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Canadian Science Advisory Secretariat
National Capital Region **Science Advisory Report 2017/041**

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

Southern Resident Killer Whale.
Photo credit: Graeme Ellis

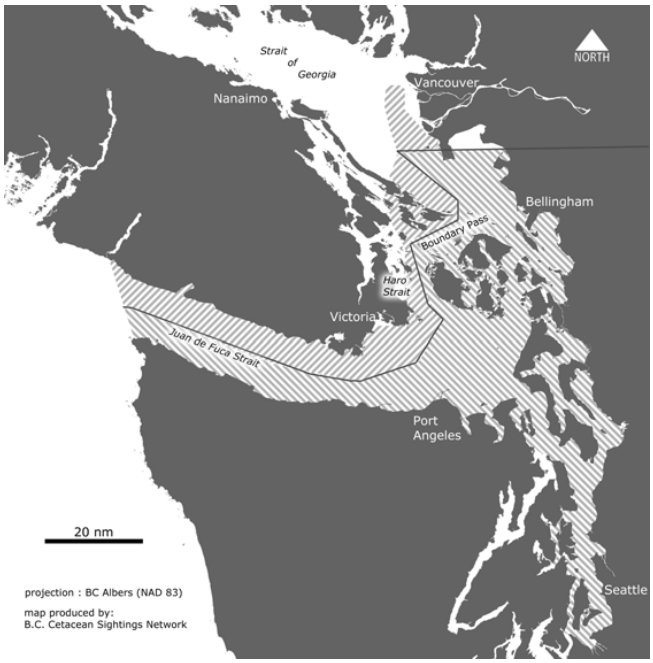

Figure 1. Southern Resident Killer Whale Critical Habitat in Canada and the United States. The hatched area in US waters depicts the approximate Critical Habitat under the US Endangered Species Act

Context:

Ambient underwater noise levels have increased significantly over the past half century, largely as a result of increasing human activities in the marine environment. Marine shipping and vessel navigation activities of all types have been identified as important contributors. However, the extent of this contribution, and its associated impacts on marine species, is not well understood, and is complex to assess. There have been growing demands for government action to address this issue domestically and internationally in order to protect the marine ecosystem, and more specifically, species at risk. In Canada, concerns are growing over the effects of underwater noise on marine mammals particularly in the south coast of British Columbia, the Estuary and Gulf of St. Lawrence, and the Bay of Fundy.

Most recently, in its review of the Trans Mountain Expansion (TMX) Project, the National Energy Board (NEB) found that the increase in marine vessels associated with the Project would further contribute to cumulative effects that are already jeopardizing the recovery of the Southern Resident Killer Whale

(SRKW). Consequently, the Board concluded that the operation of Project-related marine vessels is likely to result in significant adverse effects to the SRKW population. The NEB encouraged regulatory authorities who have jurisdiction, notably Transport Canada (TC) and Fisheries and Oceans Canada (DFO), to explore initiatives that would reduce the potential effects of marine vessels on the SRKW population. In approving TMX, the Government of Canada committed to more than mitigate the impact of additional TMX traffic on the SRKW before any shipping associated with the Project begins.

DFO's Fisheries Protection Program (FPP) has asked DFO Science to provide science advice on the effectiveness of various mitigation measures (or a combination of these) for reducing shipping-related noise levels received by SRKW.

This Science Advisory Report is from the May 30 to June 1, 2017 National Peer Review Meeting on the 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. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

SUMMARY

- In Pacific Canadian waters, the Southern Resident Killer Whale (SRKW) population is listed as Endangered under the *Species at Risk Act* (SARA). Three key threats have been identified as contributing to their decline: availability and quality of prey, environmental contamination, and both physical and acoustic disturbance.
- The SARA requires identification of critical habitat (the habitat necessary for survival or recovery) for threatened or endangered species. An area of critical habitat for SRKW has been identified and is legally protected from destruction (Figure 1). Science Advice identifying additional critical habitat has also been developed.
- Sound is vital to whales (e.g., prey sounds, environmental sounds, echolocation and social calls) to carry out their life functions, including foraging, navigating and communicating, and these functions can be interfered with by ship noise as the spectral frequency ranges overlap.
- Vessel traffic is the largest source of underwater noise in the SRKW critical habitat, which is bisected by the primary shipping lanes for the Ports of Seattle and Vancouver. This review considered mitigation measures that could apply to commercial ships, but excludes vessels such as whale watching vessels.
- The purpose of this peer review process was to evaluate the scientific evidence related to mitigation measures that could be applied to reduce shipping-related noise within identified and proposed SRKW critical habitat. The process did not consider the habitat use by SRKW within those areas, or impacts of noise on the whales. Furthermore, feasibility, safety, and socio-economic factors were not considered in the review process.
- Noise emitted from ships varies with factors such as speed, loading, draft, engine type, etc. and can vary substantially between individual vessels.
- A small proportion of ships produce a disproportionately large amount of the total noise.
- Within a given location, the total vessel noise is a combination of the source level, the time the vessels spend in the area, and the local sound propagation characteristics.
- A range of mitigation measures were evaluated for the likelihood of reducing shipping related noise.

