Transport Canada | Transports Canada

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July 6, 2018

Jocelyne Beaudet, Panel Chair;
David Levy, Panel Member;
Douw Steyn, Panel Member;
c/o Cindy Parker, Panel Manager
Canadian Environmental Assessment Agency
160 Elgin Street, Ottawa, ON K1A 0H3
Sent by email to: Panel.RBT2@ceaa.gc.ca

Dear Ms. Beaudet:

Subject: Transport Canada's Ongoing Underwater Noise Work and Southern Resident Killer Whales

Transport Canada (TC) is writing to provide information about our expertise and responsibilities relating to the effects of marine shipping on the environment and in particular the effects of underwater noise from vessel traffic on whales. Increases in underwater noise in the Marine Shipping Area (MSA), including from marine vessels, has the potential to impact the acoustic environment of the Southern Resident Killer Whales (SRKW) within its critical habitat. These impacts include masking the whales' ability to communicate, affecting their ability to forage effectively, and increasing their overall levels of stress.

The SRKW is a vital component of the local marine ecosystem and has cultural significance for coastal Indigenous peoples in British Columbia. Indigenous groups have expressed concerns that underwater noise is a key stressor adversely impacting the ability for the SRKW to recover, and are calling for immediate action to protect this iconic species.

TC serves the public interest by promoting a safe, secure, efficient and environmentally responsible transportation system, including reducing the impact of marine shipping on the environment. In this context, TC is leading federal efforts to identify, assess, and implement measures to mitigate the impacts of vessel traffic on marine ecosystems, including the impact of underwater noise from vessels on at-risk whales. Our assessment of mitigation measures considers not only the effectiveness at reducing underwater noise impacts, but also impacts on navigation safety, economic and supply chain efficiency impacts, unintended environmental consequences, as well as Indigenous, provincial, and international considerations. This work is being done in close collaboration with the Department of Fisheries and Oceans, the Canadian Coast Guard, Indigenous groups, marine industries, academia, non-governmental organizations, and international partners.

To support this work and building on the $1.5-billion Oceans Protection Plan, the Government of Canada allocated $167.4 million in Budget 2018 to Canada's Whales Initiative, of which

$85 million has been allocated to TC. The Whales Initiative will support measures to better protect, preserve and recover endangered whale species in Canada, including the SRKW. We are taking measures to address the key threats to the SRKW population, including, among other measures, reducing disturbance from underwater vessel noise.

We understand that the Department of Fisheries and Oceans already submitted the Canadian Science Advisory Secretariat 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* (CEAR 1068).

The CSAS evaluation was undertaken to identify those measures that may be effective at reducing underwater noise. Subsequent work has built off of that evaulation. We have enclosed several documents that provide additional information on, and results of, TC's work to date on underwater noise:

- Green Marine Management Corporation's January 2017 report *Understanding Anthropogenic Underwater Noise,* commissioned by TC (see Appendix A)

- The Government of Canada's paper *Collaboration to Reduce Underwater Noise from Marine Shipping,* presented to the Marine Environment Protection Committee of the International Maritime Organization in April 2017 (see Appendix B)

- JASCO Applied Sciences (Canada) Ltd.'s October 2017 report *Assessment of Vessel Noise within Southern Resident Killer Whale Critical Habitat,* commissioned by TC (see Appendix C)
  - The modelling by Jasco Applied Sciences is intended to quantify the reductions possible in various geographic areas.

- Coastal Ocean Research Institute's (CORI) 2017 report *Proposed Metrics for the Management of Underwater Noise for Southern Resident Killer Whales* (see Appendix D)
  - The metrics workshop organized by CORI, resulting in this report, was intended to provide the language we can use related to these reductions.

- The Government of Canada's paper *Reducing underwater noise utilizing ship design and operational measures,* presented to the Marine Environment Protection Committee of the International Maritime Organization in February 2018 (see Appendix E)

- Greenwood Maritime Solutions Ltd.'s April 2018 report *Ship Noise Mitigation Risk Assessment*, commissioned by TC (see Appendix F)
  - This assessment was undertaken to narrow the scope of measures or concepts to those that are considered safe and feasible enough for further consideration. Engagement with Indigenous groups on this risk assessment is ongoing and the report may be amended or added to based on the outcomes of those discussions.

TC is continuing to assess potential ways to mitigate the impact of underwater noise from vessels on at-risk whales and we will implement measures appropriately as our understanding develops. In addition to research, TC has supported the voluntary trialling of measures, such as the 2017 slowdown trial in Haro Strait led by the Vancouver Fraser Port Authority's ECHO Program. We are currently working with partners and Indigenous communities to develop another trial in 2018 that will assess laterally displacing vessel traffic further away from foraging areas for SRKW in the Strait of Juan de Fuca.

While TC is actively working to address underwater vessel noise in the near term through operational mitigation measures, we are also working with international partners at the International Maritime Organization (IMO) to address underwater noise through vessel design in the longer term; I have attached two papers that we have submitted to the Marine Environmental Protection Committee of the IMO to advance this discussion (see Appendix B and E).

There are many interesting findings in the various documents attached and we would be happy to discuss any questions the Panel may have regarding any of them.

We look forward to providing the Review Panel with updates relevant to the Roberts Bank Terminal 2 project as this important work continues. Please feel free to contact Catherine Galbrand, Senior Environmental Officer, at <email address removed> if you have any questions.

Sincerely,

<Original signed by>

Ian Chatwell,
Acting Regional Director, Programs - Pacific
Transport Canada

Attachments: Appendix A through F

Appendix A:

Green Marine Management Corporation's January 2017 report *Understanding Anthropogenic Underwater Noise,* commissioned by TC

TP 15348 E

Understanding Anthropogenic Underwater Noise

Prepared for
Transportation Development Centre
of
Transport Canada

By
Veronique Nolet
Green Marine Management Corporation

GREEN MARINE
ALLIANCE VERTE

January 2017

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TP 15348 E

Understanding Anthropogenic Underwater Noise

By
Veronique Nolet
Green Marine Management Corporation

January 2017

NOTICE

This report reflects the views of the author and not necessarily the official views or policies of the Transportation Development Centre of Transport Canada

The information presented in this report is derived from the available literature at the time of the report's preparation. Some of the data may have changed since it was last consulted. The information presented hereinafter aims to inform Transport Canada in simple language about the potential effects of underwater noise on marine life. A detailed review and discussion of the expansive literature on the subject are beyond the scope of this report. Transport Canada's request for synthetized information called for a precautionary approach that involved making discretionary decisions about the information to include based on this principle.

Un sommaire français se trouve avant la table des matières.

Une traduction de ce document est également disponible en français : «Comprendre le bruit sous-marin anthropique», TP 15348 F.

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Clean Transportation Initiative

17. Abstract

Sources of anthropogenic (human-caused) underwater noise have increased significantly over the past fifty years, largely as a result of increases in seismic exploration, military and commercial sonars, and maritime transportation. Commercial shipping is one of the main contributors to anthropogenic noise and is mainly generated by propeller cavitation and onboard machinery. The low-frequency sounds that ships generate propagate efficiently and travel vast distances in deep water marine environments. This has sparked concerns about the impacts of underwater noise on marine life, which use sound to communicate, navigate, feed and reproduce. As the agency responsible for regulating shipping in Canada, Transport Canada (TC) considered it essential to better understand the problem of underwater noise within Canadian waters. This report assembles some of the technical knowledge about anthropogenic underwater noise and its potential impacts in a marine environment. It details information about how, based on the current state of knowledge, the maritime industry contributes to ambient underwater noise and should facilitate understanding on how noise can pose a threat to the conservation of marine animals and to the recovery of species at risk.

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Initiative en matière de transport propre

17. Résumé

Les sources de bruits sous-marins d'origine anthropique (de source humaine) n'ont cessé de croitre depuis les cinquante dernières années. Ces bruits constituent en réalité un sous-produit de l'importante augmentation des activités humaines maritimes telles que l'exploration pétrolière, l'utilisation de sonars à des fins commerciales et militaires et le transport maritime. La navigation commerciale figure parmi les principaux contributeurs de bruits anthropiques à basse fréquence, principalement générés par l'hélice et les machineries à bord des navires. Ces fréquences sonores peuvent se propager très efficacement et sur de très grandes distances dans les environnements marins. Cette augmentation substantielle a éveillé plusieurs préoccupations quant à l'impact de ce bruit sur la faune marine, qui utilise les sons pour communiquer, naviguer, s'alimenter et se reproduire. En tant qu'entité régulant le transport maritime au Canada, Transports Canada (TC) a jugé essentiel de mieux comprendre la problématique des bruits sous-marins au Canada. Ce rapport détaille l'information sur comment, basé sur les connaissances actuelles, l'industrie maritime contribue aux bruits sous-marins ambiants et permet aux néophytes de saisir en quoi les bruits peuvent représenter une menace à la conservation des espèces marines et au rétablissement des espèces en péril.

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Recognizing the subject matter's complexity, and to ensure that all of the report's information is accurate, well described and up to date, most sections were sent to the relevant person/organization for review. My sincerest gratitude to the individuals who kindly agreed to review the content of one or more parts of this report: Michael Bahtiarian (Noise Control Engineering Inc.) and Tom Dakin (Ocean Networks Canada) for their technical skills in acoustics, Michael Jasny (National Resources Defense Council), Kathy Heise (Vancouver Aquarium) and Tola Coopper (Fisheries and Oceans Canada) for their incredible knowledge regarding the impacts of anthropogenic noise on marine life. I gratefully acknowledge Tom Dakin and Michael Bahtiarian for the many hours they spent with me to explain and discuss acoustics, as well as to Kathy Heise for her constant support and valuable advice.

A sincere thank you to everyone at Transport Canada, and specifically: Marie-Chantal Ross, Research Development Officer, Transportation Development Centre – Policy Group, and Paul Mudroch, Senior Advisor, Marine Air and Pollution Issues – Marine Safety and Security Group. Their comments, advice and support were pivotal to the successful writing of this report.

My thanks to all of the Green Marine team, namely: David Bolduc, executive director, Eleanor Kirtley, West Coast program manager, Manon Lanthier, communications manager, Françoise Quintus, program manager, and to editor Julie Gedeon. I also thank the members of the Green Marine Underwater Noise Working Group[1] for their input, feedback and insight on the development of an underwater noise performance indicator and to the members of the regional Green Marine's Advisory Committee.

I also wish to acknowledge a number of people for their countless hours of informative conversations, emails, reports, obscure literature, web links, and the names of others who assisted me in writing this report as comprehensively and objectively as possible: Hussein Alidina (WWF-Canada), Lindy Weilgart (Dalhousie University), Brandon Southall (Southall Environmental Associates, Inc.), Jack Lawson (DFO), Hilary Moors-Murphy (DFO), Ian McQuinn (DFO), Véronique Lesage (DFO), Yvan Simard (DFO), Corey Morris (DFO), Liisa Peramaki (DFO), Jennifer MacDonald (DFO), Chris McKesson (University of British Columbia), Orla Robinson and Krista Trounce (Port of Vancouver), Bruce Martin (JASCO Applied sciences), David Hannay (JASCO Applied sciences), Amy R. Scholik-Schlomer (NOAA), Camille Montiglio (ACCOBAMS), Heidrun Frisch (ASCOBANS and CMS), Darius Campbell (OSPAR Convention), Edward Kleverlaan (IMO), Erin Morriss (New Zealand Ministry of Foreign Affairs and Trade), Sonia Mendes (JNCC), Adi Kellermann (ICES), Clément Chion (Université du Québec en Outaouais), Jérôme Dupras (Université du Québec en Outaouais), Lauren McWhinnie (University of Victoria), Kimberley Davies and Christopher Taggart (Dalhousie University), Matthew Abbott (Conservation Council of New Brunswick), Donald Killorn (Eastern Charlotte Waterways Inc.), Kathleen Martin (Canadian Sea Turtle Network), Marianne Gilbert (Hemmera), and Dugald Thomson (Canadian Forces). I could not have completed this project without their help. The information, contacts and resources that they so generously provided were essential in guiding me through to the very last page.

[1] Marc Gagnon (FEDNAV), Lilia Khodjet El Khil (Canada Steamship Lines), Hilary Miller (SMIT Marine Canada), Orla Robinson (Port of Vancouver), Jason Scherr (Prince Rupert Port Authority), Paul Mudroch (Transport Canada), Stephanie Snider (Kinder Morgan), Hussein Alidina (WWF-Canada), Lance Barrett-Lennard (Vancouver Aquarium), Kathy Heise (Vancouver Aquarium), Tom Dakin (Ocean Networks Canada), Michael Jasny (National Resources Defense Council), Alexis B. Rudd (Hawai'i Institute of Marine Biology), Chris McKesson (University of British Columbia).

EXECUTIVE SUMMARY

Sources of anthropogenic (human-caused) underwater noise have increased significantly over the past fifty years, largely as a result of increases in seismic exploration, military and commercial sonars, and maritime transportation.

Commercial shipping is one of the main contributors to anthropogenic noise and is mainly generated by propeller cavitation and onboard machinery. The low-frequency sounds that ships generate propagate efficiently and travel vast distances in deep water marine environments. In the open waters of the North Pacific Ocean, acoustic tracking indicates that low frequency noise, < 80 hertz (Hz), has increased by 10 to 12 decibels (dB) since the 1960s, which coincides with the doubling of marine traffic. This has sparked concerns about the impacts of underwater noise on marine life, which use sound to communicate, navigate, feed and reproduce.

Recognizing that scientists and the international community worldwide have identified that noise has short and long-term consequences on marine life, the International Maritime Organization (IMO) ratified voluntary guidelines in 2014 to address the adverse impacts of shipping noise. These guidelines describe steps to reduce noise emitted by commercial ships. As an IMO signatory and the agency responsible for regulating shipping in Canada, Transport Canada (TC) considered it essential to better understand the problem of underwater noise within Canadian waters. It is within this context that TC contracted the Green Marine Management Corporation to:

- Prepare a detailed summary regarding this emerging issue and its impacts on marine life;
- Describe how commercial shipping contributes to ambient noise in the ocean;
- Identify the main sources of noise produced by ships;
- Compile the main global initiatives addressing issues related to underwater noise;
- List the various workshops/conferences held internationally on the subject in recent years;
- Report on research projects being conducted across Canada on underwater noise;
- Highlight future research needs to properly evaluate the impact of anthropogenic underwater noise on marine life; and
- Develop a list of recommendations in collaboration with industry partners and non-governmental organizations (NGOs) regarding the actions required to address the issue.

Assessing commercial navigation's contribution to ambient underwater noise and its impact on marine life is complex. This report assembles some of the technical knowledge about anthropogenic underwater noise and its potential impacts in a marine environment. It details information about how, based on the current state of knowledge, the maritime industry contributes to ambient underwater noise and should facilitate understanding on how noise can pose a threat to the conservation of marine animals and to the recovery of species at risk.

The Green Marine Management Corporation initiated its research in August 2014 with the ultimate goal of adding underwater noise issue as a new performance indicator within the Green Marine environmental program. A formal working group was created, gathering a number of experts and people concerned or affected by the issue, which include Members of the scientific community (engineers, naval architects, biologists, NGOs and academics), the maritime industry (ship owners, port authorities/administrators and terminal operators) and government agencies (TC and Fisheries and Oceans Canada).

Consultations with scientists and other experts on underwater noise in Canada and the United States helped collate documentation regarding the subject, much of which is included in the reference section. To ensure that the information contained in this report is accurate, all segments have been reviewed by one or more experts. Their names and respective organizations are listed in the Acknowledgement, although Green Marine is responsible for any errors found within this document.

FINDINGS

Underwater noise originates from a range of sources – both natural and anthropogenic. A thorough analysis of ambient noise requires consideration of all activities contributing to substantial increases in noise levels, such as industrial activities near or directly in the water, port operations and boating excursions (marina tours, whale-watching cruises, fishing expeditions, research trips, commercial shipping, pile driving, etc.). Sounds of a natural origin should also be considered: cracking ice, wind, waves, rain, thunder, earthquakes, as well as the sounds of marine life. However, it is widely recognized that anthropogenic noise has increased dramatically in recent decades, and is now recognized as a global issue.

To properly evaluate the potential impacts of anthropogenic underwater noise on marine life, it is essential to have a calibrated recording system across a broad range of frequencies to monitor ambient noise in locations considered to be ecologically important. This requires an extensive consultation process with local experts and others with an interest in underwater acoustics.

Behavioural observations of the impact of anthropogenic noise on marine animals are difficult to interpret, and likely not the best metric for impacts. Quantifying the impacts of anthropogenic noises on marine species is complex. Marine animals, regardless of the species, may differ in how they use sound, particularly animals of different age, sex and life stages, auditory systems, hearing thresholds, tolerance to strong noise sources, changes in behaviour and/or hearing resulting from past exposures, and a soundscape's integral role in the essential biological activities, social interactions and other behaviours of a species.

Identifying acoustic thresholds is difficult, especially in the case of chronic and continuous noises, such as those produced by vessels. When it comes to strong pulsating noises (pile driving, underwater dynamite and other sources), acoustic thresholds can generally be predicted in relation to the known sensitivities of a species by using monitoring auditory equipment. Numerous studies have been done in this regard, and for some species, the acoustic thresholds have been established. For chronic noise, however, the situation differs. Injuries to marine mammals from ship noise are generally indirect, and focus primarily on disturbance, sound masking (which interferes with communication and echolocation), increased stress hormones and, increased in risk of ship strikes.

Underwater noise has been recognized as a major concern for more than ten years in Canada and is identified as a major threat for marine mammals at risk. Therefore, numerous research projects are under way regarding the impacts of noise from vessels on marine ecosystems. Government agencies, universities, engineering firms and NGOs have mobilized to better understand underwater noise, and a large number of hydrophones have been deployed through coastal waters in Canada. To avoid duplicating efforts, it is essential to coordinate initiatives and to archive results.

SOMMAIRE EXCÉCUTIF

Les sources de bruits sous-marins d'origine anthropique (de source humaine) n'ont cessé de croitre depuis les cinquante dernières années. Ces bruits constituent en réalité un sous-produit de l'importante augmentation des activités humaines maritimes.

La navigation commerciale figure parmi les principaux contributeurs de bruits anthropiques à basse fréquence, principalement générés par l'hélice et les machineries à bord des navires. Ces fréquences sonores peuvent se propager très efficacement et sur de très grandes distances dans les environnements marins. Dans l'océan Pacifique Nord, des suivis acoustiques ont démontrés que depuis les années 1960, le bruit ambiant de basse fréquence, <80 hertz (Hz), a augmenté de 10-12 décibels (dB), coïncidant avec une augmentation du double du trafic maritime mondial. Cette augmentation substantielle a éveillé plusieurs préoccupations quant à l'impact de ce bruit sur la faune marine, qui utilise les sons pour communiquer, naviguer, s'alimenter et se reproduire.

Reconnaissant que les scientifiques et la communauté internationale ont identifié que le bruit des navires pouvait avoir des conséquences négatives à court et à long termes sur les espèces marines, l'Organisation maritime internationale (OMI) a publié, en 2014, des lignes directrices volontaires traitant des impacts négatifs des bruits sur la faune marine. Ces lignes décrivent quelques méthodes pouvant être appliquées afin de réduire les émissions sonores des navires commerciaux. En tant que signataire à l'OMI et entité régulant le transport maritime au Canada, Transports Canada a jugé essentiel de mieux comprendre la problématique des bruits sous-marins au Canada. C'est dans ce contexte que le ministère a commandé la présente étude à La Corporation de gestion de l'Alliance verte pour :

- Décrire l'enjeu émergent et ses impacts sur la vie marine;
- Décrire comment la navigation commerciale contribue au bruit ambiant dans les océans;
- Expliquer les principales sources de bruit sur un navire;
- Compiler les principales initiatives internationales traitant de l'enjeu des bruits sous-marins;
- Énumérer différents ateliers de travail et conférences internationales sur le sujet dans les dernières années;
- Faire état des projets de recherche sur le bruit au Canada;
- Faire ressortir les besoins en recherche pour bien évaluer l'impact des bruits sous-marins d'origine anthropique sur la faune marine;
- Dresser une liste de recommandations en collaboration avec des partenaires de l'industrie et de l'environnement sur les actions à prendre pour aborder l'enjeu.

Évaluer la contribution de la navigation commerciale et ses impacts sur la vie marine est complexe. Ce rapport constitue un rassemblement des connaissances techniques sur les bruits sous-marins et ses impacts potentiels sur l'environnement marin. Ce rapport détaille l'information sur comment, basé sur les connaissances actuelles, l'industrie maritime contribue aux bruits sous-marins ambiants et permet aux néophytes de saisir en quoi les bruits peuvent représenter une menace à la conservation des espèces marines et au rétablissement des espèces en péril.

L'Alliance verte a entamé ses recherches au mois d'août 2014 alors que son Comité consultatif Côte Ouest lui donnait le mandat de se pencher sur cet enjeu et de développer un nouvel indicateur de rendement sur les bruits sous-marins à son programme environnemental. Un groupe de travail formel a alors été créé, permettant déjà de rassembler plusieurs experts en la matière et des gens concernés par l'enjeu autour d'une même table : la communauté scientifique (acousticien, architecte naval, chercheur universitaire), l'industrie maritime (armateur, port et terminal) et le secteur gouvernemental (Transports Canada et Pêches et Océans Canada).

Plusieurs échanges avec des scientifiques et des experts en matière de bruits sous-marins du Canada et des États-Unis ont permis de commencer à dresser une liste bibliographique sur le sujet. Finalement, afin de s'assurer que l'information contenue dans ce rapport soit exacte, tous les segments ont été validés par un ou plusieurs experts. Leur nom et organisation respective sont listés dans la section remerciements de ce rapport, mais l'Alliance verte demeure responsable des erreurs qui pourraient s'être glissées dans ce rapport.

RÉSULTATS

Le bruit dans les milieux marins provient d'un large éventail de sources, autant d'origine anthropique que naturelle. Il importe de considérer toutes ces sources de bruits dans l'équation. On parle par exemple d'activités industrielles situées à proximité ou directement dans l'eau, la présence d'activités portuaires et la fréquentation de d'autres types d'embarcations (de plaisance, de croisières aux baleines, de pêche, de recherche, etc.). Les bruits d'origine naturelle sont aussi à considérer : craquement des glaces, vent, vagues, pluie, tonnerre, tremblement de terre, bruits émis par les espèces marines et autres. Il est toutefois reconnu que les bruits d'origine anthropique ont augmentés drastiquement dans les dernières décennies et qu'il s'agit d'un enjeu mondial.

Pour évaluer correctement les impacts potentiels des bruits sous-marins sur la faune marine, il s'avère essentiel d'avoir un système d'enregistrement bien calibré efficace sur une large bande de fréquence pour mesurer les bruits ambiants dans des endroits considérés écologiquement importants. Cet item requiert une consultation extensive auprès d'experts locaux et de gens impliqués dans l'acoustique sous-marine.

Les observations comportementales des espèces marines liées à l'émission de bruits d'origine anthropique sont difficiles à interpréter, et ne sont possiblement pas les meilleurs indicateurs pour évaluer le niveau d'impact. La qualification de l'impact des bruits anthropiques sur les espèces marines est d'une grande complexité. En effet, les espèces marines sont acoustiquement uniques et se distinguent de multiples façons : l'âge, le sexe, le stade de développement, le système auditif, les seuils d'audition, la tolérance face aux sources sonores puissantes, l'historique d'expériences sonores antérieures ayant modifié le comportement ou le système auditif en lui-même, l'utilisation de l'environnement sonore dans le cadre de leurs activités biologiques essentielles, les comportements sociaux et autres.

L'identification des seuils acoustiques critiques est complexe, et le devient encore plus dans les cas de bruits chroniques et continus tels que ceux émis par les navires. Dans le cas de bruits forts et pulsés (fonçage de palplanches, explosions ou autres), les seuils acoustiques critiques peuvent généralement être prédis en fonction de la sensibilité de l'espèce à certains seuils d'audition et à l'appareil auditif. De nombreuses études ont été réalisées à ce sujet et pour certaines espèces, les seuils acoustiques critiques sont connus. Or, pour les bruits chroniques, la situation diffère. En effet, on ne peut pas parler de blessures physiques liées aux émissions sonores d'un navire, mais plutôt de dérangement, d'interruption dans les comportements habituels, de masquage dans les communications et l'écholocation, d'augmentation des niveaux de stress et de risques accru de collision avec un navire.

Les bruits sous-marins sont une préoccupation majeure au Canada depuis plus de dix ans et sont identifiés comme une menace importante pour le rétablissement des espèces de mammifères marins en péril. De ce fait, les projets portant sur l'impact des émissions sonores des navires sur les écosystèmes marins sont nombreux. Ministères, universités, firmes d'ingénieries, ONG, tous se mobilisent pour mieux connaître et comprendre les bruits ambiants en des endroits très précis. Pour éviter qu'il n'y ait dédoublement des efforts, il importe de coordonner les initiatives et de faire le suivi de celles qui sont terminées. Il sera ainsi possible de profiter de l'expertise des autres pour faire avancer les recherches ailleurs.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY OF ABBREVIATIONS

ACCOBAMS	Agreement on the Conservation of Cetaceans in the Black Sea Mediterranean Sea and Contiguous Atlantic Area
ADD	Acoustic Deterrent Device
AEI	Areas of Ecological Importance
AEP	Auditory Evoked Potentials
AHD	Acoustic Harassment Device
AIS	Automatic Identification System
AMSA	Australian Maritime Safety Authority
ANSI	American National Standards Institute
ASCOBANS	Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas
BAT	Best Available Techniques
BEP	Best Environmental Practice
BOEM	Bureau of Ocean Energy Management
CBD	Convention on Biological Diversity
CIS	Cavitation Inception Speed
CMS	Convention on Migratory species
COP	Conference of Parties
CPP	Controllable Pitch Propeller
CRP	Contra-Rotating Propeller
CZMA	Coastal Zone Management Act
dB	Decibels
DFO	Department of Fisheries and Oceans
EC	European Commission
EMP	Environmental Management Plan
EPBC	Environment Protection and Biodiversity Conservation Act
ESA	Endangered Species Act
ESRF	Environmental Studies Research Fund
EU	European Union
EEZ	Exclusive Economic Zone
FPP	Fixed Pitched Propeller
GES	Good Environmental Status
GT	Gross Tonnage
HELCOM	Baltic Marine Environment Protection Commission - Helsinki Commission
Hz	Hertz
ICES	International Council for the Exploration of the Sea
IFAW	International Fund for Animal Welfare
IMO	International Maritime Organization
IQOE	International Quiet Ocean Experiment
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature
IWC	International Whaling Commission
JNCC	Joint Nature Conservation Committee
LFA	Low-Frequency Active

MEOPAR	Marine Environmental Observation Prediction and Response Network
MEPC	Marine Environment Protection Committee
MMO	Marine Mammal Observer
MMS	Marine Mammal Sanctuaries
MMPA	Marine Mammal Protection Act
MPA	Marine Protected Area
MSFD	Marine Strategy Framework Directive
MSP	Marine Spatial Planning
NEPA	National Environmental Policy Act
NGO	Non-Governmental Organization
nm	Nautical Mile
NMFS	National Marine Fisheries Service
NMSA	National Marine Sanctuaries Act
NOAA	The National Oceanic and Atmospheric Administration
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PAM	Passive Acoustic Monitoring
ppt	Parts per thousand
psi	Pound-force per square inch
PSSA	Particularly Sensitive Sea Areas
PTS	Permanent Threshold Shift
RL	Received Level
rms	Root-mean-square
SARA	Species at Risk Act
SEL	Sound Exposure level
SI	International System of Units
SL	Source Level
SOFAR	Sound Fixing and Ranging
SOLAS	Safety Of Life At Sea
SPL	Sound Pressure Level
TC	Transport Canada
TS	Threshold Shift
TTS	Temporary Threshold Shift
UK	United Kingdom
UN	United Nations
U.S.	United States
UNCLOS	United Nations Convention on the Law of the Sea
UNEP	United Nations Environment Programme
WCS	Wildlife Conservation Society Canada
WWF	World Wildlife Fund

PART 1
SOUND BASICS AND EFFECTS OF SOUND ON MARINE LIFE

1.1 INTRODUCTION

Prior to the Industrial Revolution (ca. 1850), the contribution of anthropogenic activity to the noise in the ocean was negligible and ocean noise levels were mostly determined by naturally occurring phenomena (e.g., wind, waves, earthquakes, organisms). In general, little is currently known about the changes in these levels that result from increased maritime traffic associated to industrialization (Natural Research Council (NRC), 2003).

The history of commercial shipping is defined not only by increases in the number of ships transiting to support a burgeoning global trade, but also increases in ship size, propulsion power, and sophistication (McKenna, 2012). The total gross tonnage (GT) of ships quadrupled between 1965 and 2003, at the same time as the number of commercial ships approximately doubled, which included new ship designs (NRC, 2003; McKenna,2012; Hildebrand, 2010). This expansion of shipping and ships over the past four decades correlates with an increase in deep-ocean noise levels (McDonald, 2006).

Underwater noise from shipping is increasingly recognized as a pollutant with the potential to impact marine ecosystems on a global scale (Williams *et al*., 2015; Clark, 2009). Not because of its powerfulness, but because of its chronic characteristics and because low-frequency sounds may travel great distances without losing so much energy. Low-frequency ocean noise has increased in recent decades, often in habitats with seasonally resident populations of marine mammals, raising concerns that noise chronically influences life histories of individuals and populations (Clark, 2009).

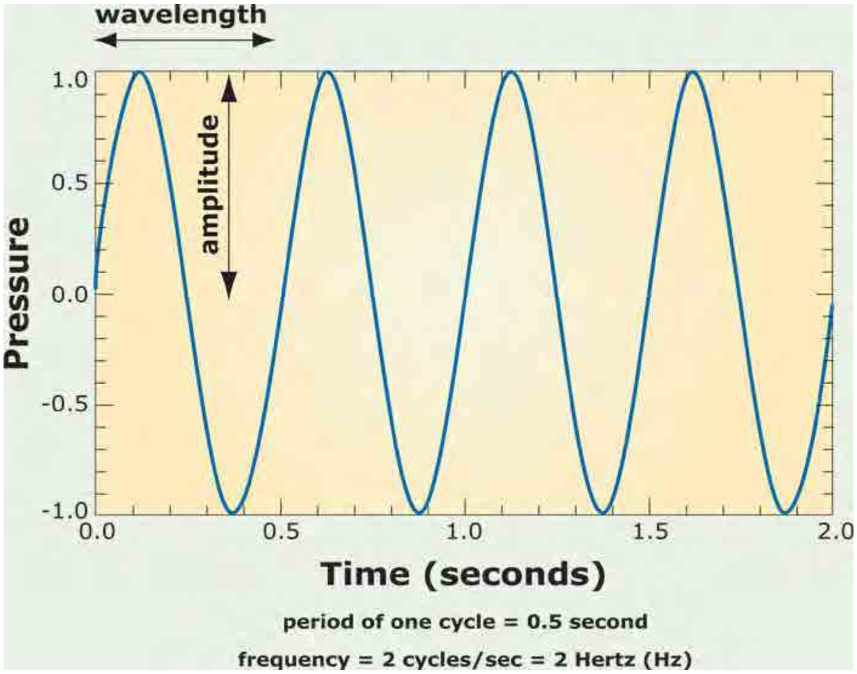
This first part of the report presents sound basics and the potential effects of anthropogenic noise, mostly coming from shipping, on marine life.

1.2 SOUND BASICS

1.2.1 Sound metrics

In outer space, no one can hear anything because there is no way for sound to travel. Sound needs a medium: an intervening substance through which sound can travel from point to point. It can be solid, liquid or gas such as ground, water and air. Sound travels by rapidly changing its pressure relative to its normal value. It is broadly described as a disturbance in the surrounding medium, a vibration that spreads out from the source, creating a series of expanding shells of high and low pressure. Left unobstructed, sound travels outward, until the medium absorbs its energy. This traveling vibration is called an acoustic wave. To describe the acoustic wave, the speed at which a small piece of the medium vibrates (called the particle velocity) can be used, or the corresponding pressure associated with the vibration.

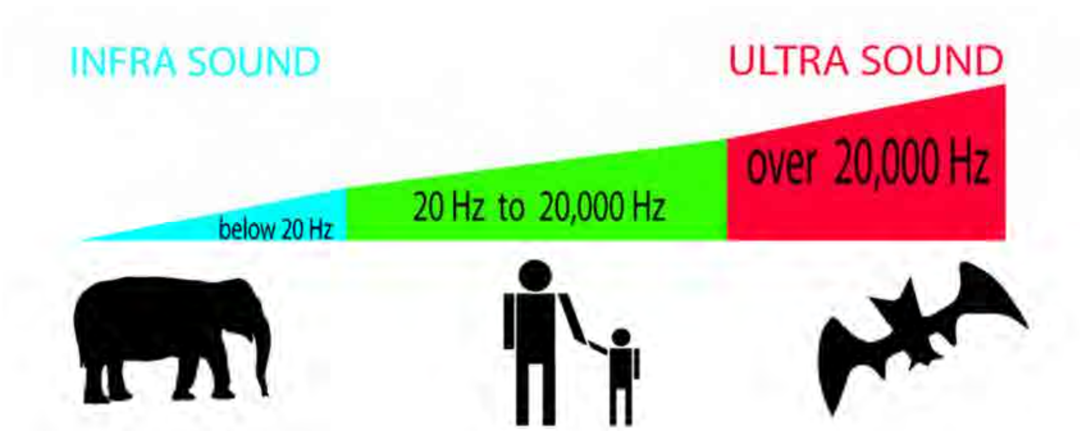
Sound waves (like water waves), illustrated in Figure 1, can be described in terms of their **frequency**, **wavelength** and **amplitude,** the basic components of a sound wave. Sounds produced by different objects are differentiated by amplitude and frequency. In this example, the period of one cycle of this wave is 0.5 seconds, and the frequency of this wave is 2 cycles per second or 2 Hertz (Hz).



Source: http://www.divediscover.whoi.edu/expedition12/hottopics/

Figure 1: Frequency, wavelength and amplitude.

Frequency (f) is the number of pressure waves that pass a point in a given time and can be measured in cycles/second or Hertz (Hz). To the human ear, an increase in frequency sounds like a higher pitched sound, while a lower frequency sounds like a lower pitched sound. As shown in Figure 2, humans can hear sounds with frequencies between 20 and 20,000 Hz. Sounds below 20 Hz are referred to as infrasonic, and above 20,000 Hz as ultrasonic. Frequency is perceived as the pitch of the sound. A **tone** is a sound of a constant frequency that continues over time, while an **impulse** is a sound of short duration. Both may include a broad range of frequencies.



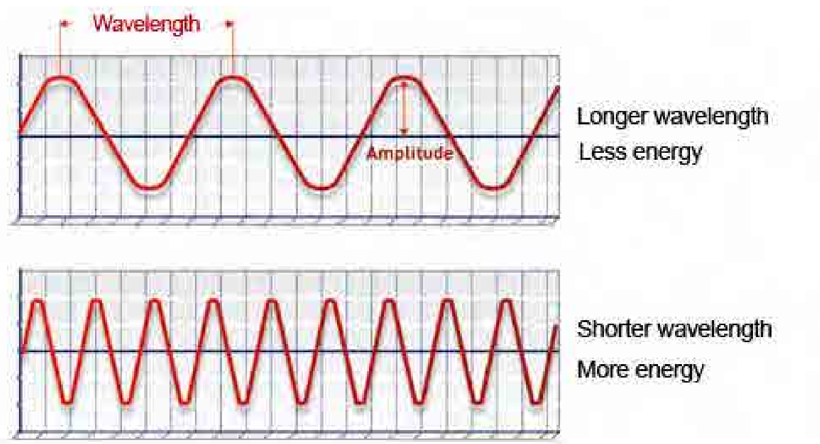
Source: http://www.howequipmentworks.com/ultrasound_basics/

Figure 2: Audible frequencies for human ears.

Wavelength (λ) is the distance between two peaks or two troughs of a wave, as shown in Figure 3. The lower the frequency of the wave, the greater the distance between crests, and the longer the wavelength. Sounds with longer wavelengths travel further than those with shorter wavelengths. Wavelength and frequency are associated by the following relationship (equation 1):

$$\lambda = c/f \qquad (1)$$

where λ is wavelength in metres, f is frequency in Hz and c is the speed of sound in metres/second.



Source: http://www.mapfre.com/fundacion/html/revistas/seguridad/n124/articulo1En.html

Figure 3: Differences between long and short wavelengths.

Amplitude is indicated by a soundwave's "height", as shown in Figure 3, measured in units of pressure, usually Pascals (Pa). It is reported in decibels (dB)[2]. Soundwaves that are "short" (i.e., have low amplitudes) are quiet sounds, while waves that are "tall" produce loud sounds. As shown in Figure 4, the maximum safe exposure limit is known to be 85 dB(A)[3] for the human ear.

It is important to note that the dB scale is a logarithmic scale[4]. The difference between a sound that is 0 dB (barely audible) and one similar to a whisper at 10 dB is an increase in the loudness by the power of 10.

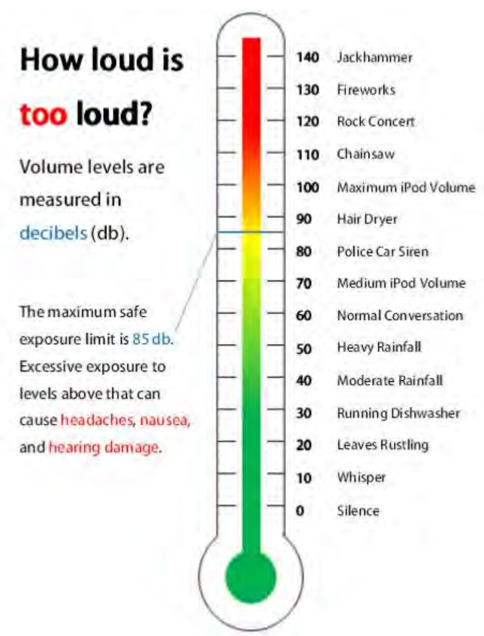


Figure 4: dB scale example for the human ear.

Source: http://edtech2.boisestate.edu/brianquerry/506/decibel.pdf

[2] The decibel is itself not part of the International System of Units (SI Unit), but it has been accepted by the International Committee for Weights and Measures for use with the SI system.

[3] The "(A)" refers to the A-weighting, an adjustment of sorts to the decibel values to match the response of the human ear. Excessive exposure to a sound level above 85 dB(A) can cause headaches, nausea, and hearing damage (if above 110 dB(A)).

[4] The decibel uses logarithms to base 10.

The difference between "sound" and "noise"

A "sound" is usually the term used to describe the effect that a vibrating object has on the surrounding environment and may be scientifically defined as mechanical wave propagating in an elastic medium. In brief, sound is a broad description of acoustic energy. In comparison, "noise" is the term used to describe sound from a diffuse array of sources that does not convey biologically significant information (Southall, 2005). It should be noted that almost all natural and anthropogenic sound is in essence noise for the animals that hear it.

1.2.2 Measuring instrumentation

This section deals with the types of instrumentation that should be used to measure underwater noise. It also presents key performance specifications as they relate to hydrophone and measuring instrumentation, system calibration, data quality assurance and storage.

A hydrophone is a microphone designed to be used underwater for recording or listening to underwater sound. It detects sound pressure signals and converts them to corresponding electrical signals. There are hydrophones for every budget. The less expensive hydrophones typically send a pre-amplified analog signal along a cable to a set of devices above water. The above-water devices amplify the analog signals for transmission, digitize the signals for transmission or digitize the signals for storage at the shore site (Guideline Dakin/Heise to be published). The more expensive state-of-the-art hydrophones digitize the electrical signal underwater, then store the data internally or send the digital data along a cable to a computer, storage system, or long-range communications system.

Before selecting any measurement system, attention should be paid to the system's performance: sensitivity, frequency response, directivity, system self-noise and the dynamic range.

a) Sensitivity

The sensitivity is described in terms of the electrical voltage (V) developed per Pascal (Pa) of acoustic pressure, and is stated in units of V/Pa (or, using units more appropriate for a typical sensitivity magnitude, in µV/Pa). The sensitivity level is most often expressed in decibels relative to 1 $V^2/\mu Pa^2$ (dB re 1 $V^2/\mu Pa^2$). Note that the choice of a 1 V/µPa as the reference value leads to hydrophone sensitivity levels having very large negative values, typically in the range of -160 to -220 dB.

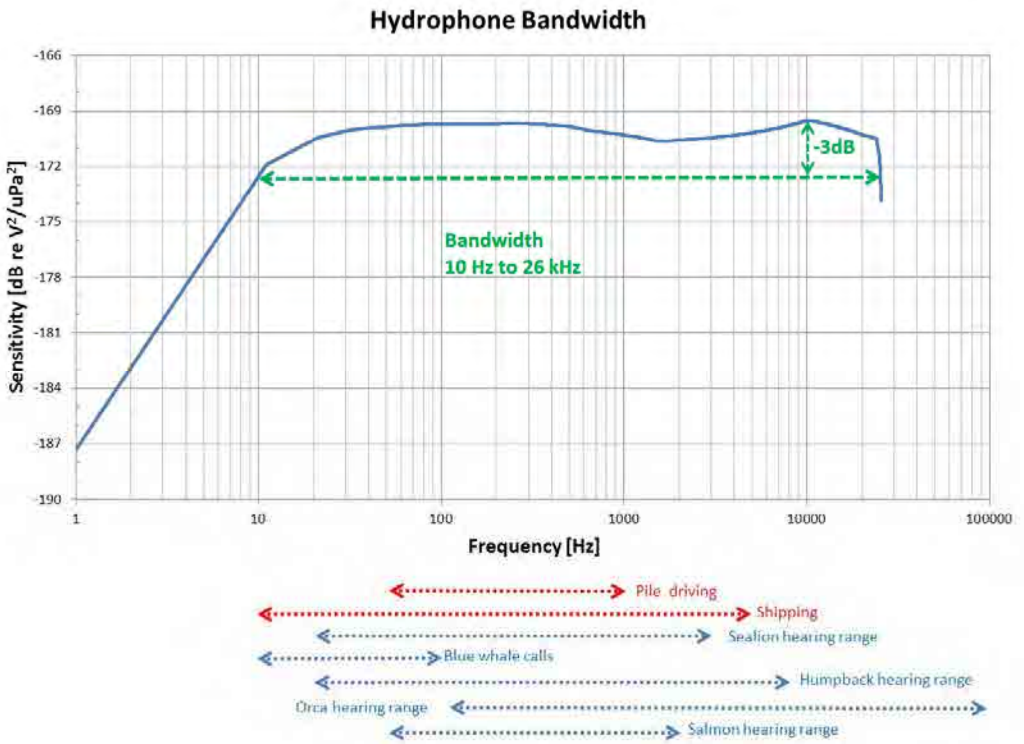
The sensitivity of the hydrophone[5] and measuring system should be appropriate for the amplitude of the sound being measured. Since most hydrophone systems do not have sufficient dynamic range to operate over the full range of acoustic intensities found in the ocean, the system sensitivity should be chosen to maximize the accuracy of the desired signals. For measurement of low amplitude signals (for example, ambient noise in a quiet location), a high-sensitivity system is preferable. However, for measuring high-amplitude signals (for example, at close range to a source of high output level), a lower sensitivity system is preferable to avoid saturating the measurement system (Robinson, 2014).

[5] Hydrophone sensitivities for digitized data are typically given in dB re $FS^2/\mu Pa^2$ where FS is Full Scale (comm. Pers. Tom Dakin, ONC).

b) Frequency response

The frequency response of the measuring system is the sensitivity as a function of acoustic frequency. It is desirable for this response to extend to a sufficiently high frequency to faithfully record all frequency components of interest within the measured signals. This requires a hydrophone with sufficient broadband capacities.

As shown in Figure 5, the sensitivity of the entire measuring system must be known if absolute measurements of the sound field are required, which necessitates a system calibration. A calibrated hydrophone with a specific bandwidth is required to be able to measure sound with accuracy.



(Source: Tom Dakin, Ocean Networks Canada)

Figure 5: Frequency versus sensitivity to illustrate bandwidth.

c) Directivity

A hydrophone should ideally have a sufficiently sensitive omnidirectional response such that its sensitivity is invariant with the direction of the incoming sound wave. There are some situations where it is advantageous for the hydrophone to exhibit directionality in sensitivity, for example in order to determine the direction of the incoming signals or to discriminate against self-noise from a deployment platform (such as a noisy vessel). This is usually accomplished by using more than one hydrophone to form an array, or by using a baffle or shield to reduce the sensitivity in a given direction (for example, from the surface). In these situations, the hydrophone or array directivity must be evident in and from the measurements.

d) System self-noise

The system self-noise is considered to be the noise originating from the hydrophone and recording system in the absence of any signal due to an external acoustic stimulus. This represents the minimum acoustic intensity the system is capable of measuring.

All hydrophones have a certain amount of self-noise regardless of where they are located, and baseline levels can be obtained from manufacturers (Dakin, 2016). In addition to the hydrophones, there is additional noise associated with the pre-amplifiers, filters, and digitizers associated with analog hydrophone systems, as well as power supplies.

e) Dynamic range

The dynamic range of the measuring system is the amplitude range over which the system can faithfully measure the sound pressure. It is the difference between the loudest sound intensity and the quietest sound intensity measurable by the system.

1.2.3 Deployment for acoustic measurements

Since there are many measurement scenarios and objectives, it is hard to describe one way to install and deploy a hydrophone system. For this reason, a specific technique will not be described within this document, but the reader is referred to a few (but not limited to) existing methodologies and/or standards to measure sound in the ocean and how to position hydrophones.

For more information on underwater noise measurement and deployment of hydrophones, please refer to these documents:

ANSI/ASA S12.64-2009/Part 1, 2009, *Quantities and Procedures for Description and Measurement of Underwater Sound from Ships - Part 1: General Requirements*, American National Standard Institute, U.S., 2009. http://webstore.ansi.org/RecordDetail.aspx?sku=ANSI%2FASA+S12.64-2009%2FPart+1+(R2014)

Dakin, Tom (ONC) and Heise, Kathy (Vancouver Aquarium), 2016, publication: *Guidelines for Installing Cabled Hydrophones for Monitoring Marine Mammals, Vessels and Other Sources of Underwater Noise*.

ISO 17208-1:2016 Underwater acoustics -- *Quantities and procedures for description and measurement of underwater sound from ships -- Part 1: Requirements for precision measurements in deep water used for comparison purposes* http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=62408

ISO/PAS 17208-1:2012 *Acoustics -- Quantities and procedures for description and measurement of underwater sound from ships -- Part 1: General requirements for measurements in deep water.* http://www.iso.org/iso/catalogue_detail?csnumber=59403

Patterson, A.M., Spence, J.H., Fischer, R.W., 2012, *Evaluation of Underwater Noise from Vessels and Marine Activities*, Noise Control Engineering, INC (NCE), Billerica, U.S., 9p.

Robinson, S.P., Lepper, P. A. and Hazelwood, R.A, 2014, *Good Practice Guide for Underwater Noise Measurement*, National Measurement Office, Marine Scotland, The Crown Estate, NPL Good Practice Guide No. 133, ISSN: 1368-6550.http://www.npl.co.uk/upload/pdf/gpg133-underwater-noise-measurement.pdf

Approaches to measurement will vary depending on the amplitude and frequency of the sound to be measured, the environment, the deployment duration, the required accuracy of the sound measurement, the available resources to deploy the instrumentation, and the available budget. It is very important to match the system to be installed with objectives and capacity. Here's the most common approaches:

- By deploying hydrophones (individually or in arrays) from a vessel, with the analysis and recording equipment remaining on the anchored or drifting vessel.
- By static deployment, as shown in Figure 6, which is more appropriate for long-term deployment: A bottom-mounted deployment is preferable to a surface deployment to: (a) minimize unwanted signals from the influence of surface wave action: (b) keep the hydrophone away from the water-air surface reflections, and (c) to minimize disturbance from the surface vessel. Figure 6 illustrates an example of static deployment.
- By drifting systems, which can be vessel- or float-based real-time systems, or drifting autonomous recorders.

Figure 6: A Hydrophone tripod mount that supports the hydrophone at a height of one metre above the seafloor.

Source: Tom Dakin, Ocean Networks Canada

1.2.4 Recommended metrics for reporting underwater sound

The metrics used to measure underwater sounds may depend on the type of sound that we want to measure. For this reason, specific metrics have been devised for impulsive sound and for continuous sound.

a) Impulsive sound

Impulsive (pulsed) sound is characterized by short bursts of acoustic energy of a finite duration, as illustrated in Figure 7 (Robinson, 2014). These bursts are sometimes referred to as transient sounds. Pile driving, explosions, air-gun popping are examples of impulsive sound. The most appropriate metrics to measure pulsed sound are:

- **Sound Exposure Level (SEL)** for both single pulse and cumulative (for a series of pulses). The sound exposure level is calculated (see equation 2) from ten times the logarithm to the base 10 of the ratio of the sound exposure, E, to a reference value, E_0. The reference value for sound exposure level is 1 µPa^{2}s.

$$SEL = 10 \log_{10} \left[\frac{E}{E_0}\right] \quad (2)$$

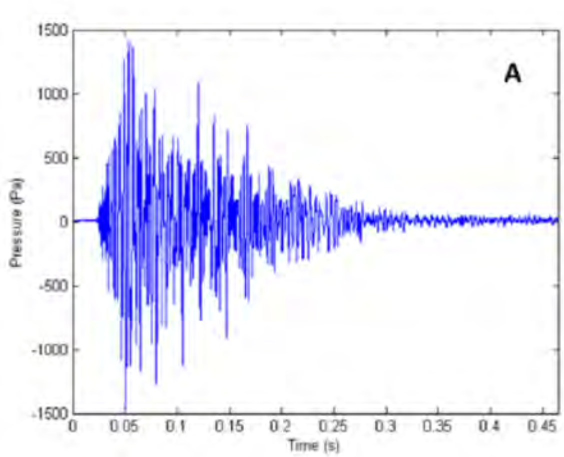
- **Peak sound pressure level**
  Peak sound pressure level is equal to twenty times the logarithm to the base 10 of the ratio of the peak sound pressure, p_{peak}, to the reference value, p_0, where the reference value is 1 µPa (equation 3).

$$L_{peak} = 20 \log_{10} \left[\frac{p_{peak}}{p_0}\right] \quad (3)$$

- **Peak-to-peak sound pressure level**
  Peak-to-peak sound pressure level, L_{pp}, is equal to twenty times the logarithm to the base 10 of the ratio of the peak-to-peak sound pressure, p_{pp}, to the reference value, p_0, where the reference value is 1 µPa (equation 4).

$$L_{pp} = 20 \log_{10} \left[\frac{p_{pp}}{p_0}\right] \quad (4)$$

For an acoustic pulse, the SEL is calculated over the pulse duration, which is commonly defined as the time occupied by the central portion of the pulse, where 90 % of the pulse energy resides (Robinson, 2014). This is useful because it can be difficult to determine the exact start of the pulse within a noise waveform. Figure 7 shows the SEL calculation over the duration of a pulse that was measured while monitoring a marine pile driving operation (Robinson, 2014).



Source: Good Practice Guide for Underwater Noise Measurement

Figure 7: Example of a pulse waveform measured during pile driving.

b) Continuous sound

Continuous sounds are sounds in which the acoustic energy is spread over a significant amount of time, typically many seconds, minutes or even hours. The amplitude of the sound may vary throughout this duration, but the amplitude does not fall to zero for any significant time. The sound may contain broadband noise and tonal (narrowband) noise at specific frequencies. Examples of continuous sound include ship noise, operational noise from machinery including marine renewable energy devices, as well as noise from drilling.

The metric most suitable for measuring continuous sound is **Sound Pressure Level (SPL)**.

The SPL may be calculated as either:

(i) ten times the logarithm to base 10 of the ratio of the mean square sound pressure over a stated time interval to the reference value for sound pressure squared;

or

(ii) twenty times the logarithm to base 10 of the ratio of the root mean square sound pressure over a stated time interval to the reference value for sound pressure.

The two definitions are mathematically identical, as evidenced by the formulaic expression (Equation 5):

$$SPL = 10\ \log_{10}\left[\frac{\hat{p}^2}{p_0^2}\right] = 20\ \log_{10}\left[\frac{\hat{p}}{p_0}\right] \tag{5}$$

where $\hat{p}$ is root mean square sound pressure, and p_0 is reference value for sound pressure.

Note that the SPL reference value for sound in water is one micropascal (1μPa), leading to SPL being expressed in units of decibels relative to 1 μPa, or alternatively dB re 1 μPa[6] (Robinson, 2014).

A SEL metric can also be used for continuous noise sources. In such case, the sound exposure level across a frequency band is integrated across a fixed time period rather than over individual events or pulses. A period of one second is sometimes used for the duration (Southall, 2007). As with the SEL assessment from impulsive sources, the SEL can be aggregated by summation to calculate the total SEL during a longer exposure period.

1.3 Effects of the Environment on Sound Propagation

Knowledge about the characteristics of ocean noise and its distribution relative to the location and movements of marine organisms is important for understanding the potential impacts of anthropogenic sound (Hildebrand, 2009).

The sound from a single source may change during propagation, and the signal received by an animal (called the received level - RL) may differ from the sound close to the source (called the

[6] Underwater sound amplitude is compared to a change in sound pressure of one micro-Pascal (1 μPa) at a distance of one metre from the source. In air, a higher standard reference sound pressure of 20 micro-Pascals is used – thus sounds of the same energy underwater as in air are recorded as 26 dB higher underwater than in air strictly based on the reference difference (i.e. 20x log(20/1)). There are also differences in sound pressure levels due to density of the medium (i.e. air versus water).

source level - SL). Propagation through water and/or a substrate may change the sound characteristics. For example, a short, abrupt sound may become lengthened and its onset smoother as a result of its transmission over long distances due to the effects of reverberation, multipath transmission, modal dispersion, and refraction, while repeated sounds and their echoes can merge together to become more continuous (Popper *et al*., 2014). It is essential to note that although various models exist to understand sound propagation, the models designed for deep ocean environments will not be appropriate in shallow water environments (Popper *et al*., 2014).

Sound propagation is different through air and water. When sound propagates from water into air, there is a 35.5 dB (about 3300 x) decrease in acoustic intensity because water's characteristic impedance is much greater than that of air (Hildebrand, 2005). This difference, along with the reflective properties of the sea surface, help explain why a high-intensity underwater sound, such as sonar, is not transmitted in the air with the same intensity. There is a kind of air-sea boundary protection. Without this boundary, there would be a strong incentive to protect human hearing from the noise of sonars and ship propeller cavitation.

Generally, the denser a material is, the better sound travels through it. Sound travels much faster through water (1500 metres/sec) than it does through air (about 340 metres/sec). Similarly, sound travels much farther underwater than it does through air. Low frequency noise (< 500 Hz) propagates efficiently across ocean basins, contributing to ambient noise levels over large distances (> 100 km). The reason for this is because low frequency sound waves experience little attenuation given the low absorptive capacities of seawater and will propagate over long ranges (Okeanos Foundation, 2008). At shorter distances (< 10 km), higher frequency noise may also be significant (NRC, 2003; Basset, 2012; Okeanos Foundation, 2008). Offshore, the ocean's thermocline[7] can create a channel (called the SOFAR for Sound Fixing and Ranging channel[8]) that facilitates sound travel. Baleen whales appear to take advantage of this channel to broadcast songs and calls at great distances. In the same way, shipping noise will be able to travel much farther distances in this channel.

There is a difference between sound propagation from sources located near the sea surface, in deep water and in shallow water. Deep water is an environment where there is no interaction of sound with the seabed from distant sources (typically commercial shipping). In contrast, shallow water is an environment where there is an important interaction of sound with the seabed. Different kind of seabed offers different reflectivity of sound (Dahl, 2007).

The radiated noise observed from a particular source depends on the characteristics of the source and on the oceanic environment. Near the source, the Sound Pressure Level (SPL) is largely

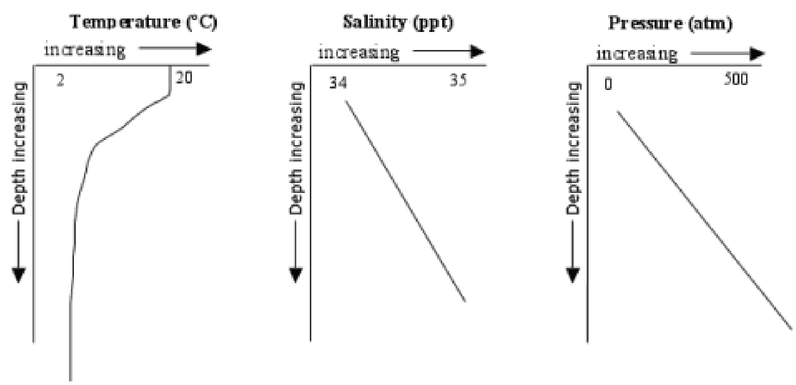
[7] Scientists define a thermocline as a region of rapid change in temperature with depth.

[8] Warm water tends to rise above cold water. In the ocean, increased depth generally corresponds with lower water temperatures. Conversely, the increasing pressure with depth hastens the speed of sound. These two competing forces create a zone (near the bottom of the thermocline) of minimum sound speed. Sound waves bend, or refract, towards the area of minimum sound speed. Therefore, a sound wave traveling through a thermocline tends to bend downward as the speed of the sound decreases with lower water temperatures, but then is refracted back upward as the speed of the sound quickens with the increasing depth and pressure. This up-down-up-down bending of low-frequency sound waves permits the sound waves to become "trapped" within a channel and travel many thousands of metres or even kilometres without the signal losing significant energy (http://mrvanarsdale.com/).

determined by the source characteristics. As sound waves propagate away from their source, they spread out and attenuate at rates that vary according to the specific conditions (Hildebrand, 2009). As the distance from the source increases, environmental factors are increasingly important in defining the sound field.

When assessing the effects of sound on an animal, it is necessary to consider not only the frequency composition, but also the temporal structure (Hildebrand, 2009). Sounds from sources may rise in amplitude as their source approaches and then fall as the source moves away from the receiving animal. With such wide variations in sound sources and changes in the characteristics of sounds as they propagate away from the source, it is necessary to employ a range of metrics to fully describe sounds. In assessing shipping noise, bioacousticians tend to look at both the contributions of local traffic, which can fluctuate substantially over the course of a day, week, or year, and the contributions of distant ships, which elevate the ocean's background noise and is relatively constant over time.

The three main environmental factors affecting the speed of sound in the ocean are temperature (°C), salinity (ppt), and pressure (atm). It is interesting to see how these different factors vary in an ocean, as shown in Figure 8.



Source : http://www.dosits.org/tutorials/sciencetutorial/speed/

Figure 8: Basic depth profiles of temperature, salinity and pressure for a mid-latitude location in an open ocean.

1.3.1 Temperature

As temperature increases, sound speed increases. Temperature, the foremost factor affecting sound speed, usually decreases with depth, which leads to an accompanying decrease in sound speed. Below approximately 1,000 metres, however, temperature is fairly constant, and the predominant factor affecting sound speed becomes pressure.

1.3.2 Salinity

As salinity increases, sound speed increases. Salinity is fairly constant in the open ocean. A change of salinity will cause a small corresponding change in density, causing variation of sound speed. The greatest variation in salinity in the open ocean exists in the vicinity of "oceanic fronts," which are narrow zones separating water masses of different physical characteristics, usually exhibiting very large horizontal gradients of temperature and salinity. Even greater variation in salinity can be expected around the mouths of rivers, heavy ice, and in areas of extraordinary rainfall, where a layer of fresh water overrides a layer of salt water.

1.3.3 Pressure

Pressure, in most circumstances, is more important than salinity in terms of establishing sound speed. In sea water, its rate of change is constant and thus predictable. Pressure also causes a change in density, resulting in greater sound speed. As mentioned previously, this is because the denser a material is, the better sound travels through it.

1.3.4 Summary Table

In summary, sound propagation in water is relative to the conditions of that water. The speed of sound in water increases with increasing water temperature, increasing salinity and increasing pressure (depth), essential considerations when assessing how shipping noise will propagate through the water when operating in different locations ranging in temperature (i.e. Arctic vs. south Vancouver), salinity (i.e. Great Lakes vs. Atlantic coast) and depth (i.e. shallow vs. deep water). The approximate change in the speed of sound with a change in each property is:

- Temperature 1°C = 4.0 m/s
- Salinity 1PSU = 1.4 m/s
- Depth (pressure) 1km = 17 m/s

Table 1 summarizes the main factors influencing the speed sound in the ocean.

Table 1: Summary of noise propagation in ocean waters:

When sound propagates from water to the air	Loss of approximately 35.5 dB
Sound speed in water: 1500 m/s	Sound speed in the air: 340 m/s
In the water and pressure increases	↗ sound speed propagation
In the water and salinity increases	↗ sound speed propagation
In the water and temperature increases	↗ sound speed propagation

Source : http://www.dosits.org/tutorials

1.4 AMBIENT NOISE

In the air, sense of sight is of great importance. Terrestrial animals usually first rely on their vision for survival. During bad weather conditions, for example foggy period, it is very difficult to see and to recognize our immediate environment, which can lead to critical situation. In the underwater environment, since the sense of hearing is as important as the vision in the air, very loud ambient noise can compromise marine animal's essential activities.

Noise budgets quantify the relative contribution of different sources to ambient noise levels (Hildebrand, 2005). Ambient noise is usually defined as the background sound that incorporates a broad range of individual sources, some identified and others not (although the type of noise source may be known, the specific sources are not necessarily identified) (Hildebrand, 2005; NRC, 2003). There are three main sources of underwater ambient noise: water motion (including the effects of surf, rain, hail and tides), manmade sources (including ships) and marine life (Wenz, 1962). The first two are illustrated in Figure 9. Principal sources of natural geophysical sounds, of cetaceans calls and anthropogenic sound sources are respectively listed in Tables 2, 3 and 4.

Background noise includes natural physical processes and, increasingly, anthropogenic sources (Dahl, 2007). It should be noted that some definitions of ambient noise exclude identifiable sources, such as individual vessels whose sound can be localized (NRC, 2003). Within this research, however, vessel traffic is included, as it represents a ubiquitous source of noise in busy coastal areas. Although ambient noise is always present, individual sources of sound that contribute to it do not necessarily create sound continuously.

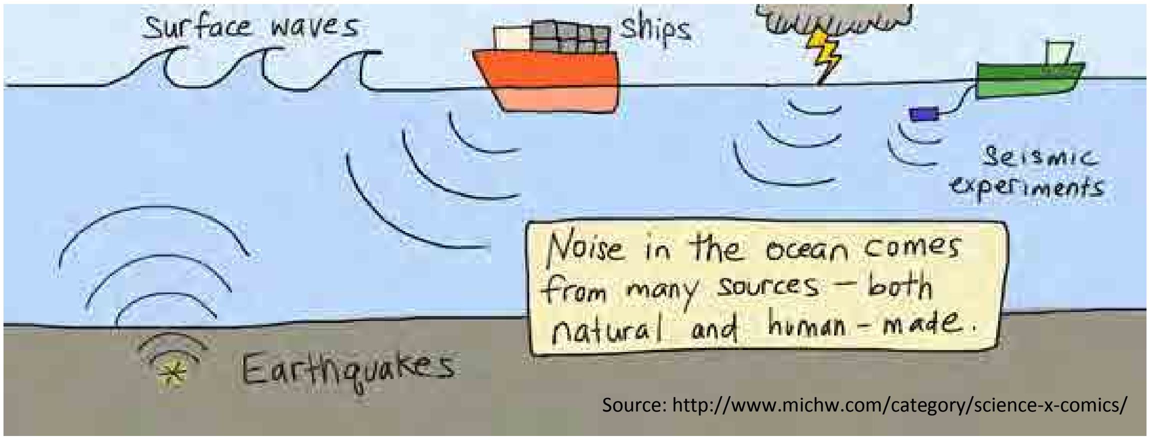


Figure 9: An illustration of difference sources of natural and anthropogenic noise.

Table 2: Principal sources of natural geophysical sound in the ocean with their associated frequency:

Natural sound source	Frequency (Hz)
Waves caused by surface wind action	1 to 100,000
Oscillating bubbles in a water column	10 to 100,000
Precipitation/rainfall	100 to 20,000
Cracking ice	up to 1,000
Thunder (from storms located at a 5- to 10-km distance)	50 to 250

Source: Hildebrand, 2005 but taken from the Wenz curves

Table 3: Examples of sound frequencies produced by cetacean calls:

Cetacean species sound source	Frequency (Hz)
Blue whales (*Balaenoptera musculus*)	15 to 25
Fin whales (*Balaenoptera physalus*)	15 to 25
Other baleen whales	25 to 2,000
Toothed whales (communication calls: whistles or clicks)	0.5 to 20,000
Small toothed whales (including directional echolocation clicks)	30 to 150,000

Source: Richardson, 1997

Table 4: Comparison of some anthropogenic underwater sound sources:

Anthropogenic sound source	Frequency (Hz)
Supertankers (337 m length, 18 knots)	23
Cargo vessel (173 m length, 16 knots)	10 to 50
Air-gun array (2000 psi and 8000 in^3)	50
Drilling	< 100
Pile driving	100 to 500
Dredging	100 to 500
Jetski	100 to 1000
Military sonar (SURTASS/LFA)	250
Fishing vessel (12 m long – 7 knots)	300
Small- to medium-sized vessel (< 50 m for pleasure craft; 50-100 m for other vessels)	300 to 1000

Source: Cluster Maritime Français, 2014; Hildebrand, 2005; McDonald, 2006

In the ocean, the ambient acoustic environment is highly variable (Hildebrand, 2005) and an important element of a marine habitat (Hildebrand, 2009), with the term "acoustic habitat" commonly used to describe this parameter. At any given place and time, a broad range of sources may be combining. The conditions (e.g. sound propagation, water depth, bathymetry, salinity, pressure, temperature) at a particular location may further affect how well ambient noise sounds are received. As mentioned above, sound is generated by a broad range of sources, both natural and anthropogenic, for intentional use or as the unintended consequence of activity in the ocean. Natural geophysical sources include wind-generated waves, earthquakes, precipitation, and cracking ice. Natural biological sounds include whale songs, dolphin clicks, and fish vocalizations. The contribution of biological noise to the ambient noise in the ocean varies with frequency, with time, and with location, so that it is difficult to generalize. In some cases, diurnal, seasonal and geographical patterns may be predicted (Wenz, 1962). Anthropogenic sounds are generated by a variety of human activities, including commercial shipping, geophysical surveys, oil drilling and production, dredging and construction, sonar systems, and oceanographic research (Hildebrand, 2009). Within the universe of anthropogenic sounds, intentional sounds are produced for an explicit purpose, such as seismic surveying to find new fossil fuel reservoirs. Unintentional sounds are generated as a byproduct of some other activity, such as the noise produced by a ship's machinery as it crosses an ocean.

Prior to the Industrial Revolution (ca. 1850), the contribution of anthropogenic activity to the noise budget was negligible and ocean noise levels were created primarily by naturally occurring phenomena (NRC, 2003). Trends in ambient noise over the past decades suggest that sound levels in the deep open water of the North Pacific have increased by 10 dB or more between 1950 and 1975 (Hildebrand, 2005). The shipping contribution to ambient noise has increased by as much as 12 dB, coincident with a significant increase in the number and size of vessels comprising the world's commercial shipping fleet. Sources of anthropogenic noise are becoming more pervasive and more powerful, increasing oceanic background noise levels as well as peak sound intensity levels (Hildebrand, 2009).

1.4.1 Noise research in Canada

Recognized as an issue of growing concern in Canada, an increasing number of projects are investigating the potential impacts of underwater noise from ships on marine life. Current projects brought to the attention of this report's author have been listed in Tables 8, 9, 10 and 11 at the end of this report. Some projects aim to fill specific gaps of knowledge regarding ambient noise in key areas.

1.4.2 Challenges for ambient noise measurements

Long-term measurement of underwater noise using similar methodology is part of the solution to gaining thorough and quantitative knowledge of the soundscape in a specific area. However, there are important items to consider in terms of facilitating data collection and analysis.

Methodology and standardization

There is a need to perform underwater noise measurements to conform to international, national and local regulatory requirements. **To date, there are no national regulatory requirements in Canada**.

Substantial variation in the methods used to measure underwater noise can exist, and the metrics used for reporting noise levels can vary depending on the application, all of which can result in ambiguity. **Discussions with relevant stakeholders should be held to ensure a standardization of collected data**.

Centralized database

Monitoring and characterizing a noise field is challenging but essential. Noise data can sometimes be difficult to analyze and compare because they are maintained by separate organizations. There is no centralized database. Given that information already gathered may not yet be published, accessing the most up-to-date information is a challenge. **A centralized database would make it much simpler to gain a greater understanding from all of the available research to date, including its current limitations.**

1.5 ANTHROPOGENIC NOISE

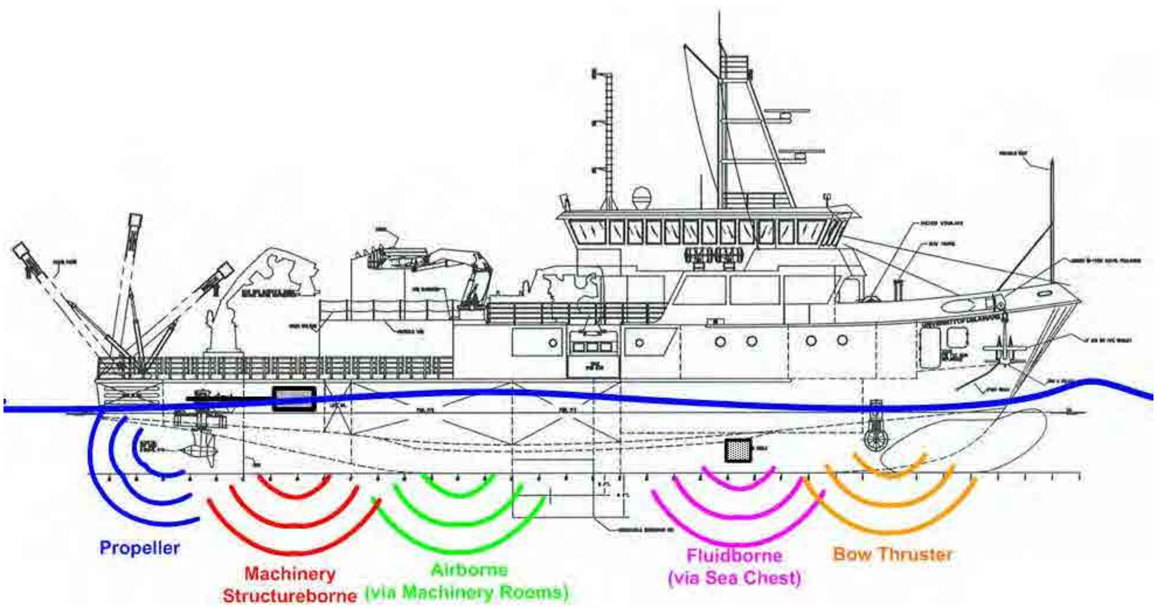
Numerous human activities produce underwater sound. Some sources of which make sound intentionally (explosions, seismic exploration, sonar and acoustic deterrent devices), and others producing sound as an unintended by-product of other activities, like it is the case for shipping and industrial activities (Hildebrand, 2009). Given the scope of this report, noise produced by large commercial ships is addressed separately from the other sources to highlight the results of the research on this topic.

1.5.1 Large commercial ships

Commercial ships are an ubiquitous feature of the world's oceans (Hildebrand, 2009). In many areas, commercial shipping is the major contributor of anthropogenic noise to the ambient noise in an ocean at low frequencies (5-500 Hz) (Hildebrand, 2005; McKenna, 2012; OKEANOS Foundation, 2008). These lower frequencies can travel great distances, resulting in ships contributing to the background noise within large geographical areas. At high latitudes, noise from vessel traffic is also particularly efficient at propagating over large distances because the SOFAR channel reaches the ocean surface in these higher regions. The degree to which shipping noise influences the ambient noise depends on the particular combination of transmission loss, number of ships and the distribution of ships pertaining to a given situation (Wenz, 1962).

Analysis of the noise from ships revealed that their propulsion systems are a dominant source of radiated underwater noise at frequencies below 200 Hz (Hildebrand, 2009; Ross, 1976; Arveson, 2000). Additional noise[9] from commercial ships is generated during normal operations, most notably from propeller cavitation which is known to peak at 50-150 Hz but can extend at least up to 100,000 Hz (Veirs, 2015). Propeller singing is caused by blades resonating at vortex shedding frequencies and emits strong tones between 100 and 1000 Hz. Noise is a form of lost energy. So when noise is created, it usually means that energy could be saved through better maintenance or silencing equipment/redesign. Traditional cavitation not only produces noise, but can damage propeller blades by creating accelerated erosion.

Ships primarily generate noise through (a) propeller action (b) propulsion machinery (c) hydraulic flow over the hull (Hildebrand, 2005; Hildebrand, 2009). Figure 10 shows principal sources of noise on a ship.

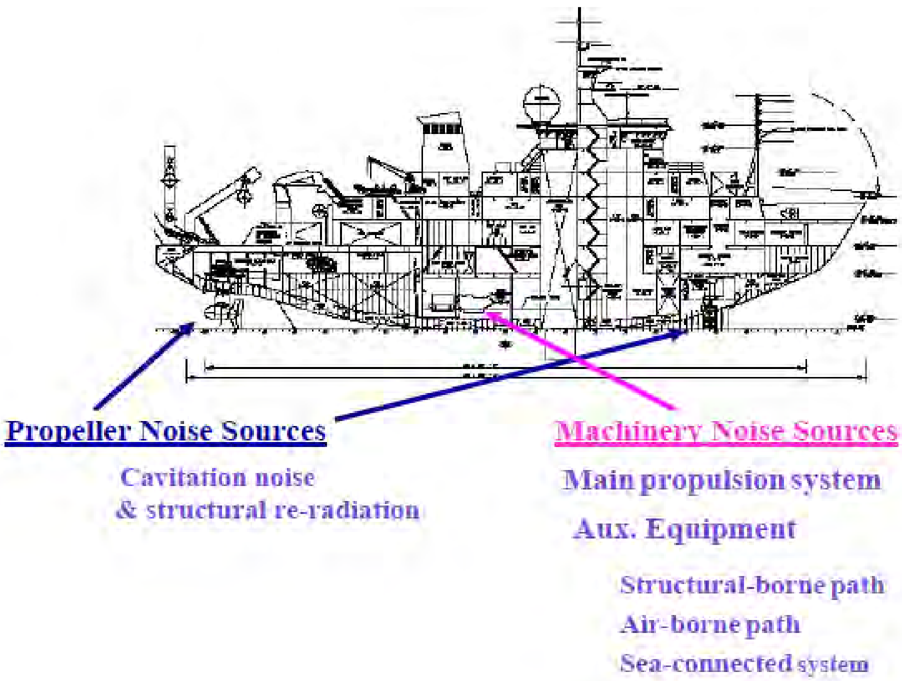


Source: Ray Fischer, Noise Control Engineering, LLC, and Michael Bahtiarian, Noise Control Engineering, Inc.

Figure 10: A vessel profile with principal noise sources.

As shown in Figure 11, there are two main sources of engine noise aboard a ship: propeller noise and machinery noise.

[9] An IMO - Safety Of Life At Sea (SOLAS) regulation (II-1/3-12) that entered into force on July 1, 2014, requires new ships to be constructed to reduce onboard noise and protect the ship's personnel from excessive noise. The regulation is in accordance with the revised mandatory code on noise levels aboard ships, which sets maximum noise-level limits for machinery spaces, control rooms, workshops, accommodations and other spaces aboard ships.



Source: Image adapted from Ray Fischer, Noise Control Engineering, LLC

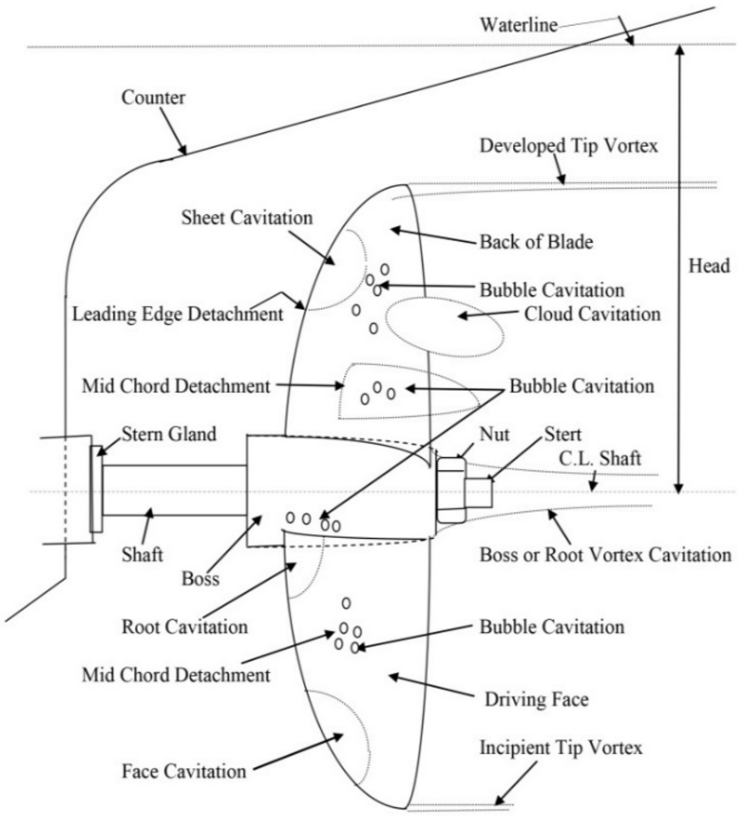
Figure 11: A vessel profile with noise sources from the propeller and machinery.

a) Propeller noise

Propeller noise is associated with cavitation, which occurs when the low pressure generated by the propeller causes thousands of tiny bubbles to form in the water (Ross, 1993; Hildebrand, 2009; IFAW, 2008). The sound these bubbles make when they burst is the major source of noise from powered boats. Cavitation (broadband when bubble collapse, but generally low frequency) and blade rate tonal (narrowband and also generally low frequency) sounds are a dominant source of underwater noise (Hildebrand, 2005; Hildebrand, 2009; Marine Environment Protection Committee (MEPC), 2009). Experiments confirm that cavitation generates high frequency noise up to at least 100,000 Hz (Veirs, 2015, Wenz, 1962). It should be noted that the broadband and tonal components produced by cavitation account for 80-85 % of powered ship-radiated noise (Hildebrand, 2005; Ross, 1987; Southall, 2005).

When a vessel experiences propeller cavitation, the whole propeller can be significantly damaged. As shown in Figure 12, the propeller's surfaces are subjected to a continuous water bombardment within a fluctuating pressure field. The propeller's material is ductile at normal seawater temperatures but the first sign of a problem is the so-called "orange peel effect" whereby the surfaces undergo a ductile deformation, causing them to become puckered like the fruit's skin.

At higher propeller load, radiated noise caused by propeller cavitation at frequencies < 100 Hz is the predominant underwater radiated noise. Depending on the pitch setting and loading of a propeller, a contra-rotating propeller (CRP) may generate higher frequency noise (MEPC, 2009).

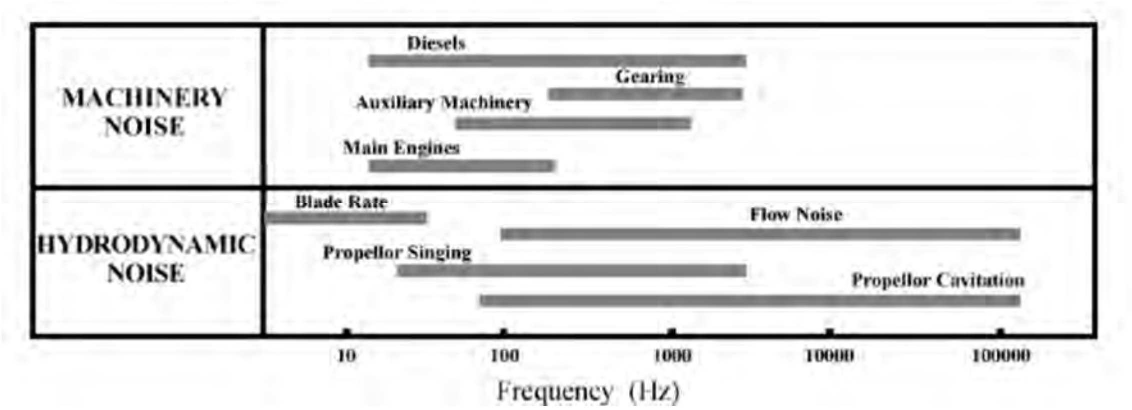


Source: http://iims.org.uk/introduction-propeller-cavitation/

Figure 12: Propeller cavitation.

b) Machinery

Main diesel engines, as well as auxiliary diesel engines, are significant sources of noise because of their potential to induce structure-borne vibrations that radiate via the hull. The hull-induced vibrations generated by the operating machinery at frequencies <100 Hz is the predominant noise source at lower vessel speeds. The reduction gears of medium-speed engines may generate noise at much higher frequencies (>1,000 Hz). Machinery noise starts to become significant for vessels operating at low speeds (e.g. with low-prop loadings for harbour approaches). For most ships, under most operational conditions, cavitation is the main source of underwater noise. At very low speeds, cavitation is considerably lowered. At these lowered speeds, machinery noise that was masked by cavitation noise, may become increasingly predominant. Although machinery-generated noise radiated through the hull is a source of underwater noise, it is less clear how significant it is as source of the total external noise generated (MEPC, 2009). Figure 13 illustrates the frequency range produced by different part of a vessel.



Source: MEPC, 2009

Figure 13: The frequency range produced by some of the noisy parts of a vessel.

c) Appendages

The noise generated due to water flow around appendages (hydrodynamic noise) is of low-intensity at frequencies below <20 Hz. Flow noise around the hull is generally minimal compared to that generated by propeller cavitation and machinery noise, but plays an increasingly significant role at low frequencies as vessel speed increases (MEPC - IMO, 2009).

1.5.1.1 Acoustic signature

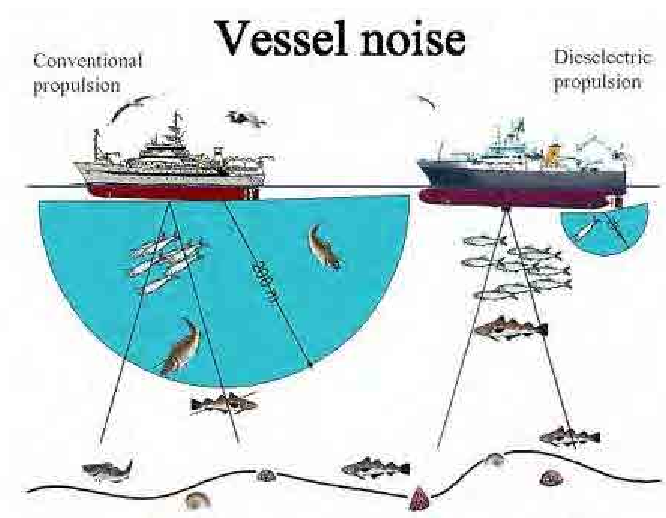
Vessels produce unique acoustic signatures[10] associated with noise levels and frequency bands. It should be noted that these signatures may change with ship speed, vessel load and the activities that may take place aboard the vessel (Hildebrand, 2009). Hydrodynamic flow over the ship's hull and hull appendages is an important broadband noise-generating mechanism, especially with increased ship speed (Hildebrand, 2005).

It is interesting to note that, according to the MEPC, internal noise from diesel engines and propellers is taken into consideration in the design of some but not all commercial ships, but not necessary the external radiated noise (MEPC, 2009). The vibrations of individual operating machinery and within accommodation spaces are routinely measured for preventive maintenance. Radiated underwater acoustic levels are generally only evaluated during the design phase for specific kinds of vessels (research or fishing, for example) and then only upon request. Noise is addressed during the design/new construction of ships only to the extent that it is necessary to achieve noise levels under regulated or contractual limits within onboard accommodations and other crew and work spaces. The purpose of a vessel (e.g. warship, fishing, research or surveying) often determines whether additional expense will be made during a ship's initial construction or later operation to minimize its noise.

Specialized types of vessels need reduced radiated noise signatures to perform their designed duty (MEPC, 2009). For example, military surface and subsurface combatants require low-radiated noise to avoid vessel detection. Vessels involved in fisheries research have been studied to reduce their noise footprint. The reason is simple: how can you accurately estimate a fish population, if

[10] Sharp tonal peaks produced by rotating and reciprocating machinery such as diesel engines, diesel generators, pumps, fans, blowers, hydraulic power plants and other auxiliaries, often form part of an acoustic signature.

the fish swim away because of the noise from the boat, as shown in Figure 14. The International Council for the Exploration of the Seas (ICES[11]) established noise limits for research vessels that must be met in order to monitor fish populations without affecting their behaviour. This explains why so many organizations and countries invest in noise-reducing technology for their fish surveying fleets. These high-tech ships have numerous strategies for reducing the noise that fish might hear.



Source: NOAA

Figure 14: The difference between conventional propulsion and dieselectric propulsion.

The best acoustic ship, for example research vessel, may have designs incorporating the following:

1) Hydrodynamics with a unique and integrated hull and propeller design.
2) Inherently quiet equipment and rotating instead of reciprocating equipment.
3) Dynamically stiff foundations for all equipment (vibration isolation).
4) The placement of noisier equipment toward the ship's centerline.
5) Double hulls or the placement of ballast and fuel tanks outboard of the engine room to help isolate engine noise.
6) Diesel electric motors that operate as generators while electric motors run the driveshaft.

Source: https://teacheratsea.wordpress.com/tag/vessel-noise/
http://www.nmfs.noaa.gov/pr/pdfs/acoustics/session2_fischer.pdf

1.5.1.2 Vessel noise measurement

The best way to demonstrate that a vessel meets certain underwater radiated noise criteria is to measure the noise directly in the proper acoustic environment. This measurement must be performed while the vessel is under way, and for practical reasons, the noise must be measured at some distance from the vessel on the rough order of the vessel's length (Patterson, 2012). There are few underwater noise measurement options available and, although more recently there has been a rise in the types of methodologies used.

[11] http://anp.gov.br/brasil-rounds/round8/round8/guias_r8/sismica_r8/Bibliografia/Mitson%201995%20-%20Underwater%20noise%20of%20research%20vessels.pdf

The main concern about vessel noise measurement is that there is still a lack of commonly agreed methodological and technical standards for underwater noise radiated from ship assessment, except the two following two methodologies for ship "source" measurement. The two methods are related as ISO grew out of ANSI.

- ANSI/ASA S12.64-2009 which defines a measurement procedure to assess the underwater noise radiated by ships, in deep water condition, but does not specify guidance on underwater noise criteria.
- ISO 17208-1:2016 which defines the general measurement system, procedure, and methodology used for the measurement of underwater sound from ships under a prescribed operating condition. It does not specify or provide guidance on underwater noise criteria or address the potential effects of noise on marine organisms.

