UNIVERSITY OF CALGARY

Evaluation of Cumulative Environmental Effects on the Endangered Southern Resident Killer Whales

by

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Abstract

With only 74 members left, the Southern Resident Killer Whales (SRKW) of the Salish Sea, are endangered under the Canadian Species at Risk Act (DFO, 2018) and the United States Endangered Species Act (US EPA, 2017). The Trans Mountain Expansion Project became a nationwide topic when the Project approval was overturned by the Federal Court of Appeal in August 2018, who cited lack of review of the predicted noise increase and its subsequent effects on the SRKW. This research study identifies the threats affecting the SRKW, assesses marine vessels that impose a cumulative noise effect, and suggests mitigation methods to manage traffic and minimize adverse effects on the SRKW. By corresponding with industry professionals, reviewing published literature and analysing case studies, it was concluded that no matter how small an increase of marine traffic in the SRKW critical habitat, it is significant considering the vulnerable state of the SRKW population.

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List of Abbreviations

AIS	Automatic Identification System
bpd	Barrels per day
BC	British Columbia
CEA	Cumulative Effects Assessment
dB	Decibels
DFO	Department of Fisheries and Oceans Canada
ECHO	Enhancing Cetacean Habitat and Observation (Canada)
EIA	Environmental Impact Assessment
NASP	National Aerial Surveillance Program (Canada)
NEB	National Energy Board (Canada)
NITS	Noise induced threshold shift
NOAA	National Oceanic and Atmospheric Administration (US)
NMFS	National Marine Fisheries Service
NRKW	Northern Resident Killer Whale
NWTT	Northwest Training and Testing (US)
PCB	Polychlorinated biphenyl
PTS	Permanent threshold shift
RBT2	Robert Banks Terminal 2
SARA	Species at Risk Act (Canada)
SRKW	Southern Resident Killer Whales
TEU	Twenty-foot equivalent unit
TMP	Trans Mountain Pipeline
TMX	Trans Mountain Expansion Project
TWG	Technical Working Groups
TWM	The Whale Museum (US)

TTS	Temporary threshold shift
VEC	Valued Ecological/Environmental Component
VTOSS	Vessel Traffic Operational Support System
WDFW	Washington Department of Fish and Wildlife
WSDOT	Washington State Department of Transportation

Chapter 1: Introduction

1.1 Background

In August of 2018, the Canadian Federal Court of Appeal overturned the decision made by the National Energy Board (NEB) to expand the Trans Mountain pipeline (TMP) (Government of Canada, 2019b). This was due, in part, to the lack of information collected regarding the Southern Resident Killer Whale (SRKW), *Orcinus orca*, population and the potentially significant adverse impacts from the project. The SRKW population has been said to be the Achilles heel of the Trans Mountain Expansion Project (TMX), as media consistently portrays the energy project as being a major threat to the already declining population (Ghoussoub, 2018). According to the Department of Fisheries and Oceans Canada (DFO), the SRKW species is endangered and is therefore protected under the Canadian Species at Risk Act (SARA) (DFO, 2018) and the United States Endangered Species Act (U.S. ESA) (U.S. Environmental Protection Agency, 2017). In 2018, their numbers had dwindled down to a mere 74 members in total (NOAA, 2018). On January 14, 2019, the population welcomed a newborn calf, increasing the current population size to 75 members (Mooney, 2019). The calf continues to be closely monitored, as the pod has not been able to reproduce a healthy calf that has been able to survive its first few months since 2015.

Major environmental threats to SRKW include marine vessel strikes, noise pollution, toxicity exposure and declining prey availability (DFO, 2018). It has been proven to be a difficult challenge for energy proponents to receive the appropriate social license to operate and to proceed with their project when the SRKW are involved. However, it has been argued that shipping vessels and oil spills may not be the biggest threats. In my research, I will identify the major cumulative threats to the SRKW populations associated with TMX on the Canadian Western Coast, and review and analyse other adverse cumulative effects when considering offshore industries, such as tourism and fishing. Because the most significant proposed threat associated with the TMX could potentially be the cumulative noise, I focus deeper into this topic and review literature studies that have been done on how the SRKW are affected by noise pollution, and ways we can mitigate these effects to minimize cumulative significant adverse impacts. It is my objective to contribute to the understanding of the cumulative effects surrounding the SRKW, to ultimately improve our understanding of energy, sustainable development and mitigation of the stresses adding to the potential extinction of the SRKW.

1.2 Problem and Importance

Orca whales have been an important topic in conservation in most recent years, as beloved movies and controversial documentaries have highlighted their struggles against anthropogenic activities. Orca whales hold spiritual, cultural and economic importance to the people residing around the Salish Sea, including Indigenous tribes from both Canada and the U.S. Because of their endangered status and trans-border distribution patterns, their protection falls under the responsibility of provincial/state and federal jurisdictions of both countries. Legislations and conservation efforts have been made in order to maximize the chance of the SRKW survival, however, the predicted growth of human activity in the Salish Sea causes nationwide concerns. It has been proven to be a difficult challenge for stakeholders to recommend and implement mitigation methods, because of the multiple factors contributing to their demise, including prey decline and contaminant exposure. A cumulative effects assessment, which considers project effects from other past, present and reasonably foreseeable future human activities, is essential to gauge the true impact of anthropogenic activity on the SRKW.

The Southern Residents are a top predator in the Salish Sea. Unlike other killer whale populations who primarily hunt marine mammals, the SRKW evolved to rely specifically on the fatty, energy-rich Chinook Salmon, *Oncorhynchus tshawytscha,* that once traversed the Salish Sea in copious numbers (NOAA, 2018). Influenced by this reliance, the SRKW adapted migration patterns that follow those of the Chinook Salmon, leading them through various streams and rivers along the coasts of California to British Columbia. Now, due to anthropogenic and natural causes, many of Chinook Salmon populations are extinct or face imminent threat (NOAA, 2018). SRKW expend more energy in order to capture the same amount of fish, who are also exhibiting smaller body mass. In addition, the Chinook Salmon are highly contaminated with human-induced organic pollutants such as polychlorinated biphenyls, or PCBs (Cullen et al., 2009). Biomagnification is therefore a major concern. Because the SRKW population is significantly influenced by the perpetuation of the Chinook Salmon species, this depicts a bottom-up food chain. The status of the Chinook Salmon and the SRKW are important indicators of the health of the overall food chain in the Salish Sea.

1.3 Environmental Impact Assessment Checklist - Analysis of Potential Project Effects

The status of the SRKW is of particular importance due to the fact that it heavily influences the approval of the controversial Trans Mountain Expansion Pipeline Project. This Project, which aims to twin the existing Trans Mountain pipeline (TMP) and increase delivery capacity of crude oil and other refined products, has been argued to be the saving grace to Canada's fluctuating economy. However, Project Proponents face scrutiny by animal rights activists and marine mammal conservationists who argue the Project will have a significant adverse effect on the survival of the SRKW whales. In order to analyse potential Project effects on the SRKW, I adopted a checklist from the Canadian SARA Registry (Environment Canada and Parks Canada, 2010) (See Table A1, Appendix A). Checklists are common tools in the Environmental Impact Assessment practice, as they are regarded as effective and interpretable. Table A1 allowed me to begin my project with an accepted common methodology.

1.4 Sustainability Aspects

This project contributes to sustainable energy development through social, environmental and economic sustainability principles in the following ways:

- This study highlights the importance of energy projects such as the Trans Mountain Pipeline Expansion project, to the economic prosperity of Canada.
- Environmental issues such as contamination and habitat destruction are significant issues associated with the development of energy projects and must be considered when proposing new projects.
- It is important to understand the distribution and behavioural patterns of the SRKW to fully comprehend how the TMX and other anthropogenic activities hinder their chances of survival.
- The impacts of energy development on species at risk, such as the SRKW, have a direct impact on societal values and perceptions.

Chapter 2: Methodology

This study was done with a four-step approach. A graphic representation of the methodology is shown in Figure 1.

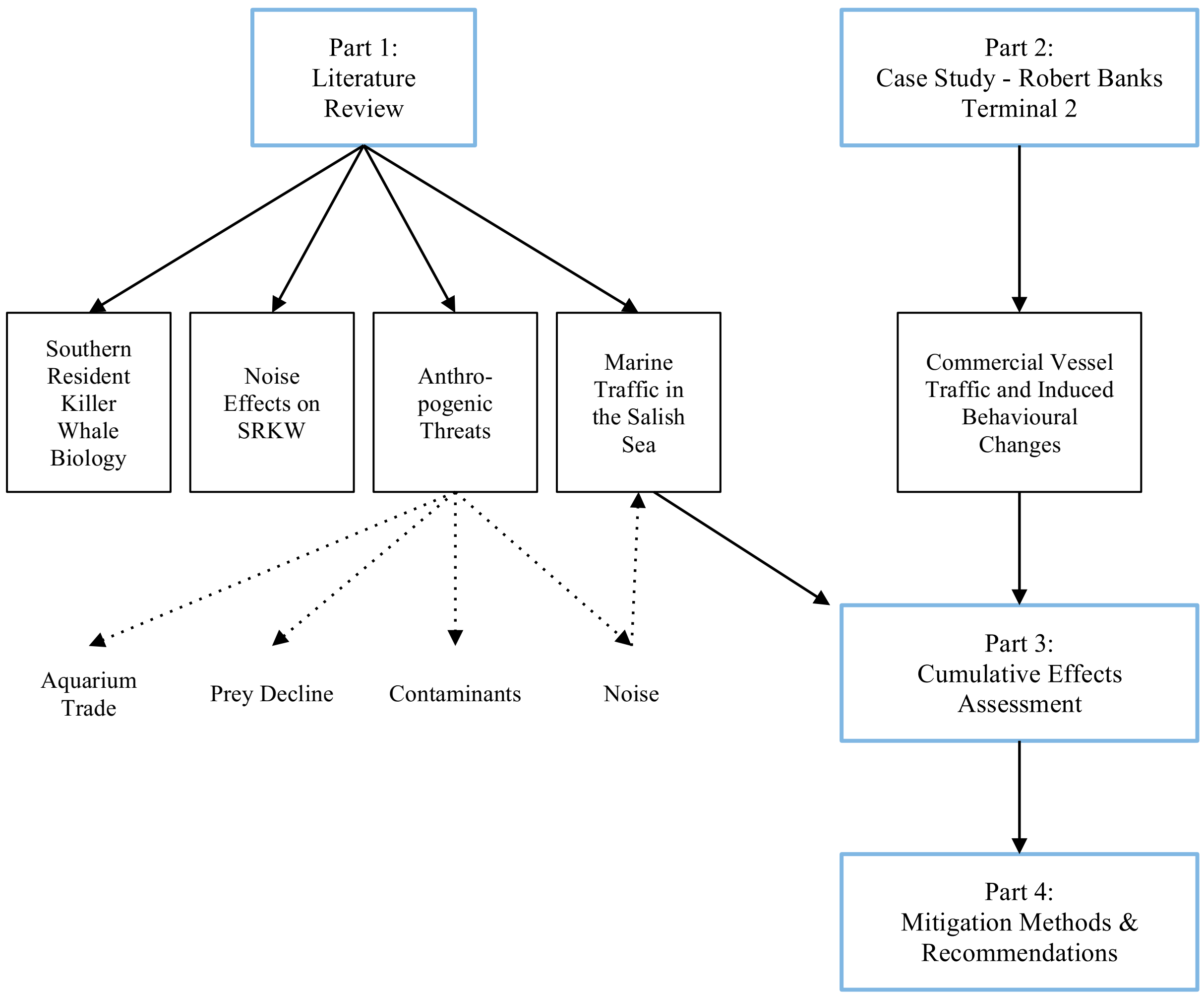
Part I was a literature review on four major topics; (1) Southern Resident Killer Whale biology, in order to understand their behavioural and migration patterns; (2) noise effects on the SRKW, to better comprehend how SRKW perceive underwater noise; (3) anthropogenic threats to the whales, including the aquarium trade, prey decline, contaminants and noise pollution; and (4) marine traffic in the Salish Sea, to identify the noise composition in the SRKW critical habitat. Literature was obtained through internet research and through interviews with various members of industry.

Part II of the methodology included a comparative case study, in which I examined the Robert Banks Terminal 2 (RBT2) SRKW Underwater Noise Exposure and Acoustic Masking Study. I chose this study due to the terminal's proximity to the proposed TMX berth, as well as its study area being within SRKW critical habitat area. This comparative analysis allowed me to obtain data on the relative commercial-vessel induced noise pollution in the Salish Sea, and how it may change with the addition of the RBT2, as well as other projects such as TMX. In this study, researchers also analyzed the consequential behavioural changes induced by the noise pollution. A follow up study included whale-watching boats, and the cumulative effect of commercial and recreational traffic on the SRKW.

