). Additionally, shipping vessels can increase background noise levels at higher frequencies (5-13 dB at 10000-40000 Hz) (Veirs et al., 2016) as some shipping vessel noise can extend to frequencies as high as 100 000 Hz (Wenz, 1962). Further, as shipping vessels move closer in range (less than 1000m), noise levels increase from 1000 to 6000 Hz, which can rise further with the addition of faster ship speeds (Arveson & Vendittis, 2000).

When these shipping vessels are in proximity to coastlines, the sound that is emitted at higher frequencies does not get fully absorbed like it would in the open ocean, and therefore can overlap and mask SRKW calls and echolocation, as it occurs in the same frequencies (Wenz, 1962). This masking, in turn, affects SRKW their foraging and social behaviour (Cominelli et al., 2018).

Whale Watching Vessel Noise

The current boom in the whale watching industry has led to whale watching vessels becoming a near-constant presence in the Salish Sea. The current boom also means that whale watching vessels have become frequent noise producers in SRKW habitat. This situation intensifies during the summer when tourism is at its peak (Holt et al., 2011).

Certain practices carried out by whale watching boat operators to get a better view of killer whale pods increases the noise levels produced by their vessels. When a vessel speeds up, the noise produced becomes higher in intensity and frequency (Bain & Dahlheim, 1994). The practice of leapfrogging, where a vessel speeds up and places itself in the predicted path of whales for a better view, is often carried out by whale watching and recreational vessels. In a leapfrogging study by Williams et al. (2002) in NRKW habitat in Johnstone Strait, BC, when a vessel increased its speed, the engine noise increased by 14 dB. This meant that the vessel would have needed to be 500m away from a NRKW pod at that speed to produce the same sound level as a slow moving vessel moving 100m away from the whales.

Whale watching duration during the summer can last up to 12 hours in length (9a.m.-9p.m.), meaning that practices like leapfrogging or the mere presence of vessels operating and producing noise near the SRKW pods can be constant (Lusseau et al., 2009). A study by Foote et al. (2004) found that whale watching vessel noise increased background noise. This increase in background noise and masked SRKW calls, causing the members to change and increase the length of their calls to compensate. Changes to their calls included altering the frequency, the repetition rate, and duration. In addition to specific practices, characteristics like the size of whale watching vessels affect SRKW specifically. Sizes of whale watching vessels vary, ranging from small speedboats or zodiacs to large yacht-like vessels. The larger engine vessels will create more noise than smaller engine vessels when moving about in the water (Erbe, 2002).

Effects of Vessel Noise on Southern Resident Killer Whales

Affected Social Behaviour

Vessel noise interferes with SRKW social communication in multiple ways, such as through a reduction in communication space. The communication space of SRKW is the predicted area where killer whale communication can occur (where killer whale signals can be perceived by another killer whale). This space can extend approximately 15 km to 26 km (Miller, 2006). Under increased underwater noise conditions, the SRKW communication space is reduced by 62% (Williams, Clark, Ponirakis & Ashe, 2014). Further, vessel engine noise can affect killer whale detection of pure tones and low frequency calls from other whales (Bain & Dahlheim, 1994). Additionally, masking can occur when anthropogenic noise overlaps or drowns out marine mammal communication (sounds or calls). Masking can occur at considerable distances, for example, a fast-moving vessel could mask SRKW calls within 14 km (Erbe, 2002).

Foote et al. (2004) found that in the presence of background noise from vessels in their proximity, SRKW significantly increased the duration of their calls to compensate for increased noise levels. Alternatively, Holt et al. (2009) found that SRKW did not increase their call duration and attributed this difference to the fact that their own study didn't measure baseline conditions when there wasn't any vessel noise. Williams, Clark, Ponirakis & Ashe (2014) found that killer whales lengthened their calls and increased the source level of their social calls when noise levels in their habitat were raised. A study by Holt et al. (2009) found that a 1 dB background noise level increase corresponded with a whale call source level increase of 1 dB. Noise from vessels also interferes with SRKW echolocation clicks, affecting navigation and foraging (Veirs et al., 2016). A comparison of research of both Bain (2002) and Au et al. (2004) by Lusseau et al. (2009) found that though there was vessel noise, whales could detect prey that was in their path.