More information about vessel noise measurement can be found in the articles referenced in section 1.2.3 of this report.

1.5.1.3 Vessel noise budget

As previously mentioned, the underwater acoustic output produced by commercial vessels contributes significantly to ambient noise in oceans (NRC, 2003). Overall, larger vessels generate proportionally more noise at low frequencies (< 1,000 Hz) because of their relatively high power, deep draft, and slower-turning (< 250 rpm) engines and propellers (Veirs, 2015, Richardson *et al*., 1995). In the open ocean or on the outer continental shelf far from shipping lanes, high frequency noise radiated by a ship will be absorbed within about 10 km, often before reaching a species of concern (Veirs, 2015). However, it should be noted that in urban estuaries, marine mammals are exposed to noise from ships at ranges of 1 to 10 km routinely, and less than 100 m occasionally (Veirs, 2015).

During vessel noise assessment, vessels are usually separated in four broad class as defined by their automatic identification system (AIS) vessel codes, as shown in Table 5. This table is presented for informational purposes, to inform the reader of approximate sound pressure levels (SPL) produced by different vessel types. These data may be different from one study to the other, depending of the methodology used, vessel speed and other specific factors.

Table 5: Vessel noise budget[12]

Vessel class	**Vessel type**	**SPL** (dB re 1µPa @ 1 m)
Commercial (AIS code 70-89, 30-32, 52)		
Cargo ships (AIS code 70-79)	Container	178 ± 4
	Vehicle carrier	176 ± 3
	General cargo	175 ± 5
	Bulk carrier	173 ± 5
Tankers (AIS code 80-89)	Oil/chemical tanker	174 ± 4
Tug (AIS code 31, 32, 52)	Tug	170 ± 5
Fishing (AIS code 30)	Fishing	164 ± 9
Passenger (AIS code 60-69)	Ferry	166 ± 8
	Cruise	180
	Other	165
Other (AIS code 90-99)		165
Various (all other codes)[13]		165
	Military	161 ± 10
	Pleasure craft	159 ± 9

Source : Veirs, 2015; Basset *et al*, 2012

Numerous efforts are being made around the world to advance ship-quieting technologies by implementing technical standards, incentive systems and/or regulations. These include (but are not limited to) organizations listed in Table 6.

[12] Veirs (2015) and Basset *et al* (2012) obtained different mean broadband source levels from measured vessels. According to Veirs (2015), the comparatively low values of their means cannot be explained by distinct methodology. The most likely explanation is a difference in distinct ship design and/or operating characteristics between Puget Sound and Haro Strait populations. Also, there is some evidence that ships measured by Basset *et al*. (2012) may have higher speeds.

[13] The 'Various (all other codes)' category is used to combine uncommon ship types (e.g. underwater operations vessels and anti-pollution equipment) as well as ship types underrepresented by AIS statistics (e.g. military vessels and pleasure craft).

Table 6: Examples of organization advancing ship-quieting technologies or encouraging ship owners to reduce their noise output

International bodies	International Organization for Standardization (ISO), International Maritime Organization (IMO)
Ship classification societies	DNV (SILENT), Bureau Veritas (BV NR614), ABS (to be done)
Green certification societies	Green Marine, Green Award, SILENV
Governments	Germany, the United Kingdom
Shipping lanes / Ship owners	MAERSK Lines, Mediterranean Shipping Company (MSC), Evergreen

Source: Robinson, 2014

1.5.2 Non-shipping noise

Non-shipping noise, i.e. anthropogenic underwater noise associated with construction and industrial development, seismic exploration, sonar use, detonations, and/or other human activities, is also a significant concern. Harbours can be particularly noisy, not only as a result of vessel traffic, but also port activities such as pile driving, dredging, and shipyard operations. In some areas, industrial activities related to offshore oil and gas production are a significant source of underwater noise. All of these on-going noise-generating activities can have cumulative effects[14] in key areas where industrialization is significant and, therefore, are also of great concern.

a) Seismic exploration

Seismic exploration is the primary technique for finding and monitoring oil and natural gas reserves.[15] Seismic reflection profiling uses high-intensity sound to image the earth's crust. Arrays of air-gun firings are made to produce the sounds necessary for seismic reflection profiling (Hildebrand, 2005). The air-guns release a specific volume of air under pressure, creating a sound pressure wave from the expansion and contraction of the released air bubble. To yield high intensities, multiple air-guns are fired with precise timing to produce a coherent pulse of sound. Typically, oil industry air-gun arrays involve 12 to 48 individual guns. To be consistent with underwater acoustic literature, air-gun array source levels are back-calculated to an equivalent source concentrated into a one-metre-radius volume, yielding source levels as high as 256 dB re 1µPa @ 1 m for the Root-Mean-Square (RMS) output pressure (Hildebrand, 2005). Of course, the far field pressure from an air-gun array is focused vertically, being about 6 dB stronger in the vertical direction than in the horizontal direction for typical arrays.

b) Sonars

Sonar systems are used to probe the ocean by intentionally creating acoustic energy. They are seeking information about objects within a water column, at the sea bottom, or within the sediment. Active sonar emits high-intensity acoustic energy and receives reflected and/or

[14] Cumulative effects result from the incremental, accumulating, and/or interacting impacts of an activity when added to the other past or present impacts (Hegmann et al. 1999).

[15] Offshore oil and gas exploration and construction activities occur along continental margins. Current with such activities include northern Alaska and northwestern Canada, eastern Canada, the U.S. and Mexican Gulf of Mexico, Venezuela, Brazil, West Africa, South Africa, the North Sea, the Middle East, northwest Australia, New Zealand, southern China, Vietnam, Malaysia and Indonesia.

scattered energy. Both civilian and military applications may involve a wide range of sonar systems, which can be categorized as low-frequency (< 1000 Hz), mid-frequency (1-20,000 Hz), and high-frequency (>20,000 Hz). To give one example, some U.S. Navy Low-Frequency Active (LFA) sonar uses an array of 18 projectors operating in a 100-500 Hz frequency range, with 215 dB re 1µPa @ 1 m source level for each projector (Hildebrand, 2005). Some commercial sonars designed to locate fish can typically generate sound at frequencies of 3 to 200,000Hz, with source level range from 150-235 dB re 1µPa @ 1 m.

c) Acoustic deterrent devices

Acoustic deterrent devices (ADD) use sound in an effort to repel marine mammal from fishery activities. The goal is to use a local acoustic annoyance to keep marine mammals away. Pingers can also be used by some fisheries to reduce the bycatch of marine mammals. These are typically producing low-power with a source level of 130-150 dB re 1µPa @ 1 m. Acoustic harassment devices (AHD), used to reduce depredation by marine mammals on caught or cultured fish, are high-powered devices with a source level of 185-195 dB re 1µPa @ 1 m. Both pingers and AHD have frequencies in the 5,000-160,000 Hz range and generate pulses lasting from 2 to 2000 msec (Hildebrand, 2005).

d) Explosions

Nuclear and chemical explosions are the two classes of manmade explosions caused in or over the ocean. Nuclear explosions are extremely strong sources of underwater sound. Chemical explosions[16] are more portable and more easily conducted in an ocean setting. In the 1960s, a surprisingly large number (300-4,000 per month) of underwater explosions were reported in the North Pacific (Hildebrand, 2005). Today, most chemical explosions continue to be used in the construction and removal of undersea structures, primarily by the oil industry.

e) Industrial activities and construction

Pile driving, dredging, drilling, tunnel boring, power plants, power-generating wind mills and canal lock operations are all industrial and construction activities contributing to underwater noise in the ocean and along shorelines. Noise produced by stationary industrial activities, such as oil drilling, construction pile driving,[17] and offshore wind farms, are typically known to have their highest energy at low frequencies (20 to 1000 Hz) (Hildebrand, 2009).

f) Small vessels

Small vessels do not greatly contribute to the global ocean acoustic environment, but may be a significant local sound source (Hildebrand, 2005). Poor documentation about the number of recreational craft makes it difficult to assess their real impact, although there is some evidence they introduce a substantial amount of noise in ocean soundscape near shore. Furthermore, no AIS device[18] is mandatory onboard smaller craft, which increases the challenges when it comes to analyzing noise data since they can rarely be tracked via AIS. This is particularly of great concern in areas where fishing activities, for example, are an important local economic industry. The

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[16] The spectral and amplitude characteristics of chemical explosions vary with the weight of the charge and the depth of the detonation.

[17] The propagation of pile driving noise away from the impact site varies according to the bottom type.

[18] The federal Navigation Safety Regulations came into force on May 10, 2005 and states: “Every ship, other than a fishing vessel, of 500 tons or more that is not engaged on an international voyage shall be fitted with an AIS”.

vessel categories are outboard, inboard, sterndrive, personal watercraft, sailboat and miscellaneous. Sound levels for whale-watching boats, for example, range from 115 to 127 dB re 1µPa @ 1 m for one-third-octave bands[19] (Hildebrand, 2005), usually making one such boat a non-issue but possibly having an impact on marine life if operating simultaneously with other such vessels.

1.6 MITIGATION MEASURES

One of the biggest challenges faced in regulating the effects of noise and to encourage the development of appropriate mitigation measures is human ignorance of the characteristics and levels of sound exposures that may pose risks to marine animals. For the purpose of describing and presenting mitigation measures, anthropogenic underwater noise can be defined as sound that causes negative effects. As a result of the work carried out for the implementation of the *Marine Strategy Framework Directive* for the European Union, noise can be classified as falling into one of two categories:

- **Impulsive noise**, defined as a sound emitted by a point source comprising one or more pulses of short duration and with long gaps between these pulses
- **Continuous noise**, commonly defined as background noise without distinguishable sources.

Depending on the kind of noise, the adverse effects on marine life will be different and, of course, will be addressed through different mitigation measures. These measures usually include a set of practical procedures and technological solutions aimed at reducing the environmental impact of noise-producing human activities at sea. It is important to note that as new technologies and/or best management practices are developed, some of these measures and/or procedures will be revised or replaced to further reduce the impact of underwater noise on marine life.

1.6.1 Impulsive noise

Impulsive noise may cause negative impacts of different orders of magnitude on species, depending on the noise characteristics. Some impacts affect individual animals only, while others affect groups or sometimes entire populations. The response of each marine mammal to noise may differ because of the species, individual characteristics, age, gender, prior experience with noise, behavioural states, as well as other possible factors. Based on the observed reactions of marine mammals to noise, the impacts may include decreased foraging efficiency, higher energetic demands, less group cohesion, higher predation, decreased reproduction – all of which can negatively affect a population.

In recent years, while science has been providing early recommendations on noise exposure limits for marine mammals and other species, some international organizations have formulated guidelines to mitigate the negative effects of human activities commonly identified as the main source of underwater noise.

[19] For practical reasons, the audible frequency range is separated into unequal segments called octaves. An octave higher means a doubling of the frequency. Each octave band may be separated into three ranges referred to as one-third-octave bands.

These include:

- High-powered active sonar use during military or civil operations;
- Seismic surveying for oil and gas exploration and geophysical research;
- Coastal and offshore industrial development;
- Port and harbour extensions;
- Use or disposal of explosives.

Some of these guidelines recommend the use of procedures and best management practices that are thought to reduce the negative effects of noise. The most frequently and broadly used mitigation measures include assessing the risk through acoustic modelling, siting species in lower-risk areas and/or during certain key times of the year, identifying an exclusion zone from a specific noise source, and gradually increasing source levels in the hope that animals will escape dangerous areas (i.e. soft-start procedures), monitoring specific zones both visually, by hiring a trained marine mammal observer (MMO), acoustically, via passive acoustic monitoring (PAM), and/or the use of best technical solutions (e.g. bubble curtains, cofferdams) to reduce noise emission. Some of these mitigation measures are presented in existing regulations mentioned in part 2 of this report.

1.6.2 Continuous noise

Noise from ships has various possible direct impacts on local marine life and contributes to background noise for long ranges at low frequencies. To mitigate the cumulative impacts of shipping (noise and the risk of collisions with whales), more research is required. Noise reduction measures need to be explored further to decrease local and long-range adverse conditions.

There is a reasonably long and successful history of quieting both surface and sub-surface military vessels to reduce their acoustic signature. Their greater silence reduces their chances of detection by adversarial passive acoustics equipment. Ship-quieting technologies are likewise rapidly advancing in terms of their use on acoustic research vessels, ferries and environmentally sensitive cruise ships (OSPAR Commission, 2009). Aboard vessels, most quieting technologies used to date have been for the benefit of the ship's crew and passengers.

Mitigating the noise from commercial vessels poses numerous challenges. The first challenge involves the current lack of neutral testing facilities. The improved efficiency and/or reduced cavitation that are claimed by developers/manufacturers are rarely confirmed by independent research. Additionally, few of the currently available results from research projects focus on before-and-after vessel propeller and hull maintenance to assess the difference in noise radiated into a marine environment. The relationships among ship efficiency, cavitation and noise must be studied further inasmuch as the efficiencies of alternative technologies in reducing noise are speculative in most cases (ACCOBAMS, 2013). To this end, scientifically demonstrated results could be very effective in prompting ship owners to further investigate and invest in reducing the noise output of their vessels.

Mitigation measures to reduce noise radiated by commercial vessels can be split into two categories: 1) ship design; and, 2) operation and maintenance. To reduce overall noise, it may be essential to combine different mitigation measures in a harmonized way. Investments in the implementation of technical mitigation measures for existing vessels should be based on a credible scientific-based measurement of a ship's noise signature in order to clearly identify the primary source(s) of noise on a specific vessel.

a) Ship design considerations

Given the fact that noise from vessels is mainly produced by cavitation and onboard machinery, the largest opportunities for underwater noise reduction are in a ship's initial design. Ship design considerations are unlikely applicable to existing vessels, even if they appear reasonable and practicable. In 2014, the International Maritime Organization (IMO) released "Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life," which was intended to provide general noise reduction advice to ship designers, builders and operators. The guidelines mainly focused on the primary sources of underwater noise, given the complexities associated with ship design and construction.

- <u>Propellers</u>: Some propellers are designed and selected to reduce cavitation. Good design to reduce cavitation includes optimizing the propeller load, ensuring as uniform a water flow as possible into the propellers, and the careful selection of the propeller characteristics (diameter, blade number, pitch, skew and sections).
- <u>Hull design</u>: Given that uneven or non-homogeneous wake fields are known to increase cavitation (with a propeller operating in the wake field generated by the ship hull), the ship hull's form and its appendages should be designed in such a way that the wake field is as homogeneous as possible.
- <u>Onboard machinery</u>: Machinery, particularly main diesel engines as well as auxiliary diesel engines, is a significant source of noise because of its potential to induce structure-borne vibrations that radiate via the hull. At lower vessel speeds, the hull-induced vibration is the predominant noise source at frequencies below 100 Hz. This being the case, consideration should be given to the selection of onboard machinery, along with appropriate vibration control measures, the proper location of equipment in the hull, and optimization of foundational structures that may contribute to reducing underwater radiated and onboard noise. Diesel-electric propulsion has been identified as an effective option to reduce noise and may even facilitate the effective vibration isolation of diesel generators.

b) Operational and maintenance considerations

With the previously outlined measures for reducing noise from vessels being mainly applicable to new-builds, operational and maintenance considerations are regarded as the main solutions for reducing underwater noise output for both new and existing ships. It should be noted that operational considerations, such as rerouting and the reduction of ship speeds, aim to reduce adverse impacts on marine life due to shipping. Hence, the presence of vulnerable species and their seasonal distribution in specific areas should be considered in order to keep operational changes efficient for the protection and conservation of marine life.

- <u>Propeller and underwater hull surface cleaning</u>: Marine fouling and the roughness of surfaces are known to increase cavitation by creating a non-homogeneous wake field. Cleaning and polishing blade propellers and maintaining a smooth underwater hull surface help to reduce cavitation and simultaneously improve ship efficiency by reducing the ship's resistance and propeller load. It should also be noted that hull coatings that reduce drag on the hull and overall turbulence can facilitate the reduction of noise, as well as improve fuel efficiency.

- Speed reduction: Reducing ship speed can be an effective operational measure for reducing noise for ships equipped with a fixed pitch propeller (FPP). Noise is further decreased if the ship speed drops lower than the cavitation inception speed (CIS)[20] of the propeller. Given that a controllable pitch propeller (CPP) doesn't have any CIS, slowing down a CPP-equipped vessel will not change the volume or travelling distance of radiated noise. Therefore, for these vessels, consideration should be given to optimum combinations of shaft speed and propeller pitch.
- Rerouting: Decisions to reroute vessels to avoid sensitive marine areas may help to reduce the adverse effects on marine life, especially for endangered whale species at high risk. As previously stated, any rerouting decision should be based on the most credible and up-to-date information regarding species distribution and seasonal locations.

As major stakeholders within the maritime industry, classification societies have an essential role to play in improving and enriching the rules they oversee to reduce the environmental footprint of the industry. To assist shipbuilders and operators in reducing underwater noise radiating from ships, some classification societies have developed notations addressing it.

- **Det Norske Veritas (DNV)** was the first to issue a class notation dealing with underwater radiated noise. DNV issued the SILENT notation in 2010, which applies to underwater noise radiation from vessels to ensure a low environmental impact and/or hydro-acoustic operational capability for vessels relying on hydro-acoustic equipment as an important part of their operation.
- **Bureau Veritas** is a leading international classification society that has developed the voluntary BV NR614 Underwater Radiated Noise (URN) notation.
- **American Bureau of Shipping (ABS)** is currently developing a notation on underwater noise, including the development of assessment criteria for new-builds that are designed and constructed to control and reduce noise emitted into waterways.

[20] *Cavitation inception speed* (CIS) is the lowest ship speed at which cavitation occurs.

1.7 Research on shipping noise in Canada

Multiple ships at distant ranges may contribute to the background noise within the open ocean, and the sum of many distant sources creates broad spectral peaks of noise inside the 5-500 Hz band (Hildebrand, 2005). Increasing concern about the environmental impacts of noise, along with the greater efficiency of acoustic-based ocean floor mapping technologies within quieter environments, has augmented the need to measure underwater radiated noise from all types of vessels (Patterson, 2012).

There is a need to further the understanding and quantification of underwater noise from the marine transportation sector in Canada. Information has already been gathered by different stakeholders but may not yet be published and, therefore, is not yet accessible. Tables 8, 9, 10 and 11 at the end of this report convey some of the current projects related to shipping noise measurements in Canada.

1.7.1 Challenges for shipping noise measurements

As stated, commercial shipping is one of the main contributors of anthropogenic noise at low frequencies. Each vessel radiates a different level of noise within the marine environment, depending on the vessel type, ship design, how well maintained the hull and the propeller are, as well as operating conditions. There are numerous challenges and gaps of knowledge that need to be addressed to achieve a better understanding of the contribution of shipping to the marine soundscape. To reduce overall noise within aquatic environments, a thorough understanding of the noise a vessel contributes, the reasons why one vessel is noisier than another, as well as advanced knowledge of ship-quieting technologies will be essential.

a) Methodology

Common noise measurement and a centralized database for ship noise signatures must be created, similar to the criteria and databases established for ambient noise measurement.

b) Shipping noise reference database

To be able to state that a vessel is noisier than average, it is essential to access a centralized database containing an inventory of ship noise signatures. No such database currently exists. Establishing a national network of vessel noise measuring stations, primarily to collect shipping noise signatures but also to measure ambient noise in different areas, would provide a reliable reference database.

c) Efficiency of ship-quieting technologies and mitigation measures

Very few ship-quieting technologies for large commercial vessels or mitigation measures to reduce noise from vessels have been tested by sea trial in Canada to date. Advancing knowledge in this area would certainly be helpful for decision- and policymakers.

d) Other anthropogenic noise contributions

When using hydrophones to measure noise from vessels, numerous other types of noise are recorded from other sources. Some of these are difficult to track. For example, smaller craft are not obligated to have an AIS device on board, which makes it more challenging to analyze these boats for their sound contribution. This challenge is particularly significant in waters used for commercial fishing because there are many of them in tight locations. Establishing a way to minimize and manage the noise from these boats must dovetail with maintaining an important local economic industry.

1.8 MARINE LIFE SOUND PRODUCTION

Many species of marine life have been identified as sound producers (Wenz, 1962). Sound is as important to cetaceans and to other species of marine animals as light is to humans. The distinctive properties of underwater sound and the limitations of other senses, such as vision, touch, taste and smell in a marine environment in terms of range and speed of signal transmission, make sound the preferential sensory medium for a large proportion of marine animals (UNEP, 2012). In most oceans, underwater visibility is limited to a few tens of metres and is regularly much less. As a result, a range of marine taxa, including marine mammals, numerous fish and some invertebrates have developed special organs and mechanisms for detecting and emitting underwater sound (UNEP, 2012).

The contribution of biological sounds to ambient ocean noise varies with frequency, time, and location, so that it is difficult to generalize. In some cases, diurnal, seasonal and geographical patterns may be predicted (Wenz, 1962). For many marine organisms, including marine mammals, fish, turtles, and invertebrates, sound is used to communicate, locate mates, search for prey, avoid predators and hazards, maintain social bonds, and for short- and long-range orientation and navigation. Anthropogenic noise introduced into a marine environment can potentially affect marine organisms in numerous ways. For example, it can mask biologically relevant signals, lead to a variety of behavioural reactions, cause hearing loss and, at very high levels, injure or even kill marine life (OSPAR Commission, 2009). Marine organisms generally choose their locations and modify their behaviour based, in part, on natural and anthropogenic background noise (Hildebrand, 2009).

1.8.1 Marine mammal sound production and hearing range

Sound production differs for mysticetes (eg. baleen whales), odontocetes (eg. toothed whales, dolphins, and porpoises), and pinnipeds (eg. seals, sea lions, and walruses).[21] Large mysticetes tend to produce sound in the low frequency range of 10 to 1,000 Hz, with a few signals extending above 10,000 Hz (Hildebrand, 2005; Southall, 2007). In comparison, odontocetes tend to produce sound in the mid- and high-frequency range of 1,000 to 150,000 Hz.

To maximize the use of the underwater acoustic environment, marine mammals have developed broader hearing frequency ranges than are typically found in terrestrial mammals (Hildebrand, 2005, UNEP).

a) Mysticete

Mysticete have developed long-range acoustic communication systems to facilitate mating and other social interactions during their sometimes solitary lives. Mysticete sounds can be broadly characterized as tonal calls, frequency-modulated sweeps and pulsed tonals. All of these types of sounds can be generated either as individual calls or combined into patterned sequences or songs. Blue whales (*Balaenoptera musculus*) produce low-frequency calls (10 to 100 Hz) with estimated source levels of 185 dB re 1µPa @ 1 m (Hildebrand, 2005). Generally, most large mysticetes (e.g., blue, fin, right, bowhead, and gray whales) are known to vocalize at frequencies

[21] The word pinniped means fin or flipper-footed and refers to the marine mammals that have front and rear flippers. This group includes seals, sea lions, and walruses. These animals live in the ocean but can spend long periods of time on land.

below 1,000 Hz, with estimated source levels as high as 180 dB re 1µPa @ 1 m (Hildebrand, 2005; Richardson, 1995).

b) Odontocete

Odontocete produce broadband clicks with peak energy between 5,000 and 150,000 Hz, varying by species. They can also produce burst-pulse click trains and tonal or frequency-modulated whistles that range from 1,000 to 25,000 Hz. Echolocation, the ability to use self-generated sounds to ascertain the features of an environment and the objects located within it, has been demonstrated for at least 13 odontocete species (Hildebrand, 2005; Richardson, 1995). The source level for odontocete clicks have been reported to be as high as 228 dB re 1µPa @ 1 m for false killer whales (*Pseudorca crassidens*) and 232 dB re 1µPa @ 1 m for male sperm whale (*Physeter macrocephalus*) (Hildebrand, 2005); these high-frequency sounds are rapidly absorbed in seawater, however, making them perceptible only at short distances. Odontocete whistles have lower source levels than clicks, approximately 169 dB re 1µPa @ 1 m for bottlenose dolphins (*tursiops truncatus)* (Hildebrand, 2005).

c) Pinniped

Pinnipeds emit a limited range of barks and clicks ranging from <1,000 to 4,000 Hz. All pinnipeds use sound to establish and maintain the mother-young bond. Only a few species of pinnipeds have been studied to estimate their source levels and frequencies for underwater calls. The Weddell seal (*Leptonychotes weddellii*), for example, produces calls from 148 to 193 dB re 1µPa @ 1 m at frequencies of 200 to 12,800 Hz (Hildebrand, 2005). These calls may be detected at ranges of several kilometres in both open ocean and under ice.

Marine mammal audition

Audition hearing is determined by the characteristics of received sound, receiving system, and background noise conditions (either external or internal) (Southall, 2007). Marine mammals have multiple sound-reception pathways and rely on signal processing at multiple levels integrated within the cochlea and nervous system to optimize perception.

Marine mammal hearing capabilities are quantified in live subjects using behavioural audiometry and/or electrophysiological techniques (Southall, 2007). For species not studied with *in vivo* audiometry, some auditory characteristics can be estimated based on sound production frequencies (Richardson, 1995; Southall, 2007). Behavioural audiograms are obtained from captive, trained animals using standard psychometric testing procedures. However, given that marine mammals are large and difficult to maintain, behavioral audiograms representing an entire species are typically based on a few individuals[22], often just one animal (Southall, 2007). Electrophysiological audiometry, which is conducted on both captive and wild animals, is another way to assess the hearing capabilities of marine mammals and involves measuring small electrical voltages produced by neural activity when the auditory system is stimulated by sound (Southall, 2007). The two procedures can produce a comparable detection threshold in at least a few cetacean species (Southall, 2007). Table 7 summarize the general hearing and vocalization ranges of marine mammals.

[22] These individuals are generally obtained opportunistically and individual differences in hearing sensitivity among subjects, as well as methodological differences among investigators, can lead to improper conclusions when nominal species audiograms are based on data from a single animal (Southall, 2007). In addition, audiograms have been measured for only about 20 marine mammal species and in each case only among a sole or few individuals (Erbe, 2012).

An auditory threshold is the level of the quietest sound audible in a specified per cent of trial (Southall, 2007). In other words, it is the minimal sound level at which there is an explicit signal detection probability. The threshold is a statistical quantity, the level at which the signal was heard 50% of the time (Erbe, 2012). Species differ in their absolute sensitivity and functional frequency bandwidth. While these studies are essential to understanding general hearing capabilities, animals in the ocean rarely listen for simple acoustic signals from point sources and do not live in a noise-controlled environment. Audibility of a sound for an animal is limited by the sound dropping below either ambient noise levels or the animal's detection threshold (Erbe, 2012).

Table 7: Summary of the general hearing and vocalization ranges of marine mammals:

Marine mammal	Hearing sensitivity (Hz)	Peak frequency (Hz)
Mysticete	20 to 20,000-30,000	10 to 2,000
Odontocete	~100 to 160,000	
- click		5,000 to 150,000
- whistle		1,000 to 25,000
Pinniped	1,000 to 20,000	<1,000 to 4,000

Source: Hildebrand, 2005

1.8.2 Fish, turtle and other marine life sound production and hearing range

The marine environment is dark for every species living within it. The way animals use their hearing and their acoustic capabilities varies widely.

a) Fish

There are more than 32,000 species of fish, showing great diversity in their physiology, behaviour and ecology. They utilize sound for navigation, communication, selection of habitat, mating, predator avoidance and prey detection (UNEP, 2012). All fish have ears to detect sound and convey sensitivity to gravity and to linear and angular acceleration (Popper *et al*., 2014; UNEP, 2012). It is important to note that hearing range and sensitivity varies considerably among species. Sensitivity to sound occurs below 100 Hz up to several thousand Hertz, depending on the species (Popper *et al*., 2014).

The lateral line system is a third way for fish to have a sense of their environment. The system's receptors respond to the relative motion between the body surface of the fish and the surrounding water. This relative motion only takes place very close to sound sources where there is a steep gradient of sound pressure and particle motion (Popper *et al*., 2014).

Fish usually create low-frequency sounds (50 to 2000 Hz, but most often 100 to 500 Hz). They can be a significant component of local ambient noise (Hildebrand, 2009). Sounds produced by fish are not only produced as individuals, but also in chorus (Hildebrand, 2009). The increase in low-frequency noise can be as much as 20 to 30 dB in the presence of chorusing fish. Most fish sounds are unknown because of a lack of detailed study.

b) Sea turtle

Scientists recognize seven living species of sea turtles: green, hawksbill, Kemp's Ridley, loggerhead, olive Ridley, flatback sea turtle, and leatherback. There are three species of sea turtle that frequent Canadian waters: leatherback, loggerhead and green. No sea turtles nest on Canadian beaches. All of these generally share a similar body form, although shell morphology is different in leatherback compared to the hard-shelled species (Popper *et al.,* 2014).

Like many marine fish and mammals, sea turtles use a range of habitats during each developmental stage (Ferrara, 2014). Post-hatchlings become epipelagic[23], exploiting currents of different scales, and swimming along multidirectional paths. After approximately seven to 10 years in this oceanic stage, a crucial development occurs whereby most sea turtles begin to actively move to either a shallow or a deep sea. At this point, they are considered juveniles. Upon reaching sexual maturity, sea turtles migrate among foraging, courtship and nesting habitats, spatially and temporally overlapping with juveniles. The ambient acoustic environment changes with each stage of their maturity (Ferrara, 2014).

It was thought for a long time that turtles were quiet animals. The fact that turtle vocalizations were not recognized until recently is probably due to their low-emission rates, low pitch, and limited amplitude (Ferrara, 2013). While very little data exist on the underwater hearing abilities of sea turtles or the potential physiological and behavioral effects of sound on sea turtles, some evidence exists that sea turtle are able to detect and behaviorally respond to acoustic stimuli (Dow Piniak *et al.,* 2012). Some tests were done on a few species by Auditory Evoked Potentials (AEP)[24], audiogram to aerial, and vibrational stimuli. However, it is difficult to extrapolate the results from these few studies to apply to all marine turtles. Other preliminary measures of hearing in sea turtles indicated that the hearing range was 50 to 1200 Hz (Lavender, 2012; Popper *et al*., 2014). Another study on loggerhead sea turtles indicated they have low-frequency hearing with best sensitivity between 100 and 400 Hz (Martin, 2012). Further anatomical investigations found that the marine turtle ear is capable of low-frequency aerial and bone conduction hearing (Martin, 2012).

Sea turtles do not appear to vocalize or use sound for communication, but may use sound for navigation, locating prey, avoiding predators, and general environmental awareness (Dow Piniak *et al.,* 2012). However, sea turtle hearing sensitivity overlaps with the frequencies and source levels produced by many anthropogenic sources (Dow Piniak *et al.,* 2012).

A recent study found that the hatchlings and embryos of leatherback turtles made multiple noises and sounds, indicating their communication with each other prior to hatching. The scientists recorded more than 300 different sounds. Not knowing whether sound transfer is critical to baby sea turtle coordination, this study carries broad implications for their conservation. The researchers noted that anthropogenic noise from motorboats and other sources may affect sea turtle hatchlings more than previously thought. It is known that turtles communicate underwater with low-pitched calls that they use to help them travel together and to find mates (Ferrara, 2014).

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[23] Constituting part of ocean where enough light is present for photosynthesis.

[24] AEP audiogram is a technique to measure sensitivity. It has been argued that AEP recordings may not fully reflect the hearing capabilities of animals because AEP does not include signal processing by the brain, and often does not mirror audiograms obtained by behavioural experiments (24).

c) Invertebrates

Relatively little is known about sound detection in invertebrates. However, many species have mechano-sensors that have some resemblance to vertebrate ears (Moriyasu, 2004). Based on the available information, it is becoming clear that many marine invertebrates are sensitive to sounds and related stimuli (Moriyasu, 2004). It is known that in crustacean species the main vibration receptors are in the statocysts[25] and the walking legs, either in the cuticule or in the joints between leg segments (Moriyasu, 2004). A study (Tautz, 1980) showed that crayfish (*Cherax destructor*) have sensory hairs on their pincers that are highly sensitive to water vibration frequencies between 150-300 Hz.

Shrimps are known to produce mid-frequency sounds. Snapping shrimps (*Alpheus spp.* and *Synalpheus spp.*) can be the dominant source of mid-frequency ambient noise (Hildebrand, 2009). The sound is produced by an enlarged claw that creates a water jet with broadband acoustic energy. To give an example, the presence of snapping shrimp can increase ambient noise levels in the mid-frequency band by 20 dB (Hildebrand, 2009).

1.9 HOW NOISE AFFECTS MARINE LIFE

1.9.1 Overview

Concerns about potential adverse effects of anthropogenic noise on marine life began in the 1970s and expanded in the 1980s because of concerns over seismic air-guns and their potential effects on Arctic whale populations. The current available data on the effects of noise on marine mammals and other marine life vary in quality. In many respects, data gaps severely restrict the derivation of scientifically-based noise exposure criteria for certain effects and are not appropriate for reference or use, given the amount and type of data available (Southall, 2007). Recent interest and concern about the effects of anthropogenic noise on marine mammals have triggered considerable new research, and systematic, objective, science-based interpretation of the existing data can inform management agencies charged with mitigating the adverse effects of anthropogenic noise on protected species (Southall, 2007). In Canada, underwater noise is identified as a high-risk anthropogenic threat in many recovery plans for species at risk protected under the *Species at Risk Act* (SARA). Evidence of disturbance and displacement because of underwater noise has been observed in several whale species. Moreover, the effects of acoustic disturbance may be greater when combined with other threats (COSEWIC, 2011).

1.9.2 Effect of noise on marine mammals

Anthropogenic noise can have negative effects at different levels of magnitudes on marine animals, according to the characteristics of the noise emissions and other factors (McDonald, 2006). The noise emitted by large commercial ships is unlikely to lead to hearing damage in marine mammals following brief or infrequent exposures (Lawson, 2013). However, ship noise overlaps with much of the sound frequency range used by many cetacean species, especially those which call at lower frequencies such as bowhead, right, blue, fin, and humpback whales and can cause signal masking (Lawson, 2013; Clark et al. 2009). Exposure to ship-related noise or overlap of distribution with shipping route may or may not lead to mortality or other negative effects on marine mammal health, behaviour, and habitat use (Lawson, 2013).

[25] Balance organ in some aquatic invertebrates.

The potential impact on individuals, groups and populations of marine mammals varies. Factors that affect the degree of reaction to noise and vessel traffic (Richardson et al., 1995) and can be characterized as follows (taken from Lawson, 2013). The noise may:

- be too weak to be heard. It may be below ambient level, or below the hearing threshold at the specific frequencies where anthropogenic noise is emitted;
- mask differing components of incoming communication calls or interfere with calls or environmental sounds useful to some vital functions such as foraging, navigation, or finding mates and reproduction
- be audible but not result in negative behavioural or physiological response;
- be audible, and result in a negative response that can range from temporary alertness, to active avoidance of the area for short to prolonged period of time;
- result in a progressive decrease in response as the animals habituate to it;
- cause repeated and persistent disturbance or physiological stress if the animal remains in the area because of its importance for vital functions or because of a lack of alternate location to fulfil essential biological needs; and,
- lead to temporary or permanent hearing damage if it is very strong.

Marine mammal response can vary depending on such factors as species, individual, sex, age, prior experience with noise and behavioural state. It should also be noted that animals showing no avoidance or changes in activities may still suffer important, even lethal, consequences. The response of marine mammals to sound depends upon a range of factors, including sound pressure level and other properties (e.g. frequency, duration, amplitude), the animal's physical and behavioural state and the ambient acoustic and ecological features of the environment (Hildebrand, 2005). Nevertheless, it is clear from the scientific investigations of numerous marine mammals that the production and reception of certain sounds are critical to various aspects of their life history (Southall, 2005).

Richardson et al. (1995) presented an approach, illustrated in Figure 15, in describing zones of noise influences such as masking, behavioural response, injury and death, and reviewed marine mammal response to a specific sound source. Essentially, the effect of noise on the animal depends to a large degree on the proximity of the animal to the noise source and the animal's received level of the signal. At very short ranges, a sufficiently loud source may cause severe physiological damage and perhaps death. At longer ranges, geometrical spreading and absorption reduce the signal level substantially and the same source may cause hearing loss and acute, short-term behavioural changes, which can contribute to death under particular circumstances (Richardson, 1995). However, it should be noted that at longer distances, the sound can still cause behavioral

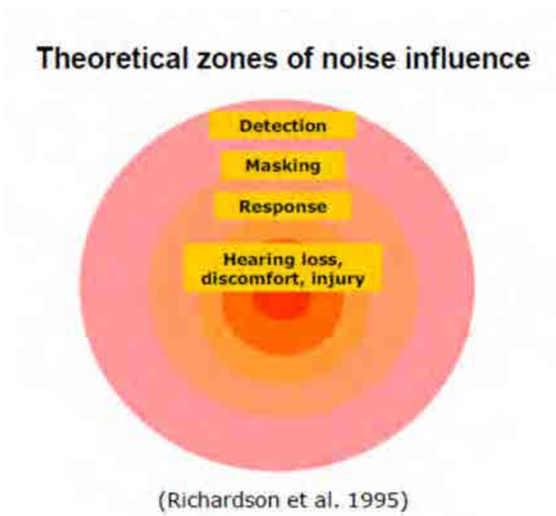


Figure 15: Conceptuel zones of noise influence.

responses, such as habitat displacement and modification as well as cessation of vocalization that can interfere with important life functions. It can elevate the ocean's background level of noise, particularly in the low frequencies, significantly reducing the perceptual space of many acoustic species.

Human-produced sound has the potential to interfere with various important biological functions (OKEANOS Foundation, 2008). There are four main areas of concern about the potential acute and cumulative effects on marine mammals from the introduction of manmade noise in the ocean (IFAW, 2008; Richardson, 1997; Rolland, 2012):

- That noise exposure may cause **behavioural changes**, disturbance reactions, and interruption or adverse modification of normal activities, from minor to severe. Noise pollution may interfere with biologically important activities including foraging, breeding and calving.
- That anthropogenic ocean noise may **mask sounds** that are vital to marine animals, such as those indicating the existence and location of prey, predators and mates, as well as navigational information. This includes masking of calls from conspecifics, the echoes of their own echolocation pulses, or other important natural sounds.
- That intense noise exposure may cause **physical injury**, including temporary or permanent hearing impairment if the noise is strong enough, and potentially death, even at low levels for some vulnerable species.
- That noise may **increase stress levels** in marine animal, leading to detrimental consequences for their immune system and reproductive health.

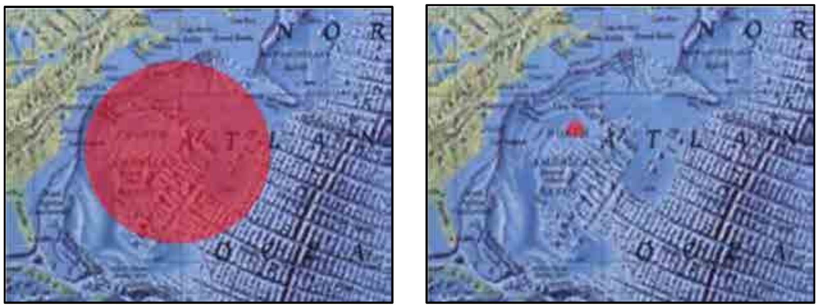
a) Behavioural changes

Behavioural response to sound is highly variable and context-specific (Southall, 2007), and includes changes in surfacing, diving and heading patterns (Nowacek, 2007). Noise has been observed to affect the behaviour of marine mammals in ways ranging from subtle to severe (Richardson, 1995; OKEANOS Foundation, 2008). Reactions to noise may include a shift in orientation toward a sound source, a cessation of feeding or social interaction, alteration of movement/diving behaviour, alteration in vocalization patterns such as shifting the frequency band or energy level of calls (Rolland, 2012), temporary or permanent habitat abandonment and, in severe cases, panic, flight, stampeding or stranding, sometimes resulting in injury or death (Richardson, 1995; Southall, 2007). These behavioural changes have a direct effect on the energetic costs and potential long-term abilities to forage, navigate and reproduce (OKEANOS Foundation, 2008).

b) Effect of masking

An important adverse effect of increased ambient noise is the potential for that noise to mask biologically significant sounds, thereby interfering with the clear reception of potentially important signals (OKEANOS Foundation, 2008; Southall, 2007; Clark, 2009). Masking occurs when a loud sound drowns out a softer sound or when noise is at the same frequency as a sound signal. This is of particular concern when the noise is at frequencies similar to those of biologically important signals, such as mating calls, prey detection and foraging. Given the widespread nature of anthropogenic activities, masking may be one of the most extensive and significant effects on the acoustic communication of marine organisms today (http://www.dosits.org/tutorials).

Anthropogenic noise can also mask important acoustic environmental cues that animals use to navigate and/or sense their surroundings. Although some species may be able to alter their communication signals to avoid being masked, the extent of such alterations is constrained behaviourally, physiologically and environmentally (OKEANOS Foundation, 2008; Clark, 2009). Figure 16 shows how noise may significantly reduce communication range for fin and blue whale.



Source: C.W. Clark, Cornell University

Figure 16: Estimated reduction in fin and blue whale communication range from prior to the advent of commercial shipping (left) to today's smaller expected ranges because of masking effects (right).

c) Physiological effects (physical injuries)

For physiological effects, it is important to distinguish between *source level* (SL) and *received level* (RL), which is the level measured at the receiver (usually a marine mammal) (Southall, 2007). The noise exposure criteria discussed below are focused on current knowledge of hearing in marine mammals and the effects of noise on hearing and/or behaviour in marine mammals.

Animals exposed to sufficiently intense sound exhibit an increased hearing threshold shift (TS) for some period of time following exposure, which is also described as a loss of hearing sensitivity (Southall, 2007). Factors influencing the amount of TS include the amplitude, duration, frequency content, temporal pattern and energy distribution of the noise exposure. The magnitude of TS normally decreases over time following cessation of the noise exposure, although recent studies suggest some temporary threshold shifts (TTS) can become permanent threshold shifts (PTS) over time.

Temporary threshold shifts (TTS)

A noise-induced TTS involves the TS eventually returning to zero, i.e. the threshold returning to the pre-exposure value. For marine mammals, data are available regarding sounds that cause modest TTS in a few species of odontocetes and pinnipeds. However, no data are available on exposures that would cause PTS (see below) in these taxa (Southall, 2007). Until recently, TTS was considered auditory fatigue (Erbe, 2012); however, recent studies in human audiology demonstrate that nerve damage leading to permanent hearing loss can occur at exposure levels associated with TTS (Kujawa, 2009).

Permanent threshold shifts (PTS)

A noise-induced PTS occurs when TS does not return to zero after a relatively long interval (on the order of weeks). A PTS is considered to be auditory injury, such as irreparable damage to the sensory hair cells, exceeding the elastic limits of certain tissues and membranes in the middle and inner ears, and resultant changes in the chemical composition of inner ear fluids (Southall, 2007).

d) Non-auditory effects

The auditory system appears to include the organs most susceptible to noise exposure, but noise has the potential to induce a range of direct or indirect physiological effects on non-auditory structures as well. It can cause relatively low-level physiological responses, including changes in cardiac rate and respiratory patterns, as well as induce stress that can impair survival and reproduction over time. While studies of noise-induced stress in marine mammals are limited, endocrine secretions of glucocorticoids and altered cardiovascular function have been documented in odontocetes exposed to high-level sound (OKEANOS Foundation, 2008; Southall, 2007). A correlation has been found between the reduction of overall low-frequency noise[26] and the decreased in baseline levels of stress-related faecal hormone metabolites (glucocorticoids) in North Atlantic right whales (*Eubalaena glacialis*) (Rolland *et al.,* 2012), and, in general, stress response is known to be highly conserved among mammalian species (Wright *et al.* 2007).

1.9.3 Effect of noise on other marine life

In comparison with marine mammals, there is limited, but increasing, scientific data available regarding the effects of sound on other marine life, including fish, sea turtles and invertebrates. For this reason, assessment procedures and subsequent regulatory and mitigation measures are often severely limited in their relevance and efficacy (Popper *et al*., 2014). It should also be noted that there are more than 32,000 species of fish, compared to about 130 species of marine mammals. Additionally, relatively few research papers link noise exposure to effects in fish and turtles. All these factors increase the complexity of managing the impact of sound on these marine animals. Even though there are only a few species of sea turtles, so little is known about their hearing and the role of sound in their life that it is very difficult to assess the real impact of anthropogenic noise within their environment (Popper *et al*., 2014).

Generally, it is possible to say that sound at higher intensities may have diverse effect on an animal, including death, hearing impairment, damage to anatomical structures, and changes in physiology, neural function, masking of communication, behaviour and development (Popper *et al*., 2014). At lower intensities, sound has been found to undermine certain vital behaviors, such as anti-predator response, and produce a physiological stress response. There are possible effects of sound upon behaviour, including communication between conspecifics and the detection of predators and prey (Popper *et a*l., 2014).

a) Fish

Many factors are likely to be important regarding the effects of sound exposure and their long-term consequences for the fitness and survival of fish (Popper *et al*., 2014). One of the most important is the presence or absence of a swim bladder in the body, a buoyancy organ that makes fish more susceptible to pressure-mediated injury to their ears and general body tissues than species without a swim bladder (Popper *et al*., 2014). It seems that this swim bladder is also likely to increase the ability of many species of fish to detect sounds over a broader frequency range and at greater distances from the source than fish without such structures, thereby increasing

[26] Following the events of September 11, 2001, there was a 6 dB decrease in underwater noise measured, with a significant reduction in frequencies below 150 Hz.

the range from the source over which manmade noises have the potential to exert influence (Popper *et al*., 2014).

Relevant studies revealed that very high intensity pure tones (over 180 dB re 1 µpa) presented for several hours may cause damage to the sensory hair cells of the ears of several fish species, while other studies suggested that some sounds will alter the behavior of marine fish (McCauley, 2003).

Fish with impaired hearing would have reduced fitness, potentially leaving them vulnerable to predators, possibly unable to locate prey, sense their acoustic environment, or, in the case of vocal fish, unable to communicate acoustically (McCauley, 2003).

b) Sea turtles

Sea turtles may be affected by marine sound both physiologically and behaviorally. Effects of noise on sea turtles are largely unknown, because of a lack of information on hearing capabilities and behavioral responses to sound. Because sea turtles are a highly migratory species, sound events in one area have the potential to impact not only the turtles that use that area to reproduce and forage, but also those simply "passing through" (Dow Piniak *et al*., 2012).

Like mammals, sea turtles might experience a TTS or PTS, or loss of hearing. Increased noise in the ocean can also mask important acoustic cues, however no information exists on critical ratios and masking in sea turtles (Dow Piniak *et al*., 2012). Repeated exposures to sound can cause habituation or sensitization increasing long-term physiological effects.

Noise pollution from human activities, once thought to be irrelevant to turtle conservation, is now generating some concern. Noise produced by ships, boats, jetskis, and other motorized watercraft may affect the reception of sound by turtles (Ferrara, 2013), and potentially interfere with their communication, to such a degree that it has a negative effect on hatchling survivorship and adult communication.

c) Invertebrates

Study of the effects of marine noise on invertebrate species is extremely limited. Most of the research deals with the effects of seismic surveys for oil and gas prospecting using air-guns and explosives and on military sonars (Moriyasu *et al*., 2004). It seems that most articles dealing with this subject are mostly gray literature, which makes access to reliable information difficult. However, based on the published information, it is reasonable to conclude that marine invertebrates are sensitive to sounds and related stimuli and that a variety of behavioural responses may be induced by these stimuli (Moriyasu *et al*., 2004). Another study (Regnault, 1983) indicated that in an aquarium under permanently high noise levels of approximately 30 dB in the 25 to 40 Hz-frequency range, the growth and reproduction rates of sand shrimp (*Crangon crangon*) was significantly reduced.

1.10 CONCLUSION

Assessing commercial navigation's contribution to ambient underwater noise and its impacts on marine life is complex. According to the scientific community, achieving a comprehensive understanding of the situation within Canadian waters will require effort, resources, collaboration, time and patience by researchers and policymakers.

Sufficient information is currently available to conclude that shipping noise is a concern for numerous marine species. Underwater noise is identified as a high-risk anthropogenic threat in many recovery plans for species at risk protected under the *Species at Risk Act* (SARA). However, there is still limited information available regarding the long-term and cumulative effects of sub-lethal exposures. The link between exposure of individuals and potential population level impacts are of increasing concern, particularly as intermittent industrial noise events and chronic ocean noise levels are expected to continue to increase. Moreover, it is not only difficult to determine the consequences of behavioural reactions to underwater noise, but the absence of a behavioural reaction as an indication of no or low impact may be misleading. For example, the increased noise from shipping activity can also raise the risk of vessel strikes for many whale species.

For these reasons, more attention should be focused on furthering the understanding and quantification of underwater noise from the marine transportation sector in Canada and its impacts on marine life in order to develop precise solutions and adapt mitigation measures in key areas.

PART 2
OVERVIEW OF INTERNATIONAL REGULATION AROUND ANTHROPOGENIC NOISE

2.1 INTRODUCTION

Underwater noise caused by humans is recognized as a form of pollution as defined by many international conventions that are addressing the larger topic of pollution,[27] such as the United Nations Convention on the Law of the Sea (UNCLOS), the Convention on the Protection of the Marine Environment of the North-East Atlantic (OSPAR), the Convention on the Protection of the Marine Environment of the Baltic Sea Area (HELCOM), and others (e.g. ACCOBAMS, 2013).

Many international bodies have responsibilities for the protection of the marine environment, including from the negative effects of anthropogenic noise. These responsibilities are established through international treaties, conventions and agreements, commissions, associations, as well as intergovernmental organizations and agencies. Most of them directly act for the conservation of cetaceans and deal with noise and other threats.

With most of the available information (including data) on bioacoustics impacts limited to short-term individual responses, the management of underwater noise is focused on specific events limited in space and time. This is one of the reasons why chronic noise from ships is much less represented within all existing regulations, and almost nonexistent in mitigation measures.

For a migratory animal, probabilities are high for experiencing multiple separate events along its migration route. Therefore, a more holistic approach is needed, but complicated by: the fact that noise can travel great distances in the ocean[28]; a lack of information on cumulative impacts; the impracticability of managing multiple events separated in space and time; and, the involvement of multiple jurisdictions.

While the full impact of ocean noise pollution is yet to be determined, there is international recognition that it poses a serious threat to marine life that must be addressed.

2.2 INTERNATIONAL REGULATION OF UNDERWATER NOISE

This section provides a brief summary of the management of anthropogenic underwater noise in an international context. Where relevant, existing mitigation measures and/or best management practices are presented following the information on regulations.

[27] Each convention states that pollution means "the introduction by man, directly or indirectly, of substances or energy" (ACCOBAMS, 2013)
[28] Low-frequency sound (< 100 Hz) can traverse entire ocean basins. Noise that originates in one country or jurisdiction often travels into neighbouring jurisdictions, making the need for its regulation an international affair (Erbe, 2013)

2.2.1 International Policy

a) IMO

As a specialized agency of the United Nations (UN), the **International Maritime Organization (IMO)** was established: to provide machinery for cooperation among Governments in the field of governmental regulation and practices relating to technical matters of all kinds affecting shipping engaged in international trade; and, to encourage and facilitate the general adoption of the highest practicable standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships (IMO website). Figure 17 shows IMO international representation. Its original mandate was principally concerned with maritime safety. However, soon after it began functioning, it assumed responsibility for pollution issues and subsequently has, over many years, adopted a wide range of measures to prevent and control pollution caused by ships and to mitigate the effects of any damage that may occur as a result of maritime operations and accidents. The work of the Marine Environment Division is primarily directed by the IMO's Marine Environment Protection Committee (MEPC).

While the IMO's broad definition of pollution from shipping vessels does not include underwater noise, work on the effects of noise on humans aboard ships commenced in the early 1980s with the adoption of Codes of Noise Levels on Board Ships. It was realized at the time that marine life could derive some benefits from these measures. The issue of underwater noise effects on marine life was initially taken into account through the Particularly Sensitive Sea Areas (PSSAs)[29] that the IMO can designate if such areas are considered vulnerable to international shipping. Through these areas, ships from IMO member states must follow measures that protect the environment. Within the context of PSSAs, the IMO recognizes that noise can be a pollutant and can adversely affect the marine environment (McCarthy, 2004).

Following an increasing body of literature that emerged on the issue starting in 2004, the MEPC commenced serious discussions on the harmful impacts of underwater noise on marine life from ships. In October 2008, the 58th session of the MEPC approved the inclusion of a new item in the agenda of MEPC 59 (July 2009) on Noise from Commercial Shipping and its Adverse Impacts on Marine Life. The basis for the new item was a proposal by the United States to develop non-mandatory technical guidelines to minimize incidental noise from commercial shipping operations in the marine environment, and to reduce potential adverse impacts on marine life[30].

In 2014, the IMO produced guidelines for commercial ships on ways to reduce underwater noise because of concerns about the short- and long-term negative impacts on marine life, especially marine mammals. Guidelines relate to features of ship design (such as hull and propeller shapes), on-board machinery, and various operational and maintenance recommendations (such as hull cleaning).

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[29] List of adopted PSSAs http://www.imo.org/en/OurWork/Environment/PSSAs/Pages/Default.aspx

[30] IMO website: http://www.imo.org/en/MediaCentre/PressBriefings/Pages/10-MEPC-66-ends.aspx#.WCDyTC3hDIU

IMO website, February 2016

Figure 17: IMO international representation[31]

b) IWC

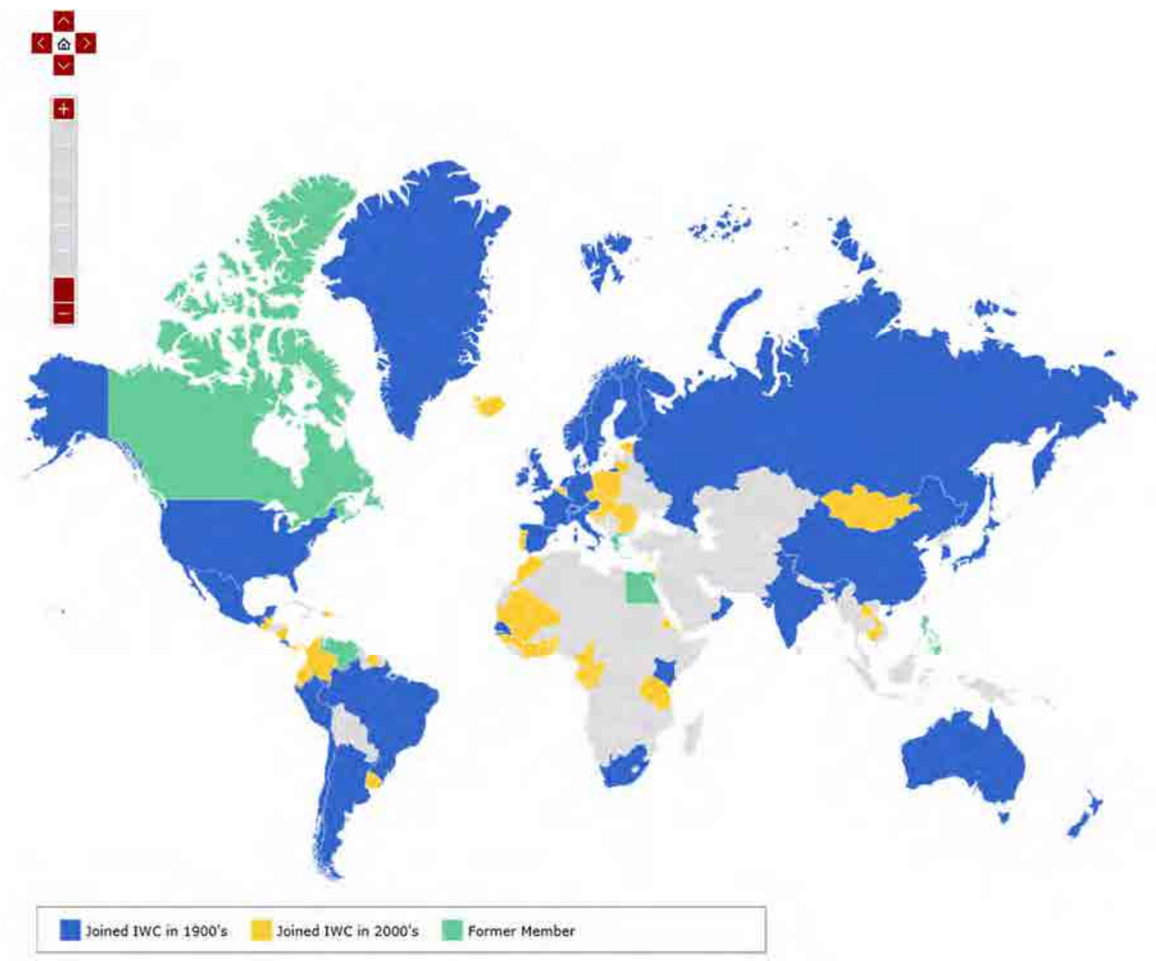
The **International Whaling Commission (IWC)** (International representation shown in Figure 18) has been concerned with the issue of anthropogenic noise in the ocean for many years. A mini-symposium was held in 2004 to consider the issue, and a 2006 meeting focused on the potential impacts of seismic surveys on various whale populations. In related efforts, several IWC Scientific Committee members contributed to the development of guidelines for mitigation and monitoring when conducting seismic surveys off Sakhalin Island in the Russian Federation, which is a primary feeding area for endangered Western grey whales.

The Scientific Committee's Environmental Concerns Group closely followed the efforts of the U.S. National Oceanic and Atmospheric Administration (NOAA) CetSound program to map cetacean soundscapes. In relation to this effort, the IWC co-sponsored a joint workshop in 2014 entitled

[31] The "Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972", the "London Convention" for short, is one of the first global conventions to protect the marine environment from human activities and has been in force since 1975. Its objective is to promote the effective control of all sources of marine pollution and to take all practicable steps to prevent pollution of the sea by dumping of wastes and other matter.
In 1996, the "London Protocol" was agreed to further modernize the Convention and, eventually, replace it. Under the Protocol, all dumping is prohibited, except for possibly acceptable wastes on the so-called "reverse list". The London Protocol entered into force on 24 March 2006.
http://www.imo.org/en/OurWork/Environment/LCLP/Pages/default.aspx

Predicting Soundfields – Global Soundscape Modelling to Inform Management of Cetaceans and Anthropogenic Noise. Twenty-six international experts from 11 countries gathered to discuss regional and ocean-basin scale underwater sound field mapping techniques. The goal was to provide support for decision-makers seeking to characterize, monitor and manage the potential impacts of chronic or cumulative anthropogenic noise on marine animals[32].

In 2016, the Environmental Concerns Group of the IWC Scientific Committee will focus on examining concerns related to the 'masking' effect of anthropogenic sound on cetaceans. Among other things, the working group will update progress made on the effects of masking sound from commercial shipping.



IWC's website, February 2016

Figure 18: International representation of IWC

[32] IWC website: https://iwc.int/anthropogenic-sound

c) UNCLOS

The **United Nations Convention on the Law of the Sea (UNCLOS)** provides a legal framework for the use of the world's oceans. Within UNCLOS, pollution of the marine environment is defined as:

> the introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities.
>
> United Nations, 1982

Under UNCLOS, states as shown in Figure 19 have the right to impose laws and regulations on any vessel within its territorial sea to limit marine pollution. Although noise was never intended to be included within this definition, noise could legitimately be considered energy within the above definition and, consequently underwater noise could be managed by states though UNCLOS (McCarthy, 2004; Scott 2004; Dotinga & Elferink, 2010).

Alexis Rudd, Consortium for Ocean Leadership, 2014

Figure 19: UNCLOS international representation

d) **ICES**

The **International Council for the Exploration of the Sea (ICES)** is a global organization that develops science and advice to support the sustainable use of the oceans. The 20 countries represented in Figure 20 that belong to ICES are Belgium, Canada, Denmark, Estonia, Finland, France, Germany, Iceland, Ireland, Latvia, Lithuania, the Netherlands, Norway, Poland, Portugal, Russia, Spain, Sweden, the United Kingdom, and the United States. ICES has a network of more than 4,000 scientists from almost 300 institutes, with 1,600 scientists participating in ICES-related activities annually. Through strategic partnerships, their work also extends into the Arctic, the Mediterranean Sea, the Black Sea, and to the North Pacific Ocean.

ICES is developing guidance on the impacts of underwater noise, either directly addressing the issue as it relates to each noise-producing activity, or including noise in the range of impacts caused by specific human activities in the marine environment, particularly wind farm development.[33]

Alexis Rudd, Consortium for Ocean Leadership, 2014

Figure 20: ICES international representation

e) IUCN

The IUCN (International Union for Conservation of Nature) is the world's oldest and largest global environmental organization with more than 1,200 government and non-governmental organization (NGO) members and almost 11,000 volunteer experts in some 160 countries. IUCN's work focuses on valuing and conserving nature, ensuring effective and equitable governance of its use, and deploying nature-based solutions to global challenges in climate, food and

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[33] Relevant works from ICES:
http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2014/WGMME/wgmme_2014.pdf
http://ec.europa.eu/environment/nature/conservation/species/whales_dolphins/docs/ices_second_report.pdf

development. IUCN supports scientific research, manages field projects all over the world, and brings governments, NGOs, the UN and companies together to develop policy, laws and best practice. IUCN has been stressing the serious impacts of underwater noise for many years now, recognizing it as a form of pollution and calling on governments to properly assess its impacts on marine biodiversity and to avoid further powerful underwater noise production.

2.2.2 Multi-national Policy

a) MSFD

The **Marine Strategy Framework Directive (MSFD)** was adopted by the European Parliament and the Council of the European Union in 2008 (2008/56/EC) with the overall objective of achieving or maintaining Good Environmental Status (GES) in European waters by 2020. The MSFD considers a multitude of anthropogenic "stressors" and their potentially cumulative effects. Eleven descriptors are used to measure the environmental status and the 11th refers to underwater noise. In order to achieve its goal, the directive establishes European marine regions[34] and sub-regions on the basis of geographical and environmental criteria. The directive requires member states to establish monitoring programs to enable the states of marine waters to be assessed and facilitate a program of measures designed to achieve GES as defined by 2015, and implemented by 2016. Cooperation among the member states of one marine region and with neighbouring countries that share the same marine waters, is already taking place through the Regional Sea Conventions.[35]

Within the MSFD, member states must ensure that any introduction of energy into the water, such as underwater noise, is at levels that do not adversely affect the marine environment. In 2010, the European Commission (EC) defined two indicators[36] for the UN:

- **Descriptor 11.1.1 for low- and mid-frequency impulsive sounds** (including noise from seismic surveying, pile driving, explosions, some sonar systems and some acoustic deterrent devices). Concerns about these intense noise sources relate to a range of impacts, including the risk of injury to -and displacement of- vulnerable species, such as marine mammals. They can also cause behavioural changes, stress, and displacement from preferred habitat.

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[34] The directive lists four European marine regions – the Baltic Sea, the North-East Atlantic Ocean, the Mediterranean Sea and the Black Sea – located within the geographical boundaries of the existing Regional Sea Conventions. For more information, please visit the MSFD website.
http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm

[35] The directive requires that, in developing their marine strategies, member states use existing regional cooperation structures to coordinate among themselves and to make every effort to coordinate their actions with those of other countries in the same region or sub region. For more information, please visit the MSFD website.
http://ec.europa.eu/environment/marine/international-cooperation/regional-sea-conventions/index_en.htm

[36] To develop indicators, a technical subgroup on noise was established in 2011. This group also provides guidance to member states for monitoring underwater sound. The goal was to measure cumulative pressure on the environment from all noise sources so that targets could be set and appropriate management action taken to achieve GES (IFAW 1/12/2013)

- **Descriptor 11.2.1 for continuous low-frequency sound** (designed mainly as a measure of shipping noise). Concerns about sounds at low frequencies relate primarily to long-term chronic effects, such as masking key sounds used for communication, finding prey or avoiding predators. It can also cause behavioural changes, stress and displacement from preferred habitat. This will require member states to establish noise monitoring programs coupled with modeling exercises to generate regional noise maps.

In order to accomplish these descriptors, the MSFD has developed indicators and the required key actions, as described in ANNEX 1.

2.2.3 Multi-national Agreements

Various regional agreements, mostly among northern European countries, are in place to manage anthropogenic impacts on the marine environment.

a) ACCOBAMS

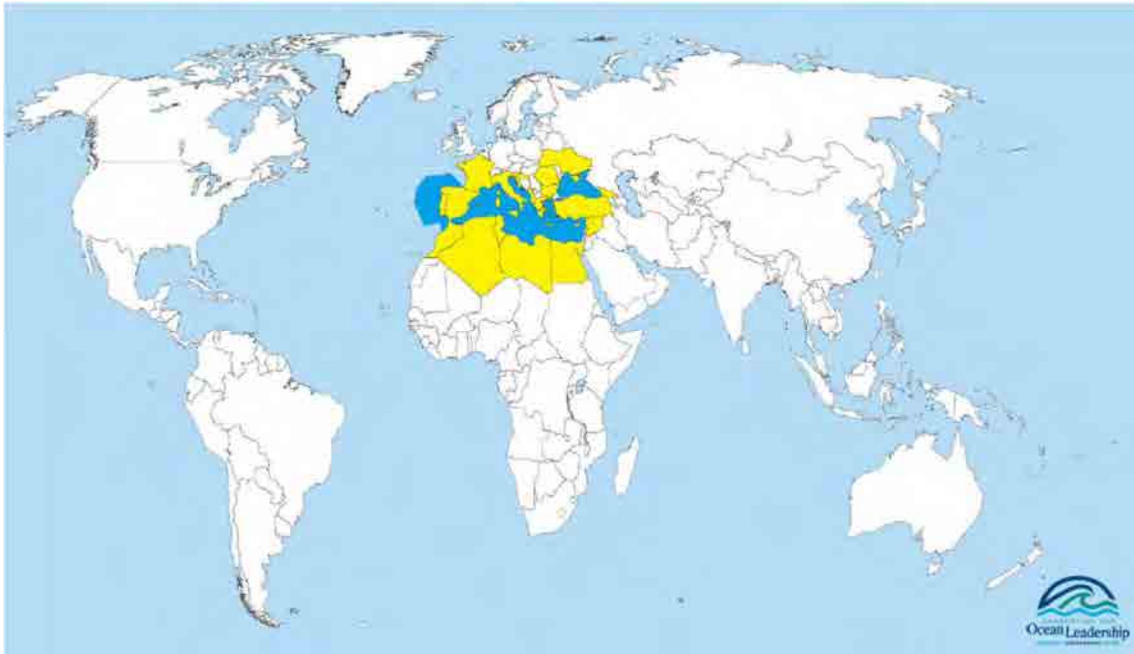
The Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS) is a cooperative tool for the conservation of marine biodiversity in the Mediterranean and Black seas. This intergovernmental agreement was signed by 23 countries of the 27 bordering these waters as represented in Figure 21. Its purpose is to reduce threats to cetaceans in Mediterranean and Black Sea waters. The work focuses on improving the knowledge of these animals and establishing guidelines to mitigate the impacts of human activities. Few explicit recommendations on shipping noise mitigation have been released, apart from reduction in vessel speeds, namely properly maintaining propellers, shifting the time of operations to when marine mammals are less present, and implementing noise-reduction mechanisms (Erbe, 2013).

The ACCOBAMS agreement has addressed the impact of underwater noise on cetaceans since 2004 through Resolution 2.16: Assessment and Impact Assessment of Man-made Noise. The Resolution 3.10 (adopted in 2007) and 4.17 (adopted in 2010) contain guidelines aimed at mitigating the impact of anthropogenic sound (ACCOBAMS, 2013).

ACCOBAMS publications:

Methodological Guide: Guidance on Underwater Noise Mitigation Measures
https://www.cbd.int/doc/meetings/mar/mcbem-2014-01/other/mcbem-2014-01-submission-accobams-01-en.pdf

Guidelines to Address the Impact of Anthropogenic Noise on Cetaceans in the ACCOBAMS Area
http://www.accobams.org/images/stories/Guidelines/guidelines%20to%20address%20the%20impact%20of%20anthropogenic%20noise%20on%20cetaceans%20in%20the%20accobams%20area.pdf



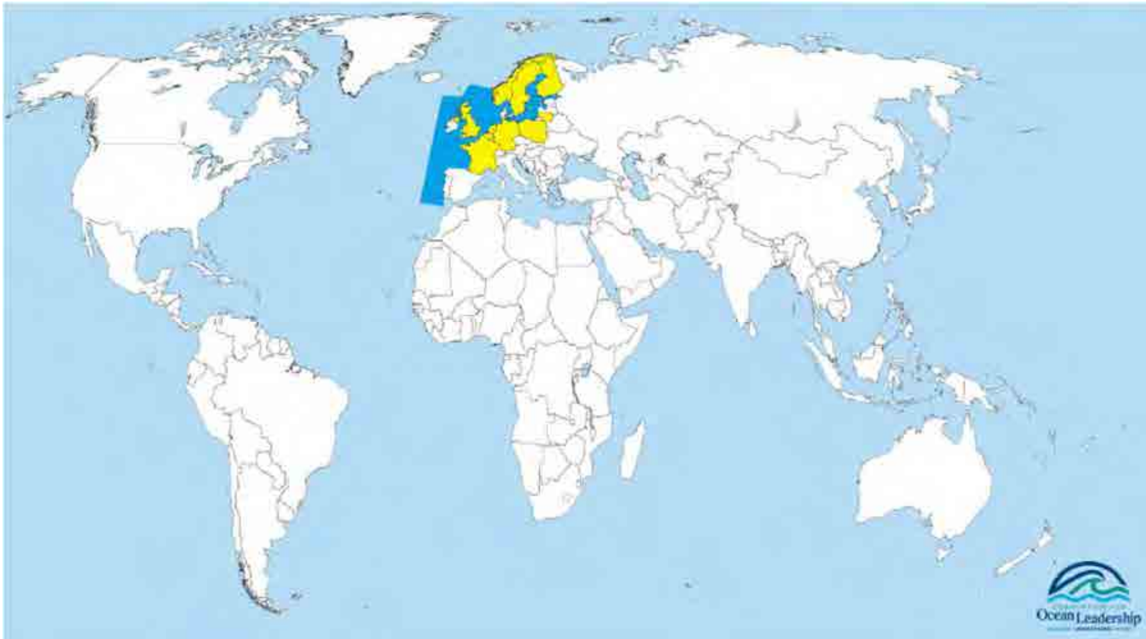
Alexis Rudd, Consortium for Ocean Leadership, 2014

Figure 21: ACCOBAMS representation

b) ASCOBANS

The Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS) was signed in 1992 and has currently 10 country members bordering these seas as represented in Figure 22. The agreement seeks to achieve and maintain a favourable conservation status for small cetaceans, with attention being focused upon issues such as bycatch, habitat deterioration and anthropogenic disturbance, including underwater noise. Several resolutions[37] have been passed which require that all parties address underwater noise. This includes mitigation measures regarding seismic surveying (i.e. reduce noise levels as much as possible, monitor marine mammal presence, establish exclusion areas) and pile driving (i.e. using alternative techniques, implementing technical measures for sound absorption and, alerting marine mammals to the onset of pile driving).

[37] http://www.ascobans.org/en/species/threats/underwater-noise



Alexis Rudd, Consortium for Ocean Leadership, 2014

Figure 22: ASCOBANS international representation

c) CBD

The **Convention on Biological Diversity (CBD)** entered into force on December 29, 1993. It has 3 main objectives: Conservation of biological diversity, sustainable use of the components of biological diversity and, the fair and equitable sharing of the benefits arising out of the utilization of genetic resources. There are 196 Parties (168 Signatures) composing CBD. The Conference of the Parties (COP) has established seven thematic programmes of work which correspond to some of the major biomes on the planet. One of them is Marine and Coastal Biodiversity[38]. Adopted in 1998, and reviewed and updated in 2004, the programme of work on marine and coastal biodiversity focuses on integrated marine and coastal area management, marine and coastal living resources, marine and coastal protected areas, mariculture, invasive alien species and, underwater noise. The CBD Secretariat produced a synthesis report in response to decision X/29 (paragraph 12) in which the COP to the Convention on Biological Diversity understood that regional progress has been made in analyzing the impacts of underwater noise on marine and coastal biodiversity, and recognized the role of CBD in supporting global cooperation. Several document related to this issue has been released since.

Report of the expert workshop on underwater noise and its impacts on marine and coastal biodiversity
https://www.cbd.int/doc/meetings/mar/mcbem-2014-01/official/mcbem-2014-01-02-en.pdf
Other related information
https://www.cbd.int/doc/?meeting=MCBEM-2014-01

[38] https://www.cbd.int/marine/

d) CMS

The **Convention on the Conservation of Migratory Species of Wild Animals** (CMS) is an environmental treaty under the aegis of the United Nations Environment Programme (UNEP). It provides a global platform for the conservation and sustainable use of migratory animals and their habitats. The negative effects of ocean noise were first recognized in 2002 when Resolution 7.5[39] on Wind Turbines and Migratory Species was passed. Subsequent conferences of parties reaffirmed anthropogenic ocean noise as an important threat for cetaceans and passed several resolutions calling for effective mitigation.

There are currently 121 parties to CMS. Both the 2008 Resolution 9.19[40] on Adverse Anthropogenic Marine/Ocean Noise Impacts on Cetaceans and other Biota, as well as the most recent specific decision on this subject, Resolution 10.24[41] on Further Steps to Abate Underwater Noise Pollution for the Protection of Cetaceans and Other Migratory Species, urge parties to carry out environmental assessments that take full account of the effects of activities on marine biota and their migration routes, apply Best Available Techniques[42] (BAT) and Best Environmental Practice (BEP), apply noise reduction techniques for offshore activities, and integrate the issue of anthropogenic noise into the management plans of marine protected areas (MPAs).
Since 2014, the joint noise working group of the cetacean-related ACCOBAMS and ASCOBANS is also responsible for providing expert advice to the CMS Scientific Council.

e) HELCOM

The **Helsinki Commission (HELCOM)** aims to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental co-operation involving Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia, Sweden, and the European Community. HELCOM was established in the 1980s to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental cooperation. HELCOM's eight main groups[43] implement policies and strategies and propose issues for discussion at the meetings of the heads of delegations, where decisions are made. HELCOM projects or ad hoc groups can be established to provide an adaptive and flexible system for dealing with specific issues from a more thematic perspective. One of the projects named CORESET (2010-2013) was to develop a set of core indicators to assess the effectiveness of the implementation of the Baltic Sea Action Plan and the above-mentioned MSFD. One indicator was related to underwater noise and its impacts on marine mammals. Mapping of anthropogenic sound sources and modelling of cumulative noise levels was part of the project. A new project, CORESET II, is operationalizing these indicators and developing additional indicators. Finally, the Baltic Marine Environment Protection Commission is currently considering a proposal[44] for a work plan on preparing a

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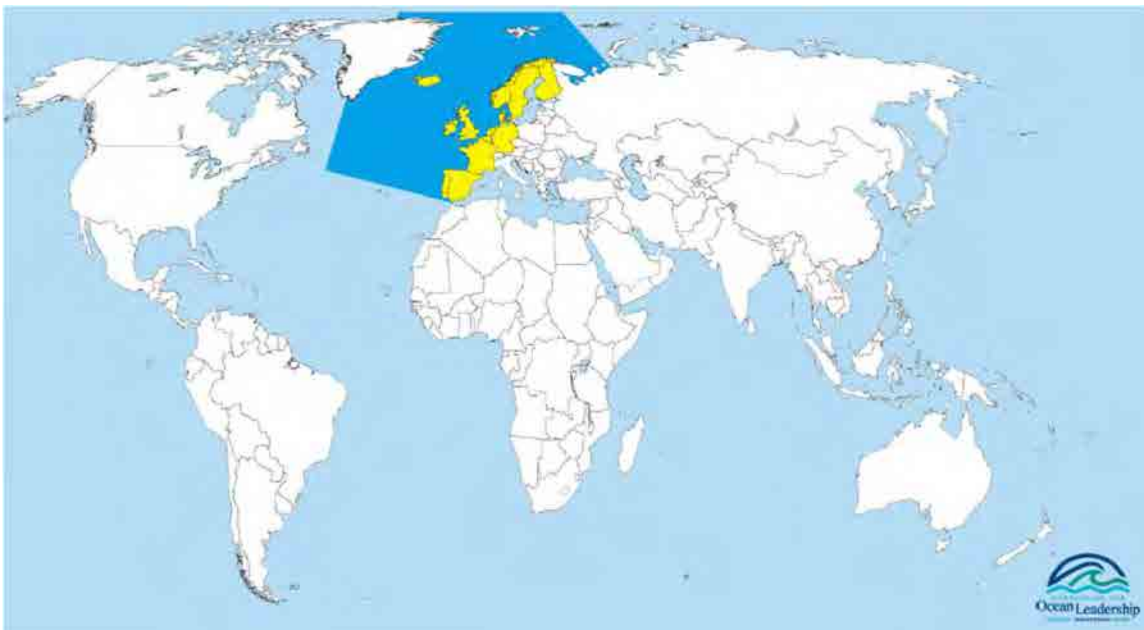
[39] http://www.cms.int/en/document/wind-turbines-and-migratory-species
[40] http://www.cms.int/en/document/adverse-anthropogenic-marineocean-noise-impacts-cetaceans-and-other-biota
[41] http://www.cms.int/en/document/further-steps-abate-underwater-noise-pollution-protection-cetaceans-and-other-migratory
[42] http://eippcb.jrc.ec.europa.eu/reference/
[43] These groups are: Implementation of the Ecosystem Approach, Maritime; Reduction of Pressures from the Baltic Sea Catchment Area (Response); State of the Environment and Nature Conservation, Sustainable Agricultural Practices; Ecosystem-based Sustainable Fisheries; and, HELCOM-VASAB Maritime Spatial Planning Working Group.
[44]https://portal.helcom.fi/meetings/PRESSURE%203-2015-278/MeetingDocuments/6-6%20Draft%20Regional%20Baltic%20Underwater%20Noise%20Roadmap%202015-2017.pdf

roadmap to building a knowledge base towards a regional action plan on underwater noise in 2017/2018.

f) OSPAR Convention

The **Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention)** was opened for signature at the ministerial meeting of the former Oslo and Paris Commissions in Paris on September 22, 1992. The Convention entered into force on March 25, 1998, although the earlier conventions on which it is based came into force in the 1970s. It has been signed and ratified by all of the contracting parties to the original Oslo or Paris Commissions (Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom), and by the European Community, as shown in Figure 23.



Alexis Rudd, Consortium for Ocean Leadership, 2014

Figure 23: OSPAR Convention

Within the OSPAR Convention, there are no regulations specifically addressing noise in the marine environment, although those contracting parties that are member states of the European Union will need to abide by EU regulation. The lack of regulations is attributed to the understanding of noise and its effects in the marine environment still being in its infancy with important gaps of knowledge regarding the effects of underwater noise on marine life existing. As a first stage, OSPAR has recently agreed upon common indicators regarding the status of both impulsive and ambient underwater noise, with monitoring to help assess the impact on the marine environment. OSPAR is also developing an inventory[45] of measures to mitigate the emission and environmental impact of underwater noise.

[45] The pile driving section is already available at: http://www.ospar.org/documents/dbase/publications/p00626/p00626_inventory_of_noise_mitigation.pdf.

2.3 NATIONAL LEVEL LEGISLATION

This section presents examples of underwater noise regulation in different countries with a more rigorous approach regarding specific events limited in space and time. In these countries, there are no particular mitigation measures that are currently implemented to address shipping noise and other marine traffic noise. Figure 24 illustrates a map of the countries where national legislation has been developed regarding underwater noise. It should be noted that this is not an exhaustive map, there might be other countries addressing this issue at a national level but these initiatives were not in the documents reviewed for this report.

Green Marine, 2015

Figure 24: Some countries with national legislation on underwater noise

2.3.1 Australia

In Australia, states and territories are responsible for managing the marine environment within three nautical miles (nm) from the coast. Under the Environment Protection and Biodiversity Conservation Act (EPBC) 1999, the onus is on the operator to decide whether or not a proposal is likely to have an impact on a matter of national environmental significance and needs to be referred to the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC) for assessment and a decision. Published by SEWPaC (2008), the EPBC Act Policy Statement 2.1 provides standards and a framework designed to minimize the risk of acoustic impacts on whales from marine seismic operations. Seismic surveys should be planned outside of whale calving, resting, breeding or feeding habitats and times. Visual observation of marine mammal is required, as well as passive acoustic monitoring, which is specifically recommended during low visibility.

Beyond the 3 nm, which means in Commonwealth waters, it is the Environment Regulation under the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) that is responsible for monitoring and enforcing compliance with the Offshore Petroleum and Greenhouse Gas Storage Act 2006 and (Environment) Regulations 2009. The Environment

Regulations require that petroleum activities in Commonwealth waters be carried out in a manner consistent with the principles of ecologically sustainable development and in accordance with an accepted Environment Plan (EP). Prior to operation, the operator must develop an EP for assessment and acceptance by NOPSEMA. Different from many other jurisdictions, NOPSEMA does not prescribe a specific approach to environmental risk reduction. Operators are encouraged to be flexible in their approach and employ innovative measures that are tailored to their specific circumstances. These regulations recognize that every situation is different so no single approach suits all situations; and, outlines what is reasonably practical in terms of change over time as technology, expertise, and the understanding of environmental impacts evolve.

The Australian Maritime Safety Authority Act 1990 specifies that the role of the Australian Maritime Safety Authority (AMSA) includes protection of the marine environment from pollution from ships and other environmental damage caused by shipping. Noise from commercial shipping is recognized among the current issues associated with AMSA's environmental activities.

2.3.2 Germany

Anthropogenic underwater noise is seen as one of the key pressures on the marine environment and marine life (OSPAR, 2009). The Federal Agency for Nature Conservation (BfN) is highly committed to minimizing underwater noise in the North and Baltic seas. As part of broad-based research conducted in the Exclusive Economic Zone (EEZ), a range of studies look at underwater noise in the North and Baltic seas. The aim of these studies is to develop verifiable standards for use in assessing the impact of underwater noise on marine life – especially harbour porpoises and grey seals, but also fish. To enhance available information on marine noise, underwater microphones were used to create a noise map for the Natura 2000 protected areas in the North and Baltic seas.

2.3.3 New Zealand

New Zealand's Exclusive Economic Zone (EEZ) and Continental Shelf (Environmental Effects) Act 2012 (EEZ Act) manages the environmental effects of activities within New Zealand's EEZ. The legislation aims to protect the ocean from the potential environmental risks of a range of activities such as underwater noise, petroleum exploration activities, seabed mining, marine energy generation and carbon capture developments. It also restricts the causing of vibrations (other than vibrations caused by the normal operation of a ship) that are likely to have an adverse effect on marine life.

Within the Coastal Marine Area (out to 12 nm), underwater noise from activities such as pile driving may also be regulated under the Resource Management Act (1991) or Regional Coastal Plans and managed by relevant regional councils.

Within New Zealand's EEZ, seismic surveying is considered to be a permitted activity (i.e. no marine consent is needed) under the EEZ Act's regulations, as long as the organization undertaking the survey complies with the 2013 Code of Conduct for Minimising Acoustic Disturbance to Marine Mammals from Seismic Survey Operations (the Code[46]).[47]

New Zealand is also taking into account the issue of anthropogenic underwater noise into the management plans of Marine Protected Areas (MPAs). Under normal circumstances marine seismic surveys would not be planned in any sensitive, ecologically important areas or during key biological periods when and where species of concern are likely to be breeding, calving, resting, feeding or migrating, or where risks are particularly evident, such as in confined waters (such as embayment or channels).

To assist with the effective consideration of such sensitivities during pre-survey planning, New Zealand's Department of Conservation (DOC) has developed a map[48] that highlights particular sensitivities for marine mammal species. This map is updated on a regular basis as new information becomes available. Where conducting surveys in Marine Mammal Sanctuaries (MMS) or Areas of Ecological Importance (AEI) is demonstrated to be necessary and unavoidable through the Marine Mammal Impact Assessment (MMIA) process, further measures (such as additional observers or observation platforms, aerial observation, acoustic source power restrictions, or designing the survey to avoid trapping marine mammals in confined areas such as narrow, constricted sea ways) may be required to minimize potential impacts.

2.3.4 United Kingdom

The Joint Nature Conservation Committee (JNCC) is the public body that advises the United Kingdom (UK) government and devolved administrations on UK-wide and international nature conservation. Its role is to provide evidence, information and advice so decisions can be made that protect natural resources and systems. JNCC itself is a forum that brings together the UK's four country conservation bodies. They advise government and a wide range of bodies to help harmonize policy.

The JNCC released a pile-driving protocol[49] in 2010 for minimizing the risk of injury to marine mammals and similar guidelines[50] for seismic surveying. A development promoter must determine what species are present in and around the area, along with when, and furthermore

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[46] http://www.doc.govt.nz/our-work/seismic-surveys-code-of-conduct/code-of-conduct-for-minimising-acoustic-disturbance-to-marine-mammals-from-seismic-survey-operations/

[47] In 2013, NZ's Department of Conservation (DOC) developed the *Code of Conduct for Minimizing Acoustic Disturbance to Marine Mammals from Seismic Survey Operations* (the Code) and its reference document to provide effective, practical mitigation measures for minimizing acoustic disturbance of marine mammals during seismic surveys. The Environmental Protection Authority (EPA) is responsible for monitoring seismic surveys within the EEZ to determine compliance with the Code. After three years of operation, the Code is currently undergoing a thorough review through a multi-stakeholder process. Building on 2006 guidelines, NZ's DOC released the Code in 2012 as part of efforts to manage impacts on marine mammals under the *Marine Mammals Protection Act* 1978 (MMPA). Although voluntary, the Code was brought into regulatory effect in 2013 within the EEZ via the EEZ Act.

[48] http://www.doc.govt.nz/our-work/seismic-surveys-code-of-conduct/areas-of-ecological-importance-and-marine-mammal-sanctuaries/

[49] Protocol - https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/50006/jncc-pprotocol.pdf

[50] Guidelines - https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/50005/jncc-seismic-guide.pdf

consider seasonal timing. The agencies recommend that all operations that include pile driving should consider producing an Environmental Management Plan (EMP), or an equivalent document that meets the requirements of the relevant regulator. Some types of noisy activities are likely to produce noise levels capable of being harmful to marine mammals.[51] Although incidental to consented activities, such effects have the potential to conflict with the legislative provisions of the Conservation of Habitats and Species Regulations 2010 (the Habitats Regulations, HR), which apply to English and Welsh waters inside 12 nm, and the Offshore Marine Conservation (Natural Habitats, &c.) Regulations 2007 (the Offshore Marine Regulations, OMR, as amended in 2009 and 2010) which apply on the UK continental shelf.