- Mitigation measures modify either the noise source (source-based) or the operation (operation-based) of the ship in space and time.
- Source-based mitigation measures (i.e., ship design and/or retrofit) have a global and long-term effect, and could be implemented incrementally as ships were modified or replaced. It does not require knowledge of whale presence, distribution or behaviour to be effective. In the long term, modification of ship design to reduce radiated noise is likely to have the greatest potential for improving the acoustic environment of SRKW.
- Operation-based mitigation measures (i.e., slowing down, relocation of traffic lanes, convoys) have the potential to reduce noise output and improve the acoustic environment of SRKW. These measures have a more local and temporary effect on the acoustic environment, and could be implemented simultaneously to multiple vessels. They also have more uncertainty in their effectiveness of mitigating noise impacts, because they require knowledge of whale presence, distribution, and behaviour.
- It is noted that some operation-based mitigation measures may have side-effects (e.g., redistributing noise into other habitats, or increasing duration of noise).
- The operation-based measures showing the most potential for improving the acoustic environment include reducing ship speed, transit time restrictions and convoying. Other measures that may have location- or spectral frequency- specific benefits include rerouting traffic and shifting traffic lanes.
- A combination of measures will likely be the most effective solution to improve the acoustic environment.

BACKGROUND

The Southern Resident Killer Whale (SRKW) population in British Columbia is listed as Endangered under the *Species at Risk Act* (SARA) because of their small population size, low reproductive rate, and the existence of a variety of anthropogenic threats preventing their recovery. Principal among these threats are reductions in the availability or quality of prey, environmental contamination, and both physical and acoustic disturbance. The *Action Plan for the Northern and Southern Resident Killer Whale (Orcinus orca) in Canada* (DFO 2017a) outlines measures that provide the best chance of achieving the population and distribution objectives for the SRKW, including measures to address threats and monitor recovery.

The SRKW population experienced declines of 3% per year between 1995 and 2001, and continues to show signs of decline. In 2017, the SRKW population consisted of 78 animals. The SRKW population is primarily found in the transboundary waters of Haro Strait, Boundary Pass, the eastern portion of the Juan de Fuca Strait, and southern portions of the Strait of Georgia. These areas are designated as ‘critical habitat’ based on consistent and prolonged seasonal occupancy by SRKW. Some members of the population typically remain in the same general area in winter and spring (J pod), but others (K and L pods) appear to range over much greater distances, and have been reported as far south as Monterey Bay, California, and as far north as Southeast Alaska (DFO 2017a).

The seasonal movement patterns of SRKW are strongly influenced by the availability of Chinook Salmon, the whales’ primary prey. Waters off southwestern Vancouver Island, particularly over the various banks including Swiftsure Bank and La Pérouse Bank, are known to be highly productive salmon habitats and have been recently identified for consideration as additional critical habitat for SRKW (DFO 2017b). Frequent observations of two of the three SRKW pods

(K and L) at Swiftsure Bank from November to May further indicate that this area is important SRKW habitat in both winter and spring (DFO 2017b).

Killer whales use sound to detect prey (echolocation), to communicate and to acquire information about their environment. Anthropogenic noise can result in disruption of communication, reduction in the distance over which social groups can detect each other, masking of echolocation signals and reduction in the distance over which the animals can detect their prey, displacement from preferred feeding habitats, displacement of prey, temporary or permanent hearing impairment, and in extreme cases death (DFO 2011).

Ambient underwater noise levels have increased significantly over the past half century, largely as a result of increasing human activities in the marine environment. Marine shipping and vessel navigation activities of all types have been identified as important contributors. However, the extent of this contribution and its associated impacts on marine species is complex to assess. There have been growing demands for government action to address the issue of underwater noise domestically and internationally in order to protect the marine ecosystem, and more specifically, species at risk. In Canada, concerns are growing over the effects of underwater noise on marine mammals, particularly in the south coast of British Columbia, the St. Lawrence Estuary, and the Bay of Fundy.

In a recent project review of the Trans Mountain Expansion (TMX) Project, the National Energy Board (NEB) found that the increase in marine vessels associated with the Project would further contribute to cumulative effects that are already jeopardizing the recovery of the SRKW. Consequently, the Board concluded that the operation of Project-related marine vessels is likely to result in significant adverse effects to the SRKW population. The NEB encouraged regulatory authorities who have jurisdiction, notably Transport Canada (TC) and Fisheries and Oceans Canada (DFO), to explore initiatives that would reduce the potential effects of marine vessels on the SRKW population. In approving TMX, the Government of Canada committed to more than mitigate the impact of additional TMX traffic on the SRKW before any shipping associated with the Project, which is forecast to commence in December 2019.

The objectives of this national peer review as outlined in the Terms of Reference were to:

1a. Provide science advice on the probability of effectiveness of the following mitigation measures (or a combination of these) in reducing shipping-related noise levels received by SRKW:

- Reducing the speed of vessels (or a specific vessel class) in areas of likely noise-whale interactions, i.e. areas where shipping and SRKW presence overlap (e.g., Haro Strait, Swiftsure Bank, etc.)
- Relocation of shipping traffic lanes (e.g., move traffic away from Swiftsure Bank, away from western San Juan Island, etc.)
- Changes in timing of ship traffic, both on the short scale (hours of day) and the long scale (time of year)
- Changes in shipping practices (station keeping vs. anchoring, number of tugs, use of on-board machinery, etc.)
- Changes in ship design (e.g., electric engines, efficient propellers, hulls, etc.)
- Modifications or retrofits to existing vessels (e.g., adding fins or plates in front of propellers to streamline flow, propeller shrouds)
- Redirecting a portion of vessel traffic (e.g. vessel classes, project-related vessels, etc.) through alternate routes (e.g., Rosario Strait)
- Changes in maintenance of ships (hull cleaning, propeller cleaning/inspection, etc.)