Part III of the methodology was conducting a cumulative effects assessment. In order to conduct a cumulative effects assessment (CEA), I obtained relative numbers of sailings for each industry per year (tankers, passenger ships, recreational, military). I estimated the effect of each industry relative to each other, based on noise, number of sailings and exposure time.

Finally, Part IV of the methodology used thorough literature review in order to suggest mitigation methods to minimize adverse effects on the SRKW, and to make recommendations for future actions related to the SRKW population.

Figure 1: Methodology Process



(Source: Author, 2019)

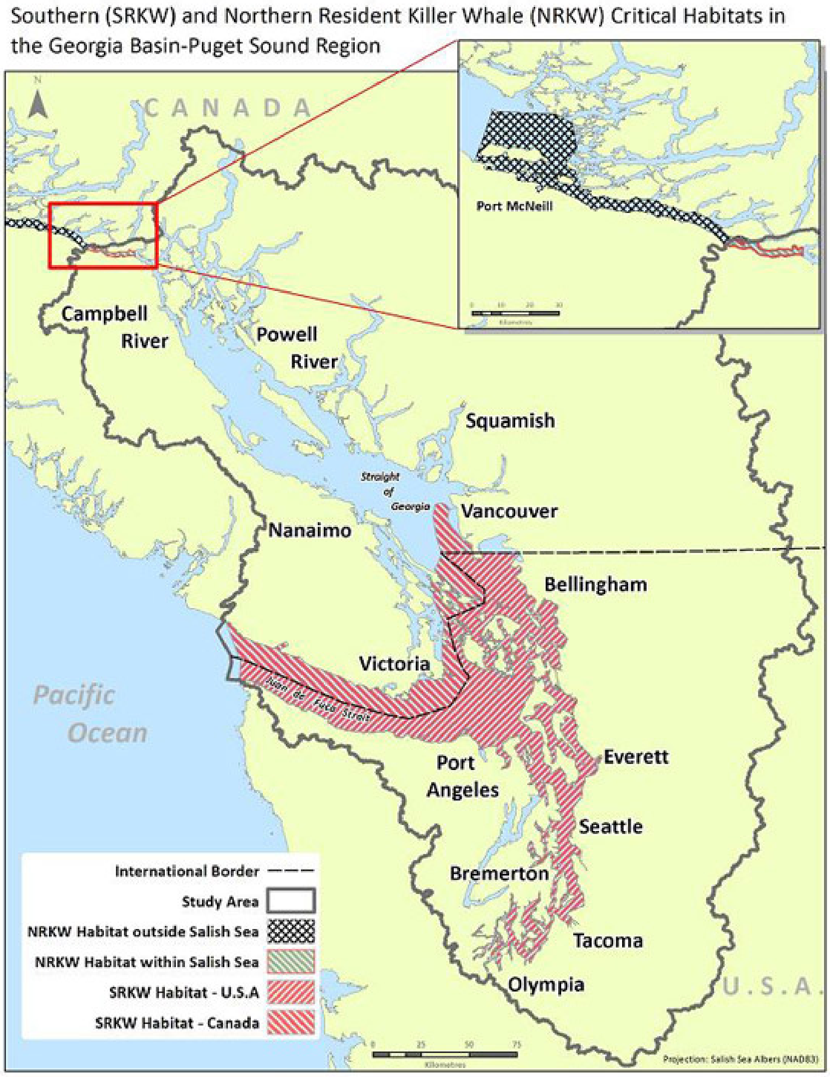
Chapter 3: Literature Review

3.1 Southern Resident Killer Whale Biology

3.1.1 Population Status and Population Decline

According to the Canadian Department of Fisheries and Oceans Canada (DFO, 2018) and the National Oceanic and Atmospheric Administration of the US (NOAA, 2018), the SRKW population is endangered. Scientists estimated the original population consisted of about 140 members, which decreased to 71 members in the 1960's, after the market called for an increase of live-capture whales to use in the aquarium industry (NOAA, n.d.). The population experienced slow propagation after there was a cease in the live-capture of whales, which allowed them to reach their peak of 98 members in 1995. However, since then, the number of individuals has been on a steady decline due to other anthropogenic threats. In 2018, their population reached 74 members in total (DFO, 2018). Due to their decreasing population size and low reproductive success, they are now protected under Canada's Species at Risk Act (SARA) and U.S. Endangered Species Act (ESA). Because of their status, both Canada and the U.S. have identified SRKW critical habitat areas, as depicted in Figure 2 below.

Figure 2: Southern and Northern Resident Killer Whale Critical Habitats in the Georgia Basin-Puget Sound Region



(Source: U.S. Environmental Protection Agency, 2013)

3.1.2 Distribution Patterns

The Northern and Southern Resident Killer Whales are found in the Pacific Ocean, where they share their waters with the other Pacific killer whale ecotypes; the Transient Killer Whales and the Offshore Killer Whales. These three ecotypes are genetically and socially isolated from each other, despite transecting the same geographical areas (DFO, 2018).

Within the resident killer whale ecotype, there further exists the Northern and the Southern resident killer whales, which are also socially isolated from each other and do not interbreed (DFO, 2018). Figure 3 below depicts the different ranges of the NRKW and the SRKW.

Figure 3: Distribution Map of the NRKW and the SRKW

(Source: Ocean Wise Conservation Association, 2017)

The SRKW, specifically, are known to populate the areas between southeastern Alaska and central California (DFO, 2018). During the summer, they are mainly found off the coast of Vancouver Island and Washington State, including the Haro Strait, Georgia Strait and the Strait of Juan de Fuca (DFO, 2018). Their population distribution is largely influenced by the migration patterns of their preferred prey, the Chinook Salmon and Chum Salmon. Although predictability of SRKW foraging patterns is fairly accurate, there has been concern of changing patterns year-to-year, especially with the constantly fluctuating migration patterns of the Chinook salmon. The Government of Canada states that ongoing investigations are underway in order to better understand the winter distribution of the SRKW, including using sightings network data, cetacean surveys and acoustic studies (DFO, 2016).

Currently, the SRKW is separated into three matriarchal pods, J, K and L (Center for Whale Research, 2019). As of January 11, 2019, the population numbers of each pod were 22, 18 and 35 members, respectively. Each pod uses very distinct calls to communicate with other pod members, however, there are a few communication signals that seem to be shared amongst the three pods (Center for Whale Research, 2019). The distinctive calls are passed through the pod by the matriarchs.

3.1.3 Biological and Physical Characteristics

The orca whale is the largest and arguably most distinctive member of the dolphin family, *Delphinidae*, due to their distinguishing black and white coloring (SARA, 2018). In order to differentiate between specific individuals, researchers use their unique dorsal fin sizes, eye patch and saddle patch markings, and any naturally accumulated scars. The dorsal fin sizes in adult males have been recorded to reach up to 1.8 meters, and up to 0.9 meters in females (Dahlheim and Heyning, 1999). The species is sexually dimorphic; the males are distinctive from their female counterparts by their size. Males reach up to 9.0 m in length, and over 5,500 kg in weight. Females reach up to 7.7 m in length and 4,000 kg in weight. The pectoral fins of the male members are also much broader. The dorsal fin of the SRKW is uniquely rounded at the leading edge and angled at the trailing edge (SARA, 2018).

The SRKW population is matrilineal, and typical family units consist of a mother, her offspring, and her daughter's offspring (SARA, 2018). The family units travel with other members of their pods, who forage, travel and rest with each other for the majority of their lives. The reproductive cycle of the SRKW consists of fifteen to eighteen month gestation periods, with a calving interval of about five years (DFO, 2018). Female individuals tend to live up to fifty years, while males tend to live up to thirty years (DFO, 2018).

3.2 Threats to the SRKW Population

3.2.1 Aquarium Trade

The aquarium trade was popularized during the 1960 era and had consequential effects on the SRKW population. It was initially thought that the population had at least 100 members before European settlers arrived at the west coast (Georgia Strait Alliance, 2019). The whales quickly garnered attention and were thought to be blood-thirsty animals, which inspired their "killer whale" nickname. Many whales were lost from being hunted, as they were seen as dangerous and a threat to salmon species. Later in the 1960's, it was realized that the killer whales were not dangerous and were in fact very intellectual creatures (Georgia Strait, 2019). This inspired a trend of capturing whales to be sold and displayed in aquariums worldwide. Because of their proximity to the coastline, the SRKW suffered from a detrimental population decrease and in twelve years, 47 members had been caught to be shipped to aquariums, while many others died from injuries sustained from the captures (Georgia Strait, 2019). When concerns started to arise in both Canada and the U.S. concerning their wellbeing, the federal governments initiated a halt on all live-capture activity until further studies could be conducted. It was in 1976 that Canada passed legislation to ban the live-capture of whales, and the population has yet to make a recovery from this industry. In June of 2019, Canada passed Bill S-203, which bans the captivity and breeding of whales and dolphins (Parliament of Canada, 2019). Although there are exceptions to this bill, such as for rehabilitation or research purposes, this particular move was celebrated by animal rights activists nationwide.

3.2.2 Prey Decline

The decline of chinook salmon species off the west coast of Canada and the U.S. is a major threat to the survival of the SRKW population. Studies have shown that unhealthy body disproportions of the SRKW are correlated with the lack of prey availability (Siegle, 2018). The SRKW mainly rely on Fraser River Chinook Salmon, especially during the months of May to September, in order to prepare for their upstream migrations (Siegle, 2018). Chinook salmon are the largest and most energy-rich of the available species for the SRKW. Alternative prey sources include Coho and Chum Salmon, when there is insufficient supply of chinook salmon. Although there was a significant decline in west coast salmon starting in the 1800s due to anthropogenic activity, numbers have seen a gradual increase in the last fifty years (NOAA, n.d.). Studies have shown that there has been an increase from 225 million juvenile salmon in 1975 to 406 million juvenile salmon in 2015, due to a combination of hatchery production and improved migratory passages (NOAA, n.d.). Currently, the Columbia and Snake rivers are responsible for most of the salmon production on the west coast, when also taking into account production from hatcheries. There is no evidence that shows SRKW can distinguish the difference between hatched and naturally-grown salmon (NOAA, n.d.).

In comparison to pinniped (seals and sea lions) consumption and commercial and recreational fishing, studies have shown that the killer whales (not limited to southern resident) off the west coast are the largest consumers of adult salmon (NOAA, n.d.). The SRKW population alone consumes approximately 200, 000 adult salmon per year. Although salmon populations have increased in the last fifty years, some salmon stocks remain threatened or endangered. More specifically, the chinook that come from the Puget Sound, Columbia, Snake, Klamath and Sacramento rivers all face imminent threats (NOAA, n.d.). This affects the SRKW who rely on these food stocks throughout the year.

There have been various mitigation methods put into place in order to support the recovery of the salmon population. This includes regulated hatchery productions, safe passageways through dams and habitat restoration (NOAA, n.d.). However, despite the recent increase in numbers, salmon populations are always fluctuating. This is due to the fact that they are highly sensitive to environmental changes, whether anthropogenically induced or natural changes, such as differing climate patterns. As well, the Puget Sound Chinook Salmon do not seem to be successfully recovering. The rivers that drain into the Puget Sound are especially important to the SRKW population because it is their main feeding ground for the majority of the year (NOAA, n.d.). A critical reason that the Puget Sound salmon have not been showing improvement is the fact that their habitat remains degraded and has not been able to support new generations of salmon. Scientists have also determined that many of the juvenile salmon are born contaminated with large quantities of chemicals and toxins, which stunt their growth and hinder their reproductive capabilities.

Mitigation and recovery plans have been put into place by both Canada and the U.S. in order to aid west coast salmon stocks. For example, NOAA Fisheries' released the Puget Sound Chinook Salmon Recovery Plan, while DFO just recently released urgent management measures to protect the chinook salmon (DFO, 2019). Mitigation measures such as restoring fish channels and tightening fishing regulations are preliminary but necessary steps to protect the survival of Chinook Salmon and the SRKW.