The JNCC has not produced specific mitigation measures regarding noise from vessels. However, the UK government is developing an ambient noise measurement program in the UK in accordance with the requirements of the Marine Strategy Framework Directive (Sonia Mendes, JNCC, personal communication, July 30, 2015). This will include a pilot study with data collection at selected locations and recommendations for the design of a monitoring program.

2.3.5 United States

In the United States, marine life and habitats are protected under the Marine Mammal Protection Act (MMPA), the Endangered Species Act (ESA), the National Marine Sanctuaries Act (NMSA), the National Environmental Policy Act (NEPA), the Magnuson-Stevens Fishery Conservation and Management Act (MSA) and/or the Coastal Zone Management Act (CZMA). Only the MMPA specifically protects marine mammals from anthropogenic noise. These acts are administered by the National Marine Fisheries Service (NMFS) and the National Ocean Service (NOS) (hereafter referred to collectively as the National Oceanic and Atmospheric Administration (NOAA[52])). Under the MMPA and the ESA, NOAA does not consider a Temporary Threshold Shift (TTS)[53] as an injury, and thus it does not qualify as Level A Harassment.[54] Nevertheless, the broad definition of “injury” under the NMSA regulations includes both Permanent Threshold Shift (PTS) and Temporary Threshold Shift (TTS),[55] as well as other adverse changes in physical or behavioural characteristics.

Section 7 of the ESA mandates that the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEM) and all other U.S. federal agencies consult with the Secretary of Commerce

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[51] The JNCC notes that other protected fauna, such as turtles, occur in waters where these guidelines may be used, and would suggest that while the appropriate mitigation may require further investigation, the protocols recommended for marine mammals would also be appropriate for marine turtles and basking sharks (JNCC, 2010).

[52] NOAA does not have jurisdiction over all marine mammals. The U.S. Fish and Wildlife Service has jurisdiction over manatees, walruses, otters and polar bears as outlined in:
http://www.fws.gov/alaska/fisheries/mmm/itr.htm
http://www.fws.gov/international/pdf/marine-mammals.pdf

[53] PTS: A Permanent Threshold Shift is a permanent shift in the auditory threshold, i.e. the threshold remains elevated after some extended period of time.

[54] Under the 1994 Amendments to the MMPA, harassment is defined as any act of pursuit, torment or annoyance that has the potential to injure (Level A Harassment) or to disturb (Level B Harassment) a marine mammal or stock in the wild. Level B Harassment includes the disruption of behavioral patterns, e.g. migration, breathing, nursing, breeding, feeding, or sheltering.

[55] TTS: a Temporary Threshold Shift is within the normal bounds of physiological variability and tolerance and does not represent physical injury (Ward 1997). Hearing threshold eventually returns to normal, and may, in some cases, result in nerve damage impairing hearing through other mechanisms.

(via NMFS) and/or Interior (via the U.S. Fish and Wildlife Service, USFWS) to ensure that any "agency action" is not likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of an endangered or threatened species' critical habitat. Also, NMFS has interim acoustic threshold levels associated with pile driving and protected fish species.

NOAA's regulations are currently undergoing a review process for its new guidance[56] (Draft Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammals) for assessing the effect of anthropogenic sound on marine mammal hearing[57]. The guidance provides acoustic threshold levels for onset of Permanent Threshold Shift (PTS) and Temporary Threshold Shifts (TTS) for all sound sources. It is intended to be used by NOAA analysts/managers and other relevant user groups/stakeholders, including other federal agencies to better predict a marine mammal's response to sound exposure. The manner of response has the potential to trigger certain requirements under one or more of NOAA's statutes[58] (MMPA, ESA and NMSA).

To address ocean noise impact and to develop adequate management actions, NOAA is in the process of developing a more comprehensive Ocean Noise Strategy.[59] The successful implementation of this strategy would aim to:

- reduce acute, chronic and cumulative effects of noise;
- fill critical gaps and best inform management decisions;
- develop publicly available tools to support assessment planning, and mitigation for noise-making activities across large spatial and temporal scale;
- promote public understanding of noise impacts in the U.S. and abroad.

Finally, the U.S. Navy has agreed in 2015 to forego entirely or limit significantly its planned explosives testing and mid-range sonar training in designated areas of special importance to the survival of majestic blue whales, deep-diving beaked whales, critically endangered false killer whales, and other marine mammals needlessly put at risk by U.S. Navy training. This agreement reflects real progress, with a solid commitment by the U.S. Navy to the most meaningful protective measures that the Natural Resources Defense Council (NRDC) and others, supported by the marine science community, have long sought.

[56] Prior to this guidance, NOAA primarily relied on two generic threshold levels for assessing auditory impacts (i.e., Permanent Threshold Shift (PTS) onset) for most underwater sound sources: one for cetaceans (180 dB_{rms}), and one for pinnipeds (190 dB_{rms}). These generic thresholds were developed in the late 1990s using the best information available at the time. Other sound sources, such as tactical naval sonar and underwater explosives, have relied on more recently developed acoustic threshold levels. Since the adoption of these original thresholds, the understanding of the effects of noise on marine mammal hearing has greatly advanced making it necessary to re-examine the current state of science and acoustic threshold levels.

[57] The guidance only updates marine mammal acoustic thresholds for PTS/TTS. There are other thresholds for behavioral harassment that are not covered in this guidance and will be updated with future guidance. http://www.nmfs.noaa.gov/pr/acoustics/draft%20acoustic%20guidance%20July%202015.pdf

[58] This covers activities such as construction, but does not regulate the noise produced from commercial shipping directly. For that, NOAA has worked with the IMO.

[59] http://cetsound.noaa.gov/ons

2.3.6 Other countries

Domestic legislation in several other countries has been developed for seismic surveying. These countries include Canada,[60] Spain[61] and Brazil,[62] as well as others in the Asia/Pacific Rim.[63] Policies and regulatory frameworks concerning marine mammals and sound are either nonexistent or in early developmental stages in most African countries (Marine Mammal and Noise, 2007).

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[60] The *Statement of Canadian Practice with respect to the Mitigation of Seismic Sound in the Marine Environment* provides minimum mitigation requirements for seismic surveys, and pile-driving standards are implemented regionally, often based on outdated criteria. (http://www.dfo-mpo.gc.ca/oceans/management-gestion/integratedmanagement-gestionintegree/seismic-sismique/statement-enonce-eng.asp). For an overview of ocean noise regulations in Canada: http://awsassets.wwf.ca/downloads/nowlan_wwf_canada_ocean_noise_regulation_backgrounder_for_workshop_june_2013.pdf

[61] http://www.lab.upc.edu/papers/BestPracticesNoiseLAB.pdf

[62] Policies and regulatory frameworks concerning marine mammals and sound are either in early developmental stages or have yet to be addressed in most Latin American countries (broadly defined as those in South and Central America, the Caribbean, and Mexico).

[63] These include China (and Hong Kong), Taiwan, the Philippines, Vietnam, Laos, Cambodia, Thailand, Malaysia, Singapore, Brunei, Indonesia, and East Timor. Although most of these nations confer full legal protection to marine mammals, the implementation and enforcement of existing laws are generally lacking, and little effort has been made to assess or manage the potential impacts of human-generated underwater sound in the region.

2.4 Conclusion

For most jurisdictions, noise mitigation relates to pulsed and high-energy noise introduced into the marine environment. The use of a 'safety zone,' which requires powering down or shutting off a powerful sound source if marine mammals are detected within a short distance, is usually the common denominator. Most of management energy is spent on designing protocols for safety zone maintenance and ramp-up, with few considerations given to the fact that the impact radius around powerful sources of noise vastly exceeds the narrow band of water space that safety zones and ramp-ups are designed to protect.

For continuous low-frequency noise, it is currently difficult to provide a quantified evaluation of the effectiveness and adequacy of the measures taken and/or planned for the protection of marine life against potential adverse effects. Because injuries to marine species from shipping noise are generally indirect and primarily focused on disturbance, sound masking and increased stress hormones, the identification of the acoustic threshold represents a real challenge.

Mitigation measures around shipping noise will require a multi-sectoral approach to management, implementing the use of best available methods and technologies for noise reduction and minimizing the risk of duplicating efforts.

It is essential to recognize that some key players operating in Canadian waters (domestic and international ship owners, ports, and terminals) are already involved or have demonstrated a strong interest in projects aiming to gain a better understanding of how commercial vessels are contributing to increasing underwater noise levels. Despite the lack of information available for these stakeholders, many of them are aware of the adverse effects of shipping noise on marine life. To this end, they hope that the agencies concerned by the underwater noise issue will focus efforts to increase knowledge to be able to act in full understanding of the situation.

PART 3
HOW NOISE IS ADDRESSED THROUGH WORKSHOPS AND RESEARCH PROJECTS

3.1 INTRODUCTION

The increasing worldwide concern about the effects of anthropogenic underwater noise on the health of ocean animals has spurred many workshops, conferences and events around the globe. Scientists, policymakers and other stakeholders are attempting to advance overall understanding by sharing the latest research, developing new collaborations and/or expertise, and demonstrating a stewardship for other countries to follow. The sheer number of events that have taken place over the past decade makes it difficult to cite them all, but these are some of the gatherings and/or resulting documents brought to the author's attention.

3.2 INTERNATIONAL NOISE WORKSHOPS

2004

FEBRUARY
The NOAA Workshop on Anthropogenic Sound and Marine Mammals
This workshop was organized to provide background information required by NOAA for developing a research program that will address issues of anthropogenic sound in the world's oceans. Experts from the U.S. Navy, academic research institutions, industry, and within NOAA were gathered at the NOAA Fisheries, Southwest Fisheries Science Center, La Jolla, CA on February 19-20, 2004, to review ongoing and planned acoustic research on anthropogenic sound, both within and outside NOAA.
Final report: http://www.pifsc.noaa.gov/tech/NOAA_Tech_Memo_361.pdf

2005

OCTOBER
The Effects of Anthropogenic Sound on Marine Mammals: A Draft Research Strategy
This report is based on the activities and proceedings of an expert group on anthropogenic sound and marine mammals convened at the joint Marine Board-ESF and National Science Foundation (U.S.) Workshop at Tubney House on October 4-8, 2005, in Oxford, with the logistical and financial support of the Marine Board-ESF.
Final report: http://www.esf.org/fileadmin/Public_documents/Publications/MBpp13.pdf

2007

MARCH
Marine Mammals and Noise: A Sound Approach to Research and Management
Final report: http://www.mmc.gov/reports/workshop/pdf/fullsoundreport.pdf

AUGUST

First International Conference on the Effects of Noise on Aquatic Life

This conference gathered more than 250 scientists, regulators and industry representatives from more than 40 countries for discussions regarding how to address the potential impacts of underwater noise. The conference proceedings were subsequently published in a special issue of *Bioacoustics*[64].

2008

APRIL

International Workshop on Shipping Noise and Marine Mammals, Germany

Final report: http://www.okeanos-foundation.org/assets/Uploads/Hamburg-shipping-report-2.pdf

2009

AUGUST

Workshop on Assessing the Cumulative Impacts of Underwater Noise with Other Anthropogenic Stressors on Marine Mammals: From Ideas to Action

California, U.S.

Final report: http://www.okeanos-foundation.org/assets/Uploads/CIReportFinal3.pdf

2010

JULY

Marine Mammals and Sound Workshop, Washington, D.C.,

In support of increased stakeholder participation and in following the recommendations of its own 2009 report on this issue, the U.S. Committee on Ocean Policy Joint Subcommittee on Ocean Science and Technology (JSOST) sponsored a July 13-14, 2010, interactive workshop with governmental and non-governmental stakeholders to solicit input on key issues related to (i) marine mammals and anthropogenic noise effects analysis and (ii) monitoring and mitigation measures development.

Final report: http://www.nmfs.noaa.gov/pr/pdfs/acoustics/mm_sound_workshop_report.pdf

AUGUST

Second International Conference on the Effects of Noise on Aquatic Life

The main focus of the conference was to define the current state of knowledge. However, delegates also assessed progress in the three years since the first conference. The second conference placed strong emphasis on presenting recent research results, sharing ideas, discussing experimental approaches, and analysing of regulatory issues.

More info: http://noiseeffects.umd.edu/index.htm

OCTOBER

ASCOBANS Intersessional Working Group on the Assessment of Acoustic Disturbance, Germany

Final report: http://www.ascobans.org/sites/default/files/document/AC17_4-08_ReportWGAcousticDisturbance_1.pdf

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[64] Bioacoustics, 2008, volume 17:1-350

NOVEMBER

Effects of Stress on Marine Mammals Exposed to Sound

The Office of Naval Research sponsored a workshop entitled, *Effects of Stress on Marine Mammals Exposed to Sound* that was held in Arlington, Va., November 4-5, 2009. The workshop brought together 20 researchers, veterinarians and the federal permitting agency personnel to discuss the current state of research on noise-related stress in marine mammals. The purpose of this workshop was to assemble a cross-section of researchers in the field of stress physiology and behavioural research to identify the state-of-the-art science in stress physiology as it may apply to marine mammals, identify research needs for marine mammal stress-related research, and evaluate available or developing technologies for measuring indicators of stress, ultimately in free-ranging marine mammals.

Final report: http://www.onr.navy.mil/Science-Technology/Departments/Code-32/All-Programs/Atmosphere-Research-322/~/media/Files/32/ONR_StressWorkshop_FINAL.ashx

2012

JANUARY

World Wildlife Fund Canada (WWF-Canada) hosted a workshop on ocean noise in Canada's Pacific Ocean on January 31 and February 1, 2012, with the goal of better understanding ocean noise pollution and how it is managed. Participants included experts from the U.S., Australia and the U.K.

Final report: http://awsassets.wwf.ca/downloads/wwf_ocean_noise_workshop_report_final.pdf

2013

FEBRUARY

Underwater Noise Workshop

HR Wallingford and Baker Consultants hosted a workshop to discuss the issue of underwater noise pollution related to marine renewables at the 10th Renewable UK Wave and Tidal Conference. The workshop's aim was to facilitate knowledge exchange among the industry, regulators and academics. A summary of the workshop is given below.

Information: http://www.hrwallingford.com/projects/predicting-the-impact-of-underwater-noise-on-marine-life?A=SearchResult&SearchID=879456&ObjectID=3954495&ObjectType=35

AUGUST

Third International Conference on the Effects of Noise on Aquatic Life

The meeting of Aquatic Noise 2013 introduced participants to the most recent research data, regulatory issues and thinking about the effects of manmade noise as well fostering critical cross-disciplinary discussion among the participants. The emphasis was on the cross-fertilization of ideas and findings across species and noise sources. As with its predecessor, The *Effects of Noise on Aquatic Life: 3rd International Conference* encouraged discussion of underwater sound's impacts, regulation, and the mitigation of its effects. With more than 100 contributions from leading researchers, a wide range of underwater sound sources were considered.

2014

FEBRUARY

Expert Workshop on Underwater Noise and its Impact on Marine and Coastal Biodiversity

At its eleventh meeting, the Conference of the Parties to the Convention on Biological Diversity, in its decision XI/18 A, requested the Executive Secretary to collaborate with Parties, other Governments, and competent organizations, including the International Maritime Organization (IMO), the Convention on Migratory Species (CMS), the International Whaling Commission, indigenous and local communities and other relevant stakeholders, to organize an expert workshop with a view to improving and sharing knowledge on underwater noise and its impacts on marine and coastal biodiversity, and towards developing practical guidance and toolkits to minimize and mitigate the significant adverse impacts of anthropogenic underwater noise on marine and coastal biodiversity, including marine mammals.

Final report:

https://www.cbd.int/doc/meetings/mar/mcbem-2014-01/official/mcbem-2014-01-02-en.pdf

APRIL

Predicting Sound Fields - Global Soundscape Modeling to Inform Management of Cetaceans and Anthropogenic Noise

A two-day workshop was sponsored by the International Whaling Commission (IWC), the International Quiet Ocean Experiment (IQOE), the U.S. National Oceanic and Atmospheric Administration (NOAA), the Office of Naval Research Global, and the Netherlands Organization for Applied Scientific Research (TNO) and the Netherlands Ministry of Infrastructure and the Environment. Twenty-six international experts came together from eleven countries to discuss regional and ocean-basin scale underwater sound field mapping techniques to provide support for decision-makers seeking to characterize, monitor and manage the potential impacts of chronic or cumulative anthropogenic noise on marine animals.

Final report:

https://www.st.nmfs.noaa.gov/Assets/turtle/documents/Predicting%20Sound%20Fields%20Report_Final.pdf

JULY

Ocean Leadership hosted a meeting with industry leaders, naval engineers, and marine scientists to build on the International Maritime Organization (IMO) Guidelines on Ocean Noise and to discuss the issue of underwater noise from ships and formulate a plan for the next steps to move forward on this issue. Information: http://oceanleadership.org/ocean-leadership-hosts-underwater-sound-workshop/

SEPTEMBER

Workshop: Effects of Noise Pollution on Marine Life and Birds

Information: http://www.sfaep.org/event/workshop-effects-noise-pollution-marine-life-birds/

2015

MARCH
WODA Workshop, Paris, France
Underwater Sound in Relation to Dredging: Translating science into first-hand guidance
Information: http://www.cedaconferences.org/UWS

MAY
Ocean Noise 2015
The increasing scientific and societal concern about the effects of underwater sound on marine ecosystems has recently been recognized through the introduction of several international initiatives aimed at measuring the environmental impact of ocean noise at large spatial and temporal scales. Ocean Noise 2015 brought together leading international experts in noise measurement, modeling and mapping, physiological and behavioural effects, as well as regulation and mitigation procedures.
Information: http://oceanoise2015.com/

2016

FEBRUARY
MEOPAR Workshop
Ships and Whales - Using AIS and acoustics to evaluate exposure and risk
MEOPAR proposes to host a two-day workshop focused on ship and whale monitoring (detection and identification) using AIS and acoustics, as well as discuss associated vessel strike and sound-field risks to whales (primarily baleen whales) and modeling thereof.

JULY
Fourth International Conference on the Effects of Noise on Aquatic Life
The *Fourth International Conference on The Effects of Noise on Aquatic Life* will take place in Dublin, Ireland, July 10-16, 2016. This meeting follows the very successful meetings held in Nyborg, Denmark (2007), Cork, Ireland (2010) and Budapest, Hungary (2013). These meetings have brought together scientists, regulators, environmentalists, and people from industry to learn about and discuss issues related to the effects of manmade noise on aquatic organisms.
Information: http://www.an2016.org/
Recap of the first meeting in Nyborg: http://link.springer.com/book/10.1007%2F978-1-4419-7311-5#section=1024310&page=1
Another book, as a result of the Budapest meeting in 2013, will be published by Springer in early 2016: http://www.springer.com/us/book/9781493929801

3.3 NOISE RESEARCH IN CANADA

Many research projects on underwater noise are ongoing throughout Canada. These are essentials towards achieving the goal to have a thorough understanding of how significantly shipping noise is interfering with marine life. It is difficult to be aware of everything occurring, especially since a number of researchers are hesitant to reveal detailed information about their work prior to its publication in a scientific journal. However, this section presents some of the initiatives by individuals who agreed to share their information.

3.3.1 Fisheries and Oceans Canada

Fisheries and Oceans Canada (DFO) has the lead federal role in managing Canada's fisheries and safeguarding its waters. Under the *Species at Risk Act* (SARA), DFO must produce recovery strategies and action plans for aquatic species listed as endangered or threatened. These recovery strategies and action plans will detail the specific steps that need to be taken to protect identified species. Also, it has been recognized for years that to prevent wildlife species from becoming extinct, their habitat must be protected. SARA presents new requirements for identifying critical habitat—and new measures for protecting it. Many whale populations are protected under SARA, and habitat degradation through acoustic disturbance from underwater noise is listed among the threat. Table 8 presents rough description of few DFO projects.

Table 8: DFO's current initiatives related to underwater noise

#	Title	Project's description	Contact person
1.	Passive Acoustic Monitoring of Species at Risk on Canada's West Coast	Many portions of Canada's west coast are remote and hard to access, which has resulted in gaps in our understanding of the occurrence and seasonality of SARA-listed cetacean species known to occur here. This project, ongoing since 2006, has been collecting data from a number of inshore and offshore areas throughout Canada's west coast waters using a variety of autonomous recorders in order to fill these gaps. These acoustic data are used in the identification of important areas and seasons for SARA-listed cetaceans, including the Resident, Transient (Bigg's) and Offshore Killer whale, Blue Whale, Fin Whale, Humpback Whale, North Pacific Right Whale, and Sei whale. Over the years, this project has fostered collaborations with Parks Canada (Gwaii Haanas NMCAR), the Marine National Wildlife Areas program (proposed Scott Islands MNWA), the Marine Protected Areas program (Bowie Seamount MPA) and the Marine Environmental Observation Prediction and Response network (MEOPAR).	Dr. John K. Ford <email address removed> James Pilkington <email address removed>

#	Title	Project's description	Contact person
2.	Blue whale exposure to anthropogenic noise in the St. Lawrence Gulf and Estuary	Development and implementation of a new probabilistic model to shipping noise exposure based on AIS, called *PSSEL*, and validated by a network of acoustic observatory. Determination and uses of ANSI acoustic signature from vessels currently transiting in the St Lawrence waterway. Production of an atlas of probability of exposure to critical threshold of shipping noise, according to actual and future vessel traffic.	Dr. Yvan Simard <email address removed>
3.	Impacts of commercial navigation in the Arctic	Impacts of commercial navigation in the Arctic on underwater noise environment for the marine mammals ecosystems and Probability of exposure to navigation noise along Northern maritime corridors Estimate ambient noise's annual cycle and map the exposure probability to navigation noise along sections of the Northern maritime corridors crossing sensitives ESBA, as proposed by the MPO-GC, taking advantage of new probabilistic models of navigation noise exposure and measured levels of noise sources.	Dr. Yvan Simard <email address removed>
4.	Record and monitoring of marine mammals and their underwater noise environment along the Nunavik shoreline in the Hudson Strait	Record and monitoring of marine mammals and their underwater noise environment along the Nunavik shoreline in the Hudson Strait during the full annual cycles and Noise levels and marine mammals in the Hudson Strait maritime corridor These projects aim at establishing : a) current, all-year long, underwater noise levels and characteristics, b) adapt the new probabilistic model of navigation noise exposure to the Hudson Strait based on traffic observations (*PSSEL*) to identify the zones and periods where and when the noise levels can exceed the critical threshold for marine mammals, for various scenarios of maritime traffic; c-e) multi-year monitoring, climate change and ecology of marine mammals visitation of the Strait.	Dr. Yvan Simard <email address removed>
5	Probabilistic Atlas of shipping noise and SEL	This newly funded 3-year project (CFI-MERIDIAN) aims at producing a year-round open series of 3D probabilistic high-resolution maps of shipping noise probability by third-octave frequency bands for the wideband where this noise source	Dr. Yvan Simard <email address removed>

#	Title	Project's description	Contact person
		dominates. Probability of exposure to different noise levels (pdfSEL), which provides the temporal structure of the exposition for a given period, is one of the possible useful outcomes of this numerical Atlas to feed marine spatial planning (MSP) needs. This groudtruthed acoustic modeling, fed with AIS shipping data and a ship SL model developed from ANSI measurements of the present merchant fleet navigating on the St. Lawrence, stems from the series of developed tools and methods applied to blue whales in the study area.	
6.	Acoustics efforts in shelf waters of southern Labrador, the edge of the Grand Banks south of Flemish Pass, and at four locations along the northern edge of the Laurentian Channel	Since 2009, Dr. Jack Lawson has been deploying autonomous acoustic receivers (AURALs) at various location in shelf waters of southern Labrador, the edge of the Grand Banks south of Flemish Pass, and at four locations along the northern edge of the Laurentian Channel. These deployments have been used to develop an acoustic energy "budget" for these areas that include abiotic, biological, and anthropogenic components (such as seismic and shipping). Efforts are shared with colleagues in the Gulf and on the Scotian Shelf, to describe whale presence and distribution, but also describe anthropogenic activities such as shipping and seismic. Efforts are also shared with colleagues in the northeastern U.S. as well ("Large Scale Western Atlantic Wide Scale Analysis of Existing Passive Acoustic data For Baleen Whales"). The intent is to describe whale presence and migration patterns, but will also describe anthropogenic activities such as shipping and seismic.	Dr. Jack Lawson <email address removed>
7.	Passive acoustic monitoring of cetaceans and ocean noise in the Gully Marine Protected Area (MPA) and adjacent areas of the Scotian Slope	As human presence and activities increase in offshore Nova Scotia, there is a greater need to collect data on the acoustic environment and when, where and how marine mammals are using these areas in order to understand and mitigate potential impacts of anthropogenic activities on marine mammals and important habitats. The Gully Marine Protected Area (MPA) is an area off	Dr. Hilary Moors-Murphy <email address removed>

#	Title	Project's description	Contact person
		Nova Scotia known for an abundance and diversity of marine mammals; however, seasonal occurrence in the area and relative importance of the MPA as compared to the adjacent slope remains unknown for most species. The project's main objective was to enhance passive acoustic monitoring (PAM) efforts within the Gully MPA and adjacent areas of the Scotian Slope to investigate the year-round presence of marine mammals and characterize natural and anthropogenic sources of noise in the area. A two-year near continuous acoustic dataset was collected from three locations in and near the Gully MPA with bottom-mounted Autonomous Multichannel Acoustic Recorders (AMARs, © JASCO Applied Sciences) between October 2012 and September 2014. Recordings were duty-cycled between 13 minutes at a sampling rate of 16 kHz and two minutes at either a 250 or 375 kHz sampling rate. Analysis of baleen and toothed whale vocalizations and ambient and anthropogenic noise sources is underway. Anticipated project completion is in 2016.	
8.	Passive acoustic monitoring of Marine Protected Areas and Species at Risk	There remain many gaps in our understanding of when and where whales occur on the Scotian Shelf throughout the year. This project aims to continue passive acoustic monitoring efforts within the Gully Marine Protected Area and expand efforts to other areas of interest, including Emerald Basin, St. Ann's Bank and the Stone Fence. Data will be collected using five Autonomous Multichannel Acoustic Recorders (AMARs, © JASCO Applied Sciences) deployed almost continuously over at least two years (from Summer 2015 to Fall 2017). Data collected during this project will also contribute to other collaborative projects, including the "Whales, Habitat and Listening Experiment" (WHaLE) led by Dalhousie University and the "Acoustic Modeling and Monitoring on Canada's East Coast" project being led by JASCO Applied Sciences.	Dr. Hilary Moors-Murphy <email address removed>

#	Title	Project's description	Contact person
9.	Effects of seismic exploration on catchability of snow crab, better understand of marine soundscape and effect of seismic on commercial fish (cod)	The is a collaborative 4-year scientific field study investigating effects of seismic exploration activity on the commercial catchability of snow crab, funded by the Environmental Studies Research Fund (ESRF). The study is located offshore on the eastern margin of Newfoundland's Grand Bank along the continental slope; a commercial crab fishing area and area of petroleum exploration. The oil and gas industry, fishing industry, government, and academia are working together to conduct studies on movement, catchability, sound, physiology and genomics. This research will help to inform industry and managers about the potential effects of seismic exploration on snow crab catchability.	Dr. Corey Morris <email address removed>
10.	Noise Action Plan for the Beluga whale, St. Lawrence Population	There is an upcoming initiative by the Species at Risk department within the DFO Québec region that will focus on ways to reduce the impact of shipping noise on the Beluga whale population in the St. Lawrence River.	M. Hugues Bouchard, DFO <email address removed>

3.3.2 The Royal Canadian Navy

The Royal Canadian Navy is committed to protecting the environment through its *Defence Administrative Order 4003-0, Environmental Protection and Stewardship*, which states that individuals must know and obey federal environmental laws and regulations, and exercise due diligence. Commanding officers, commanders and other senior authorities must ensure that Canadian Armed Forces members under their command are appropriately educated in environmental matters related to their duties, and allocated appropriate resources to properly handle their environmental responsibilities. Every other current act or regulation to protect marine ecosystems must also be respected. Responsibility for ensuring these regulations are met is applied from the platform sonar operator up to the Wing Commander, with harsh financial penalties and potential imprisonment as "regulatory enforcement actions." Table 9 presents rough description of a few projects of the Royal Canadian Navy.

Table 9: The Royal Canadian Navy's current initiatives related to underwater noise

#	Title	Project's description	Contact person
11	Ocean Observing System Tracking	The Royal Canadian Navy has an interest in tracking where and what type of acoustic and seismic sensors are being deployed, both regionally within Canada, as well as globally. We currently have a database of locations spanning ~3000 different sensors around the world, as well as information related to the owner, type of sensor and parametric information such as frequency response. Our partner on this project is the U.S. Navy's Naval Oceanography office.	Capt Dugald Thomson <email address removed>
12	Strait of Georgia Propagation Modeling and Measurement	A range-dependent modeling study was initiated to determine propagation loss in the 10 Hz – 10 kHz band for a particular site over ranges of approximately 50 km, for a receiver located near Vancouver harbor at the VENUS instrument deployments. The modeling considered sound speed profiles spanning an entire year. Physical measurements were collected and analyzed to verify the performance of the model, and found to be in good agreement.	Capt Dugald Thomson <email address removed>
13	Halifax Harbour Acoustic Range	A dynamic acoustic range consisting of two calibrated hydrophones located at the entrance to Halifax Harbour is used to assess the acoustic signature of naval vessels during complete (detailed, multi-day) range events as well as quick-look (window of opportunity, single sail-past) rangings. Source levels for 1/3-octaves are estimated using the calibrated instruments and a high-precision transmission loss calculation.	Capt Dugald Thomson <email address removed>

3.3.3 MEOPAR

The Marine Environmental Observation Prediction and Response Network (MEOPAR) is a national team of outstanding Canadian scientists meeting the challenges of changing ocean. They are working to better understand and predict the impact of marine hazards on human activities and ecosystems, and improve response when hazards occur. They work with federal and provincial partners, as well as industrial and other partners in Canada and beyond. They collaborate on large, multi-investigator, multi-disciplinary research projects and core observation and prediction research activities. Established in 2012 and hosted at Dalhousie University, MEOPAR is funded by the Networks of Centres of Excellence of Canada program. Table 10 presents rough description of a few MEOPAR projects.

Table 10: MEOPAR's current initiatives related to underwater noise

#	Title	Project's description	Contact person
14	Modeling Ship Movements: Application for Noise Exposure to the Marine Ecosystem	The exposure of animals to ship-based noise is expected to increase as marine vessel activity increases, due to longer ice-free passages in the Arctic, and planned port expansions and new marine terminal construction on Canada's Pacific Coast. This research is exploring and improving the utility and modeling of ship traffic, based on AIS and other data, as an indicator of noise to enable government, industry and, even individuals, to make better decisions to mitigate marine noise impacts.	Dr. Rosaline Canessa University of Victoria <email address removed>
15	WHaLE: Whales, Habitat and Listening Experiment	Ocean-going vessels pose a threat to large whales worldwide. Working with partners, WHaLE plans to use glider-mounted high-frequency echo sounders (whale food) and passive acoustic monitoring (whale sounds) to find and define whale habitat and to develop, test and implement a Canadian Whale Alert System whereby areas of concentrated and classified whale sounds will be available to mobile device users and can also be transmitted to vessels via an AIS-message. Trials will occur on both the East and West Coasts of Canada. The primary objective of the research is to reduce the risk of ocean-going vessel strikes to large baleen whales by giving the shipping industry and the public better information on whale locations, particularly in near real-time via satellite communication.	Dr. Chris Taggart Dalhousie University <email address removed>

#	Title	Project's description	Contact person
16	Modelling of the Acoustic Environment and Interactions Between Whales and Ships in the St. Lawrence Estuary	Marine shipping in the St. Lawrence Estuary represents a threat for marine mammals, in particular for the recovery of endangered species, such as the St. Lawrence beluga and the blue whale that are commonly found in these waters. In the worst-case scenario, interactions between whales and ships can result in collisions that can be fatal for the animals and can also cause damage to the ship. A socio-ecological model, called the Marine Mammal and Maritime Traffic Simulator (3MTSim), was developed to address the complex interactions between shipping and whales in the St. Lawrence Estuary. This project will integrate the model of underwater sound propagation into the 3MTSim simulator, as a first step, with an aim to integrate more complex models in future.	Dr. Jerôme Dupras Université du Québec en Outaouais <email address removed>

3.3.4 Other organizations

There are independent organizations and consulting firms looking for increasing knowledge around the ocean soundscape. Such is the case for Ocean Networks Canada, JASCO Applied Sciences, the Wildlife Conservation Society Canada (WCS), Port of Vancouver, and the Eastern Charlotte Waterways. Table 11 presents rough description of a few projects.

Table 11: Other Canadian organization's current initiatives related to underwater noise

#	Title	Project's description	Contact person
17	ECHO Program vessel source level monitoring system on the approach to Port of Vancouver	An advanced real-time underwater listening system consisting of two hydrophone arrays has been installed on the approach to the Port of Vancouver to track and measure acoustic source levels of visiting ships. The system provides measurements conforming to ANSI S12.64-2009 standard, and also provides a simpler ranking of vessels according to their noise emissions relative to other vessels of the same size and class. The overall goal is to make vessel noise emission performance data available to ship owners, to look for correlations in the data between source level and vessel design, maintenance and operational conditions, and to potentially develop an incentive program which will reward quieter vessels.	Mr. David Hannay, JASCO Applied Sciences <email address removed>

#	Title	Project's description	Contact person
18	ECHO Program marine mammal detection system on the approach to Port of Vancouver	JASCO Applied Sciences, Port of Vancouver, Transport Canada and Ocean networks Canada installed a listening station consisting of two hydrophone arrays near the inbound shipping lane to Port of Vancouver. The system measures underwater noise levels, and automatically detects and tracks calling marine mammals. A purpose of this system is to demonstrate the feasibility of automatic marine mammal detection near shipping lanes to develop systems that might be used in real-time mitigation applications.	Mr. Xavier Mouy, JASCO Applied Sciences <email address removed>
19	NEMES project to develop advanced vessel noise models with integrated AIS vessel track data	The NEMES project, funded under MEOPAR, is assessing the issue of characterizing spatial extent of vessel noise exposure on sensitive marine habitat in the Salish Sea. It is comparing and assessing new satellite-acquired AIS data against terrestrial AIS data, and against acoustic vessel detections from underwater monitoring stations. The end goal is to integrate AIS feeds to real-time acoustic models to be able to produce real-time vessel noise maps. The project is considering all commercial and non-commercial vessel traffic.	Dr. Harald Yurk, JASCO Applied Sciences <email address removed>
20	**Listening stations in the Arctic**	Wildlife Conservation Society Canada (WCS) – The Arctic Beringia Program assessing threats from increasing international maritime traffic to marine mammals in the Beaufort, Bering and Chukchi seas and seeking multi-lateral policy solutions	Dr. Stephen Insley <email address removed>
21	Outer Bay of Fundy Fluctuating Industrial Noise Study	Eastern Charlotte Waterways has teamed with researchers from the University of New Brunswick to quantify, for the first time, the noise levels in the open water of the Outer Bay of Fundy. The project has measured the temporal and spatial distribution of noise levels at frequencies between 4Hz and 20kHz in the marine environment between the Bay of Fundy Traffic Separation Scheme shipping lane and Passamaquoddy Bay from May to November of 2015.	Mr. Donald Killorn Eastern Charlotte Waterways <email address removed>
22	Acoustic Modeling and Monitoring on Canada's East Coast	This project is a large scale ambient noise, marine mammal, anthropogenic noise and sound propagation project underway and funded by the ESRF. It includes a two-year study at identified stations, as well as an analysis of datasets contributed by collaborators, including Dalhousie's MEOPAR WHaLE project and DFO's MPA PAM monitoring projects. A key part of the project and collaborations involves assessing metrics for describing soundscapes in meaningful ways.	Mr. Bruce Martin, JASCO Applied Sciences <email address removed>

PART 4
RECOMMENDATIONS FOR FUTURE RESEARCH AND DEVELOPMENT

4.1 INTRODUCTION

This report on anthropogenic noise has conveyed that there are many current efforts being made throughout Canada to increase knowledge about the potential impacts of shipping noise on marine life; that efforts to monitor noise from ships are expanding to different areas; and, that a considerable amount of work is still required to achieve a thorough understanding of how marine life is affected by cumulative impacts of anthropogenic noise. The following recommendations aim to relate the report's most important findings and identify knowledge gaps that became evident in the process of writing the report. The recommendations have been elaborated upon with the invaluable assistance of members of the Green Marine Underwater Noise Working Group and the insights of many other collaborators.

The following recommendations have been inspired in part by the work done by the Green Marine Secretariat to establish an environmental performance indicator on underwater noise within the North American program, and by the recommendations presented in the 2013 WWF-Canada workshop report[65] for marine planners and regulators to help find solutions for underwater noise management in Pacific Canada.

Acoustic Measurement and Monitoring

RECOMMENDATION 1:

Establish a long-term ocean noise monitoring programs covering the frequency band from 1 to 200,000 Hz in specific areas of high biological importance where shipping activities are high.

Long-term measurement of underwater noise is the only way to have thorough and quantitative knowledge of the soundscape in a representative area and to develop appropriate mitigation measures. Recognizing that underwater sound transmission varies with depth, bathymetry, temperature, current, etc., strategies to manage underwater noise should be area based, rather than in relation to individual species.

R1.1 **Existing data** on marine noise from anthropogenic sources **should be collected, centralized, organized and analyzed to provide a reference database**, to establish the limitations of research to date, and to better understand noise within oceans. Currently, data regarding noise can be difficult to analyze and compare because they are maintained by separate organizations. It would be advantageous to have all data in a single database to improve the ability of interested parties to access the data sets and use them in research, for scientific publication, in education, and for management and regulatory purposes.

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[65] In 2013, WWF-Canada hosted a two-day workshop. The workshop provided a forum to discuss various methods for minimizing and mitigating underwater noise, and to develop tools for planners and regulators to use for planning processes, reviewing environmental assessments, and recovery planning for species listed under the *Species at Risk Act* (SARA). Full report here http://www.wwf.ca/newsroom/reports/oceans/

R1.2 **Establish ambient noise baselines** for key areas, based on existing data collected during various environmental assessments and multiple research initiatives (DFO, JASCO Applied Sciences, Ocean Networks Canada, Ocean Initiatives, Cetacealab, Port Metro Vancouver, and other developments, etc.).

R1.3 **Monitor ocean noise in geographically diverse areas** with priority given to areas with endangered or commercial species.

Shipping Noise

RECOMMENDATION 2:

A Canadian-wide program to measure noise from ships should be led by a single federal agency, with a view to having a better understanding of the contribution of shipping activities in the marine soundscape environment.

Commercial shipping traffic is one of the main contributors to anthropogenic noise at low frequencies. Recognizing that sound propagation varies from one location to another, and that populations of marine animals differ as well, the impact of radiated noise from shipping activities will differ in character and extent through different locations.

R2.1 **Initiate a collaborative effort** with specialized bodies in noise measurement t**o agree upon accepted methodologies**[66] **to collect noise from vessels**[67].

R2.2 **Initiate or collaborate on multiparty projects aiming to measure noise from ships** in important Canadian locations where shipping traffic is important and may have substantial impact on endangered marine populations. Results should be mapped to indicate the significance of shipping noise versus other source of anthropogenic noise in each of the three different oceans, facilitating the identification of areas where shipping noise is likely to be a problem and where it is not.

R2.3 Conduct study to **further the knowledge on causal links between noise produced by a vessel and the efficiency of the vessel.**

R2.4 **Initiate or collaborate with efforts to understand how noise from commercial vessels relates to ship design**: length, draft, number of hulls, hull form coefficients, etc., and to ship operation and maintenance (service speed, cavitation inception speed).

R2.5 **Link noise measuring stations to the AIS system to monitor source levels from individual vessels.** This data fusion is an enabling tool for measuring vessel radiated noise levels of individual and classes of vessels. The data provided will enable mitigation strategies to reduce underwater noise within shipping lanes.

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[66] Methodologies should be in line with what is currently internationally accepted as methodologies to collect noise from vessels (ref to section 1.2.3 and 1.5.1 from this report).

[67] A pilot study which includes an advanced real-time underwater listening system consisting of two hydrophone arrays has been installed off the Port of Vancouver to measure acoustic source levels of visiting ships. The system allows measurements conforming as close as possible to the ANSI S12.64-2009 standard, grade C, and also aims to provide a simpler ranking of vessels according to their noise emissions and relative to other vessels of the same size and class. The overall goal is for Vancouver Fraser Port Authority to be able to inform vessel owners of their noise emission performance, and to identify vessels that may require maintenance of propulsion system (ref. David Hannay, JASCO Applied Sciences).

R2.6 Enhance modeling efforts by making new information available via the AIS system, e.g. information about each vessel's load conditions[68].

R2.7 Extend the AIS system to smaller vessels so that data about them can be integrated into a more complete mapping of shipping noise.

R2.8 Initiate or collaborate on efforts aimed at testing recognized mitigation measures known to reduce noise from vessels, e.g. compare radiated noise before and after hull and propeller maintenance.

Shipping Noise and Marine Life

RECOMMENDATION 3:

Improve the current understanding about the possible causal relationships between the ambient and identifiable source components of ocean noise and their short- and long-term effects on marine organisms.

There is emerging knowledge of impacts, including the ways that non-injurious effects can still accumulate and harm populations, and detailed methods for underwater noise management are required. Given the rapid evolution of underwater noise research, it is essential to maintain regular communication among the various research groups. Addressing this challenge will require a multidisciplinary effort among biologists and acousticians to establish a rigorous observational, theoretical and analytical program. The program's goal should be to obtain useful in-depth knowledge regarding the causal link between radiated noise from ships and the potential adverse effects on marine animals. To achieve this recommendation, knowledge about distribution of animals is essential and a very close and regular collaboration with relevant individuals within DFO will be essential, especially given that information already gathered may not yet be published.

R3.1 Conduct research to understand the long-term adverse effects of chronic noise on marine mammals and other marine animals. For some species of whales, data is available, while for others, very little information exists.

R3.2 Conduct research to know more about the characteristics of communication signals of marine mammals, the conditions under which animals actually produce these signals, and how they might vary their communication under different circumstances.

R3.3 Conduct research on subtle changes in behaviour resulting from masking and noise-induced stress indicators.

R3.4 Integrate modeling efforts regarding noise effects on hearing and behaviour.

Industry Awareness and Involvement

RECOMMENDATION 4:

Encourage existing industry and port environmental programs to address the underwater noise issue and all industry initiatives aiming to implement best practices to reduce noise output should be recognized and supported.

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[68] Noise source (i.e. propeller) depth will vary depending on the particular design of a vessel and the load conditions during a specific transit. Making this kind of information available via the AIS system would create a better understanding of radiated noise.

Vessel speed restrictions (with consideration given to safe speeds) are one way to reduce vessel noise, as well as ship propeller maintenance. Reducing a vessel's total noise emissions should be seen as a longer-term solution rather than spatial and temporal restrictions on noise-producing activities, and as a solution that will have implications over a vessel's entire operating area rather than just within the boundaries of a slow-down zone.

- **R4.1** **Assist port authorities located in areas recognized as important habitat for marine mammals to set both per vessel and regional noise targets** and to develop recognition and/or incentive programs to reward quieter ships (e.g. reducing ports fees for minimizing the production of anthropogenic noise).
- **R4.2** **Shipping companies and the naval architects that they work with should be encouraged to follow existing guidelines aiming to reduce noise output** (like the IMO "Guidelines for the Reduction of Underwater Noise from Commercial Shipping", the SNAME "Marine Vessel Environmental Performance Assessment Guide: General Measures: Ocean Health and Aquatic Life – Underwater Noise" or existing ship classification society notations around quitter vessels) with a view to reducing underwater noise output. Although quieter technologies have already proved their efficiency with research, fishing and navy vessels, the efficiency-viability of such technologies has not been demonstrated yet for larger commercial vessels.
- **R4.3** **Encourage marine training centers to develop academic courses** that can educate people to learn the complexities associated with anthropogenic underwater noise, its impacts and appropriate management measures.
- **R4.4** **Support development of guidelines for best management practices** regarding underwater noise and engage industry when developing these practices to increase their ownership and participation in the implementation of the guidelines

Education, Communication and Outreach

RECOMMENDATION 5:

Education programs and tools should be developed for public and industry about the impacts of underwater noise on marine life, and possible mitigation measures.

As long as the public remains unaware of the potential issue, it is very difficult for stakeholders to have the credibility necessary to obtain decision makers' attention. Dialogue among stakeholders should be maintained and promoted. Workshops attempting to promote ongoing dialogue and cross-sectoral relationships among managers, planners, industry, scientists, citizen researchers, and conservation and community groups regarding how best to incorporate managing underwater noise into best management practices should be supported.

- **R5.1** **Support any initiative that strengthens multiparty collaboration** (e.g. industry, science, government, NGOs).
- **R5.2** **Create a national multiagency work group** to properly address the underwater noise issue by gathering key people from different Canadian departments, with a view to prioritize actions.
- **R5.3** **Plan industry educational workshops** involving whale watchers, shippers, pile drivers, ferry operators, tugboat operators and other producers of underwater noise.
- **R5.4** **Support a "noise consortium" initiative** via the MEOPAR network to ensure and maintain the flow of information on anthropogenic noise and its impacts on marine life

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ANNEX 1
INDICATORS SUGGESTED BY THE MSFD AND THE REQUIRED KEY ACTIONS

This text has been taken directly from the paper: IFAW 1-12-2013

Three indicators were suggested in 2010 for descriptor 11 (Erbe, 2013), requiring:

1) The registration of low- and mid-frequency (10 Hz – 10kHz) impulsive sounds exceeding either a sound exposure level (SEL) of 183 dB re 1 µPa^{2}s @ 1m or a peak pressure level (SPLpk) of 224 dB re 1 µPa @ 1m, as well as the spatial and temporal distribution of such events;
2) The tracking and possibly limitation of number of vessels equipped with sonar systems (50 – 200 kHz) in order to reduce potential impact on high-frequency cetaceans inhabiting coastal waters in the EU;
3) The monitoring of continuous low-frequency sound with the aim of keeping the annual average ambient noise level in the 1/3 octave bands centered at 63 Hz and 125 Hz, as measured by a statistical representative set of observation stations, below the baseline value of the year 2012 or 100 dB re 1 µPa root-mean-square (rms).

Noise mapping was further suggested to analyze noise budgets. A low-frequency level of <100 dB re 1 µPa rms is very ambitious and not achievable in areas of busy commercial shipping.

Key actions needed with regard to Descriptor 11.1.1 (low and mid frequency impulsive sounds)

1. Member States should submit data to the noise sources register in accordance with the recommendations of the TSG. The register will have quite a lot of detail and there will still be a need to develop ways of using the information in the register for the most appropriate indicator. However, a suitable indicator can best be developed based on the data from a comprehensive register that also includes less intense noise sources. Hence member states should submit comprehensive data on all sources.
2. TSG Noise has recommended that information on all sources should be included in the register, including military sources in order that true cumulative effects can be addressed. Although the MSFD provides an exemption for activities of which the sole purpose is defense or national security, the implementation will be much more effective if states provide such data.
3. TSG Noise has focused on effects that cause “considerable” displacement, where considerable is defined as displacement of a significant proportion of individuals for a time period and spatial scale relevant to the MSFD. Although other impacts may be as important as displacement, for example many animals will suffer high levels of stress before they will leave their chosen habitat, it is possible to measure displacement much more easily than other responses. Most of the studies of the effects of the sound sources covered by Indicator 11.1.1 have monitored displacement rather than attempted to measure stress or other responses. TSG Noise did note that the choice to address ‘displacement’ does not preclude individual EU member states from addressing other effects (e.g. behavioral or physiological effects). When setting targets it will be important to recognize that an absence of displacement does not necessarily mean no impact and that even a small displacement reaction may be indicative of a response that has much greater biological importance than the displacement itself (e.g. stress).
4. Germany has already set noise limits for off-shore construction involving pile driving. The most effective way to address impacts from underwater noise pollution is to limit this at source. The German regulations1 have encouraged development of noise reduction methods and other states should follow this example.

Key actions needed with regard to Descriptor 11.2.1 (continuous low frequency sounds)

1. The International Maritime Organization (IMO) is the global body that will have responsibility for implementing measures to reduce shipping noise. IMO has recognized the need to do this and is expected to finalize non-mandatory technical guidelines for minimizing noise from commercial shipping and its adverse effects on marine life. There are also widely-endorsed global targets to reduce the contribution of shipping to ambient noise. Alongside the development of the targets and indicators for ambient noise within the MSFD, member states should also support the IMO process and implement IMO recommendations. In particular IMO has requested member states review their fleets to identify the noisiest ships so that these can be subject to noise reduction measures. More measurements of noise levels from individual ships will also provide the data needed to develop the modelling approaches needed for indicator 11.2.1.
2. TSG Noise has noted that a trend in ambient noise levels by itself is not sufficient to determine GES since it is the actual levels that impact on the environment. Nevertheless, in the absence of sufficient data to set limits that would achieve GES a preliminary target for a reducing trend would be appropriate within the MSFD. The IMO has agreed that scientific uncertainty should not be a reason to delay measures to reduce shipping noise and other organizations such as the Scientific Committee of IWC have endorsed noise reduction targets for shipping noise.
3. IFAW welcomes the funding for the SONIC (Suppression of underwater noise induced by cavitation – http://www.sonic-project.eu/) and AQUO (Achieve quieter oceans by shipping noise footprint reduction – http://www.aquo.eu/) projects from the European Union Seventh Framework Programme. There will be a need to build on these projects to ensure that recommended developments arising from these projects are implemented.

Appendix B

The Government of Canada's paper *Collaboration to reduce underwater noise from marine shipping,* presented to the Marine Environment Protection Committee of the International Maritime Organization in April 2017

MARINE ENVIRONMENT PROTECTION COMMITTEE
71st session
Agenda item 16

MEPC 71/16/5
28 April 2017
Original: ENGLISH

ANY OTHER BUSINESS

Collaboration to reduce underwater noise from marine shipping

Submitted by Canada

SUMMARY

Executive summary:	This document invites interested countries to join Canada in work to enhance the understanding of ship noise and measures to mitigate it. The effort aims to build on previous work of the Committee and work of Member States.
Strategic direction:	7.1, 13
High-level action:	7.1.2, 13.0.1, 13.0.2, 13.0.3
Output:	No related provisions
Action to be taken:	Paragraph 17
Related documents:	MEPC 58/19; MEPC 68/INF.26; MEPC 66/17, MEPC 66/21 and MEPC.1/Circ.833

Background

1 Scientific evidence continues to grow and demonstrate that underwater noise can be a stressor for many marine species. This is particularly true for those species that rely on sound as a means of carrying out basic survival activities, including to detect prey, communicate and acquire information about their environment.[1] The frequencies below 1,000 Hz are identified as critically important for many whale and fish species; this is the same low frequency band that characterizes the underwater noise emitted by nearly all large commercial ships. This overlap is significant as there is a direct relationship between ambient noise levels near shipping routes and increasing global ship traffic.[2]

[1] Rolland, Parks, Hunt, et al. found a decrease in stress-related faecal hormone metabolites from North Atlantic Right Whales during a 6dB decrease in low frequency underwater noise. Simpson, Radford, Nedelec et al. found noise from motorboats raised stress levels in damselfish by 33% leaving them less likely to respond to predators. Overall, there is growing global consensus that noise may affect the marine environment and living resources of the sea.

[2] Low frequency ambient noise levels have increased ~3 dB per decade in the Northeast Pacific Ocean and the Indian Ocean. The increase is linked to increases in shipping. See Redfern, J.V., Hatch, L.T., Caldow, C., et al. (2017) Assessing the risk of chronic shipping noise to baleen whales off Southern California, USA. *Endangered Species Research* Vol 32, ppl 153-167.

2 Vessel movement and navigation activities contribute to underwater noise levels. The precise impacts on marine species are not well understood and are complex to assess. These complexities result from many factors, including variations in how marine species use sound, in geographical characteristics that impact sound propagation (including water salinity, temperature and pressure) and in the underwater sound profiles of different vessels (type, technology, condition and age) in different operating conditions.

3 Significant areas of vessel activity often overlap with the habitat of marine species that are at risk. As ship traffic is expected to increase, Canada is interested in advancing knowledge on the impact of underwater noise on species, and on underwater noise management and mitigation strategies.

4 As uniform measures are important to international marine shipping and ship design, Canada reaffirms its support for IMO as the appropriate international forum for the discussion on vessel underwater noise.

5 Canada recognizes the work of the United States in its originating proposal to the Committee in document MEPC 58/19 that introduced the work item on "Noise from commercial shipping and its adverse impacts on marine life", and which ultimately resulted in the *Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life* (MEPC.1/Circ.833). Canada has taken note of a key statement in that proposal:

> "A significant and growing portion of human noise input to the ocean is attributable to the increasing number and size of commercial ships operating over wide-ranging geographic areas. Noise from such ships has the potential to disturb behaviour and interfere with critical life functions of marine animals. Given the global nature of shipping, the long lifespan of a ship, and that the Organization is the recognized entity for the consideration of issues pertaining to international shipping, it is essential that the Organization provide the forum for the comprehensive consideration of global strategies to address this issue."

6 Canada also recognizes the work of the Committee and of the former Ship Design and Equipment Sub-Committee that developed MEPC.1/Circ.833. These voluntary Guidelines provide advice to designers, builders and operators of ships, and consider technology and measures that address a wide range of ship types. Canada reaffirms that design issues and ship operations should be considered holistically as part of the overall consideration of ship safety and energy efficiency. While the Guidelines of MEPC.1/Circ.833 include other elements, Canada draws special attention to the following specific recommendations:

.1 Use of computer models to predict noise based on hull design using Computational Fluid Dynamics, propeller analysis methods, Statistical Energy Analysis for machinery noise, along with Finite Element Analysis and Boundary Element Method to estimate low-frequency noise and vibration of the structure of the ship generated by the propeller and machinery.

.2 Noise-reducing propeller design options are available for many applications and should be considered. However, it is acknowledged that the optimal propeller with regard to underwater noise reduction cannot always be employed due to technical or geometrical constraints (e.g. ice strengthening of the propeller). It is also acknowledged that design principles for cavitation reduction (i.e. reduce pitch at the blade tips) can cause decrease of efficiency.

.3 Consideration should be given to the selection of onboard machinery along with appropriate vibration control measures, proper location of equipment in the hull, and optimization of foundation structures that may contribute to reducing underwater radiated and onboard noise affecting passengers and crew.

.4 Uneven or non-homogeneous wake fields are known to increase cavitation. Therefore, the ship hull form with its appendages should be designed such that the wake field is as homogeneous as possible. This will reduce cavitation as the propeller operates in the wake field generated by the ship hull. Consideration can be given to the investigation of structural optimization to reduce the excitation response and the transmission of structure-borne noise to the hull.

.5 In addition to their use for new ships, the following technologies are known to contribute to noise reduction for existing ships and can be considered if reasonable and practicable: (1) design and installation of new state-of-the-art propellers; (2) installation of wake conditioning devices; and (3) installation of air injection to propeller (e.g. in ballast condition).

.6 Propeller polishing done properly removes marine fouling and vastly reduces surface roughness, helping to reduce propeller cavitation.

.7 Maintaining a smooth underwater hull surface and smooth paintwork may also improve a ship's energy efficiency by reducing the ship's resistance and propeller load. Hence, it will help to reduce underwater noise emanating from the ship. Effective hull coatings that reduce drag on the hull, and reduce turbulence, can facilitate the reduction of underwater noise as well as improving fuel efficiency.

.8 In general, for ships equipped with fixed pitch propellers, reducing ship speed can be a very effective operational measure for reducing underwater noise, especially when it becomes lower than the cavitation inception speed. For ships equipped with controllable pitch propellers, there may be no reduction in noise with reduced speed. Therefore, consideration should be given to optimum combinations of shaft speed and propeller pitch.

.9 Speed reductions or routing decisions to avoid sensitive marine areas including well-known habitats or migratory pathways when in transit will help to reduce adverse impacts on marine life.

7 Canada recalls that in approving the Guidelines and considering the possibility of future work, MEPC noted in document MEPC 66/21, among other things, that:

".1 a large number of gaps in knowledge remained and no comprehensive assessment of this issue was possible at this stage. In this context, it was highlighted that sound levels in the marine environment and the contribution from various sources was a complex issue. The wide variety of ship types, sizes, speeds and operational characteristics all contributed to this complexity;

.2 given these complexities, setting future targets for underwater sound levels emanating from ships was premature and would be difficult to evaluate at this time; and

.3 more research was needed, in particular on the measurement and reporting of underwater sound radiating from ships".

8 In addition, the Committee recognized the importance of the issue of underwater noise and invited Member Governments wishing to pursue these matters further to submit proposals for appropriate new outputs to a future session.

Current status

9 In Canada, the issue of the growing impact of underwater noise on marine species continues to be raised in the context of environmental assessments associated with resource development projects that rely on marine transportation. Notably, assessments of projects planned for the south-west coast of British Columbia have identified potential impacts of project activity on the killer whales (*Orcinus orca)*, including underwater noise from associated increased marine shipping. Some populations of killer whales are listed as at-risk under Canada's Species at Risk Act. In south-west British Columbia, one particular population, the Southern Resident Killer Whale, is reduced to only 78 members and has particular cultural significance to many coastal indigenous communities. Additionally, the potential negative effects of marine shipping noise may be exacerbated by increased volume from existing commercial and recreational activities.

10 Canada recognizes the importance of the voluntary Guidelines in MEPC.1/Circ.833. At this time, Canada is seeking to take measures to ensure that marine noise from commercial shipping is reduced as much as possible. Transport Canada and Fisheries and Oceans Canada are conducting research to better understand the ship noise issue and to mitigate its potential negative effects.

11 In 2016, Canada undertook a study to inventory and summarize existing information and activities on the issue of underwater noise from industrial sources, including shipping. The executive summary of this study is available online at: https://www.tc.gc.ca/eng/anthropogenic-underwater-noise.html, and the full study is available on request by emailing: TDCCDT@tc.gc.ca. This study recognized that progress on this issue has been made, but also recommended five areas for further work: acoustic measurement and monitoring; measurement of shipping noise; impacts of underwater noise on marine life; industry awareness and involvement; and education, communication and outreach.

12 There are also a number of industry-led initiatives underway in Canada focused on vessel underwater noise. The Vancouver Fraser Port Authority's Enhancing Cetacean Habitat and Observation (ECHO) Program is a global leader that is actively engaged in researching this issue. It recently completed work on identifying and quantifying vessel contributions to underwater noise in the region and an evaluation of possible vessel noise reduction measures. Engaging with marine transportation industries, government agencies, conservation groups, First Nations individuals and scientists, the ECHO Program is working to test different approaches to reducing underwater noise from vessels including hull cleaning and slowing down vessels in a specific geographic area. Other initiatives in Canada include the Vancouver Fraser Port Authority's pioneering EcoAction program, which offers financial incentives to ships carrying a quiet notation from certain ship classification societies or vessels installed with certain propeller technologies shown to reduce underwater noise. Finally, the industry-led Green Marine program now includes underwater noise as a criterion in its environmental certification program for North American shipowners and ports.

13 Canada notes that over the last few years, many different governments, organizations, academics and industry members have focused on this issue. For example, the United Kingdom recently completed a national assessment of ambient underwater noise levels to inform management applications (LC/SG 40/INF.10). In 2016, the Convention on Biological Diversity's Subsidiary Body on Scientific, Technical and Technological Advice published a Scientific Synthesis of the *Impacts of Underwater Noise on Marine and Coastal Biodiversity*

and Habitats (UNEP/CBD/SBSTTA/20/INF/8). Research was also undertaken by the European Union through the Achieve Quieter Oceans by shipping noise footprint reduction (AQUO) project.

14 Canada recognizes the international nature of commercial shipping and its importance to trade, development and the global economy. In considering measures to reduce noise from ships, Canada understands that for such measures to be effective they must work in a global context, especially when considering advancements in vessel design and retrofit technology.

15 Canada seeks to engage with Member States to identify measures to address underwater vessel noise. Canada believes that it can build on the previous work of the Committee and that of Member States to ensure a common approach that best addresses shipping noise without adversely affecting shipping activities and international trade. Canada believes it would be valuable for Member States to know the experiences gained by countries in implementing the guidelines in MEPC.1/Circ.833 or other measures they have implemented within their jurisdictions. Learning of these experiences would assist those Member States wishing to coordinate and build upon current measures.

16 Any comments from Member States, IGOs and NGOs on measures to address ship noise are welcomed, particularly on experience gained with specific measures or interest in additional collaboration on research and the identification of other potential mitigation measures. Contact points are Ms. Michelle Sanders (<email address removed>) and Mr. Paul Topping <email address removed>

Action requested of the Committee

17 The Committee is invited to note the information in this document and take action as appropriate.

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Appendix C

JASCO Applied Sciences (Canada) Ltd.'s October 2017 report *Assessment of Vessel Noise within Southern Resident Killer Whale Critical Habitat*, commissioned by TC

TP 15387

Assessment of Vessel Noise within Southern Resident Killer Whale Critical Habitat

Final Report

Prepared for:
Transportation Development Centre of Transport Canada

By:
JASCO Applied Sciences (Canada) Ltd.

October 2017

JASCO APPLIED SCIENCES

TP 15387

Assessment of Vessel Noise within Southern Resident Killer Whale Critical Habitat

Final Report

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JASCO Applied Sciences (Canada) Ltd

October 31, 2017

NOTICES

Disclaimer:

This report reflects the views of JASCO Applied Sciences and not necessarily those of the Transportation Development Centre of Transport Canada.

The results presented here could be misinterpreted if not considered in context of the acoustic sources and environments described in this report. Accordingly, if information from this report is used in documents released to the public or to regulatory bodies, such documents must clearly cite the original report, which shall be made readily available to the recipients in integral and unedited form.

Suggested citation:

Matthews, M.-N. R., L. Horwich, H. Yurk, H. Frouin-Mouy, J. Delarue, A. MacGillivray, and D.E. Hannay. 2017. *Assessment of Vessel Noise within Southern Resident Killer Whales Critical Habitat: Final Report*. Document number 01448, Version 2.0. Technical report by JASCO Applied Sciences for Transportation Development Centre of Transport Canada.

Un sommaire français se trouve avant la table des matières.

EXECUTIVE SUMMARY

Purpose of this Study

The International Maritime Organization's (IMO) Marine Environment Protection Committee recognizes that underwater noise from commercial ships may have short- and long-term impacts on marine mammals (IMO 2014). The Salish Sea is an important habitat for several marine mammal species, including the endangered Southern Resident Killer Whale (SRKW; SARA 2002). Much of the SRKW population is often found near heavily-used shipping lanes. This population therefore experiences substantial levels of noise from commercial vessels while in this region. Vessel noise has the potential to disturb or injure SRKW and could hinder recovery of their population number (DFO 2011). Shipping activity in the Salish Sea is expected to increase in the near future, and strategic management of this traffic will be necessary to ensure marine fauna are not exposed to substantial increases in underwater noise. Transport Canada recognizes the need to examine underwater noise conditions in the Salish Sea, and to investigate options for managing and reducing vessel noise exposures to marine fauna. In light of these concerns, Transport Canada has commissioned this study to assess underwater shipping noise levels in the Salish Sea in key areas of critical habitat for SRKW, and to investigate the effectiveness of several possible noise mitigation approaches.

Study Approach

This study applied sophisticated computer models to examine shipping noise levels throughout a region of the southern Salish Sea that includes SRKW critical habitat. Baseline (present) noise levels were established by modelling vessel traffic densities for 2015. A future case scenario was developed representing conditions in 2020; it assumes the presence of new oil tanker and tug traffic associated with the recently-approved Trans Mountain Pipeline Project. The study also examines the same future noise conditions in key areas when a range of possible vessel noise mitigation options are implemented. The mitigation options examined here are:

- Implementing a vessel slow-down zone near key habitat areas,
- Restricting traffic during a specific time of day (no-go period) in Haro Strait,
- Replacing the 10% of noisiest ships by quieter vessels,
- Reducing noise emissions (source levels) of specific vessel classes,
- Adjusting the traffic lanes in Haro Strait away from SRKW habitat on western San Juan Island, and
- Grouping vessels into convoys as they transit Haro Strait.

The potential effectiveness of several other noise mitigation options were examined using information published in other studies. These options are:

- Reducing noise and vibration generated by different vessel components (such as propellers and onboard machinery), and
- Reducing noise exposures through modifying vessel operating approaches (such as slowing down in the presence of animals).

The noise models applied here were developed by JASCO Applied Sciences. They account for actual vessel positions, speeds, and classes as obtained from automatic identification system (AIS) broadcasts that are mandated for most commercial vessels. The models consider ocean and seabed properties and how these parameters affect vessel noise propagation. They calculate time-varying sound levels over large areas in 1-minute time steps and as monthly averages. Results are presented as maps showing the spatial distribution of these noise levels and the differences between the mitigated future case levels and baseline levels. Temporal variations in levels are presented as noise percentiles at 8 fixed sample locations (also described as test receiver locations) in Haro Strait where SRKW are known to feed. These results are useful for interpreting the amount of time that noise is likely to disturb SRKW and reduce their foraging efficiency.

A large fraction of vessel noise occurs at low sound frequencies, below 1000 Hz. Vessel sounds do extend to many tens of kilohertz, albeit at lower levels. As killer whales are more sensitive to higher than lower sound frequencies, it is important that their frequency-dependent hearing acuity be accounted for when assessing the importance of vessel noise. This study presents noise levels in two ways: unfiltered results, which do not account for SRKW's frequency-dependent hearing sensitivity, and SRKW audiogram-weighted results, which do. While impacts to SRKW should be assessed primarily based on the weighted results, there is some evidence that high-amplitude, low-frequency sounds may be sensed through non-auditory means. The unfiltered results may be useful for that type of effects assessment. The unfiltered results are also relevant for assessing noise loudness for species that have better low-frequency hearing sensitivity, such as for pinnipeds, and particularly for the mysticetes including humpback, blue, fin, sei, and minke whales that visit the Salish Sea.

Key Findings

Slowing Vessels in Haro Strait: Reducing commercial vessel speeds in Haro Strait to 11 knots lead to slightly decreased vessel noise levels at all 7 test receiver locations inside the slow-down zone. The one receiver located in the speed transition zone (where vessels slowed down and sped up) showed a slight increase by 0.4 dB. The in-zone receivers experienced decreases in both broadband levels (more appropriate for assessing effects on mysticetes and pinnipeds) and in SRKW audiogram-weighted levels. The reductions in audiogram-weighted levels were smaller. An 11 knot speed limit reduced SRKW-weighted noise levels by 1.3 to 1.9 dB for receivers near the shipping lane, and by 0 to 0.2 dB for receivers farther away from the shipping lane. A speed limit higher than 11 knots would likelyly result in increased levels at those receivers due to the additional Trans Mountain project traffic. We also investigated slow-down speeds of 10 and 7 knots. The slowest speed evaluated (7 knots) produced approximately twice the reduction of the 11 knot speed limit. This mitigation approach may be beneficial to SRKW in areas close to the prescribed slow-down zone.

Restricting commercial vessel traffic at night: This scenario investigated the option of restricting commercial vessel traffic in Haro Strait from midnight to 04:00 (no-go period). As might be expected, this greatly decreased SRKW-weighted noise levels during the restricted period (by 1.0 to 12.8 dB depending on location). However, the restricted nighttime traffic must be rescheduled for daytime transits, which increased daytime (04:00 through midnight) noise levels. Noise levels during the non-restricted period therefore increased at the test receiver locations by 0.1 to 0.5 dB. We note that the decreases during the restricted time period appear larger (numerically) than the increases during the non-restricted period, but this is somewhat misleading. It is due partly to the decibel scale being logarithmic; the same change in acoustic energy leads to a larger decrease than increase in units of decibels. However, the most important reason is that commercial vessels represent the majority of noise contributors at night. Implementing a restricted night-time period therefore could create a very low-noise (quiet) situation for a few hours. This approach warrants consideration.

Replacing the top 10% of noisiest commercial vessels: We investigated the reduction in noise levels produced by replacing the noisiest 10% of vessels in each commercial vessel class with the corresponding quietest 10%. Importantly, the findings vary depending on how the "noisiest" vessels were defined. When the vessels were ranked using unfiltered noise results, this method produced no reduction to the perceived loudness of sounds to SRKW. When the vessels were ranked using killer whale audiogram-weighting, the perceived loudness was reduced nominally by 1 dB. This result suggests that vessel noise emissions at low frequencies are not well correlated with their emissions at high frequencies. Consequently, it is very important to consider killer whale frequency-dependent hearing acuity when ranking the noise emissions of vessels. That is rarely done, but we note the Vancouver Fraser Port Authority's ECHO program vessel measurements do implement frequency-dependent ranking. Replacing 10% of noisiest vessels potentially reduces noise levels throughout the entire study area and warrants consideration.

Reducing vessel noise emission levels: When noise emission levels from commercial vessel were reduced in all frequency bands by a fixed amount, there was a corresponding, but not equal, reduction in shipping noise levels experienced by marine fauna. The amount of reduction of received levels was less than the specified reduction to commercial vessels because non-commercial vessels also contributed to the soundscape. When emission levels from Containerships, Merchant, Passenger (≥100 m in length), Tanker, Tug, and Vehicle carriers were reduced by 3 dB, the nominal levels at the test receiver locations were reduced by 1.2 to 2.5 dB. When these vessels' noise emission levels were reduced by 6 dB, the received noise reductions were 2.2 to 5.3 dB. While this may appear to be an effective noise mitigation approach, there are presently no known methods for reducing the noise emission levels of commercial vessels at all frequencies.

Rerouting of the shipping lanes in Haro Strait: A shift of the shipping lanes westward in Haro Strait, away from the important SRKW foraging areas on the west side of San Juan Island, reduced the audiogram-weighted noise levels at test receiver locations by 0.0 to 1.9 dB. The two stations adjacent to the original lanes experienced larger decreases of 2.5 and 7.0 dB. Generally, this mitigation approach was found to be relatively effective. It is important to note that the route changes examined here were not vetted by the Coast Guard or the pilots association. This option would require full coordination of those organizations to ensure any implemented route changes are feasible and safe. This approach warrants consideration.

Vessel convoys: Two convoy interval options (2 and 4 hours) were assessed for commercial vessels passing through Haro Strait. Grouping vessels in convoys increased the noise amplitude during each convoy pass, but it allowed for some quieter times between passes. This study assumed that only Containership, Merchant, Passenger (≥100 m in length), Vehicle Carrier, Tanker, and Tugs associated with Trans Mountain operations would be convoyed. Noise from all other vessel classes that broadcast AIS was included, but those vessels were not convoyed. The analysis considered the magnitude and temporal distribution of noise levels at all 8 test receiver locations in Haro Strait. The results indicate that 2-hour convoys actually increased the median noise level at most locations. 4-hour convoys produced little change, and did not result in substantial reductions of noise during times between the vessel groups; it produced very little improvement in median and other noise percentile statistics. The lack of noise improvement from implementing convoys was surprising and led to further investigation. When noise from non-convoyed vessels was removed, the results improved substantially. Therefore, the lack of benefit of this approach is due to the noise from non-convoyed vessels that filled in the quiet times between the convoys. Importantly, this study did not include noise from whale watching vessels, which would further contribute noise received by SRKW during the times between convoy passes, thereby further reducing its effectiveness. The convoy approach may be more effective at locations such as Swiftsure Bank, where large commercial vessels make up the vast majority of vessel traffic. A follow-up study of convoys in that area could be worthwhile. Through the present study, however, our conclusion is that convoys are not beneficial in the Haro Strait region.

Other Vessel Noise Mitigation Approaches: This study reviewed literature on several other mitigation approaches. The key methods investigated included:

- Technical solutions involving ship design and retrofitting vessels;
- Operational changes involving operator behaviour;
- Operational changes at the shipping industry level, involving loading plans and timing; and
- Operational changes at the traffic management level, involving dynamic speed limits, temporal and spatial area closures in response to real-time monitoring of whale presence, etc.

Ship design changes, vessel retrofitting, and regular ship maintenance should be long term goals to reduce noise in SRKW habitat. This approaches would also benefit other oceanic habitats and result in a long lasting change in underwater noise levels everywhere. Operator behaviour changes that reduce noise levels include avoiding sudden vessel accelerations, maintaining speed limits within critical habitat, and reducing speed to maintain appropriate distances to other vessels and whales. These changes can be achieved through better education, voluntary compliance, incentives for shipping companies, or by regulations such as setting maximum noise thresholds for access to sensitive habitats. Plans for regulation of commercial traffic within the SRKW habitat, such as seasonal and/or dynamic speed limits, and temporal and spatial area closures for some or all marine traffic, may be the quickest most effective means to implement noise reduction. The noise reduction and, more importantly, improvement in acoustic quality of the SRKW habitat will need to be assessed scientifically (through modelling and in situ measuring), as incorrect assumptions are easily made.

SOMMAIRE

Objet de cette étude

Le Comité de protection du milieu marin de l'Organisation maritime internationale (OMI) reconnaît que le bruit sous-marin des bâtiments commerciaux peut avoir des effets à court et à long terme sur les mammifères marins (OMI, 2014). La mer des Salish est un habitat important pour plusieurs espèces de mammifères marins, y compris l'épaulard résident du Sud, en voie de disparition (épaulard résident du Sud; LEP 2002). Une grande partie de la population des épaulards résidents du Sud côtoie souvent des voies de navigation très achalandées. Cette population est donc exposée aux niveaux élevés de bruit causé par les bâtiments commerciaux qui sont exploités dans cette région. Le bruit des bâtiments peut perturber ou blesser les épaulards résidents du Sud et nuire au rétablissement de leur population (MPO, 2011). L'activité de navigation dans la mer des Salish devrait augmenter dans un avenir rapproché, et la gestion stratégique de ce trafic sera nécessaire pour assurer que la faune marine n'est pas exposée à une augmentation substantielle du bruit sous-marin. Transports Canada reconnaît la nécessité d'examiner les conditions du bruit sous-marin dans la mer des Salish et les options de gestion et de réduction des expositions au bruit des bâtiments parmi la faune marine. À la lumière de ces préoccupations, Transports Canada a commandé cette étude afin d'évaluer les niveaux de bruit de navigation sous-marin dans la mer des Salish dans des secteurs clés d'habitat essentiel des épaulards résidents du Sud, et d'examiner l'efficacité de plusieurs approches possibles d'atténuation du bruit.

Approche de l'étude

Cette étude a mis en application des modèles informatiques perfectionnés pour examiner les niveaux de bruit de navigation dans une région de la partie Sud de la mer des Salish qui comprend l'habitat essentiel des épaulards résidents du Sud. Les niveaux de bruit de base (actuels) ont été établis au moyen de la modélisation des densités de trafic des bâtiments en 2015. Un scénario de cas à venir a été élaboré pour représenter les conditions en 2020; il suppose la présence de nouveaux pétroliers et de remorqueurs associés au projet de pipeline Trans Mountain récemment approuvé. L'étude examine également les mêmes conditions de bruit dans les zones clés lorsqu'une gamme d'options possibles d'atténuation du bruit des bâtiments sont mises en œuvre. Les options d'atténuation examinées ici sont les suivantes :

- La mise en place d'une zone de ralentissement des bâtiments près des zones d'habitat clés
- La limitation du trafic pendant une période du jour donnée (période sans navigation) dans le détroit Haro
- Le remplacement de la tranche de 10 % des bâtiments les plus bruyants par des bâtiments plus silencieux
- La réduction des émissions de bruit (niveaux sources) de certaines classes de bâtiments
- Le réaménagement des voies de navigation dans le détroit Haro loin de l'habitat des épaulards résidents du Sud, dans la partie Sud de l'île de San Juan
- Le regroupement des bâtiments en convois pendant leur traversée du détroit Haro

L'efficacité potentielle de plusieurs autres options d'atténuation du bruit a été examinée à l'aide de l'information publiée dans d'autres études. Ces options sont les suivantes :

- La réduction du bruit et des vibrations causés par différentes composantes du bâtiment (comme les hélices et les machines à bord)
- La réduction de l'exposition par la modification des méthodes d'exploitation des bâtiments (comme le ralentissement en présence d'animaux)

Les modèles de bruit appliqués ici ont été élaborés par JASCO Applied Sciences. Ils tiennent compte des positions réelles des bâtiments, des vitesses et des classes obtenues à partir des émissions du système d'identification automatique (SIA) qui sont obligatoires pour la plupart des bâtiments commerciaux. Les modèles tiennent compte des propriétés océaniques et de fonds marins, et de la façon dont ces paramètres influent sur la propagation du bruit produit par les bâtiments. Ils calculent les niveaux sonores variables dans de grandes superficies à intervalles d'une minute et en moyennes mensuelles. Les résultats sont présentés sur des cartes montrant la répartition spatiale de ces niveaux de bruit et les différences entre les niveaux des cas futurs bénéficiant des atténuations et les niveaux de base. Les variations temporelles des niveaux sont présentées en tant que rangs centiles de bruit à huit emplacements d'échantillonnage fixes (aussi décrits comme des emplacements de récepteur d'essai) dans le détroit Haro, où nous savons que les épaulards résidents du Sud se nourrissent. Ces résultats sont utiles pour interpréter la quantité de temps pendant lequel le bruit est susceptible de perturber l'épaulard résident du Sud et de réduire sa capacité de se nourrir.

Une grande proportion du bruit des bâtiments est produite à des fréquences sonores basses, soit moins de 1 000 Hz. Les sons des bâtiments s'étendent à plusieurs dizaines de kilohertz, bien qu'à des niveaux inférieurs. Étant donné que les épaulards sont plus sensibles aux fréquences sonores élevées qu'aux fréquences sonores faibles, il est important de tenir compte de leur acuité auditive à la fréquence pour évaluer l'importance du bruit des bâtiments. Cette étude présente les niveaux de bruit de deux façons, soit au moyen des résultats non filtrés, qui ne tiennent pas compte de la sensibilité auditive à la fréquence des épaulards résidents du Sud, et au moyen des résultats pondérés par audiogramme des épaulards résidents du Sud, qui tiennent compte de la sensibilité auditive. Bien que les effets sur l'épaulard résident du Sud doivent être évalués principalement en fonction des résultats pondérés, certaines preuves indiquent que les sons à basse fréquence et à forte amplitude peuvent être détectés par des moyens non auditifs. Les résultats non filtrés peuvent être utiles pour ce type d'évaluation des effets. Les résultats non filtrés sont également utiles pour évaluer l'intensité du bruit pour les espèces qui présentent une sensibilité auditive à basse fréquence, comme les pinnipèdes, et particulièrement les mysticètes, notamment le rorqual à bosse, le rorqual bleu, le rorqual commun, le rorqual boréal et le petit rorqual qui visitent la mer des Salish.

Principales constatations

Ralentissement des bâtiments dans le détroit Haro La réduction de la vitesse des bâtiments commerciaux dans le détroit Haro à 11 nœuds a entraîné une légère réduction des niveaux de bruit des bâtiments aux sept emplacements de récepteur d'essai à l'intérieur de la zone de ralentissement. Le seul récepteur situé dans la zone de transition de vitesse (où les bâtiments ralentissaient et accéléraient) a montré une légère augmentation, soit de 0,4 dB. Les récepteurs situés dans la zone ont indiqué une réduction des niveaux à large bande (plus utiles pour évaluer les effets sur les mysticètes et les pinnipèdes) et des niveaux pondérés par audiogramme des épaulards résidents du Sud. Les diminutions des niveaux pondérés par audiogramme étaient plus faibles. Une limite de vitesse de 11 nœuds a réduit les niveaux de bruit pondérés des épaulards résidents du Sud de 1,3 à 1,9 dB pour les récepteurs situés près de la voie de navigation et de 0 à 0,2 dB pour les récepteurs plus éloignés de la voie de navigation. Une limite de vitesse supérieure à 11 nœuds serait susceptible de faire augmenter sensiblement les niveaux enregistrés par ces récepteurs en raison du trafic accru créé par le projet Trans Mountain. Nous avons également examiné des vitesses réduites de 10 et de 7 nœuds. La vitesse la plus faible évaluée (7 nœuds) a donné lieu à une réduction représentant environ le double de celle de la limite de vitesse de 11 nœuds. Cette approche d'atténuation pourrait être avantageuse pour l'épaulard résident du Sud dans les zones situées près de la zone de ralentissement instaurée.

Restriction du trafic des bâtiments commerciaux pendant la nuit Ce scénario portait sur la possibilité de restreindre le trafic des bâtiments commerciaux dans le détroit Haro entre minuit et 4 h (période sans navigation). Comme on pouvait s'y attendre, les niveaux d'exposition des épaulards résidents du Sud au bruit ont considérablement diminué pendant la période de restriction (de 1,0 à 12,8 dB, selon l'emplacement). Toutefois, le trafic limité la nuit doit être repris en expéditions de jour, ce qui a fait augmenter les niveaux de bruit le jour (entre 4 h et minuit). Les niveaux de bruit enregistrés au cours de la période sans restriction ont donc augmenté de 0,1 à 0,5 dB aux emplacements de récepteur d'essai. Nous constatons que les baisses observées durant la période de restriction semblent plus importantes (numériquement) que les augmentations observées durant la période sans restriction, mais cela est quelque peu trompeur. Cette constatation est en partie attribuable à l'échelle des décibels, qui est logarithmique : le même changement d'énergie acoustique entraîne une diminution plus importante que l'augmentation des unités de décibels. Toutefois, la raison la plus importante est que les bâtiments commerciaux causent la plus grande partie du bruit pendant la nuit. La mise en place d'une période de restriction la nuit pourrait donc créer une situation très silencieuse (calme) pendant quelques heures. Cette approche mérite d'être prise en compte.

Remplacement de la tranche de 10 % des bâtiments commerciaux les plus bruyants Nous avons examiné la réduction des niveaux de bruit produits en remplaçant la tranche de 10 % des bâtiments les plus bruyants dans chaque classe de bâtiments commerciaux par la tranche de 10 % des bâtiments les plus silencieux correspondante. Il est important de souligner que les résultats varient selon la définition des bâtiments « les plus bruyants ». Lorsque les bâtiments ont été classés au moyen des résultats du bruit non filtrés, cette méthode n'a pas permis de réduire la puissance perçue des sons chez les épaulards résidents du Sud. Lorsque les bâtiments ont été classés au moyen des résultats pondérés par audiogramme des épaulards, la puissance perçue a été réduite, au moins nominalement, de 1 dB. Ce résultat laisse croire que les émissions de bruit causées par les bâtiments à faible fréquence ne sont pas bien corrélées avec leurs émissions à des fréquences élevées. Par conséquent, il est très important de tenir compte de l'acuité auditive dépendant de la fréquence des épaulards lorsqu'on classe les émissions de bruit des bâtiments. Cela est rarement fait, mais nous constatons que le programme ECHO de l'Administration portuaire Vancouver Fraser pour les mesures des bâtiments établit un classement en fonction de la fréquence. Le remplacement de la tranche de 10 % des bâtiments les plus bruyants peut réduire les niveaux de bruit dans toute la zone d'étude et mérite d'être pris en compte.

Réduction des niveaux d'émissions de bruit des bâtiments Lorsque les niveaux d'émissions de bruit causées par les bâtiments commerciaux ont été réduits dans toutes les bandes de fréquences d'une quantité fixe, il y avait une réduction correspondante, mais non égale, des niveaux de bruit de navigation auxquels est exposée la faune marine. La réduction des niveaux reçus était inférieure à la réduction précisée des bâtiments commerciaux, parce que les bâtiments non commerciaux ont aussi contribué à l'environnement acoustique. Lorsque les niveaux d'émissions des navires porte-conteneurs, des navires de commerce, des navires à passagers (d'une longueur ≥ 100 m), des navires-citernes, des remorqueurs et des transporteurs de véhicules ont été réduits de 3 dB, les niveaux nominaux aux emplacements des récepteurs d'essai ont été réduits de 1,2 à 2,5 dB. Lorsque les niveaux d'émissions de ces bâtiments ont été réduits de 6 dB, les réductions de bruit reçues ont été de 2,2 à 5,3 dB. Bien qu'il semble s'agir d'une approche efficace d'atténuation du bruit, il n'existe actuellement aucune méthode connue pour réduire les niveaux d'émissions de bruit des bâtiments commerciaux à toutes les fréquences.

Détournement des voies de navigation dans le détroit Haro Un déplacement des voies de navigation vers l'ouest dans le détroit Haro, loin des importantes zones de chasse de l'épaulard résident du Sud, à l'Ouest de l'île de San Juan, a réduit de 0,0 à 1,9 dB les niveaux de bruit pondérés par audiogramme aux emplacements des récepteurs d'essai. Les deux stations adjacentes aux voies originales ont enregistré des réductions plus grandes, soit de 2,5 et 7,0 dB. En général, cette approche d'atténuation s'est avérée relativement efficace. Il importe de souligner que les changements d'itinéraire examinés ici n'ont pas été examinés par la Garde côtière ni l'association des pilotes. Cette option nécessiterait la coordination complète des organisations pour assurer la faisabilité et la sécurité des changements apportés aux itinéraires. Cette approche mérite d'être prise en compte.

Convois de bâtiments Deux options d'intervalle de convoi (deux et quatre heures) ont été évaluées pour les bâtiments commerciaux traversant le détroit Haro. Le regroupement des bâtiments en convois a augmenté l'amplitude du bruit lors du passage de chaque convoi, mais a permis de bénéficier de périodes plus silencieuses entre les passages. Cette étude supposait que seuls les navires porte-conteneurs, les navires de commerce, les navires à passagers (d'une longueur ≥ 100 m), les transporteurs de véhicules, les navires-citernes et les remorqueurs associés aux activités du projet Trans Mountain formeraient des convois. Le bruit causé par toutes les autres classes de bâtiments qui diffusent au moyen du SIA a été inclus, mais ces bâtiments ne naviguaient pas en convois. L'analyse a tenu compte de l'ampleur et de la répartition temporelle des niveaux de bruit aux huit emplacements de récepteur d'essai situés dans le détroit Haro. Les résultats indiquent que les convois aux deux heures ont fait augmenter le niveau de bruit médian à la plupart des emplacements. Les convois aux quatre heures ont produit peu de changement et n'ont pas donné lieu à des réductions importantes du bruit durant les périodes entre le passage des groupes de bâtiments. Ces convois ont offert une très faible amélioration des statistiques du bruit médian et des autres centiles de bruit. L'absence d'amélioration offerte par la formation de convois sur le plan du bruit a été étonnante et a mené à une enquête plus approfondie. Lorsque le bruit des bâtiments ne naviguant pas en convois a été retiré, les résultats se sont considérablement améliorés. Par conséquent, l'absence d'avantages de cette approche est attribuable au bruit causé par les bâtiments ne naviguant pas en convois présents pendant les périodes silencieuses entre deux passages de convois. Fait important, cette étude ne tenait pas compte du bruit causé par les bateaux d'observation de baleines, qui créeraient davantage de bruit pour les épaulards résidents du Sud pendant les périodes entre les passages de convoi. Cela a réduit encore plus son efficacité. L'approche des convois peut être plus efficace dans des endroits comme Swiftsure Bank, où les grands bâtiments commerciaux représentent la plus grande partie du trafic. Une étude de suivi des convois dans cette région pourrait être utile. Toutefois, dans la présente étude, notre conclusion est que les convois ne sont pas avantageux dans la région du détroit Haro.