- Real-time notification of whale presence in hot spot areas (traffic light system) leading to management action
- Slow down or minor route change when whales are detected within the vicinity of or encountered by individual vessels (e.g., using passive acoustic monitoring, a whale tracking network or marine mammal observers to determine whale presence)
- Convoy approach (staged vessel movements) for specific vessels or vessel classes, whereby vessels transit under strict and condensed timing windows
- Creation of 'quiet'/'no-go' areas, or periods of quiescence in certain areas or segments

1b. Identify the circumstances (ship type, season, location, habitat use, etc.) that would increase the probability of effectiveness of the listed mitigation measure in reducing noise levels received by SRKW.

2. Review experimental approaches to investigate the acute and long-term impacts of shipping-related noise on SRKW individuals and the population.

3. Identify any uncertainties, limitations and/or knowledge gaps of the listed mitigation measures in reducing shipping-related noise or in reducing sound levels received by SRKW and consequently their impact on SRKW, and actions to address these.

ASSESSMENT

The purpose of this peer review process was to evaluate the scientific evidence related to mitigation measures that could be applied to reduce shipping-related noise within the identified critical habitat and areas identified for consideration as additional SRKW critical habitat. The process did not consider the specific habitat use (e.g., feeding, breeding, calving) by SRKW within the identified and proposed critical habitat, or impacts of noise on the whales. Furthermore, feasibility, safety, and socio-economic factors were not considered at this meeting.

A research document by the Oceans Research and Conservation Association (ORCA) was commissioned to provide a literature review and analysis of measures and actions that could mitigate the impacts of shipping related noise on the SRKW in the Salish Sea. In addition to the research document, presentations by the Vancouver Aquarium summarizing the results of a recent workshop on noise metrics and by JASCO Applied Sciences summarizing recent underwater noise modelling work were provided as supplementary information to inform this review process Three other presentations were provided and their summaries can be found in the Proceedings.

Presentation summarizing a workshop on establishing metrics for the management of underwater noise for Southern Resident Killer Whales

The Vancouver Aquarium's Coastal Ocean Research Institute (CORI) held a workshop in early May 2017 to develop a framework of standardized metrics for measuring, comparing and detecting changes in the acoustic quality of the whale's habitats and for measuring the noise impacts on SRKW. Three metrics were proposed: broadband level, communication masking, and echolocation masking (Table 1).

Table 1. Summary of the three noise metrics that collectively describe the quality of the acoustic habitat for Southern Resident Killer Whales (SRKW).

Metric	Purpose
Broadband level noise	To indicate the risk of physical and physiological effects of low-frequency noise on SRKW, and for ship noise assessment and vessel ranking
Communication masking noise	To indicate levels of communication masking in the relevant SRKW frequency band of 0.5-15 kHz
Echolocation masking noise	To indicate levels of echolocation masking in the relevant SRKW frequency band of 15-100 kHz

Presentation on vessel noise modelling in the Salish Sea and SRKW critical habitat conducted by JASCO

JASCO provided a presentation on preliminary modelling results for the projected mean increase in noise associated with TMX at two different geographic scales [Salish Sea: 0.19 decibels (dB); Haro Strait: 0.23 dB] and the changes in noise that would be expected to occur after applying the mitigation measures listed below. It is important to note that the noise reduction values listed below are averaged over the entire area (Salish Sea or Haro Strait as listed) and do not reflect the fact that the reduction in noise may be greater in the immediate vicinity where the mitigation measure is applied (see Figure 2). The reduction values listed below are relative to current baseline conditions:

Salish Sea:

- addition of TMX and replacement of 10% of the noisiest vessels (including ferries) by the quietest 10% of vessels in the Salish Sea – mean reduction of 0.80 dB
- addition of TMX and replacement of 10% of the noisiest vessels (excluding ferries) by the quietest 10% of vessels in the Salish sea – mean reduction of 0.68 dB

Haro Strait:

- addition of TMX and vessel slow-down to 11 knots in Haro Strait – mean reduction of 0.02 dB
- addition of TMX and no-go zone from midnight to 4:00 am in Haro Strait – mean reduction of 12.52 dB during the no-go hours, but results in a mean increase of 0.87 dB outside of no-go hours