3.2.3 Contaminants

Prey declines and toxicity concerns go hand in hand when considering threats to the SRKW. Recent studies show that SRKW individuals are displaying higher concentrations of contaminants, including dioxins, DDT and polychlorinated biphenyls (Grant and Ross, 2002). There are many health risks that are associated with contaminant exposure, including interference to the immune and reproductive systems, and increased chances of cancer (Mongillo et. al, 2012). Individuals differ in their exposure to contaminants depending on the amount of time they spend near project activity, their birth order and their diet (Siegle, 2018). As individuals get older, the contaminants bio-accumulate in their bodies, meaning the concentration of toxins increase relative to the surrounding medium (ScienceDirect, 2019). The exception to this trend is with lactating mothers, who transfer fat-soluble contaminants to their calves who depend on their milk (Krahn et al., 2009). This is one of the principal reasons for the low survival rate of SRKW calves in their first few years. When prey availability is relatively low, the whales metabolize their fat reserves, subsequently releasing contaminants that are stored in their fat. This explains the correlation between Chinook Salmon declines and higher toxicity in the SRKW (Lundin et al., 2016). Contaminant exposure is an important aspect when considering the survival success rate of the whales, especially since increase in project activity would increase vulnerability to toxins.

Oil spills are another concern associated with SRKW contaminant exposure. SRKW are especially vulnerable to oil spills due to their constant proximity to commercial and recreational activity. As well, they spend a good portion of time at the surface of the water, where oil spills occur most frequently. A study was published in 2017, by the Raincoast Organization in B.C. which determined the effect of oil spills on various marine mammals (MacDuffee, 2017). In this study, researchers identified exposure pathways for twenty-one marine mammals who reside on B.C. coasts. An exposure pathway is defined as the process and extent to which an oil spill affects a specific species. This considers whether the contaminants are ingested, inhaled, surface contacted or consumed through contaminated prey. By cross-examining this with species' distribution, reproduction, prey-switch ability and conservation status, researchers determined each species' vulnerability to oil spills (MacDuffee, 2017). Using a risk calculation, researchers concluded that resident killer whales (north and south), along with sea otters, experience the highest risk of vulnerability to an oil spill. This is due to the fact that SRKW critical habitat is heavily transited by marine traffic, therefore, there is a high possibility that for every oil spill that occurs, an individual will be present. Additionally, they concurred that up to 80% of the SRKW population would be adversely affected by an oil spill if it occurs within the Haro Strait (MacDuffee, 2017). This was determined by multiplying the probability of an oil spill to occur in an area, by the consequence of the oil spill. The high vulnerability of SRKW to oil spills was exemplified after the population saw a loss of many members after Alaska's Exxon Valdez oil spill in 1989.

According to the NOAA, there are published studies suggesting that the killer whales cannot detect and actively avoid oil spills (NOAA, 2019). Because of this, mitigation methods and accident response strategies have been put into place in order to minimize harm to the mammals in the case of spilled oil. For example, the NOAA has implemented "hazing" strategies, including acoustic deterrent devices, pre-recorded whale calls, boat and helicopter traffic, and fire hoses, in order to deter individuals away from oil spills (NOAA, 2019). Depending on the location of the spill, the amount of individuals affected, and how attractive the area is to the whales, determines what method or combination of methods are best to deter individuals from the area. Currently, no capture and rehabilitation methods are established in order to aid individuals who are adversely affected by oil spills; therefore, response action must occur quickly and efficiently after a spill occurs.

3.3 Underwater Noise

In order to understand the acoustic biology of the SRKW and how they may be affected by various noise pollution frequencies, we must first delve into the physics of underwater noise. Underwater noise acts under the source-path-receiver model (Golder, 2018). The source emits energy of a certain wavelength and frequency, which travels a distance and experiences transmission loss, and ultimately reaches the receiver (Golder, 2018). Transmission loss, specifically, is the loss of energy as the noise travels the distance.

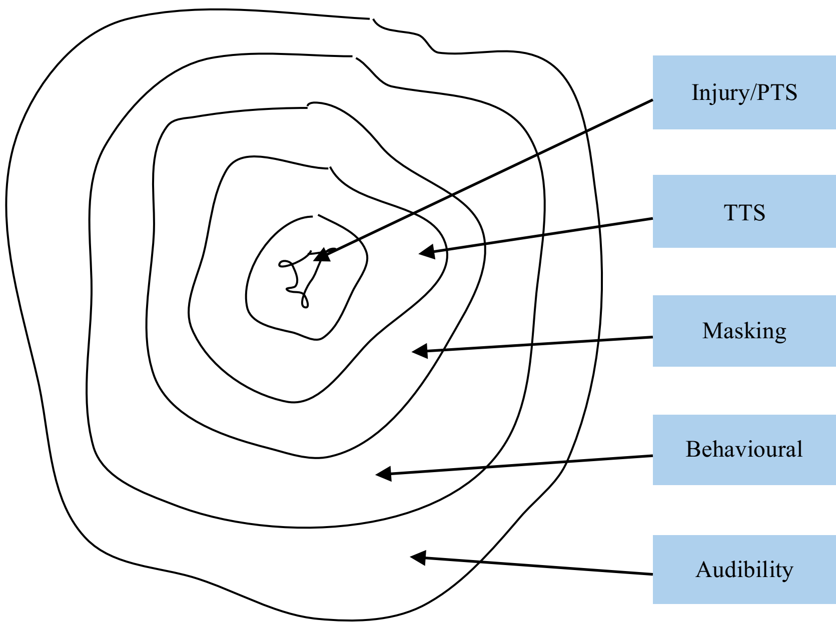
Transmission loss rates can differ with different water qualities, such as temperature, contents of the water column and the seafloor disposition (Golder, 2018). Decibels (dB) are used to measure noise levels underwater, which is a logarithmic ratio relative to a reference pressure of 1 μPa (Golder, 2018). Noise travels fairly efficiently underwater, thus many species have adopted communication, foraging and navigation methods using sound. Because of how pertinent noise is to aquatic species, noise pollution from anthropogenic sources have proven to cause distress and significant adverse effects. Noise pollution does not only interfere with communication between individuals, it can also cause permanent damage and other physiological injuries to aquatic species.

There are various sources of human-induced noise pollution. More specifically, noise pollution can be categorized as impulsive or non-impulsive/continuous. Impulsive noises are distinguished by high peak sound pressures, shorter durations and broad frequencies (Finneran, 2016). Examples include drilling and blasting. Non-impulsive/continuous noises are normally longer in duration and exist in steady-state (Golder, 2018). Examples include shipping tankers and military sonars.

3.3.1 Noise Effects on the SRKW

There are various factors that determine whether an animal will be affected by noise pollution. More specifically, whether or not an animal will be adversely affected by noise is determined on the received sound level, the amount of background noise and the frequency of the noise pollution (Golder, 2018). The differing characteristics of the noise pollution will determine whether or not it will induce small reaction, such as a change in behaviour, or a more detrimental adverse effect, such as permanent hearing loss, or in some cases, mortality. When an individual experiences reduced hearing ability due to a noise of high pressure and long duration, it is termed a noise-induced threshold shift (NITS); this shift may be further characterised as a temporary threshold shift (TTS) or a permanent threshold shift (PTS). TTS is reversible and results in a short-term loss of hearing caused by metabolic changes and cellular fatigue in the individual (Southall et al. 2007; Le Prell 2012). When an individual is undergoing TTS, subsequent noises must be louder in order for the individual to be able to hear it (Golder, 2018). Conversely, PTS is a non-reversible threshold shift, which occurs by a sound that causes hair cell loss and damage to other auditory structures (Saunders et al. 1985; Henderson et al. 2008). PTS has not yet been recorded to occur in marine mammals, however TTS occurs fairly frequently, and continual noise exposure with little recovery time can cause TTS to turn to PTS (Southall et al. 2007). Figure 4 is a visual representation of the possible adverse effects of noise on marine mammals.

Figure 4: Acoustic Impact Zones Around a Noise Source



(Information Source: Erbe, 2013)

There are three distinct categories that describe an animal's behavioral reaction to anthropogenic noise source; low-, moderate- and high-severity behavioural responses (Southall et al, 2007). Low-severity reactions are not necessarily detrimental to the overall health of the individual and are within normal reactions. Examples include change in orientation, respiration, or heart rate, started response, or alteration to group spacing (Golder, 2018). Moderate severity reactions are at risk for causing more adverse damage to the individual, either behaviourally or physically, if the individual is exposed to the noise for a longer duration of time. There are several factors that determine whether the individual will be moderately affected by the noise. Factors include the size of the individual, the magnitude of the noise source and what the animal was doing when they were exposed to the noise (i.e.: resting versus foraging) (Golder, 2018). Changes in behavioural reactions include stopping activity (i.e.: cease nursing or foraging), actively avoiding the area or showing signs of discomfort/annoyance, or changing navigation patterns (i.e.: changing speed, direction) (Golder, 2018). If the individual returns to normal behaviour after exposure, the response is deemed insignificant, however, if the behaviour persists and there are long-term changes to behavior because of the noise pollution, this is deemed significant. Finally, high severity responses are responses that immediately affect the health of the individual. Behavioural response examples include long-term avoidance of the affected area, panic, stranding or separation of mothers from offspring (Golder, 2018).

Auditory masking is another adverse effect that must be taken into consideration. Masking is the act of overshadowing noises of the individuals by noises from anthropogenic activity (Richardson et al., 1995). This can significantly reduce the ability of individuals to communicate with each other, alter navigation, and intercept echolocation effectiveness (Golder, 2018).

3.3.2 Injury and Disturbance Criteria

Sound thresholds have been implicated in order to determine baseline criteria at which marine mammals are affected. Sound thresholds are measured by sound pressure level (SPL), an instantaneous value, and sound exposure level (SEL), total noise energy that an animal is exposed to over a specified amount of time (Golder, 2018). Choosing which metric to apply is based on the noise source, its frequency, duration and exposure time. National Marine Fisheries Service (NMFS) released acoustic thresholds in 2018 that are now widely used and accepted.

3.4 Activity in the Salish Sea

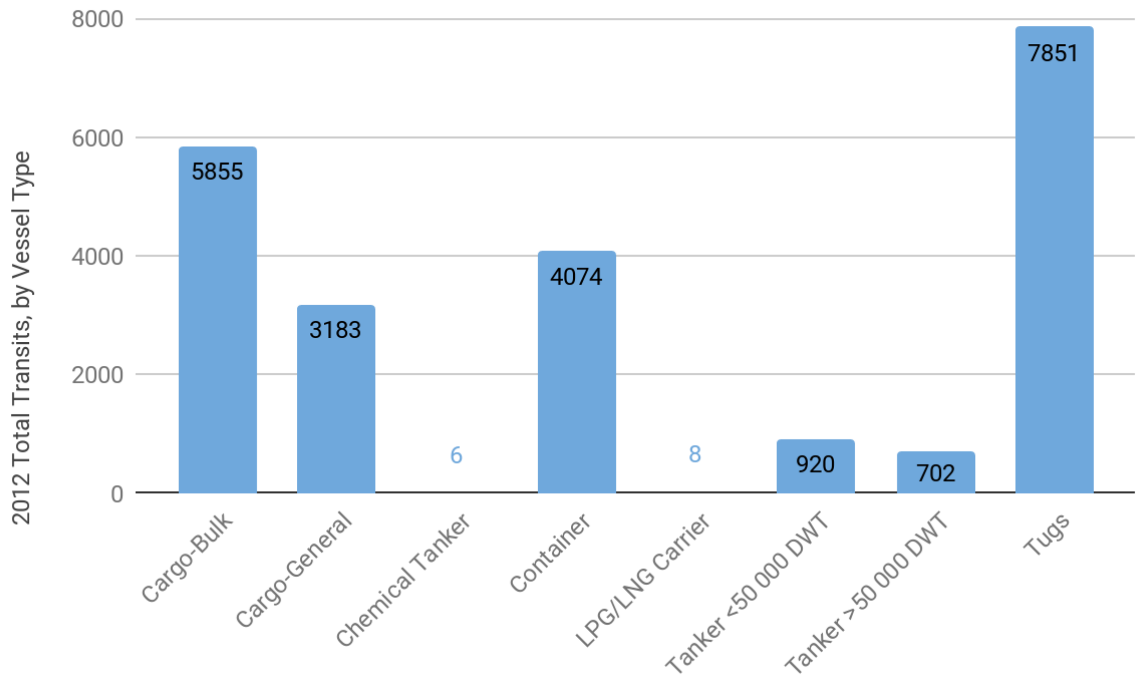
The Salish Sea is a pertinent gateway for marine traffic of all vessel shapes and sizes. The Strait of Juan de Fuca, specifically, is a main transportation route for domestic and international vessels travelling in and out of the Vancouver and Washington harbours for various industrial and commercial reasons and is expected to see an increase of traffic in the future (SMRU, 2014). In addition to vessel-induced noise, many other anthropogenic activities cause noise pollution that creates concern for the SRKW, including but not limited to; seismic exploration, fishing activities, military and commercial sonar and renewable energy sources, such as tidal turbines (SMRU, 2014). Larger ships continue to be the most common source of ocean noise pollution, with frequencies less than 300 Hz (Hildebrand, 2006; Heise and Alidina, 2012). Because of their powerful engines and slow-turning propellers, larger vessels generate high source level noise at low frequencies that tend to overlap with many whale vocalizations (Aguilar Soto et al., 2006). Noise pollution is proportionately related to ship size, power, load and speed (Richardson et al. 1995).