Further, surface-active behaviour like tail slaps, fin slaps, and jumps used for SRKW auditory and visual communication increase in the presence of vessels (Ford, Ellis & Balcomb, 2000). Noren et al. (2009) observed that surface-active behaviours occurred in SRKW up to two minutes after a vessel was at its closest. Additionally, 70% of the recorded surface-active behaviours occurred when a vessel as within 224m of a whale. The highest number of surface-active behaviours occurred when the vessel was between 75-99m from a SRKW (Noren et al., 2009). More surface-active behaviours were recorded in the study when the vessel was moving compared to when the vessel was stationary. Alternatively, a model created by Williams et al. (2009) found that surface-active behaviours were highest when no vessels were present but increased when multiple vessels were within 400m. Though Williams et al. (2009) theorized that this could be attributed to the configuration of vessels when studied and that the surface-active behaviours were used as threat displays by SRKW.

Affected Feeding Behaviour

When vessel traffic increases in the Salish Sea, SRKW spend less time foraging and more time travelling. This means that they are potentially consuming less prey in order to travel (Lusseau et al., 2009). Additionally, a study by Bain et al. (2006) found that SRKW experienced decreased foraging time and increased travelling time when vessels were within 100-400m. SRKW were also more likely to spend more time foraging when vessels weren't present. Further, as stated previously, it is theorized that vessel noise affected SRKW echolocation and made it difficult to find prey (Lusseau et al., 2009).

Avoidance Behaviour

Resident killer whales have been observed carrying out various avoidance measures when they are approached by vessels (Williams & Ashe, 2007). Avoidance measures are defined as a change of distance, trajectory, and angle in a SRKW path to distance themselves from vessels. In terms of the practice of leapfrogging, Williams & Ashe (2007) found that NRKW would deviate from their predicted path when a vessel approached. Further, the closer that approximately one to three vessels approached NRKW, the more the whales increased their distance from the vessels, decreasing path directness. Yet, when four to seventeen vessels approached the whales, the whales increased path directness. This led Williams and Ashe (2007) to hypothesize that NRKW had found a tactic to avoid a small number of vessels. In contrast, NRKW would abandon this tactic when more vessels approached them as there would be nowhere else to go but forward on their paths.

Williams et al. (2009) found that killer whales had smoother paths when a small number of vessels were close but had more variable paths when more vessels appeared. Further, when there were a small number of vessels approaching SRKW within 400m, their dives became shorter, but dives became longer when the number of vessels increased. Additionally, it was found that when in the presence of vessels within 1000m, whales took less direct paths and the time between breaths increased compared to when vessels weren't present (Bain et al., 2006).

Williams et al. (2002) discovered that as the whales' surface patterns became more variable when a vessel was within 100m parallel to them. Further, as the whales' mean directness index shifted from 94.1 to 80.5, it would cause a 17% increase in distance that the whale would need to swim to cover a straight distance of 100m. This used up energy and prevented the gain of energy later on as rest and feeding times may have been shortened to make up for less travelling time.

Energy Expenditure

The impacts of behavioural responses to vessel noise and the masking of communication on SRKW energy can be severe. Through avoiding vessels by taking less direct paths, SRKW displace themselves, essentially pushing themselves away from their preferred foraging routes. This prevents them from achieving optimal prey consumption and producing enough energy to carry out life processes (Lusseau et al., 2009). Additionally, Williams, Lusseau & Hammond (2006) theorized that though the energetic costs of behavioural responses may be minor to many killer whales, female whales with calves could experience greater negative effects. This is due to the extra energy used for lactation and caring for their offspring. With vessels approaching SRKW throughout the day and SRKW continuing to use these tactics, they could lose a large amount of their energy as they spent more energy avoiding vessels instead of foraging for food. Additionally, New et al. (2015) found that whales could experience the effects of long term stress due to constant disturbance along with the need to adjust their actions, leading to hormonal effects like limiting growth and reproduction, and weaker immune systems.

