Fisheries and Oceans Canada / Pêches et Océans Canada
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Pacific Region

Canadian Science Advisory Secretariat
Science Response 2018/050

TECHNICAL REVIEW: POTENTIAL EFFECTIVENESS OF MITIGATION MEASURES TO REDUCE IMPACTS FROM PROJECT-RELATED MARINE VESSELS ON SOUTHERN RESIDENT KILLER WHALES

Context

Trans Mountain Pipeline ULC (Trans Mountain) is proposing an expansion of its current 1,150 km pipeline system between Edmonton, Alberta (AB) and Burnaby, British Columbia (BC), along with an expansion of the Westridge Marine Terminal in Burrard Inlet, to accommodate increased marine vessel traffic. On November 29, 2016, the Government of Canada granted approval for the Project, following a 29-month environmental assessment review by the National Energy Board (NEB), which concluded that the Project is in the Canadian public interest and recommended that the federal Governor in Council (GiC) approve the expansion. On August 30, 2018, the Federal Court of Appeal (FCA) released its decision with respect to judicial review applications challenging the federal approval of the Project. The Court ordered that the Order in Council (OIC) approving the Project be set aside. On September 20, 2018, the GiC sent the NEB's Recommendation Report back to the NEB for reconsideration to address the issues specified by the FCA ruling and gave the NEB 155 days to complete its Reconsideration. Therefore, the Board must complete the Reconsideration process and issue its Reconsideration report no later than February 22, 2019.

On October 12, 2018, the NEB released Hearing Order MH-052-2018, announcing that it will hold a public hearing and set out the timelines and process for the Reconsideration. On the same day, the NEB sent a letter to federal authorities (including Fisheries and Oceans Canada) requesting specialist or expert information to support the Reconsideration. Specifically, the NEB has requested information in regard to the effectiveness of mitigation measures aimed at avoiding or reducing impacts from Project-related marine vessels on the Southern Resident Killer Whale (SRKW). Existing and proposed Project-related marine vessel traffic are expected to use the established in-bound and out-bound marine shipping lanes in the Marine Regional Study Area (Marine RSA), which intersect critical habitat for SRKW (Figure 1).

As an intervenor in the Reconsideration hearing process for the Trans Mountain Expansion Project, Fisheries and Oceans Canada (DFO) will be presenting written evidence and responding to information requests from the NEB and other Intervenors in relation to its expertise on the effects of the Project on marine fish and fish habitat and marine mammals (including aquatic species at risk), the efficacy and adequacy of mitigation measures, and monitoring and follow-up programs that were not considered in the last NEB Hearing (OH-001-2014).

Scope

DFO's Pacific Region Fisheries Protection Program (FPP) is responsible for reviewing potential effects of the marine terminal and shipping components of the Project on fish, fish habitat and marine mammals. In 2015, on the request from FPP, DFO Science Branch conducted a sufficiency and technical review of the information on the effects of marine shipping on marine mammals in the Facilities Application for the Project (DFO 2015a and DFO2015b). FPP is now seeking DFO Science Branch support in responding to information requests from the NEB regarding the effectiveness of mitigation measures for impacts to SRKW from Project-related marine shipping. This CSAS Science Response (SR) is anticipated to be a review of existing peer-reviewed information and research from DFO and other published scientific literature and proceedings.

The objective of this SR is to provide advice on the following questions:

1. Provide any information or knowledge concerning the potential effectiveness of the following potential mitigation measures:
   - altering shipping lanes to reduce adverse effects on SRKW, such as shifting lanes away from marine mammal congregation areas;
   - speed restrictions and altered shipping patterns, such as convoys, in order to reduce potential adverse effects such as underwater noise or the potential for ship strikes;
   - vessel design (including hull and propeller) and maintenance measures for reducing adverse effects such as underwater noise from Project-related marine vessels;
   - use of marine mammal on-board observers on Project-related marine vessels, and what actions need to be taken if SRKW are observed;
   - measures to increase abundance of prey to offset adverse effects from Project-related marine shipping;
   - any other measure that could avoid, reduce, and/or offset the adverse effects of Project-related marine shipping on SRKW; and
   - measures that could avoid or reduce cumulative adverse effects on SKRW.
2. Provide any information or knowledge concerning the relationship between a vessel's speed and tonnage (including the different types of Project-related marine vessels under both loaded and unloaded conditions) and how much underwater noise the vessel creates.

This Science Response Report results from the Science Response Process of October 2018 on a review of the effectiveness of potential mitigation measures to address impacts from project-related marine vessel traffic on the Southern Resident Killer Whale.

Background

The existing Trans Mountain pipeline (TMPL) system commenced operation in 1953, and transports a range of crude oil and petroleum products from Western Canada to locations in central and southwestern British Columbia (BC), Washington State, and offshore. The proposed Project would create a twinned pipeline, increasing the capacity of the system from approximately 300,000 barrels per day to 890,000 barrels per day. Key Project components include 994 km of new pipeline, reactivation of 193 km of existing pipeline, 12 new pump stations and expansion of existing pump stations and storage tanks, and the addition of three new vessel berths at the Westridge Marine Terminal in Burnaby, BC.

For this particular DFO Science review, the marine vessel traffic that will transport the petroleum products is of relevance. The proposed expansion is forecasted to increase marine vessel traffic from 5 tankers per month calling at the Westridge Marine Terminal to approximately 34 tankers per month (i.e., an additional 696 tanker transits each year). At present, the maximum size of petroleum tankers that call at the Westridge Terminal are Aframax class, which have an average cargo carrying capacity of 750,000 barrels. The maximum size of tankers is not expected to change as part of the Project. These vessels will transit the Marine Regional Study Area (Marine RSA) using existing in-bound and out-bound shipping lanes (Figure 1), and consequently will transit proposed habitats of special importance to Resident Killer Whales (DFO 2017a; Figure 2). It will take each Project-related Marine vessel approximately 12 hours to complete one transit of the Marine RSA; and, on average, there will be two transits every 24 hours. This will be in addition to existing traffic in the shipping lanes and other traffic in the Marine RSA.

An increase in marine vessel traffic associated with the Project has the potential to result in sensory disturbance to marine mammals from underwater noise and an increased risk of injury and mortality associated with mammal-vessel strikes. Disturbance responses associated with increased Project-related vessel traffic could range from temporary displacement to reduced foraging efficiency, to disruption of mating and social behaviours. The potential for these effects to affect recovery of the Southern Resident Killer Whale is of critical importance, as only 74 individuals are estimated to be present in the wild as of September 2018. Furthermore, the Proponent has noted in the Project Application that although the Project’s contribution to overall sensory disturbance effects on the species is small, the potential effects of increased Project-related marine vessel traffic are determined to be significant for Southern Resident Killer Whales. This species is therefore of the greatest conservation concern in the Marine RSA.

