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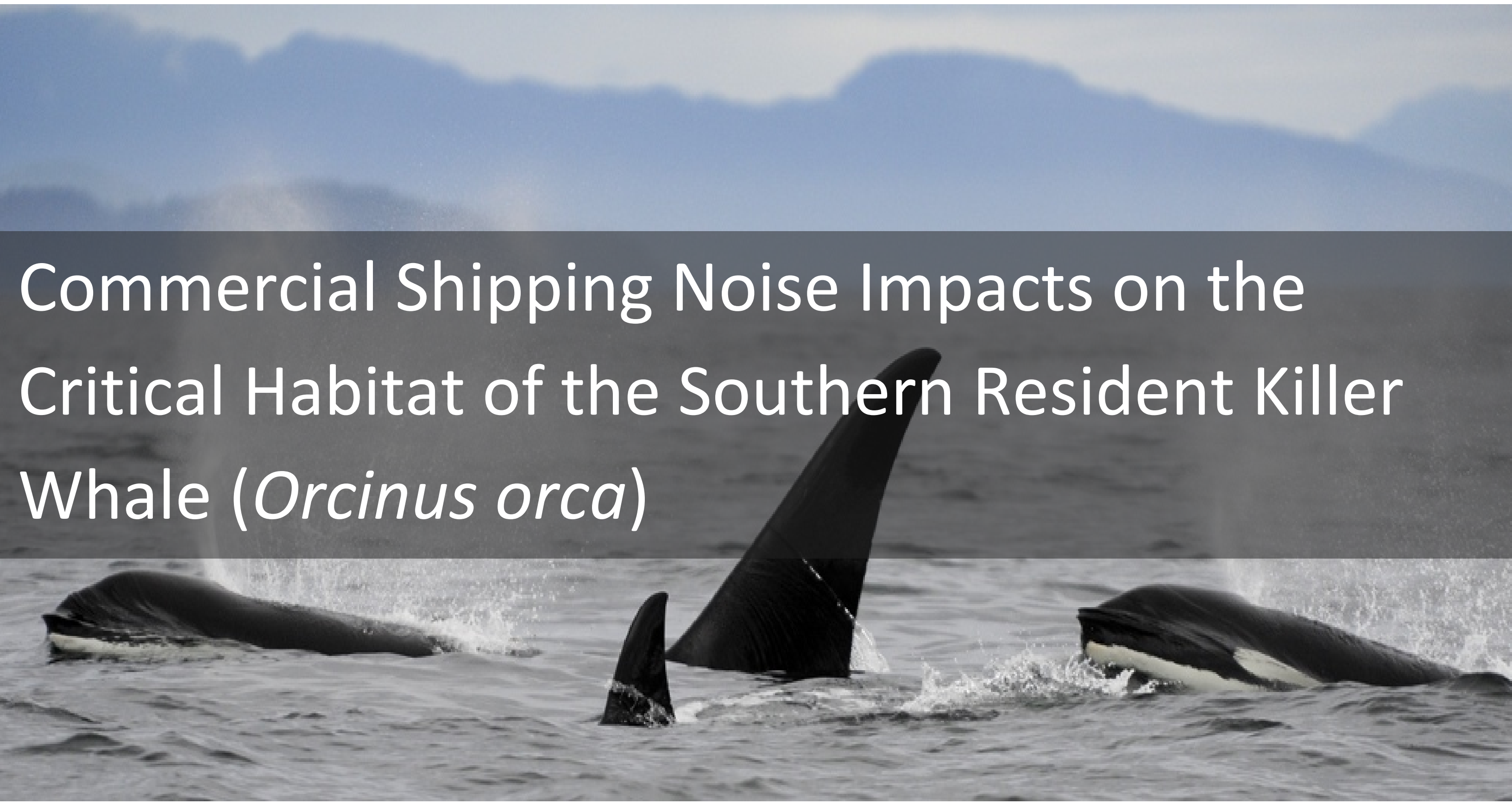

Commercial Shipping Noise Impacts on the Critical Habitat of the Southern Resident Killer Whale (*Orcinus orca*)

Danica Crystal | Kristina Moseley | Cassandra Paterson | Rebeka Ryvola | Shasha Wang

"Like the resource it seeks to protect, wildlife conservation must be dynamic, changing as conditions change, seeking always to become more effective."

- Rachel Carson, marine biologist and conservationist

This study was carried out as an undergraduate research project in environmental science (ENVR 400), a course at the University of British Columbia.
Cover photo: Steven Courson, Flickr

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About the Authors

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Executive Summary

Southern resident killer whales (SRKWs), found commonly on the south coast of British Columbia, are an endangered species struggling to maintain its population size. The critical habitat of the SRKW, an area important to the recovery of the species, is also an area traversed by commercial ships on a daily basis. Among other challenges to the whales such as habitat destruction and contamination, noise pollution produced by these commercial ships is one of the threats preventing the recovery of the SRKWs, through masking of whale communications. Masking, the interruption of killer whale vocalizations by background noise produced by ships, reduces group cohesion and forces the whales to spend more time and energy foraging, ultimately decreasing their ability to reproduce and sustain their population.

The Canadian Federal Court recently established that protection of this endangered species, managed by the Department of Fisheries and Oceans (DFO), must take into account the impact of noise pollution on the whales, a factor that has not yet been considered. With an expected increase in commercial shipping to BC facilitated by expansions at two ports, there is potential for further threats to the SRKWs through masking of vocalizations. The purpose of this study is to examine the current masking sounds created by commercial ships in the critical habitat of the SRKW and to determine whether imposing speed limits on ships can reduce the amount of masking that occurs.

The objectives of this study are to:

1. Identify the areas on the south coast of BC where ships have the potential to mask the SRKW vocalizations when the whales are inshore (May through October).
2. Determine the frequency of masking within these areas.
3. Model speed limit scenarios imposed on ships and assess the effectiveness of these limits at reducing masking sounds.
4. Recommend further research that will contribute to minimizing the effect of ship noise on this endangered population.

In order to identify the areas on the south coast of BC where masking occurs, we calculated the noise levels produced by ships traveling in and out of southern BC. Using GIS and data supplied by the Marine Communications and Traffic Services (MCTS) branch of the Canadian Coast Guard, we determined the spatial extent and frequency of masking generated by commercial ships. We then modeled speed limit scenarios of 10, 15, and 20 knots (kn) and calculated the reduction in total masking.

The key findings of this study are as follows:

1. 20% of all shipping activity produced noise loud enough to mask killer whale vocalizations.
2. The area affected by masking (Figure i) covers the majority of the Juan de Fuca Strait, Haro Strait, and Boundary Pass (Figure ii).
3. Masking was produced in Haro Strait and Boundary Pass 90% of days sampled during the study period. This area overlaps heavily with the critical habitat of the SRKW.
4. A speed limit of 20 kn did not create any reduction in masking, a 15 kn speed limit reduced the occurrence of masking by 30%, and a 10 kn limit reduced masking by 100%.