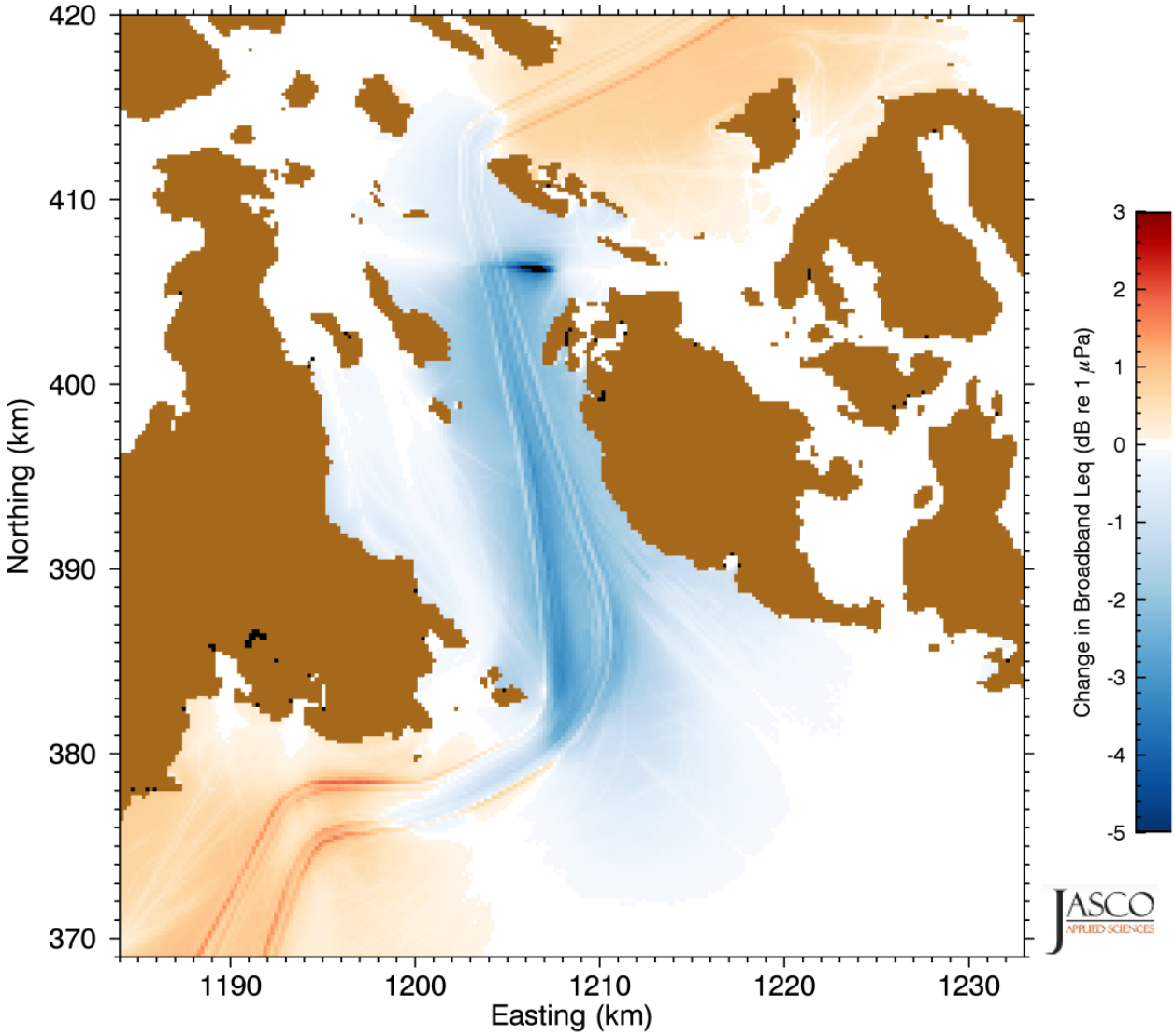

Figure 2. Model of net change in noise levels (time-averaged for month of July) after the addition of TMX traffic and implementation of an 11 knot slowdown zone in Haro Strait (JASCO Applied Sciences). Blue indicates a reduction in noise and orange indicates an increase in noise, relative to current baseline conditions.

Presentation of the research document

The research document presentation summarized ORCA's literature review and analysis of measures and actions that could potentially mitigate the impacts of shipping-related noise on SRKW in the Salish Sea through a net reduction of broadband noise within the area. The authors modeled the changes in broadband noise levels resulting from the following mitigation measures: reducing the speed of vessels, removing the noisiest ships, retrofitting vessels, changing ship design, relocating traffic lanes, and convoying in Haro Strait using ship source level data collected in Haro Strait from over 1582 unique vessels between 2011 and 2013. The authors also provided a literature review on the following mitigation measures: reducing the speed of vessels, relocation of shipping lanes, changes in timing of ship traffic, changes in shipping practices, changes in ship design, modifications or retrofits to existing vessels,

redirecting a portion of vessel traffic, changes in ship maintenance, real-time notification of whale presence in hot spot areas, the convoy approach, slow down or minor route changes, and the creation of no-go areas, or periods of quiescence (i.e. no-go time periods). The authors determined that the greatest noise reductions could be achieved by applying the following mitigation measures: imposing a speed limit of 11.8 knots, removing the noisiest ships (without replacement), retrofitting ships, or convoying ships with a speed limit of 11.8 knots.

Evaluation of the likelihood of reducing shipping-related noise

The probability of effectiveness of the listed mitigation measures in reducing shipping-related noise levels received by SRKW was assessed by considering the following factors: availability of scientific evidence; potential degree of noise reduction; geographic extent of noise reduction ; effect on “quieter times”; comments related to spatial/temporal/spectral frequency aspects of the noise reduction; permanent vs. temporary effect; uncertainties, limitations and knowledge gaps; other considerations regarding probability of reducing shipping-related noise; and, factors that could increase the effectiveness of the proposed measure (Tables A1 and A2). The effectiveness of the mitigation measures to reduce impacts on SRKW was assessed based on the likelihood of reducing shipping-related noise and by considering whether shipping-related noise would be received by whales (i.e., noise occurring in areas where shipping and SRKW presence overlap), without considering the impact of the noise on SRKWs. Mitigation measures were also assessed based on their ability to meet the Government’s commitment to “more than mitigate” the impacts of the underwater noise associated with the TMX project. The results of the assessment of mitigation measures are presented in more detail in Table A1.