Autres méthodes d'atténuation du bruit des bâtiments La présente étude a permis d'examiner la documentation portant sur plusieurs autres approches d'atténuation. Les principales méthodes examinées comprenaient notamment les suivantes :

- Les solutions techniques concernant la conception et les améliorations des bâtiments
- Les changements opérationnels liés au comportement des exploitants
- Les changements opérationnels au sein de l'industrie du transport maritime, y compris les plans et le calendrier de chargement
- Les changements opérationnels liés à la gestion du trafic, ce qui sous-tend les limites de vitesse dynamiques, et les fermetures temporelles et spatiales de zone en raison de la surveillance en temps réel de la présence de baleines

Les changements à la conception des bâtiments, les améliorations apportées aux bâtiments et leur entretien régulier devraient être des objectifs à long terme permettant de réduire le bruit dans l'habitat de l'épaulard résident du Sud. Ces approches bénéficieraient également à d'autres habitats océaniques et entraîneraient un changement durable des niveaux de bruit sous-marin partout. Les changements de comportement des exploitants qui réduisent les niveaux de bruit comprennent l'évitement des accélérations soudaines des bâtiments, le maintien des limites de vitesse dans l'habitat essentiel et la réduction de la vitesse pour maintenir les distances suffisantes par rapport aux autres bâtiments et aux baleines. Ces changements peuvent être apportés grâce à une meilleure éducation, à une conformité volontaire, aux mesures incitatives des entreprises de transport maritime ou à des règlements, comme l'établissement de seuils de bruit maximaux pour l'accès à des habitats sensibles. Les plans de réglementation du trafic de bâtiments commerciaux à l'intérieur de l'habitat de l'épaulard résident du Sud, comme les limites de vitesse saisonnières ou dynamiques, ainsi que les fermetures temporelles et spatiales de zone pour une partie ou la totalité du trafic maritime, peuvent être les moyens les plus rapides et les plus efficaces de réduire le bruit. La réduction du bruit et, aspect plus important encore, l'amélioration de la qualité acoustique de l'habitat de l'épaulard résident du Sud devront être évaluées scientifiquement (par une modélisation et des mesures in situ), car des hypothèses erronées sont facilement formulées.

CONTENTS

FIGURES

TABLES

GLOSSARY

1/3-octave-band
Non-overlapping passbands that are one-third of an octave wide (where an octave is a doubling of frequency). Three adjacent 1/3-octave-bands comprise one octave. One-third-octave-bands become wider with increasing frequency. Also see octave.

absorption
The reduction of acoustic pressure amplitude due to conversion of acoustic particle motion energy to heat in the propagation medium.

ambient noise
All-encompassing sound at a given place, usually a composite of sound from many sources near and far (ANSI S1.1-1994 R2004), e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

attenuation
The gradual loss of acoustic energy from absorption and scattering as sound propagates through a medium.

audiogram
A graph of hearing threshold level (sound pressure levels) as a function of frequency, which describes the hearing sensitivity of an animal over its hearing range.

audiogram weighting
The process of applying an animal's audiogram to sound pressure levels (SPL) to determine the sound level relative to the animal's hearing threshold (HT). Audiogram-weighted SPL have units of dB re HT.

broadband sound level
The total sound pressure level measured over a specified frequency range. If the frequency range is unspecified, it refers to the entire measured frequency range.

cavitation
A rapid formation and collapse of vapor cavities (i.e., bubbles or voids) in water, most often caused by a rapid change in pressure. Fast-spinning vessel propellers typically cause cavitation, which creates a lot of noise.

continuous sound
A sound whose sound pressure level remains above ambient sound during the observation period (ANSI/ASA S1.13-2005 R2010). A sound that gradually varies in intensity with time, for example, sound from a marine vessel.

decibel (dB)
One-tenth of a bel. Unit of level when the base of the logarithm is the tenth root of ten, and the quantities concerned are proportional to power (ANSI S1.1-1994 R2004).

frequency
The rate of oscillation of a periodic function measured in cycles-per-unit-time. The reciprocal of the period. Unit: hertz (Hz). Symbol: *f*. 1 Hz is equal to 1 cycle per second.

geoacoustic
Relating to the acoustic properties of the seabed.

harmonic
A sinusoidal sound component that has a frequency that is an integer multiple of the frequency of a sound to which it is related. For example, the second harmonic of a sound has a frequency that is double the fundamental frequency of the sound.

hearing threshold
The sound pressure level for any frequency of the hearing range that is barely audible for a given individual in the absence of substantial background noise during a specific percentage of experimental trials.

hertz (Hz)
A unit of frequency defined as one cycle per second.

intensity, acoustic
The amount of acoustic energy flowing through a unit area perpendicular to the direction of propagation, per unit time. Unit: W/m^2.

median
The 50th percentile of a statistical distribution.

octave
The interval between a sound and another sound with double or half the frequency. For example, one octave above 200 Hz is 400 Hz, and one octave below 200 Hz is 100 Hz.

parabolic equation method
A computationally-efficient solution to the acoustic wave equation that is used to model transmission loss. The parabolic equation approximation omits effects of back-scattered sound, simplifying the computation of transmission loss. The effect of back-scattered sound is negligible for most ocean-acoustic propagation problems.

power spectrum density
The acoustic signal power per unit frequency as measured at a single frequency. Unit: $\mu Pa^2/Hz$, or $\mu Pa^2 \cdot s$.

power spectral density level
The decibel level ($10\log_{10}$) of the power spectrum density, usually presented in 1 Hz bins. Unit: dB re 1 $\mu Pa^2/Hz$.

pressure, acoustic
The deviation from the ambient hydrostatic pressure caused by a sound wave. Also called overpressure. Unit: pascal (Pa). Symbol: *p*.

pressure, hydrostatic
The pressure at any given depth in a static liquid that is the result of the weight of the liquid acting on a unit area at that depth, plus any pressure acting on the surface of the liquid. Unit: pascal (Pa).

received level
The sound level measured (or that would be measured) at a defined location.

rms
root-mean-square.

shear wave
A mechanical vibration wave in which the direction of particle motion is perpendicular to the direction of propagation. Also called secondary wave or S-wave. Shear waves propagate only in solid media, such as sediments or rock. Shear waves in the seabed can be converted to compressional waves in water at the water-seabed interface.

signature
Pressure signal generated by a source.

sound
A time-varying pressure disturbance generated by mechanical vibration waves travelling through a fluid medium such as air or water.

sound exposure
Time integral of squared, instantaneous frequency-weighted sound pressure over a stated time interval or event. Unit: pascal-squared second ($Pa^2 \cdot s$) (ANSI S1.1-1994 R2004).

sound exposure level (SEL)
A cumulative measure related to the sound energy in one or more pulses. Unit: dB re 1 $\mu Pa^2 \cdot s$. SEL is expressed over the summation period (e.g., per-pulse SEL [for airguns], single-strike SEL [for pile drivers], 24-hour SEL).

sound field
Region containing sound waves (ANSI S1.1-1994 R2004).

sound pressure level (SPL)
The decibel ratio of the time-mean-square sound pressure, in a stated frequency band, to the square of the reference sound pressure (ANSI S1.1-1994 R2004).

For sound in water, the reference sound pressure is one micropascal (p_0 = 1 μPa) and the unit for SPL is dB re 1 μPa:

$$\mathrm{SPL} = 10\log_{10}\left(p^2 / p_0^2\right) = 20\log_{10}\left(p / p_0\right) \ .$$

Unless otherwise stated, SPL refers to the root-mean-square sound pressure level. See also 90% sound pressure level and fast-average sound pressure level. Non-rectangular time window functions may be applied during calculation of the rms value, in which case the SPL unit should identify the window type.

sound speed profile
The speed of sound in the water column as a function of depth below the water surface.

source level (SL)
The sound level measured in the far-field and scaled back to a standard reference distance of 1 metre from the acoustic centre of the source. Unit: dB re 1 μPa @ 1 m (sound pressure level) or dB re 1 $\mu Pa^2 \cdot s$ (sound exposure level).

spectrum
An acoustic signal represented in terms of its power (or energy) distribution compared with frequency.

thermocline

The depth interval near the ocean surface that experiences temperature gradients due to warming or cooling by heat conduction from the atmosphere and by warming from solar heating.

transmission loss (TL)
The decibel reduction in sound level between two stated points that results from sound spreading away from an acoustic source subject to the influence of the surrounding environment. Also called propagation loss.

wavelength
Distance over which a wave completes one oscillation cycle. Unit: meter (m). Symbol: λ.

1. INTRODUCTION

The International Maritime Organization (IMO) recognizes that underwater noise from commercial ships may have short- and long-term negative consequences on marine life, especially on marine mammals. The Salish Sea is an important habitat for several marine mammal species, including the endangered Southern Resident Killer Whale (SRKW; SARA 2002). Much of the SRKW critical habitat lies within the Salish Sea near high-traffic shipping lanes. The SRKW population, therefore, experiences substantial levels of noise from commercial vessels. Expected increases in shipping activity in the Salish Sea could lead to further increases in these noise levels. Man-made noise, which includes vessel noise, has the potential to disturb or injure marine animals. Man-made noise has been identified as a factor that hinders recovery of the SRKW population (DFO 2011). Strategic management of this future vessel traffic will be necessary to ensure marine fauna in the region are not exposed to substantial increases in underwater noise. Transport Canada recognizes the need to examine existing and projected underwater noise conditions in the Salish Sea due to present and projected increases in vessel traffic, and to investigate the effectiveness of options for reducing vessel noise exposures to marine fauna. This report describes a study performed to quantify vessel noise exposures and noise mitigation options using specialized computer noise models.

1.1. Study Overview

In this study, a specialized vessel noise model is used to examine the effectiveness of several potential mitigation approaches for reducing vessel noise, primarily within key SRKW critical habitat areas of the Salish Sea. A shipping noise model (developed by JASCO Applied Sciences) is used to calculate 1-month equivalent continuous underwater noise levels (L_{eq}). The model is also applied in time-dependent mode to calculate sound pressure levels (SPL) in 1-minute steps, from which 24-hour noise distributions are calculated throughout the study areas. Each model scenario represents a potential mitigation option affecting vessel traffic and/or operating conditions. The model results allow corresponding noise level to be examined and compared with baseline (present) levels. Other noise mitigation options are discussed based on published information about sound emitted by various vessel component (e.g., propellers and onboard machinery), and sound associated with various operational procedures.

The vessel noise model requires inputs including the vessel noise emission levels, densities, and speed for each vessel class. It also incorporates oceanographic data such as ocean temperature, salinity profiles, water depth variations, and seabed layer properties. Wind and ambient noise are also accounted for in the time-dependent scenarios. A large range of sound frequencies (from 10 Hz to 63 kHz) is used to model the results. This range covers frequencies emitted by ships, frequencies used by killer whales for communication, and a considerable range of frequencies used for echolocation (echolocation clicks can extend to frequencies up to and above 100 kHz). It is important to assess the frequency-dependence of noise because noise emissions from ships vary substantially across the frequencies (most sound energy is below 1 kHz), animal hearing is frequency-dependent (killer whale hearing sensitivity is generally best between 15–30 kHz; Branstetter et al. 2017), and sound propagation in the ocean varies with frequency.

For this study, vessel noise levels were obtained from a database of measurements recorded at the Strait of Georgia Underwater Listening Station (ULS) by JASCO for the Enhancing Cetacean Habitat Observations (ECHO) program, under a collaboration with Vancouver Fraser Port Authority and Ocean Networks Canada. Vessel density and speed information for multiple commercial, government, and recreational vessel classes in the Salish Sea, were derived from a high-resolution Automated Identification System (AIS) dataset that contains the location of many thousands of vessels (MarineTraffic 2017). This information was extracted for two 1-month periods: January and July 2015, representing winter and summer baseline conditions, respectively. We prepared maps of vessel densities and speed grids for different vessel classes, covering a large region of the Salish Sea and a smaller focus region encompassing Haro Strait.

The results constitute the "baseline" vessel density information. We also synthesized vessel density and speed data for traffic from oil tankers and assisting tugs, based on Trans Mountain's forecast (NEB 2016) of vessel activity as of December 2019. The Tran Mountain future tanker and tug densities were added to the baseline vessel densities to produce the projected (i.e., future) vessel density information for July 2020.

Sound levels were modelled over large regions, and tabulated at fixed sample locations in the SRKW habitat, to evaluate the baseline and projected distribution of noise levels and the differences produced by mitigations. For most scenarios, vessel noise was assessed as a monthly average. Results are presented as maps showing the spatial distribution of L_{eq}. The monthly L_{eq} was calculated similar to the 8-hour L_{eq} used for human workplace noise assessments, but using a much longer averaging time (1 month versus 8 hours). Since L_{eq} is a time average, it does not provide information about time-variability within the averaging period. Time variability is important for certain analysis, such as for determining the fraction of time that sound levels exceed marine mammal effects thresholds.

For scenarios that alter the timing and speed of vessel passes, the model was applied in time-dependent mode. In this mode, the model produced a 4-D (3 spatial coordinates plus time) version of the vessel noise field over a representative day, in time steps of 1 minute. Results from the time-dependent analysis are presented as SPL temporal variation plots and cumulative distribution functions at eight sample locations of key importance for SRKW. These result formats provide information about the fraction of time animals would be exposed to sounds above important sound level thresholds. These results are useful for interpreting the amount of time that exposures could be high enough to significantly disturb animals and reduce foraging efficiency.

This report is divided into three main sections. Section 2 presents an overview of the scenarios and methods used; more detailed descriptions of the methods are proved in Appendices A–D. Section 3 presents the results for the modelled noise mitigation scenarios and other noise mitigation options. Section 4 discusses the results.

2. METHODS

Cumulative noise modelling for all shipping traffic over specified time intervals is performed for the following scenarios, described in Section 2.2:

- Unmitigated baseline traffic,
- Unmitigated projected traffic, and
- The following mitigation approaches:
  - Implementing a vessel slow-down zone,
  - Restricting traffic during a specific time of day (no-go period),
  - Replacing 10% of noisiest ships,
  - Reducing source levels of specific vessel classes,
  - Adjusting the traffic lanes in Haro Strait, and
  - Grouping vessel into convoys.

Cumulative noise levels are calculated over a common timeframe of 1 month for all scenarios, except convoying. A time-dependent version of the model is used for the convoying scenarios over a 24-hour period. The effectiveness of additional mitigation approaches, described in Section 2.3, are qualitatively assessed through a literature review.

To produce time-averaged or time-dependent acoustic field maps, the cumulative noise model requires three main input parameters, shown in Figure 1:

- A representation of the vessel traffic throughout the study area, including individual vessel types, sail tracks, vessel densities, and speeds by class (Vessel Traffic Data),
- A description of how sound propagates away from a vessel at any location in the study area (Sound Propagation Curves), and
- A description of the noise emitted by each vessel (Vessel Source Levels).

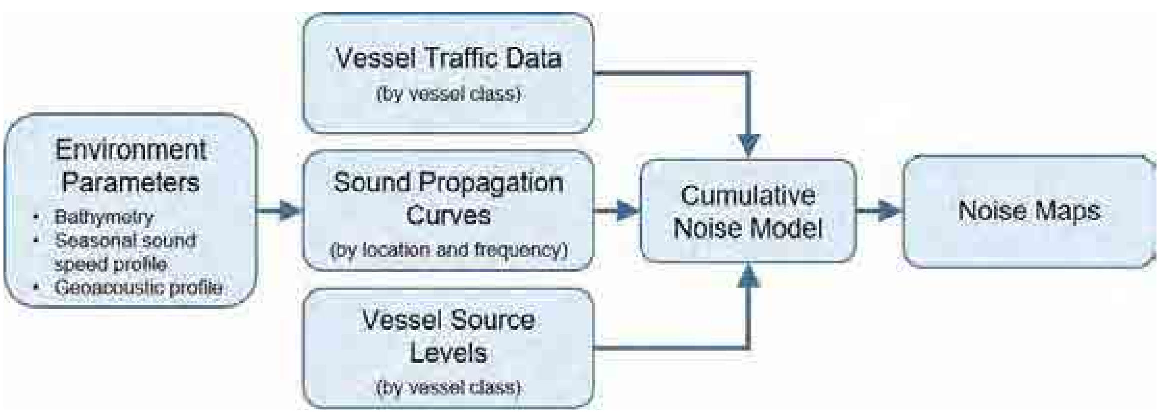


Figure 1. High-level flow chart of cumulative noise model inputs and outputs.

The sound propagation curves are computed by the noise model's internal algorithms. These calculations are independent of the modelled vessel scenarios. They account for the ocean environment at all locations in the study area. Vessel traffic densities, speeds, and source levels are adjusted based on the mitigation characteristics of each scenario.

Projected and mitigated scenarios are developed by increasing the vessel density of the tanker and tug classes to represent increases in the number of these vessels, as proposed by Trans Mountain's assessment (NEB 2016). Section 2.2 describes the modelled scenarios; the other mitigation options, listed in Section 2.3, are not modelled but instead are assessed based on published information from other studies. Sections 2.4–2.5 describe components of cumulative noise model flow chart presented in Figure 1.

We considered the following 11 vessel classes, described in Appendix B:

- Container,
- Ferry (roll-on/roll-off (Ro-ro) passenger ferries, Ro-ro cargo ferries, and Clipper ferries),
- Fishing,
- Government,
- Merchant,
- Passenger,
- Recreational,
- Tanker,
- Tug,
- Vehicle carrier, and
- Other/miscellaneous.

2.1. Study Area

The studied area, seen in Figure 2, covers the southeastern part of the Salish Sea, BC. It includes critical habitat for SRKW shown in Figure 3. This area is analyzed over two grid resolutions:

- **Regional Study Area**: A large grid (208 × 184 km) covering the southeast portion of the Salish Sea (from the western entrance of the Strait of Juan de Fuca, around the south end of Vancouver Island, and north through the Strait of Georgia; purple dashed line in Figure 2), with a grid resolution of 800 × 800 m, and
- **Local Study Area**: A small grid (50 × 50 km) extending 5 km outside the Haro Strait Boundary (purple solid line in Figure 2), with a grid resolution of 200 × 200 m.

Baseline noise levels are modelled on both grid resolutions so that unmitigated and mitigated projected scenarios can be easily compared. The projected noise levels and mitigated projected noise levels for the scenarios of replacing 10% of noisiest ships and reducing source levels are modelled over the regional grid. Mitigation scenarios for the slow-down zone, no-go period, adjusting traffic lanes, and convoying are limited to Haro Strait, and thus are modelled over the smaller, higher-resolution, local grid.

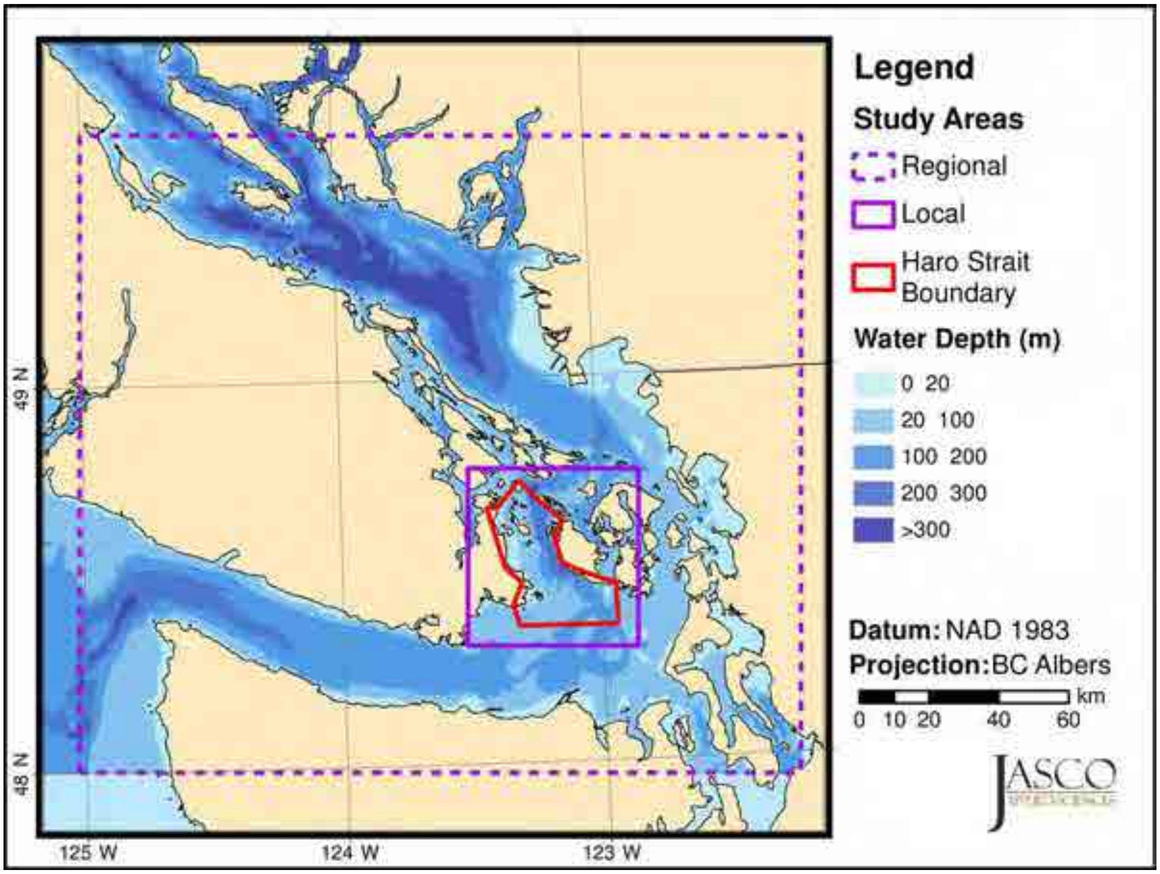


Figure 2. Extent of the two model areas referenced as the Regional (dash line) and Local (solid line) study areas.

The critical habitat for SRKW extends from Swiftsure Bank to the southeast region of the Strait of Georgia, and south into US waters off Washington State, as seen in Figure 3. All southern resident pod groups (J, K, and L) share a core region in Haro Strait, notably during spring, summer, and fall (Osborne 1999, Wiles 2004). In addition, J-pod inhabits northern Rosario Strait and areas near Active Pass, while the L-pod is often encountered in an area south of Vancouver Island in the Strait of Juan de Fuca. The location of SRKWs in winter is less understood, but whales seem to visit the Salish Sea occasionally (DFO 2011).

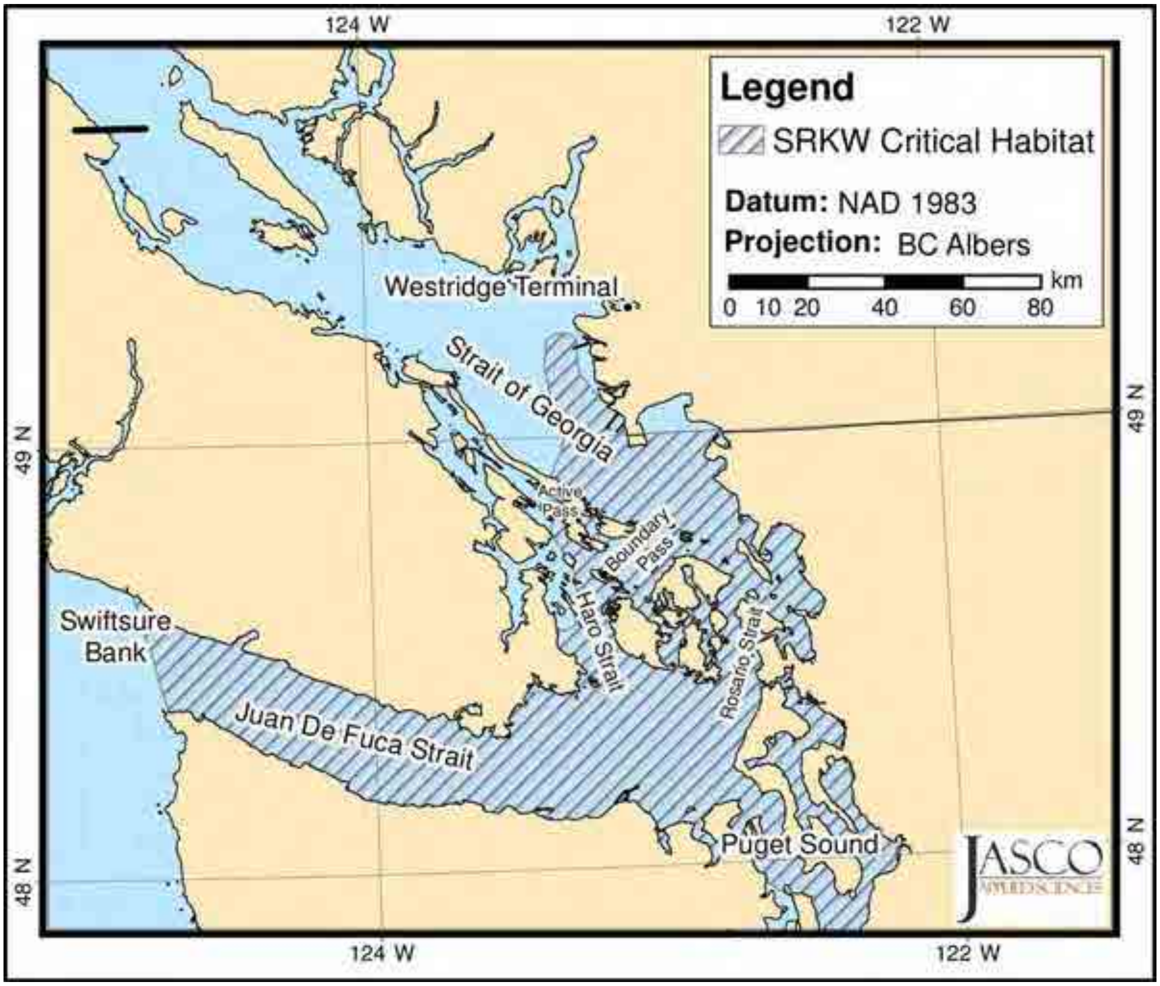


Figure 3. Overview of the SRKW critical habitat (DFO 2011).

Figure 4 shows the summer density of SRKW within the critical habitat shown in Figure 3. Eight sites in the Haro Strait model region have been selected to sample the noise fields at key locations within the SRKW habitat and in regions of high vessel density close to the traffic lanes. These sample locations are shown in Figure 5 and listed in Table 1. Sample location 1 represents an important area where SRKW travel and forage before entering Haro Strait. Sample locations 2–5, located along the shore of San Juan Island, are within important feeding areas with high SRKW density in the summer (Hauser et al. 2007). Sample location 6 is the northernmost sample location. SRKW are likely present there in summer and winter. Sample locations 6–8 are located within the shipping lanes. Results at these locations are relevant for assessing the temporal variation in noise levels, like those presented for the convoying scenarios. The monthly-averaged results (for all other scenarios) at these locations are largely influenced by the exact transit of the simulated traffic; a slight change in the position of the simulated traffic could substantially affect the results because the locations are near the ships' tracks. Thus, sample locations 1–5 are best suited for assessing the effects of most mitigation approaches.

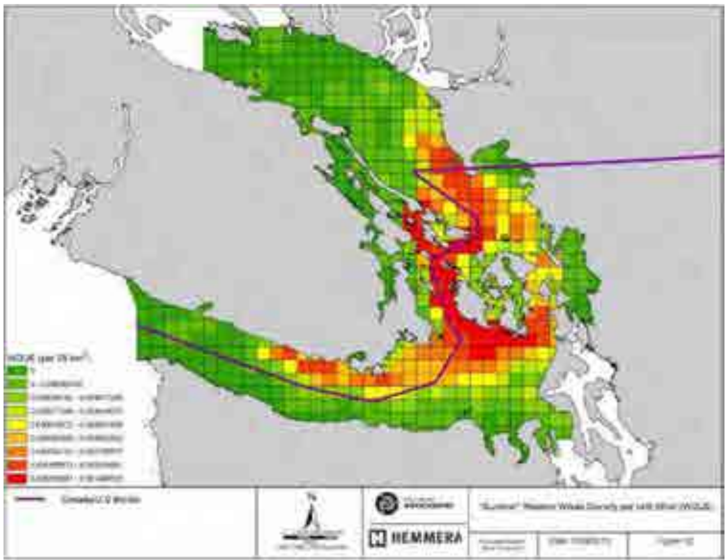


Figure 4. Relative summer killer whale density.[1] (Hemmera and SMRU 2014, Figure 12).

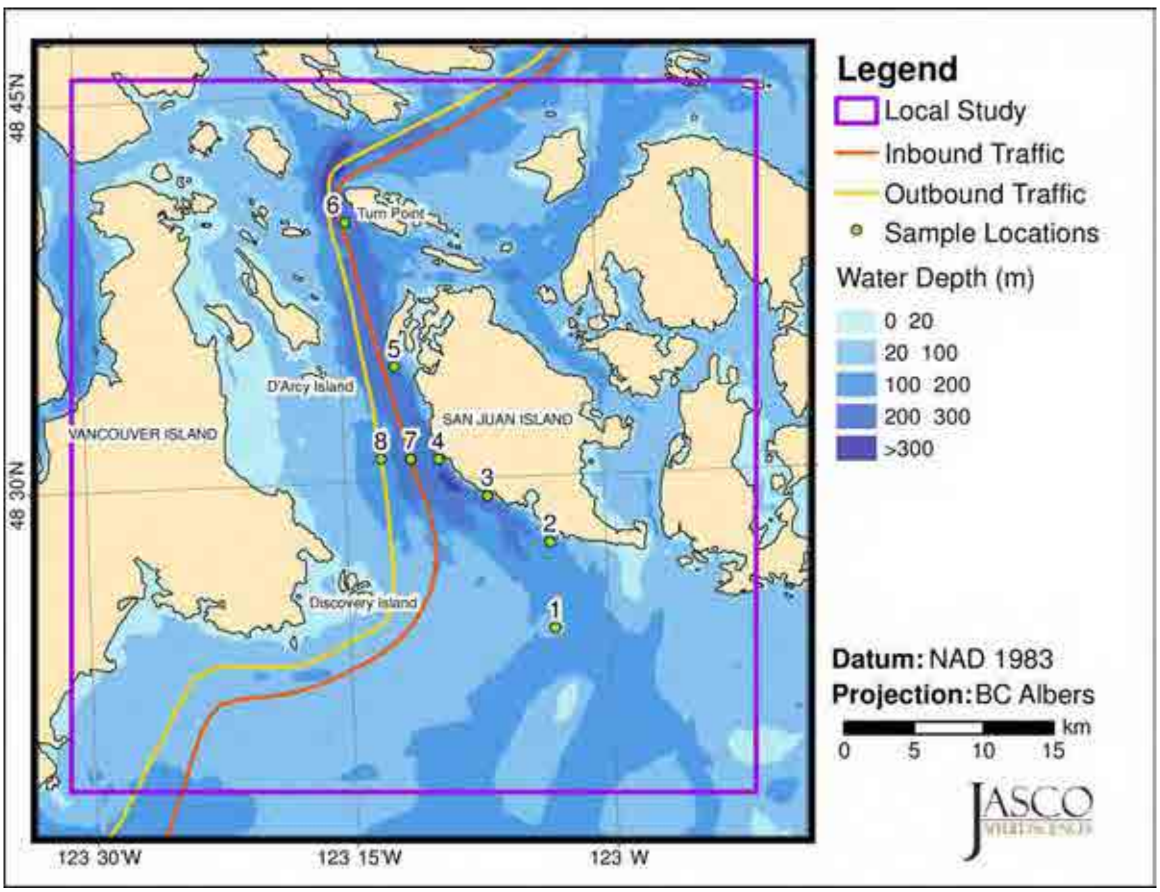


Figure 5. Noise field sample locations for the SRKW critical habitat relative to shipping lanes.

[1] Relative killer whale density per unit of effort per 25 km^2. This map does not include effort and related DFO sightings along the west coast of Vancouver Island and Brian Gisborne's Swiftsure sightings (Personal communication with Dr Dom Tollit; Hemmera and SMRU 2014).

Table 1. Noise field sample locations in the Haro Strait Boundary.

Sample location	Description	Easting/Northing (m), BC Albers Projection		Latitude	Longitude
1	South Haro Strait/Juan de Fuca	1218680 E	380765 N	48° 24' 06.0100" N	123° 03' 07.7198" W
2	South San Juan	1218303 E	386920 N	48° 27' 26.0500" N	123° 03' 13.5601" W
3	Central South San Juan	1213787 E	390220 N	48° 29' 19.0400" N	123° 06' 46.2100" W
4	Central San Juan	1210304 E	392842 N	48° 30' 48.5900" N	123° 09' 30.2101" W
5	North San Juan/Henry Island	1207105 E	399437 N	48° 34' 26.4900" N	123° 11' 52.9901" W
6	Stuart Island	1203577 E	409760 N	48° 40' 05.5200" N	123° 14' 25.0598" W
7	Inbound Traffic Lane	1208303 E	392857 N	48° 30' 51.6626" N	123° 11' 07.4354" W
8	Outbound Traffic Lane	1206185 E	392843 N	48° 30' 53.9157" N	123° 12' 50.3791" W

2.2. Modelled Noise Mitigation Scenarios

Table 2 summarizes the baseline, projected, and mitigated modelled scenarios, as well as the literature-based scenarios. The subsections below provide a full description of each scenario.

Table 2. List of scenarios, the modelled area, and time of year.

Scenario	Description	Study area	Time of year
Modelled Mitigation Options			
Baseline	Current vessel traffic	Regional	January
		Regional	July
		Local	July
Projected	Current vessel traffic plus projected increase in tanker and tug traffic due to the Trans Mountain project	Regional	July
		Local	
Slow-down zone	Slow-down zone applied to commercial vessels	Local	July
No-go period	Period of restricted traffic, applied to commercial vessels from midnight to 04:00	Local	July
Replacing noisiest vessels	Replacing 10% of noisiest commercial vessels with quieter vessels of the same class	Regional	July
Reducing source levels	Reducing all commercial vessel noise levels by a fixed amount at all frequencies	Regional	July
Adjusting traffic lanes in Haro Strait	Adjusting a portion of the traffic lanes westward, away from SRKW habitat	Local	July
Convoying	Convoying commercial vessels in 2-hour intervals	Local	July
	Convoying commercial vessels in 4-hour intervals	Local	July
Other Noise Mitigation Options			
Retrofitting vessels	Retrofitting vessels with technologies to reduce noise emissions	No modelling (literature review)	N/A
Replacing tugs	Replacing Trans Mountain tugs with noise-reduced tugs		
Changing ship designs	Changing ship designs to reduce noise emission		
Changing maintenance	Changing ships' maintenance cycle in areas relating to noise emission		
Changing operator behaviour	Changing operational behaviours such reducing acceleration rate in sensitive area		
Changing shipping practices	Changing shipping practices such as the number of tugs required and the use of onboard machinery		
Applying real-time mitigation	Applying real-time mitigation such as whale avoidance and speed reduction in hot spot areas		
Adjusting traffic lanes in Juan de Fuca Strait	Applying possible changes in traffic lanes in areas other than Haro Strait		
Using larger vessels	Using larger vessels to reduce the number of transits required		

2.2.1. Baseline Noise Levels

This scenario represents the current conditions in winter and summer over the Regional Study Area. The vessel noise levels are modelled using AIS vessel data from January and July 2015. We use these baseline levels to find seasonal variations in noise levels and changes associated with increasing shipping noise from projected additions of Trans Mountain vessel traffic, as described in Section 2.2.2. We produced results for both months over the Regional Study Area. We also produced results for July over the Local Study Area, seen in Figure 5.

2.2.2. Projected Noise Levels

This scenario assesses the increase in noise levels associated with the increase in vessel traffic for Trans Mountain's expanded shipping requirements, expected to begin in December 2019. The modelled levels include all traffic from the baseline scenario plus tankers and tugs sailing along the inbound and outbound traffic lanes between Swiftsure Bank, off the mouth of Juan de Fuca Strait, and the Westridge Marine Terminal in Burrard Inlet. These locations are indicated in Figure 6. We estimate that over 1 month, 29 new tankers will be required to export petroleum products from the Westridge Terminal. These new vessels will sail independently along the inbound route. One tug will escort each tanker along the outbound route. The 29 escort tugs will then sail back to Westridge terminal, along the inbound route. The position and speed of each vessel is simulated along the traffic lanes (inbound and outbound, as seen in Figure 6; also discussed in Section 2.4.2) and added to the baseline vessel density and speed data. The projected levels are modelled for July over both model areas (Regional and Local; as seen in Figure 5).

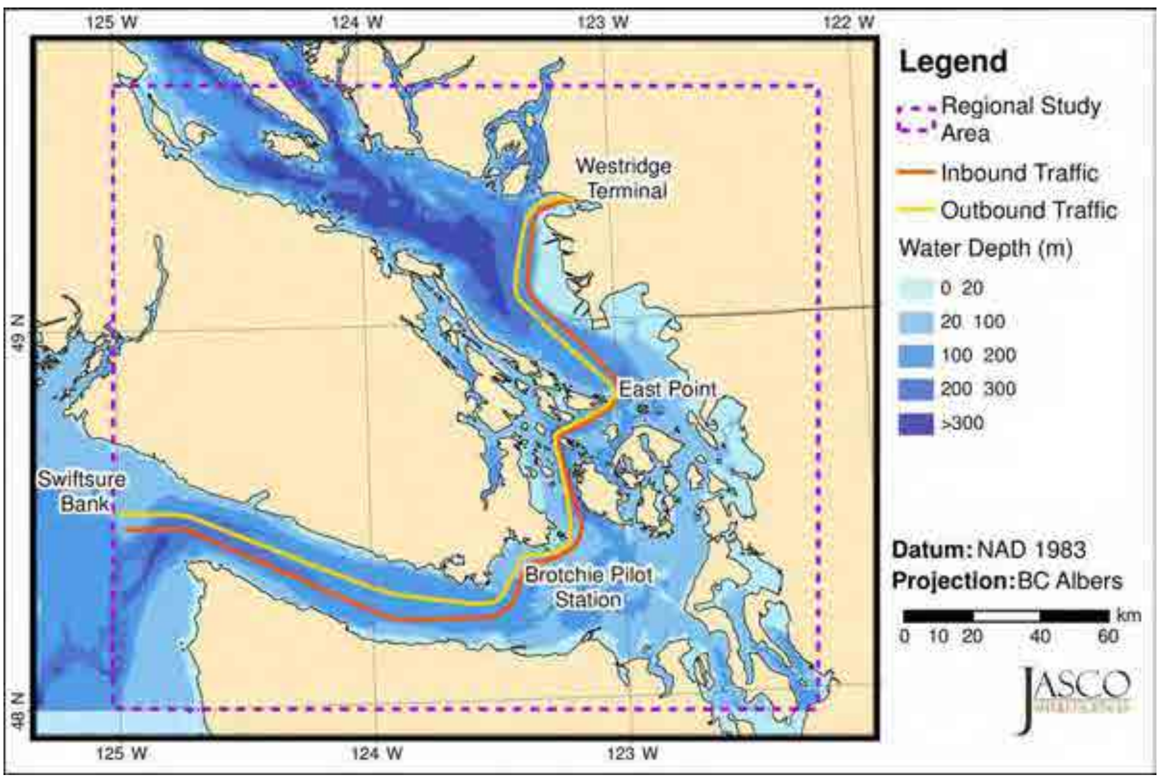


Figure 6. Traffic routes used in simulating marine traffic for Trans Mountain tankers and tugs.

2.2.3. Mitigated Noise Levels

2.2.3.1. Implementing a Slow-Down Zone

This mitigation scenario explores implementing a 'slow-down zone' where ships are required to adhere to a speed limit through Haro Strait. The simulated zone is shown in Figure 7. Changes in sound levels are evaluated for maximum speeds of 11, 10, and 7 knots. We use transition zones to model gradual changes in vessel speed as they approach and depart the slow-down zone. In the transition zone, vessels are assumed to travel at a speed that is half way between their unmitigated speed (based on average speeds used for baseline scenario) and the maximum speed in the slow-down zone.

All vessel traffic included in the projected scenario (baseline vessel classes plus additional Trans Mountain tankers and tugs) is also included in this scenario. Only specific vessel classes would have to adhere to the slow-down limit: Container, Ferry, Merchant, Passenger (≥100 m in length), Tanker, Tug, and Vehicle carrier. Since the slow-down zone only effects vessel traffic in Haro Strait, this scenario is only modelled over that area.

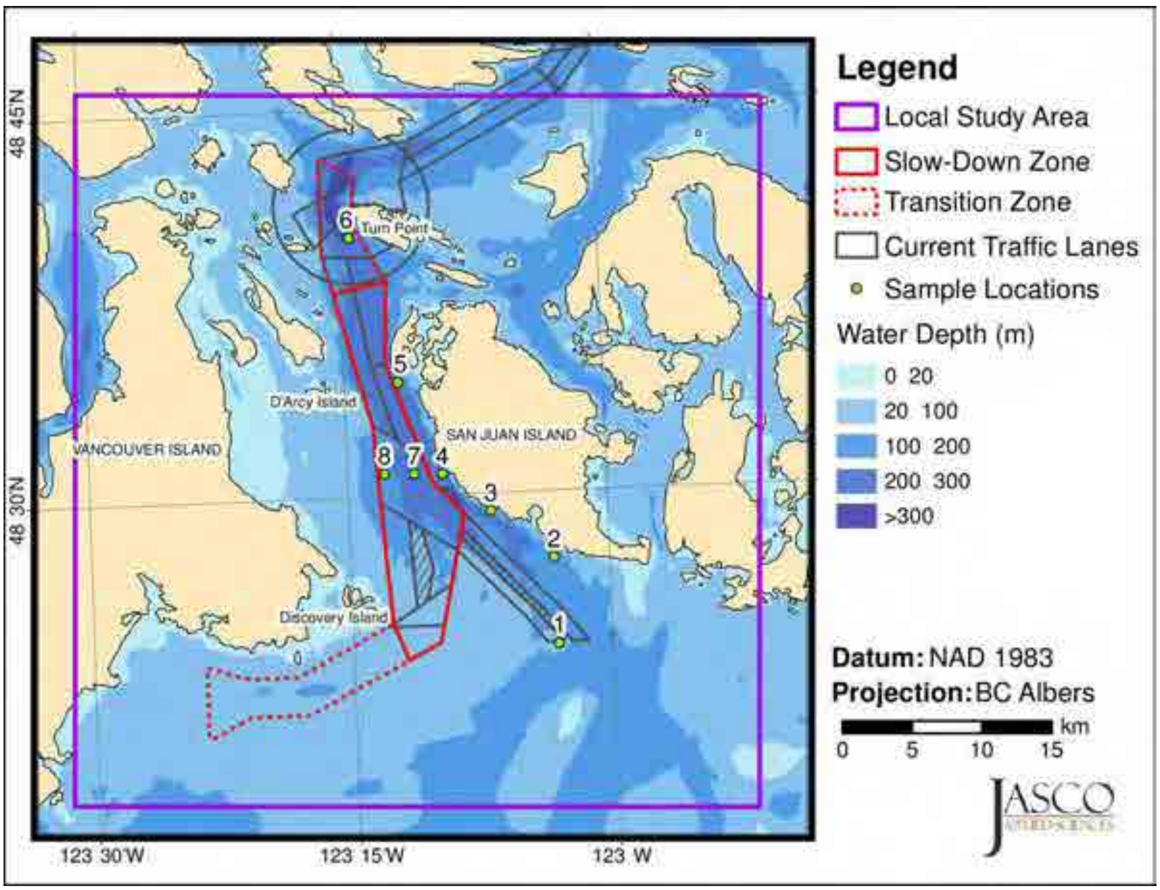


Figure 7. Extent of the modelled slow-down zone (solid red line) and speed transition zones (dash red lines).

2.2.3.2. Implementing a No-Go Period

The no-go mitigation scenario is based on restricting commercial vessel traffic in Haro Strait from midnight to 04:00. The purpose of this mitigation approach is to create a quieter period that marine mammals can use for important activities such as foraging, communicating, and resting. The restricted vessel classes in the no-go periods are Container, Ferry, Merchant, Passenger (≥100 m in length), Tanker, Tug, and Vehicle carrier. It is assumed that all vessels in these classes would delay their transit through Haro Strait to sail during unrestricted hours, as opposed to cancelling their transit. Thus, we modelled two time frames and produced two monthly average noise maps:

- **Midnight to 04:00**: Only vessels in the unrestricted classes are present. Traffic density for these classes is proportional to that recorded in the AIS database during the restricted hours, and listed in Table 3.
- **04:00 to midnight**: All vessel classes are present. Traffic density for the restricted classes is scaled up for the percentage of transits that were postponed. Traffic density for the unrestricted classes is proportional to that recorded in the AIS database during the unrestricted hours, and listed in Table 3.

Since the no-go period only effects vessels transiting though Haro Strait, this scenario is only modelled in that area.

Table 3. Percentage of traffic density applied to the restricted (midnight to 04:00) and unrestricted (04:00 to midnight) periods with and without no-go mitigation.

Vessel class	Baseline (unmitigated)		Mitigated	
	Restricted period	Unrestricted period	Restricted period	Unrestricted period
Container	20	80	0	100
Ferry (Ro-ro Passenger)	0	100	0	100
Ferry (Ro-ro Cargo)*	24	76	24	76
Ferry (Clipper)	0	100	0	100
Fishing	17	83	17	83
Government	11	89	11	89
Merchant	16	84	0	100
Other	8	92	8	92
Passenger (≥ 100 m)	38	62	0	100
Passenger (< 100 m)	0	100	0	100
Recreational	0	100	0	100
Tanker	15	85	0	100
Tug	22	78	0	100
Vehicle carrier	20	80	0	100

* This vessel class does not transit through the restricted zone (Haro Strait).

2.2.3.3. Replacing 10% of Noisiest Ships

This mitigation scenario removes 10% of the noisiest vessels in specific vessel classes and replaces them with quieter vessels. The affected vessel classes are: Container, Fishing, Merchant, Passenger (≥100 m in length), Tanker, Tug, and Vehicle carrier. For each affected vessel class, the mean source level spectrum, based on JASCO and Port of Vancouver's proprietary database of vessel noise measurements, are computed by replacing the 10% of the measurements with the highest broadband source level with the 10% of the measurements with the lowest source level. Noise levels are then modelled using the same traffic density and speed values as for the projected levels, but with the lower mean source levels for the affected vessel classes.

For this mitigation approach, two criteria are used to select the 10% of noisiest (and quietest) ships: (1) unweighted and (2) audiogram-weighted broadband source levels are used to rank ships within each class. More details are provided in Appendix D.

2.2.3.4. Reducing Source Levels of Classes of Concern

This mitigation scenario reduces the source levels for commercial classes of concern by 3 and 6 dB. The affected vessel classes are: Container, Merchant, Passenger (≥100 m in length), Tanker, Tug, and Vehicle carrier. For each of these classes, the mean source level spectrum, based on JASCO and Port of Vancouver's proprietary database of vessel noise measurements, are reduced by 3 and 6 dB across all modelled frequencies. Noise levels are modelled using the same traffic density and speed values as for the projected levels, but with the lower mean source levels for the affected vessel classes.

2.2.3.5. Adjusting Traffic Lanes–Haro Strait

This mitigation scenario investigates the effect of rerouting the shipping lanes in southern Haro Strait, away from key SRKW habitat along the southwest coast of San Juan Island. The shoals northeast of Discovery Island (dashed area in Figure 8) constrain the possible lane adjustments in that area. It is necessary to move the northbound (inbound) lane from the east side of the shoal to its west side, where the existing southbound (outbound) lane already passes. This move requires the traffic lanes to be narrowed so the south and north lanes can pass west of the shoals. This change may benefit commercial traffic because it shortens the total length of the inbound (north) shipping lane. The physical blocking of sound propagation by the shoal should also improve underwater noise conditions (reduced noise levels) for SRKW along the coast of San Juan Island.

To reroute commercial traffic through the new shipping lanes, all transits that passed through Haro Strait are mitigated by either simulating the full track through the new lanes, or by manually moving transit waypoints for a portion of the track. Tracks are simulated if transiting from Juan de Fuca to Vancouver (inbound or outbound) and manually mitigated if taking a different route (e.g., to/from the USA or north through Vancouver Islands).

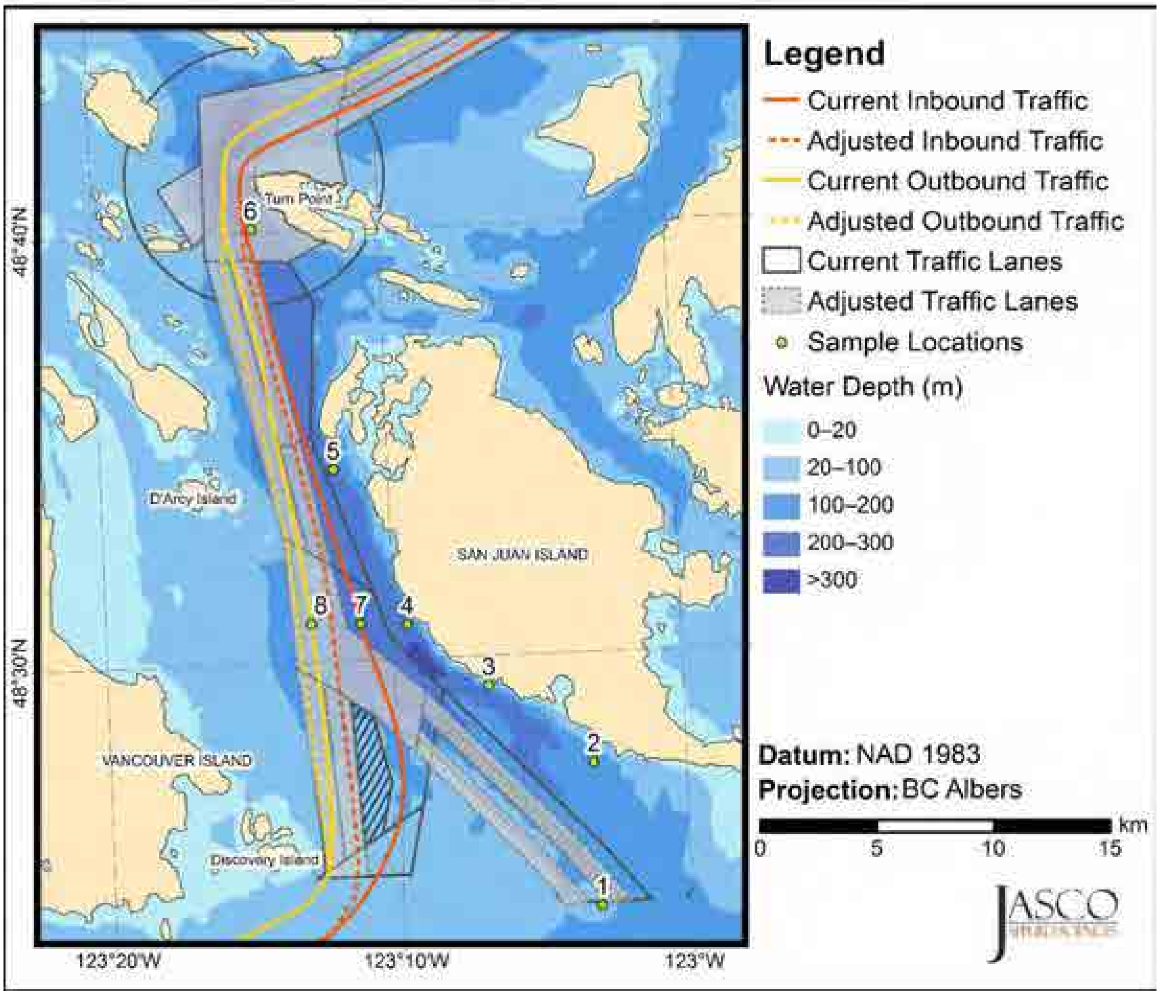


Figure 8. Current and proposed shipping routes for adjusted shipping lanes mitigation scenario.

2.2.3.6. Implementing Vessel Convoys

The convoying mitigation scenario considers commercial vessels transiting through Haro Strait in groups (convoys) every few hours, instead of their present (somewhat random) schedules. This would create quiet periods between convoys during which animals might be exposed to less vessel noise. We based this analysis on the actual traffic during July 29, 2015, which is nominally a representative day for July, based on number of vessels and class distributions in Haro Strait. Vessel classes included in convoys are Container, Merchant, Passenger (≥100 m in length), Vehicle Carrier, Tanker, and Tugs associated with Trans Mountain operations.

The convoy corridor lies between the north and south boundary of Haro Strait, as seen in Figure 9. Only one convoy at a time is present in the corridor (i.e., inbound and outbound convoys alternate their entrance in the corridor with a regular time interval). Intervals of 2 and 4 hours are modelled. The convoy speed is limited to 10 knots, in accordance with the speed of outbound Trans Mountain escorted tankers and to accommodate vessels with lower speed requirements. Vessels within a convoy transit in a single file, with a separation of 1000 m (from stern of the forward ship to bow of the following ship).

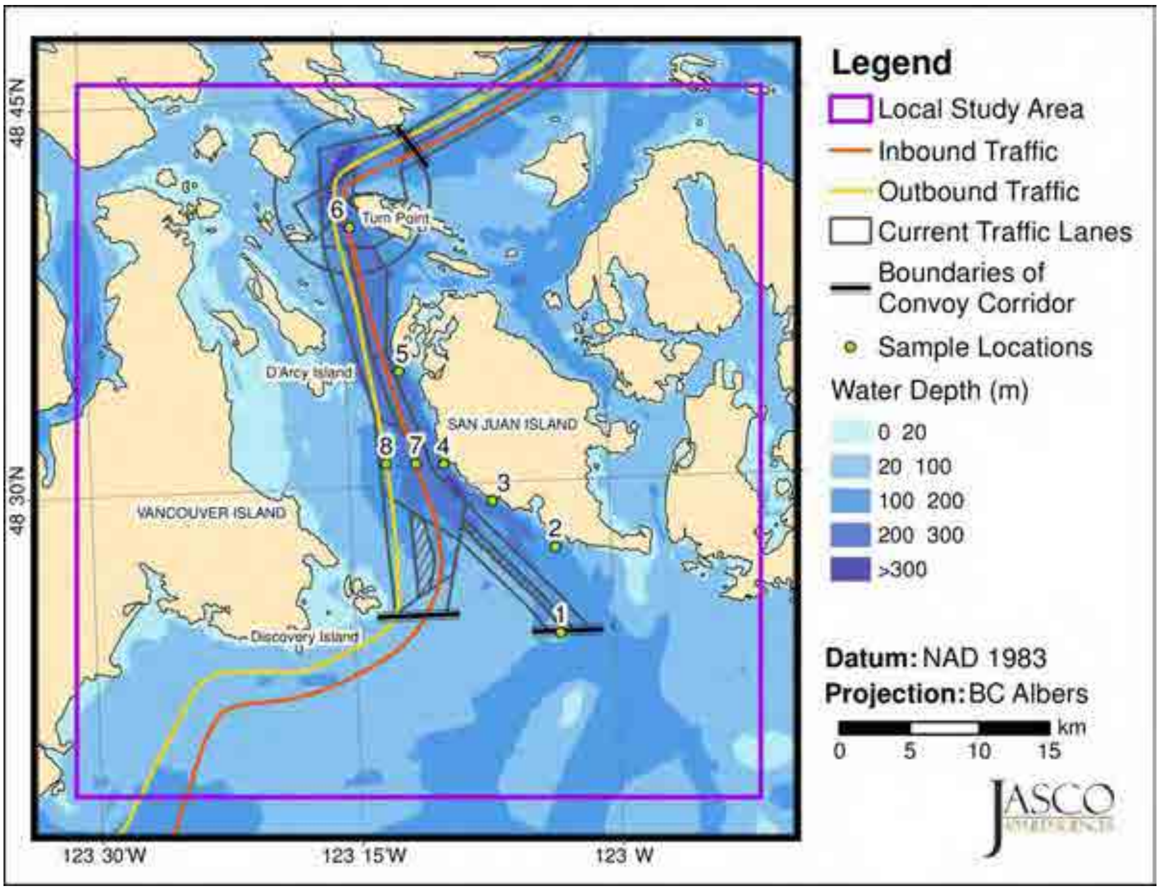


Figure 9. Boundaries of convoy corridor through Haro Strait.

2.3. Other Noise Mitigation Options

Nine mitigation approaches are assessed in a qualitative sense, because of the variety of ways they can reduce noise. These approaches use emerging technologies to address key noise-generating aspects of vessels. The literature-based mitigation assessments focus on the primary sources of hydroacoustic noise radiating from commercial vessels:

- **In-water propulsion mechanisms,** such as propellers and thrusters, which primarily create underwater noise through cavitation[2], as discussed in Appendix A.3.1, and
- **Shipboard machinery**, such as engines and generators, which create underwater noise through hull-borne vibration, as discussed in Appendix A.3.2.

If the noise from one component is more than 10 dB above other noise components in the same frequency bands, then the other components are largely irrelevant (McCauley et al. 1996). When cavitation occurs, sound from the propeller rotation is generally the dominant underwater noise source (Ross 1976). Leaper and Renilson (2012) and Renilson et al. (2012) recently demonstrated that there is considerable difference in the noise propagated by the noisiest and the quietest conventional commercial vessels, and that excessive cavitation is the dominant sound source of the noisiest ones.

Secondary sources of underwater noise include acoustic vibrations within compartments below the waterline and hydrodynamic noise created by flow interaction with hull features. However, the greatest gains in controlling underwater noise emissions from vessels are generally achieved by treating the primary sources.

2.3.1. Retrofitting Ships

This component of the literature review focuses on identifying possible technologies that can be fitted to the current commercial fleet to reduce underwater noise emissions. One focus of the literature-based assessment is the possible reduction of broadband noise levels associated with controlling cavitation with new propulsion systems, and with controlling internal machinery noise.

2.3.2. Replacing Trans Mountain Tugs with Specialized Tugs

This component of the literature review focuses on using electric or hybrid-electric/diesel tugs instead of diesel tugs to reduce broadband sound levels associated with the Trans Mountain tug fleet. Diesel-electric propulsion systems are found in vessels that have strict requirements for low onboard noise and vibration, as well as low underwater noise emissions (e.g., cruise ships and research vessels, Baudin and Mumm 2015). These tugs would escort tankers from Westridge Terminal to Swiftsure Bank.

2.3.3. Changing Ship Designs

This component of the literature review focuses on possible reductions in broadband sound levels associated with changing propeller and hull designs of commercial vessels. Newly built vessels could incorporate these designs in the future.

[2] Cavitation refers to streams of vapour bubbles that form on the surface of marine propellers when a vessel is moving quickly.

2.3.4. Changing Maintenance of Ships

This component of the literature review estimates the possible reduction in broadband sound levels associated with changing current maintenance practices, such as those relating to cleaning hulls and maintaining propellers.

2.3.5. Changing Operator Behaviour

This component of the literature review investigates the effect of operators piloting vessels with a focus on decreasing noise generation. For example, reducing acceleration rates could reduce vessel noise in sensitive areas.

2.3.6. Changing Shipping Practices

This component of the literature review investigates the effect of changing shipping practices, including station keeping versus anchoring, reducing the number of handling tugs, using onboard machinery, etc.

2.3.7. Applying Real-time Mitigation in Hot Spots

This component of the literature review investigates the effect of applying real-time mitigation in areas when whales have been detected. Ships avoidance practices and voluntary speed limits are already in use to reduce the number of ship strikes. These methods may also be effective in mitigating noise levels.

2.3.8. Adjusting Traffic Lanes–Juan de Fuca Strait

This component of the literature review estimates the possible reduction in broadband sound levels associated with shifting inbound and outbound shipping lanes entering the Salish Sea through the Strait of Juan da Fuca southward. The aim of this mitigation approach is to reduce acoustic impacts on SRKW in the Swiftsure Bank foraging area.

2.3.9. Using Larger Vessels

This component of the literature review investigates the effect of using larger vessels to reduce number of vessel transits required.

2.4. Cumulative Noise Model Input

2.4.1. Environmental Parameters

Sound propagation through the ocean depends on environmental parameters of a region, such as temperature, salinity, and water depth, as well as geological properties of the seabed, such as sediment type (e.g., sand, silt, and bedrock) and layer thickness. Once a region's environmental parameters are characterized, models are used to calculate how sound travels through the water away from a sound source.

2.4.2. Vessel Traffic Data

To assess the impact of adding vessel traffic from the Trans Mountain shipping requirements, noise levels are first calculated for historical shipping traffic to get a baseline understanding of the shipping noise in the Regional Study Area. The baseline noise levels are calculated for January and July 2015, which represent the extremes for sound propagation based on seasonal environmental changes. The regional noise levels from all other months are assumed to be contained within the levels for July (lowest) and January (highest).

By December 2019, the Trans Mountain shipping requirements are expected to increase from the current levels (5 outbound tankers per month) to projected levels (34 outbound tankers per month). The projected and mitigated level scenarios are modelled to represent levels occurring in the year 2020. These levels are only modelled for July because this month corresponds to the time of year when the SRKW are most present in the region.

Vessel positions and speeds are extracted from the AIS dataset for January and July 2015. The vessels are divided into the same class set as the source levels, described in Section 2.4.4. Vessels contribute to all map grid cell densities in the cells through which they pass. The time each vessel spends within a map grid cell is accumulated, and its speed is included in the average for that cell. Density and speed grids are produced this way for each vessel class.

For the projected scenario, traffic data is simulated for the extra tankers and tugs associated with the increased shipping requirements for Trans Mountain. Vessel movement is randomized using a normal (Gaussian) distribution of vessel position, centred along the current traffic routes. The speed of the tankers and tug escorts along the outbound route is limited to 5.144 m/s (10 knots) between East Point (northern limit of Haro Strait; as seen in Figure 6) and the Brotchie Pilot Station (south of Victoria; as seen in Figure 6). Their speed is limited to the expected maximum speed of tugs at 7.2 m/s (14 knots) north of East Point and west of Brotchie Pilot Station. The simulated speed of each vessel along the inbound route is equal to that of the current average speed for its class, based on the 2015 AIS data.

For the slow-down mitigation scenario in Haro Strait, vessel speeds are reduced in the slow-down and transition zones. For the no-go mitigation scenario, the vessel density is modified to simulate reduced traffic for certain vessel classes during the "no-go" times and higher traffic concentration during the "go" times. For the mitigation scenario of replacing 10% of the noisiest ships, the vessel densities and speeds are unchanged (from the projected case scenario), but the vessel source emission levels are modified according to a specialized analysis of vessel emission level distribution. For the adjusted traffic lanes mitigation scenario, vessel speeds are unchanged, but adjusted densities are calculated using simulated vessel tracks along the new routes.

For the convoying mitigation scenario, time-stamped vessel tracks over a 24-hour period are used for model input, with and without adjustments, to represent the baseline (no convoy) and two convoying intervals. Vessel tracks are extracted for July 29 and categorized as mitigated and unmitigated based on their presence in Haro Strait. Table 4 presents the number of transits for July 29 compared to a typical day in July (median across all days). Mitigated transits include those from affected vessel classes that pass through Haro Strait. Unmitigated transits include all transits from unaffected classes, as well as transits from affected classes that do not transit through Haro Strait. Mitigated tracks for July 29 are modified for the 2- and 4-hour convoying scenarios, with the addition of two Trans Mountain Tankers and Tugs in each direction (inbound and outbound).

Table 4. July 29 transits compared to the July daily average.

Vessel class	Mitigated		Unmitigated		Total	
	July daily average	July 29	July daily average	July 29	July daily average	July 29
Container	4	5	7	5	11	10
Ferry	n/a	n/a	512	513	512	513
Ferry (Seaspan Ro-ro)	n/a	n/a	9	11	9	11
Ferry (Clipper)	n/a	n/a	9	7	9	7
Fishing	n/a	n/a	42	27	42	27
Government	n/a	n/a	69	87	69	87
Merchant	8	7	21	20	29	27
Other	n/a	n/a	119	117	119	117
Passenger (≥ 100 m)	0	0	7	6	7	6
Passenger (< 100 m)	n/a	n/a	125	121	125	121
Recreational	n/a	n/a	478	456	478	456
Tanker	1	1	5	5	6	6
Tug	n/a	n/a	471	460	471	460
Vehicle carrier	1	1	2	2	3	3

2.4.3. Sound Propagation and Transmission Loss

Acoustic transmission loss is the decrease in intensity of a sound as it travels away from its source through an environment. JASCO's Marine Operations Noise Model (MONM) is used to calculate the regional transmission loss. MONM uses the environmental parameters, described in Section 2.4.1, to compute the reduction in sound levels with distance for each frequency band, out to a maximum of 75 km from the source. Past measurements from a transmission loss study (JASCO 2015) are used to validate MONM predictions for the study area.

The study area is divided into 20 zones, based on four unique geoacoustic regions and five water depth ranges. Transmission loss is modelled for each zone using sound speed profiles for July and January, and six source depths (1 to 6 m, every one 1 m), representing the nominal acoustic emission centres of modelled vessel classes. More details are provided in Appendices A.4 and A.5.1.

2.4.4. Vessel Noise Emission Levels

Propeller cavitation and hull vibration cuased by internal machinery are the main sources of underwater noise from vessels. Different types of vessels have characteristic source level spectra (i.e., variations of sound emission levels with sound frequency) because of their specific design and operating conditions. For the purpose of modelling noise from hundreds of vessels over a large area and long time periods, omnidirectional source level spectrum representative of the mean levels for each vessel class are used (NRC 2003).

For this study, source level measurements from the ECHO program ULS, described in Appendix A.3.3, are assigned to ten different classes, according vessel class information embedded in the AIS logs. Source levels for four additional vessel classes, not covered by the ULS data (Passenger (<100 m in length); Clipper Ferry; Recreational, and Other), are obtained from other sources. Figure 10 shows the frequency-dependent source levels, compiled in 1/3-octave frequency bands from 10 Hz to 63.1 kHz, that are used to represent noise emissions of corresponding vessels in the cumulative noise model.

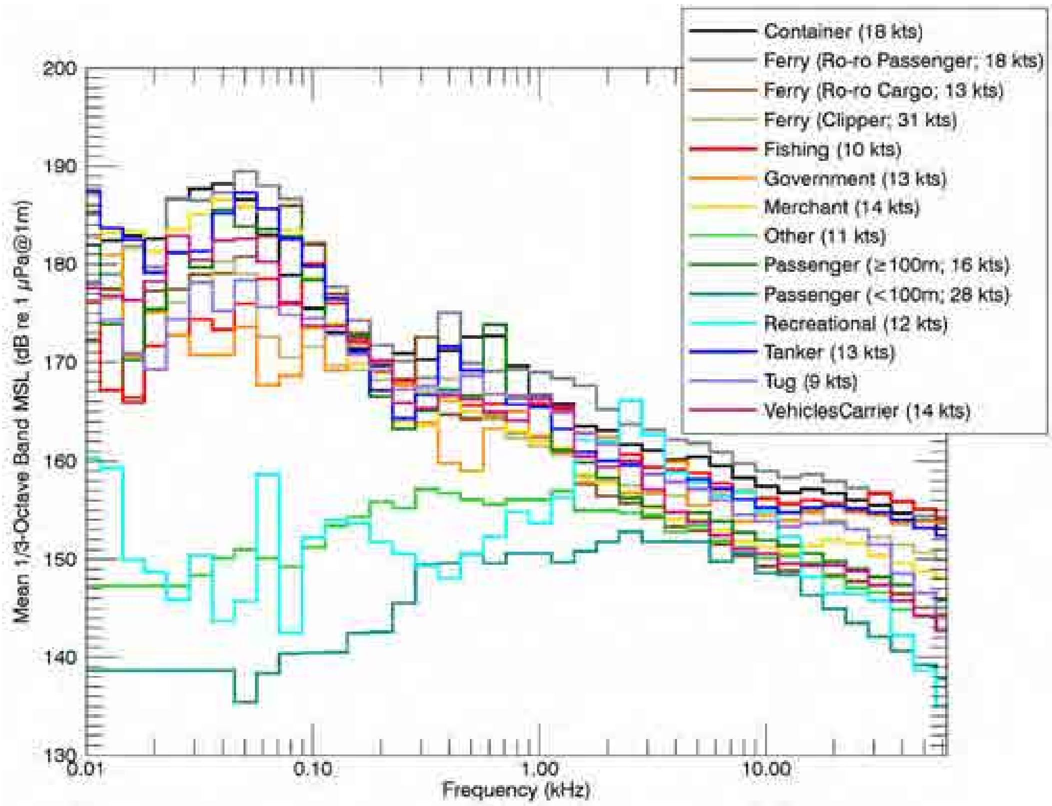


Figure 10. Frequency-dependent source levels by vessel class in 1/3-octave-bands. The reference speed (average transit speed, in knots) for each class is indicated in the legend. ULS source levels are extrapolated above 31 kHz based on the terminal slope of the 1/3-octave-band level curves.

2.5. Cumulative Noise Model

The Cumulative Vessel Noise Model can be run as a time-averaged density model or a time-dependent track model. The time-averaged version of the model is used for baseline, projected, and all mitigation scenarios except convoying, and accepts monthly averaged density and speed data described in Section 2.5.1 over the model grid. Results are presented as equivalent continuous noise levels[3] to the cumulative (total) noise level from all vessel classes, averaged over the month. The time-dependent version of the model is used for convoying and accepts time-dependent vessel track data. Because this type of modelling is more computationally expensive, these time-dependent results are calculated over a 24-hour period. Results are presented as sound pressure levels (SPL) over the model grid for each minute of the day.

The Cumulative Noise Model combines the modelled regional transmission losses described in Appendix A.5.1 with the vessel source level data for each vessel class described in Section 2.4.4. The model is based on a grid representing a region divided into equally sized square cells. For each vessel class, the vessel density or track data and average speed is assigned to each cell and the associated noise level is propagated outwards into neighbouring cells out to a range of 30 and 75 km for the small and large grids, respectively.

Source levels in the cumulative noise model are scaled according to speed using a well-established power-law model (Ross 1976). For each vessel class, a unique speed scaling parameter is calculated from ULS data, based on a multivariate analysis accounting for the effect of speed, vessel length, and measurement closest point of approach, as described in Appendix C. A default scaling parameter of 6 is used for categories with insufficient or missing data.

2.5.1. Cumulative Spatial Noise Assessment

Results for the time-averaged scenarios are presented as maps of equivalent continuous noise level (L_{eq}). L_{eq} is calculated by dividing the cumulative sound exposure level (SEL), which is modelled, by the averaging time in seconds. The L_{eq} metric is useful for presenting geographic distributions of mean noise levels. In the present study, L_{eq} is calculated over 1 month. Thus, in this report, L_{eq} represents the mean noise level that marine animals are expected to be exposed to at any time in July.

2.5.2. Temporal Noise Assessment

Vessel convoy scenarios are evaluated using the acoustic model's time-dependent calculation mode. In this mode, the model tracks the noise field from every vessel individually, in 1-minute steps, as they move through the study area. It sums those fields across all vessels to compute a composite time-varying noise field (essentially a snapshot of the overall noise every minute). To investigate the noise characteristics of convoys, vessel movement scenarios are developed based on maintaining the same number of ships as non-convoy scenarios, but adjusting their transit times so these ships sailed in groups through Haro Strait. Vessel speeds in the Strait are also adjusted to a standard speed to maintain the integrity of the convoys.

Results from the time-dependent analysis are presented as temporal variation plots and cumulative distribution functions (CFDs) at each sample location. These result formats provide information about the fraction of time animals would be exposed above important sound level thresholds. The results are useful for interpreting the amount of time that exposures are high enough to significantly disturb animals and reduce foraging.

[3] Refer to Appendix A.1 for a description of acoustic metrics.

2.6. Audiogram Weighting

When assessing the effectiveness of each mitigation approach, the frequencies contained in ship noise must be considered in association with the ability of killer whales and other marine animals to detect those sounds. It is less likely that man-made noise will affect a marine animal if the animal cannot perceive the sound well, with an exception for sound pressures high enough to cause physical injury. For noise levels that are below physical injury thresholds, frequency weighting based on audiograms can be applied to weight the importance of noise levels at particular frequencies in a manner reflective of an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007).

Audiogram-weighted levels represent sound levels above an animal's hearing threshold (dB re HT or dB_{ht}), and they cannot be directly compared with unweighted levels, nor compared to any impact threshold levels mentioned in the literature. It is not fully understood what dB_{ht} levels signify the onset of behavioural disturbance in killer whales, but Williams et al. (2014) suggest that responses can start between 56 and 64 dB re HT.

In this study, results are presented based on unweighted and SRKW audiogram-weighted noise levels; SRKW audiogram weighting, as seen in Figure A-10, is applied to sound levels generated by the cumulative noise model. In this report, audiogram-weighted equivalent continuous noise level (L_{eq}) represents the mean noise level perceived by a SRKW at any time in July.

3. RESULTS

In this section, all results are present with and without SRKW audiogram-weighting applied. The two types of results are easily identified by the different colour scale used in mapping equivalent continuous noise levels (L_{eq}).

Maps of L_{eq} for the baseline scenarios are presented in Figures 11 and 12 in Section 3.1. Maps of L_{eq} and changes in L_{eq} relative to the baseline are then presented for each time-averaged modelled scenario (i.e., projected and monthly-averaged mitigation scenarios; Figures 13–35 in Sections 3.2 and 3.3.1 to 3.3.5). Baseline levels include noise from all vessels in the July 2015 AIS data. Projected and mitigated levels include noise from vessels associated with the Trans Mountain Project expansion as described in Section 2.2.2, in addition to that from all vessels in the 2015 AIS data. L_{eq} and changes in L_{eq} relative to baseline, listed in Tables 9–22 in Sections 3.1 to 3.3.5, were also sampled at eight locations in Haro Strait.

Results for the convoying mitigation scenario are presented as temporal variation over a 24-hour period at the same eight sample locations in Haro Strait. These results are presented as:

- Received levels (SPL) versus time,
- Statistical values (percentiles, minimum, maximum, and mean) over the 24-hour period, and
- Cumulative distribution functions (CDFs).

The monthly-averaged results are summarized in Tables 5–8. Tables 5 and 6 present the unweighted and audiogram-weighted received levels (L_{eq}) at the eight sample locations. The associated change in acoustic intensity relative to baseline levels for July are shown as a percentage in parentheses. These tables may be used to compare expected received levels at locations of key importance for SRKW. Tables 7 and 8 present spatial variation statistics (percentile, minimum, maximum, and mean values) of changes in unweighted and audiogram-weighted L_{eq} across the specified area (Regional Study Area and Haro Strait Boundary; as seen in Figure 2). The changes in L_{eq} are presented in units of decibels (a logarithmic scale) and as a percentage of changes in acoustic intensity. These values may be used to assess the efficiency of the mitigation approaches over a large area.

Table 5. Unweighted mean received levels (dB re 1 µPa) and changes (%) in acoustic intensity relative to Baseline (July) for each time-averaged (monthly) scenario at sample locations in the SRKW critical habitat and current traffic lanes. SL: Source Level.

<table>
<tr><th colspan="2" rowspan="2">Scenario</th><th colspan="8">Sample location</th></tr>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th></tr>
<tr><td>Baseline</td><td>January</td><td>117.8</td><td>116.6</td><td>116.0</td><td>119.9</td><td>121.4</td><td>122.9</td><td>122.9</td><td>122.8</td></tr>
<tr><td>Baseline</td><td>July*</td><td>109.2</td><td>103.9</td><td>106.5</td><td>114.3</td><td>119</td><td>123.4</td><td>122.9</td><td>123.5</td></tr>
<tr><td colspan="2">Projected (Unmitigated)</td><td>109.3
(+2.3%)</td><td>104.1
(+4.7%)</td><td>107.1
(+14.8%)</td><td>114.9
(+14.8%)</td><td>119.6
(+14.8%)</td><td>124.1
(+17.5%)</td><td>123.5
(+14.8%)</td><td>124.0
(+12.2%)</td></tr>
<tr><td rowspan="3">Slow-down</td><td>11 knots</td><td>109.2
(0.0%)</td><td>103.5
(−8.8%)</td><td>105.1
(−27.6%)</td><td>112.5
(−33.9%)</td><td>117.0
(−36.9%)</td><td>122.8
(−12.9%)</td><td>120.5
(−42.5%)</td><td>121.0
(−43.8%)</td></tr>
<tr><td>10 knots</td><td>109.2
(0.0%)</td><td>103.3
(−12.9%)</td><td>104.7
(−33.9%)</td><td>111.9
(−42.5%)</td><td>116.3
(−46.3%)</td><td>122.4
(−20.6%)</td><td>119.6
(−53.2%)</td><td>120.3
(−52.1%)</td></tr>
<tr><td>7 knots</td><td>109.2
(0.0%)</td><td>103.0
(−18.7%)</td><td>103.5
(−49.9%)</td><td>110.0
(−62.8%)</td><td>114.0
(−68.4%)</td><td>121.1
(−41.1%)</td><td>116.6
(−76.6%)</td><td>117.6
(−74.3%)</td></tr>
<tr><td rowspan="2">No-go</td><td>Restricted period***
(midnight to 04:00)</td><td>93.8
(−97.0%)</td><td>92.0
(−88.8%)</td><td>93.1
(−95.4%)</td><td>98.6
(−97.3%)</td><td>106.3
(−94.9%)</td><td>106.4
(−98.1%)</td><td>103.5
(−98.9%)</td><td>105.5
(−98.5%)</td></tr>
<tr><td>Unrestricted period***
(04:00 to midnight)</td><td>110.0
(+17.5%)</td><td>104.9
(+17.5%)</td><td>107.8
(+34.9%)</td><td>115.6
(+38.0%)</td><td>120.3
(+38.0%)</td><td>124.9
(+41.3%)</td><td>124.3
(+38.0%)</td><td>124.8
(+34.9%)</td></tr>
<tr><td rowspan="2">Replacing 10%</td><td>Vessels ranked by unweighted SL**</td><td>106.1
(−16.8%)</td><td>103.0
(−4.5%)</td><td>104.7
(−8.8%)</td><td>115.0
(−18.7%)</td><td>118.3
(−25.9%)</td><td>120.4
(−24.1%)</td><td>119.6
(−22.4%)</td><td>119.7
(−25.9%)</td></tr>
<tr><td>Vessels ranked by weighted SL**</td><td>106.5
(−8.8%)</td><td>103.0
(−4.5%)</td><td>105.0
(−2.3%)</td><td>116.1
(+4.7%)</td><td>119.8
(+4.7%)</td><td>121.8
(+4.7%)</td><td>120.9
(+4.7%)</td><td>121.0
(0.0%)</td></tr>
<tr><td colspan="2">Reducing SL by 3 dB**</td><td>105.1
(−33.9%)</td><td>102.0
(−24.1%)</td><td>103.2
(−35.4%)</td><td>113.7
(−39.7%)</td><td>117.3
(−41.1%)</td><td>119.3
(−41.1%)</td><td>118.4
(−41.1%)</td><td>118.5
(−43.8%)</td></tr>
<tr><td colspan="2">Reducing SL by 6 dB**</td><td>103.8
(−51.0%)</td><td>101.0
(−39.7%)</td><td>101.2
(−59.3%)</td><td>111.1
(−66.9%)</td><td>114.5
(−69.1%)</td><td>116.4
(−69.8%)</td><td>115.6
(−69.1%)</td><td>115.7
(−70.5%)</td></tr>
<tr><td colspan="2">Adjusting traffic lanes</td><td>107.5
(−32.4%)</td><td>103.5
(−8.8%)</td><td>105.0
(−29.2%)</td><td>111.6
(−46.3%)</td><td>117.4
(−30.8%)</td><td>122.8
(−12.9%)</td><td>117.1
(−73.7%)</td><td>123.0
(−10.9%)</td></tr>
</table>

* Results for Baseline scenario calculated over the finer scale (200 x 200 m grid cells) Local Study Area.
** Results compared to Baseline scenario over the larger scale (800 x 800 m grid cells) Regional Study Area.
*** Results compared to Baseline scenario calculated over the same period (midnight to 04:00 or 0400 to midnight).

Table 6. Audiogram-weighted mean received levels (dB re HT) and changes (%) in acoustic intensity relative to Baseline (July) for each time-averaged (monthly) scenario at sample locations in the SRKW critical habitat and current traffic lanes. SL: Source Level.

Scenario		**Sample location**							
		1	2	3	4	5	6	7	8
Baseline	January	54.8	49	51.4	59.7	62.7	65.1	65.2	65.1
Baseline	July*	56.2	51.6	46.9	56.3	60.8	64.6	65.2	66.2
Projected (Unmitigated)		56.2 (0.0%)	51.6 (0.0%)	47.1 (+4.7%)	56.5 (+4.7%)	60.9 (+2.3%)	65.7 (+28.8%)	65.8 (+14.8%)	66.8 (+14.8%)
Slow-down	11 knots	56.2 (0.0%)	51.6 (0.0%)	46.7 (−4.5%)	56.1 (−4.5%)	60.7 (−2.3%)	65.0 (+9.6%)	63.3 (−35.4%)	64.9 (−25.9%)
Slow-down	10 knots	56.2 (0.0%)	51.6 (0.0%)	46.6 (−6.7%)	56.0 (−6.7%)	60.6 (−4.5%)	64.8 (+4.7%)	62.8 (−42.5%)	64.6 (−30.8%)
Slow-down	7 knots	56.2 (0.0%)	51.5 (−2.3%)	46.5 (−8.8%)	55.9 (−8.8%)	60.5 (−6.7%)	64.2 (−8.8%)	61.2 (−60.2%)	63.6 (−45.0%)
No-go	Restricted period*** (midnight to 04:00)	42.0 (−94.8%)	43.3 (−20.6%)	37.8 (−76.0%)	47.6 (−67.6%)	58.2 (−24.1%)	58.1 (−77.6%)	55.2 (−90.5%)	58.1 (−84.5%)
No-go	Unrestricted period*** (04:00 to midnight)	57.0 (+12.2%)	52.3 (+2.3%)	47.8 (+12.2%)	57.2 (+9.6%)	61.3 (+7.2%)	66.4 (+51.4%)	66.5 (+38.0%)	67.5 (+34.9%)
Replacing 10%	Vessels ranked by unweighted SL**	53.4 (0.0%)	48.3 (0.0%)	46.3 (0.0%)	56.1 (+2.3%)	59.1 (+17.5%)	61.9 (+17.5%)	62.9 (+20.2%)	62.6 (+17.5%)
Replacing 10%	Vessels ranked by weighted SL**	52.4 (−20.6%)	48.2 (−2.3%)	45.8 (−10.9%)	55.2 (−16.8%)	57.7 (−14.9%)	60.0 (−24.1%)	60.9 (−24.1%)	60.6 (−25.9%)
Reducing SL by 3 dB**		52.0 (−27.6%)	48.2 (−2.3%)	45.7 (−12.9%)	55.1 (−18.7%)	57.6 (−16.8%)	59.9 (−25.9%)	60.9 (−24.1%)	60.5 (−27.6%)
Reducing SL by 6 dB**		51.1 (−41.1%)	48.1 (−4.5%)	45.3 (−20.6%)	54.4 (−30.8%)	56.4 (−36.9%)	58.0 (−52.1%)	58.7 (−54.3%)	58.4 (−55.3%)
Adjusting traffic lanes		54.3 (−35.4%)	51.5 (−2.3%)	46.2 (−14.9%)	55.8 (−10.9%)	60.8 (0.0%)	63.6 (−20.6%)	58.2 (−80.0%)	63.7 (−43.8%)

* Results for Baseline scenario calculated over the finer scale (200 x 200 m grid cells) Local Study Area.
** Results compared to Baseline scenario over the larger scale (800 x 800 m grid cells) Regional Study Area.
*** Results compared to Baseline scenario calculated over the same period (midnight to 04:00 or 0400 to midnight).

Table 7. *Unweighted*: Percentiles, extremes, and mean values for changes in noise levels (dB) and acoustic intensity (%) relative to baseline levels, across the specified region, for each time-averaged (monthly) scenario. SL: Source Level. The Regional area refers to the Regional Study Area shown in Figure 2; the Haro Strait area refers to the Haro Strait Boundary in Figure 5.

Scenario		Area	Change in noise level statistics (dB)							
			Min	5th	25th	50th	75th	95th	Max	Mean
Projected (Unmitigated)		Regional	0.00 (0.0%)	0.00 (0.0%)	0.00 (0.0%)	+0.13 (+3.0%)	+0.50 (+12.2%)	+0.71 (+17.8%)	+2.26 (+68.3%)	+0.25±0.28 (+5.9%)
		Haro Strait	0.00 (0.0%)	0.00 (0.0%)	+0.07 (+1.6%)	+0.38 (+9.1%)	+0.60 (+14.8%)	+0.86 (+21.9%)	+2.01 (+58.9%)	+0.38±0.31 (+9.1%)
Slow-down	11 knots	Haro Strait	−5.68 (−73.0%)	−2.44 (−43.0%)	−1.45 (−28.4%)	−0.34 (−7.5%)	−0.05 (−1.1%)	0.00 (0.0%)	+1.55 (+42.9%)	−0.76±0.88 (−16.1%)
	10 knots	Haro Strait	−6.43 (−77.2%)	−3.26 (−52.8%)	−1.92 (−35.7%)	−0.50 (−10.9%)	−0.10 (−2.3%)	0.00 (0.0%)	+1.41 (+38.4%)	−1.04±1.15 (−21.3%)
	7 knots	Haro Strait	−8.26 (−85.1%)	−6.03 (−75.1%)	−3.28 (−53.0%)	−1.01 (−20.7%)	−0.18 (−4.1%)	−0.01 (−0.2%)	+0.64 (+15.9%)	−1.90±2.06 (−35.4%)
No−go	Restricted period (midnight to 04:00)	Haro Strait	−23.02 (−99.5%)	−19.57 (−98.9%)	−15.55 (−97.2%)	−11.40 (−92.8%)	−6.09 (−75.4%)	−2.59 (−44.9%)	0.00 (0.0%)	−11.13±5.45 (−92.3%)
	Unrestricted period (04:00 to midnight)	Haro Strait	0.00 (0.0%)	+0.13 (+3.0%)	+0.56 (+13.8%)	+1.03 (+26.8%)	+1.40 (+38.0%)	+1.70 (+47.9%)	+2.85 (+92.8%)	0.98±0.52 (+25.3%)
Replacing 10%	Vessels ranked by unweighted SL	Regional	−3.41 (−54.4%)	−1.66 (−31.8%)	−1.09 (−22.2%)	−0.66 (−14.1%)	−0.27 (−6.0%)	−0.02 (−0.5%)	+0.43 (+10.4%)	−0.72±0.54 (−15.3%)
	Vessels ranked by weighted SL	Regional	−0.92 (−19.1%)	−0.68 (−14.5%)	−0.48 (−10.5%)	−0.21 (−4.7%)	−0.02 (−0.5%)	+0.20 (+4.7%)	+1.79 (+51.0%)	−0.24±0.29 (−5.4%)
Reducing SL by 3 dB		Regional	−3.00 (−49.9%)	−2.93 (−49.1%)	−2.66 (−45.8%)	−2.30 (−41.1%)	−1.76 (−33.3%)	−0.54 (−11.7%)	0.00 (0.0%)	−2.11±0.72 (−38.5%)
Reducing SL by 6 dB		Regional	−6.00 (−74.9%)	−5.80 (−73.7%)	−5.26 (−70.2%)	−4.71 (−66.2%)	−3.27 (−52.9%)	−0.87 (−18.2%)	0.00 (0.0%)	−4.14±1.52 (−61.5%)
Adjusting traffic lanes		Haro Strait	−11.80 (−93.4%)	−3.37 (−54.0%)	−0.25 (−5.6%)	+0.06 (+1.4%)	+0.74 (+18.6%)	+3.64 (+131.2%)	+7.31 (+438.3%)	+0.11±2.14 (+2.6%)

Table 8. Audiogram-weighted: Percentiles, extremes, and mean values for changes in noise levels (dB) and acoustic intensity (%) relative to baseline levels, across the specified region, for each time-averaged (monthly) scenario. SL: Source Level. The Regional area refers to the Regional Study Area shown in Figure 2; the Haro Strait area refers to the Haro Strait Boundary in Figure 5.