Hearing Loss

Temporary hearing loss, also known as a temporary threshold shift, can occur when the inner ear hair cells have been fatigued and can eventually recover. Threshold shifts can vary with sound exposure with characteristics such as amplitude, frequency, duration and energy of a sound (Holt, 2008). For example, if a killer whale spends 30-50 minutes within 450m of a zodiac style whale watching vessel travelling at a speed of 51 km/hr, they could experience a temporary threshold shift of 5dB (Erbe, 2002). Further, with constant noise exposure, a temporary threshold shift could transform into a permanent threshold shift (Southall et al., 2007).

Permanent hearing loss, also known as a permanent threshold shift, occurs when the inner ear hair cells are permanently damaged or dead (Holt, 2008). It is important to note that permanent hearing loss hasn't been recorded in marine mammals (Southall et al., 2007). Though the Salish Sea hosts many vessels during the summer period that coincide with SRKW presence, so a permanent threshold shift could be a possibility.

Habitat Impacts

There are noteworthy impacts of having vessel noise in SRKW habitat areas. Short term avoidance by killer whales of their habitat could lead to permanent abandonment (Williams, Lusseau & Hammond, 2006). This abandonment means that these killer whales would need to find another habitat to forage, rest, and perform other life processes. Additionally, Morton & Symonds (2002) found that underwater acoustic harassment devices used to deter Resident killer whales from salmon farms caused the Residents to abandon the entirety of their historic range due to the habitat degradation in the area. Alternatively, Williams et al. (2009) discovered that SRKW persisted in areas where vessels were present rather than abandoning the area.

Discussion of Literature

After reviewing the literature presented on the topic of the SRKW population and the effects of marine vessel noise, there are certain strengths and weaknesses regarding the capacity to assess the effects of sound on the SRKW population. It is difficult to measure any killer whale population due to expenses and limitations of science, technology, staffing, and permission to perform certain experiments-this is a limitation for many studies in general. For example, New et al. (2015) noted that expenses were a main barrier to their research.

The small size of the SRKW population and small sample sizes used for studies like Williams et al. (2002) can make it difficult for researchers to determine if a behaviour is a common behaviour of the population or if the behaviour is attributed to chance. This behaviour could be interpreted to be population-wide, and lead to inferences leading research on a path that would not fully represent the behaviour exhibited by the SRKW.

There could also be limitations of some studies' data collection, such as the equipment used to measure high frequency background noise in Joy et al. (2019). In this study, there was a considerable distance between the vessels and the hydrophone recording the high frequency sound. This distance could cause a reduction in high frequency sound being received by the hydrophone, which means that there is a possibility that the high frequency sound may be affecting SRKW at levels that the hydrophone couldn't detect, limiting the study's findings.

With regards to observations, Cominelli et al. (2018) utilised opportunistic platforms like whale watching vessels and private vessels along with sightings from the Soundwatch Boaters Education Program and the Southern Resident Sighting Compilation by the Whale Museum for their data. Observational data from non-experts comes with risks because there could be a chance of misinterpreting behaviours, leading to the collection of misinformation. Though Cominelli et al. (2018) stated that their observational data compared with the British Columbia Cetacean Sightings Network's 6000 sightings, which strengthened the data that the study had collected. Another weakness could be that some organizations like the Soundwatch Boaters Education

Program records only in US waters and therefore can't provide information on SRKW in Canadian waters to the same extent.

It is difficult for studies to properly monitor killer whale behaviour because observations can only occur above the water when the whales surface to breathe. For example, Holt et al. (2008) found that accurately identifying behavioural states was important but the view of the researchers from their respective positions either from land or on a vessel, could skew the data they had collected. The study also noted that it could be difficult to obtain a baseline study of SRKW behaviour in a setting completely void of vessels. This is because when SRKW are in the Salish Sea, it is peak tourist season and SRKW are often in proximity to shipping channels. Further, Williams et al. (2007) noted the difficulty of measuring the effects of vessel traffic on SRKW behaviour because of the number of vessels interfering with the reference site of the study. This interference could lead to smaller data pools or less research included to be analyzed, leading to conclusions that don't accurately represent the situation.