The following mitigation measures were not considered due to time constraints: changes in timing of ship traffic and changes in shipping practices. Changes in ship design and modifications or retrofits to existing vessels were combined into one mitigation measure. Real-time notification of whale presence in hot spot areas (traffic light system) leading to management action and slow down or minor route change when whales are detected within the vicinity of or encountered by individual vessels were also combined into one mitigation measure.

Mitigations were determined to modify either the noise source (source-based mitigation measures) or the operation (operation-based mitigation measures) of the ship in space and time. Modifying the source of the noise through changes to ship design and/or retrofit has a global and long-term effect, and could be implemented incrementally as ships are modified or replaced (Table A1). The benefits of source-based mitigation measures include that they do not require knowledge of whale presence, distribution and behaviour to be effective at reducing noise levels received by the animals. In the long term, modification of ship design to reduce radiated noise is likely to have the greatest potential for improving the acoustic environment of SRKWs. Operation-based mitigation measures (i.e., slowing vessels down, relocation of traffic lanes, convoys) have the potential to reduce noise output and improve the acoustic environment of the SRKW (Table A1). These measures likely have a more local and temporary effect on the acoustic environment, and could be implemented simultaneously to multiple vessels. However, there is more uncertainty in the effectiveness of operation-based mitigation measures for reducing noise levels received by the SRKW, because assessing their effectiveness requires knowledge of whale presence, distribution, and behaviour. It is also important to note that some measures which modify operations may have associated negative side-effects, such as redistributing noise into other habitats, or increasing the duration of noise in an area.

Circumstances that would increase the probability of effectiveness of the listed mitigation measure in reducing noise levels received by SRKW

The probability of effectiveness of source-based mitigation measures could be increased if a proportion of the noisiest ships are replaced with quieter ship designs or retrofitted with quieter technology (Table A1). Regular ship maintenance could also reduce the noise levels emitted by vessels (Table A1), but more information is needed to determine which types of maintenance are most important in reducing noise levels and how frequently maintenance must be performed to be effective.

The probability of effectiveness of operation-based mitigation measures could be increased if the measures target specific seasons, times of day, and geographic locations that are important to SRKW vital functions (Table A1); however, the identification of these seasons, times of day, and/or geographic locations are identified either as highly variable, because they are dependent on prey availablility, or as current knowledge gaps (below; Table A2).

Review of experimental approaches to investigate the impacts of shipping-related noise on SRKW

The experimental approaches that could be used to investigate the acute and long-term impacts of shipping-related noise on SRKW individuals and the population were not reviewed due to time constraints.

Sources of Uncertainty

A few overarching uncertainties, limitations and knowledge gaps were identified for all operation-based mitigation measures and relate to either SRKW biology or acoustic data (Table A2). The spatial (geographic location and depth) and temporal (daily, seasonal) distribution of SRKWs is linked to prey availability and therefore difficult to predict. There is also a lack of reliable and accurate data that can be used to determine the impacts of noise on SRKWs and characterize the sensitivity of SRKWs to noise. To assess the effectiveness of mitigation measures on reducing the impacts of noise on SRKW more information is required on the importance of quieter periods to SRKW life functions. Although noise propagation modeling has been conducted there has been little real-world testing to validate models.

The identified uncertainties, limitations and knowledge gaps associated with source-based mitigation measures relate to a lack of accepted noise standards for the shipping industry, a limited understanding of why some ships are quieter than others, and limited studies on the effect of maintenance to reduce shipping-related noise (Table A2). It is important to note that examples of relatively quiet merchant ships already exist within the fleet, and understanding what makes these ships quieter than others should be a research priority.

CONCLUSION

Mitigation measures were classified as either modifying the source (i.e., ship design and/or retrofit) or modifying the operation of the ship (i.e., slowing vessels down, relocation of traffic lanes, convoys). Source-based mitigation measures have a global and long-term effect, which could be implemented incrementally as ships are modified or replaced. Modifying the noise source does not require knowledge of whale presence, distribution and behaviour to be effective. In the long term, modification of ship design to reduce radiated noise is likely to have the greatest potential for improving the acoustic environment of SRKW. Mitigation efforts that modify the source should first focus on identifying and remediating the small proportion of ships

producing the most noise. Operation-based mitigation measures that show the most potential for improving the acoustic environment include reducing ship speed, time restrictions and convoying. Other measures that may have location- or spectral frequency-specific benefits include rerouting traffic and displacing traffic lanes. It is important to note that operation-based measures may have associated side-effects (e.g., redistributing noise into other habitats, or increasing duration of noise). The most effective solution to improve the acoustic environment for SRKW will likely be a combination of mitigation measures.