Scenario		Area	Change in noise level statistics (dB)							
			Min	5th	25th	50th	75th	95th	Max	Mean
Projected (Unmitigated)		Regional	0.00 (0.0%)	0.00 (0.0%)	0.00 (0.0%)	+0.03 (+0.7%)	+0.37 (+8.9%)	+1.12 (+29.4%)	+3.09 (+103.7%)	+0.25±0.41 (+5.9%)
		Haro Strait	0.00 (0.0%)	0.00 (0.0%)	0.00 (0.0%)	+0.07 (+1.6%)	+0.50 (+12.2%)	+1.11 (+29.1%)	+3.96 (+148.9%)	+0.30±0.42 (+7.2%)
Slow-down	11 knots	Haro Strait	−7.97 (−84.0%)	−1.21 (−24.3%)	−0.22 (−4.9%)	−0.01 (−0.2%)	0.00 (0.0%)	+0.25 (+5.9%)	+3.13 (+105.6%)	−0.17±0.51 (−3.8%)
	10 knots	Haro Strait	−8.69 (−86.5%)	−1.60 (−30.8%)	−0.34 (−7.5%)	−0.01 (−0.2%)	0.00 (0.0%)	+0.15 (+3.5%)	+2.98 (+98.6%)	−0.26±0.61 (−5.8%)
	7 knots	Haro Strait	−9.80 (−89.5%)	−2.69 (−46.2%)	−0.71 (−15.1%)	−0.05 (−1.1%)	0.00 (0.0%)	0.00 (0.0%)	+2.39 (+73.4%)	−0.52±0.91 (−11.3%)
No-go	Restricted period (midnight to 04:00)	Haro Strait	−17.94 (−98.4%)	−9.99 (−90.0%)	−6.89 (−79.5%)	−3.90 (−59.3%)	−1.38 (−27.2%)	−0.17 (−3.8%)	0.00 (0.0%)	−4.35±3.25 (−63.3%)
	Unrestricted period (04:00 to midnight)	Haro Strait	0.00 (0.0%)	+0.01 (+0.2%)	+0.10 (+2.3%)	+0.37 (+8.9%)	+1.07 (+27.9%)	+1.82 (+52.1%)	+4.72 (+196.5%)	+0.62±0.64 (+15.3%)
Replacing 10%	Vessels ranked by unweighted SL	Regional	−5.80 (−73.7%)	−0.18 (−4.1%)	0.00 (0.0%)	+0.03 (+0.7%)	+0.10 (+2.3%)	+0.59 (+14.6%)	+2.93 (+96.3%)	+0.09±0.3 (+2.1%)
	Vessels ranked by weighted SL	Regional	−5.99 (−74.8%)	−1.95 (−36.2%)	−1.49 (−29.0%)	−0.89 (−18.5%)	−0.24 (−5.4%)	−0.01 (−0.2%)	+0.68 (+16.9%)	−0.91±0.68 (−18.9%)
Reducing SL by 3 dB		Regional	−5.80 (−73.7%)	−2.81 (−47.6%)	−2.17 (−39.3%)	−1.47 (−28.7%)	−0.56 (−12.1%)	−0.02 (−0.5%)	+0.36 (+8.6%)	−1.40±0.92 (−27.6%)
Reducing SL by 6 dB		Regional	−6.00 (−74.9%)	−5.47 (−71.6%)	−4.18 (−61.8%)	−2.77 (−47.2%)	−0.91 (−18.9%)	−0.03 (−0.7%)	0.00 (0.0%)	−2.65±1.80 (−45.7%)
Adjusting traffic lanes		Haro Strait	−10.53 (−91.1%)	−2.80 (−47.5%)	−0.04 (−0.9%)	0.00 (0.0%)	+0.50 (+12.2%)	+3.99 (+150.6%)	+10.09 (+920.9%)	+0.28±1.99 (+6.7%)

3.1. Baseline Noise Levels

Figure 11 shows maps of unweighted and audiogram-weighted equivalent noise levels for January and July 2015. The maps represent winter and summer baseline levels over the large-scale (800 × 800 m map grid cell resolution) Regional Study Area. Figure 12 presents maps of unweighted and audiogram-weighted equivalent noise levels for July 2015 for the smaller, finer-grid (200 × 200 m map grid cell resolution) Local Study Area. Tables 9 and 10 present the unweighted and audiogram-weighted noise levels for January (coarser grid) and July (coarser and finer grid) sampled at the eight locations in the SRKW critical habitat. The sample locations are listed in Table 1 and shown in Figure 12.

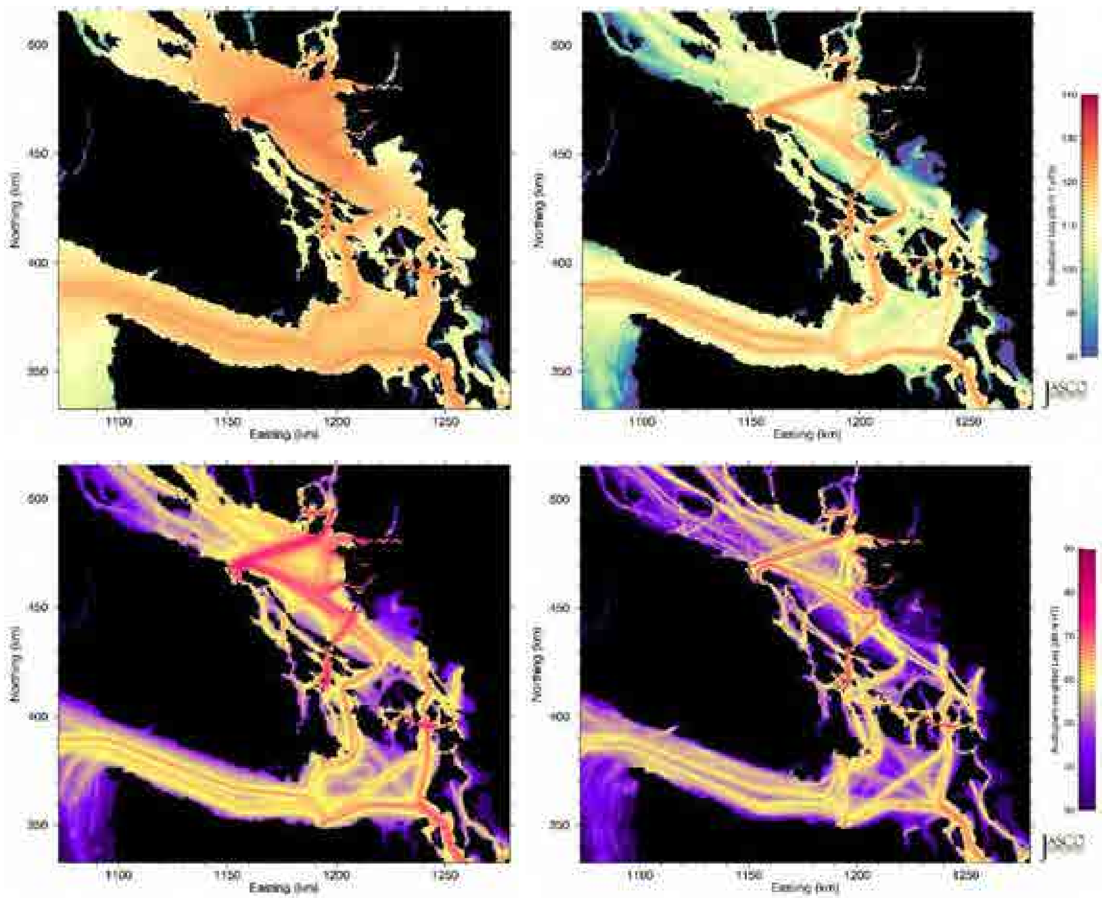


Figure 11. *Baseline, January (left) and July (right) 2015*: Unweighted (top) and audiogram-weighted (bottom) equivalent continuous noise levels (L_{eq}) over the Regional Study Area. Grid resolution is 800 × 800 m.

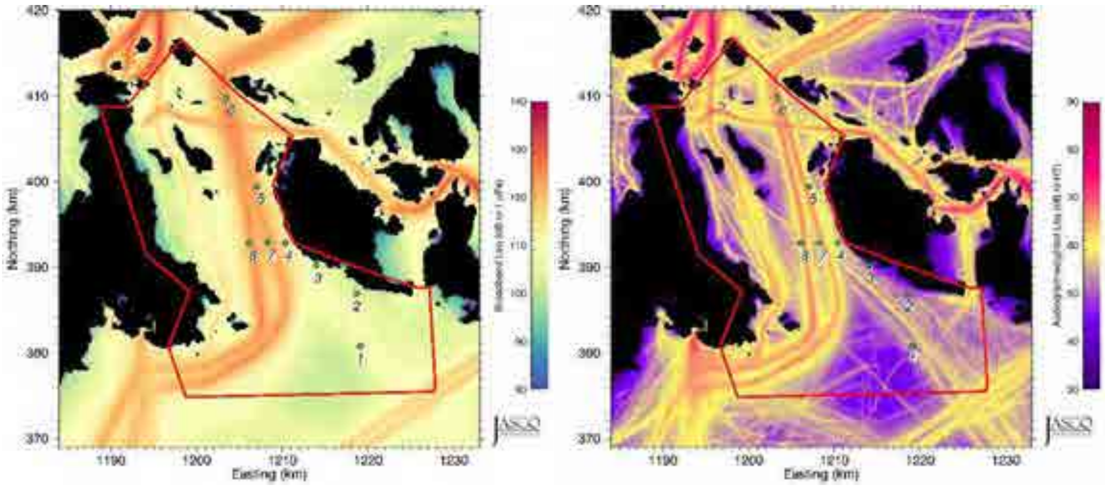


Figure 12. *Baseline, July 2015*: Unweighted (left) and audiogram-weighted (right) equivalent continuous noise levels (L_{eq}) over the Local Study Area. Grid resolution is 200 × 200 m. The green dots are located at the eight sample locations for importance for SRKW. The red line shows the Haro Strait Boundary.

Table 9. *Baseline, January and July 2015*: Unweighted received levels (dB re 1 µPa) at eight sample locations in the SRKW critical habitat.

Sample location	January	July	
	800 x 800 m	200 x 200 m	800 x 800 m
1	117.8	109.2	106.9
2	116.6	103.9	103.2
3	116.0	106.5	105.1
4	119.9	114.3	115.9
5	121.4	119.0	119.6
6	122.9	123.4	121.6
7	122.9	122.9	120.7
8	122.8	123.5	121.0

Table 10. *Baseline, January and July 2015*: Audiogram-weighted received levels (dB re HT) at eight sample locations in the SRKW critical habitat.

Sample location	January	July	
	800 x 800 m	200 x 200 m	800 x 800 m
1	54.8	56.2	53.4
2	49.0	51.6	48.3
3	51.4	46.9	46.3
4	59.7	56.3	56.0
5	62.7	60.8	58.4
6	65.1	64.6	61.2
7	65.2	65.2	62.1
8	65.1	66.2	61.9

3.2. Projected Noise Levels

Figures 13 and 14 (left) present maps of projected equivalent noise levels (unweighted and audiogram-weighted, respectively) for July 2020. The maps represent the projected (i.e., future) noise levels due to expected increase in vessel traffic associated with the Trans Mountain requirements over the Regional Study Area. Figures 13 and 14 (right) present maps of the increase in equivalent noise levels (unweighted and audiogram-weighted, respectively) relative to the 2015 baseline levels over the same area. Figure 15 also presents the changes in equivalent noise levels (unweighted on the left; audiogram-weighted on the right), but at a finer resolution (200 × 200 m), over the Local Study Area. Tables 11 and 12 compare unweighted and audiogram-weighted noise levels for the baseline and projected scenarios at eight sample locations in the SRKW critical habitat. The sample locations are listed in Table 1 and shown in Figure 15.

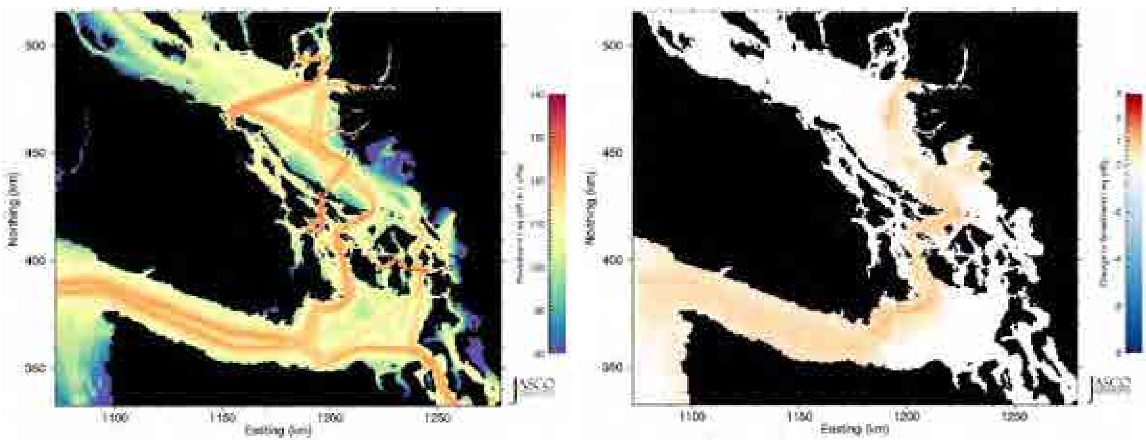


Figure 13. *Projected, July 2020*: Unweighted equivalent continuous noise levels (L_{eq}; left), and changes in L_{eq} (dB; right) relative to July 2015 baseline levels in the Regional Study Area. Grid resolution is 800 × 800 m.

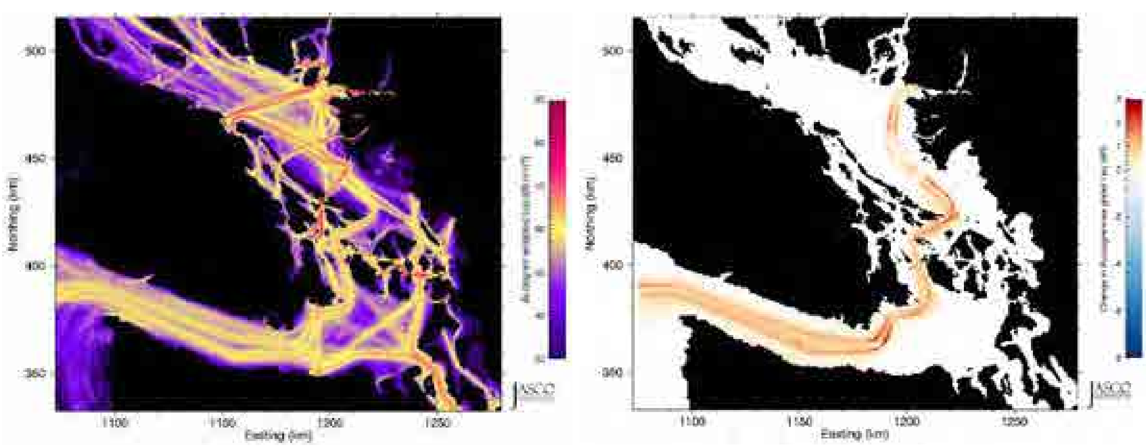


Figure 14. *Projected, July 2020*: Audiogram-weighted equivalent continuous noise levels (L_{eq}; left), and changes in L_{eq} (dB; right) relative to July 2015 baseline levels in the Regional Study Area. Grid resolution is 800 × 800 m.

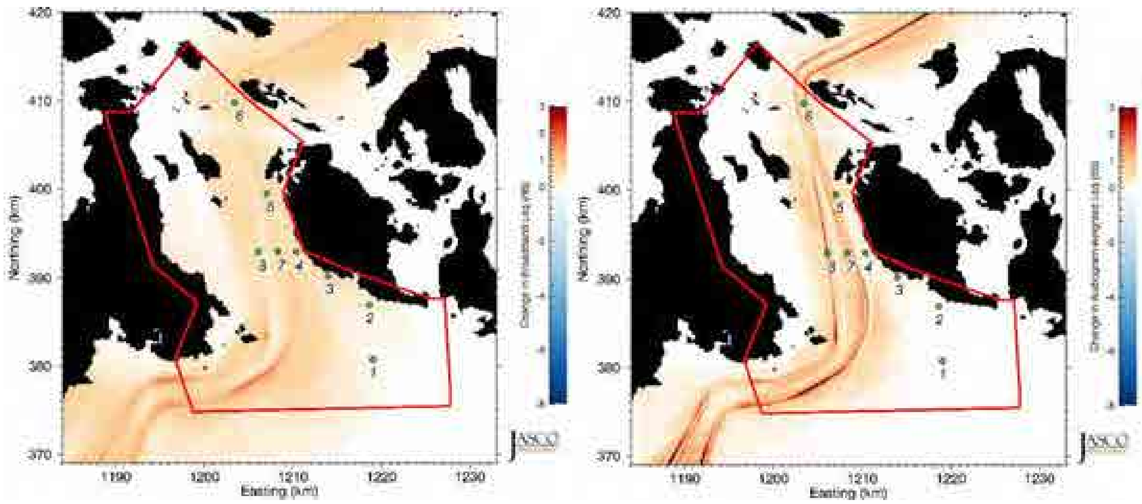


Figure 15. *Projected, July 2020*: Changes in unweighted (left) and audiogram-weighted (right) equivalent continuous noise levels (L_{eq}; dB) relative to July 2015 baseline levels in the Local Study Area. Grid resolution is 200 × 200 m. The green dots are the eight sample locations in the SRKW critical habitat. The red line shows the Haro Strait Boundary.

Table 11. *Baseline* vs. *projected*: Unweighted received levels (dB re 1 µPa), changes in received levels (dB), and changes in acoustic intensity (%) at eight sample locations in the SRKW critical habitat.

Sample location	Baseline	Projected	Change in received level	
			dB	%
1	109.2	109.3	+0.1	+2.3%
2	103.9	104.1	+0.2	+4.7%
3	106.5	107.1	+0.6	+14.8%
4	114.3	114.9	+0.6	+14.8%
5	119.0	119.6	+0.6	+14.8%
6	123.4	124.1	+0.7	+17.5%
7	122.9	123.5	+0.6	+14.8%
8	123.5	124.0	+0.5	+12.2%

Table 12. *Baseline* vs. *projected*: Audiogram-weighted received levels (dB re HT), changes in received levels (dB), and changes in acoustic intensity (%) at eight sample locations in the SRKW critical habitat.

Sample location	Baseline	Projected	Change in received level	
			dB	%
1	56.2	56.2	0.0	0.0%
2	51.6	51.6	0.0	0.0%
3	46.9	47.1	+0.2	+4.7%
4	56.3	56.5	+0.2	+4.7%
5	60.8	60.9	+0.1	+2.3%
6	64.6	65.7	+1.1	+28.8%
7	65.2	65.8	+0.6	+14.8%
8	66.2	66.8	+0.6	+14.8%

3.3. Modelled Noise Mitigation Scenarios

For each time-averaged mitigation scenario, results are presented as:

- Maps of equivalent noise levels (unweighted and audiogram-weighted L_{eq}) for July 2020,
- Maps of change in equivalent noise levels (unweighted and audiogram-weighted) relative to the 2015 baseline scenario for July 2020, and
- Tables of equivalent noise levels and change in equivalent noise levels (unweighted and audiogram-weighted) relative to the 2015 baseline scenario for July 2020, at eight sample locations in the SRKW critical habitat.

Results for the convoying mitigation scenario are presented as temporal variation in received levels (unweighted and audiogram-weighted) at eight sample locations in the SRKW critical habitat. The sample locations for the modelled scenarios are listed in Table 1.

3.3.1. Implementing a Slow-Down Zone

This section presents equivalent noise levels (L_{eq}, unweighted and audiogram-weighted) for July 2020 over the Local Study Area. The mitigated results represent the expected increase in vessel traffic associated with the Trans Mountain project, and implementing a slow-down zone for commercial vessel classes as described in Section 2.2.3.1. In Figures 16–21, the left map presents the L_{eq} and the right map presents the change in L_{eq} with respect to baseline levels for July, seen in Figure 12. Figures 16 to 21 show the mitigated L_{eq} with a maximum speed of 11, 10, and 7 knots through the Haro Strait shipping lanes. Tables 13 and 14 compare baseline and mitigated L_{eq} with three speed limits at eight sample locations in the SRKW critical habitat. The sample locations are shown in Figures 16–21.

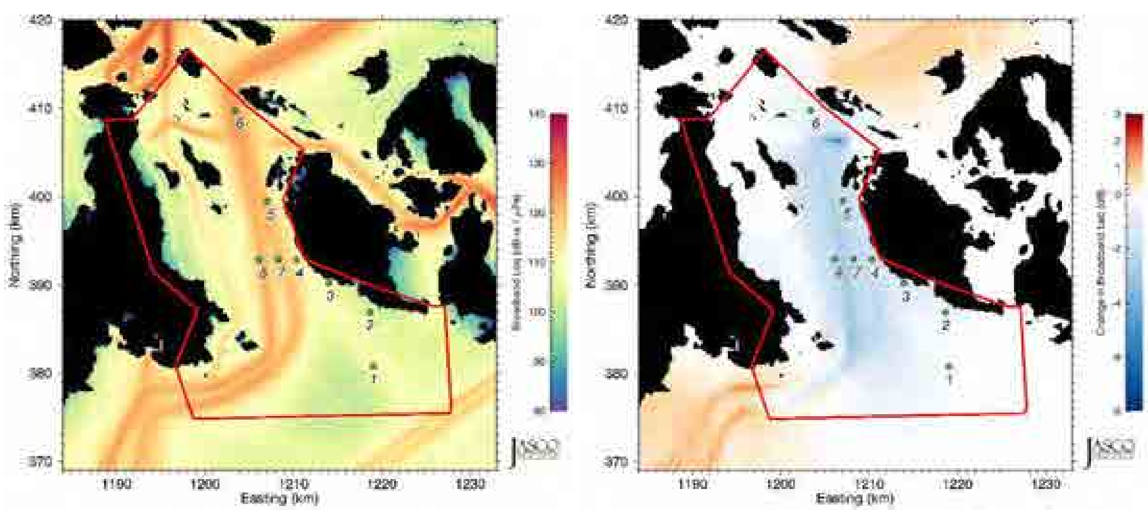


Figure 16. *11 knots, Slow-down zone*, *July 2020*: Unweighted equivalent continuous noise levels (L_{eq}; left), and change in L_{eq} (right) relative to July 2015 baseline levels in the Local Study Area. Grid resolution is 200 × 200 m. The green dots are the eight sample locations in the SRKW critical habitat. The red line shows the Haro Strait Boundary.

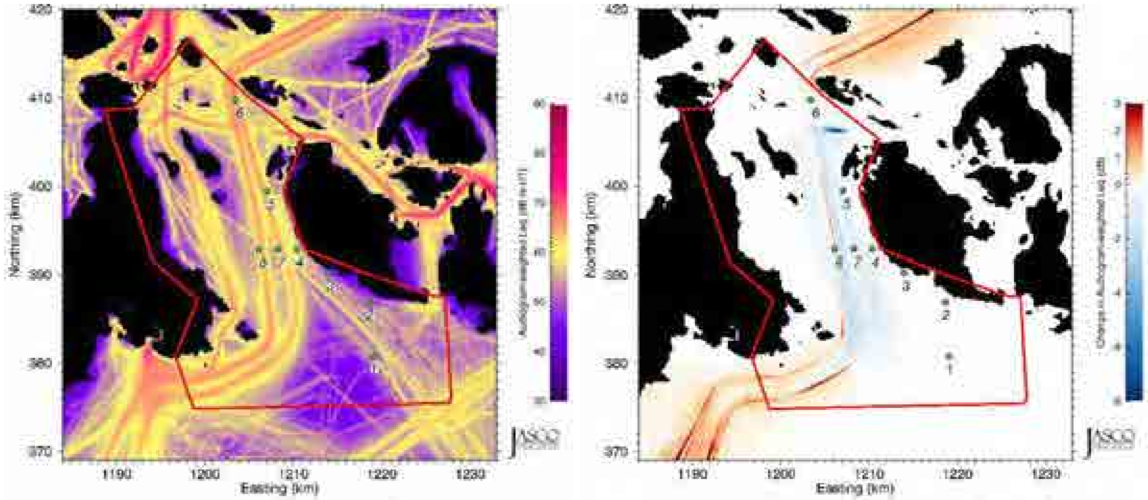


Figure 17. *11 knots, Slow-down zone*, *July 2020*: Audiogram-weighted equivalent continuous noise levels (L_{eq}; left), and change in L_{eq} (right) relative to July 2015 baseline levels in the Local Study Area. Grid resolution is 200 × 200 m. The green dots are the eight sample locations in the SRKW critical habitat. The red line shows the Haro Strait Boundary.

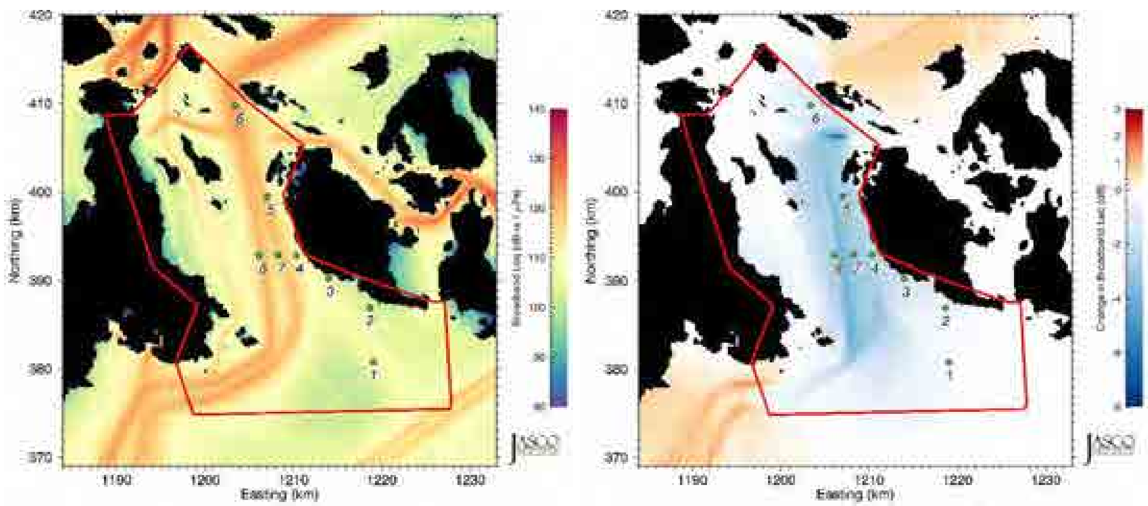


Figure 18. *10 knots, Slow-down zone*, *July 2020*: Unweighted equivalent continuous noise levels (L_{eq}; left), and change in L_{eq} (right) relative to July 2015 baseline levels in the Local Study Area. Grid resolution is 200 × 200 m. The green dots are the eight sample locations in the SRKW critical habitat. The red line shows the Haro Strait Boundary.

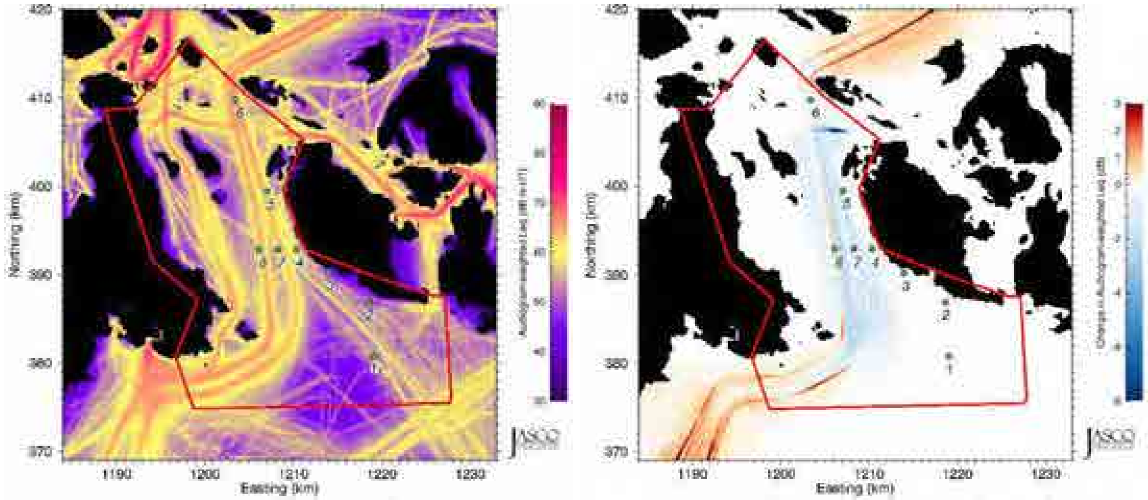


Figure 19. *10 knots, Slow-down zone*, *July 2020*: Audiogram-weighted equivalent continuous noise levels (L_{eq}; left), and change in L_{eq} (right) relative to July 2015 baseline levels in the Local Study Area. Grid resolution is 200 × 200 m. The green dots are the eight sample locations in the SRKW critical habitat. The red line shows the Haro Strait Boundary.

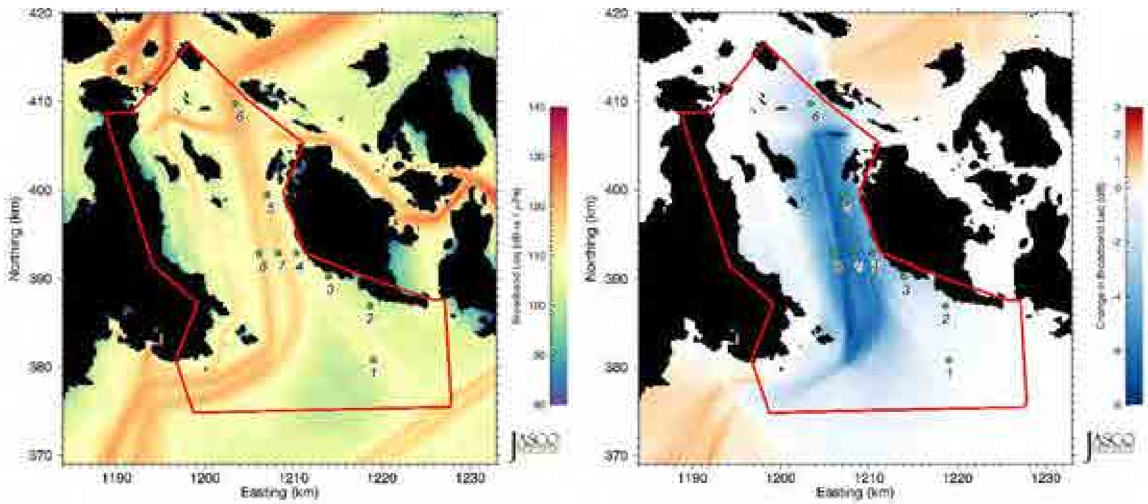


Figure 20. *7 knots, Slow-down zone*, *July 2020*: Unweighted equivalent continuous noise levels (L_{eq}; left), and change in L_{eq} (right) relative to July 2015 baseline levels in the Local Study Area. Grid resolution is 200 × 200 m. The green dots are the eight sample locations in the SRKW critical habitat. The red line shows the Haro Strait Boundary.

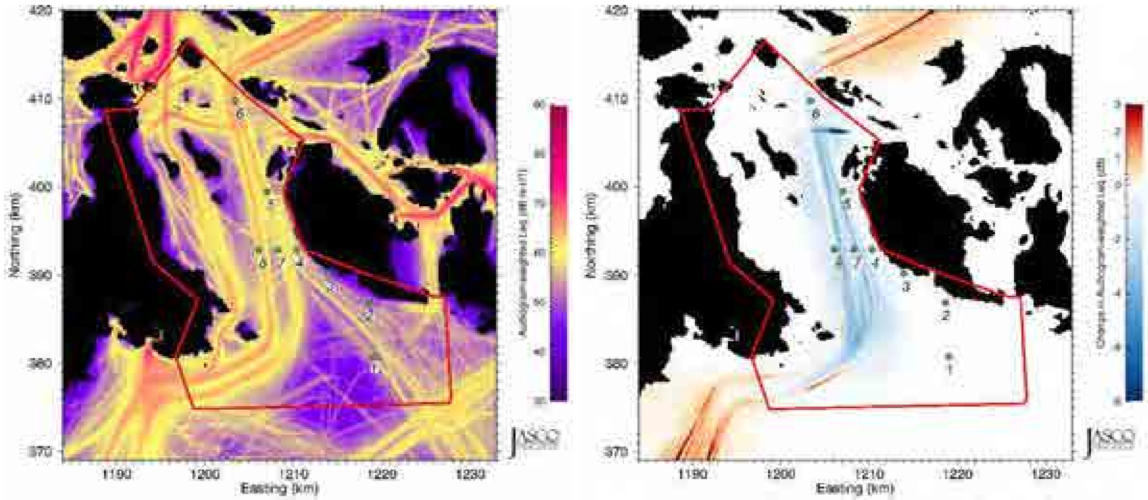


Figure 21. *7 knots, Slow-down zone*, *July 2020*: Audiogram-weighted equivalent continuous noise levels (L_{eq}; left), and change in L_{eq} (right) relative to July 2015 baseline levels in the Local Study Area. Grid resolution is 200 × 200 m. The green dots are the eight sample locations in the SRKW critical habitat. The red line shows the Haro Strait Boundary.

Table 13. *Baseline* vs. *slow-down zone*: Unweighted received levels (dB re 1 µPa), changes in received levels (dB), and changes in acoustic intensity (%) at eight sample locations in the SRKW critical habitat.

Sample location	**Baseline**	**11 knots**			**10 knots**			**7 knots**		
		Mitigated	Change in received level		Mitigated	Change in received level		Mitigated	Change in received level	
			dB	%		dB	%		dB	%
1	109.2	109.2	0.0	0.0	109.2	0.0	0.0	109.2	0.0	0.0
2	103.9	103.5	−0.4	−8.8	103.3	−0.6	−12.9	103.0	−0.9	−18.7
3	106.5	105.1	−1.4	−27.6	104.7	−1.8	−33.9	103.5	−3.0	−49.9
4	114.3	112.5	−1.8	−33.9	111.9	−2.4	−42.5	110.0	−4.3	−62.8
5	119.0	117.0	−2.0	−36.9	116.3	−2.7	−46.3	114.0	−5.0	−68.4
6	123.4	122.8	−0.6	−12.9	122.4	−1.0	−20.6	121.1	−2.3	−41.1
7	122.9	120.5	−2.4	−42.5	119.6	−3.3	−53.2	116.6	−6.3	−76.6
8	123.5	121.0	−2.5	−43.8	120.3	−3.2	−52.1	117.6	−5.9	−74.3

Table 14. *Baseline* vs. *slow-down zone*: Audiogram-weighted received levels (dB re HT), changes in received levels (dB), and changes in acoustic intensity (%) at eight sample locations in the SRKW critical habitat.

Sample location	**Baseline**	**11 knots**			**10 knots**			**7 knots**		
		Mitigated	Change in received level		Mitigated	Change in received level		Mitigated	Change in received level	
			dB	%		dB	%		dB	%
1	56.2	56.2	0.0	0.0	56.2	0.0	0.0	56.2	0.0	0.0
2	51.6	51.6	0.0	0.0	51.6	0.0	0.0	51.5	−0.1	−2.3
3	46.9	46.7	−0.2	−4.5	46.6	−0.3	−6.7	46.5	−0.4	−8.8
4	56.3	56.1	−0.2	−4.5	56.0	−0.3	−6.7	55.9	−0.4	−8.8
5	60.8	60.7	−0.1	−2.3	60.6	−0.2	−4.5	60.5	−0.3	−6.7
6	64.6	65.0	+0.4	+9.6	64.8	+0.2	+4.7	64.2	−0.4	−8.8
7	65.2	63.3	−1.9	−35.4	62.8	−2.4	−42.5	61.2	−4.0	−60.2
8	66.2	64.9	−1.3	−25.9	64.6	−1.6	−30.8	63.6	−2.6	−45.0

3.3.2. Implementing a No-Go Period

This section presents equivalent noise levels (L_{eq}, unweighted and audiogram-weighted) for July 2020 over the Local Study Area. The mitigated results represent the expected increase in vessel traffic associated with the Trans Mountain requirements, and implementing daily no-go periods for commercial vessel classes for the hours of midnight to 04:00, as described in Section 2.2.3.2. Figures 22 and 23 present maps of the L_{eq} over the hours of midnight to 04:00, for baseline (top left) and mitigated (top right) scenarios, and change in L_{eq} with respect to baseline (bottom). Figures 24 and 25 present similar maps for L_{eq} over the hours of 04:00 to midnight (unrestricted period). Tables 15 and 16 present the L_{eq} for the baseline and mitigated scenarios at eight sample locations in the SRKW critical habitat. The sample locations are shown in Figures 22–25.

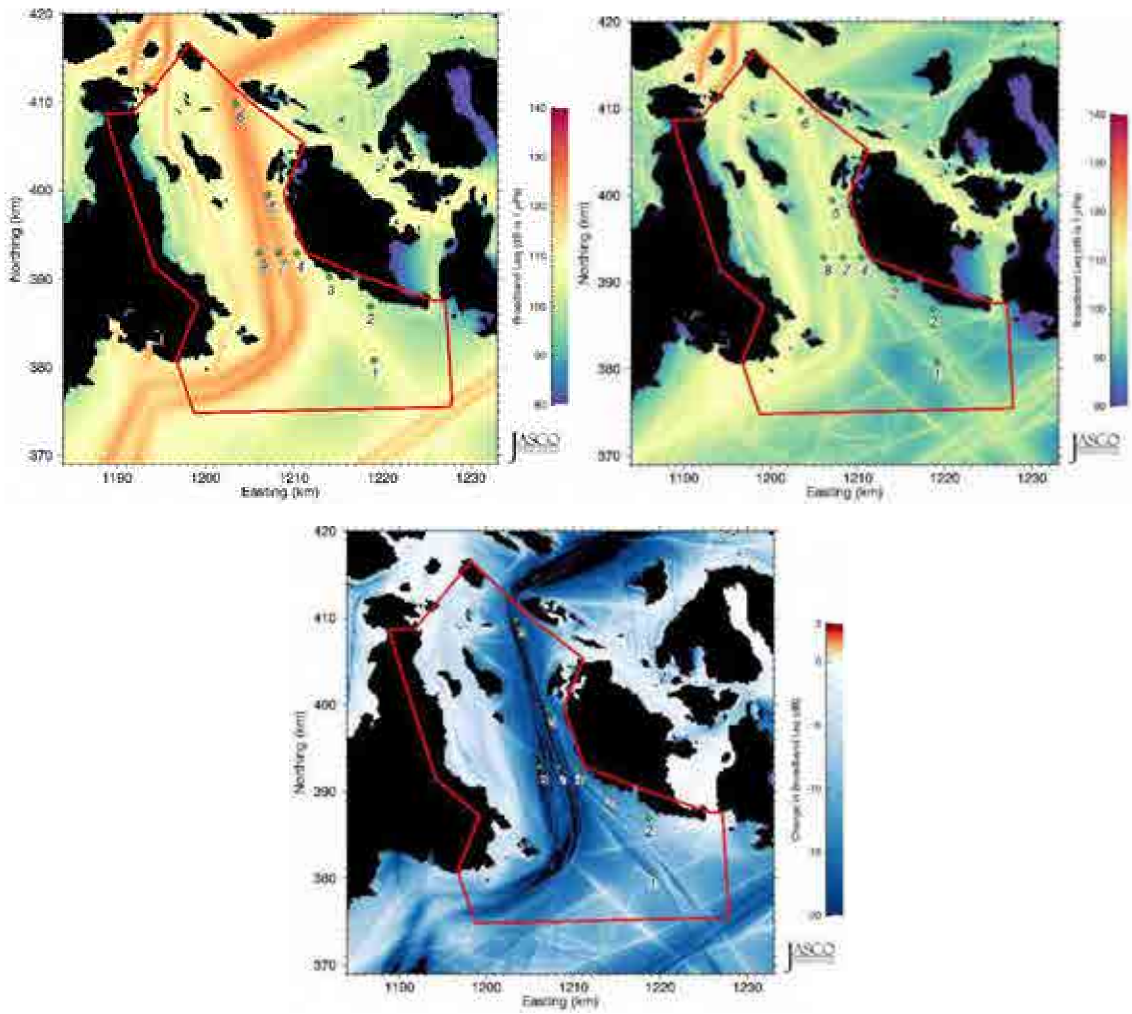


Figure 22. *Restricted period (Midnight to 4:00), July 2020:* Unweighted equivalent continuous noise levels (*L_{eq}*; top right), and change in L_{eq} (bottom) relative to July 2015 baseline levels (top left) in the Local Study Area. Grid resolution is 200 × 200 m. The green dots are the eight sample locations in the SRKW critical habitat. The red line shows the Haro Strait regional boundaries.

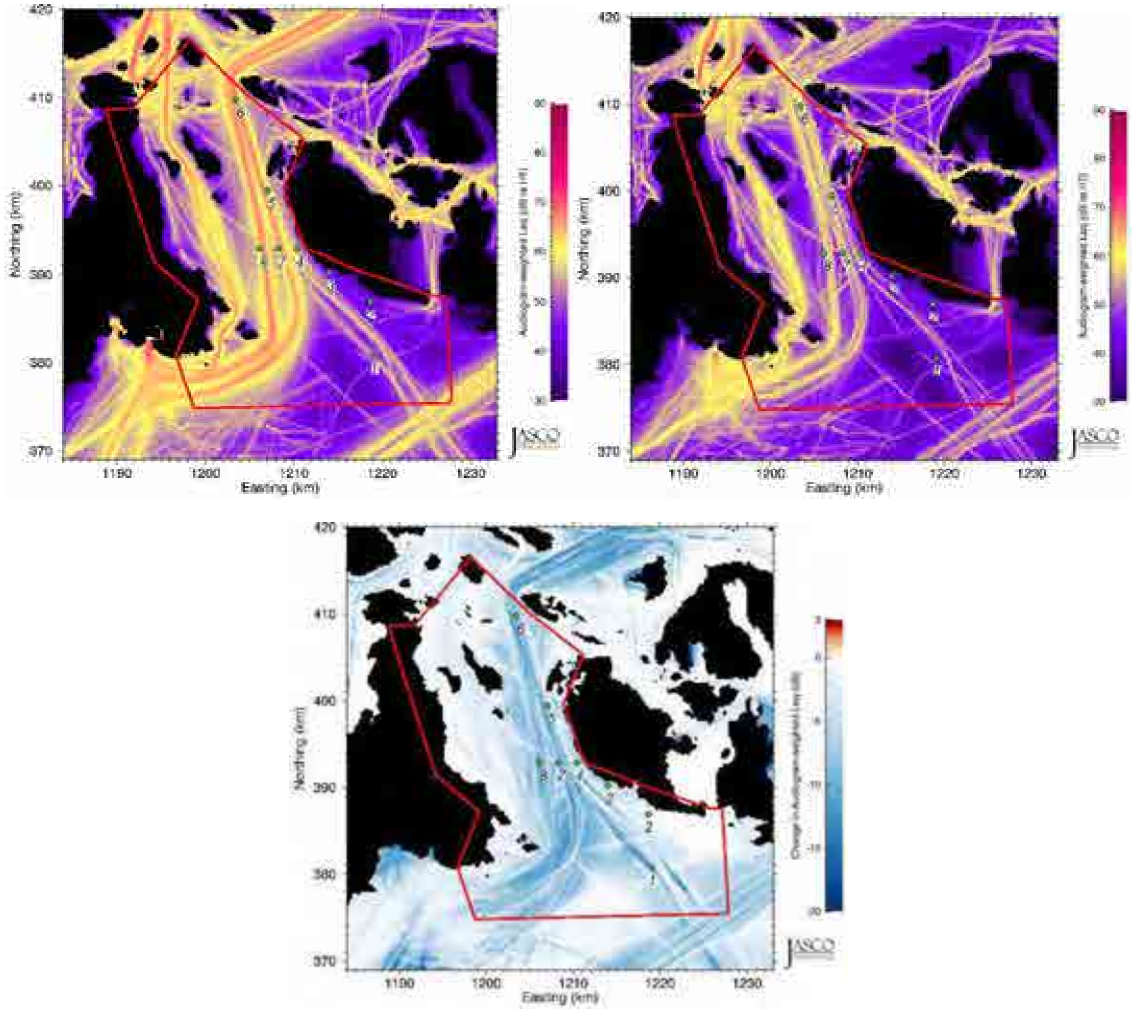


Figure 23. *Restricted period (Midnight to 4:00), July 2020:* Audiogram-weighted equivalent continuous noise levels (L_{eq}; top right), and change in L_{eq} (bottom) relative to July 2015 baseline levels (top left) in the Local Study Area. Grid resolution is 200 × 200 m. The green dots are the eight sample locations in the SRKW critical habitat. The red line shows the Haro Strait regional boundaries.

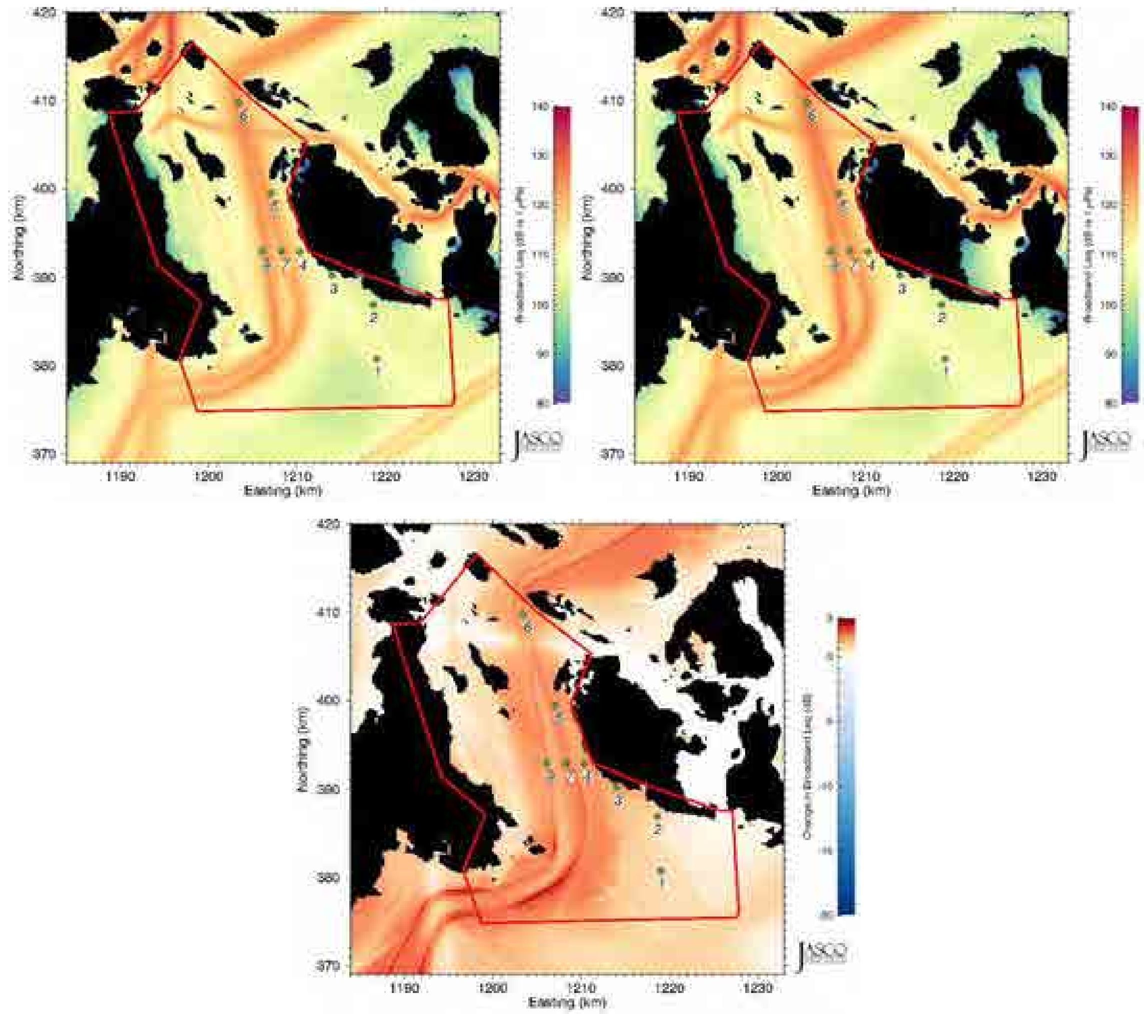


Figure 24. *Unrestricted period (4:00 to Midnight), July 2020:* Unweighted equivalent continuous noise levels (L_{eq}; top right), and change in L_{eq} (bottom) relative to July 2015 baseline levels (top left) in the Local Study Area. Grid resolution is 200 × 200 m. The green dots are the eight sample locations in the SRKW critical habitat. The red line shows the Haro Strait regional boundaries.

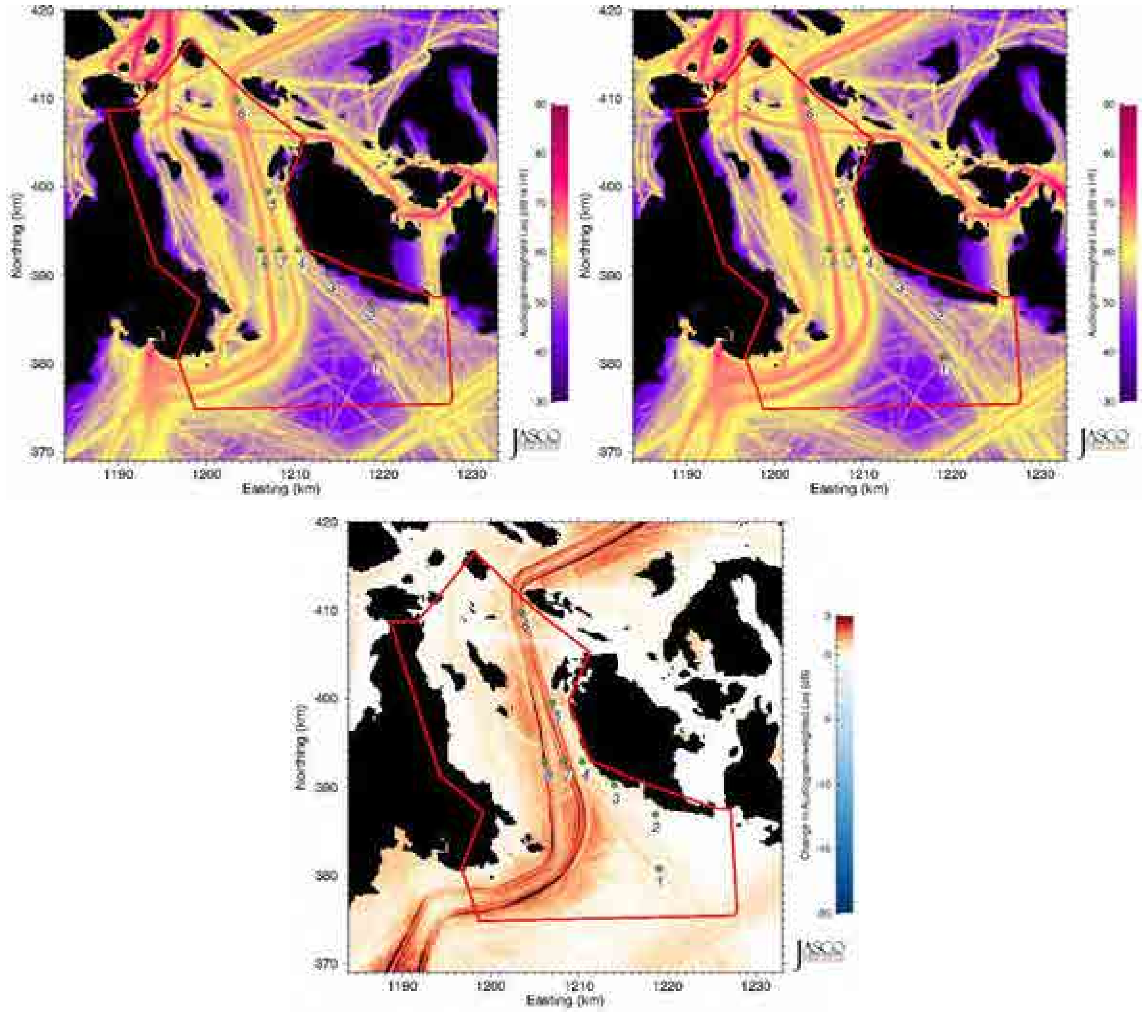


Figure 25. *Unrestricted period (4:00 to Midnight), July 2020:* Audiogram-weighted equivalent continuous noise levels (L_{eq}; top right), and change in L_{eq} (bottom) relative to July 2015 baseline levels (top left) in the Local Study Area. Grid resolution is 200 × 200 m. The green dots are the eight sample locations in the SRKW critical habitat. The red line shows the Haro Strait regional boundaries.

Table 15. *Baseline* vs. *no-go period*: Unweighted received levels (dB re 1 µPa), changes in received levels (dB), and changes in acoustic intensity (%) at eight sample locations in the SRKW critical habitat.

Sample location	Restricted period (Midnight to 04:00)				Unrestricted period (04:00 to midnight)			
	Baseline	Mitigated	Change in received level		Baseline	Mitigated	Change in received level	
			dB	%			dB	%
1	109.1	93.8	−15.3	−97.0	109.3	110.0	+0.7	+17.5
2	101.5	92.0	−9.5	−88.8	104.2	104.9	+0.7	+17.5
3	106.5	93.1	−13.4	−95.4	106.5	107.8	+1.3	+34.9
4	114.3	98.6	−15.7	−97.3	114.2	115.6	+1.4	+38.0
5	119.2	106.3	−12.9	−94.9	118.9	120.3	+1.4	+38.0
6	123.5	106.4	−17.1	−98.1	123.4	124.9	+1.5	+41.3
7	123.2	103.5	−19.7	−98.9	122.9	124.3	+1.4	+38.0
8	123.8	105.5	−18.3	−98.5	123.5	124.8	+1.3	+34.9

Table 16. *Baseline* vs. *no-go period*: Audiogram-weighted received levels (dB re HT), changes in received levels (dB), and changes in acoustic intensity (%) at eight sample locations in the SRKW critical habitat.

Sample location	Restricted period (Midnight to 04:00)				Unrestricted period (04:00 to midnight)			
	Baseline	Mitigated	Change in received level		Baseline	Mitigated	Change in received level	
			dB	%			dB	%
1	54.8	42.0	−12.8	−94.8	56.5	57.0	+0.5	+12.2
2	44.3	43.3	−1.0	−20.6	52.2	52.3	+0.1	+2.3
3	44.0	37.8	−6.2	−76.0	47.3	47.8	+0.5	+12.2
4	52.5	47.6	−4.9	−67.6	56.8	57.2	+0.4	+9.6
5	59.4	58.2	−1.2	−24.1	61.0	61.3	+0.3	+7.2
6	64.6	58.1	−6.5	−77.6	64.6	66.4	+1.8	+51.4
7	65.4	55.2	−10.2	−90.5	65.1	66.5	+1.4	+38.0
8	66.2	58.1	−8.1	−84.5	66.2	67.5	+1.3	+34.9

3.3.3. Replacing 10% of Noisiest Ships

This section presents equivalent noise levels (L_{eq}, unweighted and audiogram-weighted) for July 2020 over the Regional Study Area. The mitigated results represent the expected increase in vessel traffic associated with the Trans Mountain requirements, and replacing 10% of the noisiest vessels by the same amount of the least noisy vessels of that class, as described in Section 2.2.3.3. Two sets of results are present:

- 10% of noisiest vessel selected based on unweighted broadband source levels, and
- 10% of noisiest vessel selected based on audiogram-weighted broadband source levels.

Figures 26–29 present maps of (left) L_{eq} and (right) change in L_{eq} with respect to baseline levels for July, seen in Figure 11 (right). Tables 17–18 present L_{eq} for the baseline and mitigated scenarios at eight sample locations in the SRKW critical habitat. The sample locations are shown in Figure 5.

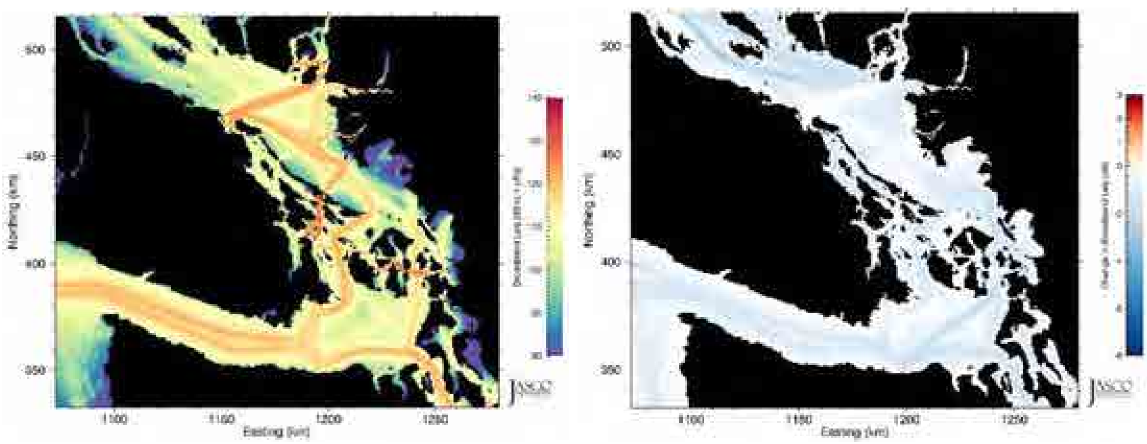


Figure 26. *Replacing 10% of ships with highest unweighted broadband source levels, July 2020*: Unweighted equivalent continuous noise levels (L_{eq}; left), and changes in L_{eq} (dB; right) relative to July 2015 baseline levels in the Regional Study Area. Grid resolution is 800 × 800 m. Sample locations are omitted in figures since, at this scale, they would have obscured the results in Haro Strait.

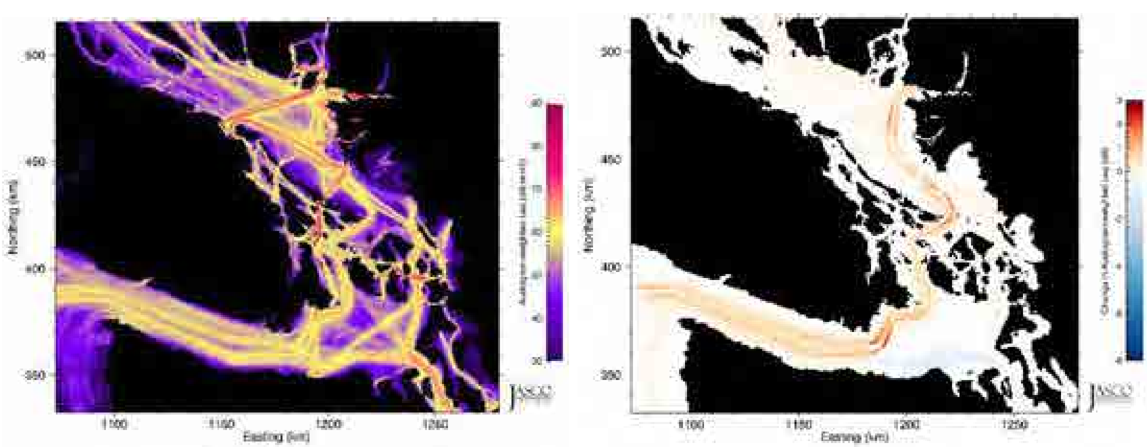


Figure 27. *Replacing 10% of ships with highest unweighted broadband source levels, July 2020*: Audiogram-weighted equivalent continuous noise levels (L_{eq}; left), and changes in L_{eq} (dB; right) relative to July 2015 baseline levels in the Regional Study Area. Grid resolution is 800 × 800 m. Sample locations are omitted in figures since, at this scale, they would have obscured the results in Haro Strait.

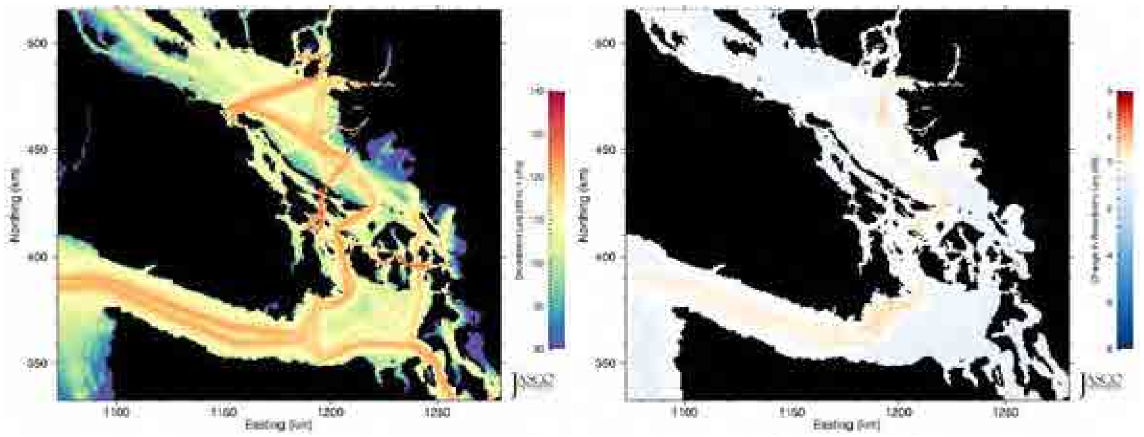


Figure 28. *Replacing 10% of ships with highest audiogram-weighted broadband source levels, July 2020*: Unweighted equivalent continuous noise levels (*Leq*; left), and changes in *Leq* (dB; right) relative to July 2015 baseline levels in the Regional Study Area. Grid resolution is 800 × 800 m. Sample locations are omitted in figures since, at this scale, they would have obscured the results in Haro Strait.

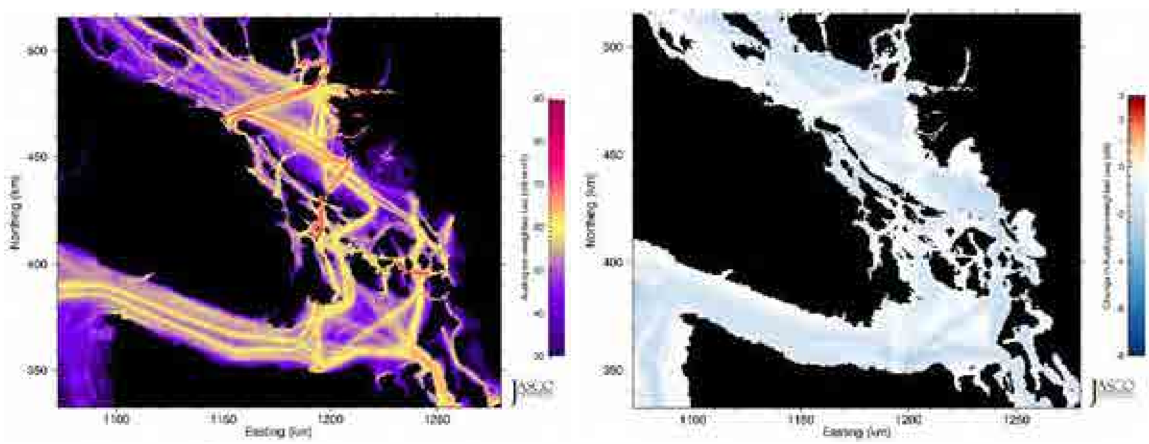


Figure 29. *Replacing 10% of ships with highest audiogram-weighted broadband source levels, July 2020*: Audiogram-weighted equivalent continuous noise levels (L_{eq}; left), and changes in L_{eq} (dB; right) relative to July 2015 baseline levels in the Regional Study Area. Grid resolution is 800 × 800 m. Sample locations are omitted in figures since, at this scale, they would have obscured the results in Haro Strait.

Table 17. *Baseline* vs. *replacing 10% of ships with highest source levels*: Unweighted received levels (dB re 1 µPa), changes in received levels (dB), and changes in acoustic intensity (%) at eight sample locations in the SRKW critical habitat.

Sample location	Baseline	Selected based on unweighted broadband source levels			Selected based on audiogram-weighted broadband source levels		
		Mitigated	Change in received level		Mitigated	Change in received level	
			dB	%		dB	%
1	106.9	106.1	−0.8	−16.8	106.5	−0.4	−8.8
2	103.2	103.0	−0.2	−4.5	103.0	−0.2	−4.5
3	105.1	104.7	−0.4	−8.8	105.0	−0.1	−2.3
4	115.9	115.0	−0.9	−18.7	116.1	+0.2	+4.7
5	119.6	118.3	−1.3	−25.9	119.8	+0.2	+4.7
6	121.6	120.4	−1.2	−24.1	121.8	+0.2	+4.7
7	120.7	119.6	−1.1	−22.4	120.9	+0.2	+4.7
8	121.0	119.7	−1.3	−25.9	121.0	0.0	0.0

Table 18. *Baseline* vs. *replacing 10% of ships with highest source levels*: Audiogram-weighted received levels (dB re HT), changes in received levels (dB), and changes in acoustic intensity (%) at eight sample locations in the SRKW critical habitat.

Sample location	Baseline	Selected based on unweighted broadband source levels			Selected based on audiogram-weighted broadband source levels		
		Mitigated	Change in received level		Mitigated	Change in received level	
			dB	%		dB	%
1	53.4	53.4	0.0	0.0	53.4	52.4	−20.6
2	48.3	48.3	0.0	0.0	48.3	48.2	−2.3
3	46.3	46.3	0.0	0.0	46.3	45.8	−10.9
4	56.0	56.1	+0.1	+2.3	56.0	55.2	−16.8
5	58.4	59.1	+0.7	+17.5	58.4	57.7	−14.9
6	61.2	61.9	+0.7	+17.5	61.2	60.0	−24.1
7	62.1	62.9	+0.8	+20.2	62.1	60.9	−24.1
8	61.9	62.6	+0.7	+17.5	61.9	60.6	−25.9

3.3.4. Reducing Source Levels for Classes of Concern

This section presents equivalent noise levels (L_{eq}, unweighted and audiogram-weighted) for July 2020 over the Regional Study Area. The mitigated results represent the expected increase in vessel traffic associated with the Trans Mountain requirements, and reducing the source levels of classes of concern by 3 and 6 dB, as described in Section 2.2.3.4. In Figures 30–33, the left map presents the L_{eq} and the right map presents the change in L_{eq} with respect to baseline levels for July, shown in Figure 12. Figures 30 and 31 show the mitigated levels with a source level reduction of 3 dB. Figures 32 and 33 show the mitigated levels with a source level reduction of 6 dB. Tables 19 and 20 present the L_{eq} for the baseline and mitigated scenarios at eight sample locations in the SRKW critical habitat. The sample locations are shown in Figure 5.

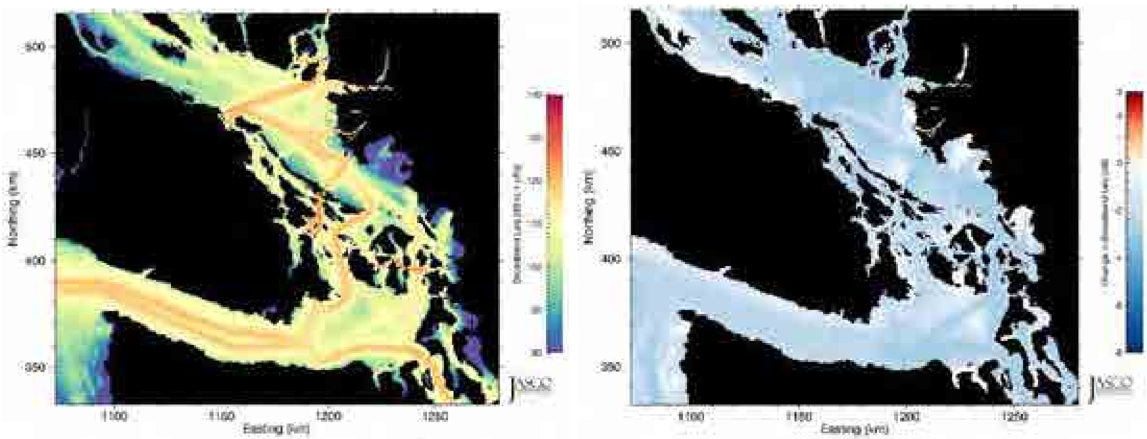


Figure 30. *Reducing spectral source levels by 3 dB, July 2020*: Unweighted equivalent continuous noise levels (L_{eq}; left), and changes in L_{eq} (dB; right) relative to July 2015 baseline levels in the Regional Study Area. Grid resolution is 800 × 800 m. Sample locations are omitted in figures since, at this scale, they would have obscured the results in Haro Strait.

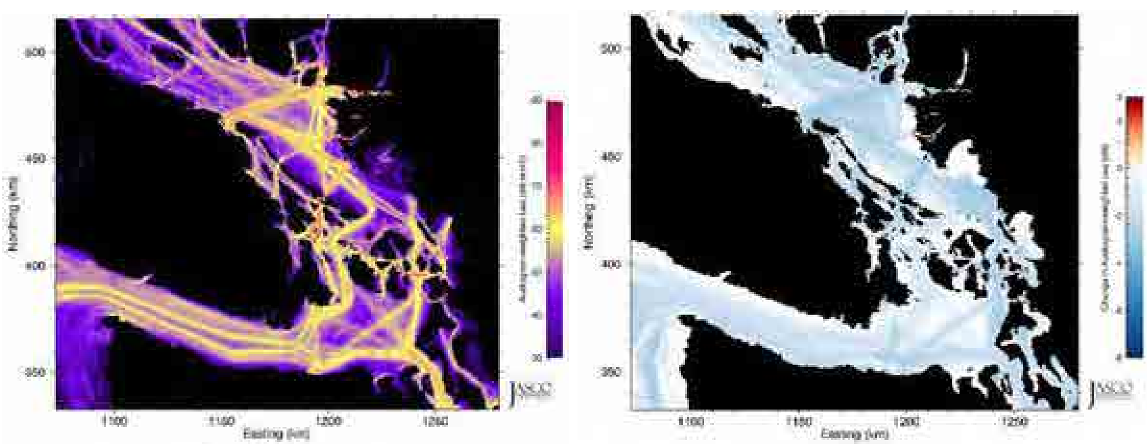


Figure 31. *Reducing spectral source levels by 3 dB, July 2020*: Audiogram-weighted equivalent continuous noise levels (L_{eq}; left), and changes in L_{eq} (dB; right) relative to July 2015 baseline levels in the Regional Study Area. Grid resolution is 800 × 800 m. Sample locations are omitted in figures since, at this scale, they would have obscured the results in Haro Strait.

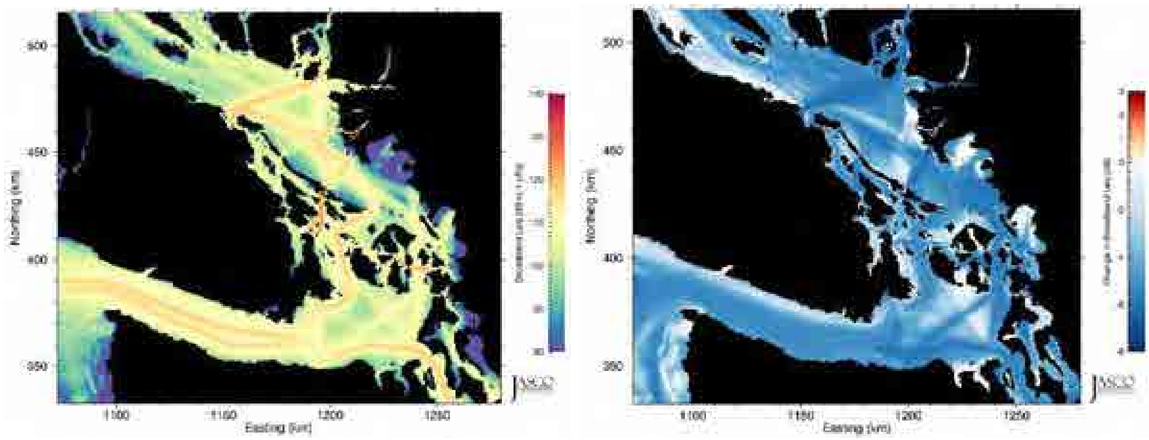


Figure 32. *Reducing spectral source levels by 6 dB, July 2020*: Unweighted equivalent continuous noise levels (L_{eq}; left), and changes in L_{eq} (dB; right) relative to July 2015 baseline levels in the Regional Study Area. Grid resolution is 800 × 800 m. Sample locations are omitted in figures since, at this scale, they would have obscured the results in Haro Strait.

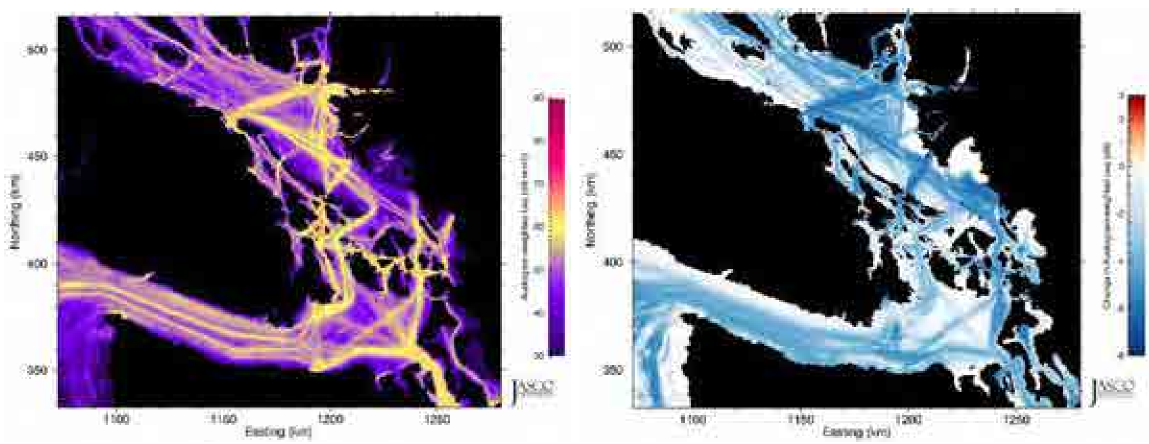


Figure 33. *Reducing spectral source levels by 6 dB, July 2020*: Audiogram-weighted equivalent continuous noise levels (L_{eq}; left), and changes in L_{eq} (dB; right) relative to July 2015 baseline levels in the Regional Study Area. Grid resolution is 800 × 800 m. Sample locations are omitted in figures since, at this scale, they would have obscured the results in Haro Strait.

Table 19. *Baseline* vs. *reducing spectral source levels by 3 dB and 6 dB*: Unweighted received levels (dB re 1 µPa), changes in received levels (dB), and changes in acoustic intensity (%) at eight sample locations in the SRKW critical habitat.

Sample location	Baseline	3 dB			6 dB		
		Mitigated	Change in received level		Mitigated	Change in received level	
			dB	%		dB	%
1	106.9	105.1	−1.8	−33.9	103.8	−3.1	−51.0
2	103.2	102.0	−1.2	−24.1	101.0	−2.2	−39.7
3	105.1	103.2	−1.9	−35.4	101.2	−3.9	−59.3
4	115.9	113.7	−2.2	−39.7	111.1	−4.8	−66.9
5	119.6	117.3	−2.3	−41.1	114.5	−5.1	−69.1
6	121.6	119.3	−2.3	−41.1	116.4	−5.2	−69.8
7	120.7	118.4	−2.3	−41.1	115.6	−5.1	−69.1
8	121.0	118.5	−2.5	−43.8	115.7	−5.3	−70.5

Table 20. *Baseline* vs. *reducing spectral source levels by 3 dB and 6 dB*: Audiogram-weighted received levels (dB re HT), changes in received levels (dB), and changes in acoustic intensity (%) at eight sample locations in the SRKW critical habitat.

Sample location	Baseline	3 dB			6 dB		
		Mitigated	Change in received level		Mitigated	Change in received level	
			dB	%		dB	%
1	53.4	52.0	−1.4	−27.6	51.1	−2.3	−41.1
2	48.3	48.2	−0.1	−2.3	48.1	−0.2	−4.5
3	46.3	45.7	−0.6	−12.9	45.3	−1.0	−20.6
4	56.0	55.1	−0.9	−18.7	54.4	−1.6	−30.8
5	58.4	57.6	−0.8	−16.8	56.4	−2.0	−36.9
6	61.2	59.9	−1.3	−25.9	58.0	−3.2	−52.1
7	62.1	60.9	−1.2	−24.1	58.7	−3.4	−54.3
8	61.9	60.5	−1.4	−27.6	58.4	−3.5	−55.3

3.3.5. Adjusting Traffic Lanes–Haro Strait

This section presents equivalent noise levels (L_{eq}, unweighted and audiogram-weighted) for July 2020 over the Local Study Area. The mitigated results represent the expected increase in vessel traffic associated with the Trans Mountain requirements, and rerouting the traffic lanes within Haro Strait. Figures 34 and 35 present maps of the mitigated L_{eq} (left) and changes in L_{eq} (right) with respect to baseline levels for July, seen in Figure 12. Tables 21 and 22 present L_{eq} for the baseline and mitigated scenarios at eight sample locations in the SRKW critical habitat. The sample locations are shown in Figures 34–35.

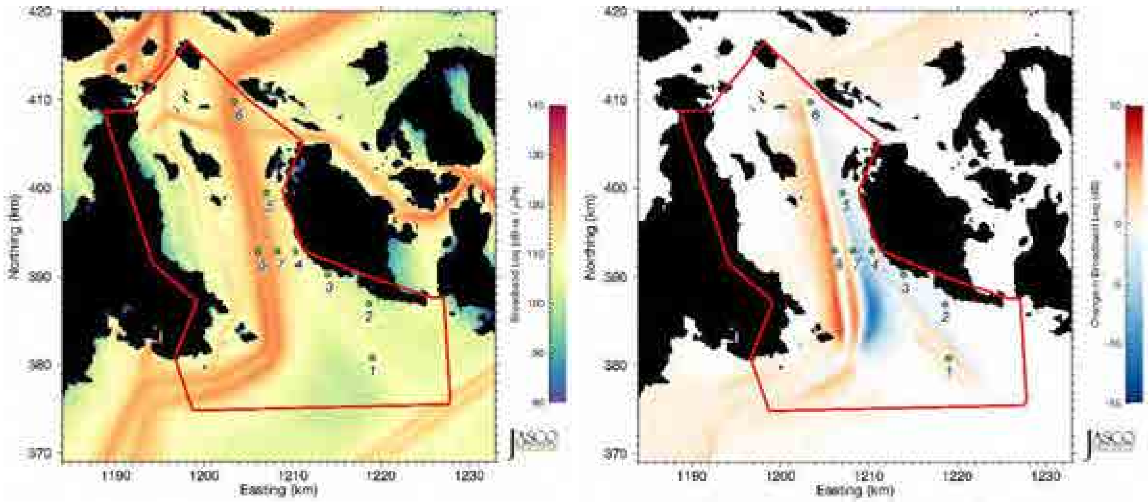


Figure 34. *Adjusting traffic lanes, July 2020*: Unweighted equivalent continuous noise levels (L_{eq}; left), and change in L_{eq} (right) relative to July 2015 baseline levels in the Local Study Area. Grid resolution is 200 × 200 m. The green dots are the eight sample locations in the SRKW critical habitat. The red line shows the Haro Strait Boundary.

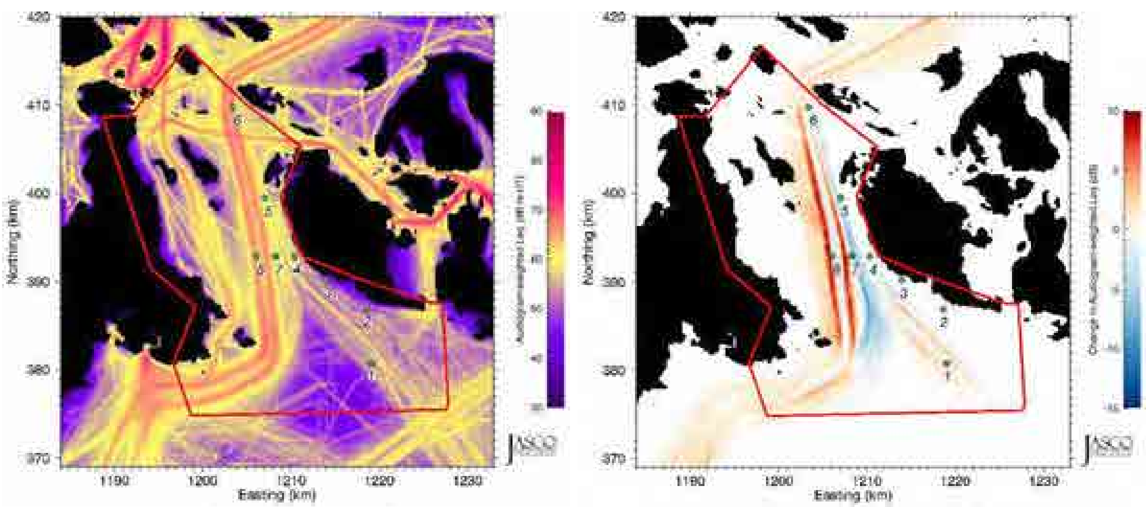


Figure 35. *Adjusting traffic lanes, July 2020*: Audiogram-weighted equivalent continuous noise levels (*Leq*; left), and change in *Leq* (right) relative to July 2015 baseline levels in the Local Area. Grid resolution is 200 × 200 m. The green dots are the eight sample locations in the SRKW critical habitat. The red line shows the Haro Strait Boundary.

Table 21.*Baseline vs. adjusting traffic lanes*: Unweighted received levels (dB re 1 µPa), changes in received levels (dB), and changes in acoustic intensity (%) at eight sample locations in the SRKW critical habitat.

Sample location	Baseline received level	Mitigated received level	Change in received level	
			dB	%
1	109.2	107.5	−1.7	−32.4
2	103.9	103.5	−0.4	−8.8
3	106.5	105.0	−1.5	−29.2
4	114.3	111.6	−2.7	−46.3
5	119.0	117.4	−1.6	−30.8
6	123.4	122.8	−0.6	−12.9
7	122.9	117.1	−5.8	−73.7
8	123.5	123.0	−0.5	−10.9

Table 22.*Baseline vs. adjusting traffic lanes*: Audiogram-weighted received levels (dB re HT), changes in received levels (dB), and changes in acoustic intensity (%) at eight sample locations in the SRKW critical habitat.

Sample location	Baseline received level	Mitigated received level	Change in received level	
			dB	%
1	56.2	54.3	−1.9	−35.4
2	51.6	51.5	−0.1	−2.3
3	46.9	46.2	−0.7	−14.9
4	56.3	55.8	−0.5	−10.9
5	60.8	60.8	0.0	0.0
6	64.6	63.6	−1.0	−20.6
7	65.2	58.2	−7.0	−80.0
8	66.2	63.7	−2.5	−43.8

3.3.6. Implementing Vessel Convoys

This section presents the temporal distribution of received noise levels for July 2020, representing mitigated projected levels with the expected increase in vessel traffic associated with the Trans Mountain requirements and implementing convoying of commercial vessels in Haro Strait, as described in Section 2.2.3.6. The convoying occurs between points east of Discovery Island and north of Turn Point, as seen in Figure 9. Results are presented for 2- and 4-hour convoy interval scenarios, which include 2020 Trans Mountain vessel traffic, as well as for the unmitigated baseline scenario (no convoy, no 2020 Trans Mountain vessel traffic). All scenarios are modelled over the fine-grid model area (200 × 200 m; Local Study Area). The SPL snapshots from the model simulations were rendered as animations to show the time evolution of the vessel traffic noise in the study area. Examples of snapshots are presented in Figure 36.

The modelled received levels at eight locations in the SRKW critical habitat were sampled every 1-minute over the 24-hour period. The sample locations are shown in Figure 5. Figures 37–44 present plots of unweighted (left) and audiogram-weighted (right) noise levels as a function of time, at each sample location. These plots compare the levels from all traffic (and ambient noise) to that from only the commercial traffic. In each plot, the top, middle, and bottom graph shows results for the baseline (2015 traffic, no convoys), 2-hour convoy interval, and 4-hour convoy interval scenarios.

To interpret the time-varying model outputs, a statistical analysis was applied to the sampled received levels. Tables 23 and 24 present the percentile, minimum, maximum, and mean values of the temporal variation in received noise levels (SPL) at each sample location, for the baseline and the two convoy scenarios. The received levels were also used to generate cumulative distribution functions (CDFs) at each sample location. These functions presented in in Figures 45 and 46, show the percent of time that modelled received levels were below a specified value. As an example, the CDF curves can be interpreted as follows: At Sample location 3 (Central South San Juan), the SPL was 100 dB at the 40th percentile level for the baseline scenario and at the ~50th percentile level for both convoy scenarios. This means that baseline noise levels at this location were at or below 100 dB 40% of the time, and the mitigated noise levels were at or below 100 dB 50% of the time. Thus, at this location, noise levels lower than 100 dB occur more often if this mitigation approach is applied.