According to a study released in January 2019 by the Department of Ecology at the State of Washington, the Strait of Juan de Fuca experiences about 8, 300 deep-draft vessel arrivals and departures per year. Of these, approximately 5, 500 travel to the Port of Vancouver, while the remaining travel to the entrance of Puget Sound (Department of Ecology, 2019). In addition, the Strait experiences about 230, 000 transits annually by tug and barges, ferries, fishing vessels and recreational vessels (Department of Ecology, 2019).

3.4.1 Tankers and Cargo Vessels

In 2013, the B.C. Ministry of Environment commissioned the Nuka Research and Planning Group to prepare the West Coast Spill Response Study. This three-volume report consisted of the marine spill and prevention program that was in place at the time, vessel traffic analysis, and suggestion and enhancement visions for Canada's West Coast (British Columbia Ministry of Environment, 2013). Analysts used AIS methods to collect data regarding barge movement in the Salish Sea. It was pertinent to use barge movements rather than port calls, so that ship movement going in and around US ports could be included in the study as well (British Columbia Ministry of Environment, 2013). Between the years of 2011-2012, information from 54 000 vessels were collected, including type, size, age of vessel and country. The study area of this report focuses around the major B.C. ports including Stewart, Prince Rupert, Kitimat, Port Hardy, Nanaimo, Port Alberni, Port Alce, Port Metro Vancouver and Victoria. This study area intersects with the Canadian SRKW critical habitat. In 2012, the overall transits for tanker and cargo vessels was around 22 600. All the vessels depicted in Figure 5 below fall under the "larger vessel" category and are equipped with AIS.

Figure 5: Total Transits, by Vessel Type in 2012



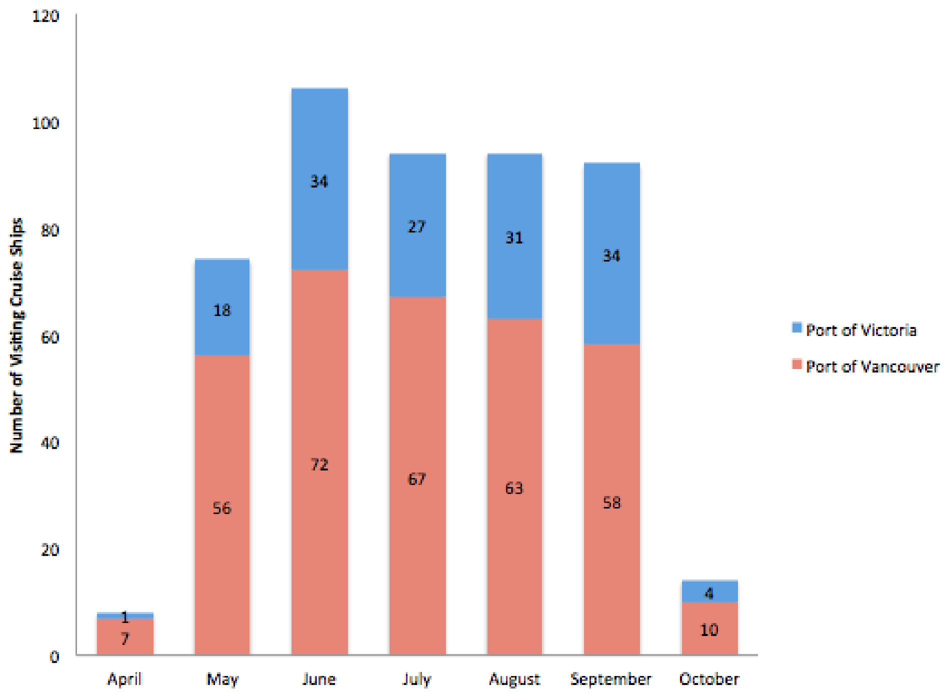
(Source Information: British Columbia Ministry of Environment, 2013)

3.4.2 Passenger Vessels

3.4.2.1 Cruise Ships - Canada

The cruise ship industry has been a major source of income for the Vancouver Harbour for thirty-three consecutive years, hosting various international cruise ships of different sizes and passenger loads. In 2018, the Vancouver Harbour welcomed a total of 333 cruise ships between the months of April through October, with July being the busiest month. In addition, the Port of Victoria, which is also found within the SRKW critical habitat, welcomed 149 cruise ships to their port in 2018, adding to the marine traffic in the Haro Strait. Figure 6 below highlights cruise statistics in the Vancouver Harbour.

Figure 6: Number of Cruise Ships Entering the Vancouver and Victoria Harbours During the 2018 Season



(Source: Crew Center, 2017)

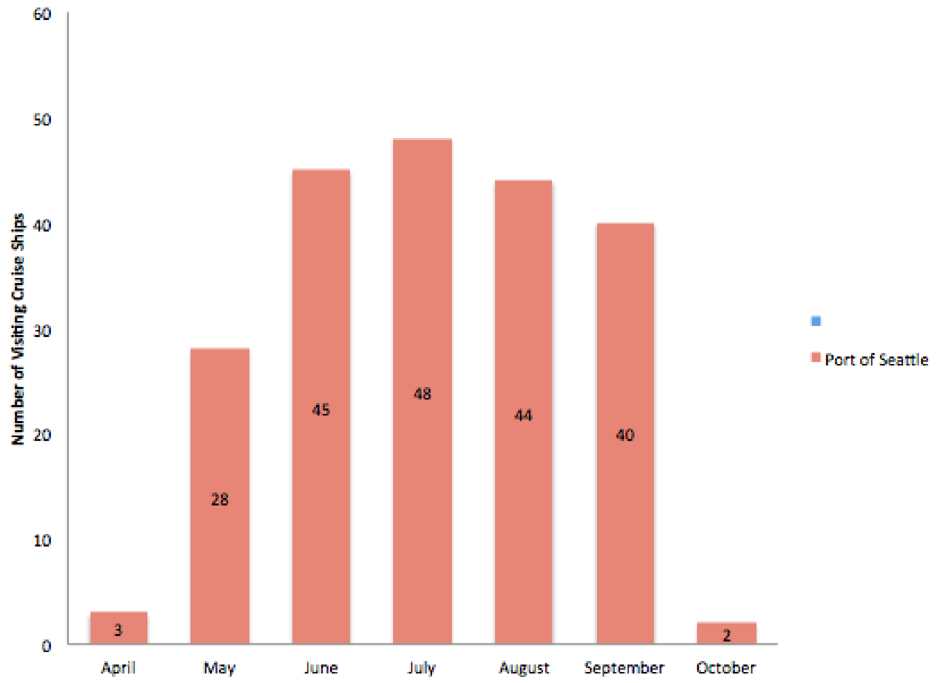
Each visiting cruise ship generates about three million dollars to the local economy, and in 2018, cruise visits increased a total of seven percent from the 2017 season (Cruise Industry News, 2018). It was predicted that cruise-ship passengers visiting Vancouver in 2019 would increase by twenty one percent from 2018 numbers, which would be the busiest year to date (Port of Vancouver, 2019). The million dollar industry continues to flourish and thus is predicted to continue growing in the near future.

Currently, there is no regulation in place to control the speed of the cruise ships transiting the Haro Strait. In 2017, the Port of Vancouver introduced the Enhancing Cetacean Habitat and Observation (ECHO) program, in which researchers urged ships to slow speeds down to 11 knots (20 km/h), which is about a forty percent reduction from the normal 18 knots (33 km/h) (Pynn, 2017). The program asked for the speed reduction to occur between August and October, which are critical months for the SRKW, but also critical months in the tourism industry. Although the reduction would incur a thirty to sixty minute delay in arrivals, a few cruise ship companies voluntarily obliged.

3.4.2.2 Cruise Ships - United States

The Port of Seattle is also a major tourist point for international cruise ships for the past twenty years. Like the Canadian West Coast, the U.S. West Coast also relies on the cruise industry for a significant portion of annual revenue. In 2018, the port welcomed 149 ships, with July being the busiest month (Port of Seattle, 2018).

Figure 7: Cruise Ships Visiting Port of Seattle in 2018

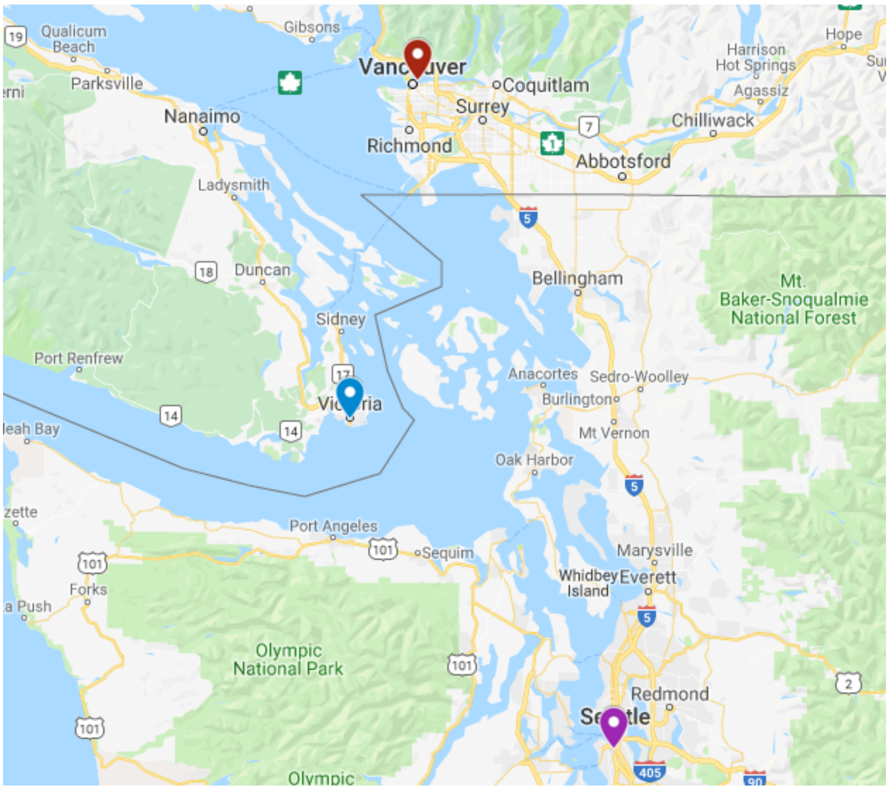


(Information Source: Cruise Port Insider, 2018)

The Port of Seattle has also experienced growth in the cruise industry, surpassing one million visitors in 2018, and generating a $501-million dollar annual revenue. Similar to the Vancouver and Victoria Harbours, each ship that docks at the Seattle harbour brings in about $2.7-million dollars to the local economy (Port of Seattle, 2018). The numbers are predicted to increase, as the port prepares for the arrival of ships with larger passenger loads in 2019.

Much like their Canadian counterparts, the Port of Seattle currently does not have any regulations in place to control the speed of cruise ships transiting the SRKW critical habitat. Figure 8 below depicts the three ports and their location within SRKW habitat.

Figure 8: Port of Vancouver (red), Port of Victoria (blue) and Port of Seattle (purple), All Found Within SRKW Critical Habitat



(Source: Author, 2019 - Accessed from Google Maps)

3.4.2.3 Ferries - Canada

Ferries have been an integral way of transportation for B.C. residents travelling to and from the West Coast islands since 1960. In B.C. Ferries 2018-2019 Annual Report, it was disclosed that in one year, there were 176 000 sailings, which was a 1.0% increase from the previous year. This calculated out to be about 482 sailings per day, with a total of 1.3 million nautical miles between the fleet (B.C. Ferries, 2019a). According to the B.C. Ferries website, there are currently 35 active vessels that transit 30 different routes within the Salish Sea (B.C. Ferries, 2019b). Between these 35 vessels, maximum speeds range from 8.50 knots (15.74 km/h) to 23 knots (42.60 km/h), with the average being about 15.76 knots (29.20 km/h). B.C. ferries operate year-round, with a spike in service during the summer months. According to Figure 9 below, accessed from the B.C. Ferries website, about half of the routes transect SRKW critical habitat.