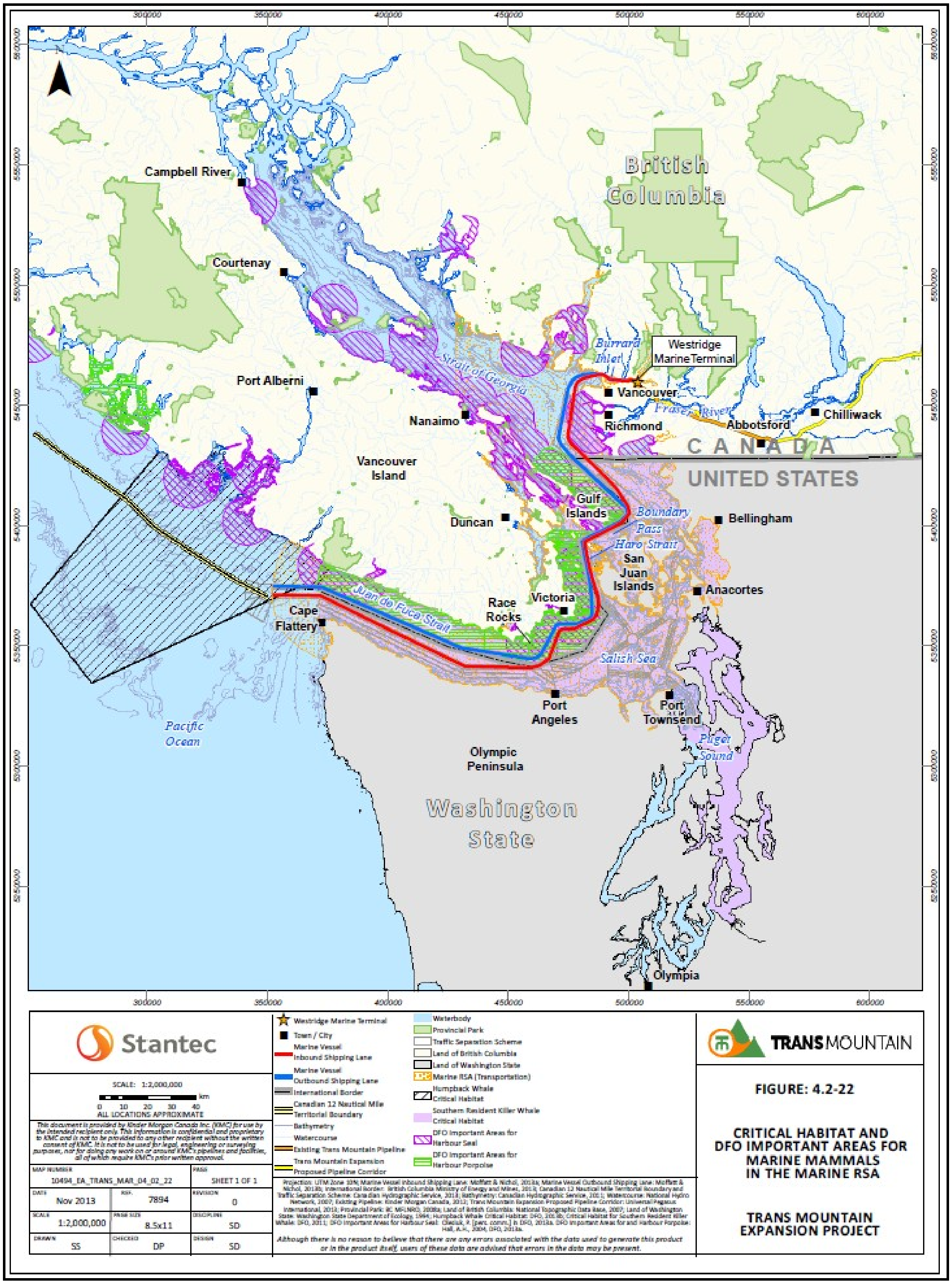

Figure 1. The marine shipping lanes, critical habitat for Southern Resident Killer Whales, proposed Critical Habitat for Humpback Whales and other important areas for marine mammals in the Marine RSA (from Trans Mountain Pipeline ULC, 2013. Trans Mountain Expansion Project – An Application Pursuant to Section 52 of the National Energy Board Act, Volume 8A - Marine Transportation).

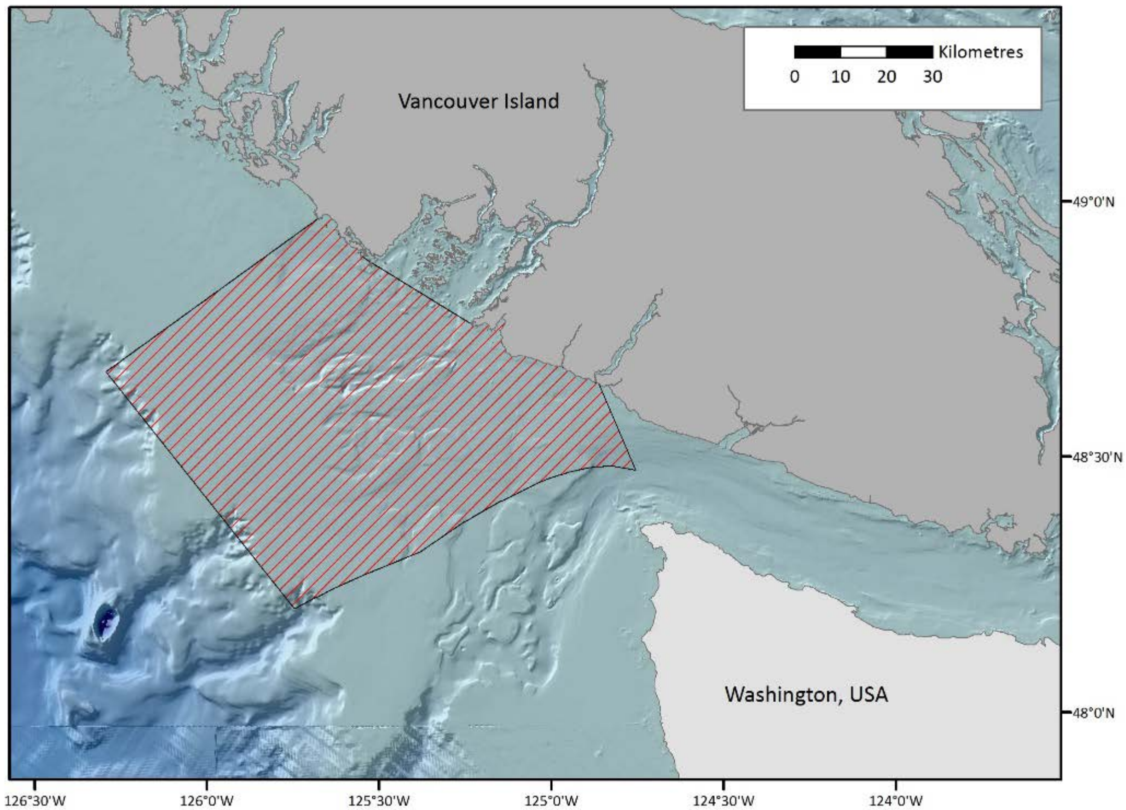

Figure 2. Habitat of special importance for SRKW and NRKWs off south western Vancouver Island. This habitat is currently proposed additional Critical Habitat for these two killer whale populations. (from DFO 2017a. Identification of Habitats of Special Importance to Resident Killer Whales (Orcinus orca) off the West Coast of Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/011.

Analysis and Response

Altering shipping lanes to reduce adverse effects on SRKW, such as shifting lanes away from marine mammal congregation areas

The direct potential advantage of altering shipping lanes is to decrease noise exposure levels and duration by increasing the distance between the vessels creating the noise and the SRKW occupying a given habitat. While this action will result in a potential increase in the noise propagation losses between the vessel and the marine mammals, it will however result in an increase in the noise exposure levels in the area surrounding the new shipping lane location.

The effectiveness of the measure is strongly dependent on several factors including:

1. The knowledge available on the frequency and duration with which SRKW use different portions of their critical habitat, the precision of information regarding where SRKW are located, and when they are in sensitive parts of the critical habitat (e.g. known foraging areas), and whether it is possible to re-route the shipping lane away from these sensitive areas.
2. The initial propagation range between the route and the sensitive area. Noise levels decrease more rapidly close to a ship in the lane than farther away, as noise propagation

losses tend to be logarithmic with respect to propagation range. For example, if a sensitive area is located very close (e.g., 100 m) to a shipping lane, received noise levels could be lowered dramatically (half the intensity) by moving the vessels only 20-100 m further away. However, if the initial range between shipping lane and sensitive area is larger (e.g., 2000 m), then a 50% reduction in intensity would require the lane to be shifted an additional 800-2000 m (i.e. between 2800 and 4000 m) away from the sensitive area (DFO 2017b).