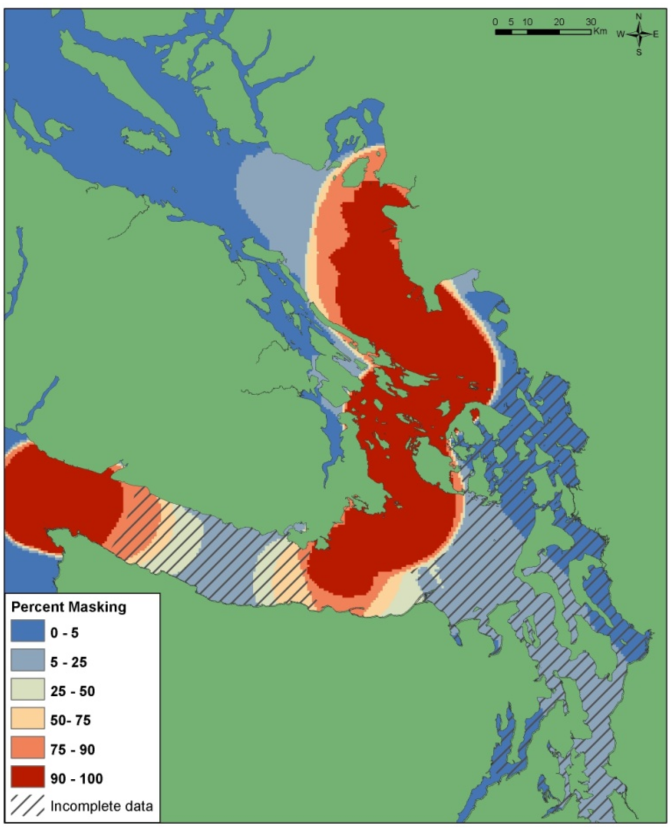

Figure i – Percent of time areas along the south coast of BC are subject to masking. Areas of incomplete data are shown due to limitations in available data. Data from: MCTS, UBC Geography, Washington Department of Ecology.

Figure ii. Geography of the south coast of BC. Areas that are important to this study are labelled here. Data from: UBC Geography, Washington Department of Ecology.

As a result of these findings, we present the following recommendations to better inform SRKW protection:

1. Further research is needed to better understand the ecologically important areas for the SRKW and to identify their physiological responses to masking.
2. Critical times of day for SRKW feeding, mating, and other social behaviour need to be researched in order to better inform shipping schedules.
3. Management strategies, including the development of marine protected areas, should consider the acoustic environment of the killer whales, which encompasses noise pollution created by nearby shipping traffic.
4. Because a 10 kn speed limit would cause a 100% reduction in masking, discussions around limiting speed should seriously consider implementing a 10 kn limit, especially in areas of concern for the SRKWs.
5. Because of the trans-boundary nature of the species, recovery of the SRKWs needs to involve cooperation and coordination between U.S. and Canadian organizations, both governmental and non-governmental.

This study has established that, within the study period, masking occurs on an almost daily basis on the south coast of BC. Masking has the potential to reduce the fitness of the endangered southern resident killer whales, a species that the DFO is mandated to protect. Further research is needed to determine the specific physiological effects of ship noise on killer whales; however, it is clear that masking occurs within their critical habitat and this could have detrimental impacts on the recovery of the species.

Introduction

Killer whales are a wildlife icon of the Pacific Northwest and are highly regarded by First Nations communities in British Columbia (BC) both culturally and spiritually (Fisheries and Oceans Canada [FOC], 2008). Killer whales also play an important role in BC's marine ecosystems as a top predator (Estes *et al.*, 1998). Ocean recreation, which includes whale watching, currently contributes $3.8 billion to the provincial economy (Ministry of Environment, 2008). Thus, killer whales serve important roles culturally, environmentally, and economically.

BC's coast is home to three populations of killer whales: southern resident, northern resident, and transient (FOC, 2008). The southern resident and northern resident populations have been identified as endangered and threatened respectively (FOC, 2008). To protect these populations, areas that are important for their recovery have been identified (FOC, 2008). Known as critical habitat, these areas are delineated by the Department of Fisheries and Oceans (DFO).

Due to port expansions on the south coast of BC, and an expected increase in shipping traffic, this research centres on the effects of commercial ships on the southern resident killer whales (SRKWs). Using geographical analysis, the extent of noise pollution along the south coast of BC was determined. In particular, this study focuses on noise pollution created by commercial ships with the potential to negatively affect the recovery of the SRKWs within their critical habitat.

In September of 2008, nine environmental groups, including the David Suzuki Foundation (DSF), Greenpeace, and Dogwood Initiative, took the Minister of Fisheries and Oceans (MFO) and the Minister of Environment (MOE) to federal court over the inadequate protection of the critical habitat of the SRKW (DSF v. MFO, 2010). On December 7, 2010, the court ruled in favour of the environmental groups and established that the current Protection Statement outlined by the DFO:

> "...fails to prevent the most significant threats to critical habitat: reduction in prey availability, toxic contamination, and physical and acoustic disturbance" (DSF v. MFO, 2010).

This ruling redefined the legal obligations of the DFO to protect the SRKWs. Following from this decision, our report focuses on acoustic disturbance as mentioned in the court's decision, and determines the prevalence of this disturbance generated by commercial shipping on the south coast of BC and its potential threats to the SRKW population.

Southern Resident Killer Whales

Killer whales (*Orcinus orca*) belong to the family Delphinidae and are the world's largest dolphins (FOC, 2008). The name "killer whale" originates from early whalers and is based on the species' predatory habits (FOC, 2008). This species is distributed throughout the world's oceans most commonly in coastal waters and at mid to high latitudes with fewer sightings in tropical regions (FOC, 2008).

As mentioned above, BC's coast is home to three populations of killer whales: southern resident, northern resident, and transient. Resident killer whales differ from transients in vocalization patterns, skull traits, prey, and pod size (National Marine Fisheries Services [NMFS], 2008). Furthermore, residents form large stable pods comprised of approximately 10 to 60 whales and feed primarily on salmon (NMFS, 2008). Resident killer whales spend about 50 to 67 percent of their time foraging and detect their prey through a combination of echolocation and passive listening (FOC, 2008). It has also been observed that most foraging occurs during the day (FOC, 2008).

The SRKW population is organized into pods. Pods share a common maternal ancestor making them more closely related to one another than to individuals from other pods (NMFS, 2008).The SRKW population consists of three pods – J, K, and L (FOC, 2008). As of 2008, there are 25 individuals in J pod, 19 in K pod, and 43 in L pod, for a total of 87 individuals (FOC, 2008).

During the months of May to October, the SRKWs are frequently sighted between Vancouver Island and the mainland (Ford, 1998). A high concentration of Chinook salmon migrating toward the Fraser River attracts the SRKWs to this region as the salmon are the primary food source for this population. In general, killer whales spend most of their time in the top 20 metres of the water column because salmon populations are highest within this depth (Baird *et al.,* 1998). Further, most mating is believed to occur from April to October (FOC, 2008). Distribution of and mating within the population during winter and early spring is largely unknown (FOC, 2008).

In 2003, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), under the Species at Risk Act (SARA), listed the SRKW as endangered because of its small population size, low reproductive rates, and anthropogenic threats to the species (FOC, 2008). Southern resident killer whales experienced an almost 20 percent decline from 1996 to 2001 (NMFS, 2008). The number of whales recorded in 1996 was approximately 100; however, the population declined to approximately 80 in 2001 (FOC, 2008). Since 2001, the population has shown some increase, and as of 2008, there were 87 SRKWs (FOC, 2008). In both Canada and the US, recovery plans were implemented with the goal of restoring the endangered southern residents to the point where they are no longer required to be protected under SARA and the Endangered Species Act (FOC, 2008; NMFS, 2008). This point is met when the populations demonstrates long-term persistence (FOC, 2008).

One of the recovery strategies outlined was to identify zones of critical habitat along BC's coast. Critical habitat is the area that is important to the recovery of the wildlife species and is based on breeding sites, nursery areas, and feeding grounds (FOC, 2008). Critical habitat for the southern resident killer whales (Figure 1) includes the Juan de Fuca Strait, Haro Strait, and Boundary Pass (FOC, 2008). Notably, commercial ships coming into the south coast of BC have increased dramatically between 1973 and 2003 (Figure 2), which is likely to have had adverse effects on the SRKW. Under SARA, the federal government is required to make sure that critical habitat is not destroyed and can develop restrictions on development and construction to protect these areas (FOC, 2008; DSF v. MFO, 2010).