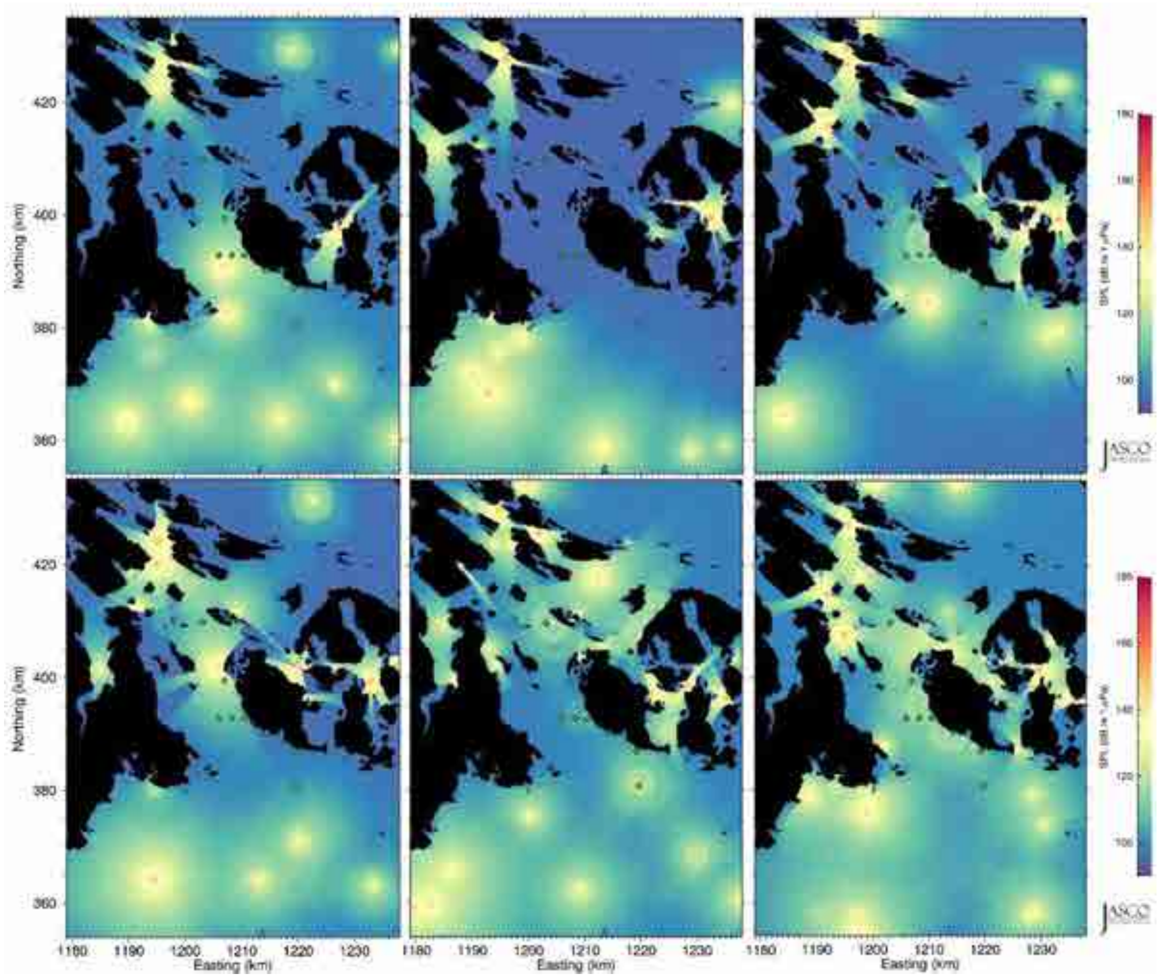


Figure 36. Example time snapshots of SPL (unweighted with ambient, 10 Hz to 50 kHz) for the study area for baseline scenario from 08:00 to 13:00 (local time) in 1-hour increments. Easting and northing are BC Albers projected coordinates.

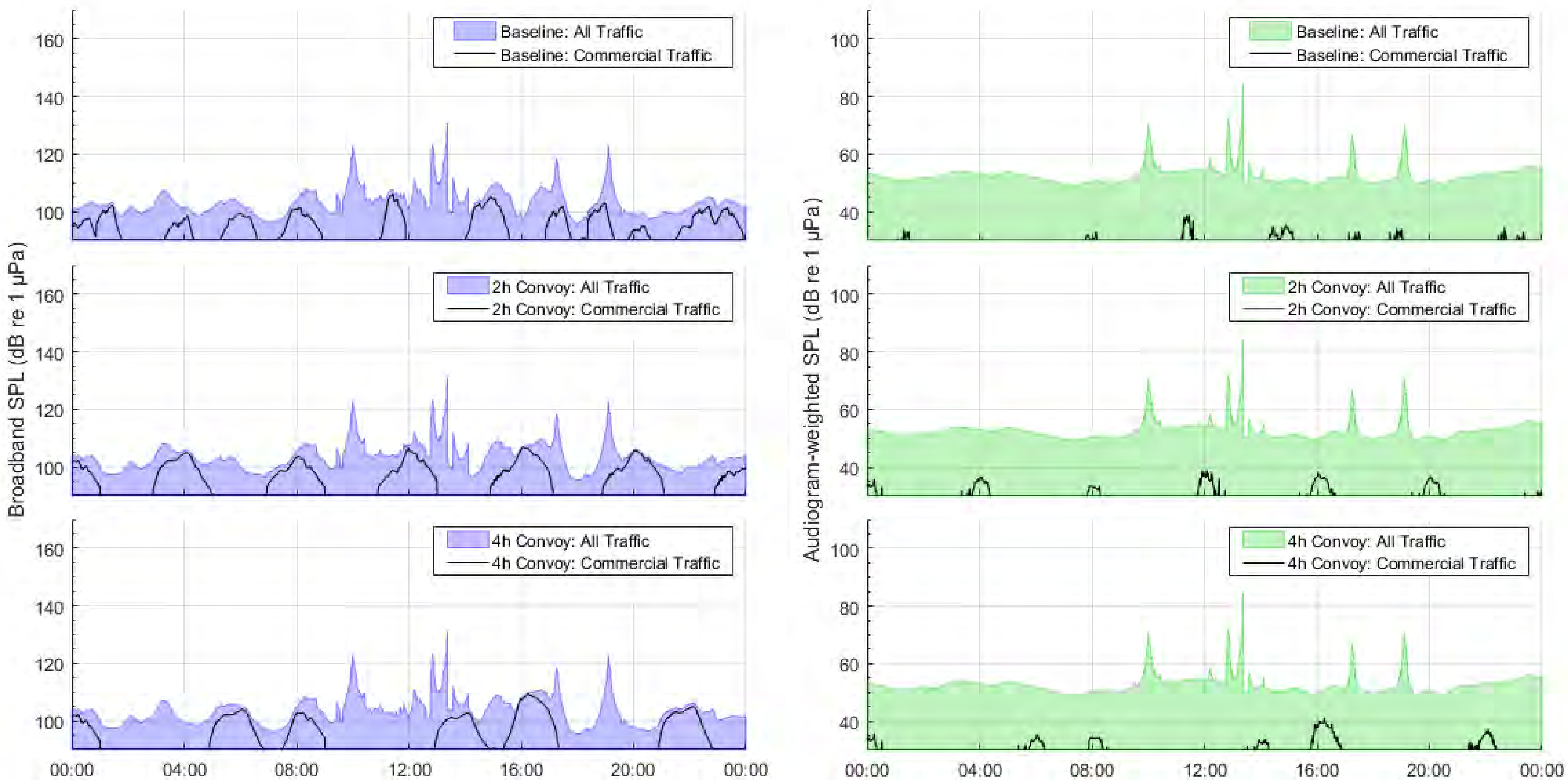


Figure 37. *Sample location 1*: Temporal variability of unweighted (left) and audiogram-weighted (right) received levels for (top) baseline (no convoy), (middle) 2-hour convoy, and (bottom) 4-hour convoy scenarios. The blue and green lines above the shaded area show received levels caused by all traffic and ambient noise. The black lines show received levels caused by commercial traffic only. The receiver location is shown in Figure 5.

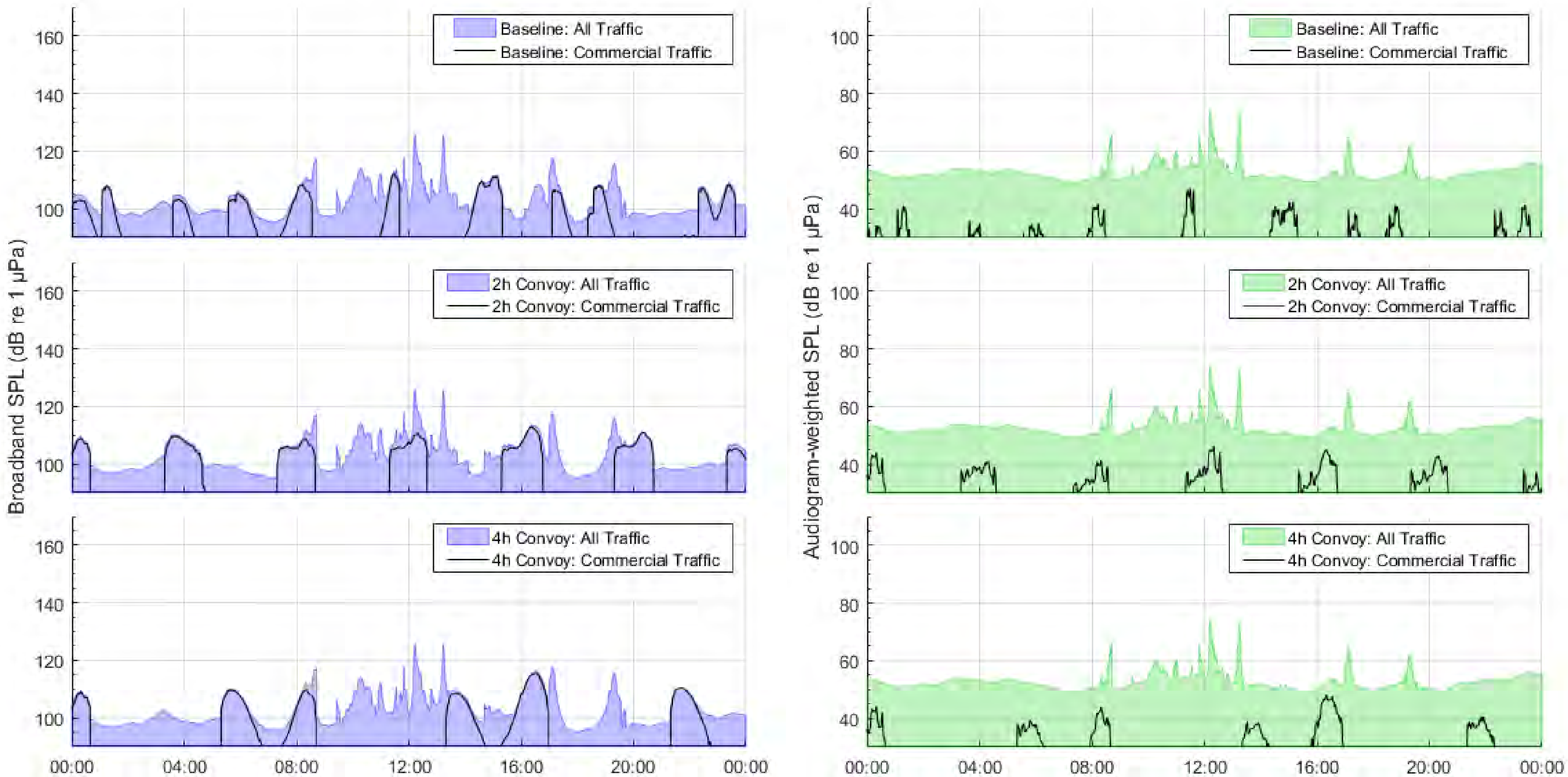


Figure 38. *Sample location 2*: Temporal variability of unweighted (left) and audiogram-weighted (right) received levels for (top) baseline (no convoy), (middle) 2-hour convoy, and(bottom) 4-hour convoy scenarios. The blue and green lines above the shaded area show received levels caused by all traffic and ambient noise. The black lines show received levels caused by commercial traffic only. The receiver location is shown in Figure 5.

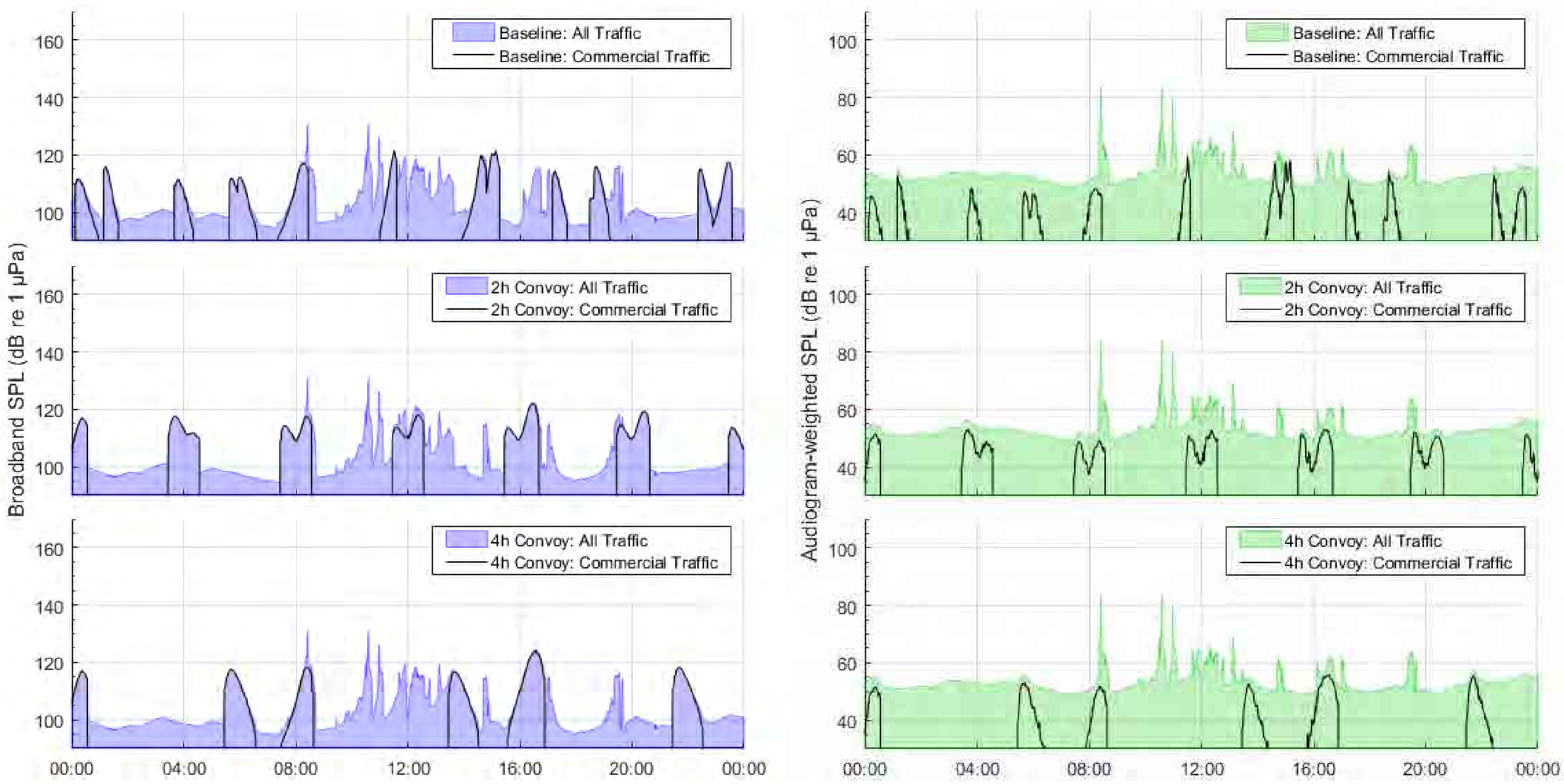


Figure 39. *Sample location 3*: Temporal variability of unweighted (left) and audiogram-weighted (right) received levels for (top) baseline (no convoy), (middle) 2-hour convoy, and(bottom) 4-hour convoy scenarios. The blue and green lines above the shaded area show received levels caused by all traffic and ambient noise. The black lines show received levels caused by commercial traffic only. The receiver location is shown in Figure 5.

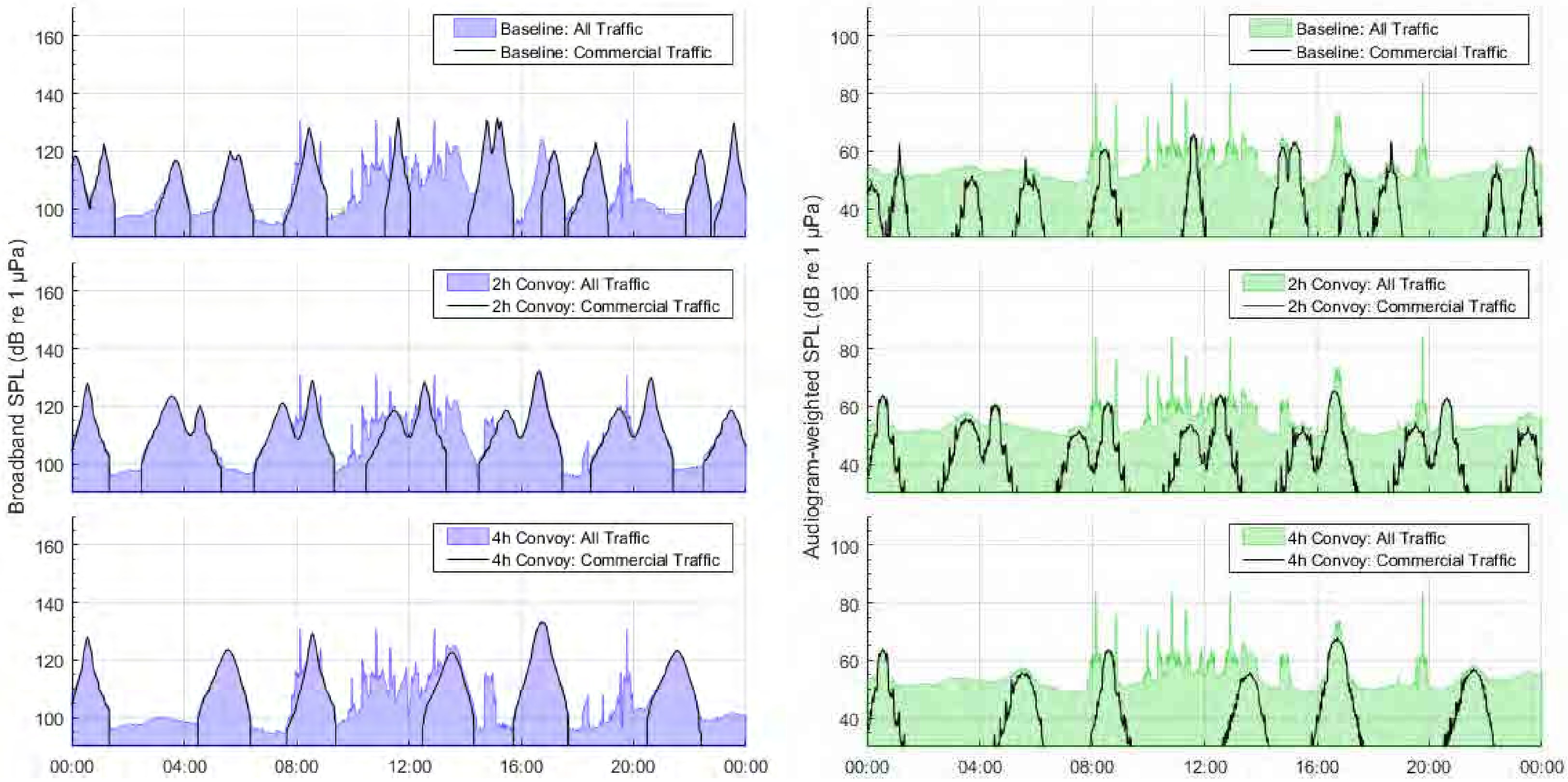


Figure 40. *Sample location 4*: Temporal variability of unweighted (left) and audiogram-weighted (right) received levels for (top) baseline (no convoy), (middle) 2-hour convoy, and(bottom) 4-hour convoy scenarios. The blue and green lines above the shaded area show received levels caused by all traffic and ambient noise. The black lines show received levels caused by commercial traffic only. The receiver location is shown in Figure 5.

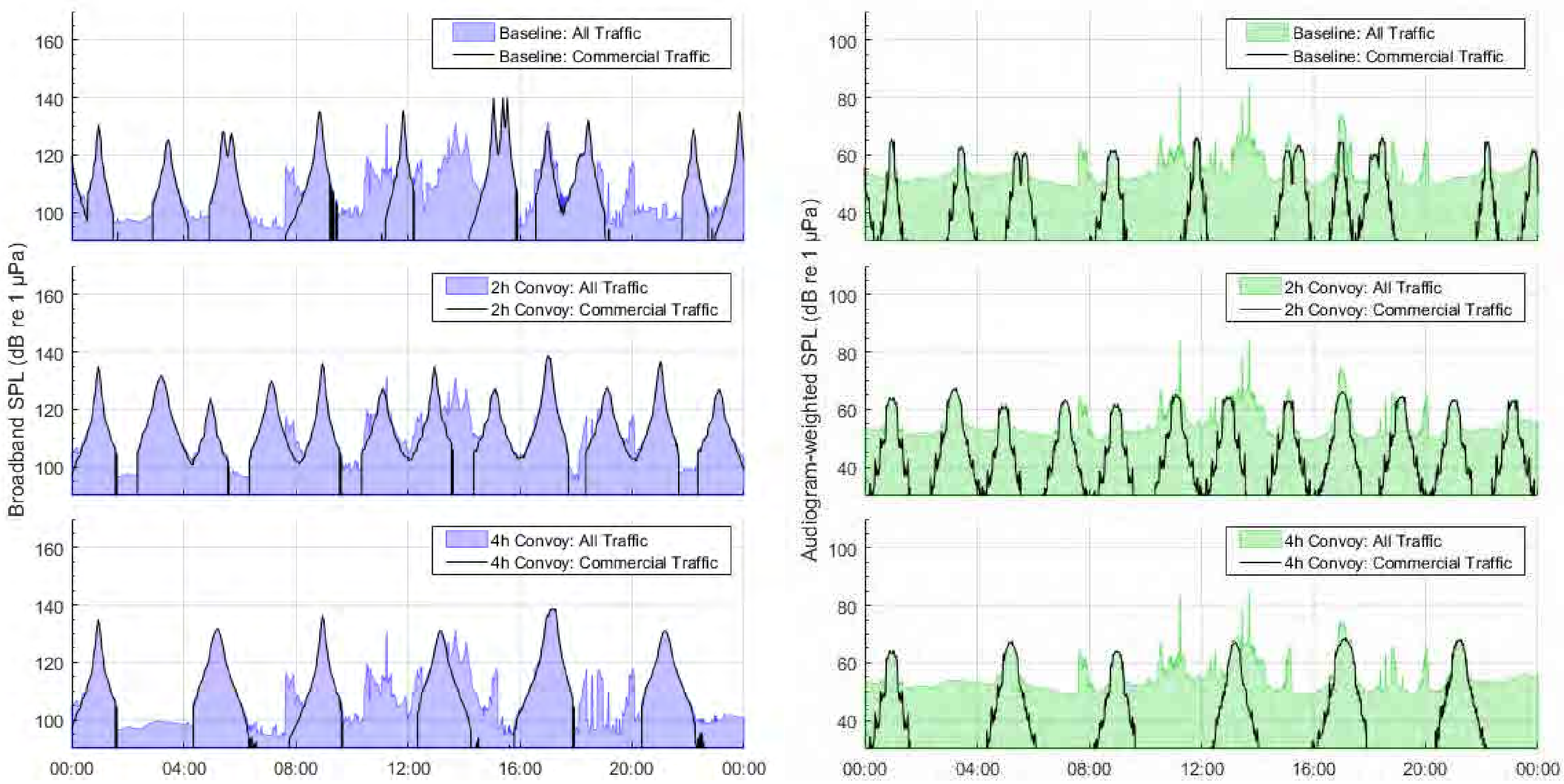


Figure 41. *Sample location 5*: Temporal variability of unweighted (left) and audiogram-weighted (right) received levels for (top) baseline (no convoy), (middle) 2-hour convoy, and(bottom) 4-hour convoy scenarios. The blue and green lines above the shaded area show received levels caused by all traffic and ambient noise. The black lines show received levels caused by commercial traffic only. The receiver location is shown in Figure 5.

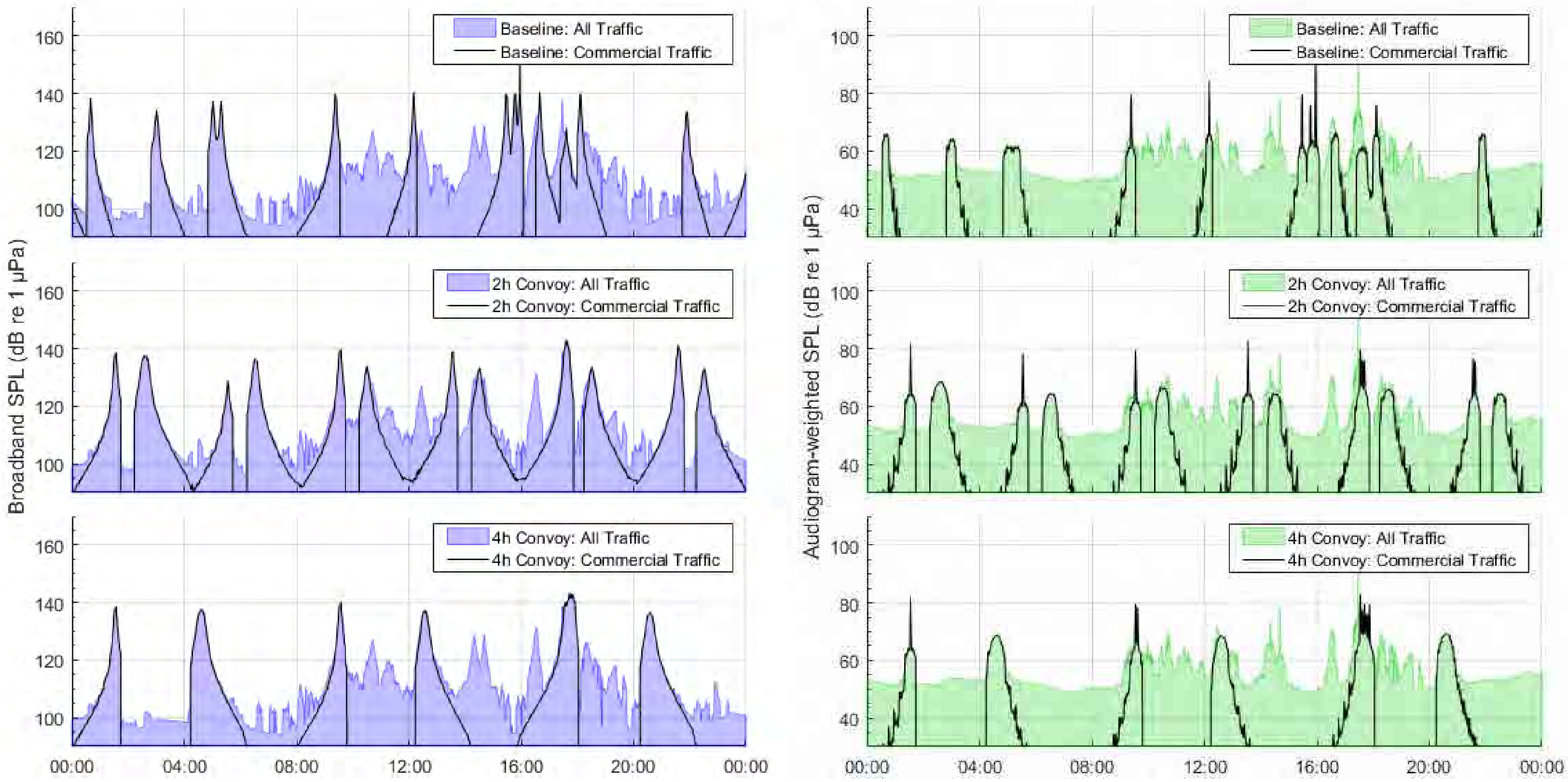


Figure 42. *Sample location 6*: Temporal variability of unweighted (left) and audiogram-weighted (right) received levels for (top) baseline (no convoy), (middle) 2-hour convoy, and(bottom) 4-hour convoy scenarios. The blue and green lines above the shaded area show received levels caused by all traffic and ambient noise. The black lines show received levels caused by commercial traffic only. The receiver location is shown in Figure 5.

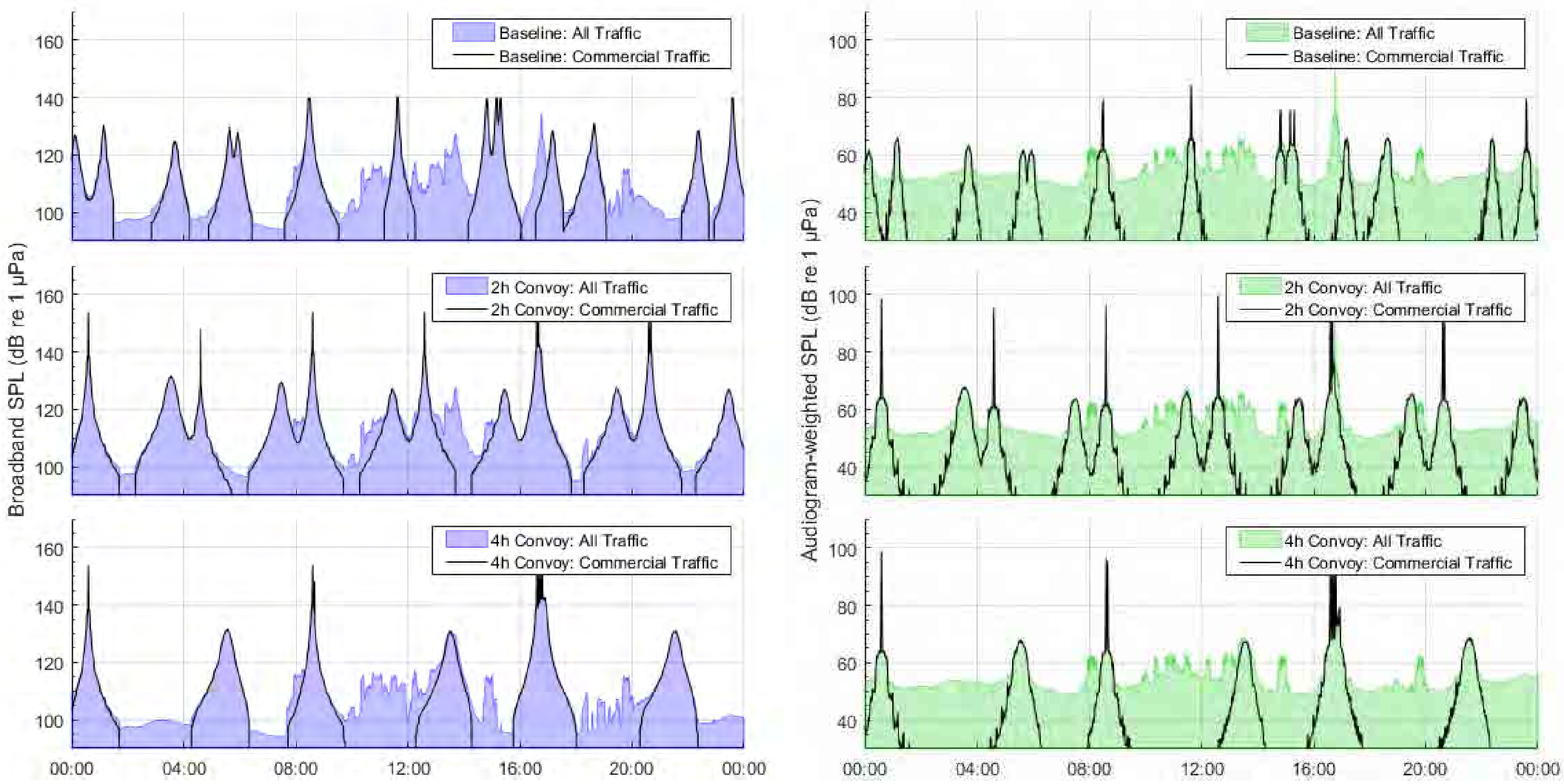


Figure 43. *Sample location 7*: Temporal variability of unweighted (left) and audiogram-weighted (right) received levels for (top) baseline (no convoy), (middle) 2-hour convoy, and(bottom) 4-hour convoy scenarios. The blue and green lines above the shaded area show received levels caused by all traffic and ambient noise. The black lines show received levels caused by commercial traffic only. The receiver location is shown in Figure 5.

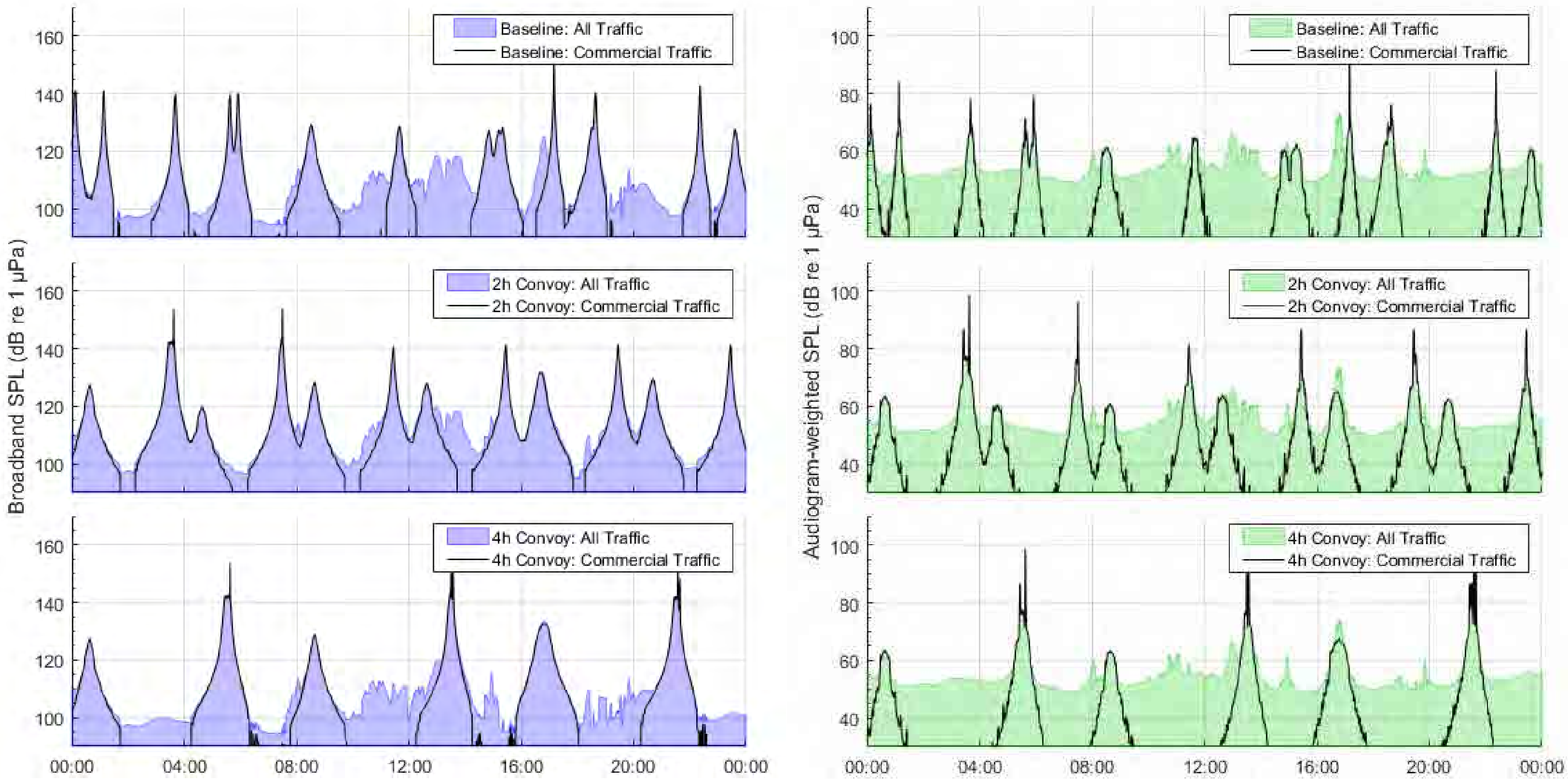


Figure 44. *Sample location 8*: Temporal variability of unweighted (left) and audiogram-weighted (right) received levels for (top) baseline (no convoy), (middle) 2-hour convoy, and(bottom) 4-hour convoy scenarios. The blue and green lines above the shaded area show received levels caused by all traffic and ambient noise. The black lines show received levels caused by commercial traffic only. The receiver location is shown in Figure 5.

Table 23. Percentiles, extremes, and mean unweighted received noise levels (dB re 1 µPa) over a 24-hour period with and without convoying, at eight locations within the SRKW critical habitat.

Sample location	Scenario	Noise level statistics (dB)							
		Min	5th	25th	50th	75th	95th	Max	Mean
1	Baseline	95.6	97.5	97.5	102.6	105.4	111.3	130.9	103.3±4.7
	2-hour convoy	95.4	97.3	100.3	103.2	106.3	111.4	130.9	103.6±4.8
	4-hour convoy	95.3	96.8	99.9	103.2	105.8	111.4	130.9	103.4±4.9
2	Baseline	95.2	96.3	98.5	101.6	106.9	112.7	125.9	103.0±5.4
	2-hour convoy	95.0	96.1	98.2	102.5	107.7	113.3	126.0	103.4±5.8
	4-hour convoy	95.1	96.1	98.2	101.4	107.8	114.3	125.9	103.1±5.9
3	Baseline	94.6	95.7	98.4	101.4	110.8	117.4	130.8	104.5±7.4
	2-hour convoy	94.5	95.7	97.8	99.9	111.9	118.6	130.9	104.5±8.1
	4-hour convoy	94.5	95.7	97.9	100.5	110.3	118.0	131.0	104.0±7.8
4	Baseline	94.4	95.9	99.8	107.7	116.0	124.5	131.6	108.5±9.3
	2-hour convoy	95.0	96.5	103.1	111.7	117.7	125.8	132.5	110.9±9.2
	4-hour convoy	94.4	95.6	99.0	106.6	115.1	125.0	133.5	107.8±9.9
5	Baseline	94.1	95.8	100.0	108.6	116.8	128.5	140.0	109.4±10.5
	2-hour convoy	95.0	97.3	106.3	112.5	119.7	130.3	138.9	113.2±9.7
	4-hour convoy	94.2	95.5	99.2	107.5	116.3	130.5	139.0	109.2±11.0
6	Baseline	94.1	96.2	102.3	109.9	118.5	131.8	154.0	111.1±11.0
	2-hour convoy	96.4	98.6	104.7	112.1	121.4	134.2	143.1	113.8±11.1
	4-hour convoy	94.1	96.5	101.5	109.2	118.5	135.4	143.3	111.3±11.6
7	Baseline	94.2	96.2	101.3	108.2	116.7	128.6	140.4	109.9±10.5
	2-hour convoy	94.9	97.5	104.4	112.4	119.1	130.8	154.1	113.0±10.5
	4-hour convoy	94.2	95.4	99.8	107.3	115.2	130.5	154.1	109.1±11.2
8	Baseline	94.2	96.3	100.9	108.0	115.9	128.1	155.6	109.4±10.4
	2-hour convoy	94.8	97.4	104.4	111.5	118.3	132.0	154.0	112.6±10.5
	4-hour convoy	94.2	95.5	99.6	107.1	113.5	131.9	154.1	108.7±11.2

Table 24. Percentiles, extremes, and mean audiogram-weighted received noise levels (dB re 1 μPa) over a 24-hour period with and without convoying, at eight locations within the SRKW critical habitat.

Sample location	Scenario	Noise level statistics (dB)							
		Min	5th	25th	50th	75th	95th	Max	Mean
1	Baseline	49.2	49.6	50.8	52.2	53.7	57.0	84.4	52.7±3.3
	2-hour convoy	49.2	49.7	50.8	52.2	53.7	57.0	84.4	52.8±3.3
	4-hour convoy	49.2	49.7	50.8	52.2	53.7	57.0	84.4	52.8±3.3
2	Baseline	49.2	49.5	50.8	52.2	53.6	59.1	73.8	52.8±3.2
	2-hour convoy	49.2	49.6	50.9	52.2	53.6	59.1	73.8	52.8±3.2
	4-hour convoy	49.2	49.6	50.8	52.2	53.6	59.1	73.8	52.8±3.2
3	Baseline	49.2	49.5	51.1	52.5	53.9	61.9	84.0	53.5±3.9
	2-hour convoy	49.2	49.9	51.1	52.5	54.1	61.9	84.0	53.5±3.9
	4-hour convoy	49.2	49.5	51.0	52.6	54.3	61.9	84.0	53.5±4.0
4	Baseline	49.2	49.6	51.4	53.3	56.2	63.5	84.0	54.8±5.1
	2-hour convoy	49.6	50.3	51.8	53.4	57.7	63.7	84.0	55.3±5.1
	4-hour convoy	49.2	49.5	51.2	53.4	56.6	63.8	84.0	54.8±5.2
5	Baseline	49.2	49.6	51.4	53.3	59.0	65.4	85.0	55.3±5.3
	2-hour convoy	49.3	50.0	51.9	53.5	60.9	65.8	85.0	56.0±5.6
	4-hour convoy	49.2	49.5	51.4	53.4	57.7	67.1	85.0	55.3±5.7
6	Baseline	49.2	49.9	51.6	53.5	60.5	66.5	97.4	56.1±6.1
	2-hour convoy	49.2	49.6	51.8	54.5	61.7	68.4	97.4	56.9±6.5
	4-hour convoy	49.2	49.6	51.6	53.6	60.7	68.8	97.4	56.4±6.4
7	Baseline	49.2	49.6	51.5	53.5	59.1	64.7	92.6	55.4±5.4
	2-hour convoy	49.6	50.4	51.9	53.7	60.8	65.5	99.6	56.4±6.4
	4-hour convoy	49.2	49.5	51.2	53.5	57.6	67.0	99.6	55.4±6.4
8	Baseline	49.2	49.7	51.5	53.3	57.5	66.2	101.1	55.1±5.4
	2-hour convoy	49.6	50.4	51.9	53.6	59.2	69.0	98.9	56.2±6.5
	4-hour convoy	49.2	49.6	51.3	53.4	55.7	69.2	99.6	55.2±6.6

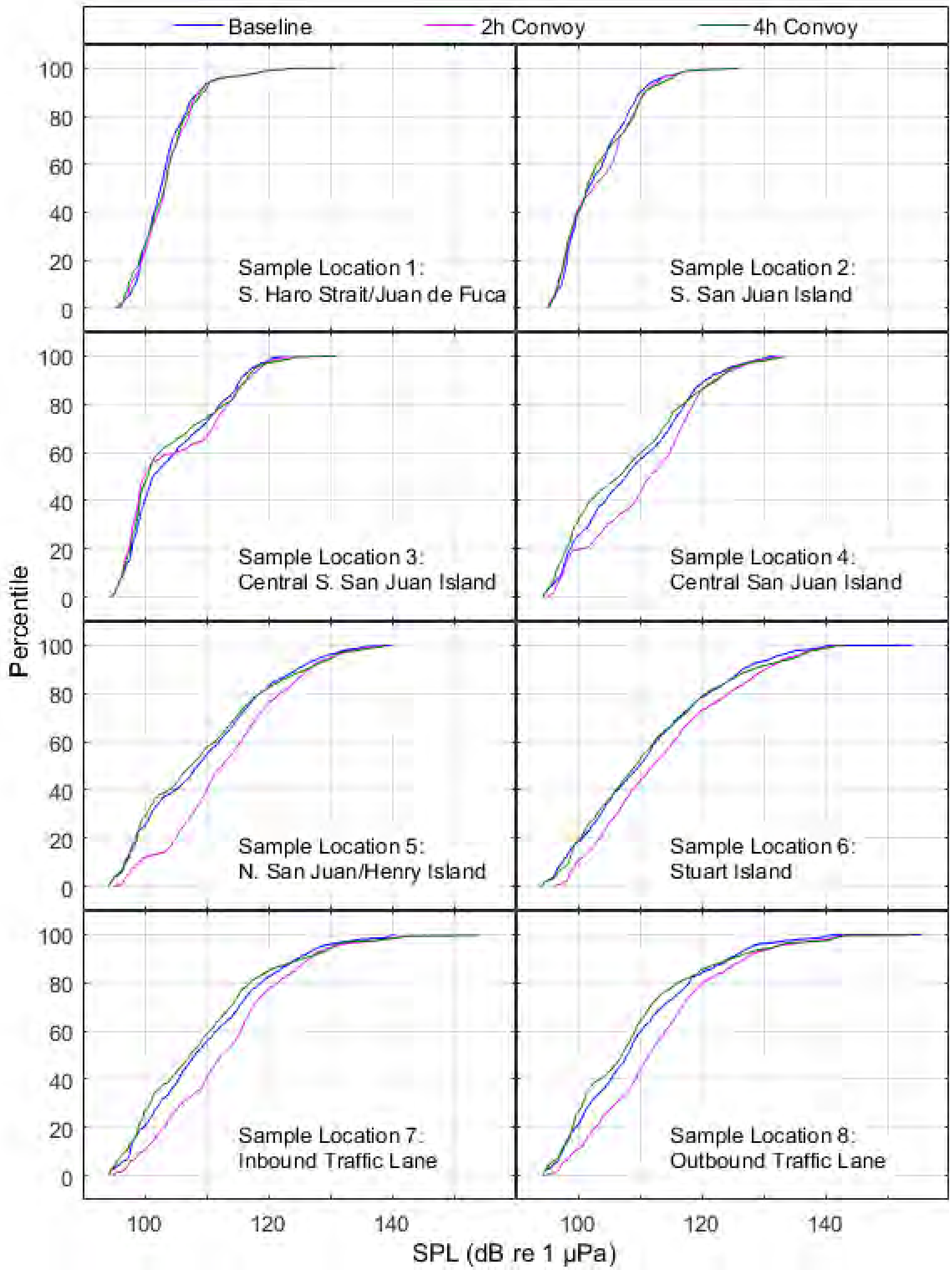


Figure 45. CDF curves of time-dependent unweighted SPL for baseline, 2-hour, and 4-hour convoy scenarios at the eight sample locations shown in Figure 5.

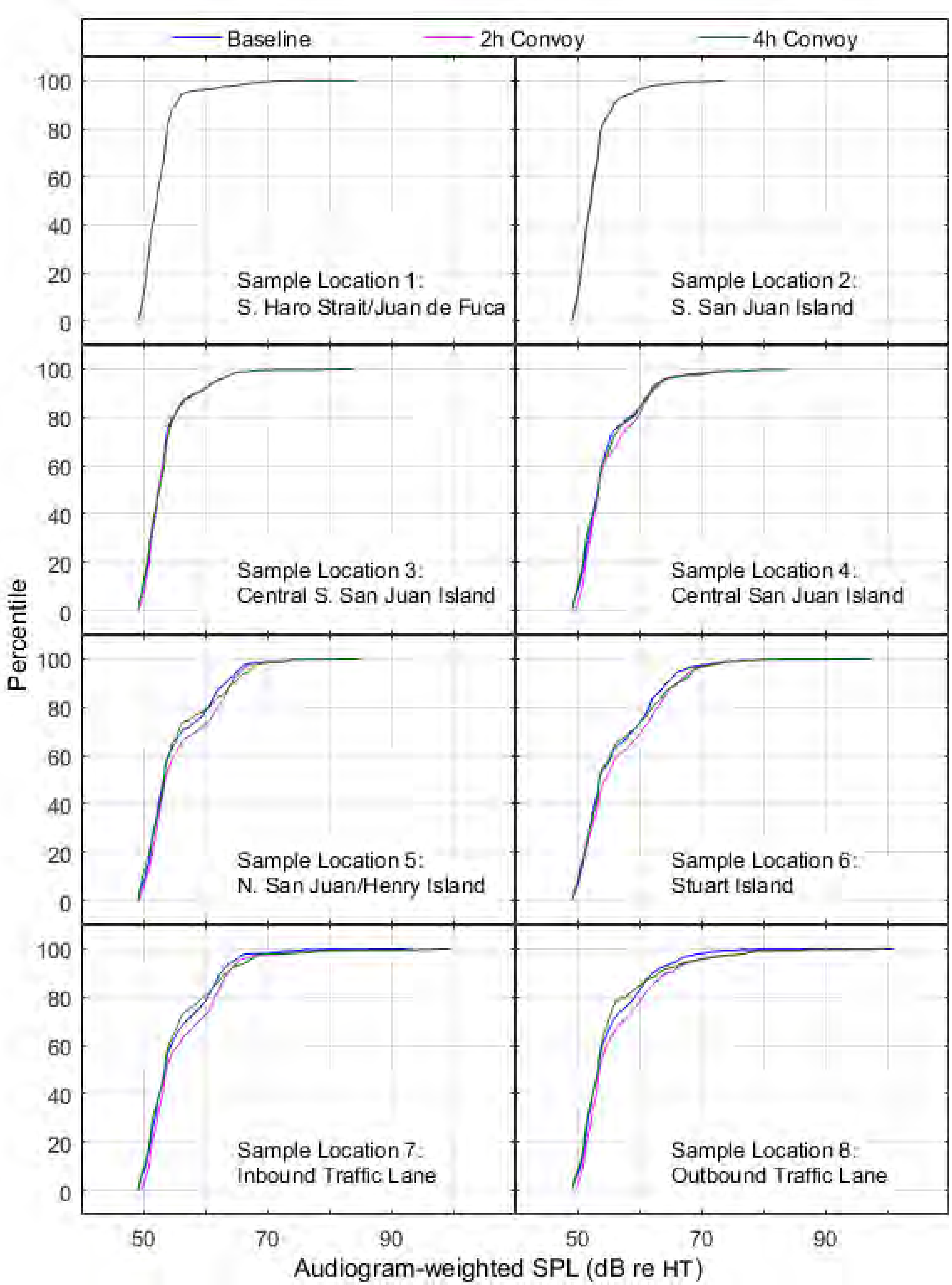


Figure 46. CDF curves of time-dependent audiogram-weighted SPL for baseline, 2-hour, and 4-hour convoy scenarios at the eight sample locations shown in Figure 5.

3.4. Other Noise Mitigation Options

This section presents published methodologies for mitigating shipping noise and discusses their applicability to noise mitigation approaches in SRKW critical habitat.

While the review focused on noise mitigation, the applicability discussion includes potential benefits for SRKW acoustic habitat (i.e., the quality of the habitat) and considers several potential outcomes, such as whether:

- The magnitude of the potential benefits to the SRKW habitat is considerable (i.e., noise reduction may not considerably impact the quality of the acoustic habitat),
- The benefits of the noise reduction are temporally or spatially limited and may be countered by increased negative effects on the habitat outside the time and space limits.
- The measures taken to reach the benefits lead to potential negative effects on the quality of the habitat as relevant for other species.

Effects on shipping safety are not part of this review and are not discussed here. Direct impact on SRKW is not part of the discussion of applicability of mitigation measures.

Sections 3.4.1 to 3.4.4 discuss published information on mitigating sound emitted by various vessel component. Sections 3.4.5 to 3.4.9 focus on mitigation procedures for operating vessels in a manner that may reduce noise.

3.4.1. Retrofitting Ships

Commercial ships are generally designed with little consideration of underwater noise emissions. Most noise control is currently associated with minimizing noise exposures to vessel crews and passengers. While those controls often provide some corresponding reduction in underwater noise emissions, they are usually not highly effective for that purpose. This section provides a summary of the current technologies commonly available for retrofitting ships to improve hydrodynamics and decrease noise propagation, as well as the expected reduction in broadband source levels, if available.

3.4.1.1. Cavitation Noise Control

The onset of cavitation is usually delayed by increasing the Cavitation Inception Speed (CIS; as seen in Appendix A.3.1) as much as possible (Spence and Fischer 2017). This is primarily achieved by using propeller shapes that are less susceptible to cavitation and by optimizing hydrodynamic flow around the propellers. Circumferential variations (i.e., non-uniformities) in the wake inflow of the propeller are a major cause of cavitation. Cavitation creates mechanical wear on propellers, thrusters, and other hull components. It also affects propulsion efficiency. Reducing cavitation, therefore, has many other direct benefits besides reducing underwater noise emissions.

3.4.1.1.1. Reduced Cavitation Propeller Designs

Different design techniques are currently available for reducing cavitation from propellers and thrusters. For a given propeller blade design, a greater blade area can produce a given thrust with a smaller difference in pressure between the face (pressure side) and the back (suction side) of the blade. The current trend is toward manufacturing large-diameter, slow-turning propellers, which cause in less cavitation, since large propellers generate more thrust at lower turning rates.

Flow-optimized blade shapes also reduce cavitation. For example, forward-skew propellers have blades with the leading edge curved toward the rotation direction. They may have better cavitation performance than conventional propellers. Kappel propellers are designed with modified blade tips smoothly curved to the suction side of the blade, increasing efficiency. The end plate on Contracted and Loaded Tip (CLT) propellers reduces the tip vortices, thereby enabling the radial load distribution to be more heavily loaded at the tip than with conventional propellers (optimum propeller diameter is smaller, and cavitation may be reduced). New Blade Section (NBS) propellers are smaller and lighter. This might provide higher efficiency and reduce cavitation. Another design technique is to add more propeller blades so the thrust on individual blades is reduced. Reduced-cavitation propeller designs are becoming more widespread in commercial shipping. Manufacturing and replacement costs are higher than for conventional propeller designs. The benefit of these designs is that they increase propeller life due to decreasing wear from cavitation.

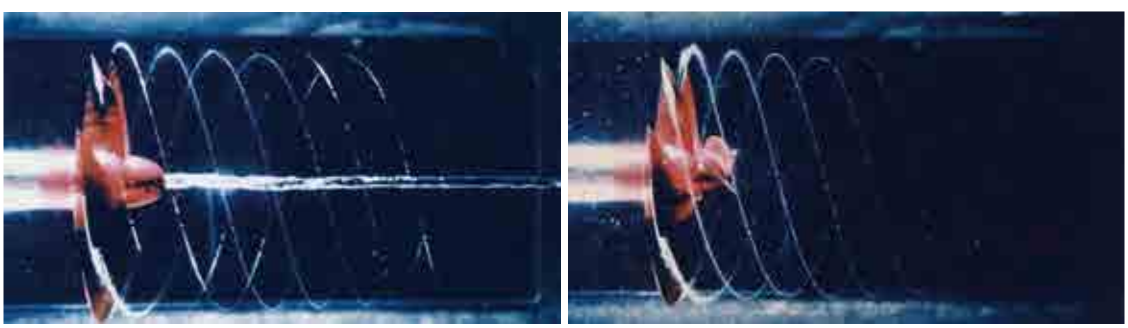
The likely noise reduction from reduced cavitation propeller design is 3–20 dB (Spence et al. 2007a p. 124, Andersen et al. 2009).

3.4.1.1.2. Reduced Hub Vortex Cavitation

Cavitation also occurs near the centre of the propeller, as seen in Figure 47(a). This central portion of the propeller is known as the hub and its cover is referred to as the boss cap. Properly designed boss caps can reduce the hub vortex cavitation[4], thus decreasing the hydroacoustic noise and improving propeller efficiency. This is particularly important for controllable pitch propellers, for which the size and design of the hub and cap influence the reliability of the system (Wind 1978, Ghassemi et al. 2012).

Propeller cap turbines are comprised of many hydrofoil-shaped blades integrally cast into the hub cap. Propeller Boss Cap Fins (PBCF; seen in Figure 47b) are small fins attached to the propeller hub cap. Both systems reduce the magnitude of the hub vortices and propeller vibrations.

The effect on noise reduction from propeller cap turbines is unknown. Conversely, the PBCF reduces cavitation, and it is claimed to reduce the sound pressure level by 3 to 6 dB (Ouchi et al. 1991, Abdel-Maksoud et al. 2004, Mewis and Hollenbach 2006).



(a) (b)

Figure 47. Vortex cavitation around a propeller (a) without and (b) with boss cap fins. Pictures reproduced with the permission of MOL Techno-Trade, Ltd. http://www.mol.co.jp/en/pr/2015/15033.html

[4] Hub vortex cavitation occurs when the lift is heavy on inward sections of the propeller blades.

3.4.1.1.3. Ducted Propulsion

Ducted propellers are affixed with a stationary, ring-like nozzle around the propeller to improve hydrodynamic flow over the blades. The improved character of the flow field, which becomes more uniform when guided by a nozzle, can reduce propeller cavitation. The nozzle itself may also provide acoustic shielding at higher frequencies. Kort nozzles are widely-used ducted propulsion for tugs. The Mewis Duct and Schneekluth's Wake Equalizing Duct (WED) are fore-propeller appendages based on the essential science of the Kort nozzle, but adapted for larger scale commercial vessels. Ducted propulsion is currently in widespread use in marine vessels. Ducted propellers improve the wake, increase propulsion efficiency, and decrease propeller wear.

The noise reduction from this design is not currently well understood.

3.4.1.1.4. Wake Inflow Optimization

Cavitation performance can be greatly improved by placing propellers along the hull where hydrodynamic flow is more uniform. The hull shape and the presence of nearby appendages is important in determining flow characteristics. Furthermore, it is essential to have adequate clearance between propeller tips and the hull to avoid boundary layer turbulence. Computational fluid dynamics simulations predict flow around vessel hulls and can be used to optimizing propeller placement.

Other means to improve wake flow include:

- A simplified compensative nozzle (a nozzle that has a more vertical or cylindrical shape instead of being circular), which improves uniformity of wake flow into the propeller,
- Grothues spoilers, a small series of curved fins attached to the hull just ahead of the propeller, and
- Pre-swirl stators, or Vortex generators, added appendages used to improve the wake flow.

Pre-swirl stators are especially suitable for the larger hull forms (container and tanker vessels for example). CFD simulations are widely used in designing vessel hulls. Wake inflow optimization improves propeller efficiency and decreases propeller wear.

The likely noise reduction from these design options is currently unknown.

3.4.1.1.5. Propeller/Rudder Interaction

Various concepts have been developed to increase propeller and rudder efficiency. Those concepts include Twisted rudder (to account for the swirling flow from the propeller), Rudder fins (the propeller recovers some of the rotational energy), and Costa Propulsion Bulb (CPB; the propeller is integrated hydrodynamically with the rudder by fitting a bulb to the rudder in line with the propeller shaft). Changes to propeller/rudder interaction increase propulsive efficiency.

CPB is claimed to reduce the hydroacoustic radiated noise levels by 5 dB (Ligtelijn 2007).

3.4.1.1.6. Air Injection to Propeller, Thruster, and Bubble Curtain

Bubbles can be produced in a deliberate arrangement to act as a barrier/curtain to break or reduce the sound propagating from the propeller, thruster, or hull. Air injection can minimize the cavitation erosion in propeller ducts.

The likely noise reduction from this design varies following treatment:

- Propeller bubble emission reduces the noise by at least 10 dB for frequencies above 500 Hz, but increases the noise (0–10 dB) for frequencies between 20–80 Hz,

- Thruster bubble emission reduces the noise by 0–20 dB for frequencies above 100 Hz, but possibly increases the noise for frequencies below 100 Hz, and
- Air bubble masker reduces the noise by at least 10 dB for frequencies above 500 Hz, but increases the noise (0–10 dB) for frequencies between 20–80 Hz (Spence et al. 2007a).

3.4.1.2. Alternative Propulsion Designs

Alternatives to conventional, direct-drive propulsion can decrease noise. These technologies benefit from improved flow characteristics (i.e., less cavitation) and from reduced mechanical coupling of drive components to the hull. Another advantage is that they eliminate the need for conventional bow thrusters, which can be a significant noise source on direct-drive vessels.

3.4.1.2.1. Azimuth Propulsion

These systems (also called Z-drive and L-drive thrusters), feature a conventional propeller mounted on the base of a 360° rotating pod affixed to the bottom of the vessel. The main benefit is that flow is improved due to the separation between the hull and the propeller. Azimuth thrusters offer greater flexibility in terms of hull placement than direct-drive propulsion. Azimuth propulsion also benefits from the cavitation control treatments described in the previous section. Azimuth propulsion is currently in widespread use.

The likely noise reduction from this design is 5–10 dB (Spence et al. 2007a, p. 124).

3.4.1.2.2. Voith-Schneider Propulsion

Voith-Schneider propulsion (VSP) is a unique technology that generates thrust using a rotating arrangement of vertical blades that protrude from a base mounted near the bottom of the hull. The VSP blades have a lower turn rate than conventional propellers, and may therefore be less susceptible to cavitation. VSP also offers greater flexibility in terms of hull placement, similar to that of azimuth propulsion systems. This system is currently employed in many tug designs; however, it is more costly than conventional propulsion, and may be unsuitable for operations in very shallow water.

The likely noise reduction from this design is not specified.

3.4.1.3. Machinery Noise Control

The main goal of machinery noise control is to decouple equipment vibrations from the structure of the vessel. A secondary goal is to reduce airborne noise emissions from equipment, which also couple to the structure of the vessel and radiate underwater noise. Besides reducing underwater noise, vibration isolation is also beneficial for occupational health and for vessel maintenance. It substantially reduces structure-borne noise and vibration in vessel compartments, improving the comfort and longer-term well-being of crews. It also reduces mechanical fatigue on the vessel itself, thus reducing maintenance costs.

3.4.1.3.1. Resilient Mounting

Resilient mountings are stiff, elastic, or elastomeric couplings that isolate equipment vibrations from the surfaces they are affixed to. They are most effective at reducing noise transmission at frequencies above 100 Hz. Resilient mountings are a mature, and highly effective vibration isolation technology. For deck-mounted equipment, improved noise isolation can be achieved if the deck itself is resiliently mounted. If they are improperly installed or poorly maintained, however, they can worsen vibration problems. Resilient mountings are currently in widespread use. They are low cost, reduce maintenance, and improve crew comfort.

The likely noise reduction from this design is 0–25 dB (Spence et al. 2007a, p. 149).

3.4.1.3.2. Damping Layers

Applying a layer of damping material to surfaces before mounting equipment isolates vibration. Typically, decoupling cladding or constrained layers of viscoelastic material is used, with the latter being generally most effective. The greatest benefit is achieved when damping layers are used in combination with resilient mountings. Dampening layers can be costly to install and may increase vessel weight. They do, however, reduce maintenance and improve crew comfort.

The likely noise reduction from this design is 0–10 dB (Spence et al. 2007a, p. 149).

3.4.1.3.3. Low-noise Equipment

Different models of the same equipment often generate quite different noise and vibration levels; therefore, selecting inherently low-noise equipment will result in reduced underwater noise emissions. Diesel-electric engines may be quieter and more efficient than geared diesel engines, and they are ordinarily better suited to vibration isolation. Most manufacturers provide information regarding the noise emissions of their equipment. Low-noise equipment may be more expensive. One benefit of this equipment is that it improves crew comfort.

The likely noise reduction from this design is variable, but 5 dB is common (Spence et al. 2007a, p. 149).

3.4.1.3.4. Equipment Placement

Machinery generates more underwater noise when it is located in compartments adjacent to the hull. Noise transmission is generally reduced when equipment is situated toward the centerline of the vessel, away from the hull. The location of the engine room is an important consideration, since this compartment usually contains the largest and loudest vessel machinery. Replacing equipment may require large-scale modification of a ship’s structure and thereby necessitate a complete refit, unless considered at the design stage.

The likely noise reduction from this design is not specified.

3.4.1.3.5. Acoustic Enclosures

Radiated noise can be mitigated by surrounding loud machinery in a sound-dampening enclosure. Acoustic enclosures are large, costly, and make equipment maintenance difficult. Situating noisy equipment inside a well-isolated engine room is usually a better option, and provides similar advantages. One benefit of this equipment is that it improves crew comfort.

The likely noise reduction from this design is 10–20 dB (Spence et al. 2007a, p. 161).

3.4.2. Replacing Trans Mountain Tugs with Specialized Tugs

As discussed in Section 3.4, shipboard machinery is the main source of underwater noise produced by ship at speeds lower than the cavitation inception speed. Most large vessels or tugs in service today use diesel-powered internal combustion engines. However, alternatives, in the form of electric and hybrid-electric engines, now exist that provide some noise reduction benefits. Beyond the cavitation inception speed as seen in Appendix A.3.1, the gain from machinery noise mitigation measures may be shadowed by cavitation noise.

3.4.2.1. Electric Tugs

Electric tugs use an electric motor driven by a battery pack. This system reduces the shipboard machinery components of the propulsion system, thus eliminating machinery noise. Because the battery bank needs to be charged through onshore connection, electric tugs are best suited to smaller, short-range, low-speed operations, such as harbour-assist operations.

Electric engines are used on ferries and pleasure craft, but are only recently being used on tugs. The retro-fitting of older tugs may be difficult since they may not have the space available for the required battery banks. The limitation in transit range may make this type of tug unpractical for use as escort tug based on the expected Trans Mountain shipping requirements. The benefits for electric tugs are that they eliminate fossil fuel consumption (unless a generator is used for off-grid charging), eliminate gas emissions, and improve crew comfort.

The amount of noise reduction would depend on the tug’s speed. If the tug was moving below cavitation speed, then substantial noise savings could be achieved, as noise generation is limited to flow interaction with hull features.

3.4.2.2. Hybrid-electric Tugs

A marine hybrid-electric system includes an internal combustion engine, a generator, an electric storage unit, and an electric motor. These tugs can use the internal combustion engine and electric motor separately or together, depending on their operational mode. This allows tugs to maximize each system’s efficiency, to reduce fuel consumption and gas emissions, and to minimize their acoustic footprint. They are more versatile than all-electric tugs. Their noise reduction characteristics depend on the operational mode (namely if and how the internal combustion engine is running), but they are generally noisier than all-electric tugs.

The amount of noise reduction depends on their speed and operational mode. If the tug is moving below cavitation speed and using only its electric system, noise is mainly created by flow interaction with hull features.

Hybrid-electric tugs are used in Europe and the US. They are becoming more popular as harbour managers consider ways to reduce environmental footprints. It is worth noting that the noise signature of hybrid electric vessels (LNG engine running electric generator, powering electric drive motors) has been measured at the ULS (JASCO, unpublished data). Once publicly available, these measurements could provide insight into the potential benefits of equipping tugs with hybrid-electric engines.

Diesel-electric (a form of hybrid-electric) propulsion systems are used in cruise ships (Kipple 2002). At low-speed (10 knots), noise levels produced by cruise ships equipped with these systems were generally higher than cruise ships with conventional propulsion systems. However, hybrid vessels showed less noise dependency to speed, making them substantially quieter at greater speeds (15 and 19 knots; Kipple 2002).

3.4.3. Changing Ship Designs

A recent study estimates that the cost of engineering and mechanical work to reduce noise by propeller redesign for a new vessel could be from 1–5% of the total cost of the commercial vessel (Spence and Fischer 2017). Similarly, the total cost for machinery noise control would be ~1–5% of the cost of the vessel. In both cases, retrofitting with a quiet propeller or installing treatments (for machinery noise) will always be more costly (Spence and Fischer 2017).

The two critical components influencing cavitation performance are the propeller design itself and the management of the wake. The wake is influenced by the shape of the hull. Careful propeller and hull designs are essential for improving the cavitation performance. For new ships, the wake flow can be improved by more careful design, which requires an increased design effort, including careful model testing and computational fluid dynamic analysis.

Predictions of noise for new-build ships could be valuable in ensuring that they are as quiet as possible. Kellett et al. (2013) reports that waiting until the ship is fully designed and built before taking measurements leaves little scope for alteration and improvement. They suggest building a numerical noise prediction model to predict the noise of a newly built vessel. Such models would be of increasing value if validated by empirical full-scale measurements.

3.4.3.1. Propellers

The first aspect to consider is whether the propeller has been designed for the actual operating conditions. In many cases, propellers are optimized for the service speed and full load condition in calm water. In practice, a ship usually operates at a reduced speed and draught, and often in a seaway.

For a given ship fitted with a fixed pitch propeller, reducing the speed decreases the overall noise (Kipple 2002). Ships with controllable pitch propellers are unlikely to exhibit the same reduction in noise with speed. In many cases, the noise from those ships may actually increase when they operate at reduced speed due to face cavitation, unless they are fitted with new propellers designed for the lower speed.

3.4.3.2. Changes to the Hull Form

Numerical methods, such as computational fluid dynamics tools used in early design stages, could optimize hull forms for noise reduction. A well-designed hull form requires less power for a given speed, which likely results in less underwater noise. Moreover, a well-designed hull form provides a more uniform inflow to the propeller, thereby increasing the propeller efficiency and reducing noise and vibration caused by an uneven wake flow.

3.4.4. Changing Ship Maintenance

The ship maintenance procedures that reduce or control noise primarily involve propeller and hull maintenance, including cleaning routines as well as engine maintenance (Baudin et al. 2015, Audoly et al. 2016).

Regularly inspecting and repairing propellers and thrusters increases the inception speed of cavitation (Spence and Fischer 2017) and reduces noise resulting from propeller and propeller shaft movements. Furthermore, McKenna et al. (2013) suggests that tonal components of ship sounds may be related to propeller damage and contribute greatly to the radiated underwater noise of ships. Engine vibration is another source of noise that can be reduced by regular maintenance (Spence et al. 2007b).

Regularly maintaining and cleaning the hull reduces friction noise from water flow (Hollenbach and Friesch 2007). In combination with regularly maintaining and cleaning the propeller, hull maintenance increases fuel efficiency and reduces noise output (Baudin and Mumm 2015). Ships can run at higher speeds with lower consumption than ships with less scheduled maintenance and fewer cleaning routines, which lowers noise outputs at any given location due to higher transit speeds (Baudin and Mumm 2015).

Propeller cleaning and polishing has been shown to smooth the hull and propeller surface, which controls noise. Applying anti-fouling agents or coatings to propeller and hull as part of routine maintenance schedules maintains smoothness longer, thereby decreasing noise increase due to fouling longer (Southall 2005, Baudin and Mumm 2015). Overall, regular ship maintenance is expected to reduce noise output between 0.5 to 3.5 dB (Baudin and Mumm 2015).

3.4.5. Changing Operator Behaviour

While operator behaviour is intuitively an important component of ship noise mitigation, given that operators are controlling vessel operations, there is little mentioning of specific behaviours that can reduce noise in the reviewed literature. Using vague terms, such as ‘optimized ship handling’, Audoly et al. (2017) refers to operational changes as beneficial for noise mitigation; however, the authors do not explain what is involved in optimization.

Operational changes that seem to be important are loading and speed. The load of a vessel appears to affect the noise output ,and vessels not fully loaded (i.e., in ballast condition) have higher noise outputs due to lower hydrostatic pressures acting on the propeller higher in the water column causing more cavitation (André et al. 2011) In addition, propeller efficiency is optimized for full load travelling in calm seas, potentially increasing engine noise when travelling the same speed as under full load (Renilson et al. 2013a). These ideal conditions hardly ever exist in the real world, and vessel operators could be trained to operate their vessels optimally by varying speed based on environmental conditions and percentage of load, for the purpose of reducing noise emissions. This may include operating their vessels just below cavitation inception speed whenever possible, especially when in critical whale habitat (Spence and Fischer 2017). The actual inception speed can be increased with very regular propeller and hull maintenance regimes, as mentioned in Section 3.4.4. Vessels equipped with air injectors near the propellers may reduce noise output when air is injected if not fully loaded (IMO 2014).

Quick acceleration above optimal cruising speed is also a potential source for increased noise levels (Audoly et al. 2016), and so is selecting optimal trim for sea conditions and speed (Hollenbach and Friesch 2007, IMO 2014, Baudin and Mumm 2015). Operators should pay special attention to trim conditions and when and how to speed up. If possible, ships should be equipped with a trim optimization aid (Baudin and Mumm 2015). Vessels equipped with a controllable pitch propeller (CPP) do not reduce noise output linearly with reduced propeller speed. To minimize noise emission, it is important for vessels with CPP to operate with the optimal shaft speed for design propeller pitch (Baudin and Mumm 2015).

Doubling of acoustic power (+ 3 dB) occurs from two sound sources with equal source levels. Thus, if vessels with similar source levels are in a mitigation hot spot without a speed limit, operators may reduce total noise output by keeping optimal space between the ships (Baudin and Mumm 2015). In contrast, operators of vessels with different source levels may keep closer spacing to reduce the time whales are exposured to noise. This is the underlying concept of convoying described in Section 2.2.3.6.

Within the narrower waterways of the Salish Sea, it may also be useful to have a Marine Mammal Observer (MMO) on the bridge, in addition to the coast pilot responsible for safe navigating. An MMO familiar with the area could keep contact with whale watch operators and others with knowledge of SRKW presence. The MMO would alert the pilot of whales nearby.

3.4.6. Changing Shipping Practices

Noise may be possibly be reduced by planning the spatial arrangement and timing of commercial vessel traffic. Other changes in shipping practices related to load, general speed reductions, temporal closures, and convoying are presented elsewhere and/or are part of this modelling exercise. They will only be addressed here in combination with marine traffic plans.

Marine spatial planners make recommendations to ship traffic regulators to arrange port arrival and departure times of vessels. They can make recommendations to manage traffic composition to minimize noise presence in sensitive habitat areas (Audoly et al. 2017). Specific measures resulting from spatial traffic management could result in grouping vessels with lower underwater noise emission and spacing vessels with higher noise emission farther apart (Baudin and Mumm 2015, Williams et al. 2015, McKenna et al. 2017).

Other regulatory mechanisms to reduce noise include forbidding vessels with a certain gross tonnage and a noise level above a set threshold from entering whale sensitive areas (Redfern et al. 2017), and applying temporal area closures for all motorized vessels (McKenna et al. 2017). These measures are unlikely to affect the majority of commercial vessels travelling in shipping lanes, but may require vessels, such as cruise ships travelling into sensitive areas, to either re-route or slow down (McKenna et al. 2017). This measure would only improve noise conditions in localized areas, and could increase sound levels in other areas do to re-routing. Such regulations may, however, lead to an increase in retro-fitting vessels with quieting measures. Similarly, speed reductions in whale sensitive areas where vessels travel often (i.e., several times daily such as along ferry routes) could immediately reduce the overall noise level in those areas. It may also lead to an increase in retro-fitting vessels with quieting measures (Hatch et al. 2008).

Measures such as speed reductions in choke points (areas with high densities of ships and whales) are presented in Section 3.3.1. An alternative approach to slow-down zones is temporal changes in speed limits between locations with changes in whale occurrence, such as discussed in Section 3.4.7. In addition to the notification method described in Section 3.4.7, a traffic control system (flashing lights warning ships of whale presence) could be installed in choke points (e.g., Haro Strait, Boundary Pass, and Active Pass for SRKW). The traffic control system could be used to regulate the speed of commercial vessels, but could also limit access of other vessel classes to sensitive habitat.

3.4.7. Applying Real-time Mitigation in Hot Spots

In many cases, real-time mitigation does not focus on mitigating noise, but on mitigating ship strike risk (Ward-Geiger et al. 2005, Silber et al. 2012). Underwater observatories simultaneously collecting marine mammal vocalizations and ship sounds, while sending the data to land base receiver stations, however, are a promising tool for developing real-time noise mitigation in some coastal areas (Simard et al. 2006, Zaugg et al. 2010, André et al. 2011, Moloney et al. 2014).

Some ocean observatories, connected to land-based receiver stations via cables allowing high-speed data transmission, transmit acoustic data in quasi real time. These observatories can also collect other data that can be used to identify acoustic environmental properties. One typical acoustic application of observatories is assessing noise contributions of individuals ships to the ambient noise by measuring the variation in source levels between vessels (Simard et al. 2006). Another important function is assessing where, when, and how often ship noise is received by whales within their habitat. Underwater listening projects such as the LIDO project (André et al. 2011) and the PortListen project (JASCO, unpublished data) allow good assessments of whale presence and noise levels to estimate the impact at the Underwater Listening Station (ULS).

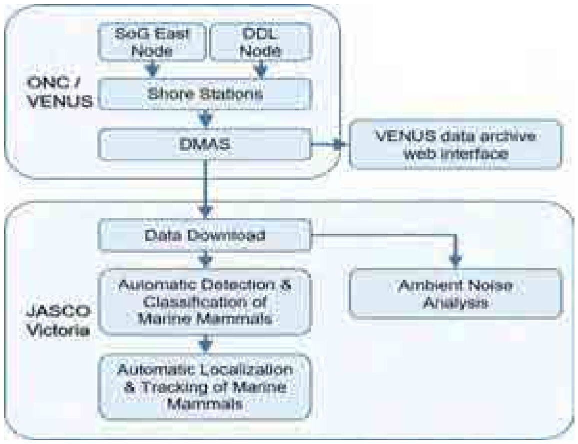


Figure 48. Schematic data process flow from two ocean observatories in the Strait of Georgia operated by Ocean Networks Canada with integrated real-time marine mammal detection and ambient sound analysis components operated by JASCO (Moloney et al. 2014).

Data collection and automated analysis technology may allow real-time mitigation of noise exposure of whales around underwater listening stations, by using automated ship/pilot notification of whale presence. These notifications could initiate appropriate vessel operation around whales and in areas of expected presence of whales, and therefore, reduce noise output. This type of alert system is already used in whale strike reduction management tools at several locations.

Whale presence notifications are sent to ships travelling through a sensitive whale area via specialized communications systems such as satellite internet or telex (e.g., NAVTEX) or via Automated Identification Systems (AIS). The alert systems is part of the Mandatory Ship Reporting System (MSRS) in the right whale critical habitat off Massachusetts and Florida (Ward-Geiger et al. 2005). The MSRS, an IMO sanctioned management tool to reduce whale strikes, requires ships entering a whale-sensitive area to report the vessel name, call sign, course, speed, location, destination, and route (waypoints). In return, the system automatically sends whale locations established via acoustic monitoring and appropriate vessel operations including speed limits to reduce strike risk.

There is a relationship between the relative distance of vessels and noise levels received by the whales, which can be deduced based on transmission loss and hearing abilities (Hatch et al. 2008). Similar to the ship strike alerts system, a noise mitigation alert system would alert ships with regularly updated information on whale presence, anticipated travel direction based on modelling of typical whale behaviour, and guidance on vessel operating procedures within sensitive habitat areas. Speed limits are a common management tool for reducing ship strikes on whales in high whale density areas (Russell et al. 2001, Ward-Geiger et al. 2005). Speed limits could also be used to reduce noise exposure in sensitive areas (Baudin et al. 2015). The resulting noise reductions would be proportional to the reduction in source level due to lower speed, minus the increase in exposure due to the increase in the time it takes for a vessel to clear the sensitive area.

Real-time mitigation using acoustic monitoring systems is limited by the system's detection accuracy. All automated acoustic whale detection algorithms produce some errors in the form of false positive (whales are detected but not present) and false negative (whales are present but not detected) detections (Mouy et al. 2009). The error rate usually increases with higher ambient noise levels, which would limit the distance over which whales can be detected with high accuracy in areas and times with high ambient sound levels, such as areas with dense ship traffic. Accuracy also differs with environmental conditions because rain, wind, and sea state effect ambient noise levels, and those conditions differ by season. The ambient noise level affects signals with different spectral composition differently. For example, detecting high-frequency echolocation clicks may not be affected as strongly by low-frequency ambient noise, but detecting the clicks over greater distance is associated with the lower-frequencies within clicks. These limitations are important for SRKW because many areas within their critical habitat are characterized by high ambient sound levels. While SRKW signals contain spectral components that differ from ambient sound, their detection distance is mostly affected by the travel distance of the lower frequencies (Miller 2006), where ambient sound is loudest.

Another limitation is dependent on a whale's acoustic behaviour and behaviour state. Whales are often silent and, therefore, undetectable by acoustic monitoring. Acoustic signalling rates varies greatly, depending on the activity that the whales engage in (e.g., foraging/travelling versus socializing versus resting). For example, the SRKW vocalization rate is high in social contexts, when foraging, and sometimes when travelling. The rate is much lower when the whales travel slowly, and SRKW may be completely silent when resting (e.g., Ford 1989). The vocalization rate may not always be a good indicator of possible disturbance, however, since whales may be most easily disturbed when resting. The vocalization rate is also affected by group size, which is lower in single pod encounters versus multi-pod encounters. Single pod encounters are much more common in late fall, winter, and early spring when ambient noise is also generally higher than in the summer.

Visual observers may therefore be needed to augment acoustic whale detections in sensitive areas and whale hotspots. A project to improve the detection of non-vocal SRKW and small vessels was conducted by researchers from the University of Victoria as part of the MEOPAR-funded NEMES project. It uses camera images taken at regular intervals at underwater listening stations, to assess detection accuracy of whales and to report the presence of small vessels. The study is ongoing and initial results are encouraging in that the method may allow ground-truthing of acoustic detections (L. McWhinnie, pers comm. Aug 2017).

3.4.8. Adjusting Traffic Lanes–Juan de Fuca Strait

This section presents a qualitative analysis of possible changes in noise levels due to shifting outbound and inbound traffic lanes in the Swiftsure Bank area. This analysis is based on a literature review and on modelled results from the adjusting traffic lanes in Haro Strait presented in Section 3.3.5.

In 2014, the IMO released non-mandatory guidelines asking owners, operators, and regulatory bodies of their member states to mitigate commercial ship noise. Even before the guidelines were released, studies on the impact of noise on whales suggested that certain ship strike mitigation methods may also reduce noise exposure (e.g., Hatch et al. 2008). Researchers, conservation managers, and the IMO have considered ships striking whales a serious problem for many years (Jensen et al. 2004). Attempts to mitigate ship strikes lead to several specifically mandated actions (Silber et al. 2012). Among those actions were adjusting ship traffic management schemes, such as geographically moving traffic lanes to account for marine spatial planning for whales.

The goal of adjusting traffic lanes is to increase the separation between vessel traffic and whales. Shipping lanes adjustments, which include moving shipping lanes geographically, have been primarily discussed as a regulatory measure to avoid collisions between whales and ships or to lower the potential risk of ship strikes on whales in areas of high whale density (Russell et al. 2001, Vanderlaan et al. 2008, Abramson et al. 2009, Silber et al. 2009, Silber et al. 2012, Wiley et al. 2016). Noise exposure reduction can be a another effect of moving shipping lanes, with benefits such as reducing high noise level concentration in whale sensitive areas (e.g., foraging or breeding areas; Haren 2007, Hatch et al. 2008, Baudin and Mumm 2015, McKenna et al. 2017) and/or decreasing cumulated noise levels in the soundscape of a larger area and thereby improving the acoustic quality of a habitat (Chion et al. 2017, Redfern et al. 2017).

Shipping lane adjustments have been implemented in a few locations around the world, but the direct effects in sound exposure to marine life have not been fully studied. For example, to reduce the risk of collisions between ships and North Atlantic right whales, the shipping lanes leading traffic into Boston Harbour that traversing through a Marine Protected Area (Stellwagen

Bank Marine National Sanctuary) were moved based on whale distribution and oceanographic factors, as seen in Figure 49. Moving the shipping lane to an area with lower expected whale density also increased the average distance of most whales from the ship noise sources, thereby potentially reducing noise exposure for whales in the Sanctuary. This reduction is inferred from the spatial distribution pattern of whales, but the difference in received levels before and after the change in shipping lanes has not been measured. Hatch et al. (2008) reports that the median received levels over the most important shipping noise bandwidth (10–1000 Hz) varied by 3 dB between quietest and loudest locations in the Sanctuary, and the loudest locations were closest to the Boston shipping lanes. Since other noise mitigation measures, such as reducing vessel speed in the Sanctuary, were implemented at the same time, the direct effect of the change in shipping lanes cannot be established. Nevertheless, the experience gathered from studying acoustic impact of shipping lanes on the soundscape of North Atlantic right whales has been used to consider changes in shipping lanes in other areas, such as the entry in the San Francisco Bay, to reduce both ship strike risk and noise impact on blue and fin whales (Impacts 2012).

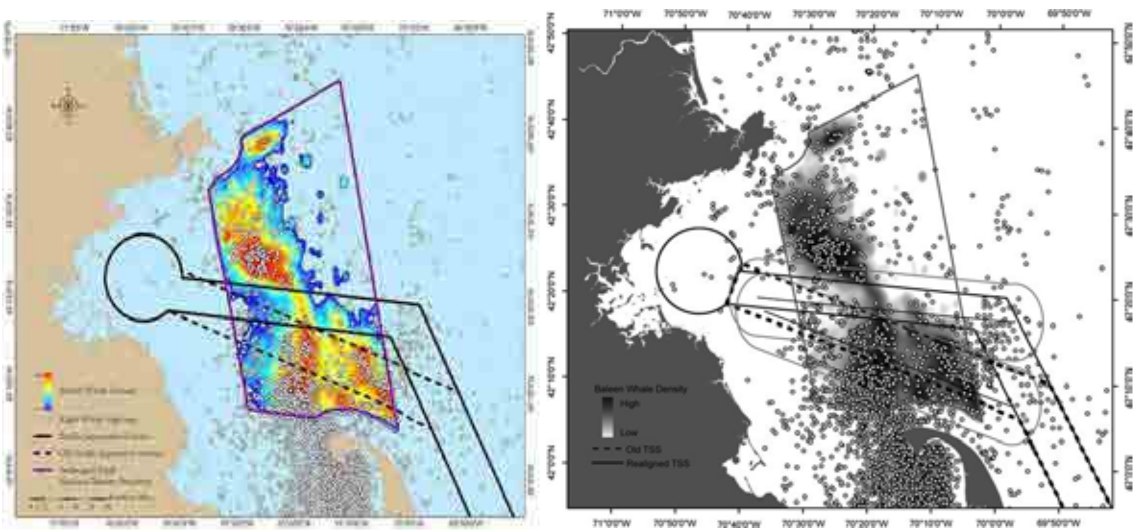


Figure 49. (Left) Traffic Separation Scheme change through Stellwagen Bank National Marine Sanctuary (map from Wiley et al. 2006, courtesy of NOAA). (Right) Change in ensonified areas above 120 dB re 1 µPa (rectangular shapes with rounded short sides) based on a simple transmission loss calculated from the centre by Hatch et al. (2008).

The first steps in developing ship traffic management regulations to reduce impact on whales is to identify temporal and spatial overlaps between whale occurrence and shipping routes and to establish a spatial or temporal profile for the whales' habitat preference in an area that overlaps with shipping routes (Berman-Kowalewski et al. 2010, Hazen et al. 2016).

If research establishes that:

- The area is characterized by a high density of whales at certain times of the year or year-round, and/or
- Oceanographic and biological data support a high expectancy of whale presence in the area (Hazen et al. 2016),

then a high risk of mortality due to ship strikes is likely, and so is a high risk of disturbance due to noise exposure from ships (Hildebrand 2005).