Discussion of SRKW Regulations

The current regulations established for the protection and safety of the SRKW population contain initiatives to aid in the recovery of the SRKW population. There are regulations from both the US and Canada. Many establish approach distances, speed reductions, critical habitat areas, as well as fines for noncompliance. A listing of current legislation and regulations is found in Table A1 in Appendix 1.

Comparing Canada's and the United States' main pieces of legislation, there is a difference in the type of legislation pertaining to SRKW. Primarily, Canada's main pieces of legislation like the Species at Risk Act, the Whales Initiative, and the Oceans Protection Plan were all created and carried out by the Government of Canada. Alternatively, Washington State has created multiple pieces of legislation and regulations like the Southern Resident Killer Whale Executive Order and Task Force in addition to federal legislation like the Endangered Species Act. There are positive and negative aspects of having state regulations in addition to federal regulations. A positive aspect is that a state can increase measures if they feel that the federal government isn't doing enough to protect SRKW. A negative aspect is that by having multiple federal and state regulations and legislation, it could make it difficult for the public to understand specific laws or guidelines due to the amount of changing legislation.

The lack of an intensive transboundary regulations or legislation between Canada and the US is a downfall in terms of SRKW legislation. The waters of the Salish Sea are present in both Canada and the US and SRKW spend time within the borders of each country. There should be a legally-binding transboundary agreement specifically for SRKW that is similar in structure to the Great Lakes Water Quality Agreement (Climate Change Canada, 2020).

Some studies reviewed found that certain aspects of the regulations created for the SRKW population weren't living up to expectations. Williams et al. (2014) found that the noise levels they recorded for their study were at their highest within the frequencies that killer whales were using for social communication in their critical habitat areas. These critical habitat areas are specifically designated to protect the species from disturbances like high noise levels, yet they are still being degraded. The precautionary principle has also been used regarding noise levels, but this can either unnecessarily limit industries or may not be properly addressing the SRKW pressures. The problem with limiting industries is that if it turns out that an industry is being unnecessarily limited, they may be less likely to comply with rules or fight against them and then SRKW still suffer.

A large problem with legislation is that it has made some regulations voluntary with no legal obligations for boaters to abide by in terms of speed or distance, which reduces their effectiveness (Government of Canada, 2019). An article by Giles & Koski (2012) noted that a study found that vessels were constantly out of compliance with the voluntary guidelines put in place regarding SRKW in the United States. Additionally, the response to regulations put in place to limit impacts to the SRKW were met with reluctance as it was perceived that there would be negative economic impacts to the whale watching industry.

Further, Lusseau et al. (2009) found that the probability of SRKW to continue foraging was significantly less when vessels were between 100m and 400m. This is important as the boundaries that legislation like the Marine Mammal Regulations have set, regulate a 400m protection zone in SRKW critical habitat areas but a 200m protection zone for all killer whales outside of critical habitat areas. Meaning that vessels like whale watching vessels can spend long periods of time within 400m of SRKW outside of critical habitat areas. Further, though the effects of the vessels outside of 400m were smaller than within 100m, behaviour was similar to what it was when vessels were within 100m (travelling instead of foraging). Therefore with the 400m boundaries, it reduces the effects of vessels but doesn't eliminate them. The study used a 400m boundary between the research vessels and the killer whales and still found a behavioural change. This reveals that the legislation mandated barriers aren't doing enough to protect the whales from vessel noise.

If vessels were to abide by these regulations, with a decrease in vessel traffic around SRKW, this could reduce masking SRKW communication, which would therefore increase foraging and echolocation (Bain & Dahlheim, 1994). This finding was supported by Williams et al. (2002) as the study showed that vessel noise decreased at further distances and the paper suggested that boaters shouldn't operate their engines at full speed when within 500m of killer whales as vessel speed made a big difference to noise levels. Therefore, the legislation regarding barriers can be effective, though it depends on whether or not they are followed by society.

With regards to enforcement of some regulations, a study by Lachmuth (2008) found that enforcement was limited but noted that commercial and recreational whale watchers had been charged under the "Marine Mammal Regulations of the Fisheries Act". The paper noted that recreational whale watchers usually didn’t know of the guidelines set in place and therefore it’s common for violations to occur.