3. The SRKW sensitivity to specific acoustic frequencies relative to the propagation of these sound frequencies. As noted in (2) above noise levels decrease more rapidly closer to the source than farther away, but in addition higher frequencies decrease faster relative to lower frequencies. The latter is important as impacts related to auditory masking of sounds relevant to SRKW depend on the animals' ability to hear the sounds and noise in question. The optimum hearing range (+/- 20 dB of the maximum sensitivity which is near 30 kHz) for SRKW is between 3 and 80 kHz (Branstetter et al 2017), and overlaps with the frequency range of vessel noise which has its maximum energy below 1 kHz but ranges up to 40 kHz (Veirs et al 2016). Hearing sensitivity is higher for higher frequency components of the noise, which tend to be lower in energy and faster to dissipate with distance from the source because spreading losses generally increase dramatically with acoustical frequency (i.e. higher-frequency noise will not propagate as far as lower frequency noise). Shifting vessel traffic lanes away from sensitive areas will result in reductions in received broadband noise levels in those sensitive areas; but uncertainty exists with regards to spreading losses at higher frequencies where the noise can be more directional. Shipping noise is generated in the upper 20 m of the water column, which is also the depth range most often used by SRKW. In addition, knowledge of noise impact at low frequencies outside of SRKW best hearing frequency range is also mostly unknown.
4. The local sound propagation characteristics. These characteristics are defined by: water depth, bottom types, sea state, the sound speed in the water column as a function of depth, temperature, and salinity, and, the frequency characteristics of the sound (lower-frequency sounds that are common from large vessel output propagate further than higher frequencies). It is challenging to predict the potential effectiveness of this mitigation measure given that several of these parameters vary spatially (e.g. depth and bottom type) and temporally (e.g. sea state and sound speed).

In the Salish Sea, and especially among the Gulf Islands (i.e., Boundary Pass, Haro Strait and Rosario Strait) there are physical constraints to altering shipping lanes. The Juan de Fuca Strait and Swiftsure and La Perouse Banks are more favourable areas for altering shipping lanes.

The Vancouver Fraser Port Authority's (VFPA) Enhancing Cetacean Habitat and Observation (ECHO) Program is currently leading a voluntary trial in Juan de Fuca Strait to investigate the efficacy of this mitigation approach at reducing vessel noise and impacts in key SRKW feeding areas. Specifically, outbound vessels are being asked to navigate as far south as possible through the Strait of Juan de Fuca, provided it is safe and operationally feasible to do so (Figure 3), and underwater noise is being measured before, during, and after the trial using DFO hydrophones deployed in the Strait of Juan de Fuca. Analysis of the trial results is expected to commence as soon as the trial concludes on October 31, 2018, and will provide quantifiable insights into the efficacy of altering shipping lanes as a mitigation measure.

DFO Science recognizes that modifications to existing shipping lanes is a responsibility of other regulatory agencies including Transport Canada.

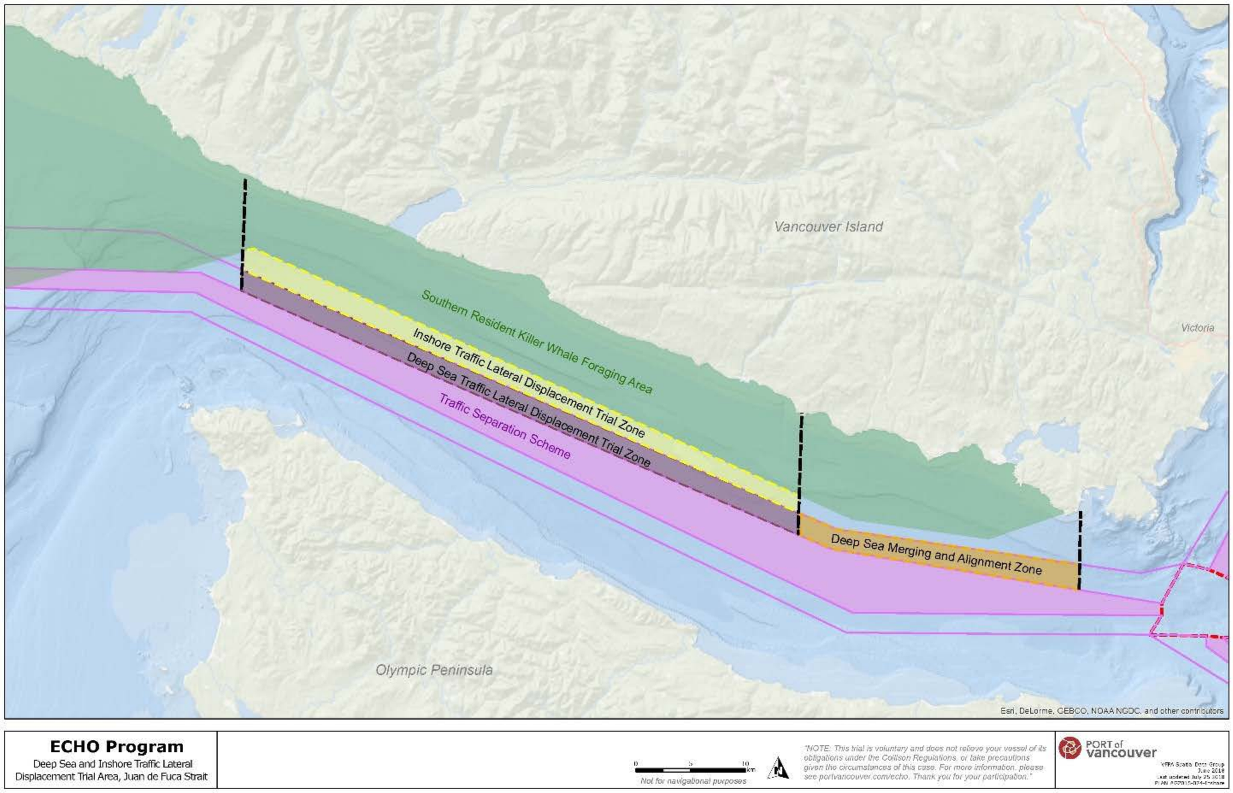

Figure 3. Map of the Strait of Juan de Fuca Lateral Displacement Trial of shipping traffic adjacent to important Southern Resident Killer Whale foraging habitat, sourced from the Vancouver Fraser Port Authority's ECHO Program website

Speed restrictions and altered shipping patterns, such as convoys, to reduce potential adverse effects such as underwater noise or the potential for ship strikes

Generally a reduction in vessel speed results in an immediate reduction in the overall noise exposure levels, but it also in turn increases the duration of noise exposure. Reduced vessel speeds also have the potential to reduce the risk of lethal vessel strikes in larger whales. This has been demonstrated by Laist et al. (2014) and van der Hoop et al. (2015) for North Atlantic right whales (NARWs) following the 2008 implementation by the National Oceanic and Atmospheric Administration (NOAA) of a general speed limit of 10 knots in critical habitats and 20 nautical miles around major ports on their migratory path in US waters.

In the summer and autumn of 2017 the Vancouver Fraser Port Authority's ECHO Program initiated a voluntary vessel slowdown trial in Haro Strait. Large commercial and government vessels were asked to reduce their speeds to 11 knots in the trial area. During the trial, noise levels measured at a hydrophone located at Lime Kiln Lighthouse on San Juan Island, Washington State, an important SRKW foraging area, were reduced by a median value of 1.2 dB (range: 0.6 dB low traffic day to 1.5 dB high traffic day; ECHO 2018). This result is approximately equivalent to a 24% reduction in sound intensity (ECHO 2018). When time periods with small vessel presence and periods with strong winds and currents were eliminated from the data set leaving only large vessel traffic as the predominant noise source, the noise reduction due to slow-down increased to 2.5dB (~44 % reduction in intensity). Consequently, it is unlikely that a permanent slow down would result in a 44% reduction in noise intensity. However, as only 61% of piloted commercial vessels participated in the trial slowdown, were there a higher rate of compliance, then the noise reduction may be greater.

While a slow down reduces sound energy, the trade-off is that it results in an increase in the duration of exposure to noise as the vessels take longer to move through a given area. There is currently insufficient published data and analyses available to characterize the effect of increasing exposure duration on SRKW's abilities to communicate and echolocate efficiently. Some researchers have suggested that the loss of listening space (i.e. the relative reduction of distance over which animals can hear important sounds due to noise exposure of a certain intensity) may be biologically more relevant than the change in sound exposure duration of a lower intensity sound, because cetaceans such as SRKW need to forage at specific locations where and when the prey is available (Pine et al. 2018, Heise et al. 2017). This would also suggest that lower sound intensity may generally be an effective mitigation; however, the available information is not definitive.

Sound propagation properties, however, vary greatly among locations and some authors have shown conditional increases in overall vessel noise exposure in the St. Lawrence River estuary mainly due to variation in local sound propagation properties vs. effect of speed reduction on ship source noise levels (Chion et al. 2017).