A detailed analysis of resident killer whale density and habitat quality in both areas (current and proposed traffic lane locations) is necessary for assessing if there are sufficient benefits from moving and/or separating shipping lanes across Swiftsure Bank and inside Juan De Fuca Strait. DFO acoustically monitored killer whales and other cetaceans on Swiftsure Bank (Riera et al.

2011) and found that southern and northern resident killer whales, and Bigg's killer whales, frequently use the area, presumably to forage. Acoustic monitoring allows rough density estimates of resident killer whales that are present during a recording because of the social organization and dialects of these whales (Ford 1991). Resident killer whales remain in their natal family group for life. A yearly census of all residents conducted by DFO and the Centre of Whale Research in Washington State provides exact numbers of whales in each natal group. DFO is in the process of extending the designation of critical habitat of SRKW to include Swiftsure Bank and adjacent areas, such as the entrance to Juan de Fuca Strait. More work is likely required to determine spatial and temporal variation in habitat use by SRKW before a specific change in traffic lanes around Swiftsure Bank can be considered.

Based on our results for adjusting traffic lanes in Haro Strait, presented in Section 3.3.5, we expect that moving traffic lanes would results in little to no decrease in noise levels over the entire entrance to Juan de Fuca Strait. This is because the same amount of traffic would continue to pass through the region, but along a different path. The changes in noise levels would be localized. A decrease of up to 10 dB could be expected along the old shipping lane location; similarly, there would be an increase in sound levels at the new shipping lane location.

Another consideration for adjusting traffic lanes is the potential effects on other cetaceans, particularly large baleen whales such as blue and fin whales that also occur frequently in the area. Both species have better hearing in lower frequencies (<100 Hz), and the negative effects of ship noise on their communication range is usually greater than the same effects on the killer whale communication range. Moving shipping lanes should take the potential effects on these whales into account, not only with regard to negative acoustic impacts, but also the potential for increased ship strike risk (Nichol et al. 2017).

3.4.9. Using Larger Vessels

Length is a proxy for the vessel gross tonnage and, therefore, the amount of cargo a vessel transports (i.e., longer vessels can move greater amounts of goods). Generally, larger vessels (longer, greater gross tonnage, and deeper draft) have a higher noise output, especially at frequencies below 1 kHz, than smaller ones (Richardson et al. 1995). A possible increase in noise level could be compensated for, however, by reducing the number of transit required to move the same amount of goods.

The relationship between vessel length and broadband noise level is complex, and varies between vessel classes. Propeller cavitation and hull vibration due to internal machinery are the main sources of vessel noise. Since vessels of the same length and class can have a different hull design, propeller type and size, and internal components, their broadband noise levels can also be different. For example, Kipple and Gabriele (2007) estimate noise emission from vessels entering Glacier Bay, AK. Generally, ships longer than ~183 m (600 ft) are large cruise ships, while ships between 30 and 76 m (100 and 250 ft) are mostly tour boats entering the Bay daily. The estimated source levels from the large cruise ships (indicated as “more than 600 ft” in Figure 50) are lower than for tour boats (indicated as “100 to 250 ft” in Figure 50) transiting at the same speed. The broadband source levels for each vessel length class also vary by at least 10 dB.

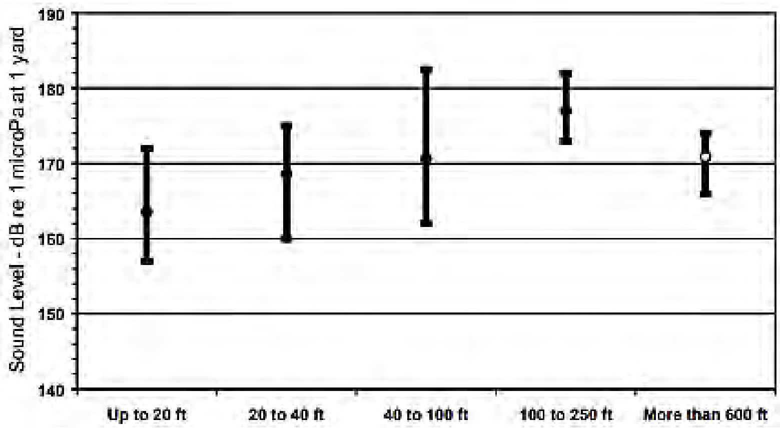


Figure 50. Estimated sound source levels of vessels entering in Glacier Bay, AK, at speed of 10 knots (figure from Kipple and Gabriele 2007).

McKenna et al. (2013) investigate the relationship between ship length, gross tonnage, horse power, service speed (the speed the ship was designed to travel with max efficiency), actual speed, draft, and oceanographic conditions. Their work supports earlier suggestions of a positive relationship between speed (service and actual) and length with broadband noise levels. Although variation in actual speed explains most of the noise level variations in all estimated 1/3-octave-bands, vessel length is the second most important parameter. The authors also present positive relationships between vessel length, gross tonnage, and draft. Therefore, length can be considered as a proxy for the amount of cargo a vessel can transport. The study also shows considerable variation in source levels among ships of the same size, and between measurements of the same ship. Thus, factors other than size, such as speed and the year a vessel was of built, are also correlated to noise levels. These results match findings made by JASCO (unpublished results) from an underwater listening station in the Strait of Georgia.

Multivariate statistical analysis on a large number of vessels, for multiple commercial classes, is required to estimate the relationship between vessel size (i.e., length) and source level spectra. An increase in the proportion of larger container vessels could reduce the number of transits, which could mean an overall reduction in average noise levels. Such analysis could be used to determine the number and size of vessels required to reduce noise level over a large area. The vessel size may, however, be limited because of the available water space along the commercial route and/or the port's facilities.

4. DISCUSSION

In this study, we modelled and compared two measures of underwater sound levels for a number of future case scenarios and corresponding current (2015) baseline sound levels, over a wide area of the Salish Sea. The models predicted unweighted and Southern Resident Killer Whale (SRKW) audiogram-weighted equivalent continuous noise levels (L_{eq}) for each scenario. The scenarios included: 2015 baseline vessel traffic, projected (future) traffic for 2020, and projected traffic scenarios with six potential noise mitigation approaches. The mitigation approaches were:

- Slowing vessels,
- Implementing a no-go period at night,
- Replacing the noisiest vessels with quieter ones,
- Reducing noise levels of certain vessel classes by fixed amounts,
- Rerouting the shipping lane in Haro Strait, and
- Grouping vessels in convoys so there are quiet periods between the groups.

We included qualitative analyses of nine additional possible mitigation approaches, based on information published in other studies.

4.1. Baseline Traffic

This modelled scenario represents vessel traffic conditions in 2015 as determined by the AIS dataset over the Regional Study Area (MarineTraffic 2017). A small percentage of commercial vessels may be absent from this dataset due to a lack of broadcast compliance and the lack of AIS coverage over the full area. Also, most small vessels (less than 20 m in length) are not required to broadcast AIS. Therefore, the results in this report likely do not contain contributions from a large fraction of recreational vessels and small commercial vessels. Those vessels are similarly absent from the future case scenarios, described in the following sections, so their comparisons with baseline case are unaffected.

Baseline results are presented for two 1-month periods, January and July 2015. These months represent environmental conditions that are respectively the most and least favourable to long-range sound propagation in the upper water column, at depths above the thermocline. These months also represent contrasting probabilities of SRKW presence in the area; this population has historically had higher presence in the Salish Sea in summer than in winter.

Shipping noise caused the monthly L_{eq} levels near the sea surface to be higher in January than July throughout the Regional Study Area. L_{eq} for other months are expected to fall between these two extremes. SRKW are most common in the area in July. Thus, our study limited analysis of mitigation options to July.

4.2. Projected Traffic

Projected monthly L_{eq}, tentatively representing vessel traffic of the year 2020, were computed by adding tanker and tug traffic associated with the Trans Mountain shipping requirements as defined in NEB (2016) to baseline traffic. For this scenario, 29 additional tankers and 29 additional tugs were modelled in July, transiting along the inbound and outbound traffic lanes between Swiftsure Bank and Burrard Inlet (Vancouver), passing through Haro Strait. This scenario did not account for other possible increases in commercial traffic, as traffic has been relatively constant between 2015 and early 2017. However, the Vancouver Fraser Port Authority recently (15 Aug 2017) reported an overall shipping increase of 4% for the first half of 2017 relative to 2016. It is therefore important to note the assumptions made here with regard to projected traffic; interpretations should account for differences in true future shipping rates as forecasts are updated.

Under the above assumptions for future commercial vessel traffic, the mean increase in unweighted noise levels over the Regional Study Area is estimated at 0.25 dB, with a 95th percentile increase of 0.71 dB over all map grid cells; the mean increase over the Haro Strait Boundary is estimated at 0.38 dB, with a 95th percentile increase of 0.86 dB over all map grid cells within that region, as listed in Table 7. With respect to SRKW's perceived loudness, the increase in traffic results in a mean increase in audiogram-weighted noise levels of 0.25 dB with a 95th percentile of 1.12 dB over the Regional Study Area, and mean increase of 0.30 dB of with a 95th percentile of 1.11 dB over the Haro Strait Boundary, as listed in Table 8.

The increase from baseline to projected noise levels is concentrated along the traffic lanes, since all additional traffic was simulated along this route. This can be seen in Figures 13 and 14. The audiogram-weighted source levels for the tankers and tugs is higher than that of the other classes, while the opposite is true when comparing unweighted source levels. Thus, the additional tankers and tugs have a greater influence on the audiogram-weighted sound field then unweighted sound field. This results in a higher maximum change in L_{eq} over the modelled areas.

The largest difference in noise levels is expected to occur south of Haro Strait, near the Brotchie Pilot Station, where traffic would increase/decrease speed when transitioning in/out of Haro Strait piloted area. While we expect these levels to only slightly increase SRKW's perceived loudness, the increase in levels would likely reduce their communication distances and decrease the travel distance of echolocation clicks used for detecting prey.

4.3. Implementing a Slow-Down Zone

This modelled mitigation approach applied a slow-down zone along the Haro Strait portion of the traffic lanes, as seen in Figure 7, where commercial vessels would be required to limit their speed. Vessel density and speed data from the projected scenario were modified to simulate traffic slowing down to a maximum speed of 11, 10, and 7 knots through Haro Strait. This slow-down zone would result in a general decrease in L_{eq} from the baseline levels along the traffic lanes in Haro Strait, as seen in Figures 16–21 and Tables 13–14. At Sample location 7, unweighted levels would decrease from 2.4 to 6.3 dB, and audiogram-weighted levels from 1.9 to 4.0 dB, depending on the speed limit. The same increase in L_{eq} as for the projected scenario is estimated along the traffic lanes outside Haro Strait, due to the additional traffic associated with the Trans Mountain project. The large decrease in L_{eq} in the northern region of the slow-down zone (e.g., dark blue region seen in Figures 16–21) is caused by the slowing of Ferry (Ro-ro passenger) traffic from Anacortes, WA, to Sidney, BC. Generally, these results indicate that, even with the increased tanker and tug traffic proposed by the Trans Mountain project, projected monthly average noise levels in and near the slow-down zone may be lower than current noise levels.

This effect is not as important, however, when SRKW audiogram-weighting is applied. Since projected tankers and tugs are expected to be tethered in the outbound transit, their expected maximum speed was limited to 10 knots. Thus, they would be unaffected by the 11 and 10 knot limits in the slow-down zones. Since they have a larger influence on the audiogram-weighted than the unweighted sound field, as discussed in Section 4.2, the mitigated results show an increase in audiogram-weighted sound levels along the traffic lanes (mainly the outbound lane) relative to baseline levels.

Although it is known that changing a vessel's speed changes its noise level, the exact relationship for various vessel classes is difficult to establish. Thus in this study, source levels from vessels at slower speeds were simulated by reducing the levels by a fixed amount at all frequencies, as described in Appendix C. With more available data, a frequency dependence in the relation between vessel source and speed may be established. This relationship might change the audiogram-weighted results for the slow-down mitigation approach.

4.4. Replacing 10% of Noisiest Ships

This modelled mitigation approach assessed replacing the top 10% of noisiest commercial vessels by the quietest 10% of vessels of the same class. Two criteria for selecting the noisiest vessels were examined: first, vessels were ranked based on their unweighted broadband source level, and then based on their audiogram-weighted broadband source level. For each criterion, the unweighted and audiogram-weighted mitigated levels were compared to baseline levels.

By selecting the noisiest vessels based on unweighted source levels, the mitigation approach significantly reduces unweighted sound levels throughout the Regional Study Area. The mitigation approach has almost no benefit, however, with respect to SRKW's perceived loudness of mean noise levels. This can be seen by comparing Figures 26 and 27. On the other hand, selecting the noisiest vessels based on SRKW audiogram-weighted source levels produces unweighted sound levels slightly lower than the projected levels, and significantly reduces audiogram-weighted levels, as seen by comparing Figures 28 and 29. Thus in implementing this type of mitigation, it is important to consider the hearing of the key species in the area. For mid-frequency hearing species such as SRKW, assessing vessels based on their unweighted broadband source level is likely inappropriate. Other criteria that include biological causality could be considered for selecting the noisiest vessels. For example, vessel spectra could be filtered to emphasize frequencies used in a species' communication signals or echolocation signals. We note that the Vancouver Fraser Port Authority's ECHO program implements a vessel noise emissions measurement system that calculates both unweighted and audiogram-weighted vessel source levels.

4.5. Implementing a No-Go Period

This modelled mitigation approach assessed restricting commercial vessels from transiting in Haro Strait from midnight to 04:00 (no-go period). This would provide 'quiet hours' for marine animals that are otherwise subjected to vessel traffic noise for almost 24 hours each day. This scenario assumed that the commercial traffic from the 4 hour no-go period was redistributed into the unrestricted 20 hours of the day. It also assumed that non-commercial traffic would not be restricted during the no-go period and that the traffic densities in this period would be equal to the current densities, as listed in Table 3. The AIS dataset shows that the density of non-commercial traffic is, however, very low at night.

The mitigated results for the restricted and unrestricted period can be compared to baseline results calculated over the same averaging period (i.e., top right maps versus top left maps in Figures 22–25). The traffic density of most vessel classes decreases in the restricted period, but increases in the unrestricted period. Thus, the results show a significant decrease in L_{eq} from midnight and 04:00, with a mean decrease over the model area of 11.13 dB (unweighted) and

4.35 dB (audiogram-weighted), and an increase in L_{eq} from 04:00 to midnight, with a mean increase over the model area of 0.98 dB (unweighted) and 0.62 dB (audiogram-weighted).

Although the decrease in noise levels during restricted hours seems much larger (numerically) than during non-restricted hours, it must be taken into consideration that the changes are calculated in units of decibels, i.e. on a logarithmic scale, and over different periods (4 versus 20 hours). Thus, the same change in energy leads to a larger decrease than increase, in units of decibels. Still, the most important reason for the difference in changes in L_{eq} between the two periods is that commercial vessels represent the majority of noise contributors at night. Implementing a restricted night-time period therefore could create a very low-noise situation for a few hours.

4.6. Reducing Source Levels of Classes of Concern

This mitigation approach assessed reducing source levels by 3 and 6 dB for classes of concern: Containers, Merchant, Passenger vessels greater than 100 m in length, Tankers, Tugs, and Vehicle carriers. For both source level reductions, this mitigation approach produces net decreases from baseline in both unweighted and audiogram-weighted levels throughout the Regional Study Area, as seen in Tables 19 and 20 and Figures 30–33. It is important to note that the decrease in shipping source levels is not equal to the reduction in noise levels experienced by marine fauna: the amount received levels are reduced is less than the specified reduction to commercial vessels, because non-commercial vessels also contribute to the soundscape.

Although this mitigation approach seems the most efficient, its feasibility may be questionable. Presently, there are no known methods for reducing the source levels of commercial vessels at all frequencies by a specific amount.

4.7. Adjusting Traffic Lanes–Haro Strait

This mitigation approach assessed the impact of shifting the shipping lanes through Haro Strait away from key locations in the SRKW critical habitat. The outbound (west) lane was narrowed and shifted farther west by less than 500 m. The inbound lane was rerouted to the west side of the shoals northeast of Discovery Island where the outbound lane is currently located. For this scenario, as expected, there is no significant net decrease in noise levels relative to baseline when considering the full Haro Strait Boundary region. That is because all traffic continues to pass through this region, but along different routes. Consequently, the mean change in L_{eq} is positive and attributed to the additional projected traffic. The largest changes, both positive and negative, in noise levels are localized near the traffic lanes, as seen in Figures 34 and 35. The largest decreases in mean monthly noise levels occur along the current inbound traffic lane because shifting the lane moves traffic away from these locations. For example, a 5.8 dB (unweighted) and 7.0 dB (audiogram-weighted) decrease is estimated at Sample location 7, which lies in the current lane.

The maps of changes in L_{eq} between the baseline and adjusted route scenarios, seen in Figures 34 and 35, show some local decreases in noise levels in the traffic lanes north of the adjusted lanes through Haro Strait, despite adding projected Trans Mountain tankers and tugs in the mitigation scenario. That is a modelling artifact, due to the randomization width in the simulated vessel tracks being larger than that of the actual baseline traffic.

4.8. Implementing Vessel Convoys

This modelled scenario assessed the temporal variations in noise levels (over 24 hours) due to implementing commercial vessel convoys for passage through Haro Strait. Similar to the no-go scenario, the goal of this mitigation approach was to provide periods of lower noise levels throughout the day, between convoys. Two convoy intervals (2 and 4 hours) were assessed and compared to baseline levels (without convoying). Figures 37–44 compare the levels from all traffic (with ambient noise; shaded areas) to that from only the commercial traffic (black lines). Results show the black line much lower than shaded area at Sample locations 1 and 2, meaning that non-commercial traffic is the largest contributor of noise at the two locations farthest from the traffic lanes. Thus at these locations, there is little to no difference in noise levels between baseline and mitigated scenarios. The black lines are higher relative to the shaded area at the other locations, meaning that commercial traffic was a larger noise contributor. Thus, applying mitigation management to commercial traffic would have a larger effect at these locations.

At all locations, the black lines are higher relative to the shaded area for unweighted levels than for audiogram-weighted levels. Thus while looking at unweighted results, commercial traffic dominates the sound field, especially at night (midnight to 08:00, and 20:00 to midnight) at Sample locations 3–8. With respect to SRKW perceived loudness, however, commercial traffic only dominates the sound field at the locations closest to the traffic lanes (Sample locations 5–8).

The 2-hour convoy scenario does not appear to be an effective approach. It increases the mean noise level relative to baseline (mean level up to 3.8 dB higher than baseline mean level; as seen in Tables 23 and 24 at all sample locations). This increase is due, in part, to the additional traffic associated with the Trans Mountain expansion (two tankers and two tugs were added, relative to baseline), and to commercial vessels slowing down in the convoy corridor, which increases the time spent close to the sample locations. Figures 39–44 show that the 2-hour interval between convoys (middle graph) decreases the period of low received levels relative to baseline (top graph), especially at night (after 20:00 hours and before 08:00). This is also seen in the CDF plots in Figures 45 and 46, for Sample locations 3–8, which show that received levels between 100 and 130 dB re 1 µPa (or 55 to 65 dB re HT) are the least present (lowest percentile) for the 2-hour convoy scenario.

The 4-hour convoy interval, on the other hand, results in unweighted mean noise levels lower than baseline (up to 0.8 dB lower than baseline) over the 24-hour period, with the largest difference seen in the traffic lanes (Sample locations 7 and 8). This effect is not as clear in the audiogram-weighted results where mean levels increase only slightly (up to 0.7 dB higher than baseline). Figures 39–44 show that the 4-hour interval between convoys (black line) increases the period of low received levels (at or slightly above ambient level), especially at night (before 08:00 and after 20:00 hours). This is also seen in the CDF plots, in Figures 45 and 46, which show that lower received levels are present a higher percent of the time for the 4-hour convoy scenario (i.e., the line for the 4-hour convoy scenario (green line) is generally higher than that for the other scenarios). Therefore, the 4-hour interval is possibly long enough to compensate for the increase in traffic associated with the Trans Mountain expansion and due to the slow-down in the convoy corridor. Even so, a longer convoy interval may be needed to lower noise levels more effectively, with respect to SRKW perceived loudness.

4.9. Other Mitigation Options

The literature review on the effectiveness of several additional mitigation approaches found several ways to possibly reduce noise levels, including:

- Technical solutions involving changing ship designs and retrofitting vessels;
- Operational changes at the vessel level, involving operator behaviour and regular ship maintenance schedules planned by ship owners;
- Operational changes at the shipping industry level, involving loading plans and timing; and
- Operational changes at the traffic management level, involving dynamic speed limits, temporal and spatial area closures in response to real-time monitoring of whale presence, etc.

Carefully planning ship designs with noise output in mind and retrofitting older ships with quieting technology has been suggested as a very effective means to reduce noise in the long term (Audoly et al. 2017). The noise reduction due to these technical upgrades is estimated as high as 15 dB, which is the current spread between the quietest and loudest ships in similar ship classes (Baudin and Mumm 2015).

The most effective technical solutions involve reducing a) cavitation and b) engine and other machinery noise travelling through the hull into the water (Renilson et al. 2013b, 2013a, Wittekind and Schuster 2016). The cavitation inception speed of propellers can be increased by increasing the size of propellers (Baudin and Mumm 2015), changing blade design (Spence and Fischer 2017), or equipping vessels with blade bubble injectors and propeller guards (Southall and Scholik-Schlomer 2008). Noise output from engines can reduced by changing engine type (Baudin and Mumm 2015), applying dampening material to the inside of the hull to reduce airborne noise transmission from inside the vessel into the water (Spence and Fischer 2017), and placing the engines on isolation mounts to reduce transmission of vibration into the water (Spence and Fischer 2017). Possible improvements to hull design, including the use of bulbuous bows, special hull paints, as well as overall optimized hull design to reduce wind and sea state impact, also reduce noise (Hollenbach and Friesch 2007, Baudin et al. 2015).

Ship design changes and vessel retrofitting should be long term goals to reduce noise in SRKW habitat. They would also benefit other oceanic habitats and results in a long lasting change of underwater nois levels everywhere. These changes can be achieved through better education and incentives for shipping companies, or by setting maximum noise thresholds for access to sensitive habitats.

Regular ship maintenance is expected to reduce noise output by up to 3.5 dB (Baudin et al. 2015). Regular maintenance schedules increase cavitation inception speed and lower fuel consumption. This should be an incentive for vessel operators. Operating costs are associated with fuel costs; if fuel costs are lower than maintenance costs, the likelihood for implementing regular maintenance schedules through voluntary compliance, however, are low. Ship noise measurements when travelling, combined with hull inspections at port, could be used to incentivize ship maintenance via port fees imposed on vessels with low maintenance conditions.

Operator behaviour changes include avoiding sudden vessel accelerations, maintaining speed limits within critical habitat, and reducing speed to maintain appropriate distances to other vessels and whales. These changes can be achieved either through voluntary compliance or by regulations within SRKW critical habitat. Adding marine mammal observers to piloted ships as a requirement to accessing critical habitats would likely further increase compliance with regulations. The effectiveness these measures would need to be tested before implementation.

Shipping companies would need to voluntarily make operational changes at the shipping industry level. Within the Salish Sea, the port authorities could use incentives to improve the behaviour of shipping companies. For example, port authorities could report the noise level of vessels arriving at and leaving the port over the course of a year (via ULS measurements, for example) combined with loading information, and offer monetary incentives to vessels below a certain noise level threshold.

Plans and regulations for commercial traffic within the SRKW habitat, such as seasonal and/or dynamic speed limits, and temporal and spatial area closures for some or all marine traffic, may be the quickest most effective means to implement noise reduction. An added benefit is that regulations can be tailored to vessel type, time of day or year, as well as small- or large-scale areas. The noise reduction and, more importantly, improvement in acoustic quality of the SRKW habitat will need to be assessed scientifically during implementation trials. While noise reduction is a mitigation goal, improved habitat quality leading to increased foraging and better habitat use by SRKW is the ultimate goal of any mitigation procedure.

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APPENDIX A. UNDERWATER ACOUSTICS

A.1. Acoustic Metrics

Underwater sound pressure amplitude is measured in decibels (dB) relative to a fixed reference pressure of p_0 = 1 μPa. Because the perceived loudness of sound, especially pulsed noise such as from seismic airguns, pile driving, and sonar, is not generally proportional to the instantaneous acoustic pressure, several sound level metrics are commonly used to evaluate noise and its effects on marine life. We provide specific definitions of relevant metrics used in the accompanying report. Where possible we follow the ANSI and ISO standard definitions and symbols for sound metrics, but these standards are not always consistent.

The sound pressure level (SPL; dB re 1 μPa) is the rms pressure level in a stated frequency band over a specified time window (*T*, s) containing the acoustic event of interest. It is important to note that SPL always refers to an rms pressure level and therefore not instantaneous pressure:

$$L_p = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)dt \Big/ p_0^2\right) . \tag{A-1}$$

The SPL represents a nominal effective continuous sound over the duration of an acoustic event, such as the emission of one acoustic pulse, a marine mammal vocalization, the passage of a vessel, or over a fixed duration. Because the window length, *T*, is the divisor, events with similar sound exposure level (SEL), but more spread out in time have a lower SPL.

The sound exposure level (SEL, dB re 1 μPa²·s) is a measure related to the acoustic energy contained in one or more acoustic events (*N*). The SEL for a single event is computed from the time-integral of the squared pressure over the full event duration (*T*):

$$L_E = 10\log_{10}\left(\int_T p^2(t)dt \Big/ T_0 p_0^2\right) , \tag{A-2}$$

where T_0 is a reference time interval of 1 s. The SEL continues to increase with time when non-zero pressure signals are present. It therefore can be construed as a dose-type measurement, so the integration time used must be carefully considered in terms of relevance for impact to the exposed recipients.

SEL can be calculated over periods with multiple acoustic events or over a fixed duration. For a fixed duration, the square pressure is integrated over the duration of interest. For multiple events, the SEL can be computed by summing (in linear units) the SEL of the *N* individual events:

$$L_{E,N} = 10\log_{10}\left(\sum_{i=1}^{N} 10^{\frac{L_{E,i}}{10}}\right) . \tag{A-3}$$

Energy equivalent SPL (L_{eq}; dB re 1 μPa) denotes the SPL of a stationary (constant amplitude) sound that generates the same SEL as the signal being examined, *p*(*t*), over the same period of time, *T*:

$$L_{eq} = 10\log_{10}\left(\frac{1}{T}\int_T p^2(t)dt \Big/ p_0^2\right) . \tag{A-4}$$

The equations for SPL and the energy-equivalent SPL are numerically identical; conceptually, the difference between the two metrics is that the former is typically computed over short periods (typically of one second or less) and tracks the fluctuations of a non-steady acoustic signal, whereas the latter reflects the average SPL of an acoustic signal over times typically of one minute to several hours.

Audiogram-weighted SPL, or SPL above hearing threshold, is calculated by subtracting species-specific audiograms from the received 1/3-octave-band sound pressure level. Audiogram-weighted levels are expressed in units of dB above hearing threshold (dB_{ht}(species)). If applied, the frequency weighting of an acoustic event should be specified, as in the case of auditory-weighted SPL ($L_{p,ht}$).

A.2. 1/3-Octave-Band Analysis

The distribution of a sound's power with frequency is described by the sound's spectrum. The sound spectrum can be split into a series of adjacent frequency bands. Splitting a spectrum into 1 Hz wide bands, called passbands, yields the power spectral density of the sound. This splitting of the spectrum into passbands of a constant width of 1 Hz, however, does not represent how animals perceive sound.

Because animals perceive exponential increases in frequency rather than linear increases, analyzing a sound spectrum with passbands that increase exponentially in size better approximates real-world scenarios. In underwater acoustics, a spectrum is commonly split into 1/3-octave-bands, which are one-third of an octave wide; each octave represents a doubling in sound frequency. The centre frequency of the ith 1/3-octave-band, $f_c(i)$, is defined as:

$$f_c(i) = 10^{i/10} , \quad \text{(A-5)}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the ith 1/3-octave-band are defined as:

$$f_{lo} = 10^{-1/20} f_c(i) \text{ and } f_{hi} = 10^{1/20} f_c(i) . \quad \text{(A-6)}$$

The 1/3-octave-bands become wider with increasing frequency, but on a logarithmic scale the bands appear equally spaced. This is illustrated in Figure A-1.

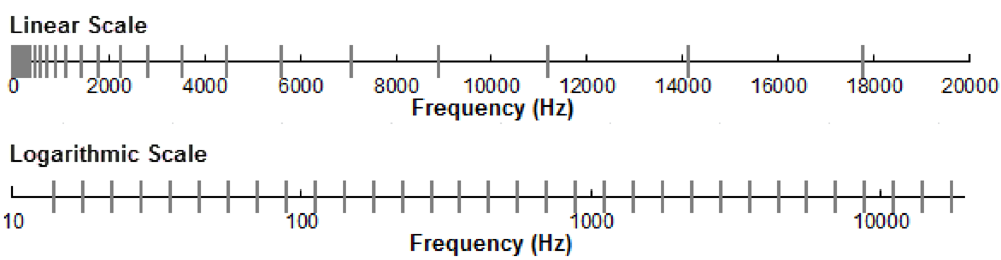

Figure A-1. One-third-octave-bands shown on a linear frequency scale and on a logarithmic scale.

The sound pressure level in the ith 1/3-octave-band $(L_b^{(i)})$ is computed from the power spectrum $S(f)$ between f_{lo} and f_{hi}:

$$L_b^{(i)} = 10 \log_{10} \left(\int_{f_{lo}}^{f_{hi}} S(f) df \right) . \quad \text{(A-7)}$$

Summing the sound pressure level of all the 1/3-octave-bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10 \log_{10} \sum_i 10^{L_b^{(i)}/10} . \quad \text{(A-8)}$$

Figure A-2 shows an example of how the 1/3-octave-band sound pressure levels compare to the power spectrum of an ambient noise signal. Because the 1/3-octave-bands are wider with increasing frequency, the 1/3-octave-band SPL is higher than the power spectrum, especially at higher frequencies. Acoustic modelling of 1/3-octave-bands require less computation time than 1 Hz bands and still resolves the frequency-dependence of the sound source and the propagation environment.

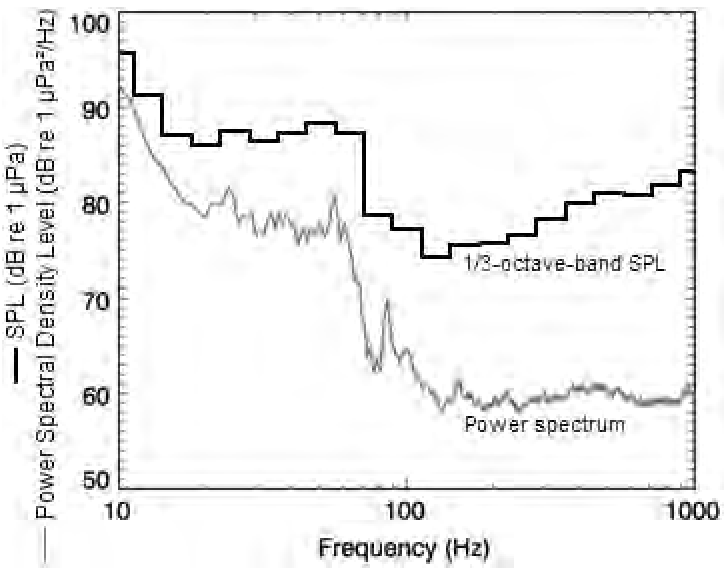

Figure A-2. A power spectrum and the corresponding 1/3-octave-band sound pressure levels of example ambient noise shown on a logarithmic frequency scale.

A.3. Vessels Sounds

Underwater sound that radiates from vessels is produced mainly by propeller and thruster cavitation, with a smaller fraction of noise produced by sound transmitted through the hull, such as by engines, gearing, and other mechanical systems. Sound levels tend to be the highest when thrusters are used to position the vessel and when the vessel is transiting at high speeds. A vessel's sound signature depends on the vessel's size, power output, propulsion system (e.g., conventional propellers vs. Voith Schneider propulsion), and the design characteristics of the given system (e.g., blade shape and size). A vessel produces broadband acoustic energy with most of the energy emitted below a few kilohertz. Sound from onboard machinery, particularly sound below 200 Hz, dominates the sound spectrum before cavitation begins—normally around 8–12 knots on many commercial vessels (Spence et al. 2007a). Noise from vessels typically raises the background sound level by tenfold or more (Arveson and Vendittis 2000).

A.3.1. Cavitation Noise

The term cavitation refers to streams of vapour bubbles that form on the surface of marine propellers when the vessel is moving quickly. Cavitation bubbles make a lot of underwater noise when they collapse in the vessel's wake. Cavitation occurs when the propeller tip speed exceeds a certain onset threshold, which depends on the propeller design and wake field. Generally, the onset of cavitation is between 8–12 knots, although it may occur at even lower vessel speeds for heavily loaded propellers (Spence et al. 2007a). The lowest speed cavitation occurs at is known as the Cavitation Inception Speed (CIS).

Cavitation noise is very broadband (5 Hz to 100 kHz) and may therefore be important when considering effects on SRKWs, which have their best hearing at frequencies above 10 kHz. The spectrum of cavitation noise typically has a peak between 40−300 Hz and a steady −6 dB/decade roll off at higher frequencies (Ross 1976). Cavitation noise increases rapidly with vessel speed: the difference between cavitation onset and full cavitation may be up to 30 dB (Spence et al. 2007a). Cavitation also results in the phenomenon of blade-rate tonals, which are strong, low-frequency tones appearing at harmonics of the blade-passing frequency (Arveson and Vendittis 2000). Most control treatments for propulsion noise are therefore concerned with delaying the onset of cavitation.

Another source of propulsion noise is vibration induced by unsteady flow around the propellers. Oscillating fluid forces, created by turbulence, can cause the propeller blades and hull to vibrate, thereby radiating low-frequency underwater noise. Usually, vibration noise is quieter than cavitation noise.

A.3.2. Mechanical Noise

Machinery noise may be less audible to SRKWs than cavitation noise. Because machinery noise is primarily structure-borne, most noise control treatments are concerned with isolating machine vibrations from the structure of the vessel.

In general, main and auxiliary machinery are the dominant sources of radiated noise at speeds lower than the CIS. The most important transmission path for shipboard machinery noise is via structure-borne vibration. Mechanical vibration is coupled through the vessel structure to the hull, where it radiates as underwater noise. Airborne sound transmission is of secondary importance to structure-borne vibration. The main engines and electric generators are usually the greatest sources of mechanical vibration. Machinery noise is predominantly concentrated at mid-to-low frequencies (10–1000 Hz), and is dominated by strong low-frequency tones at harmonics of the piston firing rate.

A literature review was carried out to identify the best available underwater noise control technologies currently available for ships as described in Section 3.4.

A.3.3. Vessel Source Levels

Since September 2015, the Underwater Listening Station (ULS) has been measuring vessel noise emissions (i.e., source levels) in the Strait of Georgia. The ULS is situated in the inbound shipping lane, on the VENUS East Node seen in Figure A-3. It captures noise emissions from commercial vessels bound for the Port of Vancouver, as well as ferry traffic along several passenger and cargo routes. Automated processing of vessel source levels is performed by JASCO's ShipSound software, which uses AIS data to detect when vessels transit through the measurement funnel of the ULS. Valid vessel tracks, as selected by automated system, are used for the vessel source level analysis, which conforms approximately to the ANSI standard for ship sound measurements (ANSI/ASA S12.64/Part 1 2009). As of April 2017, the ShipSound system had collected over 2700 valid source level measurements.

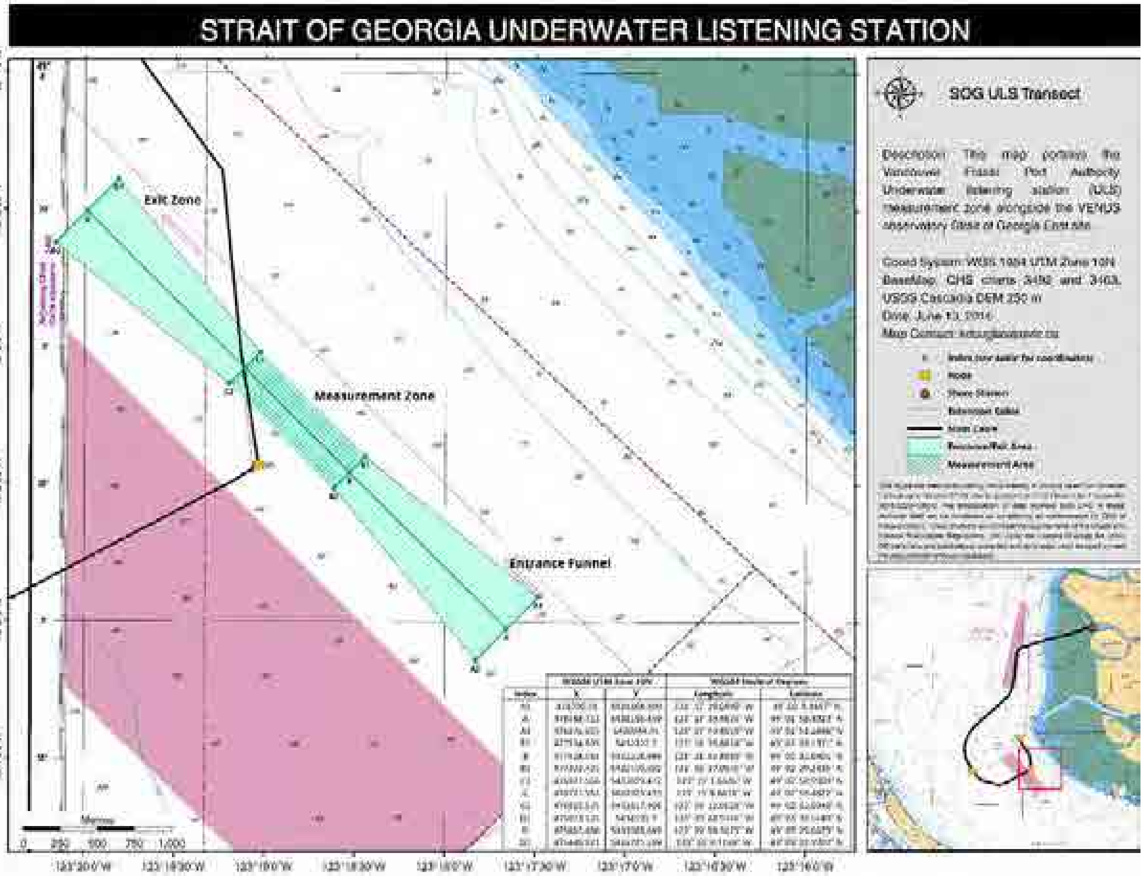

Figure A-3. ULS location (yellow circle) at the VENUS East Node in Georgia Strait. Pilots use the measurement funnel (cyan) to ensure vessel source level measurements are accurate.

For this study, source level measurements from the ULS were assigned to ten different classes, according vessel class information embedded in the AIS logs. The classes are listed Table A-1. Average frequency-dependent source levels were calculated for each vessel class. These source levels were used to represent noise emissions of corresponding vessels in the cumulative noise model. Source levels for four additional vessel class were not covered by the ULS data (Passenger (<100 m); Clipper Ferry[5]; Recreational, and Other[6]) and were obtained from other sources. For each vessel class, average source levels (MSL) were compiled in 1/3-octave frequency bands from 10 Hz to 63.1 kHz; the spectra are shown Figure 10. This is the frequency range where noise emissions from vessels overlap the hearing sensitivity of marine mammals and fish inside the study area.

[5] Clipper Ferry jet catamarans source levels were based on passenger vessel source levels from Veirs et al. (2016).
[6] Recreational and Other source levels were based on a prior review of published vessel measurements carried out for the Roberts Bank Terminal 2 cumulative modelling assessment (MacGillivray et al. 2014).

Table A-1. Number of measurements used to calculate mean (power average) source levels for each vessel class represented in the ULS data. The Merchant category includes both Bulk Carriers and General Cargo. The Government category includes Navy and Research vessels. Ferries measurements are grouped before averaging to properly account for repeat vessel passes.

Category	Measurements	Unique vessels
Container	233	118
Ferry (Ro-ro Passenger)	1505	8
Ferry (Ro-ro Cargo)	134	3
Fishing	23	20
Government	6	5
Merchant	464	445
Passenger (≥100 m)	17	11
Tanker	86	50
Tug	206	67
Vehicle carrier	31	28
Total	**2705**	**755**

A.4. Environmental Parameters

The temperature and salinity profile of oceans change over the seasons. These changes affect the speed that sound travels through the water. Water column sound speed profiles for the study area for January and July were computed from historical temperature and salinity data (ONC and U Vic 2017). Monthly sound speed profiles are most variable in the upper 80 m of the water column, as seen in Figure A-4. Solar heating in summer increases the surface water temperature, which increases the sound speed at the top of the water column and, therefore, redirects sound toward the seafloor. Wind-driven mixing in winter combined with atmospheric cooling results in lower surface water temperatures, which decrease the sound speed at the top of the water column and redirects sounds toward the surface. The mean sound speed profiles for January and July, the two months when the difference in sound speed in the upper 80 m of water is greatest, were used to represent the acoustic properties of the water column in the model. Analysis of the sound speed profiles showed no strong geographical variations in the data; therefore, single sound speed profiles were assumed throughout the study area for each month.

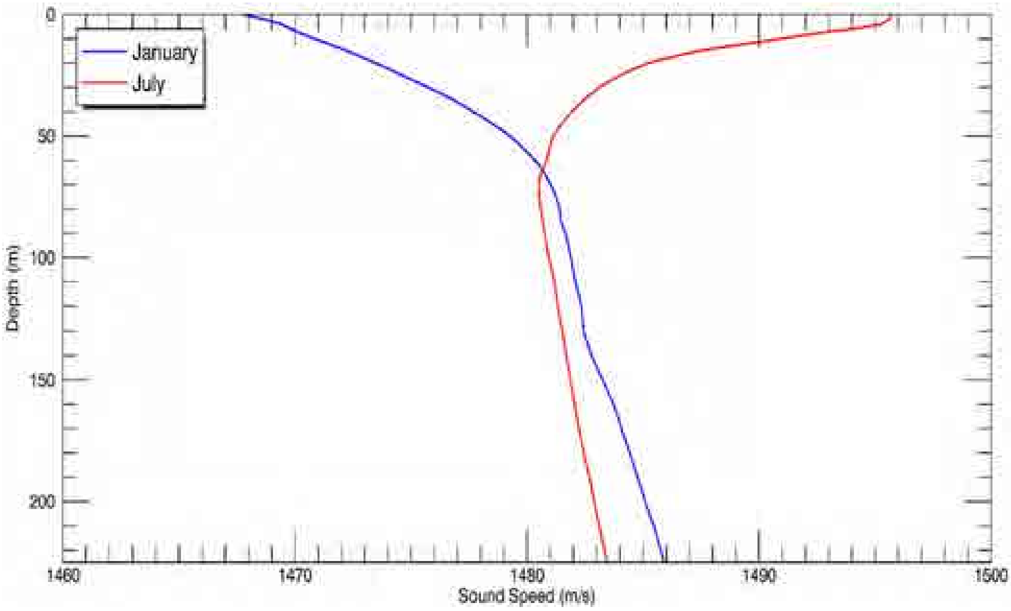

Figure A-4. Mean sound speed profiles for the study area, based on historical ocean temperature and salinity profiles for January and July.

The bathymetry (depth contours) inside the study area was modelled on a 20 m resolution BC Albers grid. The bathymetry was compiled from the following sources:

1. NOAA digital elevation model (NGDC 2013) for data south of latitude 49°N.
2. Canadian Hydrographic Service digital elevation map from Nautical Data International Inc. for data north of latitude 49°N.

The water depths in the region range from 0 to 870 m.

The geoacoustic properties of the seabed strongly influence how sound travels through the water. Reflection and absorption of sound energy at the seabed is the dominant mechanism by which sound is attenuated in shallow water (Urick 1983). The seabed geoacoustic properties for the study area were obtained by combining geoacoustic inversion results from acoustic measurements (JASCO 2015) and reviewing scientific literature (Hamilton 1980, Erbe et al. 2012). To account for geographic variation inside the study area, it was divided into four geoacoustic regions with similar bottom types: Strait of Georgia, Haro Strait, east Strait of Juan de Fuca, and west Strait of Juan de Fuca, as seen in Figure A-5. A different set of geoacoustic properties was used to represent each region, as listed in Table A-2.

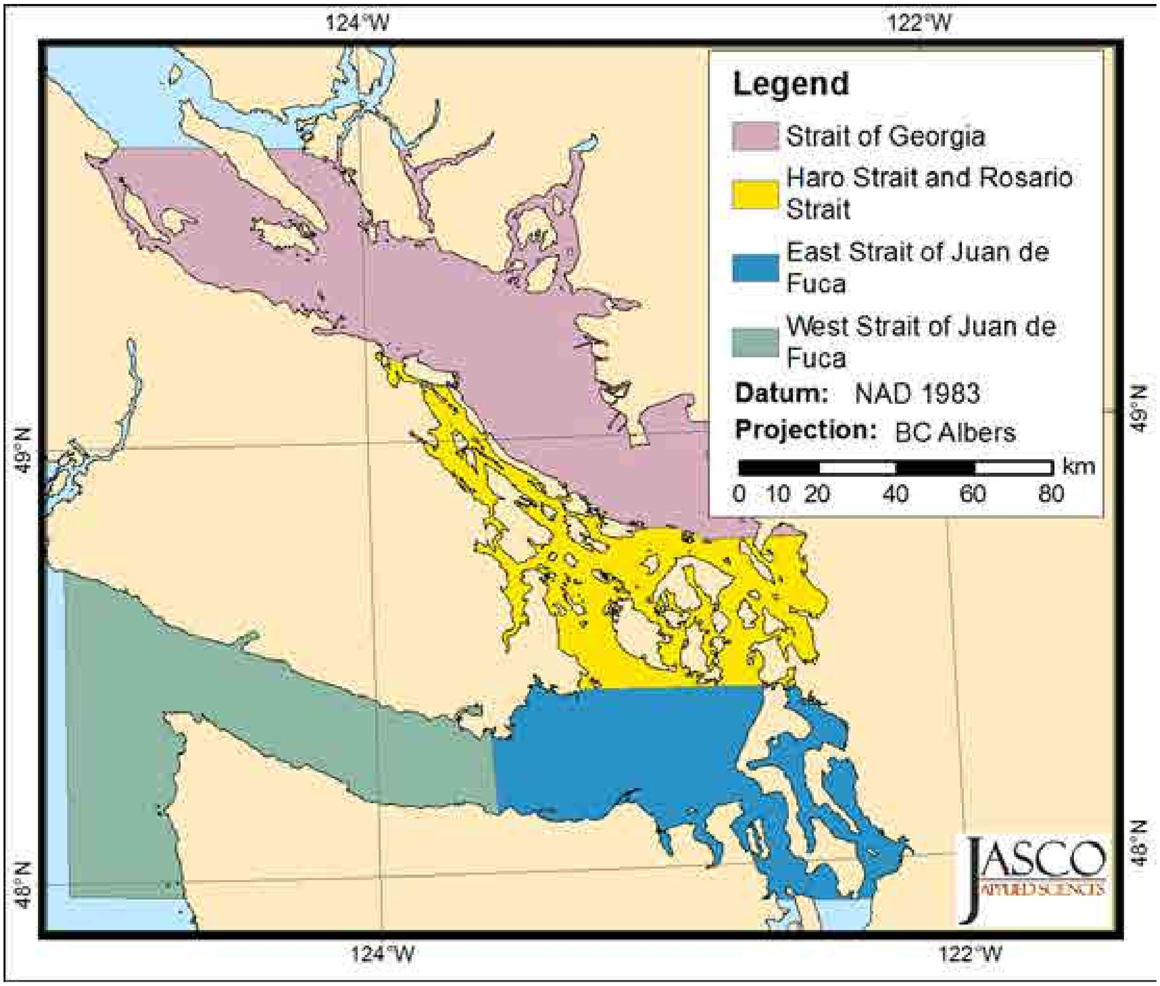

Figure A-5. Map of geoacoustic regions for defining sound propagation in the model. Pink for Strait of Georgia, yellow for Haro Strait and Rosario Strait, blue for east Strait of Juan de Fuca, and green for west Strait of Juan de Fuca.

Table A-2. Seabed profiles for the four geoacoustic regions.

Depth below seafloor (m)	**Sediment type**	**Compressional speed** (m/s)	**Density** (g/cm³)	**Compressional attenuation** (dB per wavelength)	**Shear speed** (m/s)	**Shear attenuation** (dB per wavelength)
Strait of Georgia						
0–100	Clayey-silt	1502–1602	1.54	0.61	125.0	2.2
> 100	Bedrock	2275	1.90	0.10		
Haro Strait and Rosario Strait						
0–50	Sand-silt-clay	1541–1591	1.80	0.72	250	1.2
> 50	Bedrock	2275	1.90	0.10		
East Strait of Juan de Fuca						
0–50	Silt	1558–1608	1.64	0.83	250	3.4
> 50	Bedrock	2275	1.90	0.10		
West Strait of Juan de Fuca						
0–50	Sand	1713–1763	1.94	0.90	500	3.4
> 50	Bedrock	2275	2.20	0.10		

Wind-driven ambient noise was included in the time-dependent version of the cumulative noise model, based on historical wind speed data for Haro Strait for a 24-hour period in July, as seen in Figure A-6. Time-dependent wind noise was calculated in 1/3-octave frequency bands, based on published curves of ambient noise vs. frequency and wind speed, as presented in Figure A-7. Aggregate sound levels in all map grid cells were computed from the sum of the vessel noise plus the wind-driven ambient noise, for each time step in the model.

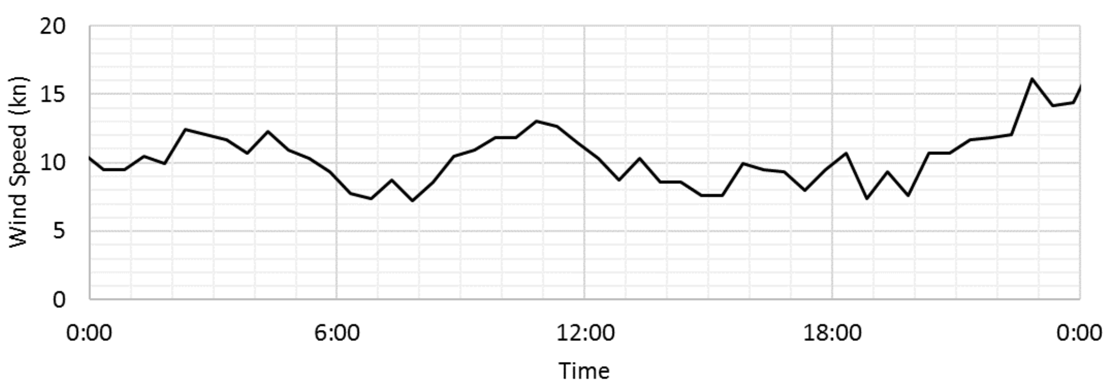

Figure A-6. Simulated wind speed in Haro Strait during a 24-hour period in July. Wind speeds are based on historical data from the NOAA National Buoy Data Centre[7] for 26 Jul 2015. Mean wind speeds on this day (10.5 knots) were closest to the average value for the month.

[7] Station 46088 New Dungeness Met Buoy: http://www.ndbc.noaa.gov/station_history.php?station=46088

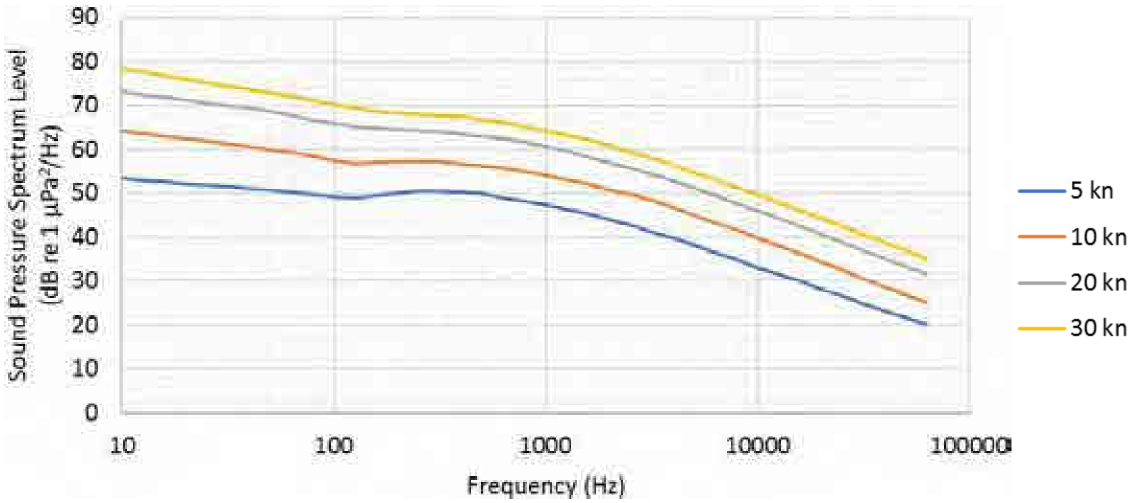

Figure A-7. Wind-driven ambient noise level as a function of frequency, for wind speeds ranging from 5 to 30 knots (Cato 2008).

A.5. Sound Propagation Models

A.5.1. Transmission Loss Model

The propagation of sound through the environment was modelled by predicting the acoustic transmission loss—a measure, in decibels, of the decrease in sound level between a source and a receiver some distance away. Geometric spreading of acoustic waves is the predominant way by which transmission loss occurs. Transmission loss also happens when the sound is absorbed and scattered by the seawater, and absorbed scattered, and reflected at the water surface and within the seabed. Transmission loss depends on the acoustic properties of the ocean and seabed; its value changes with frequency.

If the acoustic source level (SL), expressed in dB re 1 µPa @ 1 m, and transmission loss (TL), in units of dB, at a given frequency are known, then the received level (RL) at a receiver location can be calculated in dB re 1 µPa @ 1 m by:

$$RL = SL – TL \,. \tag{A-9}$$

Transmission loss was calculated using JASCO's Marine Operations Noise Model (MONM). MONM computes acoustic propagation via a wide-angle parabolic equation solution to the acoustic wave equation (Collins 1993) based on a version of the U.S. Naval Research Laboratory's Range-dependent Acoustic Model (RAM), which has been modified to account for elastic seabed properties (Zhang and Tindle 1995). The parabolic equation method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins et al. 1996). MONM incorporates the following site-specific environmental properties: a bathymetric grid of the model area; underwater sound speed as a function of depth; and a geoacoustic profile based on the overall stratified composition of the seafloor. Past measurements obtained during a dedicated transmission loss study (JASCO 2015) are used to validate MONM predictions for the study area.

The study area was divided into 20 zones, as seen in Figure A-8, based on the four unique geoacoustic regions shown in Figure A-5, and the five water depth ranges listed in Table A-3. MONM was used to compute curves of transmission loss compared to range for each zone in 1/3-octave-bands between 10 Hz and 5 kHz, out to a maximum distance of 75 km from the source Transmission loss for each zone was modelled assuming uniform bathymetry (i.e., range-independent water depth) for a receiver depth of 10 m. Transmission loss was averaged over five frequencies inside each 1/3-octave-band and the transmission loss compared to range curves are smoothed inside a 200 m window to remove fine-scale interference effects. At high frequencies, mean transmission loss computed by MONM is expected to converge to a high frequency (i.e., ray-theoretical) limit; therefore, transmission loss values for bands above 5 kHz are approximated by adjusting transmission loss at 5 kHz to account for frequency-dependent absorption at higher frequencies (François and Garrison 1982a, François and Garrison 1982b). For each zone, transmission loss was modelled using two different sound speed profiles, representing July and January conditions, and six source depths (1 to 6 m, in 1 m step), representing the nominal acoustic emission centres of small and large draft vessels. Figure A-9 presents plots that help visualizing how the modelled transmission loss varies by distance from the source and frequency, as well as with zones and seasons.

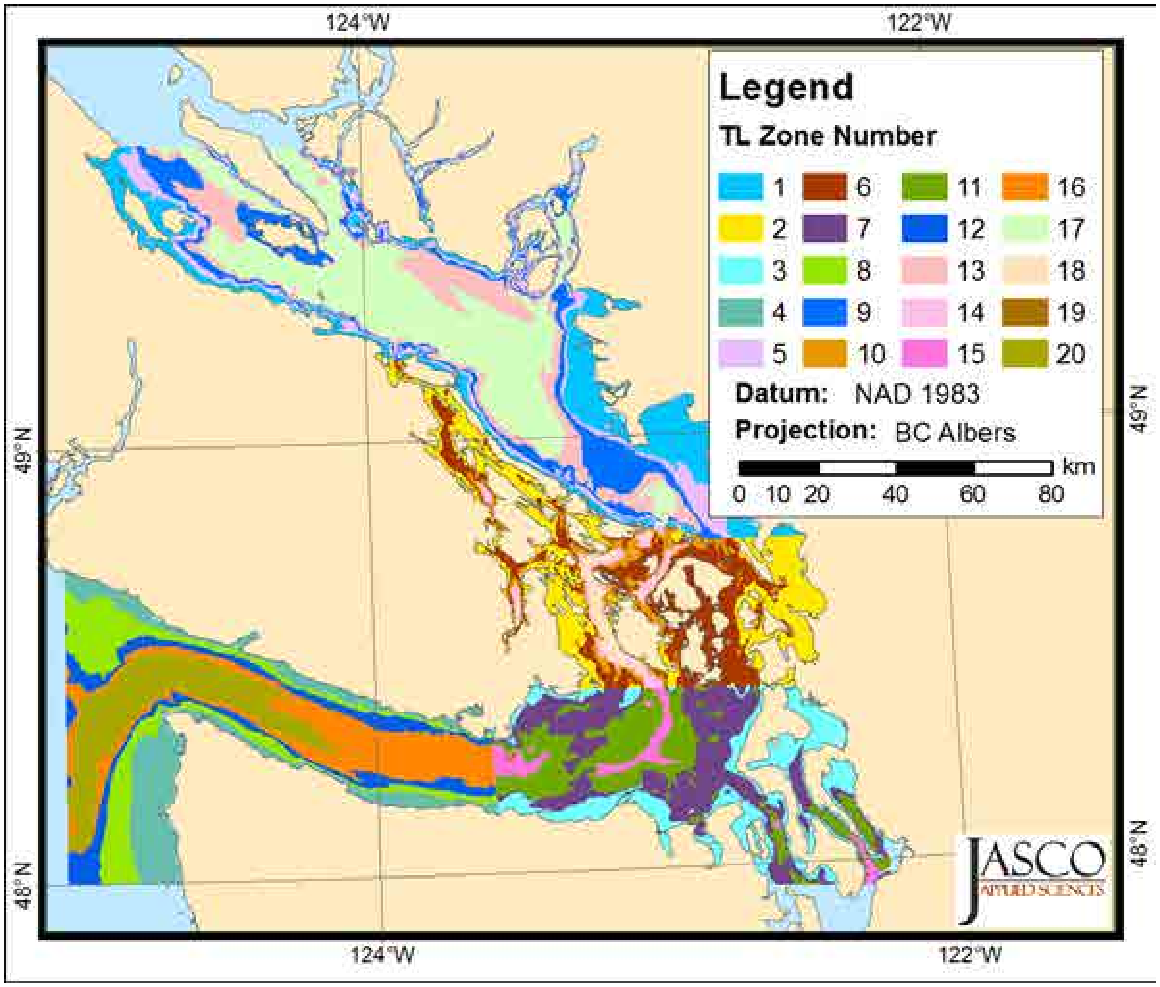

Figure A-8. Map of transmission loss (TL) zones (1–20) used for modelling sound propagation in the study area.

Table A-3. Description of zone numbers and corresponding geoacoustics and water depths. Geoacoustic properties of each region are listed in Table A-2.

Zone	Water depth range (m)	Modelled water depth (m)	Geoacoustic region
1	0–50	25	Strait of Georgia
2	0–50	25	Haro Strait and Rosario Strait
3	0–50	25	East Strait of Juan de Fuca
4	0–50	25	West Strait of Juan de Fuca
5	50–100	75	Strait of Georgia
6	50–100	75	Haro Strait and Rosario Strait
7	50–100	75	East Strait of Juan de Fuca
8	50–100	75	West Strait of Juan de Fuca
9	100–150	125	Strait of Georgia
10	100–150	125	Haro Strait and Rosario Strait
11	100–150	125	East Strait of Juan de Fuca
12	100–150	125	West Strait of Juan de Fuca
13	150–200	175	Strait of Georgia
14	150–200	175	Haro Strait and Rosario Strait
15	150–200	175	East Strait of Juan de Fuca
16	150–200	175	West Strait of Juan de Fuca
17	> 200	225	Strait of Georgia
18	> 200	225	Haro Strait and Rosario Strait
19	> 200	225	East Strait of Juan de Fuca
20	> 200	225	West Strait of Juan de Fuca

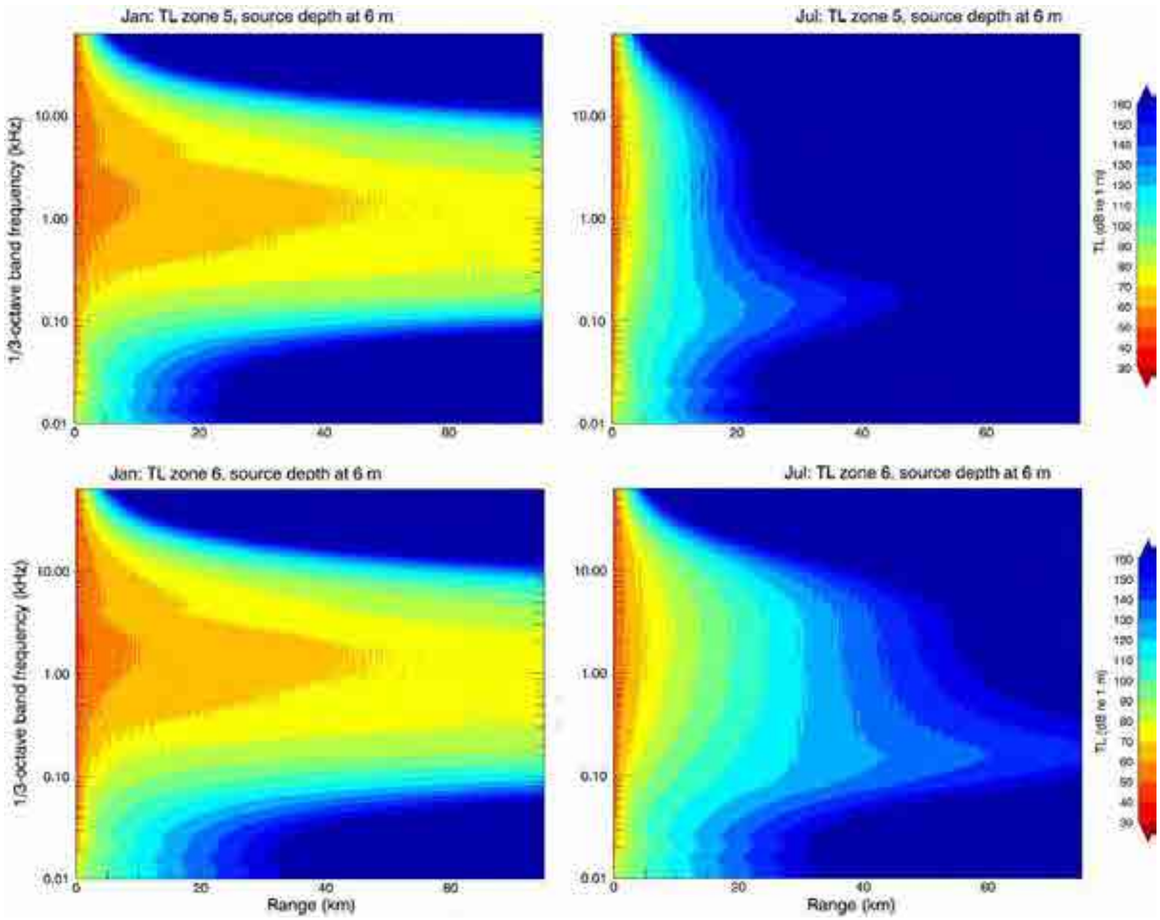

Figure A-9. Example plots of modelled transmission loss as a function of distance from the source and frequency. This example represents the transmission loss in Zone 5 (top) and Zone 6 (bottom) seen in Figure A-8, for January (left) and July (right). Source depth is 6 m and receiver depth is 10 m.

A.5.2. Cumulative Noise Model

Maps of cumulative monthly commercial vessel traffic noise were modelled for six vessel traffic scenarios, based on the vessel source level data described in Section 2.4.4, the vessel density data described in Section 2.4.2, and the tabulated transmission loss compared to range curves described in Section 2.4.3 and Appendix A.5.1. For the scenarios modelled over the Regional Study Area, the study area represented a 208 × 184 km BC Albers grid, where acoustic sources and receivers were assumed to be at the centre of each 800 × 800 m map grid cell. For the scenarios modelled over the Local Study Area, the study area represented a higher resolution 50 × 50 km BC Albers grid, where acoustic sources and receivers were assumed to be at the centre of each 200 × 200 m map grid cell. The 1/3-octave-band SEL in each map cell was computed as the total vessel noise energy originating from all adjacent map cells within a 75 km radius for the large study area, and 30 km for the small study area. The maximum propagation range from the sources was limited for computational efficiency, but long enough to cover the width of channels where vessels transited. SEL is a measure of the total acoustic energy received at some location over a specific time duration, and is the standard metric for quantifying the total sound exposure of marine organisms.

To compute transmission loss between pairs of cells, geometric rays were projected from each cell where the density in a given vessel class was non-zero (the source cell) to all nearby cells (the receiver cells) not blocked by land within maximum propagation range. The 1/3-octave-band transmission loss between source and receiver cells was then interpolated from the tabulated transmission loss compared to range curves, based on the midpoint separation of the cells and on the transmission loss zone traversed by the ray. For the range-dependent case, where the ray between a source cell *i* and a receiver cell *j* traverses more than one zone, the transmission loss was computed as the weighted-average value:

$$TL_{ij} = -10\log_{10}\sum_{n} 10^{-TL^{(n)}(r_{ij})/10} \times d_n / r_{ij} \quad \text{(A-10)}$$

In the above equation, r_{ij} is the source-receiver separation, $TL^{(n)}$ is the tabulated transmission loss in zone *n*, and d_n is the distance traversed by the ray in zone *n*. For the special case where the source and receiver cell are identical, transmission loss was estimated by assuming that the sound power radiated by all sources in a cell is distributed evenly over the cell's area, resulting in a horizontally uniform sound field. For a square cell of size *D*, this assumption results in the following expression:

$$TL_{ii} = 10\log_{10}(4\pi / D^2) = 20\log_{10} D - 11 \quad \text{(A-11)}$$

For an 800 m square cell, the corresponding TL_{ii} value is 47.1 dB.

The total ship noise energy transmitted from each source cell *i* to receiver cell *j* was computed using the source level and corresponding cell-to-cell transmission loss values summed over all vessel categories and adjusted for vessel speed and cumulative vessel class time in each source cell:

$$E_{ij} = \sum_{k} 10^{\left(SL_k - TL_{ij}\right)/10} \times \left(\frac{v_k}{v_{ref}}\right)^{C_{v,k}} \times T_k \quad \text{(A-12)}$$

In the above equation, the source level for each vessel class *k* is computed by adjusting the reference source level SL_k for speed v_k according to the power-law model (Ross 1976). The power of the ratio of speeds, $C_{v,k}$, depends on the modelled vessel class. The source energy is then computed by multiplying the source power by the cumulative time T_k that vessels from class *k* occupied the source cell. The total SEL in the receiver cell *j* was then computed as the sum of the sound energy transmitted from all cells with vessels within maximum propagation range:

$$SEL_j = 10\log_{10}\left(\sum_{j} E_j\right) \quad \text{(A-13)}$$

The mean monthly equivalent continuous noise level (L_{eq}) was equal to the total noise energy in all 1/3-octave-bands, divided by the number of seconds in the month, T_{mon}, that is:

$$L_{eq} = SEL - 10\log_{10}(T_{mon}) \quad \text{(A-14)}$$

A.5.3. Time-Dependent Noise Model

Time-dependent SPL over 24 hours were modelled for the convoy scenario, based on the vessel source level data described in Section 2.4.4, the vessel traffic distribution described in Section 2.4.2, and the tabulated transmission loss compared to range curves described in Section 2.4.3 and Appendix A.5.1. SPL in 1/3-octave-bands were modelled on a 50 × 50 km BC Albers grid, where acoustic sources and receivers were assumed to be at the centre of each 200 × 200 m map grid cell. For every time increment of the simulation, vessels were assigned to map grid cells based on their interpolated coordinates from the track data. For each source cell, a fan of geometric rays was projected to all receiver cells not blocked by land within 75 km range. Along each ray, the 1/3-octave-band transmission loss between source and receiver cells was computed from the tabulated transmission loss versus range curves, based on the transmission loss zones traversed by the ray. To accommodate range-dependent transitions between zones, a composite transmission loss curve was created for each ray, based on a recursive sum of the range-dependent transmission loss curve at each range step along the ray:

$$\mathrm{TL}(n\Delta r) = \mathrm{TL}((n-1)\Delta r) + (\mathrm{TL}'[n;k] - \mathrm{TL}'[n-1;k]) \quad , \qquad \text{(A-15)}$$

where Δr is the range increment, n is the range step (an integer), k is the zone number corresponding to step n along the current ray, and $\mathrm{TL}'[n;k]$ denotes the tabulated TL value at step n for zone k. For the special case where the source and receiver cells are identical, TL was calculated by assuming that the radiated sound power in a cell is distributed evenly over the cell's area, resulting in a horizontally uniform sound field. This assumption gives an in-cell TL value of $20\times\log D - 11$, where D is the edge-length of a cell.

The contribution of wind-driven ambient noise was also included in the model. Tabulated curves of 1/3-octave-band ambient noise versus frequency and wind speed were obtained from Wenz (1962) and Cato (2008). Hourly mean wind speed data were obtained from NOAA weather station 46088, located at New Dungeness, ~7 nm northeast of Port Angeles, WA (NOAA 2017). Wind noise SPL for the study area were interpolated from the Wenz and Cato curves according to the recorded wind speed versus time data from the weather station. Aggregate SPL in all map grid cells were computed from the cumulative sound field of all vessels in the simulation, plus the wind-driven ambient contribution, for each time step in the model.

A.6. Marine Mammal Frequency Weighting

The potential for noise to affect animals depends on how well the animals can hear it. Noises are less likely to disturb or injure an animal if they are at frequencies that the animal cannot hear well. An exception occurs when the sound pressure is so high that it can physically injure an animal by non-auditory means (i.e., barotrauma). For sound levels below such extremes, the importance of sound components at particular frequencies can be scaled by frequency weighting relevant to an animal's sensitivity to those frequencies (Nedwell and Turnpenny 1998, Nedwell et al. 2007).

A.6.1. SRKW Audiogram-Weighting

Audiograms represent the hearing threshold for tonal sounds (i.e., single-frequency sinusoidal signals) as a function of the tone frequency. These species-specific sensitivity curves are generally U-shaped, with higher hearing thresholds at low and high frequencies. Noise levels above hearing threshold are calculated by subtracting species-specific audiograms from the received 1/3-octave-band noise levels. The audiogram-weighted 1/3-octave-band levels are summed to yield broadband noise levels relative to each species' hearing threshold. Audiogram-weighted levels are expressed in units of dB re HT, which is the decibel (dB) level of sound above hearing threshold. Sound levels less than 0 dB re HT are below the typical hearing threshold for a species and are likely inaudible to those animals.

SRKW use sound actively when foraging to echolocate their prey. The echolocation signals range in frequency from 15 and 100 kHz (Au et al. 2004). SRKW also produce communication calls when foraging. Groups can spread out over several kilometres while foraging, but the area they cover is limited by the distance over which they can detect calls. Calls typically range in frequency from 500 Hz to 40 kHz (Miller 2006). Although significantly louder below 1 kHz, ship noise reaches above 60 kHz. Thus, shipping noise may determine the distance between SRKWs while foraging.

The SRKW audiogram used in this study is presented in Figure A-10. Based on values from Szymanski et al. (1999) and Branstetter et al. (2017), it was extrapolated from the lowest measured frequency down to 10 Hz using a 12 dB/octave slope, which represents the hearing roll-off toward the infrasound range for mammals (Marquardt et al. 2007). Although the validity of the extrapolation for marine mammals is not physiologically confirmed, it is likely these animals have a higher hearing threshold at frequencies outside their hearing range than the terminal trend of their audiogram would predict.

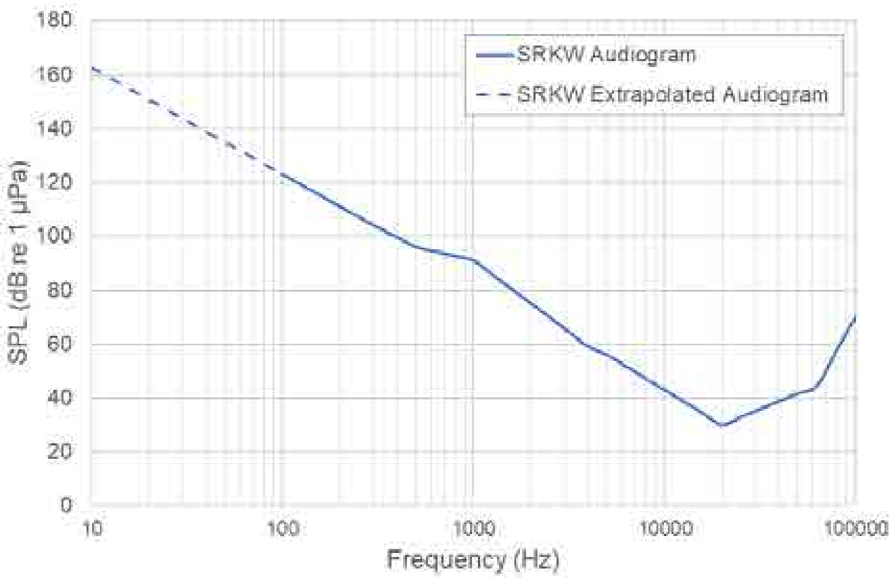

Figure A-10. Southern Resident Killer Whale audiogram used for this study, based on Szymanski et al. (1999) and Branstetter et al. (2017). Dashed curve is extrapolated low-frequency threshold.

APPENDIX B. AIS VESSEL CATEGORY ASSIGNMENTS

B.1. AIS Vessel Category Assignments

Table B-1 shows how vessel type codes from the Marine Traffic AIS dataset (Vessel type) were assigned to the vessel categories in the cumulative noise model (Model class). Note that Clipper Line vessels travelling the Victoria-Seattle route and roll-on/roll-off vessels in the Seaspan Ferries fleet were manually assigned to the Ferry category. Sailing vessels were excluded from the Recreational vessel category and were not included in the model (i.e., they were assumed not to be under power).

Table B-1. Vessel type from the Marine Traffic AIS dataset and their vessel class for modelling.

Model class	Vessel type
Container	Cargo/containership
	Container ship
Ferry	Ro-Ro/Passenger ship
Fishing	Factory trawler
	Fish carrier
	Fish factory
	Fishing
	Fishing vessel
	Trawler
Government	Buoy-laying vessel
	Fishery patrol vessel
	Fishery research vessel
	Law enforcement
	Logistics naval vessel
	Military ops
	Patrol vessel
	Replenishment vessel
	Research/survey vessel
Merchant	Bulk carrier
	Cargo
	Cargo - Hazard A (major)
	Chemical tanker
	General cargo
	LPG tanker
	Rail/vehicles carrier
	Reefer
	Ro-Ro cargo
	Ro-Ro/Container carrier
	Self-discharging bulk carrier
	Timber carrier
	Vehicles carrier
	Wood chips carrier
Miscellaneous	Anti-pollution
	Cable layer
	Dive vessel
	Drill ship
	Heavy lift vessel
	High speed craft
	Hopper dredger
	Local vessel
	Other
	Pilot vessel
	Port tender
	Reserved
	SAR
	Tender
	Unspecified
	Wing In Grnd
Passenger	Passenger
	Passengers ship
Recreational	Pleasure craft
	Yacht
Tanker	Crude oil tanker
	Oil products tanker
	Oil/Chemical tanker
	Tanker
Tug	Anchor handling vessel
	Fire fighting vessel
	Multi-purpose offshore vessel
	Offshore supply ship
	Pollution control vessel
	Pusher tug
	Towing vessel
	Tug

APPENDIX C. MULTIPLE LINEAR REGRESSION MODELS–PREDICTING MSL FROM THREE PARAMETERS

C.1. Multiple Regression Model

Vessel noise emissions generally increase with speed through water, due to speed-related increases in machinery vibration and propeller cavitation. A multivariate analysis was applied to the Underwater Listening Station (ULS) source level data to determine an appropriate speed scaling parameter for each category of vessel in the model. To control for the effect of parameters other than speed on the measurements, multiple regression was used to fit MSL (20–31,600 Hz) to an equation of the following form for each category:

$$MSL = C_v \times 10\log_{10}\left(\frac{v}{v_{ref}}\right) + C_l \times 10\log_{10}\left(\frac{l}{l_{ref}}\right) + \beta \times d + MSL_{ref}\ .$$

The terms in this equation are:

- MSL = monopole source level (dB re 1 µPa @ 1 m),
- C_v = speed power law coefficient (dimensionless),
- v = speed over water (knot),
- v_{ref} = reference speed (1 knot),
- C_l = length power law coefficient (dimensionless),
- l = length overall (m),
- l_{ref} = reference length (1 m),
- β = closest point of approach (CPA) correction slope (dB/m),
- d = vessel CPA (m), and
- MSL_{ref} = intercept term (MSL @ v_{ref}, l_{ref}, and d = 0).

Table C-1 shows the best-fit MSL scaling parameters from the multiple-regression analysis. Categories that are missing or insufficiently represented in the ULS data were assumed to have a default scaling coefficient of C_v = 6, per the original Ross power-law model.

Table C-1. Terms of the MSL linear regression model for different vessel classes based on speed, length, and closest point of approach (CPA). The r^2 value is the percent of the total data variance explained by the multiple regression model. Length and speed were strongly correlated for fishing vessels, so length was not included as an independent parameter for this category.

Vessel class	Cv	Cl	β	r^2 (%)
Container	3.384	−0.604	0.00346	34
Ferry (Ro-ro passenger and Ro-ro cargo)	8.061	−4.878	0.00067	50
Fishing	3.634	NA	0.00305	52
Merchant	4.544	0.725	0.00320	20
Other	4.070	0.240	0.00126	43
Passenger (≥ 100 m)	5.069	−2.283	0.00358	46
Tanker	2.999	0.845	0.00582	16
Tug	0.949	1.055	0.00564	28
Vehicle carrier	3.312	−0.335	−0.00041	41

C.2. Partial Residual Plots

For each vessel class, the plots below show the trend of monopole source levels (MSL) with speed, length, and closest point of approach (CPA) derived from the multivariate analysis (red lines), along with the partial residuals (black dots) of the MSL data for each parameter. These plots show the relationship between a given independent variable (speed, length, or CPA) and the MSL of the vessel class. A steep slope in the multivariate analysis (red lines) translates to the strong relation between the variable and the MSL. For fishing vessels, the speed and length of the vessels are highly correlated. Thus, the partial residual plots for this vessel class are only shown for the independent variables used in the linear regression: speed and CPA.

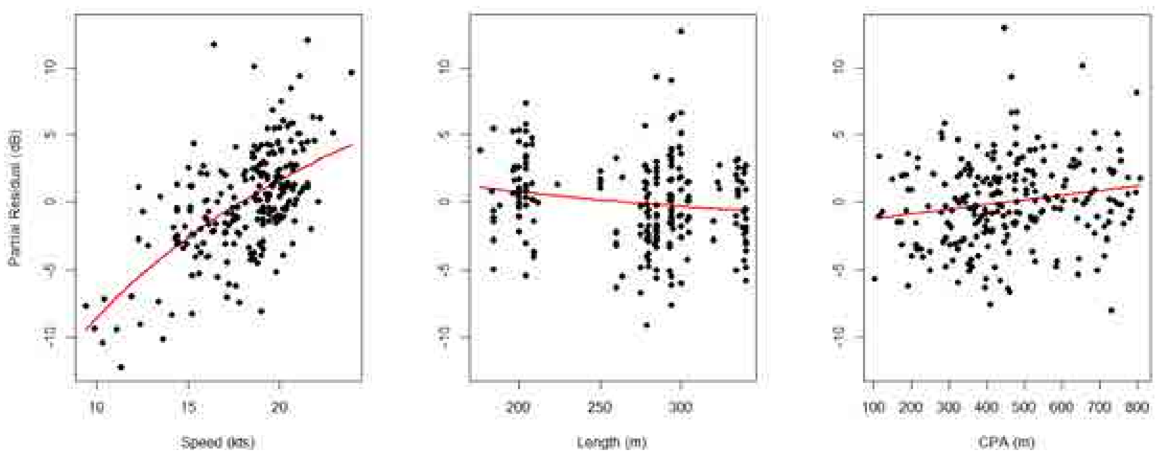

Figure C-1. *Container ship*: Partial residual plots for speed (left), length (centre), and CPA (right) derived from the multivariate analysis (red line), along with the partial residuals (black dots) of the MSL data.

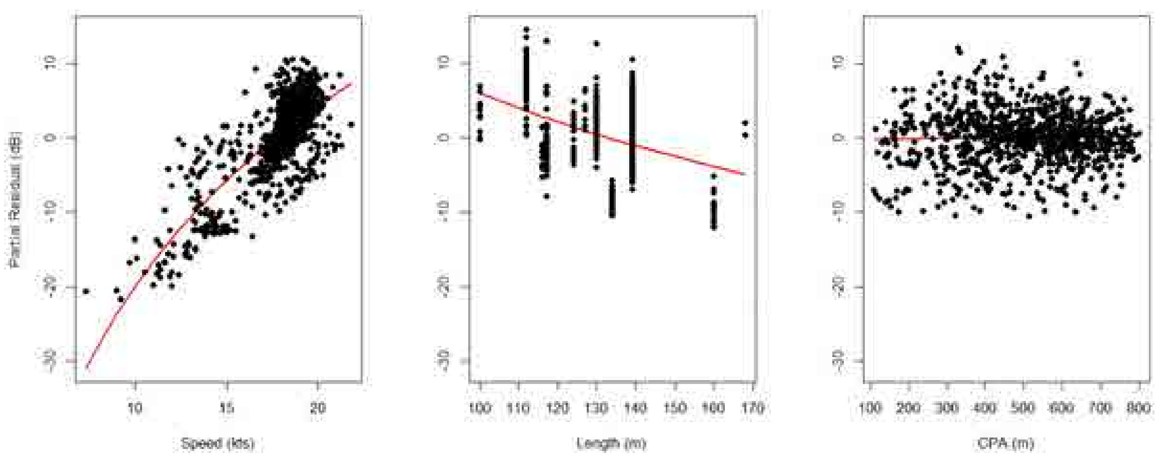

Figure C-2. *Ferry*: Partial residual plots for speed (left), length (centre), and CPA (right) derived from the multivariate analysis (red line), along with the partial residuals (black dots) of the MSL data.

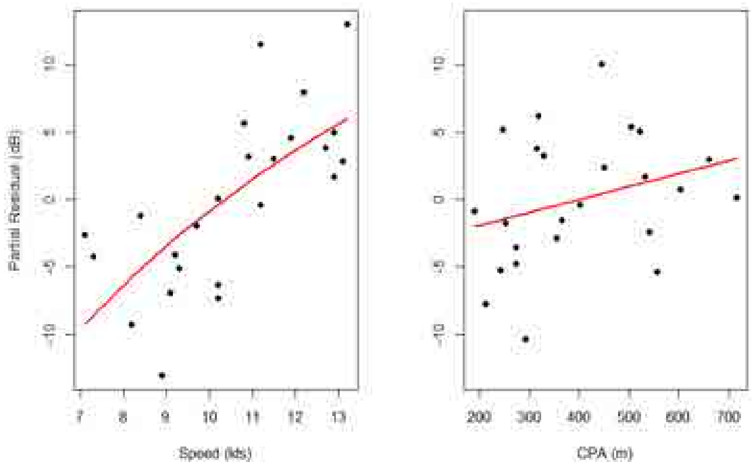

Figure C-3. *Fishing vessel*: Partial residual plots for speed (left), length (centre), and CPA (right) derived from the multivariate analysis (red line), along with the partial residuals (black dots) of the MSL data.

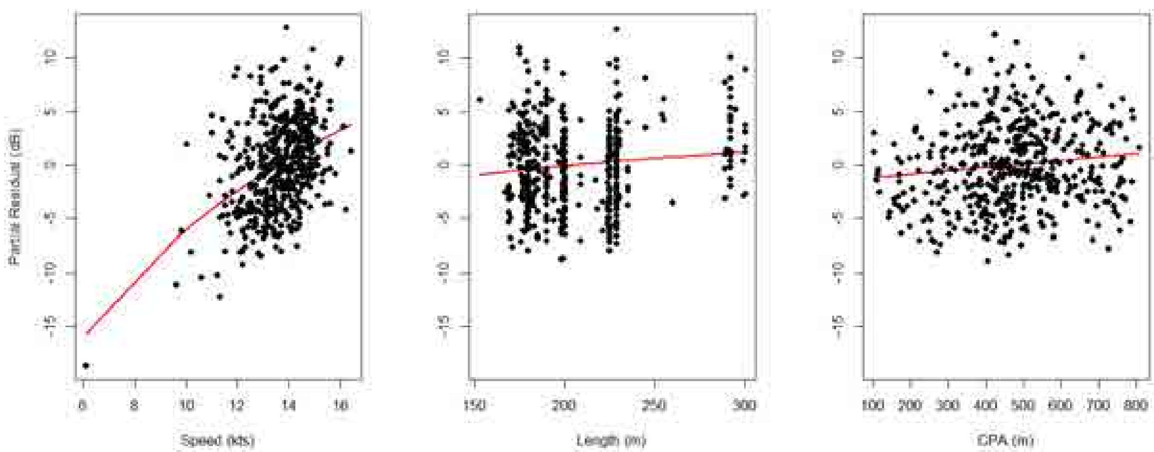

Figure C-4. *Merchant*: Partial residual plots for speed (left), length (centre), and CPA (right) derived from the multivariate analysis (red line), along with the partial residuals (black dots) of the MSL data.