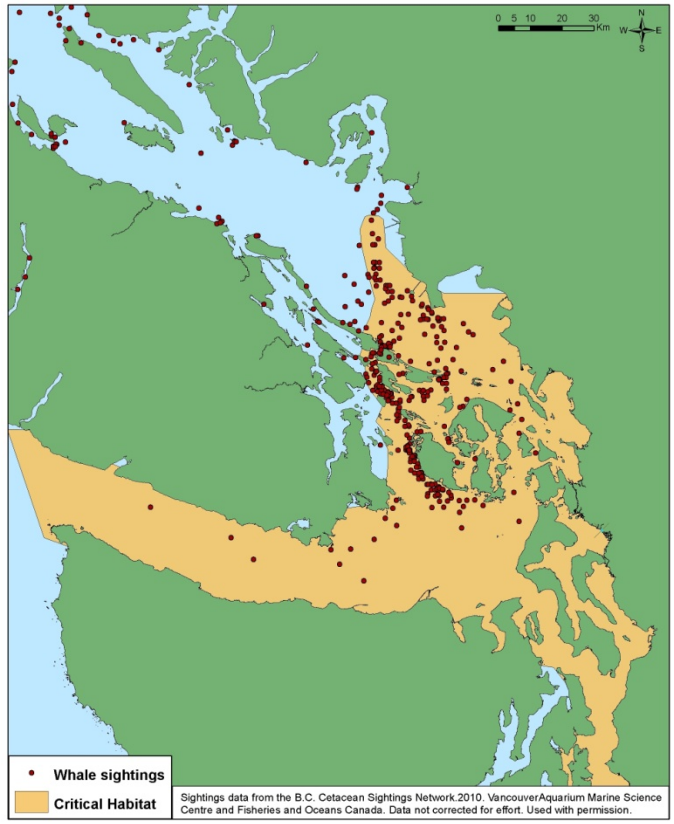

Figure 1 - Critical habitat of the southern resident killer whale, adapted from FOC (2008) and killer whale sightings. Data from: BCCSN, UBC Geography, Washington Department of Ecology.

Further, threats to the population identified by both the Recovery Strategy of the DFO and the U.S. Endangered Species Act (ESA) are prey availability, pollution, and effects from vessels and sound (FOC, 2008; NMFS, 2008).

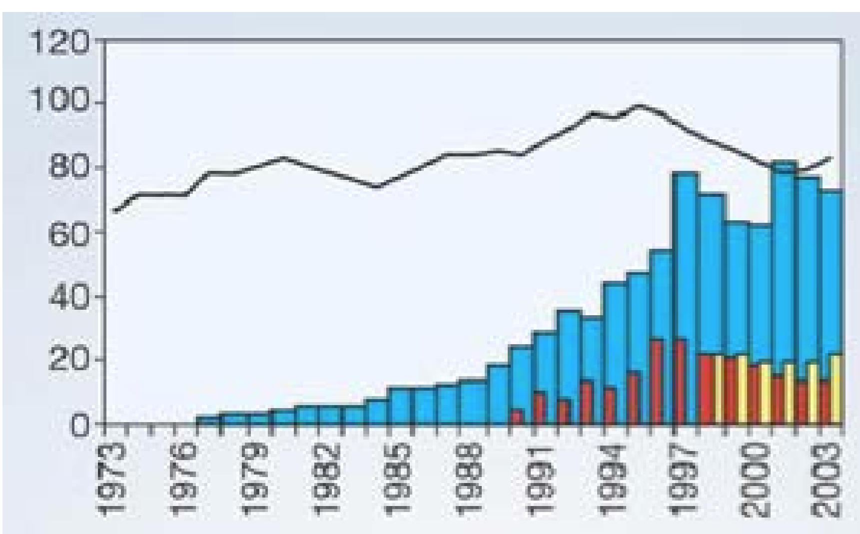

Figure 2 - Fleet size of commercial ships and whale watching boats as well as the southern resident killer whale population between 1973 and 2003. The solid line shows the size of whale population; blue bars show the number of active commercial ships per year; red bars show number of boats following whales; yellow bars show number of vessels following whales. (Adapted from Foote *et al.* 2004).

Port Expansions and Ship Traffic

In the summer of 2010, Port Metro Vancouver (PMV) completed Deltaport 3 (DP3), a port expansion at Robert's Bank, which is roughly 5 km from the nearest opening to the Fraser River (Terminal Systems Inc [TSI], 2009). This expansion increased the number of berths from two to three, allowing for more ships to dock at a time, and creating the potential for an increase in commercial shipping traffic. In addition, another expansion at Robert's Bank is currently in the planning stages; Port Metro Vancouver is set to develop a second terminal with three berths called the Terminal Two (T2) project (PMV, 2010). This expansion is proposed to be completed by 2020 and will increase the total capacity of the Deltaport to six berths. As the port increases in number of berths, there will be an increase in capacity and the ability to accommodate larger ships. Furthermore, container traffic from Asia-Pacific, the largest source of BC ship traffic, is predicted to increase by 300% by 2020 from 2005 numbers (Figure 3) (Ministry of Transportation and Infrastructure [MTI], 2005). Port capacity and shipping activity is increasing, necessitated by economic expansion throughout the Lower Mainland. Both of these expansions occur in the critical habitat of the endangered SRKWs. Concerns have been raised by the DFO as well as many Canadian environmental groups about the effects of noise pollution and ship traffic on the recovery of this species (FOC, 2008; DSF v. MFO, 2010).

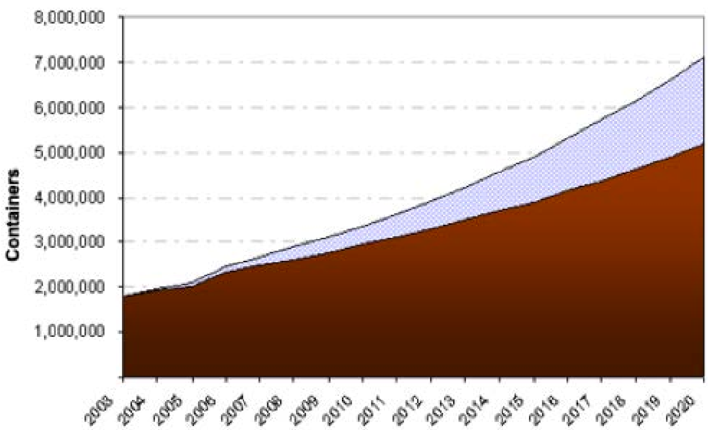

Figure 3 – Predicted upper limit (blue shading) and lower limit (brown shading) of containers (in twenty-foot equivalent units [TEUs]) coming through ports in BC from 2003 to 2020 (from Ministry of Transportation and Infrastructure [2005]).