Figure 9: Map Depicting B.C. Ferry Routes

(Source: British Columbia Ferries, n.d.)

3.4.2.4 Ferries - United States

Washington State ferries have also been experiencing a surge in ridership in the past few years (Sterling, 2018). In 2017, Washington ferries accommodated approximately 24.5 million passengers, resulting in their highest year for business since 2002. A total of over 161 000 sailings were completed, equating to about 902 000 nautical miles. All twelve routes between twenty ports are located within the SRKW critical habitat. Similar to

B.C., Washington State experienced a 1.0% increase in ridership between 2016 and 2017, which only continues to grow (Sterling, 2018). Within their fleet, the speed range was between 13-18 knots, and the average speed was 16.6 knots.

3.4.3 Recreational Vessels

3.4.3.1 Recreational Boats

Data regarding smaller vessels is not always readily available, due to the fact that vessels under a certain size or passenger load are not legally required to be equipped with an automatic identification system (AIS) (Serra-Sogas, Canessa, O'Hara, Smallshaw and Warrior, 2018). This causes discrepancy in documentation of small vessel traffic patterns because there is currently no reliable tracking system in place. A study was released in 2018 by the Geography Department at the University of Victoria, in which relative numbers of vessel traffic traversing the Salish Sea were collected, regardless of whether or not they were equipped with an AIS (Serra-Sogas et al., 2018). Researchers used opportunistic aerial surveys carried out by the National Aerial Surveillance Program (NASP) and Google Earth Pro in order to collect photographic evidence of vessel traffic. The NASP used the De Havilland DHC-8-102 Dash-8 aircraft, travelling at 150 knots at 1000 ft in order to capture images between 2015 and 2017 (Serra-Sogas et al., 2018). Researchers cross-examined the images with ArcMap to determine whether the vessels were equipped with AIS. Through this method, they inferred that at least 70% of marine traffic in the Salish Sea are smaller vessels that are not equipped with AIS, which include recreational boats, small tugboats and fishing vessels (Serra-Sogas et al., 2018). Frequencies and type varied throughout the year, more particularly seasonally, to highlight the spike in summer marine activities (Serra-Sogas et al., 2018). More specifically, they determined that in the summer months about 399 of 529 vessels recorded were non-AIS, and in the winter months, about 176 of 285 vessels were non-AIS. As predicted, most of the non-AIS vessels were recreational vehicles. The difference between the commercial non-AIS and AIS vessels was more comparable, as most commercial vessels will voluntarily have an AIS for safety reasons. For the sake of the study, tanker, cargo, tug boats, fishing boats and passenger vessels are described as commercial, while sailboats and motorboats are described as recreational.

In terms of size, the majority (67%) of the non-AIS vessels were estimated to be between 6-12 metres in length (20-40 feet), which is about the average size of the typical recreational sailboat or motorboat. The majority (60%) of the AIS vessels were longer than 12 metres (40 feet). In terms of speed, the majority (63%) of the non-AIS vessels were travelling at speeds of less than 10 knots (Serra-Sogas et al., 2018). Data for the AIS vessels were not available at the time.

Researchers also collected data for distribution patterns of the different vessels. The critical habitat of the SRKW for both Canada and the U.S. were identified and cross-examined with the vessel traffic patterns. Data confirmed that non-AIS vessels traversed critical habitat more than AIS vessels. Recreational motorboats made up the majority (59%) of these non-AIS vessels. For AIS vessels, commercial motorboats made up the majority (71%). In total, for both AIS and non-AIS traffic, 49% of the total vessel traffic in the SRKW critical habitat were recreational vessels (Serra-Sogas et al., 2018).

3.4.3.2 Whale-Watching Industry

The whale watching industry has been a major source of income for West Coast since the 1990s. In 2018, marine-based tourism accounted for $1.2 billion dollars of B.C.'s overall income and provided thousands of jobs for B.C. residents (Bartlett, 2018). The non-profit organization, the Whale Museum (TWM), published a study in 2017 in which they investigated whale-watching activity in the Salish Sea for eighteen years. TWM initiated the Soundwatch Boater Education Program in order to highlight the safety risks that the whale-watching industry imposes on the endangered SRKW (Seely, Osborne, Koski & Larson, 2017). TWM used methods such as monitoring vessels in order to collect data on frequency, type and vessel interactions with the SRKW. Frequency of whale-watching vessels since 1998 have seen fluctuations, from 63 active commercial vessels in 1999 to 96 in 2015 (Seely et al., 2017). There had also been a significant increase in the number of recreational kayakers in the Salish Sea, who engaged in whale-watching activities. The amount of kayakers added complexity to the study, and in 2015, there were about 12, 230 reported kayakers, which is equivalent to about 6, 100 commercial vessels. (Seely et al., 2017). During the eighteen-year time period, TWM also recorded the amount of SRKW incidents associated with whale-watching vessels. The majority of the accidents included vessels crossing whale's paths, vessels motoring inshore of whales, vessels stopped within the regulated 100 metres of the whales, and vessels motoring within the regulated 0.5 km no-go zone. Vessels that committed the above infractions were mostly private, recreational vessels (60%), followed by Canadian commercial vessels (19%), US commercial vessels (11%), kayakers (4%), monitoring and research vessels (2%), aircraft (2%) and others (2%) (Seely et al., 2017). As the whale-watching industry continues to grow, so does the number of incidents that occur per year. In 1998, Soundwatch researchers found that there were 398 incidents, which increased to 1635 in 2015 (Seely et al., 2017). The highest recorded year for vessel incidents was 2012, with a significant 2621 incidents.

3.4.4 Military

Military activity in the Salish Sea also induces noise pollution that is of concern for the surrounding marine mammals. The U.S. Military released the Northwest Training and Testing Report in 2019, which outlined all proposed activity in the area. Military practices have been conducted in the study area since the early 1990s, changing in frequency, type, location and duration depending on developing technologies, political climates and governmental influence (United States Department of the Navy, 2019). Noise sources associated with the military industry include, but are not limited to;

- Submarines, ships and aircrafts;
- Communication systems and radar;
- Underwater explosives;
- Sonar, laser and magnetic detectors; and
- Guns, missiles and bombs (United States Department of the Navy, 2019).

These noise sources can be categorized into impulsive or continuous, and differ in duration and frequency, thus affecting the SRKW to various extents. For example, sonar-induced acoustic resonance is a particular concern associated with the military industry and is described as amplified vibrations when an object is exposed to resonant frequencies, that can be harmful to marine mammals by damaging their tissue (United States Department of the Navy, 2019).

The following proposed testing and training activities are among the military activities that produce continuous noise pollution, including but not limited to; tracking exercises, electronic warfare training, and surveillance. Examples of testing and training activities that produce impulsive noise pollution are as following; torpedo exercises, mine neutralization, bombing and gunnery exercises and small boat attacks. According to the report, the frequency of these activities can range from a couple times a year to up to a couple hundred times a year. By manually calculating the number of military training and tests predicted to occur in 2019, I concluded that there will be about 6800 vessel sailings and 1200 activities that induce impulsive noise that occur in a one year time span. The study area for each of the listed activities also vary, and can be conducted in the offshore area, the inland waters or in the western Behm canal.

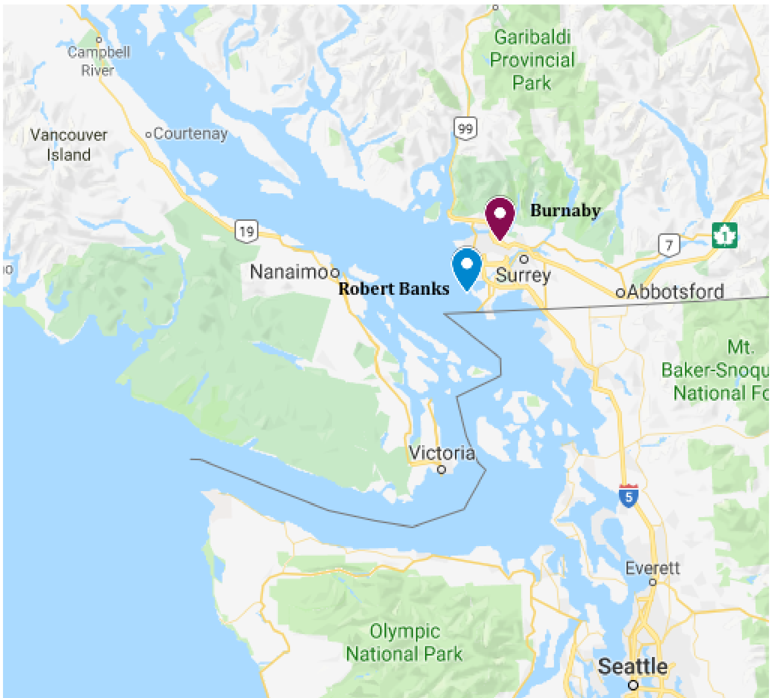
According to Nuka Research who released the 2013 West Coast Spill Response Vessel Traffic Study, government and military vessels are not always readily available to track by AIS. They do have AIS transponders for safety reasons, however, are not required to use them (British Columbia Ministry of Environment, 2013).

Chapter 4: Case Study I - Robert Banks Terminal 2

A study released in 2014 by SMRU Consulting included an EIA for the Roberts Bank Terminal 2 (RBT2), which is also located in the Salish Sea. In this study, proponents studied the existing and foreseeable commercial vessel traffic and its overlap with the SRKW population density (SMRU Canada, 2014). I will be adopting this data for the analysis of my report, as the distribution patterns of the whales from 2014 to 2019 have remained relatively similar, and assuming traffic conditions are also relatively the same.

The study area was chosen to represent the waters surrounding the RBT2 project, as well as the Canadian and US critical SRKW habitats. Figure 10 below shows the similar study area between the TMX and the RBT2.

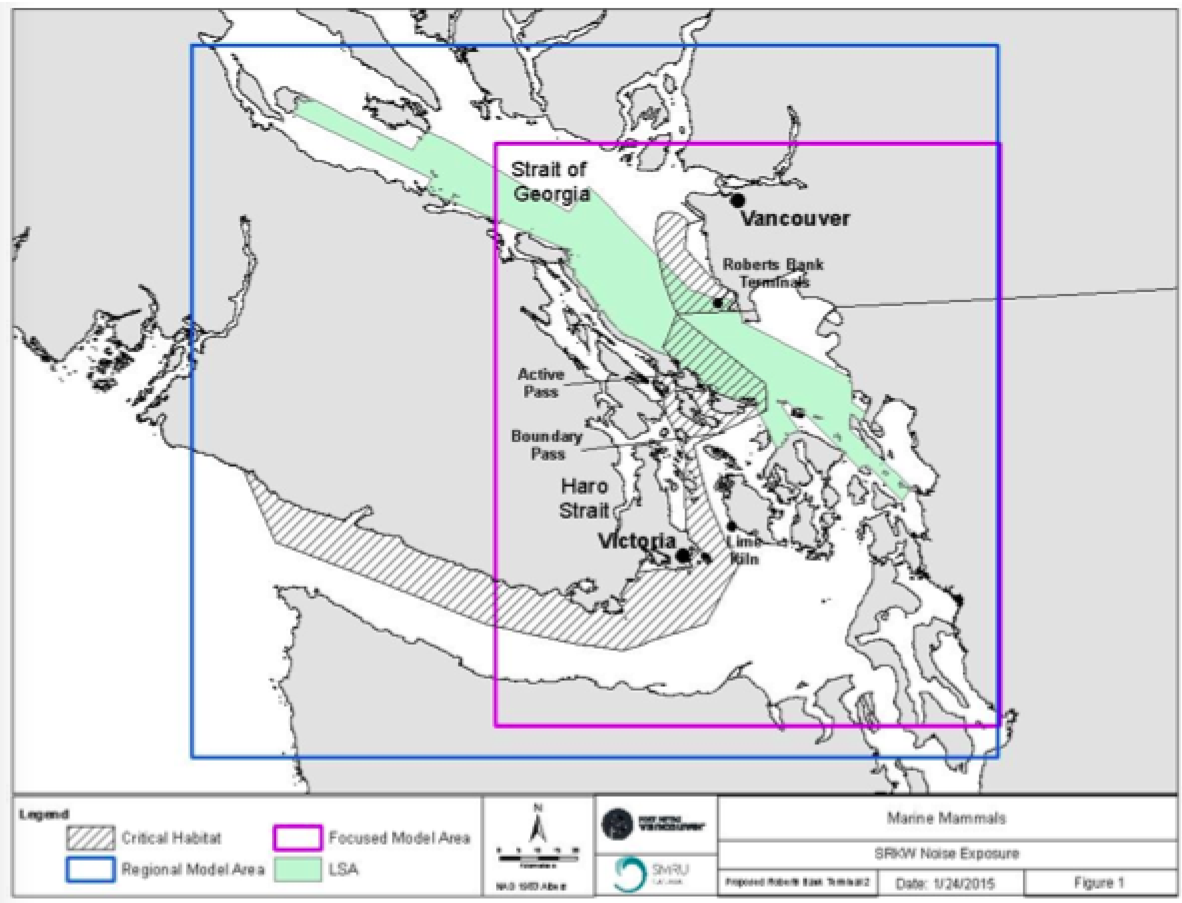
Figure 10: Relative Distance Between Robert Banks Terminal 2 and Proposed TMX Berths



(Source: Author, 2019 - Accessed from Google Maps)

Two specific areas of study were chosen, a modelled regional study area, which was 184 km by 208 km and covered 14, 750^2 km. Another smaller, more focused study area was also chosen to limit the scope and accommodate higher resolutions of marine traffic and SRKW frequencies in the area (refer to Figure 11) (SMRU Canada, 2014).