Consideration of area-based vessel speed limitations may also need to account for potential vessel accelerations in other locations to maintain the shipping schedule resulting in an overall increase in sound exposure along other areas of the vessel route. For example, if mandatory speed restrictions were in place within the area of Canada's territorial sea on the west coast, vessels could potentially increase speed after entering the Exclusive Economic Zone (EEZ) to stay on schedule. Were the latter to occur it may increase ship strike risk for other whale species in Canadian waters (Nichol et al. 2017).

The effectiveness of a speed reduction mitigation measure is therefore a trade-off depending on:

1. The local fleet characteristics - where the broadband noise reduction is typically between 0.5 and 1.5 dB per knot reduction in speed (DFO 2017b). However, studies have shown that there is significant variability in any vessel's source level as a result of speed changes, and variability between vessels of the same class. Simard et al. (2016) found that measured source spectral levels exhibited large variability, exceeding 30 dB even when aggregated by ship types or length classes. Some ships may actually show an increase in noise with reduced speed, depending on propeller type and propulsion system. Loading levels of any given ship will also affect the effect of vessel speed on noise levels primarily due to the draft of the vessel. A vessel speed reduction regulation will also not affect the noise output of slow moving vessels, such as tugs.
2. The local noise propagation characteristics that are driven by sound frequency characteristics, water depth, bottom types, sea-state and ocean water properties (sound-speed profiles).
3. Whether the potential decrease in sound energy levels is a net improvement for SRKW over the resulting longer exposure to sound, and possible increased noise exposure in other areas.

Convoys:

Assuming all vessels involved in a convoy will still travel at their normal speed, grouping vessels in convoys will maintain the overall noise exposure level, and change noise spatial and temporal patterns (DFO 2017b). Using convoys will increase the sound level and duration of a single transit event (several ships in line), and increase the duration of quiet times (spatial and temporal overlap between ship acoustic signature) for any given area along the convoying lane.

Currently, little is known about the importance of quieter periods to SRKW. In practice, a number of the convoying vessels would have to reduce their speeds to match the slowest ship in the convoy and this might result in overall reduction in noise output. However, the noise level might be increased in the staging areas at both ends of the convoying lanes. The timing of these convoys could also affect the impact on SRKW biologically important activities (foraging, reproduction, social communication).

Convoying may also reduce the risk of vessel strikes as it slows down the speed of all vessels to the speed of the slowest vessel, in this case the Project vessel accompanied by tugs.

Thus, the effectiveness of this measure will depend on:

1. convoy speed;
2. inter-ship interval;
3. the number of convoys per day; and
4. convoy timing in relation to the occurrence of SRKW biologically important activity.

In summary, the effectiveness of a vessel speed reduction and alteration of shipping lane mitigation measure is a trade-off depending on fleet characteristics, propagation characteristics for vessel sounds, and whether the vessels alter their passage pattern (such as through altered routes or convoys).

Vessel design and maintenance measures

Design and maintenance can reduce both noise exposure level and duration. For example, vessel design and maintenance can reduce a ship's acoustic source level immediately and with proper maintenance and monitoring these reduced levels can be maintained. Additionally, designing larger vessels that are able to carry larger loads can result in fewer vessels being required to move the same overall load. The reduction in the number of required vessel passages to move the same goods and materials has an additional effect of reducing the duration of exposure.

In general, changes in ship design, and retrofitting ships to reduce source level noise, are considered more effective than reducing speed limits or altering shipping lanes because they are not limited to the spatial area where the mitigation effort takes place, nor to a particular time. Furthermore, any ship design mitigation measure is independent of the behaviour of SRKW (DFO 2017b).

New vessel designs that generate lower sound emissions are available but are typically more costly to purchase and older noisier vessels may be in operation for a number of years. However, incentives may be possible to encourage the adoption new vessel designs, such as a lowering of fuel consumption and/or reduced port fees for quieter vessels, as suggested by VFPA. The effectiveness of this mitigation measure on noise reduction will depend on the number of Project related ships that will receive a retrofit and the number of newer design ships that will be put in operation.

However, there is a potential that quieter ships may also pose an increased risk of whale collision – however, there have been insufficient investigations to confirm or quantify this. At the same constant speed as vessels travel currently, reducing the number of ships will reduce the overall collision risk. It is likely that combining speed and ship-source noise level reduction will be necessary to minimize both noise impact and collision risk.

The effectiveness of this measure will depend on:

1. Ship source level reduction obtained from design, retrofit and maintenance. The noise radiating from a vessel comes primarily from two sources: the in-water propulsion mechanisms (propeller cavitation), and onboard machinery inside the hull. Both of these have large potential for noise reduction from changes in ship design and retrofits (DFO 2017b, Baudin and Mumm, 2015). Changes in propeller design can result in 3-18 dB reduction in noise levels. Isolating diesel engines and associated parts can reduce the source level by as much as 15-20 dB within certain frequency bands. Hull modifications or treatments can also reduce the noise levels by up to 10 dB at medium frequencies and as much as 20 dB at the highest frequencies.
2. Vancouver Fraser Port Authority’s ECHO Program commissioned a study to identify technical ways to make vessels quieter. One of their conclusions was that replacing old propellers with new ones had only minor effects on the underwater noise, while modifications to existing propellers by adding Propeller Boss Cap Fins and ducting of the flow around the propeller (e.g., Schneekluth or Mewis duct) have the potential to significantly reduce the noise levels (ECHO 2017).
3. With regards to maintenance, the ECHO Program found that regular propeller cleaning and repair as well as regular cleaning of the hull lead to significant noise reduction effectiveness, with keeping the propeller clean and in good shape to be the overall best approach to minimize the noise level for any individual vessel (ECHO 2017).
4. Ship speed. It is expected that reducing ship source levels and speeds would be effective for reducing collision risk. However, further investigation is required on this point.
5. Ship size/number.

In summary, vessel design changes and regular maintenance of propeller and hull are some of the most effective measures to reduce a vessel’s underwater noise field and would lessen the impact of this vessel in all waters where they travel. However, these are likely to require significant time to implement.

Use of marine mammal on-board observers

In addition to generating underwater noise, fast moving large vessels can pose a strike risk for killer whales, as highlighted by the recent mortality of J34, a prime age male found to have died from blunt force trauma. The small size of the SRKW population and the low numbers of prime age males and females (< 20 animals) that support the reproductive potential and genetic diversity of the population means that the loss of even one animal could have significant consequences (DFO 2017c).

Vessel speed has been found to be an important factor contributing to both the likelihood of a strike and the severity of its effects (Conn and Silber 2013; Vanderlaan and Taggart 2007). The probability of a lethal injury to a whale when struck by a vessel increases significantly above 9 knots and almost certainty results in whale death above 15 knots. Studies on NARWs suggest that an effective mitigation measure to reduce the risk of ship strikes includes routing modifications (e.g., Vanderlaan et al. 2008; Vanderlaan and Taggart 2009; Lagueux et al. 2011; van der Hoop et al. 2012), however changes to vessel routes is not always feasible due to navigational safety constraints. This is especially true in SRKW critical habitats; therefore, reductions in vessel speed in the presence of whales would be the most effective mitigation measure and has been demonstrated for other whale species (Kite-Powell et al. 2007; Pace 2011). In addition, for most vessel classes, slowing down would immediately result in a reduction of the noise levels received by SRKW (Veirs et al. 2016, see previous section of this SR), which could in turn reduce masking effects and other detrimental impacts of underwater noise on SRKW and their ability to forage effectively (Veirs and Veirs 2011).

Any action by vessel operators requires timely detection of SRKW by on-board visual or acoustic means, or other means of alerting ships to the presence of whales in their paths. Posting trained marine mammal observers (MMOs) or video monitoring systems on the bows of ships is likely to be useful only when sighting conditions are good (low sea state, low swell, no fog, daylight sufficient to detect surfaced or barely-submerged animals, large or highly-visible target species), and when there is sufficient time for the vessel to safely react and avoid striking a marine mammal.