Various recommendations were developed on how to increase the probability of effectiveness of the assessed mitigation measures in reducing shipping-related noise levels received by SRKW. It was recommended that any implemented measure should incorporate monitoring to assess the efficacy, and be applied through an adaptive management approach to iteratively improve the outcome. The potential benefits of the mitigation measures will depend on how the noise affects the whale's life functions (echolocation, feeding, communication, behaviour, etc.); therefore, the selection of local operation-based mitigation measures should consider the current knowledge of the presence and behaviour of SRKWs. To make effective mitigation decisions, further research is needed on the presence and behaviour of whales as well as the impacts of noise on SRKWs and their prey. To assist in studying the impacts of noise on SRKW, modelling studies should be undertaken to assess the efficacy of the proposed mitigation measures using the noise metrics (broadband level noise, communication masking noise, and echolocation masking noise) provided above (Table 1).

SOURCES OF INFORMATION

This Science Advisory Report is from the May 30 to June 1, 2017 National Peer Review Meeting on the "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". Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

DFO. 2011. Recovery Strategy for the Northern and Southern Resident Killer Whales (*Orcinus orca*) in Canada. *Species at Risk Act* Recovery Strategy Series, Fisheries & Oceans Canada, Ottawa, ix + 80 pp.

DFO. 2017a. Action Plan for the Northern and Southern Resident Killer Whale (*Orcinus orca*) in Canada. *Species at Risk Act* Action Plan Series. Fisheries and Oceans Canada, Ottawa. iii + 32 pp.

DFO. 2017b. 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.

APPENDIX

Table A1. Assessment of the probability of mitigation measures to reduce shipping-related underwater noise levels experienced by SRKWs by considering the scientific evidence available, potential degree of noise reduction, comments related to spatial/temporal/spectral frequency aspects of reduction and factors that could increase the effectiveness of the proposed measures. Refer to the research document for a description of the scientific evidence available for each mitigation measure.

Global Measures

Mitigation measure	Scientific evidence available?	Potential degree of underwater noise reduction	Comments related to spatial/temporal/spectral frequency aspects of underwater noise reduction	Considerations regarding probability of reducing shipping-related noise levels	Factors that could increase the effectiveness of the proposed measure to reduce underwater noise
Changes in ship maintenance (hull cleaning, propeller cleaning/inspection, etc.)	Yes	A review of the EU project "Achieve QUieter Oceans by shipping noise footprint reduction" (AQUO) suggested 1-2 dB reduction might be achieved if maintenance could improve service speeds by 5%. No empirical evidence was provided of whether such a change was achievable.	Amplitude and frequency range of the noise reduction achieved depends on the specific maintenance issue and the maintenance performed	Requires a mechanism to identify vessels requiring maintenance and encourage/incentivize regular maintenance	Regular maintenance is important Knowledge on the proportion of the fleet that is currently 'under maintained' (if high, this measure will be quite effective; if low, this will have a minimal effect)
Ship design and retrofit	Yes	Large potential for noise reduction, especially for loudest vessels Potential reduction from retrofits varies with specific change(s) made. Propeller design: 3-18 dB reduction. Isolating diesel engines and associated parts: 15-20 dB reduction. Hull modifications or treatments: 10 dB (medium frequencies) reduction, 20 dB (high frequencies) reduction.	Minimal increases in duration of quieter times near shipping lanes Broadband reductions likely Quieter ships have a smaller noise footprint, so reduced spatial extent of noise	Reductions depend on the extent of retrofit and design applied to each ship, and the number of ships treated	Incorporation of hull and propeller noise emission modelling in early design process Proportion of the fleet replaced with new designs or retrofitted

Local measures

Mitigation measure	Scientific evidence available?	Potential degree of noise reduction	Comments related to spatial/temporal/spectral frequency aspects of reduction	Considerations regarding probability of reducing shipping-related noise levels	Factors that could increase the effectiveness of the proposed measure
Reducing speed of vessels (or specific vessel class) in areas of likely noise-whale interactions	Yes	Broadband: ~0.5 to 1.5 dB reduction per knot reduction	Potential to reduce noise intensity but likely increases the duration of noise Ships may increase speed elsewhere to compensate for slowdown There is a high expectation that reducing vessel speed will reduce broadband levels, but effects on the communication and echolocation frequency bands of the SRKW are less clear	There appears to be potential for a net positive effect in reducing sound exposure levels, but uncertainty remains	Spatial and temporal knowledge of whale distribution in relation to proposed slowdown areas Degree and duration of slowdown Propagation characteristics of the environment (varies seasonally and spatially) Vessel class targeted for slowdown Proportion of vessels targeted Targeting the noisiest ships

Mitigation measure	Scientific evidence available?	Potential degree of noise reduction	Comments related to spatial/temporal/spectral frequency aspects of reduction	Considerations regarding probability of reducing shipping-related noise levels	Factors that could increase the effectiveness of the proposed measure
Lateral displacement of shipping traffic (lane displacement – distance related mitigation)	Yes	Dependent on propagation characteristics of the environment Re-locates the noise source If critical habitat is located very close (e.g., 100 m) to a shipping lane, received noise levels could be lowered dramatically by moving the ships only 20-100 metres further away. However, if the range to a species of concern is initially higher (e.g. 2000 m, or ~1 nautical mile), then mitigation to achieve a 3 dB reduction requires moving the ship an additional 800-2000 metres. Highly frequency dependent; higher frequencies attenuate rapidly, so the effect of moving a traffic lane would be greater for these frequencies	Should increase duration of quieter times in the areas where ship traffic has been moved away from, but will increase noise in the area where traffic is moved Magnitude of noise reduction is less for lower frequencies, more for higher, due to attenuation	Physical constraints on moving lanes (i.e., depth, channel width, etc.) Limited geographic scope. Requires site fidelity by the whales for efficacy.	Site-specific propagation conditions Whale distribution (spatial and temporal)