Acoustic Impacts

Killer whales have 3 types of vocalizations: clicks, whistles and discrete calls. Clicks are used as echolocation signals and are emitted at frequencies up to 85 kHz (Ford, 1989). Whistles are used for close-range social activities and are emitted in the frequency range of 0.5 to 10.2 kHz, with an intensity range of 133 to 147 dB (Miller, 2006; Thomsen *et al.,* 2001; Thomsen *et al.,* 2002). Discrete calls are the most commonly observed vocalizations of killer whales and are used for foraging, travel, and social cohesion (Ford, 1989; Holt, 2008). While foraging, killer whales have been observed to use discrete calls 94% of the time (Thomsen *et al.,* 2002). For this reason, we chose to focus on this type of vocalization. Killer whales emit discrete calls in the frequency range of 1 to 10 kHz and in an intensity range of 133 to 168 dB (Holt, 2008; Miller, 2006). When these vocalizations are masked, the whales are

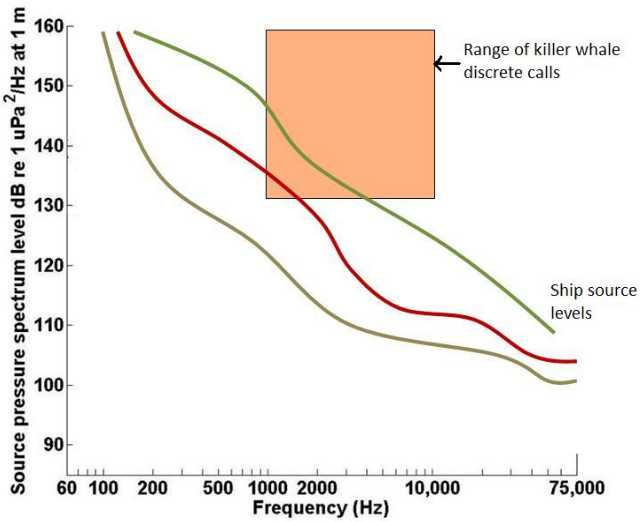

Figure 4 – Overlap of frequency and intensity between killer whale discrete calls and sound generated by commercial ships. Frequency, measured in Hertz (Hz), is depicted on the x-axis, and source pressure spectrum level is measured in decibels (dB) on the y-axis. Source pressure spectrum level is the intensity of sound at a standard unit of dB re 1 uPa^2/Hz at 1 m. The three lines represent high, moderate, and low estimates of source level produced by a ship traveling at 17-21 knots. (Adapted from Holt [2008]).

forced to spend more time and energy foraging, which can potentially decrease their fitness (Lusseau *et al.,* 2009).

There is an overlap between the frequency of sound generated by commercial ships and the frequency of discrete calls used by killer whales to communicate and forage (Figure 4) (Holt, 2008). When this overlap occurs at the same point in space and time, it is called masking. Furthermore, the ability of a ship to mask the discrete calls of killer whales depends on the intensity of the noise produced (Figure 4), measured in decibels (dB). Source level, the intensity of sound produced by a ship, is a function of ship length and the speed at which the ship is travelling (NRDC, 1946). With this knowledge, we were able to investigate the extent of masking within the SRKW critical habitat.

Objectives

Considering the potential negative effects of ship-generated noise on the killer whales' fitness, and the recent developments surrounding the Canadian government's commitment to the protection of the endangered southern residents, this report addresses the spatial and temporal characteristics of sounds generated by commercial ships traveling in and out of BC's ports. GIS (Geographic Information Systems) was used to determine the geographic areas along the south coast of British Columbia where ship-generated noise has potentially masked the discrete calls and, consequently, decreased the fitness of SRKWs. Since a decrease in speed reduces source level, we modeled speed limit scenarios of 10, 15, and 20 knots. By calculating areas of acoustic impact and evaluating the effectiveness of speed restrictions, we hope to identify ways in which the acoustic threats to the SRKWs can be minimized.

The objectives of this study are:

1. Identify the areas on the south coast of BC where ships have the potential to mask the SRKW vocalizations when the whales are inshore (May through October).

2. Determine the frequency of masking within these areas.

3. Model speed limit scenarios imposed on ships and assess the effectiveness of these limits at reducing masking sounds.

4. Recommend further research that will contribute to minimizing the effect of ship noise on this endangered population.

Methods

Study Design

Shipping data was obtained from the Canadian Coast Guard's Marine Communication and Traffic Services (MCTS) and whale sightings data was obtained from the BC Cetacean Sightings Network (BCCSN), a program run jointly by the Vancouver Aquarium and Fisheries and Oceans Canada. Shipping data included the coordinates, speed, lengths and ship type of all ships travelling near the coast of British Columbia. These data points were recorded every 1 to 6 minutes for all ships within the study area. Killer whale data was comprised of coordinates from reported sightings of killer whales near the coast of BC. It is important to note that the collection of BCCSN data is opportunistic and may not cover the entire range of the killer whales equally.

Because of the high density of commercial shipping arriving through the Juan de Fuca Strait, Haro Strait and Boundary Pass, we chose to limit our study area to the critical habitat of the endangered southern resident killer whales (Figure 2).This paper focuses on the impacts of commercial shipping, so ships types not directly related to commercial shipping were excluded (Appendix A). Any speeds below 1 kn were not included since they would result in an error in our calculation of source level, and any speeds above 30 kn were removed on the assumption that the ships considered cannot realistically reach such high speeds. All data analyzed is limited to the months from May through October of 2010, as those are the months when the southern resident killer whales are commonly found along the coast of British Columbia.

Data Analysis

We first calculated the source level for each data point from the MCTS ship data, using equation (1) (Adapted from National Defense Research Council, 1946),

$$SL = S_0 + 60\log(S) + 20\log(L) \quad [dB] \qquad (1)$$

where SL is source level (dB), S_0 is the baseline source level for a given ship type (dB), S is speed (kn), and L is length (m). We calibrated this equation using data presented by the National Research Council (2003), which was generated using the RANDI II model (Appendix B). By classifying the ships based on their length (National Research Council 2003), we were able to determine S_0 for each ship type at 1 kHz (Appendix C). Using S_0, the equation can be calibrated for each ship type and can take into account the speed and length of each ship in order to determine the source level for each individual data point. We used 1 kHz as a representative frequency within the band of communication of the whales, because this is a frequency at which ships emit noise loud enough to mask discrete calls of killer whales, the type of call most commonly used for foraging (Ford 1989, Holt 2008).

In order to determine how far the sound of any given ship would travel in water, we calculated the attenuation coefficient of sound at 1 kHz in seawater, using equation (2), the Thorp formula (Brekhovskikh and Lysanov, 2003). This formula is best suited for frequencies below 3 kHz even though it does not take into account the physical properties of the water body (Box 1) (Brekhovskikh and Lysanov, 2003).

$$\beta = \frac{0.11f^2}{1+f^2} + \frac{44f^2}{4100+f^2} \quad \text{[dB/km]} \qquad (2)$$

The attenuation coefficient, found to be 0.0657 dB/km, was inverted to determine the distance it takes for the source level to decrease by 1 dB. This distance is 15 km and represents the distance in which intensity remains within the range of masking. We buffered every ship location with a source level between 133 and 165 dB by 15 km to create an area where whale communication could be masked by the noise generated by ships. This range of sound intensity was chosen because it corresponds to the intensity range of killer whales' discrete calls (Miller, 2006). The total area affected by masking within our study period was calculated as the area of cumulative masking.

Box 1 – Ocean Acoustics

Sound propagation in sea water is subject to a number of variables that degrade the signal's intensity through the water and thus affect the levels received by killer whales. Sound produced by ships is referred to as source level, and is based upon the size (length) of the ship and the speed at which it is travelling. It is interesting to note that sound travels more than twice as fast in water than it does in the air. Our study assumed a perfect spherical attenuation of sound as each ship travelled through the water. In reality, other variables such as bathymetry, the Doppler effect, ocean currents and ocean chemistry would need to be taken into account. Bathymetry is the depth of the water column which is dictated by the topography of the ocean floor, and contributes to how sound reverberates around islands. Our analysis does not consider these extra variables but still provides a strong representation of masking within the ocean.

After calculating this area of cumulative masking, the 2010 data was analyzed on a daily basis. We calculated the area of masking for 100 random days out of the 184 days of our study period (May 1st to Oct 31st 2010). Each day was weighted as 1% and overlaid to represent the areas that were most frequently affected by masking.