In critical habitat areas, such as Juan de Fuca Strait and Swiftsure Bank, the Project tankers (Aframax class with an average length of 245 m) are too large and moving at speeds too great to allow for much manoeuvrability should an animal be detected ahead of the ship; ships travelling at speeds >15 knots require more than two kilometres to stop, and many ship strike records indicate that the whales surfaced close to the front of the ship. Moreover, as water passes a large hull, it can advect a nearby whale towards the side of the ship, and likely thereafter into the propeller and rudder at the rear – in effect creating a “hazard zone” larger than the cross section of the hull (Silber et al. 2010), and thus requiring ships to avoid whales by a wider margin. Within the narrower waterways of the Salish Sea, from Haro Strait to Burrard Inlet, when Project vessels are accompanied by tugs, their speed may be lower than 15 knots, making MMO whale detection more likely. However, the ability to manoeuvre the ship away from SRKW is limited and likely poses a safety risk in those narrow waterways. Therefore, it is unlikely that MMO posted on vessels will achieve a significant reduction in the risk of ship strike in critical habitat both inside and outside the Salish Sea. Crews of large vessels generally are unaware of collisions and typically notice the kill only when a whale becomes stuck on the bow (e.g., Félix and Van Waerebeek 2005; Jensen and Silber 2003).

Technologies to detect marine mammals under low visibility conditions (e.g., at night, in fog) such as night vision systems, radar, active sonar, forward-looking infrared cameras and infrared binoculars, have undergone limited testing and have generally been found to perform poorly except for detecting large cetaceans at distances of several kilometres in calm sea states. Infrared systems are "practically useless" in conditions with rain, fog or haze (Baldacci et al. 2005). Even if such systems were in place, the vessel operators would still require sufficient time to safely react to detected marine mammals.

Onboard passive acoustic monitoring is not a viable option as most acoustic monitoring equipment that can be operated on a moving vessel would not provide reliable detections of marine mammals located in front of the vessel. Therefore, it is not a reliable method of detecting marine mammals to ensure absence from an impact area. Moreover, many cetaceans, including SRKW, vocalize intermittently and are often silent for periods of time. Bottom-mounted acoustic arrays have been deployed to monitor calling baleen whales, specifically North Atlantic Right Whales, but also Fin Whales and Humpback Whales (Clark and Charif 1998; Morano et al. 2012). In the northeastern U.S., this information is provided to vessel operators in real-time, allowing for an agreed-upon response such as reducing vessel speed when a calling whale is detected in or near the shipping lane within a 24 hour period. Such an approach might constitute a way to supply advance warnings to transiting tankers. There is an effort within the Federal Government’s Ocean Protection Plan Ship collision avoidance program to evaluate methods and technology that could be useful for real-time ship alerts of whale presence, such as acoustic monitoring networks in areas of high collision risk, infrared automated detection in narrow waterways, and automated delivery of sightings via mariner sightings networks among other approaches. It is therefore expected that in coming years, such systems will become functional and at that time could become part of a ship alert system used by the Canadian Coast Guard to alert onboard MMOs and vessel operators.

In summary, in most cases onboard monitoring of marine mammals by visual and/or acoustical technologies would be inadequate to determine with a reasonable level of confidence that cetaceans would be present or absent from an area ahead of a transiting tanker. In addition, due to the limited number of documented cases of SRKW fatal collisions, there is uncertainty regarding the efficacy of slowing down Aframax tankers to mitigate vessel collision fatalities. In spite of the limited information, the limitations in the ability of a loaded Aframax tanker to slow down and/or alter course in the confined waterways of the Salish Sea and the shipping channels suggest that this approach would not provide an acceptable level of ship strike risk mitigation from Project related ships. However, there may be utility with this approach near the Project facility, and thus it is recommended that MMOs coordinate with existing whale sighting networks to receive advance warning of SRKWs to facilitate mitigation, such as reducing speed.

Measures to increase abundance of prey to offset adverse effects from Project-related marine shipping

Multiple lines of evidence indicate that the observed poor body condition in the SRKW population is associated with increased mortality of fetuses, calves and adults and is a result of nutritional stress (Matkin et al. 2017). SRKW feed primarily on Chinook Salmon and considerable effort has been undertaken to identify measures to increase the availability of this key prey species. Availability could be increased by attempting to increase absolute abundance of Chinook Salmon stocks, but also by increasing SRKW access to presently available fish by reducing competition from fisheries and associated vessel disturbance in key foraging areas, as well as reducing masking effects due to underwater noise.

Research on the cumulative effects of the multiple threats to SRKW suggests that, although prey limitation is likely the most important factor affecting population growth, both reductions in acoustic disturbance and increases in prey abundance are needed to achieve population growth (Lacy et al. 2017). These results suggest that it would be theoretically possible to offset parts of the marine shipping effects by

1. increasing Chinook Salmon abundance coast-wide,
2. increasing availability of Chinook Salmon in key SRKW foraging areas, and
3. increasing SRKW access to Chinook Salmon by limiting interference from vessel disturbances.

Increasing the absolute abundance of Chinook Salmon stocks is a long term goal of SRKW recovery efforts as well as Fisheries Management. However, a number of key uncertainties are associated with the current understanding of Chinook Salmon productivity of the different stocks. For instance, the productivity of hatchery populations may differ from associated natural populations, but the available data does not provide a means of differentiating between hatchery and natural populations, limiting our ability to make inferences about natural productivity (DFO 2018). Large-scale patterns of environmental change and increased environmental variability have been associated with broad declines in productivity of Chinook Salmon across their range in recent decades. Chinook Salmon productivity is estimated to have declined 25-40% since the early 1980s across many BC indicator stocks; however, contrary to the basin-scale pattern of declines in productivity, increases in escapement have been observed for some Vancouver Island stocks. At present, the specific natural and/or human-caused mechanism(s) leading to these increases have not been isolated (DFO 2018).

Because of this, increasing overall abundance may not necessarily result in increased prey availability in the most relevant areas for SRKW. In contrast, management actions that limit Chinook Salmon removals in close proximity to SRKW foraging areas may increase the likelihood that these Chinook Salmon would be available to SRKW, as the risk of removals by other predators will be reduced (Hilborn et al. 2012). Information from sightings, acoustic detections, and expert opinion has been compiled to support the identification of SRKW foraging habitat. Four key locations were identified: Juan de Fuca Strait, the west side of Pender Island, the south side of Saturna Island, and the mouth of the Fraser River (Sheila Thornton [DFO, West Vancouver, BC], John Ford [retired DFO, Nanaimo, BC], Lance Barrett-Lennard, [University of British Columbia, Vancouver BC], pers. comms.).

Based on the best available information, and operating under a precautionary approach, the following measures have been proposed to increase prey availability for SRKW in the identified foraging areas:

1. a complete closure of Chinook Salmon removals from the four key foraging areas;
2. a combination of area closures and a decrease in Chinook Salmon retention that achieves the greatest reduction in removals from the foraging areas; and
3. a reduction in removals of 4- to 5- year old Chinook Salmon throughout the season, acknowledging that there is currently no effective means to differentiate between returning 3, 4, 5, or 6 year olds.

In 2018, DFO implemented spatially- and temporally-relevant fisheries closures for the purposes of increasing Chinook Salmon availability for SRKW in the Salish Sea and at the times where foraging has been most frequently observed.

While it is possible to identify methods by which Chinook Salmon removals in key SRKW foraging areas can be reduced, this may not necessarily translate into a direct proportional increase in accessible prey and foraging success, and in turn this may not result in a full mitigation of Project-related effects on SRKW. For instance, a workshop that assembled scientists and managers with technical expertise on killer whales and Chinook Salmon suggested that limiting vessel disturbances to make the Chinook Salmon that are already present easier for SRKW to catch would be beneficial (Trites and Rosen 2018).

In summary, recent population viability analysis modelling does suggest it is theoretically possible to offset effects of marine shipping by increasing Chinook Salmon abundance, availability and access in key SRKW foraging areas. However, because of the complexity of the interactions between stressors, it is not currently possible to provide reliable information on the exact increase of prey abundance needed to offset other adverse effects.