Recommendations

Based on the examination and analysis of literature pertaining to the effects of marine traffic noise on the SRKW population along with the current regulations related to SRKW, there are a number of recommendations that can add to and strengthen the current regulations and legislation on marine traffic and SRKW:

1. Education and awareness are the most important factors to be considered and expanded regarding the SRKW regulations that are currently in effect. Education campaigns should be carried out by the federal government as it would reach a larger proportion of society than if a private whale watching company were to educate their customers. Education can shift societal values as well as support existing and future legislation. If society doesn't understand or value the importance of protecting killer whales then regulations aren't created. Widespread awareness campaigns on the impacts of vessel noise on SRKW through public channels like social media could be a way to go about this. Further, making critical habitat zones and approach distances for SRKW a major part of

recreational pleasure craft or boating license exams would introduce the issue to many recreational boaters in the Salish Sea (S.B. 5918, 2019).

2. Clear communication regarding SRKW regulations between researchers, policy-makers, and the public must be understandable; without this, there is no way that effective action can be taken. If there's tension or confusion between different actors regarding an environmental issue, they are less likely to work together to come to a solution. This can be done through having clear channels between government researchers and policy makers and aided through the creation of a universal and accessible international database of sightings and critical habitat zones (Williams, Ashe, Blight, Jasny, Nowlan, 2014).
3. Create one widespread and intensive piece of legislation that pertains specifically to SRKW. Canada has SARA, the Fisheries Act, and Canada Shipping Act that apply to SRKW. Combining the aspects of these pieces of legislation that pertain to SRKW into one piece of legislation could make it easier to mitigate and manage operations involved with SRKW and marine traffic (Williams, Ashe, Blight, Jasny, Nowlan, 2014).
4. Enforce changes to shipping routes to completely avoid critical habitat areas set out by the DFO in the summer during SRKW. This would help to mitigate noise in these areas (Cominelli et al., 2018).
5. Voluntary measures such as shutting off engines within a certain distance of killer whales, and speed reductions, should become obligatory with consequences such as fines to enforce noise reduction in SRKW zones.

Conclusion:

The SRKW population has been affected by a number of anthropogenic pressures that have impaired their health and population numbers, with an important factor being vessel noise from the growing Salish Sea human population. Vessel noise can come from physical properties of a vessel such as length, load, or propeller characteristics, as well as from speed and distance to SRKW. Vessel noise affects SRKW behaviour as it can mask SRKW calls and echolocation clicks that are used for both social communication and foraging. In response SRKW will alter their calls to continue communicating or stop communication or foraging behaviours, when vessels approach. Further, when vessels decrease their distance to SRKW, the whales will mainly engage in avoidance behaviour to distance themselves from the vessels. These affected behaviours due to vessel noise can deplete SRKW energy and can make it difficult to carry out tasks, like foraging and travelling, later on. Vessel noise can physically impact SRKW as they can lose their hearing abilities both temporarily and permanently. Whale watching practices such as leapfrogging can create noise that affects SRKW communication. Additionally, shipping vessels significantly increase background noise and can affect SRKW calls and echolocation.

There is much legislation in both Canada and the United States that addresses many different aspects of vessel noise and SRKW. Conservation measures including vessel slowdowns and critical habitat zones have been established, though some of these are voluntary and therefore are limited in their effectiveness. Because SRKW travel between the two countries, a transboundary agreement between the US and Canada is needed. As human development in the Salish Sea continues to grow, resulting in increased vessels moving about in SRKW habitat, it is important to understand how exactly vessel noise is affecting the SRKW as their small population continues to reside there. Further, by understanding the effects of vessel noise, regulating bodies can improve legislation that can decrease the negative effects on SRKW moving forward.