Figure 11: RBT2 - Modelled Regional Study Area (blue) and Focused Study Area (purple)



(Source: SMRU Canada, 2014)

4.1 Regional Study Area

Researchers identified four scenarios to be investigated: (S1) Existing commercial vessel traffic in 2012; (S2) Future commercial vessel traffic with no new projects except RBT2, and future incremental vessel traffic associated with RBT2 in 2030; (S3) Future commercial vessel traffic due to certain and foreseeable projects without RBT2 in 2030; and (S4) Future commercial vessel traffic with RBT2, incremental shipping traffic associated with RBT2, and future vessel traffic due to certain and foreseeable projects in 2030, which would include the TMX (SMRU Canada, 2014). For each of the four scenarios, the researchers investigated the spatial extent that the SRKW were exposed to noise pollution, the consequential behavioural differences, and the degree of acoustic masking affecting the whales (SMRU Canada, 2014).

4.1.1 Temporal Scope

Data was divided into two categories, due to seasonal variability of marine traffic and SRKW sightings - summer (May through September) and winter (October through April). The two seasons also account for differences in sound transmission (JASCO, 2015). Vessel Traffic Operational Support System (VTOSS) data was analysed between January and July 2010 and were compared against SRKW data between 2001 and 2011 (SMRU Canada, 2014). Data was adjusted where applicable to reflect 2012 marine traffic.

4.1.2 Data Inputs

4.1.2.1 Modelled Ship Noise

Data was adopted from four 2010 VTOSS acoustic model scenarios (JASCO, 2015) and AIS data. Vessels were categorized based on type, location, track, size and speed, and subsequently placed into fourteen different categories based on their classifications (SMRU Canada, 2014). Month-long average broadband noise levels were generated by commercial vessels in each of 800 m by 800 m grid cells in the regional study area (SMRU Canada, 2014). It was determined that broadband model outputs would be used due their appropriateness for noise exposure metrics for the SRKW.

4.1.2.2 SRKW Relative Density

Data was adopted both from the Canadian-based B.C. Cetacean Sightings Network (BCCSN, 2014) and the U.S.-based Orcamaster. Sightings from both these programs were provided by a number of whale-observers including scientists, researchers, lighthouse keepers and the general public, located mainly in the southern coast of B.C. and the northern coast of Washington (SMRU Canada, 2014). Data was adjusted to account for observer efforts, based on a model developed by the Vancouver Aquarium (Hemmera, 2014).

4.1.3 SRKW Behavioural Responses

Data showed that the areas in which exposure levels were highest for all four scenarios were in the Haro Strait, Boundary Pass and Active Pass (SMRU Canada, 2014). Although there was an increase in exposure levels from S1 to S2, it was a fairly negligible change and was also concentrated in the three aforementioned locations, highlighting that the commercial traffic was already high in the existing conditions of S1. As predicted, exposure levels were lower in the winter season, demonstrating the differing distribution patterns of the SRKW during these months.

In terms of behavioural changes induced by noise pollution, researchers developed a finer-scale "focused" simulation model to investigate low-severity and moderate-severity changes for each of the scenarios (SMRU Canada, 2014). High-severity behavioural changes were not included in this study, as it was not predicted to occur as a result of any of the four scenarios. Researchers collected data regarding broadband underwater noise estimates in 24-hour time windows, the relative density of the SRKW, the monthly probability of occurrence of the SRKW, and finally behavioural disturbance dose-response curves in order to calculate the severity of the behavioural changes (SMRU Canada, 2014).

4.2 Focused Study Area

The second part of the RBT2 Study was the Focused Noise Exposure Study, which was based on a smaller study area, as mentioned earlier. This was to allow for a higher temporal and spatial resolution, consequently allowing for more accurate results (SMRU Canada, 2014). The main objective for this study was to determine the underwater sound levels in the study area every five minutes, and the effect on the SRKW, over a one-year study period. Like Part 1, researchers investigated low-severity and moderate-severity behavioural responses to noise pollution, as well as acoustic masking when behavioural changes were not predicted (SMRU Canada, 2014). Because of the focused study area, researchers were also able to study the SRKW based on their respective pods; J, K and L.

4.2.1 Temporal Scope

Data inputs were based on VTOSS noise exposure estimates of two full 24-hour days; January 19, 200 and July 16, 2010. These two dates were used to represent the winter and summer seasons, respectively, because of their most complete temporal coverage (SMRU Canada, 2014). This data was then cross-examined with SRKW relative density data, similar to the regional study.

4.2.2 Data Inputs

4.2.2.1 Modelled Ship Noise

The methodology used to model the ship noise was the same method as in Part 1. Broadband underwater noise estimates were taken from JASCO 2014 and modeled for two scenarios; (1) a day during the summer months with complete coverage over time (288 5-minute windows); and (2) a day during the winter months with incomplete coverage over time (286 5-minute windows). The incomplete coverage of the winter data was due to incomplete or unusable track segments, and was corrected for by infilling with the median response of the JASCO noise levels (SMRU Canada, 2014). Due to variability in underwater noise propagation during different seasons, the summer data was used to represent the months from April to October, and the winter data was used to represent the months from November to March.

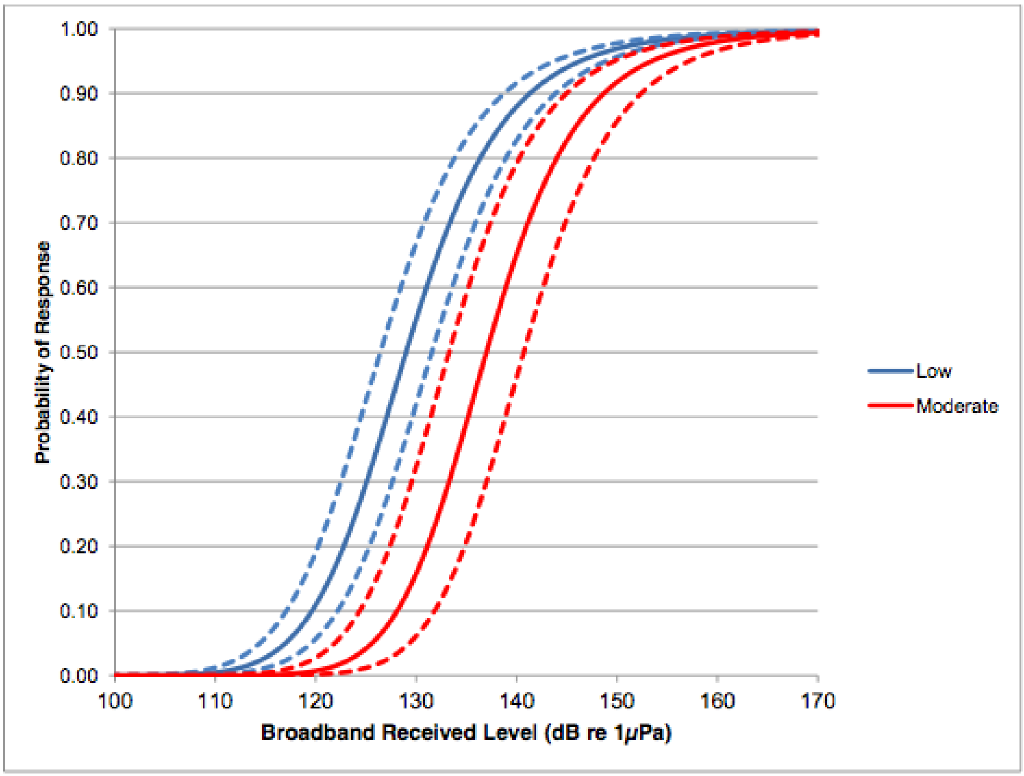
4.2.2.2 SRKW Relative Density

Similar to Part 1, the same SRKW effort-corrected sightings were used for the focused area study. The data was further divided into the three respective pods, and monthly marginal probabilities were investigated of each of the pods' occurrences. For all three pods, July and August were found to be the highest-sighted months, which are also the months in which the three pods are most likely to be found together. For each day of the 365-day study period, the whales were modeled to be in various locations in the study area, based on their monthly occurrence estimate.

4.2.2.3 Dose-Response Curves

Dose-response curves were modelled to investigate the relationship between ship-noise and SRKW behavioural changes. Again, high-severity behavioural responses were not predicted to occur, due to the unlikeliness of the situation.

Figure 12: Dose-Response Curves Depicting Low-Severity and Moderate-Severity Behavioural Changes due to Ship Noise, with 95% Confidence Intervals



(Source: SMRU Canada, 2014)

4.2.3 SRKW Behavioural Responses

After studying the combined data between ship-noise and SRKW sightings, it was determined that SRKW were in the study area 182 days of the 365-day time period. It was determined that there was 1,482 low-severity behavioural responses and 624 moderate-severity behavioural responses per year per whale during pre-existing conditions, or Scenario 1, as described in the regional study (SMRU Canada,, 2014). Between Scenario 1 and Scenario 2, there was a 5.0% increase in low-severity behavioural responses, and a 4.2% increase in moderate-severity behaviour responses per whale per year (SMRU Canada, 2014). As predicted, behavioural changes were more common in the summer due to the higher SRKW occurrence during these months. Spatially, the highest response changes occurred in the Haro Strait during the summer months, while in the winter, the responses were more evenly distributed through the study space (SMRU Canada, 2014).

Chapter 5: Case Study II - Enhancing Cetacean Habitat and Observation (ECHO) Program

A significant factor that was missing in the initial RBT2 study was the consideration of recreational vessels. Whale-watching vessels are of particular concern, because of their extended exposure time and proximity to the whales. A follow-up study was published in 2017, which was commissioned by the Port of Vancouver's "Enhancing Cetacean Habitat and Observation (ECHO)" Program, to assess recreational vessels and their added impact on the SRKW. Researchers used a computer modelling system, much like the initial 2014 study, in order to predict SRKW distribution patterns during the summer months (May to September), and cross-analyzed this with whale-watch activity data (Tollit, Joy & Wood, 2017). Because recreational vessels are not required to be equipped with an AIS, an alternative approach was used to estimate the number of whale-watching vessels in the SRKW critical habitat. Researchers collected data in order to answer four significant questions; (1) if the boats are with the whales, (2) how many boats are with the whales, (3) how loud are the boats, and (4) how close the boats are to the whales (SMRU, 2017). The study area used was identical to the Focused Study Area of the initial 2014 study.

5.1 Whale-Watch Data Inputs

In order to assess the additive effect of whale-watching vessels, researchers needed to systematically consolidate their noise levels into the noise-exposure model. There is a proportional relationship between noise levels and the amount of boats that are present with the whales, which is prompted by the presence and location of the whales (Tollit, Joy & Wood, 2017). To answer the four questions highlighted above, proponents adopted data from several sources including the Whale Museum's Soundwatch Boater Education Program (Eisenhardt, 2012) and proximity data from Giles (2014).

5.1.1 The presence of boats with the SRKW

To determine whether the whale-watching boats were with the SRKW, researchers collected data of home ports and assessed how many of boats leave the ports on a daily average, and their average travel distances (Hemmera, 2014). They consulted with industry professionals and experienced marine biologists in order to better understand the commercial whale-watching activities in the area. Through this, they calculated relative whale-watching efforts and SRKW density during the summer months. They concluded that whale-watching activity is most prominent in July and divided the monthly averages of the other four months with the July average to obtain monthly modifiers. This allowed for each month to have its own spatial probability of whale-watching vessels being present with the whales (Tollit, Joy & Wood, 2017). Once a whale was found, it was assumed that the whale would be followed by whale-watching vessels for the rest of the day.