Other measures that could avoid, reduce and/or offset the adverse effects of Project-related marine shipping on SRKW

A number of additional mitigation measures have been suggested to reduce the impact of vessel noise on SRKW critical habitats, but their noise reduction potentials are presently uncertain and further studies are on-going, or need to be started, to evaluate their possible effectiveness (DFO 2017b). These measures were discussed originally for a large range of commercial vessels and measures were not specific to Project-related vessels. There is a general uncertainty about the effectiveness of the mitigation if only applied to Project-related vessels.

One suggested measure is to **redirect a portion of vessel traffic from Haro Strait to Rosario Strait.** The effect on SRKW critical habitat areas of great importance will depend on the proportion and types of vessels being rerouted. Such an approach will also necessarily lead to increased noise levels in Rosario Strait. The importance of Rosario Strait for SRKW would need to be reassessed to make sure the benefit is equally distributed among all SRKW. There are also physical and geographical constraints in Rosario Strait that would prevent the largest, and sometimes noisiest ships from being rerouted. Lastly, the waters of Rosario Strait are in the US and re-routing of shipping would require negotiations between the US and Canada. The negotiations would take time to complete, therefore the impacts would not be mitigated until the changes were implemented.

Another measure would be to implement **real-time notification of whale presence**; leading to management action, such as slow-downs or minor route changes. Uncertainty exists about the ability to reliably detect SRKW in real-time under various environmental conditions. The initiation of a vessel slow-down requires a lead time that changes relative to the speed of the vessel in order to effectively reduce the noise near the whales. Route changes are limited to certain areas of the critical habitat of SRKW where these can be safely performed.

A third approach would be to **create year-round or seasonal quiet or “no-go” zones** in certain critical habitats, e.g. known SRKW feeding areas which may shift due to prey type and/or abundance either seasonally or yearly. This would result in significant noise level reductions in the areas affected, but would result in increased noise levels in other areas. Also, these areas would have to be much larger than the actual sensitive critical habitat areas because of long-range underwater sound propagation. For this mitigation to be effective it would likely require dynamic management with spatial and temporal flexibility to respond to SRKW behaviour, foraging needs, and prey availability; this management strategy would be challenging due to the potential difference in preferred areas by different SRKW pods at different times of the year (Cominelli et al 2018). This mitigation measure may be applicable for other traffic but may not be directly applicable for TMX related vessel traffic because Project vessels travel in the international shipping lanes. Alternatively, areas outside the shipping lanes, and their separation zone, could be considered a ‘no go zone’.

A fourth approach would be to **restrict commercial vessel traffic at night** through sensitive critical habitat zones like Haro Strait. This would make it quiet at night, with the goal of creating quiet periods for SRKW to forage more easily (with reduced noise and vessel presence interference) but would increase the noise levels during daytime when an increased number of vessels would have to pass through a given area. The effectiveness of this mitigation measure depends on SRKW being able to make use of the quiet night-time periods to feed. This is still uncertain but night-time foraging behaviour is currently subject to scientific study in both Canada and the US.

A fifth mitigation measure would be **to replace the top 10%, or another percentage, of the noisiest vessels in a given vessel class, with ships having noise levels corresponding to the quietest 10% of the vessels in the same vessel class.** This approach applied to Project specific vessels may not have a large impact on the overall noise profile of the SRKW habitat areas. The mitigation measure should have an impact on the overall noise field in a given area if applied to the noisiest vessels, which may be container and large cargo ships according to Veirs et al (2016). DFO Science acknowledges this mitigation would potentially require multi-agency engagement of regulatory authorities in both Canada and the US.

Other possible mitigation techniques include training vessel operators to change vessel operating behaviour to avoid rapid acceleration and deceleration and the use of fewer but larger vessels to transport the same amount of product. This last mitigation is dependent on the number of larger Project-related vessels that will be in operation but an upper limit is given by the size restriction of vessels allowed to enter Burrard Inlet and dock at the Westridge Terminal.

Measures that could avoid or reduce cumulative adverse effects on SRKW

In the cumulative effects assessment undertaken by the Proponent in 2015, it was concluded that “past and current activities (including all forms of mortality, high contaminant loads, reduced prey, and sensory and physical disturbance) have resulted in significant adverse cumulative effects to the southern resident killer whale population” (Trans Mountain Pipeline ULC. 2013: section 4.4.5.3.1).

Relative to the Project’s contribution to cumulative effects to SRKW, it was concluded that “the Project will contribute additional underwater noise that could affect the southern resident killer whale population and this noise will act cumulatively with noise from existing and reasonably foreseeable marine vessel traffic. As such, even though the Project contribution to overall underwater noise represents only one component of current and future marine transportation sources for underwater noise, the Project’s contribution to potential cumulative effects of sensory disturbance is determined to be significant for southern resident killer whales” (section 4.4.5.3.1). Thus, sensory disturbance from noise from vessel traffic was determined to be an adverse unmitigated cumulative effect.

The present information request seeks new information or knowledge concerning the effectiveness of mitigation that could avoid or reduce cumulative adverse effects on SRKW.

A cumulative effects model developed by Lacy et al. (2017) projected that reducing acoustic disturbance by 50% in combination with increasing Chinook Salmon abundance by 15% would allow the SRKW population to increase by 2.3%, which is the US recovery target for this population (National Marine Fisheries Service, 2008).

In the model, the baseline conditions (i.e., empirical observations from 1976-2015) were predicted to result in a continued decline of SRKW with a 5% probability of a population size less than 30 individuals in 100 years and 0% probability of extinction (Table 1). This negative population trend reflects the losses of individuals in the population in recent years. A scenario with ‘no anthropogenic threats’ (baseline levels of Chinook Salmon, but no noise, contaminants, oil spills or ship strikes) was predicted to result in a small population growth rate, and eliminated the probability of extinction in 100 years or $N<30$. The ‘low development’ and ‘high development’ scenarios were both predicted to increase the rate of population decline, which was worse under the ‘high development’ scenario. ‘Low’ and ‘high’ development increased the probability of $N<30$ individuals in 100 years to 31% and 70%, respectively. Probability of extinction increased to 5% and 25%, respectively, under the two development scenarios (Lacy et al. 2017).

In single-threat mitigation scenarios, population growth was predicted in scenarios involving increased prey, elimination of noise, or elimination of contaminants. The highest population growth ($r=0.036$, or 3.6% annual rate of growth) was observed in a multi-threat mitigation scenario with a 30% increase in prey abundance and a 50% reduction in noise from baseline levels (Lacy et al. 2017).

*Table 1. Comparison of modelled SRKW population growth under different scenarios involving baseline and modified Chinook Salmon abundance, noise, contaminants, oil spills, and ship strikes (from Lacy et al. 2017). Baseline conditions are the rates observed in years 1976-2015. Modified parameters are expressed as a percentage of baseline unless otherwise indicated. Population growth rates marked with * are the highest rates for a range of scenarios tested (Increased prey: baseline to 130%; noise: 0% to baseline; PCBs: 0% to baseline; Chinook Salmon: baseline to 130% combined with 50% noise)*

Scenario	Environmental conditions (as % of baseline conditions)					SRKW population growth (r)
	Chinook Salmon	Noise	Contaminants (PCBs)	Oil spills	Ship strikes	
Baseline	Baseline	Baseline	Baseline (2 ppm)	Baseline (0)	Baseline	-0.002
No anthropogenic threats	Baseline	0%	0%	0%	0%	+0.019
Low development	Reaching 75% in 100 years	109%	Baseline	0.21% (big spill) 1.08% (small spill)	1 per 10 years	-0.008
High development	Reaching 50% in 100 years	118%	Baseline	0.42% (big spill) 2.16% (small spill)	2 per 10 years	-0.017
Increased prey	130%	Baseline	Baseline	Baseline	Baseline	+0.025 *
No noise	Baseline	0%	Baseline	Baseline	Baseline	+0.017 *
No PCB	Baseline	Baseline	0%	Baseline	Baseline	+0.004 *
Increased prey and reduced noise	130%	50%	Baseline	Baseline	Baseline	+0.036 *

Given that the adverse unmitigated cumulative effect identified by the Proponent was the result of repeated exposure to underwater noise from marine traffic, the measures identified in earlier sections of this document will also reduce the cumulative noise.