Summary of Main Points:

- The Southern Resident Killer Whale population is impacted by vessel noise.
  - Vessel noise can affect the social behaviour of SRKW pods as it reduces the communication space of SRKW and masks SRKW calls. It can also disrupt echolocation and navigation, making it difficult for SRKW to forage for food. Vessel noise also affects SRKW hearing and detection of calls from other whales and SRKW will alter their calls to accommodate for increased noise levels.
  - In the presence of vessels and vessel noise, SRKW switch to travelling behaviours, reducing the time spent foraging or resting. Avoidance behaviour is exhibited when vessels approach SRKW, which reduces SRKW energy and affects future actions of SRKW. If underwater noise is significant enough, SRKW can permanently abandon their habitat.
  - SRKW can both temporarily and permanently lose their hearing due to noise levels of vessels.
  - Vessel noise comes from many parts of a ship including engines, the interaction between the water and the hull, cavitation from propellers, and propeller singing. Noise increases with the speed, size, length, power, and load of the vessel. Further, distance of vessels to a whale affects the level of vessel noise.
  - Whale watching practices to view SRKW such as leapfrogging can increase noise levels near SRKW pods, masking SRKW communication. This can cause SRKW to alter their calls like changing the frequency and duration in order to communicate.

    - Shipping vessel noise contributes to background noise levels, is relatively low frequency, and is another main source of noise in the Salish Sea. This masks SRKW communication calls and echolocation making it difficult to forage and socialize.
- Though SRKW regulations exist and address many issues of vessel noise and presence experienced by SRKW, there can be improvements to optimize the existing legislation to better benefit the SRKW. Improvements include:
    - Education campaigns.
    - The creation of an international database to facilitate clear communication between SRKW researchers, policy-makers, and the public.
    - The creation of one universal SRKW legislation to better manage SRKW issues.
    - Change shipping routes in the summer to reduce noise near SRKW critical habitat areas.
    - Make voluntary measures like vessel slowdowns obligatory.

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Appendix 1: Legislation

Table A 1

Pieces of legislation pertaining to SRKW and marine traffic from Canada and the United States

Name of Legislation	Jurisdiction	Creator	Purpose of Legislation	Relation to SRKW
Oceans Protection Plan	Canada-Federal	Transport Canada, 2016	A Canada-wide plan created to protect the country's coastal and water environments of waterways that host marine shipping. Violation penalties will correspond with those of SARA and MMR.	Voluntary marine vessel noise reduction measures. The creation of the Coastal Restoration Fund in the Salish Sea, which includes aiding salmon population migration, allocating funding to the 'whale alert system' to reduce ship strikes, and to research projects focused on marine vessel noise impacts on SRKW. Displacement trials in the Juan de Fuca Strait moving shipping traffic away from SRKW critical habitats to reduce marine vessel noise, as well as creating research projects focusing on the health of SRKW populations relating to prey availability and underwater noise. (Government of Canada, 2019)
Whales Initiative	Canada-Federal	Transport Canada 2018	A branch of the Oceans Protection Plan, A $167.4 million, 5 year initiative focusing on the SRKW population's recovery through addressing the major threats to the population including: increasing the availability of prey, decreasing marine vessel noise, increasing surveillance of the population in the sky and sea, developing better education, and enforcement	SRKW foraging areas are to be protected, a minimum 200m approach distance around all West Coast whales for all boats, vessel slowdowns in Haro Strait, hydrophones placed in SRKW critical habitat to measure underwater marine vessel noise, and capital investment directed toward more fishery officers engaging in SRKW-specific education and enforcement measures. (Government of Canada, 2018)

			techniques. Violation penalties will correspond with those of SARA and MMR.	
Species At Risk Act Action Plan- Recovery Strategy for the Northern and Southern Resident Killer Whales (Orcinus orca) in Canada	Canada-Federal	Fisheries and Oceans Canada 2017	The strategy aims to recover and protect Northern and Southern Resident Killer Whale populations by maintaining their ideal ecosystem conditions that allow for long-term species' survival and success. For indictable offenses. Corporations that violate the Act face fines of up to $1 million, non-profit corporations face fines of up to $250 000, and anyone else faces a fine of up to $250 000 and/or up to five years imprisonment. For summary offenses, corporations face a fine of up to $300 000, non-profit corporations face up to $50 000, anyone else faces up to $50 000 and/or up to one year imprisonment.	Monitor population characteristics of SRKW through annual censuses, research and understand SRKW foraging areas and prey availability to discern prey abundance, as well as monitor how anthropogenic activities impact SRKW recovery. Ensure that biological and chemical pollutants aren't affecting SRKW recovery as well as the protection of critical habitat areas of the SRKW population. (Fisheries and Oceans Canada, 2017; Legislative Services Branch, 2020a)
Canada Shipping Act- Interim Order for the Protection of Killer Whales (Orcinus orca) in the Waters of Southern	Canada-Federal	Transport Canada June 1,2019-October 31, 2019	Enforces a 400m protection zone for all killer whales in SRKW habitat for all vessels. Exceptions to this order include: working Canadian government employees and peace officers, those acting under authorized disturbance section (38(1)) of the Marine Mammal Regulations as well as the Species at Risk Act, people fishing for educational, scientific, and	