To test the effect that speed has on source level, we modeled scenarios in which speed limits were enforced. Three speed limits of 20, 15 and 10 knots (kn) were imposed by taking any speeds above the limit and reducing them to the speed limit. The average speed observed in the data was 13.4 kn, however speed ranged from 1 to 30 kn. Source level was then recalculated using these new speed values, to assess any changes in the new extent of masking.

Results

A high concentration of masking source levels was seen in the Juan de Fuca Strait and the Strait of Georgia (Figure 6). The average source level over the entire study area was 127 dB. Of the ships studied, 68% were found to produce sounds in the intensity range of SRKW discrete calls at least once during the study period (May to October). Furthermore, after calculating the source level for each data point, it was found that 20% of shipping activity produces source levels greater than 133 dB. All areas that were affected by masking during our study period, known as the area of cumulative masking, cover the entire study area (Figure 7). Areas of masking were found within a majority of the Juan de Fuca Strait, Haro Strait and Boundary Pass during at least 90% of the days sampled (Figure 8). When comparing the daily and cumulative masking maps, both areas of masking overlap with the critical habitat of the SRKW (Figure 7; Figure 8).

The application of speed limits produced varying degrees of reduction in masking (Figure 9). The greatest decreases in source level were observed in the Juan de Fuca Strait, Boundary Pass, and the Strait of Georgia (Figure 9). The percent decrease in the amount of masking (data points above 133 dB) was 0% in the 20 kn scenario and 30% in the 15 kn scenario. Most importantly, limiting the speed of the ships to 10 kn created a 100% reduction in masking, reducing the maximum source level produced to 132.998 dB.

Box 2 – Geography of BC's South Coast

Boundary Pass, Haro Strait, the Juan de Fuca Strait and the Strait of Georgia are areas on the south coast of BC that are frequently occupied by commercial ships (Figure 5). These areas are also within the critical habitat of the SRKWs.

Figure 5. Geography of the south coast of BC. Areas that are important to this study are labelled here. Data from: UBC Geography, Washington Department of Ecology.

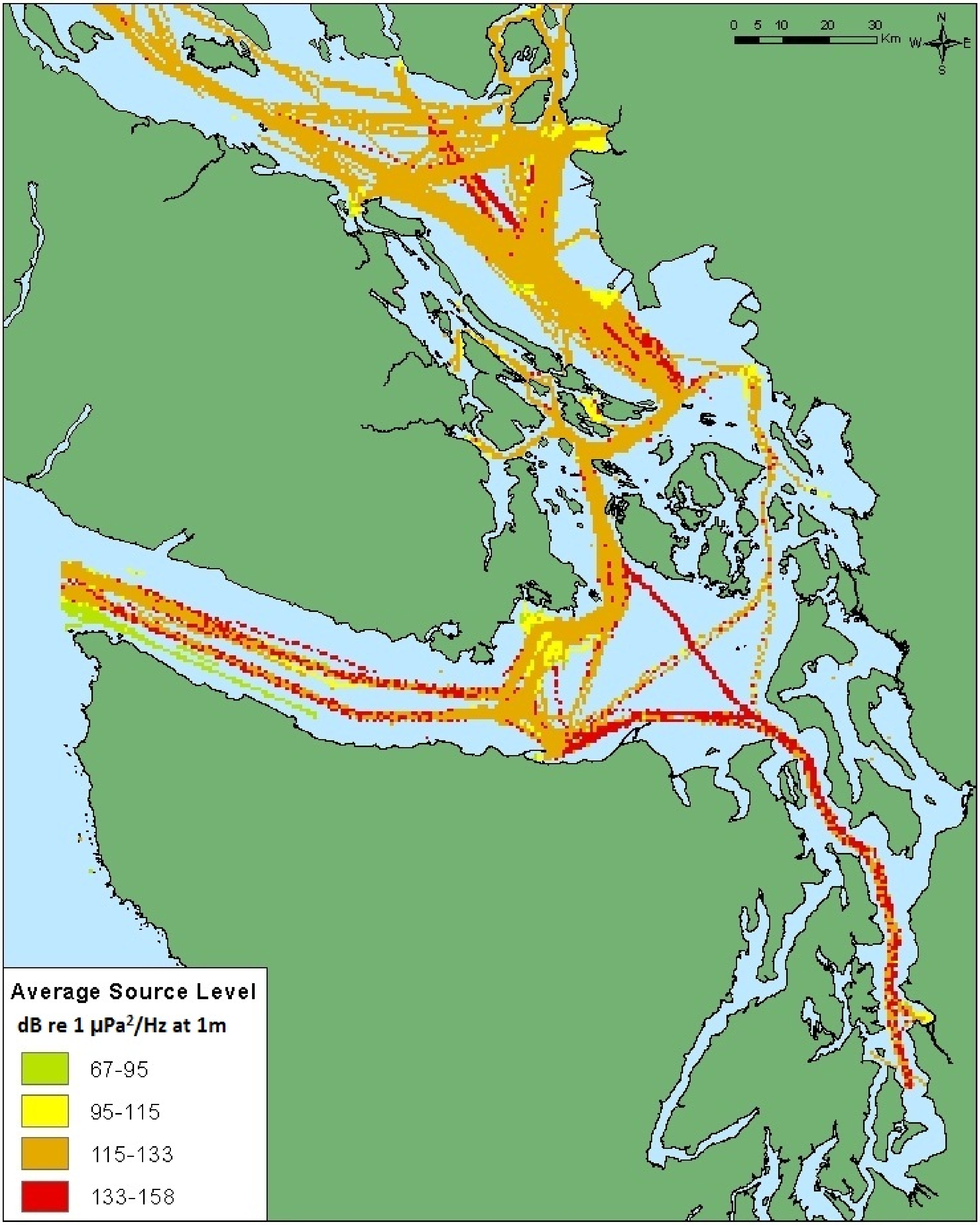

Figure 6 – Average Source Level of commercial shipping traffic along the South Coast of BC. Data from: MCTS, UBC Geography, Washington Department of Ecology.