Relationship between vessel speed and tonnage and magnitude / extent of underwater noise

The vessel speed dependent broadband noise reduction is typically found to be between 0.5 and 1.5 dB per knot across all vessel classes (DFO 2017b). Studies also indicate that vessel class plays a bigger role in defining the noise level than size although most reported differences in noise output between vessel classes is confounded by vessel speed (McKenna et al 2012, McKenna et al 2013, Simard et al 2016, Veirs et al. 2016).

Vessel size appears not to be linearly associated with generated noise. McKenna et al. (2012) estimated the source levels of different types of vessels based on received levels measured from transiting vessels and found the levels to vary between 181.3 dB and 182.7 dB for tankers between 228 and 229 m in length and travelling at 15 knots. These levels were similar to vehicle carriers, but lower than for bulk carriers (187.4 dB).

Simard et al. (2016) reported large variations in sound source levels of more than 25 dB for commercial vessels ranging from 200-250 m in length. In 2013, McKenna et al. looked at the variation of underwater noise generation by container ships based on speed, length, gross tonnage and draft (draft, length and tonnage were linearly related and confounded into length) and found that variation for vessels of the same length varied greatly possibly due to differences in speed. Length was still seen as a predictor for noise generation but at a much coarser scale resolution (i.e., only very large size differences were good predictors of noise differences).

Load differences have been found to affect the noise generated by a given vessel. However it is not immediately obvious whether lighter loads will reduce or increase the noise. Lighter loads result in shallower draft and reduced energy input to the propeller to move a vessel forward, which should result in reduced noise. However, with shallower draft the propeller is closer to the surface, or might actually break the surface, resulting in less efficient energy transfer and cavitation, potentially increasing the noise generated and also shifting the noise to different acoustic frequencies.

The source levels from any given vessel is a result of complex multifactorial processes that depend on propeller, machinery, machinery mounting and hull design (Baudin and Mumm, 2015, Ross 1976, Wagstaff 1973) and ship speed and tonnage are only two parameters amongst many that play a role in defining a vessel's overall noise field.

In summary, due to large variations in noise output of vessels of the same length and gross tonnage, mitigation that would consider size restriction of tankers may not be very useful unless large size differences of Project-specific vessels would be considered. Furthermore, any mitigation measure based on restriction of only Project-related vessel sizes may be obscured by the relative noise generation of other commercial vessels operating in the same waters as the tankers.

Uncertainties

This evaluation of the effectiveness of mitigation measure to reduce impacts from Project-related marine vessels in SRKW has been conducted with the acknowledgement that there are key uncertainties associated with the information available. Examples include, but are not limited to:

- uncertainties associated with the data available for SRKW;
- uncertainty regarding noise spreading losses at higher frequencies;
- uncertainty regarding the efficacy of slowing down Aframax tankers to mitigate vessel collision fatalities; and,
- uncertainty regarding how reliable real-time detection would need to be, and how much notification lead time would be necessary, to enable vessels to effectively initiate the reviewed real-time mitigation measures.

Conclusions

- Redirecting a portion of vessel traffic from Haro Strait to Rosario Strait will reduce impacts on SRKW critical habitats in Haro Strait, but will increase the impact on other areas. Also, the physical constraints of Rosario Strait are a limitation to the type and size of vessels that could be redirected.

- A reduction in vessel speed generally results in an increase in **duration** of noise exposure, but a reduction in the overall **level** of noise, and reduced vessel speeds also have the potential to reduce the risk of lethal vessel strikes in larger whales. The effectiveness of a vessel speed reduction mitigation measure to reduce noise levels will be influenced by fleet characteristics, propagation characteristics for vessel sounds, and whether the vessels alter their passage pattern (such as through altered routes or convoys).
- Vessel design changes are possibly the most effective measures to reduce a vessel's underwater noise field. Keeping the propeller clean and well maintained and the hull clean also makes a large difference.
- In most cases, onboard monitoring of marine mammals by visual and/or acoustical technologies would be inadequate to determine with a reasonable level of confidence that SRKW would be present or absent from an area ahead of a transiting tanker that would provide an acceptable level of ship strike risk mitigation. It is recommended that MMOs coordinate with existing whale sighting networks to receive advance warning of SRKWs approaching the construction area to facilitate mitigation, such as reducing speed.
- Population viability analyses suggest it is theoretically possible to offset effects of marine shipping by increasing Chinook Salmon abundance, availability and access in key SRKW foraging areas. However, because of the complexity of the interactions between stressors, it is not currently possible to provide reliable information on the exact increase of prey abundance needed to offset other adverse effects.
- Implementing real-time notification of whale presence could lead to earlier initiation of other mitigation procedures, such as vessel-slow down, but only if real-time detection were reliable year-round and notification can reach vessels in due time.
- Year-round or seasonal quiet or "no-go" zones in certain critical habitats will have limited applicability in the constrained areas in the Gulf Islands. Sound also travels far, requiring careful studies to identify the size of such area to make a difference.
- Restricting commercial vessel traffic at night might be a useful mitigation measure if it can be demonstrated that SRKW forage at the same rate and capacity at night as during the day. However, night traffic restriction will result in increased noise levels during daytime.
- Replacing the top 10%, or another percentage, of the noisiest vessels in a given vessel class, with ships having noise levels corresponding to the quietest 10% of the vessels in the same vessel class would reduce the noise impact on critical habitats. However, except for regulating the Aframax tankers directly associated with the Trans Mountain Expansion Project, it will be difficult to implement.
- Due to large variations in noise output of vessels of the same length and gross tonnage, mitigation that would consider size restriction of tankers may not be very useful unless large size differences of Project-specific vessels would be considered. Furthermore, any mitigation measure based on restriction of Project-related vessel sizes is further confounded by the much bigger noise generation of other commercial vessels operating in the same waters as the tankers. Particularly large container ships travelling at higher speed in the vicinity of tankers would mask the noise produced by tankers.
- Given that the adverse unmitigated cumulative effect identified by the Proponent was the result of repeated exposure to underwater noise from marine traffic, the measures identified in earlier sections of this document will also reduce the total noise from all shipping. According to a cumulative effects model by Lacy et al. (2017), a reduction in noise relative to

baseline levels would be required to maintain the SRKW at current population levels, unless improvements in prey abundance and/or reduced contaminant levels are also implemented.

- In considering mitigation approaches, potential effects on other species should also be considered; in particular other threatened species that are known to be affected by low-frequency ship noise, such as blue and fin whales.

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Sources of Information

Baldacci, A., Carron, M. and Portunato, N. 2005. Infrared detection of marine mammals. NATO Undersea Research Centre Technical Report SR-443. NATO Undersea Research Centre, New York, New York, USA.

Baudin, E. and Mumm, H. 2015. AQUO/SONICS EU project report: Guidelines for regulation on UW noise from commercial shipping.

Branstetter, B.K., St Leger, J., Acton, D., Stewart, J., Hauser, D., Finneran, J.J., Jenkins, K. 2017. Killer whale (*Orcinus orca*) behavioural audiograms. J. Acous. Soc. of Amer.

Chion, C., Lagrois, D., Dupras, J., Turgeon, S., McQuinn, I. H., Michaud, R., and Parrott, L. (2017). Underwater acoustic impacts of shipping management measures: Results from a social-ecological model of boat and whale movements in the St. Lawrence River Estuary (Canada). Ecological modelling, 354, 72-87.

Clark, C.W., and Charif, R.A. 1998. Acoustic monitoring of large whales to the west of Britain and Ireland using bottom-mounted hydrophone arrays, October 1996 - September 1997. Rep. from Bioacoust. Res. Prog., Cornell Lab. Ornithol., Ithaca, NY, for Joint Nature Conserv. Commit., Aberdeen, Scotland. JNCC Rep. 281.

Cominelli, S., Devillers, R., Yurk, H., MacGillivray, A., McWhinnie, L. and Canessa, R., 2018. Noise exposure from commercial shipping for the southern resident killer whale population. Marine Pollution Bulletin, 136, pp.177-200.

Conn, P.B., and Silber, G.K. 2013. Vessel speed restrictions reduce risk of collision-related mortality for North Atlantic right whales. Ecosph. 4(4):1-15.

DFO 2015a. Sufficiency review of the information on effects of underwater noise and the potential for ship strikes from Marine Shipping on Marine Mammals in the Facilities Application for the Trans Mountain Expansion Project. DFO Can. Sci. Advis. Sec. Sci. Resp. 2015/007.