Mitigation measure	Scientific evidence available?	Potential degree of noise reduction	Comments related to spatial/temporal/spectral frequency aspects of reduction	Considerations regarding probability of reducing shipping-related noise levels	Factors that could increase the effectiveness of the proposed measure
Redirecting a portion of vessel traffic (e.g. vessel classes, project-related vessel, etc.) through alternate routes (shifting traffic from Haro to Rosario Strait)	Yes	Depends on proportion of ships rerouted. Displaces noise sources to another location Equivalent reduction in noise to removing ships from Haro Strait from the local modelling perspective Limits on traffic in Rosario Strait due to physical/geographic constraints (depth, width, etc.) would prevent the largest, noisiest ships from being rerouted	Would increase duration of quiet time in Haro Strait while decreasing quiet times in Rosario Strait. Effects would depend on the propagation characteristics of the receiving environment. Rosario Strait is narrower and therefore, high frequency noise could increase due to shorter propagation distances. Increased vessel transit distance and slow speeds needed to navigate Rosario Strait could actually increase noise exposure Additional vessel traffic may greatly change the noise spectrum in Rosario Strait.	Physical constraints on moving lanes Composition of the fleet; which ships and how many can be rerouted	Understanding the spatial and temporal distribution of SRKWs in Rosario Strait Speed reduction required to safely navigate Rosario could also have a noise reduction effect
Real-time notification of whale presence in hot spot areas (traffic light system) leading to management action such as slow downs or minor route changes	Yes	Potential reduction in noise if ship slows down upon warning of whale presence Change in course could reduce exposure of whales to noise or displace noise to other areas	Refer to specific mitigation measure/management action applied (e.g., “reducing speed of vessels”)	Refer to specific mitigation measure/management action applied (e.g., “reducing speed of vessels”)	Refer to specific mitigation measure/management action applied (e.g., “reducing speed of vessels”)

Mitigation measure	Scientific evidence available?	Potential degree of noise reduction	Comments related to spatial/temporal/spectral frequency aspects of reduction	Considerations regarding probability of reducing shipping-related noise levels	Factors that could increase the effectiveness of the proposed measure
Convoy approach for specific vessels or vessel classes	Yes	Reduces the temporal 'footprint' of the noise produced Noise output remains the same, assuming that all ships normally travel at the same speed, but the spatial and temporal patterns of noise are changed due to sound propagation	Increases duration of quiet time within the convoy area There may be increased noise in 'staging' areas where ships wait to join a convoy Convoying vessels would have to reduce their speeds to match the slowest ship in the convoy	Ship spacing in convoy Number of ships in a convoy; number of convoys per day Composition of convoys (ship types and number) Timing of convoys Potential change in vessel strike risk Location of staging area: potential noise increases while ships waiting	Reducing speed of convoy Timing relative to whale presence Location of staging areas Opportunistic 'convoys' could give a chance for testing Single file vs tandem convoys Number of convoys per day Wake-induced bubbles could limit propagation of following ships' high frequency noise emissions, 'masking' the noise from additional ships

Mitigation measure	Scientific evidence available?	Potential degree of noise reduction	Comments related to spatial/temporal/spectral frequency aspects of reduction	Considerations regarding probability of reducing shipping-related noise levels	Factors that could increase the effectiveness of the proposed measure
Creation of 'quiet'/'no-go' periods of quiescence	Yes	Large reduction during the 'quiet'/'no-go' time Shifts the noise to different times, so may increase noise outside of 'no-go' time	Expected to extend the contiguous duration of quiet times in specific locations Location dependent: islands within the Salish Sea can help create quiet spots by preventing noise from spreading further This would help reduce high frequency especially Would be most effective during times and in locations of whale feeding activity Consideration should be given to seasonal 'no-go' zones in addition to daily traffic management	Refer to "convoy approach"	Ensuring that quiet zones or times overlap with the locations and times that are of particular importance to SRKWs in allowing them quiet time/space to carry out vital life processes
Creation of year round or seasonal 'quiet'/'no-go' areas, in certain areas or segments	Yes	Large reduction if ships excluded, but noise energy will be shifted to another location	Increases quiet time in 'no-go' area, decreases quiet time in area that vessels are diverted into 'No-go' zones would have to be bigger than area to be protected to factor in the acoustic footprint of vessel noise – buffer zone Could be permanent or seasonal areas	Refer to "convoy approach" and "redirecting a portion of vessel traffic"	Ensuring that quiet zones or times overlap with the locations and times that are of particular importance to the SRKW in allowing them quiet time/space to carry out vital life processes

Table A2. The limitations, uncertainties, knowledge gaps and actions to address the knowledge gaps identified for each mitigation measure. Uncertainties and knowledge gaps are paired with actions to address the identified uncertainty or knowledge gap.