British Columbia			experimental purposes, and authorized commercial whale watching. Sanctuary zones of SRKW critical habitats have been established where vessel traffic is prohibited with certain exceptions similar to those stated above, excluding commercial whale watching vessels. Violations include penalties of up to $250 000, or a fine of up to $1 million and/or up to 18 months' imprisonment. (Transport Canada, 2019)	
Marine Mammal Regulations- The Fisheries Act	Canada-Federal	Department of Fisheries and Oceans Updated 2019	Protects marine mammals and regulates their interactions with humans in Canadian oceans. Penalties include a fine of up to $100 000 and/or imprisonment of up to one year, indictable offenses include penalties of up to $500 000 and/or up to two years imprisonment.	Regulates a 400m protection zone around all killer whales in SRKW critical habitat areas from June 1-October 31 as well as a 200m protection zone for all killer whales in the Pacific Ocean. (Legislative Services Branch, 2020b; Legislative Services Branch, 2020c)
2019 Management Measures to Protect Southern Resident Killer Whales	Canada-Federal	Fisheries and Oceans Canada 2019	Measures implemented within and around Canadian SRKW areas. Includes voluntary measures: turning off eco-sounders, leaving engines off or idling when in distance of a killer whale, fishery avoidance zones within 1000m of killer whales, as well as 'go slow zones' when vessels should go up to 7 knots within 1000m of killer	The recommendations can help reduce vessel traffic and noise when in SRKW habitat which can help SRKW forage for food. (Fisheries and Oceans Canada Communications Branch, 2020)

			whales. Sanctuary Zones prohibit general traffic from June 1-October 31 in critical habitat areas.	
Marine Mammal Protection Act	USA-Federal	US Fish and Wildlife Service, NOAA Fisheries & the Marine Mammal Commission	Prohibits the collection of marine mammals, as well as interactions such as harassment or killing. Protects marine mammal populations from being depleted to the point where they are unable to participate and contribute to their specific ecosystems.	Killer whales are protected under the MMPA. (NOAA Fisheries, n.d.; NOAA's National Marine Fisheries Service, 2019)
Endangered Species Act	USA-Federal	NOAA Fisheries & US Fish and Wildlife Service	Assigns and protects *threatened* and *endangered species* as well as critical habitat areas to preserve the natural environment and its ecosystems. Penalties include up to a $50 000 and/or imprisoned up to one year.	SRKW are classified as an *endangered species*. (NOAA Fisheries, n.d.; U.S. Fish and Wildlife Service/Endangered Species Program, 2020)
The Southern Resident Killer Whale Executive Order and Task Force	USA-Washington State	Washington State Governor Jay Inslee, Washington Department of Fish and Wildlife	Identification of SRKW areas of prey availability, increase enforcement and education regarding vessel regulations of the public as well as the whale watching industry, and reduce ferry vessel noise in SRKW area critical habitats. (Inslee, 2019)	
RCW 77.15.740-Protection of southern resident orca whales-Unlawful	USA-Washington State	Washington State Legislature	Vessels must keep a 300 yard distance around as well as 400 yard distance in front of or behind a SRKW. A vessel must stay below 7 knots within one half of a nautical mile of a SRKW. Persons exempted of these activities include	