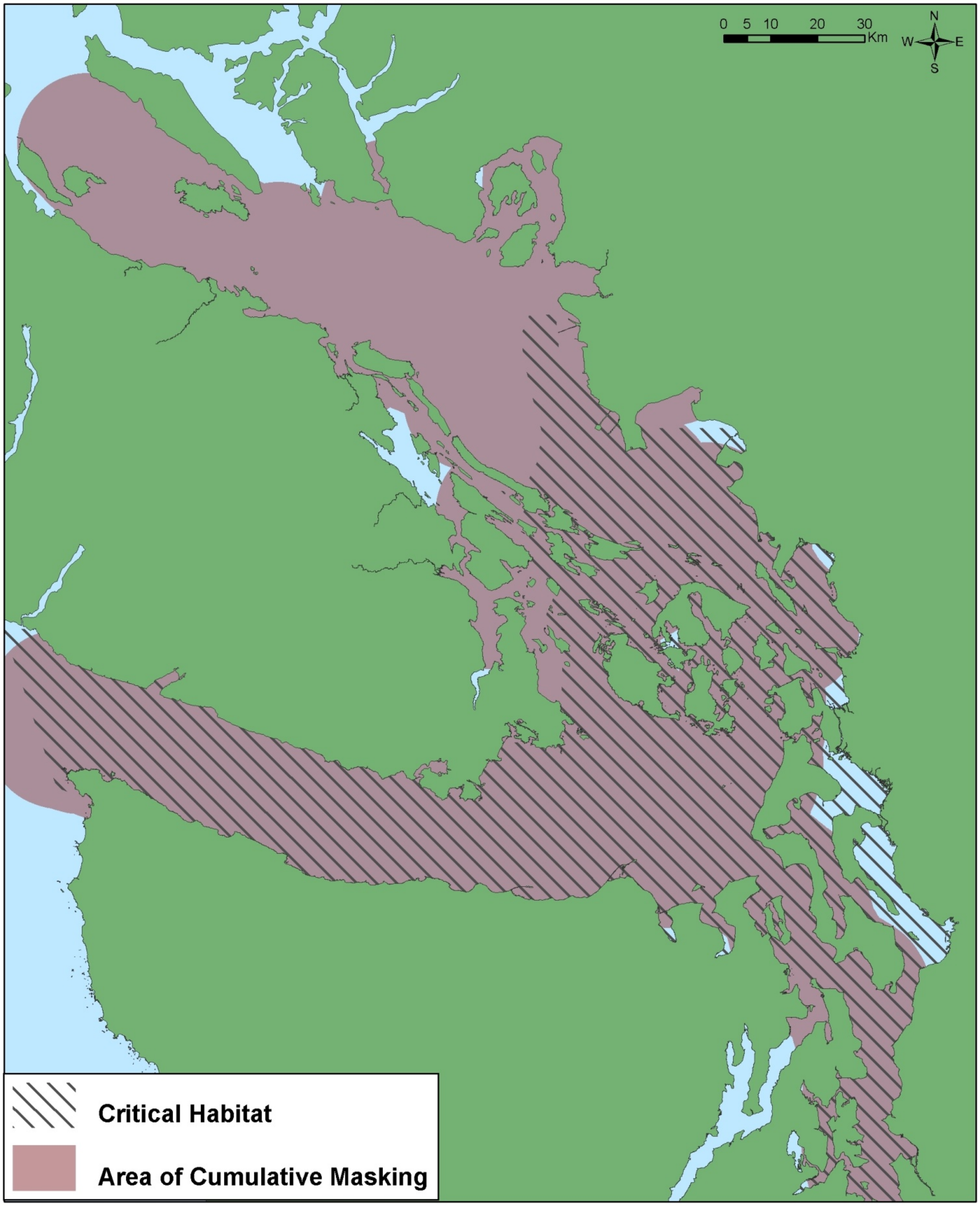

Figure 7 – Area of cumulative masking calculated from all the data within our study period. Data from: MCTS, UBC Geography, Washington Department of Ecology.

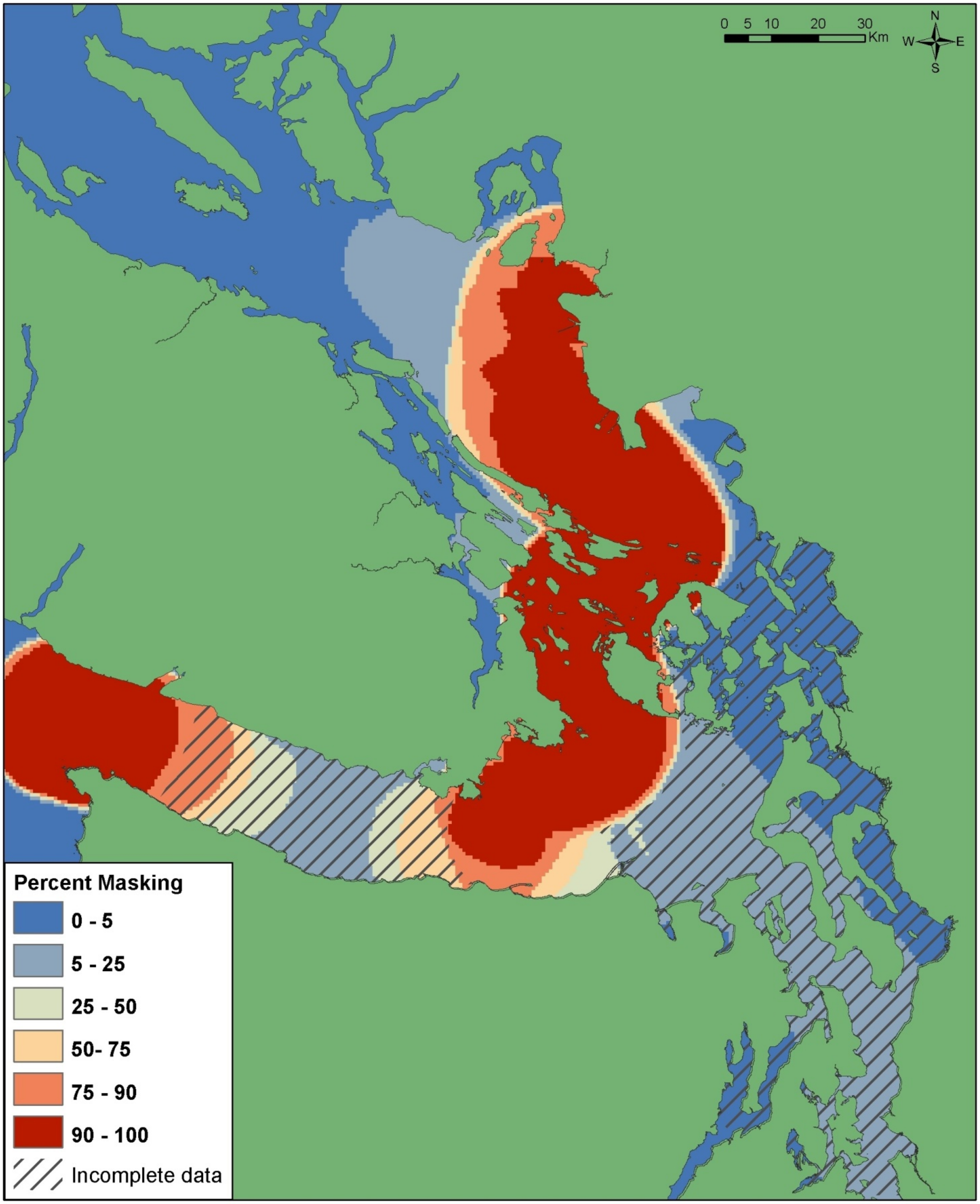

Figure 8 – Percent of time areas along the South Coast of BC are subject to masking. Areas of incomplete data are shown due to limitations in available data. Data from: MCTS, UBC Geography, Washington Department of Ecology.