DFO 2015b. Technical review of predicted effects and proposed mitigation of underwater noise and potential vessel strikes on marine mammals, from the December 2013 Facilities Application and supplemental information for the Trans Mountain Expansion Project. DFO Can. Sci. Advis. Sec. Sci. Resp. 2015/022.

DFO 2017a. Identification of Habitats of Special Importance to Resident Killer Whales (*Orcinus orca*) off the West Coast of Canada. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/011.

DFO. 2017b. Evaluation of the Scientific Evidence to Inform the Probability of Effectiveness of Mitigation Measures in Reducing Shipping-Related Noise Levels Received by Southern Resident Killer Whales. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2017/041.

DFO. 2017c. Southern Resident Killer whale. A Science based review of recovery actions for three at-risk whale populations. 71pp.

DFO. 2018. Science information to support consultations on BC Chinook Salmon fishery management measures in 2018. DFO Can. Sci. Advis. Sec. Sci. Resp. 2018/035

ECHO. 2017. ECHO Program. An Evaluation of Vessel Quieting Design, Technology and Maintenance Options. January 2017.

ECHO. 2018. ECHO Program. Voluntary Vessel Slowdown Trial Summary Findings. June 2018.

Félix, F., and Van Waerebeek, K. 2005. Whale mortality from ship strikes in Ecuador and west Africa. Latin Amer. J. Aquat. Mamm. 4(1): 55-60.

Heise, K.A., Barrett-Lennard, L.G., Chapman, N.R., Dakin, D.T., Erbe, C., Hannay, D.E., Merchant, N.D., Pilkington, J.S., Thornton, S.J., Tollit, D.J., Vagle, S., Veirs, V.R., Vergara, V., Wood, J.D., Wright, B.M., Yurk, H. 2017. Proposed Metrics for the Management of Underwater Noise for Southern Resident Killer Whales Coastal Ocean Report Series (2), Ocean Wise, Vancouver, 31pp.

Hilborn, R., S.P. Cox, F.M.D. Gulland, D.G. Hankin, N.T. Hobbs, D.E. Schindler, and A.W. Trites. 2012. The Effects of Salmon Fisheries on Southern Resident Killer Whales: Final Report of the Independent Science Panel. Prepared with the assistance of D.R. Marmorek and A.W. Hall, ESSA Technologies Ltd., Vancouver, B.C. for National Marine Fisheries Service (Seattle. WA) and Fisheries and Oceans Canada (Vancouver. BC). xv + 61 pp. + Appendices.

Jensen, A.S., and Silber, G.K. 2003. Large whale ship strike database. U.S. Department of Commerce. NOAA Tech. Memo. NMFS-OPR-25. 37 p.

Kite-Powell, H.K., Knowlton, A., and Brown, M. 2007. Modeling the effect of vessel speed on right whale ship strike risk. NOAA. Project report for NOAA/NMFS Project NA04NMF47202394. 8 p.

Lacy RC, Williams R, Ashe E, Balcomb KC, Brent LJN, Clark CW, Croft DP, Giles DA, MacDuffee M, Paquet PC. 2017. Evaluating anthropogenic threats to endangered killer whales to inform effective recovery plans. Scientific Reports 7: 14119. DOI: 10.1038/S41598-017-14471-0

Lagueux, K.M., Zani, M.A., Knowlton, A.R. and Kraus, S.D., 2011. Response by vessel operators to protection measures for right whales Eubalaena glacialis in the southeast US calving ground. Endangered Species Research, 14(1), pp.69-77.

Laist, David & Knowlton, Amy & Pendleton, Daniel. 2014. Effectiveness of mandatory vessel speed limits for protecting North Atlantic right whales. Endangered Species Research. 23:133-147. 10.3354/esr00586.

Matkin, C. O, Moore M. J., and Gulland F.M.D. 2017. Review of Recent Research on Southern Resident Killer Whales (SRKW) to Detect Evidence of Poor Body Condition in the Population. Independent Science Panel Report to the SeaDoc Society. 3 pp. + Appendices. DOI 10.1575/1912/8803

McKenna, M.F., Ross, D., Wiggins, S.M. and Hildebrand, J.A., 2012. Underwater radiated noise from modern commercial ships. The Journal of the Acoustical Society of America, 131(1), pp.92-103.

McKenna, M.F., Wiggins, S.M. and Hildebrand, J.A., 2013. Relationship between container ship underwater noise levels and ship design, operational and oceanographic conditions. Nature Scientific reports, 3, p.1760.

Morano, J.L., Rice, A.N., Tielens, J.T., Estabrook, B.J., Murray, A., Roberts, B.L., and Clark, C.W. 2012. Acoustically detected year-round presence of right whales in an urbanized migration corridor. Conserv. Biol. 26(4):698-707.

National Marine Fisheries Service. 2008. Recovery Plan for Southern Resident Killer Whales (*Orcinus orca*) National Marine Fisheries Service Northwest Region, Seattle, WA.

Nichol, L.M., Wright, B.M., O'Hara, P., and Ford, J.K.B. 2017. Assessing the risk of lethal ship strikes to humpback (*Megaptera novaeangliae*) and fin (*Balaenoptera physalus*) whales off the west coast of Vancouver Island, Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/007. vii + 33 p.

Pace, R.M. 2011. Frequency of whale and vessel collisions on the US Eastern seaboard: Ten years prior and two years post ship strike rule. U.S. Department of Commerce, Northeast Fisheries Science Center Ref. Doc. 11-15. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026.

Pine, M. K., Hannay, D. E., Insley, S. J., Halliday, W. D., & Juanes, F. (2018). Assessing vessel slowdown for reducing auditory masking for marine mammals and fish of the western Canadian Arctic. Marine pollution bulletin, 135, 290-302.

Ross, D. 1976. Mechanics of Underwater Noise. Pergamon, New York. pp. 272–287.

Silber, G.K., Slutsky, J., and Bettridge, S. 2010. Hydrodynamics of a ship/whale collision. J. Exp. Mar. Biol. Ecol. 391(1-2):10-19.

Simard, Y., N. Roy, C. Gervaise and S. Giard, 2016. Analysis and modelling of 255 source levels of merchant ships from an acoustic observatory along St. Lawrence Seaway. J. Acoust. Soc. Am. 140(3), 2002-2018.

Trans Mountain Pipeline ULC. 2013. Trans Mountain Expansion Project – An Application Pursuant to Section 52 of the National Energy Board Act, Volume 8A - Marine Transportation. Submitted to the Secretary of The National Energy Board

Trites, AW and Rosen, DAS (eds). 2018. Availability of Prey for Southern Resident Killer Whales. Technical Workshop Proceedings. November 15–17, 2017. Marine Mammal Research Unit, Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, B.C., 64 pages

van der Hoop, J.M., Vanderlaan, A.S.M., and Taggart, C.T. 2012. Absolute probability estimates of lethal vessel strikes to North Atlantic right whales in Roseway Basin, Scotian Shelf. Ecol. Appl. 22(7): 2021-2033.

Vanderlaan, A.S.M., and Taggart, C.T. 2007. Vessel collisions with whales: the probability of lethal injury based on vessel speed. Mar. Mamm. Sci. 23(1):144–156.

Vanderlaan, A.S.M, and Taggart, C.T. 2009. Ships voluntarily alter course to protect endangered whales. Conserv. Biol. 23(6):1467-1474.

Vanderlaan, A.S.M., Taggart, C.T., Serdynska, A.R., Kenney, R.D., and Brown, M.W. 2008. Reducing the risk of lethal encounters: vessels and right whales in the Bay of Fundy and on the Scotian Shelf. Endang. Spec. Res. 4:283–297.

Veirs, S.R., Veirs, V.R. 2011. Masking of southern resident killer whale signals by commercial ship noise. The Journal of the Acoustical Society of America. 129(4):2606

Veirs, S., Veirs, V. & Wood, J.D., 2016. Ship noise extends to frequencies used for echolocation by endangered killer whales. PeerJ, 4, p.e1657.

Wagstaff. 1973. RANDI: Research Ambient Noise Directionality Model. Undersea Surveillance and Ocean Sciences Department.

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