activities-penalty			government workers carrying out official duties relating to enforcement or safety, vessels working with the vessel traffic service including tugboats accompanying shipping vessels into traffic lanes. Vessels conducting scientific research, treaty Indian/commercial fisheries working with their fishing gear. Fine of $500 for violating this act. (S.B. 77.15.740, 2019)	
Engrossed Substitute House Bill 1578-Approved	USA-Washington State	Washington State Legislature	Requires barges containing oil to have tugboats to accompany them through Rosario Strait in Puget Sound.	Lowers the risk of oil spills in Rosario Strait, a frequented area of SRKW. (E.S.H.B. 1578, 2019)
Senate Bill 5918-Approved	USA-Washington State	Washington State Legislature	Updates the boater safety education program to include whale watching guidelines which will make it a mandatory learning objective to obtain a boater education card.	Increasing public knowledge on boating rules and restrictions regarding SRKW and their habitats in their area, protective measures are more likely to be followed. (S.B. 5918, 2019)

Note. All sources of information are included within the table.

Glossary

List of Abbreviations

Term	Abbreviation	Definition
British Columbia	BC	
Department of Fisheries and Oceans	DFO	
Dichloro-Diphenyl-Trichloroethane	DDTs	
Hexachlorobenzene	HCBs	
Marine Mammal Protection Act	MMPA	
Marine Mammal Regulations	MMR	
National Oceanic and Atmospheric Administration	NOAA	
Non-Governmental Organization	NGO	
Northern Resident Killer Whale(s)	NRKW	
Persistent Organic Pollutants	POPs	
Polychlorinated Biphenyls	PCBs	
Revised Code of Washington	RCW	
Southern Resident Killer Whale(s)	SRKW	
Species at Risk Act	SARA	
United States of America	USA	
	dB re 1 μPa	The sound pressure level at one micropascal

List of Definitions

Term	Abbreviation	Definition
Absorption Loss		When sound energy is reduced to another form due to factors in its material medium (ITS, 1996).
Affect(ing)		The act of making a change or difference to something (Lexico, n.d.a)
Auditory Sensitivity		The arrange of frequencies that SRKW have the ability to perceive (Erbe, 2011).
Broadband Source Levels		The intensity of noise produced over a range of frequencies at a distance of one metre from a source (University of Rhode Island & Inner Space Center, 2018b).
Combined Spreading		Occurs when a sound wave moves spherically when its near its source and once it makes contact with a material, will move cylindrically (Erbe, 2011).
Combined Spreading Loss		Spreading loss that occurs both spherically and cylindrically (Erbe, 2011).

Cumulative Noise Model		A model that combines broadband source levels with the total sound energy from vessels over certain time periods (O'Neill et al., 2017).
Cylindrical Spreading		When energy from a sound source propagates as a cylindrical wave through a medium (University of Rhode Island & Inner Space Center, 2018a).
Cylindrical Spreading Loss		Occurs when the energy intensity of a sound source is reduced uniformly in proportion to a cylindrical area (University of Rhode Island & Inner Space Center, 2018a).
Decibel	dB	Measures the amplitude of a sound wave, characterizes the intensity of a sound (Clason, 2018)
Effect(ing)		The result of a change or difference to something (Lexico, n.d.b).
Hertz	Hz	Measures the frequency of a sound wave, the number of sound vibrations/second (Clason, 2018).
Hydrodynamic Noise		Noise created from water flowing past a vessel's hull (Veirs et al., 2016).
Kilohertz	kHz	Equivalent to 1000 Hz.
Knot	kn	One nautical mile per hour. A measure of speed.
Propeller Cavitation		The formation of air bubbles on a vessel propeller.
Propeller Singing		The reverberation of a propeller blades at vortex shedding frequencies (Veirs et al., 2016).
Reverberation		When sound waves echo, scatter, and reflect off surfaces in a medium (Erbe, 2011).
Sound Pressure		"The difference between the actual pressure at any point in the field of a sound wave at any instant and the average pressure at that point" (Sound Pressure, n.d.)
Spherical Spreading		When energy from a sound source propagates equally in a spherical shape in all directions (University of Rhode Island & Inner Space Center, 2018a).
Spherical Spreading Loss		Occurs when the energy intensity of a sound source is reduced uniformly in proportion to a sphere's area (University of Rhode Island & Inner Space Center, 2018a).

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