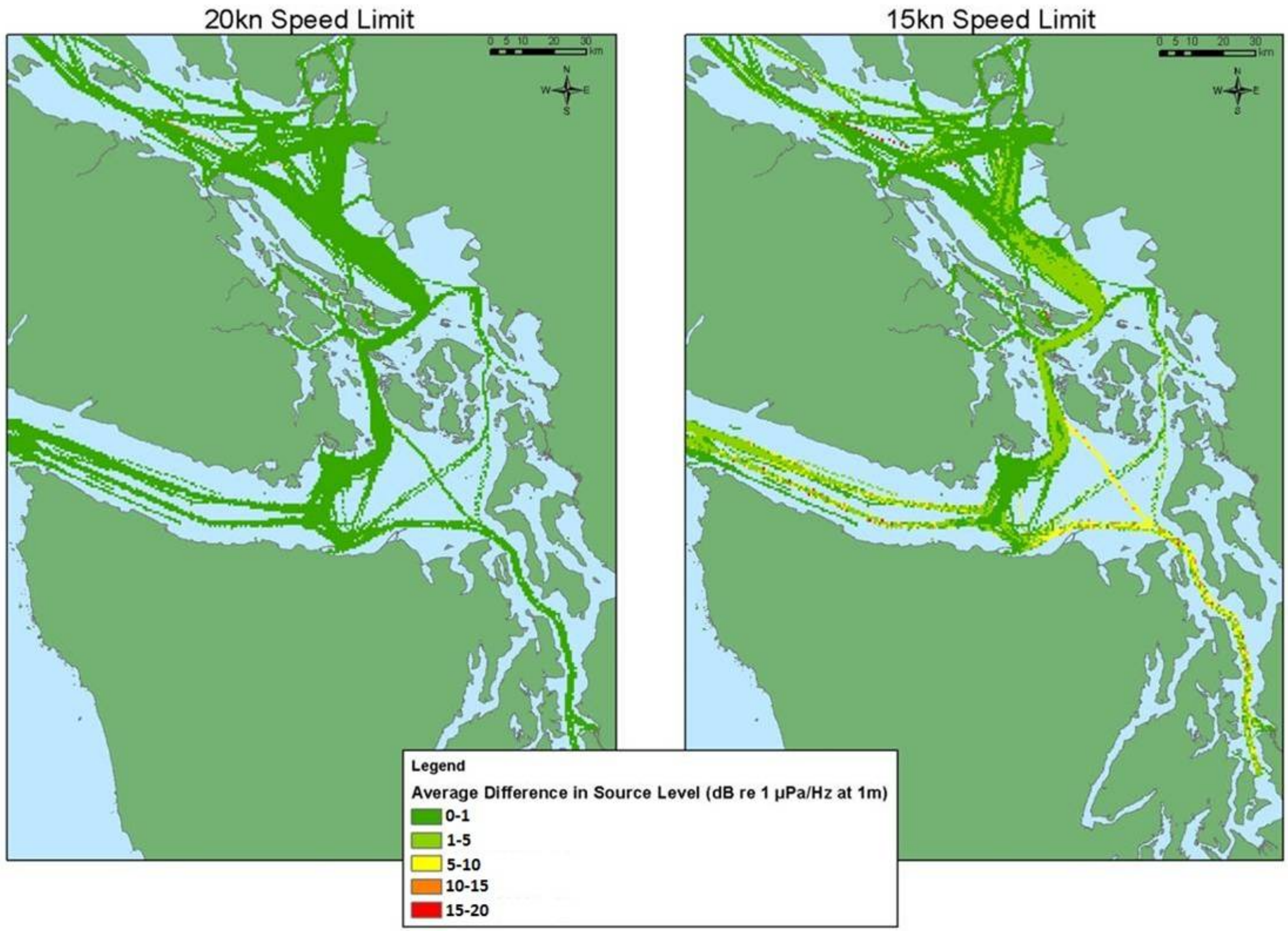

Figure 9 - Speed limit scenarios showing a reduction in source level from imposing a 20 kn and 15 kn limit. 10 kn was not displayed as there was a 100% reduction in masking and the maximum source level was reduced to less than 133dB. Data from: MCTS, UBC Geography, Washington Department of Ecology.

Discussion

Ship-generated noise frequently masks the discrete calls of the SRKWs within their critical habitat (Figure 6). Specifically, masking is prevalent throughout the critical habitat of the SRKW on over 90% of the days sampled (Figure 6). Killer whales use discrete calls 94% of the time when foraging; however, when these vocalizations are masked, the whales are forced to spend more time and energy searching for food, which could decrease their fitness (Thomsen *et al.,* 2002; Lusseau *et al.,* 2009). Furthermore, whales spend less time foraging, beach rubbing and socializing in the presence of boats (Williams, 2006). With 20% of all shipping activity shown to generate noise intensities above 133 dB, substantial areas of masking, both daily and cumulative, cover large portions of the SRKW critical habitat. The amount and extent of masking determined here warrants a deeper investigation into the acoustic effects of commercial shipping traffic on the SRKWs.

Growth in shipping traffic has greatly increased the ambient noise in the ocean by as much as 10 to 16 dB at low frequencies from 1950 to 2000 (Mazzuca, 2001). This growth is present on the BC coast. Port Metro Vancouver handled 118 million tonnes of cargo in 2010 (PMV, 2010). This is an approximate 16% increase in total cargo handled from 2009 (PMV, 2010). The presence of wide-spread masking generated by commercial ships creates concern for the whales, as they are forced to compensate by increasing vocalization frequency, intensity, and duration (Holt, 2008). When ambient noise reaches a point at which the whales can no longer compensate, their fitness will be threatened (Holt, 2008). By examining the extent of noise pollution generated by commercial ships in 2010, our findings can be used as a baseline to analyse future port expansions and their contributions to noise pollution.

Speed limits have been discussed as a possible solution to reducing masking within the SRKWs critical habitat (personal communication Misty MacDuffee, March 2011). A speed limit of 15 kn would reduce the amount of masking noise by 30% while a 10 kn speed limit eliminated the amount of masking completely. However, a 10 kn limit may be impractical, as it lowers the maximum allowable speed to below 13.4 kn, the average speed currently observed. This limit may have other implications for the SRKWs, such as stress from prolonged presence of ships in their critical habitat.

The effect of ship generated noise may be more extensive than the results indicated due to limitations of the data. In waters where ships crossed over into the USA, the quality of the data received was inadequate to consider in the analysis since many values for ship length and speed were not recorded. The Juan de Fuca Strait is an example where masking may not be evident due to a lack of adequate data (Figure 6).

Our results look solely at sounds produced at 1 kHz with an intensity between 133 and 165 dB. This restricts our research to the masking of whale communication, excluding other negative acoustic effects such as temporary and permanent hearing loss. We were unable to examine the effects of noise generated by ships at frequencies higher than 1 kHz. Future research should be completed to establish thresholds at which killer whales experience hearing loss. Our study assumed a perfect spherical attenuation of sound as each ship travelled through the water. In reality, other variables such as bathymetry, the Doppler effect, ocean currents and ocean chemistry would need to be taken into account. There is considerable uncertainty regarding which threats may be directly responsible for the decline in the population, as well as which threats are most important to address for recovery (NMFS 2008).

Photo: no ceiling, Flickr

Recommendations

Further research is needed if the Department of Fisheries and Oceans is to adequately protect the SRKW habitat from acoustic threats. Killer whales' hearing is the most sensitive of any odontocete tested to date (Szymanski *et al.* 1999). Threats such as temporary and permanent hearing loss and damage due to high sound intensity, lead to a higher risk of ship collisions and whale mortality (Williams, 2006). Increased ambient noise intensity created by commercial shipping could cause this hearing damage; however, it is still unclear how ship-generated noise affects the whales' physiology (Holt, 2008). Also, identification of hot spots, where whale protection is most needed within the critical habitat, will lead to prioritization in noise reduction. By examining hourly-averaged source levels generated by commercial shipping, guidelines could be developed for shipping traffic based on the sensitivity of killer whales through different times of the day. Projects such as VENUS (Victoria Experimental Network Under the Sea) run out of the University of Victoria and hydrophone data being collected by the DFO will increase our knowledge of the potential effects of ship source levels on the SRKW population.

Marine protected areas (MPAs) are a viable option for the protection of endangered species. This legal protection of a marine area should include refuge from acoustic threats such as masking and hearing damage. Furthermore, to allow for greater habitat heterogeneity and decrease risk of mortality, multiple MPAs should be distributed throughout and beyond the critical habitat of the SRKWs (Williams *et al.*, 2009). As shown by our results, ship-generated acoustic threats are widespread along BC's south coast, which poses a challenge to the development of MPAs. One objective of the Recovery Strategy for this species is to "ensure that disturbance from human activities does not prevent the recovery of resident killer whales" (FOC, 2008, vi). Based on the recent federal rulings and the findings outlined in our study, actions must be taken to reduce the acoustic impacts of commercial shipping on the fitness of the SRKW. Development of a network MPAs could achieve this goal.