5.1.2 The amount of boats with the SRKW

Using TWM Soundwatch data from 2012, researchers were able to analyse how many boats were with the whales at a given time. The Soundwatch employees conducted a boat count, in which they calculated how many boats were within half a mile of the whales every thirty minutes. They deduced that during July peak season, whale-watching activity runs between the hours of 0900 and 1900 daily. Using this data, monthly distributions were created to use in a computer simulation model, which randomly predicted the number of boats with the whales per hour per day.

5.1.3 The amount of noise produced by the whale-watch vessels

The third important data input was the noise levels of the cumulative whale-watch vessels on a given day. Researchers adopted data from Holt et al. (2009), Hunt (2007) and Jensen et al. (2009) to calculate noise level generation of whale-watch vessels. Different factors influence the noise levels of whale-watching vessels including number of vessels, type, orientation, surrounding environmental conditions and speed (Holt et al., 2009). Researchers modelled ship noise relative to SRKW position by using a stationary research vessel and computer software. One hundred iterations were run in order to accurately predict both broadband and high frequency noise levels.

5.1.4 The proximity of the boats to the SRKW

Finally, in order to determine the whale-watch boat proximity to the whales, data was adopted from previous studies using aerial surveys and GPS locations. Researchers analyzed two possible whale pod distribution scenarios; clustered, when there were less than nine whale-watching vessels and assuming all the individuals are affected evenly, or distributed, when there were more than nine vessels and the individuals are affected at larger proportions (Tollit, Joy & Wood, 2017).

5.2 Key Findings and Conclusions

Adding the data inputs into the initial noise-exposure study, analysts found:

- Recreational vessels, more specifically whale-watching boats, cause behavioural changes that increase lost foraging time from 3 hours a day to 3.2 hours a day;
- There was a cumulative effect on the reduction of prey detection range when combining commercial and recreational vessels of around 12 percent to 37 percent;
- Whale-watching noise was the primary reason for acoustic masking of echolocation clicks; the whale-watching vessels added 1.7 to 2.3 hours of lost foraging time;
- Whale-watching vessels were responsible for one-third of overall lost foraging time, while commercial vessels made up the rest; and
- The study highlighted the different effects that vessels of different size, speed, and behaviour inflict on the SRKW (Tollit, Joy & Wood, 2017).

In conclusion, there is an additive cumulative effect when considering both recreational and commercial vessels that traverse the Salish Sea. It is important to examine all different vessel activities in the SRKW critical habitat, because although individual activities may appear insignificant, when added together, their impacts can be detrimental to SRKW survival.

Chapter 6: Cumulative Effects Assessment

Cumulative effects are defined on the Government of Canada website as “changes to the environment that are caused by an action in combination with other past, present and future human actions” (Canadian Environmental Assessment Agency, 2016). A cumulative effect assessment (CEA) is a study of the potential effects of a proposed project, taking into consideration the effects of other human projects and activities. Human actions, in this case, are defined as activities that cause disturbance to the surrounding environment (CEAA, 2016). Many professionals argue that CEAs are necessary, but difficult assessments to accomplish, as they normally require extensive data, longitudinal research, participation from multiple stakeholders and often complex prediction strategies. Due to these variables, the scoping phase of a CEA is complicated, in that practitioners are often faced with difficult decisions on regional scoping, temporal scoping, and how deep complex interactions should be assessed (CEAA, 2016). CEAs often require fairly large budgets, specialized professionals and long time commitments; however, CEAs are pertinent when considering environmental adverse effects because anthropogenic projects and activities very rarely occur in isolation of other activities. Project-specific Environmental Impact Assessments (EIAs) consider adverse effects of individually proposed projects, however, may not accurately represent real-life scenarios as cumulative effects are not assessed. In some cases, negative impacts may seem insignificant when considering only single project-specific effects, however, when including incremental effects by other projects and activities, the overall impact may be consequential. Currently, only certain Canadian projects require a CEA to be completed prior to project approval. In the recently released edition of the TMX EIA, Project proponents stated that although they recognize potential cumulative effects of the expansion project on the endangered SRKW, a cumulative effects assessment was not done due to the fact that marine traffic continues to grow in the Salish Sea regardless of whether or not the Project was to be approved. They further argue that the predicted sevenfold increase of tanker traffic induced by the Project is not a significant change when considering the growth of overall marine traffic that is predicted to occur in the next few years.

Throughout my research, it was evident that a CEA must be conducted on marine traffic and its effects on the SRKW, due to the whales' current vulnerable state and the ongoing growth in activity within their critical habitat. Regardless of project or activity size, it is pertinent to consider all incremental additive effects, as the whales are considered a Valued Ecological Component (VEC) due to their endangered status. This will also allow for a better understanding of mitigation methods and techniques that should be adopted by the various industries in an attempt to conserve the SRKW population.

6.1 Trans Mountain Expansion Project

The Trans Mountain Expansion Project has made national headlines, with citizens from different parts of the country either pushing for its economic benefits or fighting against its environmental impacts. The controversial Project sparked back-and-forth discussion for the past few years, as it was approved, overturned, and finally approved again by the federal cabinet in June of 2019. The Project is expected to be completed by 2022, despite social backlash regarding adverse impacts on the SRKW and disapproval from various Indigenous Nations.

The initialTrans Mountain pipeline is 1,150-km in length and was constructed in the 1950s. It has since transported thousands of barrels daily of crude oil and refined products from Edmonton, Alberta to export terminals in BC and Washington (The Narwhal n.d.). Figure 13 below is the profile of the Trans Mountain Pipeline.

Figure 13: Pipeline Profile: Trans Mountain

(Source: National Energy Board, 2019)

The original project was regarded as an outstanding feat, as the pipeline transects different geographical regions, including mountainous terrain and rivers of various sizes. Initially, the pipeline throughput reached 75 000 barrels per day (BPD), with two operating pump stations (Kheraj, 2013). With additional pump stations, the pipeline eventually reached a maximum capacity of 300 000 bpd (Kheraj, 2013). Stakeholders pushed for the construction of the TMX and argued that it was essential in the future of Alberta's oil and gas, and it's competition in international markets. BC government was also fully onboard with the idea of the project and supported its approval.

Since its initial operation, the TMP has undergone numerous expansion and renovation projects, including the Westridge Marine Terminal project in 1957 and the Anchor Loop Project in 2008. It was in 2012, that Kinder Morgan, the previous owners of the pipeline, proposed the TMX project, in order to parallel the existing pipeline and increase delivery capacity. With the completion of the expansion, throughput capacity is expected to reach up to 890, 000 bpd. Consequently, marine traffic would also increase from around 5 tankers per month to up to 34 tankers per month. Two berths will also be added to the marine terminal in order to accommodate the increase in delivery capacity (Government of Canada, 2019b).

6.2 Salish Sea Marine Traffic CEA

In order to conduct a meaningful cumulative effects assessment, I collected the data from the literature and published studies of the different industries, and compared the amount of sailings per year, their approximate exposure times to the whales and finally, their average speeds. By studying these factors, I am able to highlight which industries and to what extent their noise pollution affects the whales. Table 2 below displays the relative number of sailings for each industry and average speeds, based on literature review.

Table 1: Annual sailings and average vessel speeds of the vessel types in the Salish Sea

Vessel Type	**Sailings per Year**	**Average Vessel Speed (knots)**
Cruise Ships	650	18
Military	14, 000	-
Tankers/Cargo	22, 600	18-20
Ferries	340, 000	16
Recreational	420, 000	10

(Source: Author, 2019)

6.3 Environmental Impact Assessment Leopold Matrix

Leopold matrices are used in the Environmental Impact Assessment industry as a tool to visually assess various project activities and their level of impact on the environment and other VECs. Shown below is a Leopold matrix that depicts the different marine traffic vessels that occur in the Salish Sea and their estimated impacts on the SRKW. The matrix is organized with project descriptions/activities on the horizontal axis, and environmental concerns on the vertical axis. In this study, I included only those environmental concerns associated with the SRKW. Each cell of the matrix is divided into magnitude of the impact on the environmental aspect, and significance of the impact (Saurab, 2016). Researchers subjectively assign a rating between 1 and 10 to each cell, according to collected data. Empty cells represent project activity with no significant impact on SRKW.

Figure 14: Leopold Matrix

VEC / Project/Activity	Cruise Ships	Military	Tankers/Cargo	Ferries	Recreational
SRKW Habitat Disruption	4 / 4	6 / 8	7 / 8	7 / 9	10 / 10
Noise Levels	4 / 3	7 / 8	8 / 8	7 / 8	8 / 9
Proximity to Whales	2 / 6	7 / 8	6 / 8	8 / 8	10 / 9
Contamination Risks	4 / 6	6 / 6	8 / 9	6 / 8	6 / 7
Speed Concerns	8 / 7	7 / 8	7 / 8	6 / 8	5 / 6

(Source: Author, 2019)

6.3.1 SRKW Habitat Disruption

Cruise ships were rated of least significance and magnitude to habitat disruption due to their comparatively low number of sailings per year and their minimal amount of time spent in the SRKW critical habitat. Recreational vessels, on the other hand, were rated of highest significance and magnitude. This is due to the fact that whale-watching vessels, specifically, follow the whales for consequential amounts of time during the summer months, and often committing no-go zone infractions. Recreational vessels also have the highest amount of sailings in one year. All other industries were rated in the middle and were graded based on their time spent in the habitat and the amount of sailings per year.

6.3.2 Noise Levels

Tankers, military and ferries were all rated relatively the same in terms of noise levels. This is due to their similar, large sizes, which is proportionally related to noise-levels. Larger, deeper ships have been proven to cause noise levels that are harmful to the whales. Although cruise ships also cause similar noise levels, their time spent in the critical habitat and the relative number of sailings caused their ratings to be lower. Recreational vessels are rated at the highest, because it was shown that smaller vessel-induced noise does affect the whales. It is particularly concerning due to their time spent in the critical habitat and their constant proximity to the whales.

6.3.3 Proximity to the Whales

Highest rating for proximity to the whales goes to recreational vessels. Whale-watching vessels, specifically, often commit no-go zone infractions and are guilty of colliding with marine mammals. Although the other industries traverse the SRKW habitat, they are not purposely in search of the location of the whales.

6.3.4 Contamination Risks

Tankers had the highest rating for contamination risks due to the fact that they carry oil. Tankers are able to transport oil and by-products, which create different risks for the SRKW depending on the type and amount of product being transported. Currently, there are no rehabilitation methods for individuals affected by oil spills, which increases problem significance.

6.3.5 Speed Concerns

All of the above vessels operate at speeds that are higher than the recommended speed by the ECHO program. Cruise ships and ferries are particularly concerning because of the fact that they must comply with strict passenger schedules and are less likely to voluntarily lower speeds.

Although the Leopold matrix lacks temporal and spatial effects of the activities on the VECs, its simplicity allows for easy completion and interpretation. Each assessment is assigned subjectively, based on the assessor and the available data. Completing the matrix allowed for reflection on each of the industries and their relative impacts on the whales. From the matrix, it is evident that each of the industries impact the whales to various extents, as individual, isolated activities.

It was proven in the RBT2 case study that commercial and recreational marine traffic create noise that causes adverse impacts on the SRKW populations, including reducing foraging range, increasing acoustic masking and causing behavioural responses. In addition, when considering all activities together, they increase the adverse effects by significant percentages. Although there is some truth to the statement made by TMX proponents that the predicted added tanker traffic is minimal compared to future activity in the Salish Sea, the status of the SRKW and the baseline conditions of their critical habitat causes any and all addition of activity to be concerning.

Chapter 7: Mitigation Methods and Recommendations

7.1 Canadian Mitigation Measures and Recovery Strategies

After one year of lengthy consultation sessions with SRKW Technical Working Groups (TWGs), the DFO released an "Update on Recovery Measures for the Southern Resident Killer Whale report" in April 2019. TWGs are made up of subject matter experts including individuals from academia, Indigenous communities, whale-watching industry and various levels of government, who were assigned to propose mitigation plans that can be implemented in late 2019 and onwards (Government of Canada, 2019c). The three main threats identified in the mitigation plan were prey availability, physical and acoustic disturbance and contaminants.