Global measures

Mitigation measure	Limitations	Uncertainties and knowledge gaps	Actions to address knowledge gaps
Changes in ship maintenance (hull cleaning, propeller cleaning/inspection, etc.)		Limited studies available on the effect of ship maintenance Not clear which types of maintenance are most important for reducing noise	Studies to examine relationship between a ship's noise profile and state of specific ship systems (propeller damage or fouling, hull fouling, shaft rub, etc.) Monitoring of ship noise profiles to identify noisy ships and follow up to determine reasons for higher noise emission levels
Ship design and retrofit	The application of vibration isolation technologies may not be consistent across all vessel types/sizes	Understanding of why some existing ships are much quieter than others Lack of accepted underwater radiated noise design standards for quiet merchant ship design Unclear whether existing noise reduction designs are sufficiently quiet to benefit whales	Examine existing vessel noise signature data to characterize what factors contribute to making a vessel quiet or noisy. Accessing vessel specific data requires collaboration with ship owner/operators Develop standards for quiet merchant ship design Study how retrofits change the noise signature of individual vessels Study the impacts of noise from existing noise reduction designs on whales

Local measures

Mitigation measure	Limitations	Uncertainties and knowledge gaps	Actions to address knowledge gaps
Reducing speed of vessels (or specific vessel class) in areas of likely noise-whale interactions	Effective at reducing intensity of underwater noise for most ship types, although ships with certain propulsion systems may show an increase in noise with reduced speed	Some ships may show an increase in noise with reduced speed Uncertainty remains about the effect of increasing the duration of exposure Spatial and temporal location of slow-down areas will need to be planned with knowledge of SRKW distribution and activities	Undertake experiments to understand reasons for variability between noise level and ship speed. More studies are required to understand vessel cavitation inception speeds and optimal operating speeds. Experiments are needed to examine the effect of exposure duration vs. noise intensity on SRKWs More experiments are needed with satellite tags to track spatiotemporal activity of SRKWs
Lateral displacement of shipping traffic (lane displacement – distance related mitigation)		Location-specific propagation characteristics (e.g., geophysics, substrate type, bathymetry, oceanography etc.) Knowledge of whale distribution in space (including depth, not just geographical location) and time (e.g., seasonal variation in habitat use)	Validation of acoustic propagation modelling More studies using satellite tags to track spatiotemporal activity of SRKWs are needed
Redirecting a portion of vessel traffic (e.g. vessel classes, project-related vessel, etc.) through alternate routes (shifting traffic from Haro to Rosario Strait)		Importance of Rosario Strait to SRKWs. Possible increased impacts to Rosario Strait and Salmon Bank Noise propagation characteristics of Rosario Strait Magnitude of the noise reduction depends on the types and number of ships rerouted	Study SRKW distribution and usage in affected areas Determine bathymetry and geographic limitations (e.g., width, depth, substrate etc.) of Rosario Strait Modelling of changes in noise from traffic rerouting

Mitigation measure	Limitations	Uncertainties and knowledge gaps	Actions to address knowledge gaps
Real-time notification of whale presence in hot spot areas (traffic light system) leading to management action such as slow downs or minor route changes	Difficult to quantify or predict noise reductions Some of the noise reduction will be based on ships reducing power to slow down, not on the ship's speed Ships have limited scope for reaction in many places Ships changing speed or direction could confuse the whales. Potential increase in strike risk due to lack of predictability of ship movement. Whale movement could make it difficult to choose a management action in time to make a difference	The management action to be taken would influence the reduction in noise (e.g., slow down, avoidance of area, etc.) Uncertainty about efficiency of whale detection systems. Detection will be imperfect, and notification currently has a delay. Technical fixes will reduce delays, but detection is not guaranteed. Whales sometimes travel quietly and cannot be acoustically detected	Determine which situations would benefit most from a slow down or minor route change Examine which mitigation actions would result in the greatest reduction in noise Improve whale detection systems and associated technology Test technologies other than passive acoustic monitoring (PAM) for whale detection (e.g., thermal cameras)
Convoy approach for specific vessels or vessel classes		Lack of spatial understanding of received sound levels Little real world testing to validate models Little is known about the importance of periods of quiescence to whales	Further noise propagation and ship traffic modelling to better describe the convoy process and noise levels. Validation of convoy models Need research to determine the importance of quiescence. How long a period is needed?
Creation of 'quiet'/'no-go' periods of quiescence		If quiet periods occur at night there is uncertainty in whether SRKWs engage in feeding at night, but it is logical to think that they would (can forage with echolocation and therefore, do not depend on visual signals)	Night-time D-tag studies could be used to assess night-time foraging rates

Mitigation measure	Limitations	Uncertainties and knowledge gaps	Actions to address knowledge gaps
Creation of year round or seasonal 'quiet'/'no-go' areas, in certain areas or segments		Refer to "convoy approach" and "redirecting a portion of vessel traffic"	Refer to "convoy approach" and "redirecting a portion of vessel traffic"

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Canadian Science Advisory Secretariat (CSAS)
National Capital Region
Fisheries and Oceans Canada
200 Kent Street Ottawa, ON, K1A 0E6

Telephone: 613-990-0293
E-Mail: csas-sccs@dfo-mpo.gc.ca
Internet address: www.dfo-mpo.gc.ca/csas-sccs/

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