If speed limits are to be considered a viable option for reducing acoustic impacts on the SRKWs, a decrease to a maximum between 15 and 10 kn will be needed. Considering that the average speed currently observed on the south coast of BC is 13.4 kn, a speed limit of this magnitude may be difficult to implement. Reducing the speed of ships will also increase the amount of time ships spend in the water, and the effect of prolonged exposure to ships, whether or not they are producing masking noise, is yet unknown. The results of imposing a speed limit are uncertain and further examination is needed if this is to be considered as a viable solution.

The endangered SRKW population is in need of further attention and research. Consideration of the acoustic environment will be crucial in further development of management strategies. This should include expanding the number of marine protected areas along BC's coastline, focusing on the SRKWs' habitat. Speed limit scenarios suggest that a significant reduction in masking will only occur if a 15 to

10 kn limit is enforced. Additionally, because the distribution of the SRKW crosses the Canada-US border and the protection of this species requires mitigation of multiple threats, recovery of this population will be a long-term process requiring cooperation and coordination of trans-boundary organizations, both governmental and non-governmental.

Photo: Justin Bugsy Sailor, Flickr

Conclusion

The southern resident killer whales and commercial ships occupy the same water off the coast of British Columbia. As BC's ports continue to expand, leading to an increase in shipping traffic, the southern resident killer whales' ability to adapt will be challenged. Our research shows that potential masking of southern resident killer whale vocalizations at a frequency of 1 kHz and an intensity range of 133-165 dB encompasses the majority of this species' critical habitat. Additionally, this masking is occurring on a daily basis, creating concern for the overall fitness of the SRKWs and the recovery of this endangered species' population.

To reduce the masking generated by ships, the most effective speed limit was 10 kn since it reduced the area of masking by 100%. However, before any steps are taken regarding a speed limit, research needs to be completed to understand the impacts of ships spending longer periods of time in the water as they travel to their destination. Other management strategies, such as the development of marine protected areas, should be considered in a recovery strategy for the SRKWs.

While research has been carried out observing the relationship with certain boat types, such as whale-watching boats, minimal work has been done to understand the impacts of other types of ships on killer whales. Despite current and future port expansions, little has been done in the way of understanding what these developments mean for surrounding ecosystems. Our research has addressed one facet of the interaction between increasing shipping activity and the SRKW, helping to identify how noise from ship traffic affects the species. Additionally, we have highlighted flaws within the current species protection system; although the southern resident killer whale has been documented to be in decline, more research is needed to understand how human activities are negatively impacting this species.

Our research has shed light on some of the hardships faced by this endangered species. Whether this ecologically and culturally significant species will be protected before it is too late depends on research and actions in the near future.

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Appendix A: Utilized Ship Classifications

Table A-1. Ship types included in analysis based on categorizations by the MCTS with the Canadian Coast Guard (MCTS, 2010). Tug boats were not included since they do not contribute significantly to noise intensity near the surface compared to other ships (Hatch *et al.,* 2007).

Ship Types Included	Ship Types Excluded
Bulk Carrier	Tug
Chemical Carrier	Tug Tow Barge
Chemical Tanker	Charter Vessel
Coastal Tanker	Dredge
Container Ship	Drill Rig
General Cargo	Ferry
Ocean Oil Tanker	Fish Processor
Oil Tanker	Fish(ing) Factory
Reefer	Fishing Vessel
Refrigerated Cargo	Government Vessel
Ro-Ro	Hovercraft
Ro-Ro Cargo/Container Ship	Landing Craft
Vehicle Carrier	Misc
	Motor Yacht
	Navy Vessel
	Passenger
	Passenger Ship
	Rail Ferry
	Research (Government)
	Trawler
	US Coast Guard
	Warship
	Yacht

Appendix B: RANDI (Research Ambient Noise Directionality) II model

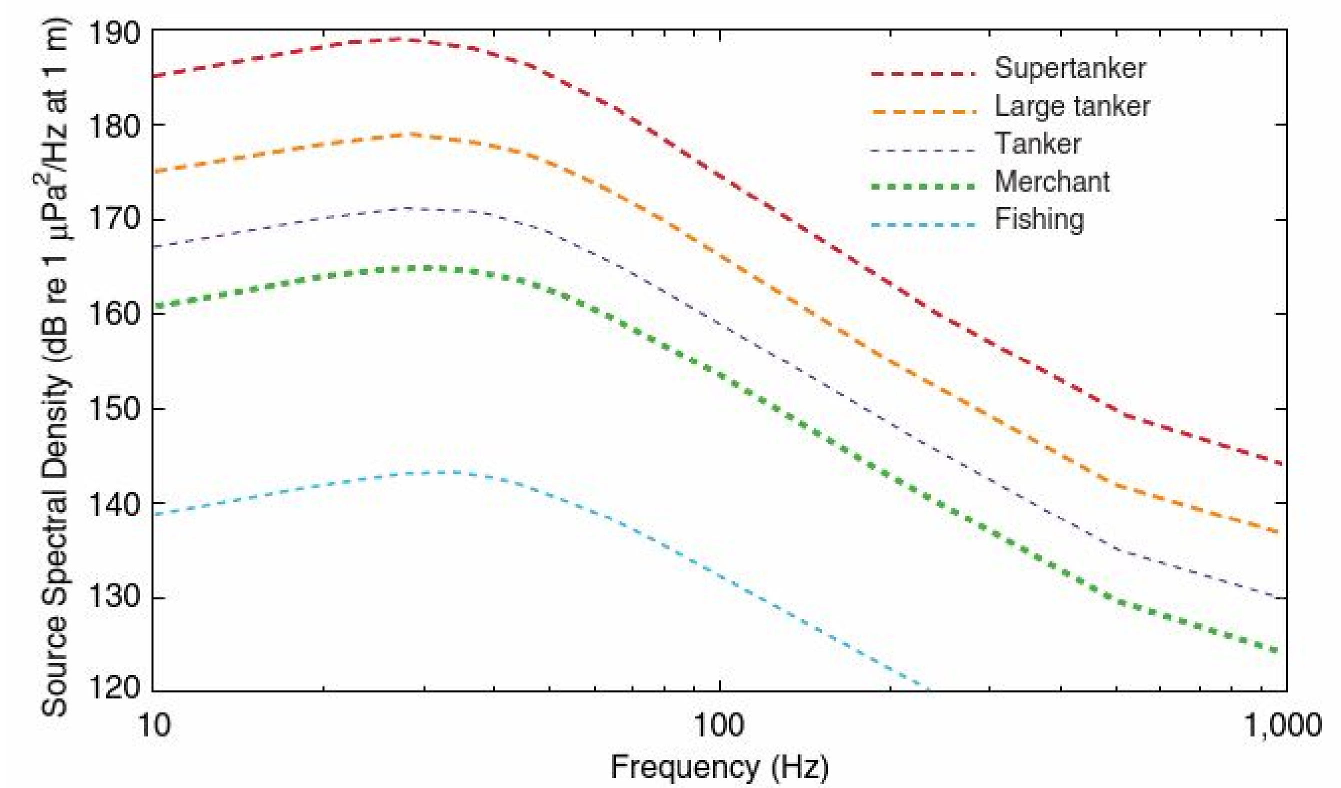

Figure B-1. Intensity of sound produced by five types of ships, classified by length, within a frequency range of 1 to 1,000 Hz. Data was produced using the Research Ambient Noise Directionality (RANDI) II model (from National Research Council [2003]).

Appendix C: Classification of Ship Types

Table C-1. Average speed (kn), length (m), and baseline source level (S_0) for five typed of ships. Ship length and average speed was taken from National Research Council (2003); baseline source level (S_0) was calculated using equation 1.

Ship Types	Average Speed (kn)	Length (m)	S_0
Supertanker	18.5	244-366	19.28
Large Tanker	16.5	153-243	13.18
Tanker	14	122-152	18.50
Merchant	12.4	121-84	19.18
Fishing	8.5	15-83	0