In terms of vessel management, TWGs proposed suggestions for mitigating small vessels, commercial vessels and contaminants. Different areas of focus were chosen, the SRKW critical habitat, proposed enhanced management areas and key foraging areas, as depicted in the image below. Small vessel management measures include voluntary and mandatory measures in each of the areas of focus. Among these measures included turning off echo sounders when not in use, 400 metre approach distances in Fishery Closure Areas, 1000 metre go-slow zones and no-go zones in Swiftsure Bank, South Saturna Island and West Pender Island (Government of Canada, 2019c). For commercial vessels, there are currently no mandatory regulations regarding the safekeeping of the SRKW in any of the areas of focus. The same ECHO Committee members of Port of Vancouver discussed in Part 6, also proposed an expanded slowdown area trial, starting June 1, 2019. It was suggested that commercial vessels travel between 11.5 and 14.5 knots in the 29.6

nautical-mile zone, which was extended from the 2018 trial (Government of Canada, 2019c). Committee members anticipate an 80% voluntarily participation rate, noting an 88% participation rate in 2018.

In an attempt to mitigate contaminants, TWGs are focusing on long-term impacts and solutions. Measures include extending the 2012 “Amend the Prohibition of Certain Toxic Substances Regulations” to include five more chemicals, including flame retardants and oil and water repellent (Government of Canada, 2019c). The TWG also aim to increase monitoring of waste disposal and studying the sources of contaminants to determine their pathway to aquatic environments. There is currently a 2020 goal of identifying which contaminants are specifically affecting the whales and their preferred prey and establishing a database to estimate and mitigate pollutants in the Salish Sea.

7.2 United States Mitigation Measures and Recovery Strategies

In December of 2017, the NOAA released “Reducing Disturbance from Vessels to SRKW: Assessing the Effectiveness of the 2011 Federal Regulations in Advancing Recovery Goals” (Ferrara, Mongillo & Barre, 2017). In this report, professionals assessed the effectiveness of past vessel regulations and made suggestions for changes to these regulations. In March of 2013, the NMFS held workshops for stakeholder input regarding the regulations and their effect on the SRKW. This allowed an opportunity to review monitoring measures, study available industry and economic data and recognize data gaps (Ferrara, Mongillo & Barre, 2017). In addition to workshops, the NOAA supported education and outreach initiatives to promote compliance within the marine vessel industry. Voluntary and mandatory education programs were established to reach out to the public and enhance regulatory compliance. This program was in partnership with TWM Soundwatch Boater Education Program, who employed staff and volunteers to educate the public on proper SRKW etiquette, and mandatory federal and state regulations (Ferrara, Mongillo & Barre, 2017). It was in 2010 that the NMFS determined that voluntary compliance was not an adequate approach to protect the whales. It is especially important for recreational vessels to be educated on regulations, as they are proven to commit the most infractions when it comes to proximity to the whales. Continual reviews and changes to education programs are within the NOAAs mitigation goals.

Like Canada, the U.S. has also implemented voluntary and mandatory regulations for vessels traversing the SRKW critical habitat. Most vessel operators, once educated on the rules, show motivation to protect the whales out of moral obligation, social influences or fear of sanctions (Ferrara, Mongillo & Barre, 2017). As predicted, vessel operators are more likely to comply with mandatory regulations as opposed to voluntary guidelines. This is especially true when regulations are clear and easy to follow. Since 2004, the NOAA has adjusted vessel regulations to better abate harm to the whales. Law enforcement officers were officially given funding between 2004 and 2009, to conduct summer patrols focusing on vessel harassment to the SRKW. In 2013, there was a growth in summer patrols, in which warnings and citations were given to vessels of various industries. It was proven in 2015 that with officers from the Washington Department of Fish and Wildlife present, numbers of observed incidents decreased significantly, as depicted in the graph below. This concludes that education and outreach programs are insufficient in guaranteeing compliance, while law enforcement proves to influence operator cooperation from both commercial and recreational vessels.

Figure 15: Number of Observed Incidents With and Without Law Enforcement Present

(Source: Ferrara, Mongillo & Barre, 2017)

In terms of vessel slow-downs, the NOAA recognized the importance of travelling at certain speeds in order to reduce noise-exposure levels. However, unlike Vancouver's ECHO Program, there was no voluntary regulations established to influence vessel speed in the SRKW critical habitat. NOAA researchers continue to study the relationships between sound levels and adverse effects and aim to propose mitigation plans that will minimize negative impacts.

7.3 Recommendations

Both Canada and the U.S. have tried and tested different methods in order to protect the whales. It is evident that vessel slow-down regulations, education programs and law enforcement are all pertinent steps in ensuring compliance. During my research, it became obvious that the main missing key in mitigation measures by both governments was working collaboratively in order to bridge the gap between regulatory differences. This is especially important when considering the whales' trans-border migratory patterns. It is essential that regulations from either side of the border are similar, to ensure the whales do not experience different stressors from different parts of their critical habitat. For example, right now, Canada does not have a law-enforcement program in place to ensure regulatory compliance, while the U.S. has not invested in a slow-vessel down program. These are measures that should be analysed by both countries to maximize success.

Chapter 8: Conclusions and Recommendations

8.1 Conclusion

The SRKW population holds historical and cultural importance to the communities living around the Salish Sea, economic significance to both Canada and the United States, and biological importance to the Salish Sea habitat. The objective of this study was to investigate the major adverse impacts on the endangered SRKW and to determine whether the marine traffic noise in the Salish Sea induces a cumulative adverse effect. This is especially important because Proponents of the Trans Mountain Expansion Project experienced backlash against the Project, from regulatory bodies and the general public who expressed a concern for the lack of review on the SRKW. Although the Project was eventually approved in June 2019, efficient mitigation measures and cooperation between stakeholders is very pertinent in order to ensure the survival of the SRKW population.

A literature review was conducted in order to fully comprehend the background of the SRKW. Specifically, a literature study was done on (1) Southern Resident Killer Whale biology, (2) noise effects on the SRKW, (3) major threats to the SRKW, including the aquarium trade, prey decline, contaminants and noise exposure, and (4) marine traffic in the Salish Sea. Marine traffic was the main focus of this study, because the main associated threat with the TMX Project is the increased noise exposure levels. Literature review of marine traffic in the Salish Sea revealed the vessels that traverse the SRKW critical habitat and their type, size, speed and number of annual sailings. Two case studies; the Robert Banks Terminal 2 Project and the Enhancing Cetacean and Habitat

Observation (ECHO) Program, were studied in order to determine the extent to which the SRKW are affected by commercial vessels and recreational vessels. Through the literature review and case studies, it was evident that all vessel traffic in the Salish Sea causes an adverse effect on the SRKW, which is augmented cumulatively by the various industries. Commercial vessels were proven to induce behavioural changes in the SRKW individuals, which increased when including recreational vessels as well, as shown by the two case studies.

Using a Leopold matrix, I determined which of the vessel industries, tankers/cargo, military, cruise ships, ferries and recreational vehicles, induce an adverse effect on the VECs associated with the SRKW. This includes habitat disruption, noise levels, proximity to the whales and contamination risks. Subjective grading was given to each of the categories, to investigate their individual effect on the SRKW. Through this visual, it became evident that each industry induces a significant adverse effect, by affecting a VEC in one way or another. This is especially true when considering the very sensitive status of the SRKW, and their predicted low survival rates.

8.2 Recommendations

It has become evident that CEAs are necessary, albeit often difficult, to complete in the EIA process in order to thoroughly investigate the effects on VECs. In the case of the endangered SRKW, there are many studies that have been done, but the lacking piece was the cooperation between different stakeholders. This includes but is not limited to; governmental bodies, project proponents, commercial and recreational businesses, scientists and researchers, and environmental groups. If cooperation between the different stakeholders was encouraged, data gaps could be more easily addressed. As well, if there was more collaboration between different jurisdictions, such as the provincial/state and federal governments of the United States and Canada, there may be easier techniques to implement mitigation strategies that are more effective and uniform throughout the critical habitat.

Now that the TMX Project has been approved and is set to begin construction by 2022, the new focus for the Proponents should be the Monitoring and Follow-up portion of the CEA. In order to conduct a meaningful follow-up on the adverse effects on the SRKW, it is still significant to consider the other past, present and reasonably foreseeable future anthropogenic activities and projects that can induce a cumulative effect on the SRKW.

Chapter 9: Limitations and Future Research

9.1 Limitations

Research limitations that came up were as follows:

- Limitations on military information. Although the NWTT highlighted proposed testing and training activity, information on military vessels (ie: speeds, types) were not as readily available
- Temporal variance in data. This is especially true for the Soundwatch data, where recreational vessels were gathered in 2012. Although this data is not very outdated, activity in the Salish Sea is constantly growing, thus may not be as representative of 2019 vessel traffic.

9.2 Future Research

- Future research would include considering the other major adverse threats, such as contaminants and prey decline, into the CEA
- Currently, there are studies using drone technology to study the whales and other marine mammals. This would aid in updated data for the SRKW distribution, especially in the winter.

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Appendix A

Table I: Analysis of Potential Project Effects on the Southern Resident Killer Whales

Information Elements	**Considered (Y/N)**	**Description**
Species at Risk (SAR) Information		
Name of the SAR	Y	Southern Resident Killer Whale (*O.orcinus*)
What is the status of the SAR?	Y	Endangered, under: - Canada Species at Risk Act, 2003 - U.S. Endangered Species Act, 2005
What are the current population trends?	Y	Declining
Which threats have been identified as being the cause of the precarious status of the SAR?	Y	Aquarium trade, prey decline, contamination and marine noise and disturbance
Has the SAR recovery team been consulted?	Y	Yes
Are there any other known vulnerabilities that should be taken into consideration?	Y	SRKW are most commonly present in the Salish Sea during the summer months (May to September), which coincides with peak anthropogenic marine activity such as tourism
Are any residences or known critical habitat present?	Y	Critical habitats for the SRKW are identified by both the Canadian and U.S. governments
Are there any key ecological processes on which the SAR particulary depends?	Y	The SRKW rely heavily on the proliferation of Chinook Salmon, who are facing imminent threats of extinction and toxin bioaccumulation
Any timing considerations or other relevant considerations?	N	
SAR Interactions with Project		
Which project components could interact with SAR?	Y	- Increased marine traffic (predicted sevenfold increase) and associated noise-levels - Construction of terminal berths

		- Contamination risks (ie: oil spills)
Where is the SAR located within the project zone of influence?	Y	Project location and SRKW critical habitat intersect
Has a habitat map of the project area or zone of influence been developed?	Y	Yes
What is the proportion of the population that uses the project study area?	Y	Up to 100% of the population at a given time
Can the project affect potentially limiting intrinsic attributes of the SAR?	Y	Including communication methods such as echolocation clicks
How will the project contribute to the threats to the SAR that have been identified in a recovery strategy, action plans or management plans?	Y	Through the additive effects of noise pollution with a predicted sevenfold increase in tanker traffic
Cumulative Effects		
What are the pressures that are thought to be negatively affecting SAR population viability, other than the project?	Y	- Prey decline, specifically Chinook Salmon - Contaminant exposure - Aquarium trade recovery - Noise from other anthropogenic activities
How would the project contribute to/affect these other pressures?	Y	Added noise pollution and contamination risks
Are there other existing activities or projects, or likely future activities or projects, that will exacerbate the pressures?	Y	Growth of activity in the Salish Sea including commercial and recreational activities
Recovery		
Has the SAR recovery team been able to recommend appropriate alternatives or mitigation measures?	Y	Example: Port of Vancouver Enhancing Cetacean Habitat and Observation (ECHO) Program

How can the project influence recovery of the SAR?	Y	May hinder the recovery of the SRKW
Analysis of All Effects		
Summarize all potential effects listed above	Y	Incremental additive effects between the continuously declining prey populations, bioaccumulation of toxins, habitat disturbance through marine traffic, and recovery from whale captivity
How many individuals may be affected?	Y	Up to 75 members, the total number of members in the population
What would be the overall effect on the local/regional/national population?	Y	May lead to extinction
How long would the effect last? Is it reversible?	Y	In terms of noise pollution, there are multiple factors that will dictate if the effect is temporary or permanent, including but not limited to: - Source and size of noise - Frequency and duration - Proximity - Repetitiveness
Policies and Legal Requirements		
Are there legal requirements for listed wildlife species or habitat protection under SARA or territorial or provincial legislation?	Y	Both Canada and the US are working towards implementing legislation to help the future viability of the SRKW population

(Source: Author, 2019 - Adapted from Environment Canada and Parks Canada, 2010)