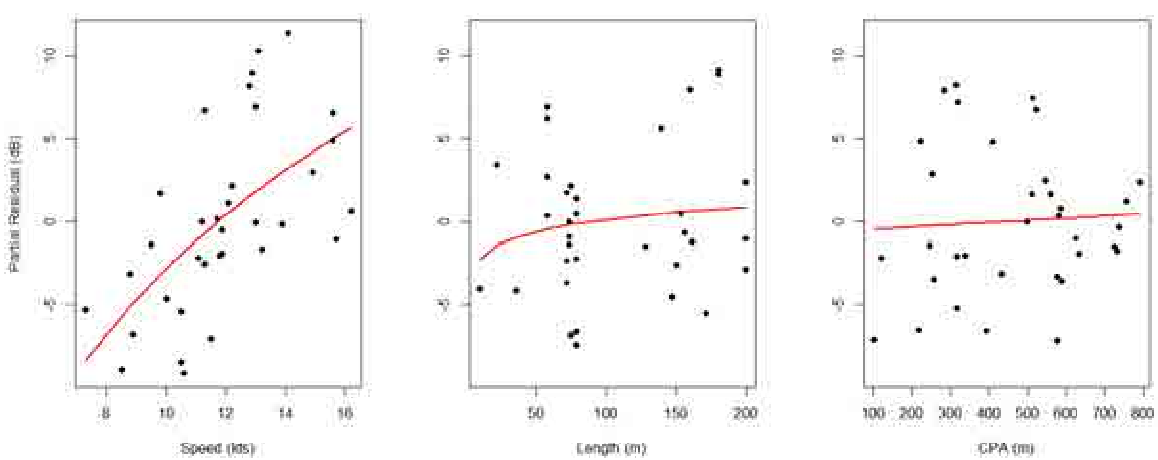

Figure C-5. *Other*: Partial residual plots for speed (left), length (centre), and CPA (right) derived from the multivariate analysis (red line), along with the partial residuals (black dots) of the MSL data.

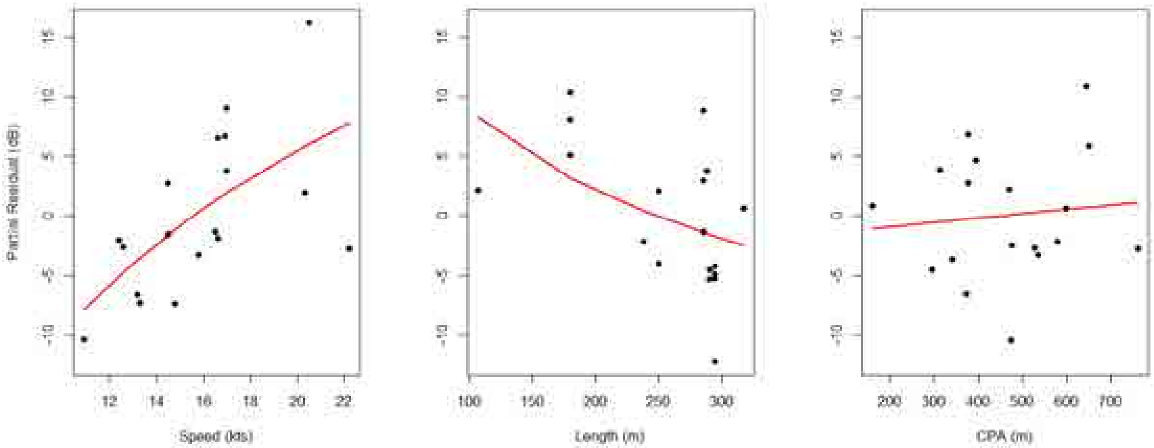

Figure C-6. *Passenger (≥ 100 m):* Partial residual plots for speed (left), length (centre), and CPA (right) derived from the multivariate analysis (red line), along with the partial residuals (black dots) of the MSL data.

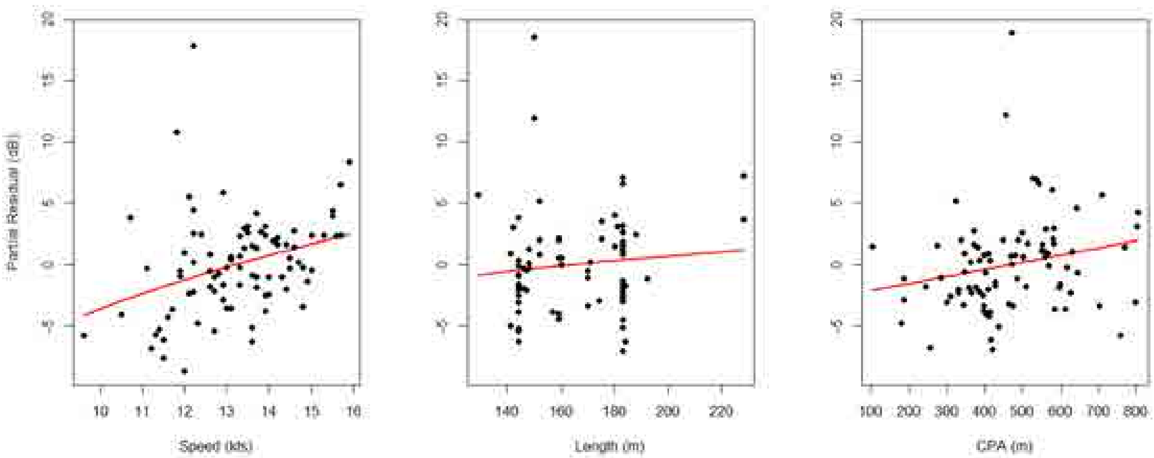

Figure C-7. *Tanker*: Partial residual plots for speed (left), length (centre), and CPA (right) derived from the multivariate analysis (red line), along with the partial residuals (black dots) of the MSL data.

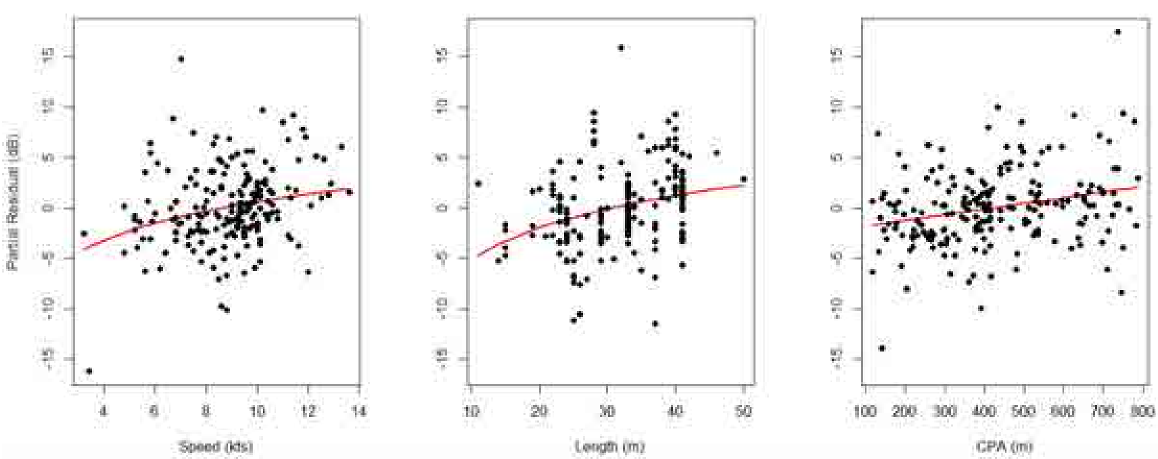

Figure C-8. *Tug*: Partial residual plots for speed (left), length (centre), and CPA (right) derived from the multivariate analysis (red line), along with the partial residuals (black dots) of the MSL data.

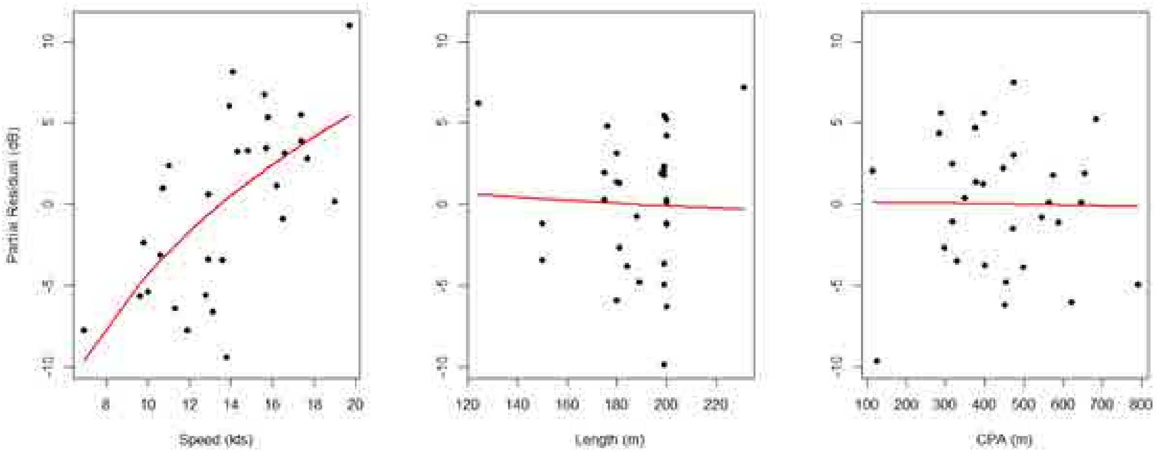

Figure C-9. *Vehicle carrier*: Partial residual plots for speed (left), length (centre), and CPA (right) derived from the multivariate analysis (red line), along with the partial residuals (black dots) of the MSL data.

APPENDIX D. REPLACING 10% OF NOISIEST SHIPS

What constitutes a “noisy ship” can be defined in many ways. It can be based on the vessel’s noise emissions (i.e., source levels) at one frequency, over a small frequency band, or over the entire frequency range from low to high frequencies (i.e., broadband source levels). It can also be defined for source levels with or without frequency weighting applied. In this study, vessels within each commercial class were ranked according to their unweighted and audiogram-weighted broadband source level. The audiogram used is presented in Figure A-10

Vessel noise emissions are generally much higher at frequencies below 1 kHz than above. In addition, vessels with the highest low-frequency levels may or may not have the highest levels at frequencies above 1 kHz. Since the SRKW hearing is better at frequencies above 1 kHz, applying audiogram-weighting results in a different ranking for noisiest vessel then when no frequency-weighting is applied. The left-hand images in Figure D-1 to Figure D-6 show the measured spectra for each class of commercial vessels, highlighting the noisiest 10% and quietest 10% of vessels according to their unweighted broadband source levels. The right-hand images present the same information, according to the SRKW audiogram-weighted source levels.

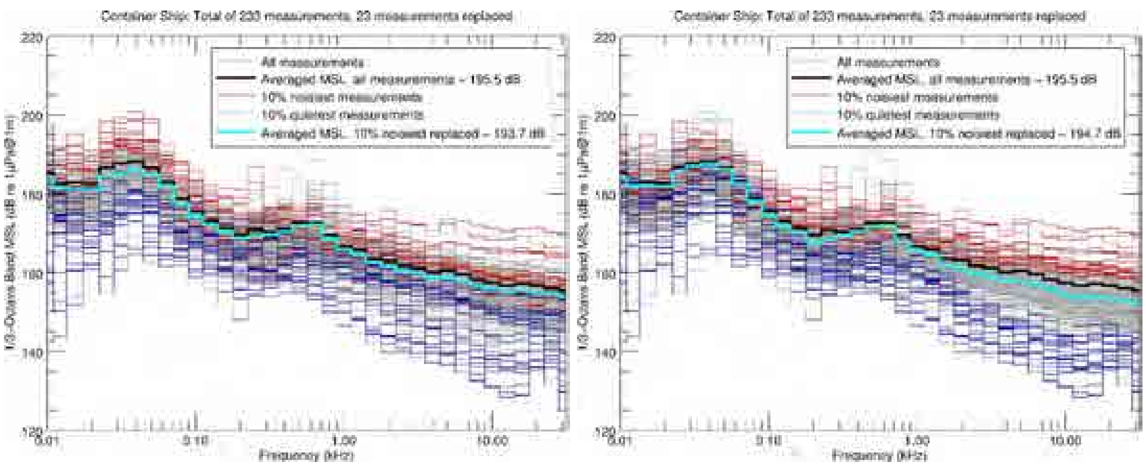

Figure D-1. *Container Ships*: Third-octave-band source level spectra for all measured vessels in the class. The spectra are ranked according to their (left) unweighted and (right) audiogram-weighted broadband level. The 10% of spectra with the highest broadband levels are red, the 10% of spectra with the lower broadband level are blue. The averaged spectra for all measurements is black, the average spectra after replacing the highest 10% by the lowest 10% is cyan.

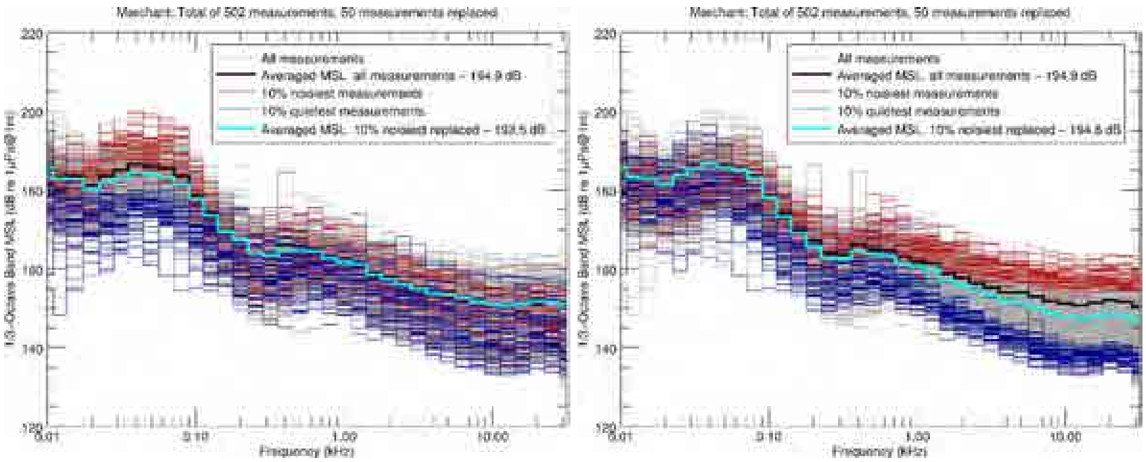

Figure D-2. *Merchant vessels*: Third-octave-band source level spectra for all measured vessels in the class. The spectra are ranked according to their (left) unweighted and (right) audiogram-weighted broadband level. The 10% of spectra with the highest broadband levels are red, the 10% of spectra with the lower broadband level are blue. The averaged spectra for all measurements is black, the average spectra after replacing the highest 10% by the lowest 10% is cyan.

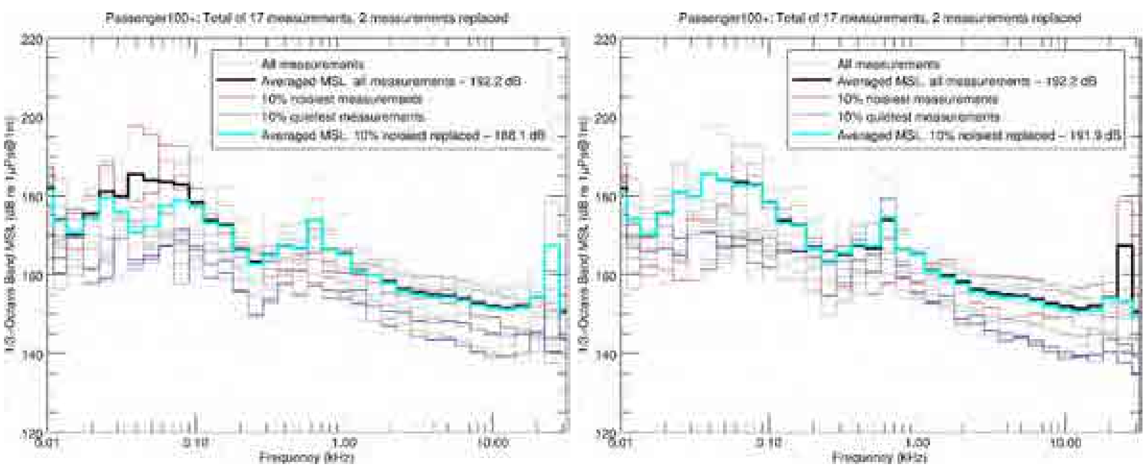

Figure D-3. *Passenger vessels (≥ 100 m):* Third-octave-band source level spectra for all measured vessels in the class. The spectra are ranked according to their (left) unweighted and (right) audiogram-weighted broadband level. The 10% of spectra with the highest broadband levels are red, the 10% of spectra with the lower broadband level are blue. The averaged spectra for all measurements is black, the average spectra after replacing the highest 10% by the lowest 10% is cyan.

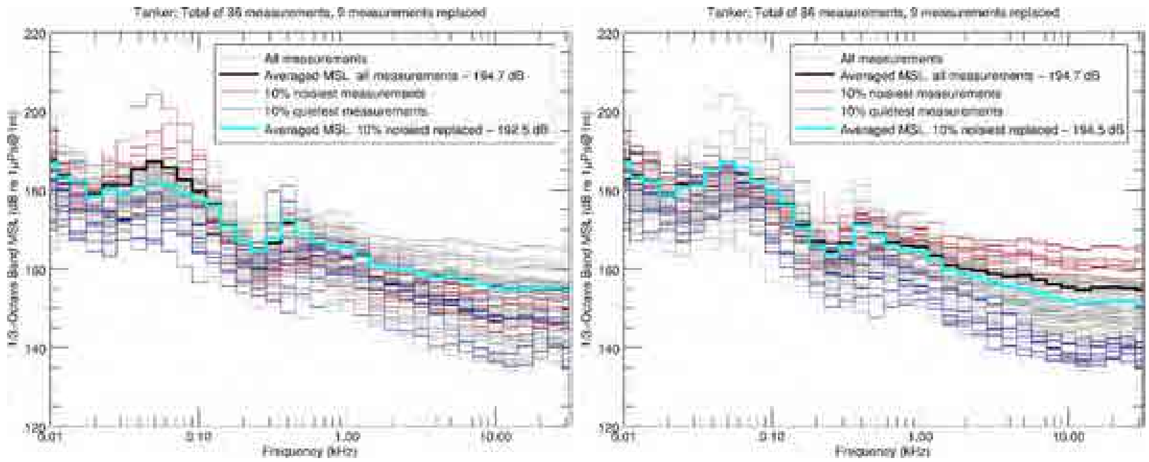

Figure D-4. *Tankers:* Third-octave-band source level spectra for all measured vessels in the class. The spectra are ranked according to their (left) unweighted and (right) audiogram-weighted broadband level. The 10% of spectra with the highest broadband levels are red, the 10% of spectra with the lower broadband level are blue. The averaged spectra for all measurements is black, the average spectra after replacing the highest 10% by the lowest 10% is cyan.

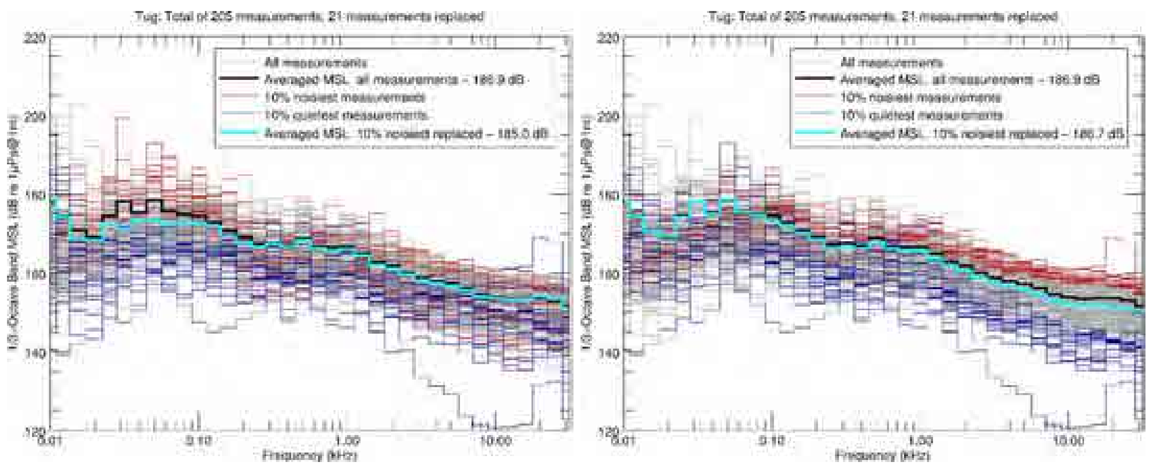

Figure D-5. *Tugs:* Third-octave-band source level spectra for all measured vessels in the class. The spectra are ranked according to their (left) unweighted and (right) audiogram-weighted broadband level. The 10% of spectra with the highest broadband levels are red, the 10% of spectra with the lower broadband level are blue. The averaged spectra for all measurements is black, the average spectra after replacing the highest 10% by the lowest 10% is cyan.

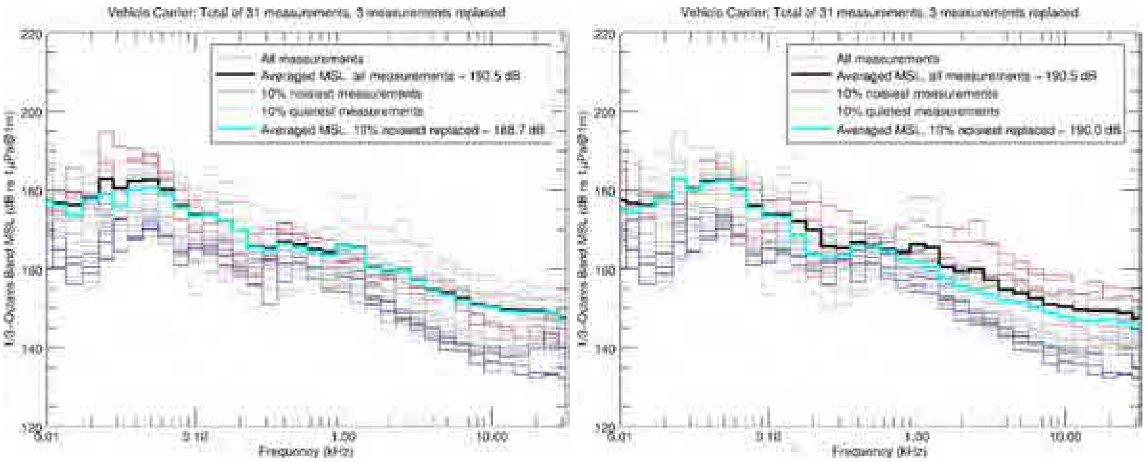

Figure D-6. *Vehicle carriers:* Third-octave-band source level spectra for all measured vessels in the class. The spectra are ranked according to their (left) unweighted and (right) audiogram-weighted broadband level. The 10% of spectra with the highest broadband levels are red, the 10% of spectra with the lower broadband level are blue. The averaged spectra for all measurements is black, the average spectra after replacing the highest 10% by the lowest 10% is cyan.

Appendix D

Coastal Ocean Research Institute's (CORI) 2017 report Proposed Metrics for the Management of Underwater Noise for Souther Resident Killer Whales

PROPOSED METRICS FOR THE MANAGEMENT OF UNDERWATER NOISE FOR SOUTHERN RESIDENT KILLER WHALES.

Authors: Kathy Heise, Lance Barrett-Lennard, Ross Chapman, Tom Dakin, Christine Erbe, David Hannay, Nathan Merchant, James Pilkington, Sheila Thornton, Dom Tollit, Svein Vagle, Val Veirs, Valeria Vergara, Jason Wood, Brianna Wright, Harald Yurk

COASTAL OCEAN RESEARCH INSTITUTE

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ocean wise.

About the Coastal Ocean Report Series

The Coastal Ocean Report Series presents scientific summaries and practical recommendations to decision-makers, stakeholders, and the public based on the best available science. The Reports represent the work of experts from different disciplines, locations, and affiliations who come together in an atmosphere of cooperation and reason to focus on a specific topic or geographic area for a limited amount of time.

Experts are convened by the Coastal Ocean Research Institute (CORI) in Vancouver, Canada. CORI was established by Ocean Wise to produce and communicate scientific knowledge and understanding in service of protecting aquatic life and habitats, informing responsible human activity, and safeguarding communities.

Credits

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PREFACE

Dear Reader,

Consider the last time you were trying to do something important, and a loud noise began - a truck or motorcycle, a siren, hammering, yelling, loud music…. Maybe you were trying to sleep, talk on the phone, work, communicate with your child in a park, or have dinner on a patio. Recall, if you will, how distracting and annoying the noise was, and how much of a relief it was when the noise ended.

Now imagine you live in the ocean, where sound travels easily and is fundamental for your survival.

And further imagine that your once thriving community is down to just 78 individuals. Every birth, and every death, is critical to your survival.

Fortunately, your critical habitat –which includes most of the waterways in southern British Columbia and northern Washington State, known as the Salish Sea-- has been scientifically-identified and legally-designated. Recovery plans prepared by both the Canadian and US governments identify underwater noise from ships and other sources as a key threat. Still, ship traffic is heavy and is projected to increase in the coming years with new projects and expansions. Noise is (for now at least) integral to human's economic development, transport, and recreation.

How will human activity be reconciled with your survival and recovery?

The answer to this question is on the mind of anyone concerned about the Southern Resident Killer Whale (SRKW) population, or other marine life around the world facing similar challenges. Progress has been made in understanding more about underwater noise and its effects, but we have far to go.

In our conversations with research colleagues and decision-makers, we concluded that a critical step was to establish a framework of metrics that measure the qualities and characteristics of noise that have the greatest impact on the whales. Such a framework would inform the planning of mitigation measures and make it possible to detect, measure and describe changes in the quality of acoustic environment from a whale's perspective in a standardized, repeatable way. Ultimately they would be used to gauge the success of efforts to improve that quality.

But such steps are easier to identify than to complete. We needed to garner government support, gather some of the world's best minds on the subject, and then work together to create a defensible framework that reflected the diverse experience and knowledge of those efforts. We succeeded only because everyone involved was committed to answering the question above. We all agree that it is no longer an option to leave such questions - -and the fate of entire populations – with question marks. Our answers will change with more science and technology, but we need to do what we can now.

I am grateful for the incredible commitment of everyone that contributed to this report, and to you for your interest. Hopefully this report inspires you to contribute to ocean science and conservation.

<Original signed by>

Andrew Day, LLB, Ph.D
Executive Director, Coastal Ocean Research Institute
Vice President, Ocean Wise

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Anthropogenic noise interferes with the ability of the critically-endangered southern resident killer whales to communicate and to detect prey with echolocation. As such, noise has been identified as a key threat to the survival and recovery of the population. Efforts to address this issue both by learning more about noise sources and impacts and by reducing source emissions have begun. Social and regulatory imperatives to protect the whale's critical habitat are likely to increase the intensity of these efforts for some years to come, as will a growing body of scientific evidence of negative impacts of noise on other aquatic animals. Detecting trends in the acoustic quality of the whales' habitat and planning mitigation efforts have both been hampered by the absence of a set of broadly-accepted noise assessment metrics focused on the qualities and characteristics of sound that are most impactful to the whales. An expert workshop was convened in Vancouver, Canada in May of 2017 to develop such a framework of impact-focused metrics.

The workshop participants first reviewed the most important negative impacts on killer whales of noise from existing anthropogenic sources. They determined that motorized vessels are the most significant sources of impactful, chronic noise in the southern resident killer whale's critical habitat area. They identified three principal impacts of this noise. The first is behavioural disturbance, the impacts of which can be increased physiological stress, disruption of important activities such as resting and foraging, avoidance behaviours and hearing sensitivity threshold shifts. The second is communication masking, which impacts group cohesion and coordination and interferes with important social behaviours. The third is echolocation masking, which reduces foraging efficiency and may also impair navigation, orientation and hazard avoidance.

There was agreement that properly assessing the acoustic quality of the southern residents' habitat requires distinct metrics for each of the three impact categories. The first metric addresses behavioural disturbance and focuses on broadband noise, measuring change in the 95th percentile of unweighted sound pressure levels from 10Hz -100 kHz. The second focuses on communication masking in the 0.5-15 kHz frequency band and measures change in the size of the space in which the whales can communicate effectively. The third focuses on echolocation masking in the 15-100 kHz frequency band and is a measure of change in foraging space. All three metrics are selected to detect trends rather than assess levels relative to a threshold.

Although much of the identified critical habitat of southern resident killer whales is in active shipping lanes, ship traffic is not continuous and noise that the whales are exposed to in and near the shipping lanes varies considerably over periods of hours. Additionally, there is considerable spatial variation in shipping noise levels, depending on bathymetry and proximity to the shipping lanes. The workshop participants recognized that quiet periods and places may provide important foraging and communication opportunities. Although primarily intended to measure trends over periods of years, they are also suitable for short-term and spatial comparisons of acoustic quality.

CONTEXT

The Southern Resident Killer Whale Population

The endangered transboundary Southern Resident Killer Whale population (SRKW) is a distinct, reproductively- and demographically-isolated population of salmon-eating killer whales that is most often found in the waters of the western coast of North America. It numbers only 78 individuals at present and has shown no net increase in numbers in four decades (Centre for Whale Research-whaleresearch.com). Its inherently low reproductive rate gives it very limited capacity to sustain elevated mortality rates. Its scientifically-identified and legally-designated critical habitat includes most of the network of waterways in southern British Columbia and northern Washington State known as the Salish Sea (DFO 2011). Other important areas include the north side of the Strait of Juan de Fuca and Swiftsure Bank (James Pilkington, pers. comm. this workshop. Ford et al. 2017). Ship traffic is heavy throughout all of these areas.

Underwater Noise Primer

It is well known that sound propagates over great distances in water while light attenuates rapidly. Many anthropogenic activities on or near water (eg. shipping, construction, sonar use) produce underwater noise. Noise may cause behavioural disturbances and increased stress levels (Noren et al. 2009, Rolland et al. 2012) amongst other impacts, which can include indirect consequences, such as reducing the ability to detect predators and find food and mates.

Killer whales use sound actively for both communication and echolocation. The efficiency and effective range of both activities are reduced by the masking effect of noise. The impact on survival of this increased difficulty depends on context (for eg. impairment of foraging efficiency via reduced echolocation range is of greater consequence when prey are scarce than when abundant), and is difficult to estimate.

Noise and Southern Resident Killer whales

Recovery plans for the SRKW prepared by both the Canadian and US governments identify anthropogenic underwater noise from ships and other sources as a key threat to the population. In Canada, the recently-finalized Resident Killer Whale Action Plan (January 2017) contains over 40 measures that address the issue. When the Canadian government approved the Trans Mountain Pipeline Expansion Project (TMX), it committed to ensuring that no net increase in underwater noise would result from the project. Subsequently, it committed to the even more ambitious target of reducing noise in SRKW critical habit by the end of 2019 (ie. more than mitigate increases in noise). However, no targets were specifically set for noise reduction.

Workshop Goal

The workshops goal was to identify characteristics of anthropogenic underwater noise that negatively impact southern resident killer whales and use them to develop a framework of standardized metrics for measuring, comparing and detecting changes in the quality of the whales' acoustic environment. The ultimate purpose of the framework is to help inform a broad, yet-to-be developed program of mitigation actions that reduce the threats posed by anthropogenic noise to the survival and recovery of the population.

Caveats

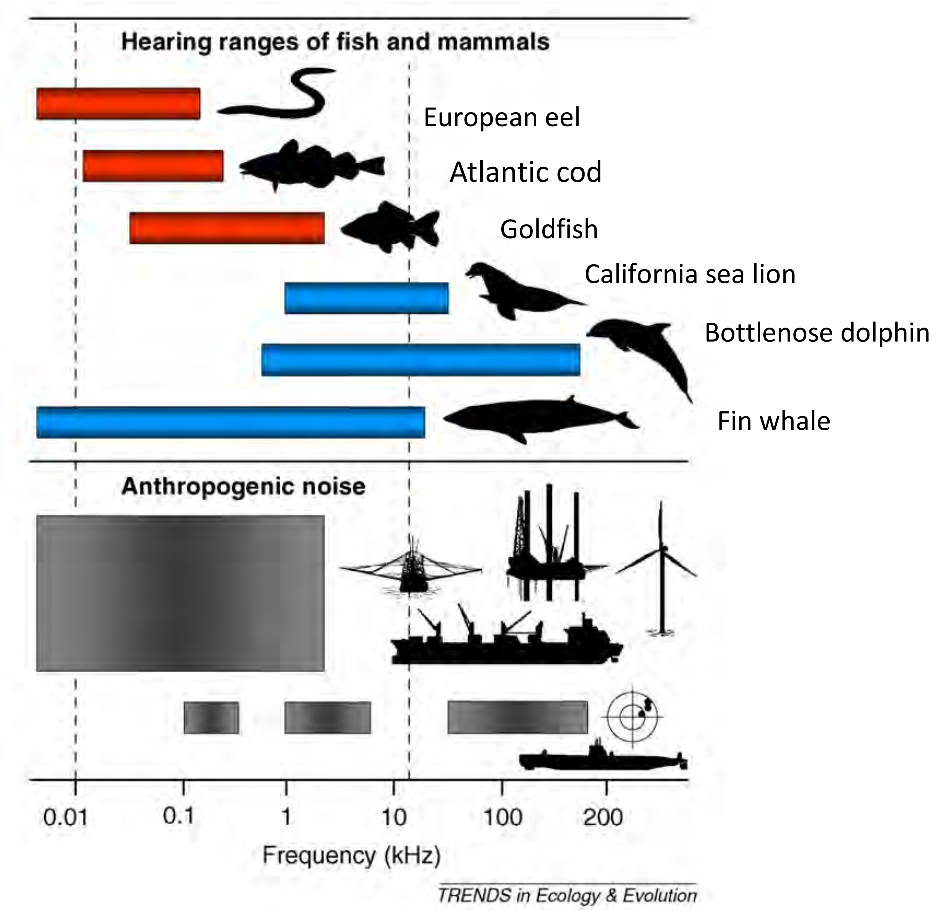
- Workshop participants agreed that approaches to managing underwater noise must be precautionary, and the process must be adaptive, particularly as knowledge around the impacts of noise on marine mammals grows and as technologies to mitigate underwater noise develop.
- As described below, the participants recommended 2018 as the acoustic reference year for data collection due to the proposed Trans Mountain Pipeline activities that are to begin in 2019. The use of the word 'baseline' was avoided as it implies an acoustically 'better' time for the whales, yet current conditions for SRKW which will likely be the same in 2018 are not sufficient to promote recovery (the population has not increased since the mid- 1970's) and efforts must be made to reduce all threats to SRKW (disturbance, contaminants and lack of prey availability/accessibility).
- As acknowledged by the Canadian National Energy Board, full operation of the TMX project is likely to result in significant adverse effects on this endangered population. The workshop participants therefore emphasized the urgent need to address the knowledge gaps identified in this report in order to direct adaptive management approaches to include a noise-focused component to protect this population.
- Vessel traffic contributes the majority of noise to which SRKW are exposed and discussions during the workshop focused on noise from this source. Mitigation of impulsive noise sources such as sounds from pile driving and seismic surveys were not discussed.

KEY CONSIDERATIONS IN IDENTIFYING THE IMPACTS OF NOISE

Killer whales use sound for a variety of purposes

- Passive listening: Like other marine mammals, killer whales likely listen for environmental sounds (e.g., the sound of surf on shore) and the sounds of other species to assist with navigation, orientation, and foraging. Figure 1 shows the overlap in cetacean, pinniped and fish hearing ranges, as well as those generated by human-generated noise.
- Echolocation: Killer whales use trains of broadband clicks with variable spectral characteristics and inter-click intervals to find prey, avoid obstacles and navigate. Under good weather and sea conditions, killer whales can detect salmon up to at least 250 m away (Au et al. 2004, SMRU 2014).
- Communication: killer whales use pulsed calls to communicate over a range of distances, (potentially up to 15 km or more – Miller 2006, etc.) and whistles, for short-range communication.

Figure 1. There is considerable overlap in cetacean, pinniped and fish hearing ranges, as well as those generated by human-generated noise (modified from Slabekoorn et al. 2010).



Hearing sensitivity varies with frequency

- The good hearing range of killer whales extends from approximately 600 Hz to over 100 kHz. In common with other mammals, they have a U-shaped audiogram. Their best sensitivity is between 20 and 50 kHz (Branstetter et al. 2017).
- Noise impacts effecting audition are generally presumed to be most severe in the areas of greatest sensitivity, although the distribution of energy in killer whale calls suggests that sounds near the top and bottom of their hearing range may also be functionally important for them.

Quiet periods are important

- Although most of the identified critical habitat of southern resident killer whales is in busy shipping lanes, ship traffic is not continuous. Temporal variability and the intermittency of noise are functionally important to whales, in that quiet periods provide windows of opportunity for communicating or echolocating with minimal masking. Recent evidence of bowhead whales delaying calling until noise levels are lower when exposed to various levels of seismic survey noise (Blackwell et al. 2015) and of fin whales halting singing and waiting until a seismic survey ended before resuming (cited in Weilgart, 2007), support this. We also see examples of this effect in birds (e.g., Brumm and Zollinger 2014), insects, anurans, and several terrestrial mammals (reviewed in Tyack, 2008a, 2008b).
- This disproportionate importance of quiet periods exists whether or not whales choose to concentrate vocal activity during such times. It is a consequence of the relationships between noise and both echolocation range and communication space.

Behavioural responses to sounds must be taken into account

- Convincing empirical evidence exists that shows that killer whales respond to low frequency sounds that are thought to be near the lower limit of their hearing range
- Context and acclimation to sounds must be considered. As with other species, behavioural reactions to certain sounds might decrease or increase as exposure increases. Interpretation of behavioural responses can be complex.

Acoustic quality reference sites

- Acoustic quality at any given location depends on the types, levels and proximity of sound sources and on factors that affect sound propagation, such as water depth, sound speed ducting, bottom substrate type, thermal or saline stratification, etc.
- Meaningful assessment of the patterns and trends of acoustic quality of SRKW critical habitat therefore requires the careful selection of reference sites. To provide the greatest insights into noise impacts, these sites should be located in or near areas of particular importance to the whales, such as foraging hotspots and commonly-used travel routes.

WORKSHOP OUTCOMES

The workshop participants agreed that the range of the most important noise impacts could be captured in three key metrics: one focused on noise-induced changes in behaviour, physiology and/or health; a second focused on communication masking (which impairs social integrity, social interactions and foraging coordination), and a third focused on echolocation masking (which impairs foraging and navigation). Figure 2 illustrates the different frequency bands that these metrics focus on. Based on empirical evidence that noise outside the whales' known hearing range can cause behavioural changes, the first metric assesses broadband noise. The second and third metrics assess noise within the frequency ranges of echolocation clicks and communication calls, respectively.

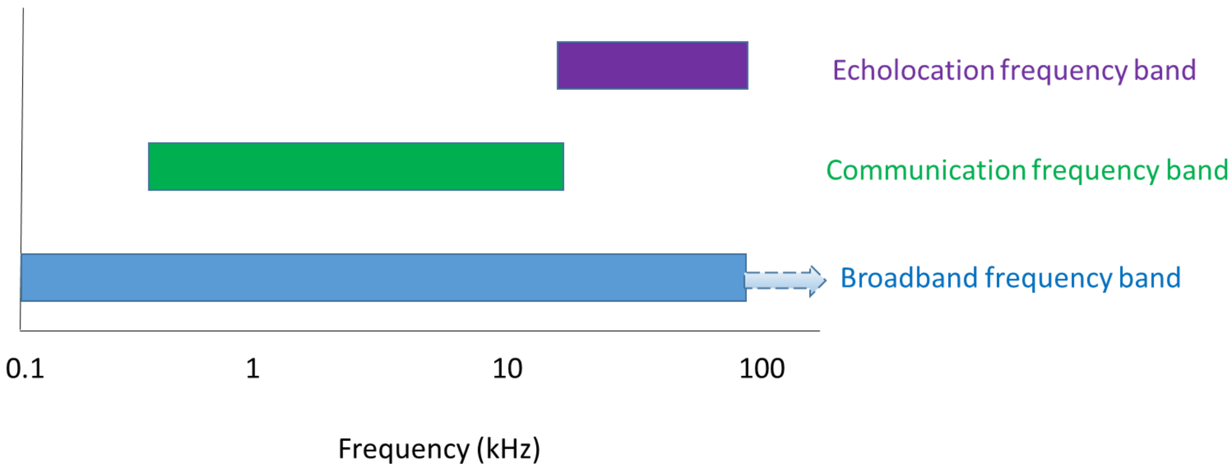


Figure 2. The three key frequency bands that the metrics focus on are broadband, communication and echolocation signals.

In addition to achieving the goal of measuring, comparing and detecting changes in the quality of the whales' acoustic environment, the suite of metrics were designed with the following additional uses in mind:

- to inform initiatives for reducing noise outputs, such as vessel quieting and speed reductions,
- to facilitate assessment of acoustic quality at reference sites in key foraging areas and/or other locations of importance to the whales,
- to identify ways in which changes in the temporal and/or spatial distribution of noise sources might reduce impacts on the whales, such as convoying ships to create relative quiet periods and/or creating acoustic sanctuaries with reduced vessel traffic, and,
- to better understand the effects of noise on salmon--the principal prey of resident killer whales.

The participants strongly agreed that metrics that detect trends in impactful noise over time and differences in impactful noise levels between locations (ie the delta or differential between noise levels) are more robust and useful in meeting the stated goal than threshold-based metrics that focus on sound levels relative to a target. This approach is a departure from many noise assessments which use thresholds as a basis for binary decision making---for example determining whether or not a noise-making activity should be allowed. Although necessary for such decisions, fixed, biologically-meaningful thresholds are inherently difficult to determine. Part of the reason for this is that impacts of noise a) vary according to time, location, and contextual factors such as behavioural activity, and b) include factors with consequences that are challenging to quantify, such as stress or changes in speed and direction. An additional advantage to change-based metrics is that they lend themselves readily to an adaptive conservation approach where the relative effectiveness of mitigation strategies is reflected in changes in the metrics.   Figure 3 A and B illustrate how these change based metrics can be better understood.

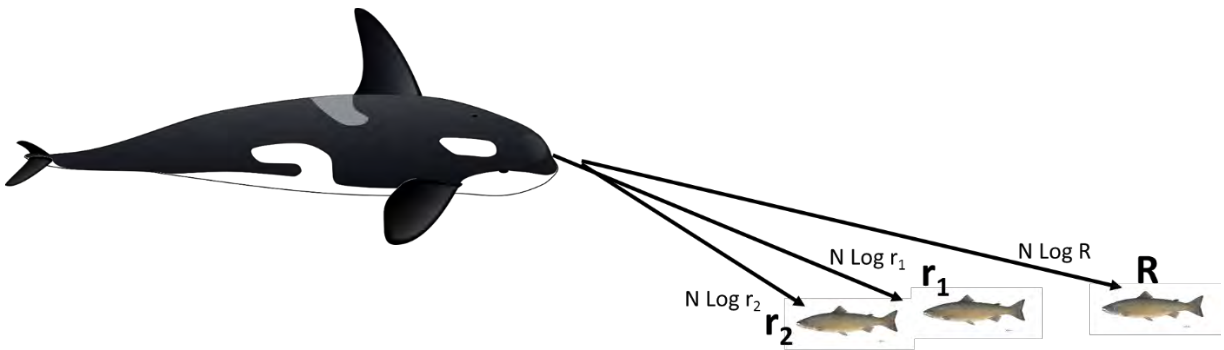


Figure 3A. Signal detection distance depends on acoustic transmission loss which can be expressed as N log r or R. R is the detection distance under natural ambient noise conditions, r_1 is the detection distance under pre-TMX noise conditions (with 2018 as a reference year) and r_2 is the detection distance after TMX implementation. N is dependent on local sound propagation conditions and typically varies between 10 and 20.

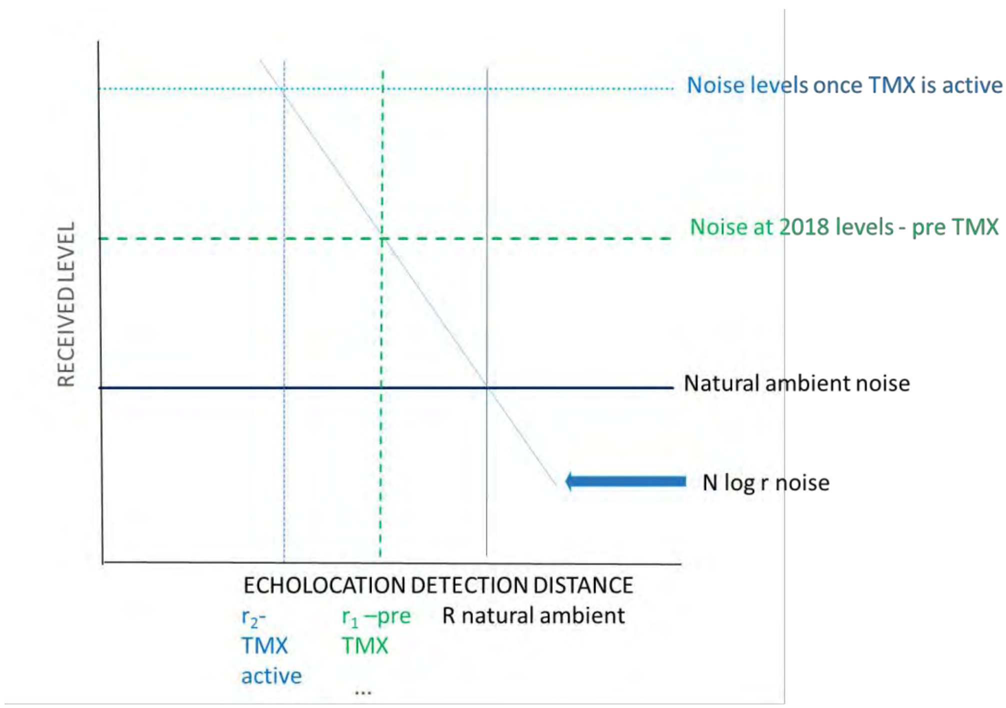


Figure 3 B. The levels of noise killer whales receive depend on acoustic conditions.

There was also agreement that in some cases, such as determining the quality of 'acoustic sanctuaries' or the quality of planned 'quiet periods' between ship passages, measuring the proportion of time that noise falls below a benchmark level reflective of natural sound level variation without anthropogenic noise would be useful and informative. The three principal metrics are described below and summarized along with the rationale for their selection and their 'ideal world' values.

In view of the Government of Canada's commitments to reduce underwater noise in SRKW habitat, (which the participants took to mean improve the acoustic quality of that habitat), the participants recommended that 2018 be considered an acoustic reference year for assessing subsequent improvement or deterioration of the whales' acoustic environment.

Broadband Noise

Underwater noise can cause killer whales and other marine mammals to alter their behavior, change dive patterns and respiration rates, and interrupt foraging, socializing or resting. (eg. Lusseau et al. 2009). Furthermore, noise appears to be associated with higher than normal stress hormone levels (Roland et al. 2012). It can also cause animals to leave important habitat (Gomez et al. 2016). The workshop participants agreed that these behavioural or physiological impacts constitute a threat and warrant a specific metric: 95th percentile of unweighted sound pressure levels (SPL) from 10 Hz to 100 kHz. This recommended metric would be measured with at least 1/3 octave band frequency resolution, which is sufficient for determining noise in critical hearing bands. Important sounds occurring in limited frequency ranges are masked predominantly by noise at nearby frequencies; mammalian hearing can filter out masking noise that occurs at much higher or lower frequencies. The relatively small frequency band centred on the sound of interest (referred to as the critical band) defines the range of frequencies that contribute to masking –noise outside of the critical band does not contribute or at least contributes much less to this masking (Erbe et al. 2016). There was some discussion of using the 50th percentile instead, but the 95th was agreed on in reflection of the fact that loud noise sources are the most impactful, and detecting change at the top end of the noise spectrum is therefore most important.

Communication Masking

The communication space of killer whales typically covers distances out to approximately 15 km, but can extend to over 26 km (Miller 2006) and in some cases even further (James Pilkington, Lance Barrett-Lennard- pers. comm. this workshop). Acoustic communication is important for maintaining group cohesion, particularly when the whales are widely dispersed during foraging. Communication sounds may transmit information about prey patches and threats, and also mediate social interactions (including prey sharing). Cow-calf pairs are especially vulnerable because it is likely that killer whale calves, like beluga whale calves, vocalize at lower intensity than adults, particularly at higher frequencies, which makes the disruption of their communication bond, and thus the potential for unwanted separations, more likely (Valeria Vergara pers. comm. during this workshop). Miller et al. (2014) showed that killer whale calves had stronger responses to military sonar than did adults, further supporting the possibility that they are more sensitive to noise.

The recommended metric for assessing the effects of communication masking is the percentage reduction in baseline communication space, which is the distance that a signal can be detected and decoded by a conspecific (see for eg. Tervo et al. 2012). Active space is limited by the masking of the sound of interest by natural and anthropogenic noise. The relative listening space metric quantifies the fractional decrease in caller-listener separation distance necessary for increasing received call sound levels to overcome increases in masking noise (Barber et al. 2009). The calculation examines noise increases (or deltas) from 2018 levels in consecutive critical hearing bands within the 0.5 to 15 kHz frequency range. These can be averaged, or a percentile taken, to yield a single metric representing the full communication band.

Echolocation Masking

Since the demonstration of a strong negative correlation between coast-wide Chinook salmon abundance and mortality rates in both southern and northern resident killer whales (Ford et al. 2009), much attention has been paid to the hypothesis that nutritional stress is a key threat to the survival and recovery of SRKW (e.g. Hilborn et al. 2012). Resident killer whales echolocate extensively while foraging (Barrett-Lennard et al. 1996), presumably to locate and capture fish. Masking of echolocation by noise therefore reduces foraging efficiency, an effect that is likely to be most consequential during periods of low salmon abundance. In light of the importance of echolocation, the workshop participants agreed that a metric was needed to assess and measure echolocation masking noise.

The metric, referred to as foraging space reduction, has been proposed to characterize the relative decrease in echolocation signal detection distance due to noise masking. This is calculated using the same approach described for the relative communication distance metric above. It is expressed as the percent change (or delta) of the original echolocation distance based on 2018 conditions in the presence of increased masking noise in the echolocation band (Barber et al. 2009). Calculating this metric (the delta in echolocation space) requires a measure of the change in masking noise levels in the audiogram weighted 15-100 kHz band, together with an estimate of acoustic transmission loss (the rate at which received echolocation signal levels decrease with distance between a whale and its prey).

Table 1. Summary of the three metrics that collectively describe the quality of the acoustic habitat for southern resident killer whales.

Metric	Purpose	Definition	Rationale	Optimal Value
Broadband level noise	To indicate the risk of behavioural, physical and physiological impacts of low-frequency noise on SRKW, and for ship noise assessment and vessel ranking.	The proportion of time that the unweighted sound pressure level (SPL) in frequencies from 10 Hz to 100 kHz does not exceed 95% of the measured level relative to 2018 levels.	Noise in frequencies across the spectrum, and especially low-frequency noise, that has the potential to cause physical and physiological effects on SRKW may not be adequately captured by hearing range (audiogram)-weighted metrics (e.g. for masking). This metric acts as a proxy indicator of this risk. The broadband SPL is chosen since low-frequency components are expected to dominate this metric. Although intended to indicate the probability of behavioural responses in SRKW, this metric may also provide a measure of noise impacts on salmon, which may be sensitive to low-frequency noise and are important prey for SRKW. Further, the metric could also be used to rank vessels based on their acoustic signatures, providing criteria for targeting and prioritizing mitigation efforts.	The proportion of time that the broadband SPL in frequencies from 10 Hz to 100 kHz does not exceed the 95th percentile of the level present in the animal's natural soundscape. (The 95th percentile of the natural soundscape is the value below which 95% of measured sound pressures fall.) Note that this requires a consistent definition of how natural soundscape would be estimated, but its definition was outside the scope of this workshop.
Communication masking noise	To indicate levels of SRKW communication masking, most of which occurs in the 0.5-15 kHz frequency band.	The change in the communication space relative to 2018 levels, taking into account site-specific propagation conditions.	Communication is a vital behaviour for SRKW, and supports important functions such as reproduction, socializing, and foraging, including prey sharing. SRKW calls may be masked by shipping noise, which means that their communication area or space over which calls can be effectively received by conspecifics can be significantly reduced.	Optimal communication space is defined as 95% of the space available under natural noise conditions at any location and varies with time.

Echolocation masking noise	To indicate levels of SRKW echolocation masking, most of which occurs in the 15-100 kHz frequency band	The change in foraging space relative to 2018 levels, taking into account site-specific transmission loss rates..	Echolocation is used in foraging and hence is a vital behaviour for SRKW. It is likely also used for navigation and orientation. SRKW echolocation clicks may be masked by shipping noise. While seeking prey, volume of water searched is the primary consideration when considering impacts.	Optimal echolocation space is defined as 95% of the space available under natural noise conditions at any location and varies with time.

Applications of the Noise Metrics to Mitigation: Two Examples

Acoustic Sanctuaries

Strategies to identify acoustic sanctuaries should include areas both of high value to SRKW and where reducing noise or preventing increases in noise is feasible. By these criteria, there are several potential locations for effective acoustic sanctuaries in SRKW critical habitat. Salmon Banks and/or the south end of Lopez Is. (in US waters), Swiftsure Bank, and possible locations along the north side of the Strait of Juan de Fuca. Haro Strait could also be declared an acoustic sanctuary in its entirety, with special measures to reduce noise impacts (such as greater minimum approach distances to SRKW by whale-watch vessels). Sanctuaries could be seasonal and/or dynamic, and should be adaptive and subject to revision as new information becomes available. All three metrics (for broadband sounds, as well as echolocation and communication masking) would be appropriate for describing acoustic sanctuaries.

Vessel Ranking

The ranking of the sound signatures of vessels is extremely useful for managers for developing incentive or performance based programs, such as those initiated by the Fraser River Port Authority's (FVPA) ECHO program. Power spectral densities (PSD in 1 Hz bins) and 1/3-octave band source radiated noise levels can be calculated according to standards such as ANSI 12.64 (2009) and ISO 17208-1 (2016). These measurements can be used to inform ship owners of their vessels' noise emissions performance relative to their peers. Ranking vessels requires some scaling of measured levels prior to the comparisons, to account for vessel class, dimensions and speed at time of measurement. Rankings can be used to identify the acoustic "worst offenders" in the fleet, or more positively, be provided to vessel owners for identifying maintenance issues that may require attention, and to provide outreach on the acoustic impacts of their vessels on SRKW. An important use of vessel ranking is for identifying "best in class" vessels, that could then be provided incentives such as reduced berth fees, such as recently implemented by the Vancouver Fraser Port Authority (VFPA) for vessels with 'quiet vessel' notations from ship classification societies. These rankings could also be used by Green Marine, a voluntary environmental certification program for the North American marine industry which recently established underwater noise standards for member shipping companies. Note that received levels from shipping are unlikely high enough to cause PTS, though TTS is a possibility in some cases, and as discussed earlier, may be of greatest concern for young animals. The appropriate metrics for vessel ranking should include the radiated source levels and spectra in each of the three categories described in Table 1.

IDENTIFIED KNOWLEDGE GAPS

Key topics that were not addressed in the workshop but were identified to be important to future work in assessing the effectiveness and improving the design of the metrics include:

- The hearing abilities and impacts of noise on Pacific salmon, particularly Chinook and chum.
- More information about the spectra and source levels of small vessels is needed.
- Potential locations on which to focus mitigation: Salmon Bank, and/or the south end of Lopez Island in US waters, and Swiftsure Bank and possibly the north side of the Strait of Juan de Fuca in Canadian waters merit further consideration, as does Haro Strait. There are likely others.
- The night time foraging behavior of resident killer whales- further research is needed, and may have consequences for mitigation, including the use of convoys and vessel exclusion time periods.
- What are the optimal and acceptable sizes or bounds of acoustic search and communication spaces for recovering SRKW and how do they vary in different conditions and environments?
- How is killer whale hearing impacted (particularly young animals) by chronic noise exposure in all three metric bands?
- More information about the use and effective range of killer whale echolocation.
- More research is needed to inform dose/behavioural response curves, particularly at low frequencies, and how they may vary between times of exposure (eg. night versus day/ expected quiet period versus expected noisy period, etc.).
- Are there synergies between ship strike risk assessment vs. vessel speed changes for SRKW?
- Are killer whale audiograms accurate, especially at lower frequencies?
- To what extent and by what non-auditory pathway(s) do killer whales perceive sound energy in frequencies that fall outside of their primary hearing sensitivity?
- What are killer whale source levels for echolocation and communication signals across the full spectrum?

Next steps

This approach- using three metrics- is consistent with Tougaard et al. (2015) and with the EU Marine Strategy Framework Directive (MSFD). The MSFD focuses on sustaining populations, the habitats that support them, and the ecosystems they live within, and differs from the US Marine Mammal Protection Act approach of allowable 'takes' of individual species. Monitoring programs and reference sites need to be identified and systems put in place before the end of 2017, as 2018 will be the target year for establishing reference noise levels before Kinder Morgan vessel activity begins to increase. A recently-completed DFO science review of Canada's recovery measures for killer whales (Fisheries and Oceans Canada 2017), and the results of this metrics meeting could inform this process, and may also be helpful informing efforts to protect St. Lawrence beluga and North Atlantic right whales. It may be appropriate to establish a 'stoplight' monitoring program that is updated daily to identify the noisiest reference sites. Mitigation measures such as vessel slow-downs and/or convoys may be put forward if areas of concern are repeatedly identified and the measures are deemed to be sufficient for noise reduction actions while maintaining vessel safety. Current research by the VFPA's ECHO program will greatly inform future efforts.

Participants are considering submission of a follow-up paper for submission to a peer-reviewed journal: Endangered Species Research, PLOS, Marine pollution bulletin, or PeerJ open access with collective authorship

CONCLUSIONS

Expert workshops are brainstorming exercises that are usually motivated by some sense of urgency. They allow colleagues to efficiently and quickly consider and discuss specific topics in depth, to share new information and existing information in new lights, to share and challenge ideas, to identify fundamental knowledge gaps and plan studies to address them and, sometimes, just sometimes, to arrive at a consensus on an issue or question. In this case, the urgency was the desperate plight of the southern resident killer whales---which has only 78 members, shows no positive growth trend over the last three decades, and is negatively impacted by a number of anthropogenic activities and pollutants.

To the relieved surprise of the workshop organizers and participants alike, a high degree of consensus was achieved. There was agreement that the most important noise related impacts for southern resident killer whales are behavioural disruption, and the masking of communication and echolocation. There was agreement that quiet periods and the identification of acoustic sanctuaries could reduce noise impacts significantly, and to be most useful, the metrics need to measure the quality of the environments with respect to these parameters. There was agreement on the metrics themselves, and finally there was agreement on a general approach to identifying reference sites for monitoring the effectiveness of mitigation efforts.

However, there was not general consensus re: whether and how the three metrics might be combined into one for a broad evaluation of acoustic quality. Generally, it was felt that this approach would not be helpful for planning, prioritizing and assessing the effectiveness of noise mitigation approaches specifically for SRKW, but that it might have utility in a broader coast-wide assessment of general acoustic quality. Also discussions remain ongoing as to the use of 95th percentiles (as opposed to 50th percentile and potentially others, reaffirming the need for management approaches to be adaptive).

Finally, a comment about mitigation. The workshop focused on metrics for identifying the need for mitigative actions, and where needed, for planning them, and evaluating their effectiveness. That said, mitigation options naturally arose and were briefly discussed. Without reiterating those discussions, suffice to say in this report that the participants focused the metrics on areas where practical mitigation options do exist, or might exist in the near future. For example, in discussing quiet periods, participants considered that larger vessels transiting critical habitat could be convoyed to create noisier and quiet periods, and furthermore that discussions with pilots and industry representatives have indicated that such a strategy is within the realm of possibility. Similarly, they discussed whether any areas in the SRKW critical habitat could usefully serve as acoustic sanctuaries, and determined that while most or all candidate areas would still experience some ship noise, speed or routing changes could reduce it significantly.

APPENDICES

Appendix 1: Glossary (largely derived from ASA 2015 and Erbe 2011)

Audiograms are plots of absolute hearing detection thresholds (dB) under quiet conditions vs frequency (kHz) and are derived from tests that either rely on behavioural training, or on measurements of auditory brainstem responses (referred to as ABRs or as auditory evoked potential tests -AEP). Both types of tests are usually performed on captive animals although more recently ABR/AEP test have been done with wild cetaceans that have stranded or been captured. Generally, behavioural auditory response testing is considered more accurate for testing hearing sensitivities at the boundaries of good hearing range, especially with regard to lower frequency hearing in cetaceans and other mammals. Marine mammal audiograms are U-shaped, just as they are in humans. The results of audiogram testing vary depending on the subject's history (eg. past noise exposure, age, sex, medical history and whether the individual had been treated with certain antibiotics, etc.), As a result, audiograms should be interpreted in a precautionary way in view of this variability. To date, there are audiograms from 11 captive killer whales of which 9 are useful, and these are discussed in more detail in Appendix 2.

Behavioural response or dose- response curves are graphs based on estimates of the percentage of a population that may respond behaviourally to exposure to different levels or doses of a potential stressor. In this case, the stressor is anthropogenic sound, ie. noise. The response may include changes in swimming speed or direction, the duration of dives, time at the surface, respiration rate etc. How animals respond to noise exposure will depend on a number of factors, including age, gender, health, previous exposures and behavioural state (for eg. will vary depending on whether foraging or resting).

Critical band is the bandwidth of sound frequencies perceived by the inner ear which can effectively mask a tone or signal at the centre of a particular frequency band which interferes with the perception of the tone, due to masking.

Critical ratio is the ratio between the sound pressure of a signal and the power spectral density of noise at the detection threshold- ie how much louder a signal has to be than background noise before it is perceived by an animal.

M-weighting accounts for the ways in which the relative hearing sensitivity of marine mammal species affects the hearing of sounds at different frequencies. It is an auditory weighting function similar to the C weighting systems used for humans.

1/3rd octave bands (Hz) are divisions of sound frequencies into bands that reflect the size of auditory filters (critical bands) in the hearing of most land mammals and birds. An octave represents a doubling in frequency. The European Union Marine Strategy Framework Directive on Underwater Noise has based its targets for Good Environmental Status on the 1/3 octave bands that have central frequencies at 63 and 125 Hz. The centre frequencies are the geometric means of the frequencies within bands. While 1/3 octave band are the most commonly reported noise metric, octave bands, and other fractual bands such as 1/6 and 1/12 octave bands are also used to describe sound impact in marine mammals, particularly toothed whales.. Table 2 shows sample octave and 1/3 octave bands and their centre frequencies.

Table 2: A sample of octave and 1/3 octave band centre frequencies and band limits. In general, the lower the frequency, the further the sound will travel, in both air and water, although this is not necessarily true in shallow water.

Frequency (Hz))					
Octave Band			1/3 Octave Band		
Lower Band Limit (Hz)	Centre Frequency (Hz)	Upper Band (Hz)	Lower Band Limit (Hz)	Centre Frequency (Hz)	Upper Band (Hz)
11	16	22	14.1	16	17.8
			17.8	20	22.4
			22.4	25	28.2
22	31.5	44	28.2	31.5	35.5
			35.5	40	44.7
			44.7	50	56.2
44	63	88	56.2	63*	70.8
			70.8	80	89.1
			89.1	100	112
88	125	177	112	125*	141
			141	160	178
			178	200	224
177	250	355	224	250	282
			282	315	355
			355	400	447

* The EU Marine Strategy Framework Directive on Noise[1] has selected the 63 and 125 Hz 1/3 octave bands as the focus of their long term underwater noise monitoring program, because shipping noise is assumed to have the highest sound pressure levels in those two bands This metric, however, does not take variation of underwater sound propagation in different environments into account which can lead to changes in the the perception of loudness of other bands.

Percentiles are useful when measured sounds change with time- for bioacousticians, the *nth* percentile gives the level below which the signal falls within *n*% of the time. For engineers, the *nth* percentile gives the level above which the signal falls within *n*% of the time.

Power Spectral Density (PSD) units are dB re 1µPa^2/Hz and show the power of a sound distributed within 1 Hz frequency bins. The figure below is from Veirs et al. (2016) and shows sound source levels in PSD. PSD is used to compare sound sources and acoustic environments. PSD units, however, do not reflect how a sound is perceived by an animal or human.

[1] http://ec.europa.eu/environment/marine/pdf/MSFD_reportTSG_Noise.pdf-

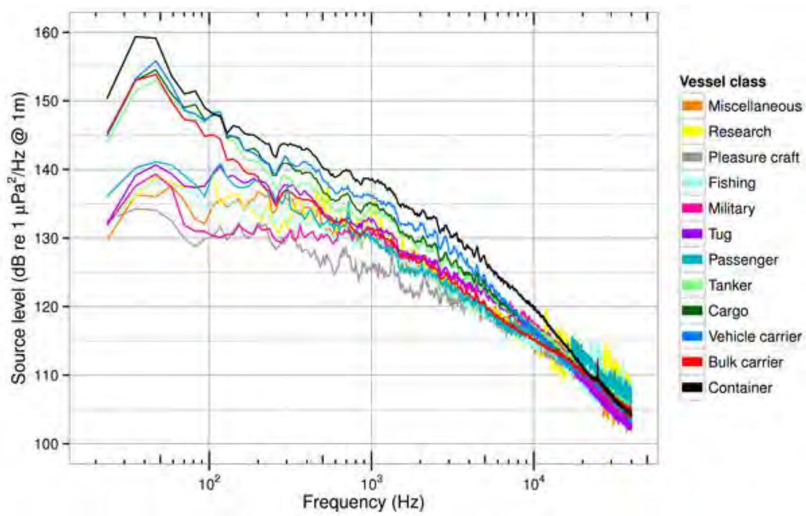


Figure 1. Power spectral densities of different vessel classes. From Veirs et al. (2016)

Root Mean Square (RMS) units are dB re 1 µPa, or sound pressure levels, and describe how sound pressure is averaged over a specified period of time, and is a useful metric for continuous sound, but must be interpreted cautiously if it issued to describe a pulsed or acute sound.

Sound exposure levels (SEL, also known as Leq) units are dB re 1 µPa^2/s and are the measure of the total energy of a signal over a specified time, which at minimum is usually 1 second. SELs need to be specified over the time which the sound exposure is summed.

Sound pressure levels (SPL), also known as RMS SPL units are dB re 1 µPa- describe the square root sound pressure over a specific period of time. The time period is variable and should be specified, but is typically 1 second.

Appendix 2: Audiograms, weighting functions and the assessment of noise impacts.

An audiogram is a curve showing sound pressure level variation over the range of frequencies detected by an animal in hearing tests. The curve represents the absolute hearing sensitivity per sound frequency of each individual tested. The underlying general assumption of using audiograms to assess noise impact is that if a sound cannot be perceived by the animal, the impact of that sound is negligible. In order to use audiogram weighting in noise impact assessments, one has to assume low uncertainty with regard to a) whether the available audiogram data are representative of best hearing of the target species, and b) whether perception is captured completely by an audiogram. Hearing sensitivity is tested using behavioural responses or Auditory Brain Stem Responses (ABR) to the playback of tones. A description of the methods can be found in the studies referenced in this section (e.g. Szymanski et al. 1999, Branstetter et al. 2017). In general, behavioural response are considered to provide more accurate test results for frequencies under 3 kHz.

The best audiograms can be established in species for which multiple tests have been performed with individuals from different age and sex classes and with different noise exposure histories, which includes humans, bottlenose dolphins and beluga whales. The number of individual audiograms available for most cetacean species is low. Eleven killer whales have been tested in three different studies (Hall and Johnson 1972, Srymanski et al. 1999, Branstetter et a.l 2017) but only nine were considered usable because two animals had severe hearing loss in some frequency bands not consistent with age related hearing loss (Branstetter et al. 2017). There is a great deal of variability among these nine animals which cannot be explained by single or multiple influences, such as age related hearing loss, or age and sex related hearing. (Branstetter et al. 2017).

Audiogram-weighted noise levels to assess behavioural and health impact of noise on animals have also been proposed, most prominently by Nedwell et al. (2007), although there are some concerns with this approach. This includes the perception of sound levels in frequencies that may disturb animals does not always align with hearing sensitivities. That means even if the tested hearing sensitivity is low for a certain frequency, disturbance in terms of annoyance, behaviour change and health effects can still occur. For example, the low frequency sounds of wind turbines and their effects on humans has been the subject of intense investigation and although the frequencies in question are below the typical hearing range of humans, there are complaints by people living near wind turbines. It has been suggested that the outer hair cells, which are not thought to play a huge role in the detection of sound frequency but respond to mechanical stimulation such as vibrations, also respond well to low frequencies and may be responsible for high sensitivity to low frequencies in some individuals (Salt and Hullar 2010).

Resident killer whales may also respond behaviourally to frequencies for which the whales have low sensitivity. Holt et al. (2009) demonstrated that killer whales increase the call source levels by 1 dB when the background broadband noise increased by 1 dB. Since the background sound levels were primarily influenced by ship noise, which has most of its sound energy below 1 kHz, the whales may have responded behaviourally to a sound level increase in frequencies that they do not hear well. A broadband metric that includes pressure levels at frequencies that may not be perceived well by the whales, but where most of the noise occurs, can still be appropriate for behavioural impact and health impact assessments. For the purpose of assessing noise impacts, the participants achieved consensus on measuring change over time (the delta) rather than on describing absolute threshold values and fully acknowledge that current noise levels are likely too high to ensure SRKW recovery, and that the focus must be on significantly reducing them.

Appendix 3: Participant List

- Lance Barrett-Lennard (Coastal Ocean Research Institute, Vancouver)
- Ross Chapman (University of Victoria)
- Tom Dakin (Ocean Networks Canada, Victoria)
- David Hannay (JASCO Applied Sciences, Victoria)
- Kathy Heise (Coastal Ocean Research Institute, Vancouver)
- Nathan Merchant (Centre for Environment, Fisheries and Aquaculture Science, UK)
- James Pilkington (Fisheries and Oceans Canada, Nanaimo)
- Sheila Thornton (Fisheries and Canada, Vancouver)
- Dom Tollit (SMRU Consulting, Vancouver)
- Svein Vagle (Fisheries and Oceans Canada, Sidney)
- Val Veirs (Salish Sea Hydrophone Network, San Juan Island, WA)
- Valeria Vergara (CORI, Vancouver)
- Jason Wood (SMRU Consulting, San Juan Island, WA)
- Brianna Wright (Fisheries and Oceans Canada, Nanaimo)
- Harald Yurk (JASCO Applied Sciences, Vancouver)

Workshop Coordinator and Rapporteur

- Kathy Heise

Facilitator

- Lance Barrett-Lennard

Conveners

- Andrew Day (Coastal Ocean Research Institute)
- Patrice Simon (Fisheries and Oceans Canada)
- Michelle Sanders (Transport Canada)

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Appendix 4: Workshop Agenda

Monday May 1, 2017

8:30-9:10 am Welcome, Introductions, Mission and Context

8:30 am Andrew Day (Coastal Ocean Research Institute) – Welcome & Mission

8:35 am Introductions

8:45 am Lance Barrett-Lennard (Coastal Ocean Research Institute- CORI) – Workshop Context

8:55 am Patrice Simone (Fisheries and Oceans Canada) – Department of Fisheries and Oceans commitment to underwater noise reductions for southern resident killer whales

9:00 am Michelle Sanders- (Transport Canada) - Transport Canada's commitment to underwater noise reductions for southern resident killer whales

9:00-9:10 am Questions and Discussion on the Mission and Context

9:10-11:40 am Knowledge Sharing

9:10-9:30 am James Pilkington (Fisheries and Oceans Canada) - An overview of acoustic research on SRKW obtained through passive acoustic monitoring

9:30-9:50 am Brianna Wright (Fisheries and Oceans Canada) - An overview of the results of D-Tag foraging studies on killer whales

9:50-10:10 am Harald Yurk (JASCO Applied Sciences) - Current noise metrics used in environmental assessments and noise mitigation in Canada

10:10 am Break

10:30-10:50 am Jason Wood (SMRU Consulting)/Val Veirs (Salish Sea Hydrophone Network) – An overview of the Salish Sea Hydrophone Network, and the results of ship signature studies

10:50-11:10 am Jason Wood/ Dom Tollit (SMRU Consulting) - Insights into underwater noise impacts on southern resident killer whales gained from environmental impact assessments

11:10-11:20 am Valeria Vergara (CORI) - Impairment of acoustic behavior of beluga cow/calf pairs: the consequences of underwater noise

11:20-11:40 am Nathan Merchant (Centre for Environment, Fisheries and Aquaculture Science-UK, CEFAS) - Acoustic soundscape characterization: a European perspective

11:40 am -12:10 pm Discussion: Key Questions

The group discussed whether questions posed in the remainder of the agenda adequately capture key components of a framework of impact-focused metrics for underwater noise.

12:10-1:00 pm Lunch

1:00- 2:15 pm Question 1:

- *How should chronic and acute noise sources be accounted for when characterising underwater soundscapes and establishing trends of significance to killer whales? And in the case of chronic noise, over what time intervals should sound exposure levels be measured to detect meaningful trends (eg hourly, daily, seasonally, etc).*

2:15—2:30 pm Break

2:30 – 5:00 pm Question 2

- *How can we best identify impact trade-offs between noise duration and intensity? Assuming a given noise exposure level over the course of day, under what conditions, if any, are quiet periods punctuated by high noise episodes less impactful than constant noise at lower levels?*

3:30—3:45 pm Break

3:45-5:00 pm Question 2 continued….

5:00 pm Adjourn

Tuesday May 2, 2017

8:30-10:50 am Question 3:

- *How should killer whale audiograms and vocalization frequency weightings be incorporated into underwater noise metrics?*

10:50 am BREAK – coffee, tea and light snacks to be provided

11:15 am-12:00 pm Check-In With Group

12:00-1:00 pm Lunch

1:00 pm-2:30 pm Question 4:

- *Is communication and echolocation masking the main source of impacts of noise on resident killer whales, or should/can we consider other impacts?*

3:30 pm Break

3:45 -5:00 pm Question 5:

- *What are the noise levels below which impacts are negligible?* If so, would special monitoring measures and/or metrics be useful for managing acoustic sanctuaries with negligible noise impacts?

Wednesday May 3, 2017

8:30-10:30 am

Address issues and questions "parked" or not fully answered during the discussion of the previous two days.

10:30 am Break

10:45 am -12:30 pm Review of Preliminary Consensus

Review the preliminary consensuses recommendations and made modifications as needed There was an opportunity for DFO/TC to comment and reflect on what information should be synthesized to best accommodate the federal government's commitment to underwater noise reduction targets

12:30 -1:30 pm Lunch

1:30- 2:15 pm Next Steps

Articulate a metrics framework and outline plans and assignments for a workshop report and publications.

2:15 pm Workshop concludes

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Appendix 5: Presentation Summaries

Patrice Simon (DFO) and Michelle Sanders (TC) opened the meeting after Andrew Day welcomed the participants. They noted that the federal government is committing to do more than mitigate underwater noise for the benefit of southern resident killer whales, and that science will inform policy. The government is committed to mitigating the three key threats that have been identified for this population- disturbance (both physical and acoustic), contaminants and prey availability. Targets are driven by the government's approval of the TMX pipeline.

Oral presentations:

1. James Pilkington: Outside the core: insights into SRKW seasonal distribution from PAM efforts outside of designated critical habitat

It is important that we know where whales are when they are NOT in SRKW critical habitat- and when they are in critical habitat, but rarely. These locations could be biologically important, despite their rarity. Metrics should not ignore this possibility. Swiftsure Bank, Cape Flattery and the Columbia River are important areas outside of current Critical Habitat.

It is also important to note that visual detections of SRKW occur in areas where there are no acoustic detections (such as at Orcalab)- acoustics are very useful, but do not define important areas. Swiftsure Bank is an important area to both SRKW and NRKW, despite its proximity to shipping lanes. Mitigation should consider conversations around moving the shipping lanes to quieten Swiftsure Bank.

2. Brianna Wright: D-tags as a tool for behavioural studies of resident killer whales

D-tags have shown that killer whales dive deep to get chinook, and that chinook are often at about 100 m when the whales find them, and dive to deeper depths to escape the whales (200-300 m).

The whales' click rates and the proportion of time they spend echolocating is higher during prey capture than afterwards.

3. Harald Yurk: Not all acoustic metrics measure impact equally

Periods of time when whales are silent or quiet may be more biologically important than those when they are vocalizing. These are considered non-acoustic metrics. What are the night time consequences of noise for whales? In humans they are significant, and they may be for whales as well. Killer whales have a 20 dB critical ratio, with their highest sensitivity in 1/3 octave bands. He also believes that using behavioural responses as a metric for impacts of noise can be challenging and will submit an appendix for the final report specifically on this topic.

4. Jason Wood and Val Veirs: Salish Sea hydrophone network

To quieten critical habitat, Jason and Val recommend the slowing of vessels to 11.8 knots, under the assumption that there is a 1 dB decrease in noise with every knot in speed reduction. Preliminary indications are that the use of convoys may help maintain quiet times in a way that benefits the whales.

5. Jason Wood and Dom Tollit: Noise metrics workshop and ongoing work at Lime Kiln

There is a great deal of variation among the acoustic signatures of vessels. The use of one minute intervals to quantify noise is important and lost foraging time is an extremely important metric when looking at the impacts of noise on SRKW. Future shipping activities will increase the predicted 'baseline' level of acoustic disturbance, particularly in Haro Strait. AIS vessels contribute 57-64% of the total lost foraging time for killer whales, but whale watching also adds significantly to acoustic masking (about 1/3rd). There is an urgent need to improve SRKW critical habitat, and this should be done by focusing on the delta, rather than frequency weighting and behavioural response curves. Briefly described the upcoming speed reduction trials in Haro Strait later this summer.

6. Valeria Vergara: Impairment of acoustic behavior of beluga cow/calf pairs: the consequences of underwater noise

Valeria highlighted the importance of communication between cows and their calves, particularly as calf vocalizations are quieter than those of adults, and thus they are more prone to the negative consequences of masking, to the point that they may lose contact with their mothers. The higher frequency components of calf calls has less energy than lower frequencies.

7. Nathan Merchant: Acoustic soundscape characterization: a European perspective

Nathan provided a brief overview of the European Marine Strategy Framework Directive (EU MSFD). Its focus has been on SPL rather than on the impacts of noise. Nathan has found that using SPL as a metric means that it can take decades to detect trends in noise levels (Merchant et al. 2016). He supports looking at percentiles rather than absolute values.

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Appendix E

The Government of Canada's paper *Reducing underwater noise utilizing ship design and operational measures,* presented to the Marine Environment Protection Committee of the International Maritime Organization in February 2018

MARINE ENVIRONMENT PROTECTION COMMITTEE
72nd session
Agenda item 16

MEPC 72/16/5
2 February 2018
Original: ENGLISH

ANY OTHER BUSINESS

Reducing underwater noise utilizing ship design and operational measures

Submitted by Canada

SUMMARY

Executive summary:	This document seeks to enhance understanding of ship noise and measures to mitigate it, by sharing information from three recent case studies. This document builds on previous work of the Committee and work of Member States
Strategic Direction, if applicable:	4
Output:	No related provisions
Action to be taken:	Paragraph 23
Related documents:	MEPC 58/19; MEPC 66/17, MEPC 66/21; MEPC 68/INF.26 and MEPC 71/16 and MEPC.1/Circ.833

Background

1 Scientific evidence continues to support previous findings that underwater noise is a stressor for many marine species, especially for those mammals that rely on sound as a means of carrying out key life functions.[1] While the majority of underwater noise from large commercial ships is generated at frequencies below 1,000 Hz, these ships emit noise across a wide spectrum of frequencies, and therefore can impact the life functions of a variety of aquatic animal species, including whale and fish species. The level of ambient noise in a specific area is greatly influenced by anthropogenic activity, including ship traffic. The noise contribution from shipping is likely to continue rising, including in sensitive habitats, as global ship traffic increases.

[1] See Redfern, J.V., Hatch, L.T., Caldow, C., et al. (2017) Assessing the risk of chronic shipping noise to baleen whales off Southern California, USA. *Endangered Species Research* Vol 32, ppl 153-167.

2 In addition to initiatives being undertaken within individual Member States, the issue of underwater noise is increasingly recognized on the international agenda. It has been on the agenda at various multilateral meetings, including the International Maritime Organization (IMO), the Convention on Biological Diversity, the OSPAR Commission[2], the Arctic Council, the International Whaling Commission, the Baltic Marine Environment Protection Committee (HELCOM), and the United Nations.

3 Canada reaffirms its support for IMO as the forum for discussion on underwater noise from commercial traffic, while recognizing that other international bodies serve to advance global awareness and action. Canada acknowledges the efforts of this Committee in addressing underwater noise through the *Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life* (MEPC.1/Circ.833) (the Guidelines). It is Canada's view that mitigation measures can generally be classified into two broad categories:

.1 routing and operations: applies to those mitigation measures directly affecting the movement, location, or running of the ship. They are normally variable and can be changed relatively quickly in response to local conditions. These measures include, for example, areas to avoid, reducing speed, or limiting the use of unnecessary equipment; and

.2 ship design and maintenance: applies to those mitigation measures directly affecting the physical structure of a ship. They are normally planned and more difficult to change quickly. They are likely to be implemented during the design stage for new ships or as part of a planned dry dock for those already existing. These measures include propeller optimization and polishing, hulls that minimize drag and uneven wakes, and resilient mounting of machinery.

4 Routing and operations offer important mitigation options that can provide an immediate acoustic benefit but that may result in higher operating costs. Therefore, ship design is likely to provide the best long-term solutions to the challenge of underwater noise but can only be introduced gradually as new ships are built and existing ships refitted. It is important to underscore that mitigation measures will have a different impact on different ships and different classes of ships. As such, not all measures are applicable to all ships.

Current status

5 Canada is actively looking at ways to reduce underwater noise from ships in its coastal waters. Recent work in this regard includes a synthesis report on anthropogenic underwater noise (available by emailing: TDCCDT@tc.gc.ca), support for work to standardize noise impact measurements, workshops and meetings with experts on noise metrics and the scientific underpinning of noise mitigation measures, advanced modelling of operational mitigation measures, and innovative approaches for monitoring noise from ships and detecting marine mammals.

6 The marine industry in Canada is taking a leading role in the piloting of ship noise mitigation measures. Two particularly important studies were undertaken in 2017 that assessed the impact of key operational measures on underwater noise from different ships.

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2 The OSPAR Commission ensures the 16 Contracting Parties to the Convention for the Protection of the Marine Environment of the North-East Atlantic are able to work together in the North-East Atlantic and to deliver on their collective commitments.

Both of these studies were conducted in the Salish Sea region, which is home to the Port of Vancouver, Canada's largest port, and to the endangered Southern Resident Killer Whale (SRKW), for which underwater noise has been identified as one of three main threats to survival of the population. One study examined the acoustic benefit achieved by slowing ships down through an important SRKW feeding area, while the second looked at underwater noise profiles for ferries under different operating scenarios and for different fuel types i.e. liquefied natural gas (LNG).

7 In the first study, piloted commercial ships transiting a 16 nautical mile corridor in Haro Strait in the Salish Sea, were requested to voluntarily reduce their speed to 11 knots (through the water), between 7 August and 6 October, 2017. This voluntary ship slowdown trial was led by the Vancouver Fraser Port Authority's Enhancing Cetacean Habitat and Observation (ECHO) Programme and had the broad support of shipping associations, commercial shipowners and operators, marine pilots, as well as other ECHO Programme collaborators including government departments, conservation and environmental groups and several First Nations.

8 Important questions that were to be answered through this study included:

.1 How does reduced speed change the underwater noise generated by specific ships (ship source level) and by class of ships?

.2 How does reduced speed change the total underwater ambient noise received at specific locations within the critical habitat of the Southern Resident Killer Whale?

.3 What are the predicted resultant effects on killer whale behaviour and foraging given the changes in noise as answered by questions .1 and .2?

9 Hydrophones were placed in the slowdown zone to systematically measure the change in underwater source radiated noise levels (RNL) resulting from slower ship speeds. At the time of submission of this document, hydrophone recordings were still being cross-referenced with AIS data and undergoing further fine-scale multivariate analysis to draw conclusions about the overall effects of the slowdown and its predicted impact on SRKW behaviour, however, some positive preliminary results have already been released.

10 Approximately 61% of piloted ships participated in the trial. Containerships reduced speed by approximately seven knots during the trial, which resulted in an average ship source noise reduction of nine decibels (dB), while bulk cargo ships reduced speed by approximately two knots and experienced an average ship RNL reduction of five dB. Comparison of ambient noise data for pre-trial control versus trial months, and corrected for ship presence, wind and current, indicated a median reduction in the 10 Hz – 100 kHz frequency range of 2.5 dB re 1 µPa received at a specific location, roughly equivalent to a 44% reduction in sound intensity. Preliminary results also show that slowing ships down means that they are generating less noise but are in a given area for a longer period of time. This in turn means that the quieter times experienced between ship transits under normal ship speed conditions are reduced in duration and are less quiet during slowdown conditions. These preliminary results are available here: https://www.portvancouver.com/wp-content/uploads/2017/05/2017-11-09-Preliminary-results-of-slowdown-trial-Summary.pdf. Final study conclusions will only be available once the data has been fully analyzed.

11 The second study was conducted by BC Ferries, which is a regulated private Canadian company that operates one of the world's largest ferry services. In support of its commitment to the ECHO program and to environmental stewardship, it commissioned JASCO

Applied Sciences to accurately measure noise profiles for key parts of its fleet, including recently acquired LNG-fueled ferries. The selected ferries were each measured in five operating scenarios in order to determine the effects of speed and other propulsion system settings on the ships' underwater noise emissions. This information can lead to the optimization of the settings to produce quiet ship operations.

12 Results from the testing reaffirmed that the same operational mitigation measures, such as speed reduction, can have different results across a variety of ship types, however, trends can be observed.

13 Generally, ferries 10 years of age or less, including both the LNG and non-LNG fueled ferries, were the quietest in the study when operating at service speed. The RNL was higher at reduced speeds for ships with controllable pitch propellers rotating at constant speed. Frequency spectrum analysis showed that ships of identical construction had very similar noise emission characteristics, both in level and spectral shape. At service speed across all tested ships, the emitted noise with frequency above 500 Hz was almost the same sound level despite significant variations in ferry size, power, age and configuration.

14 The more than 500 measured transits of eight ferries while in route service required detailed planning, communications and real time feedback between ship and shore to acquire the high quality ANSI Grade C source RNL. The initial conclusions from this work are that:

.1 an overall RNL of 185 dB in the frequency range 1 Hz – 64 kHz is a typical value for ferries that are designed for cost effective short sea operation (multiple daily crossings of less than two hours);

.2 although the speed-sound relationship is variable for different ferry types, reduced speed will increase noise for some ferries and thus should be applied only as mitigation for marine mammal strike risk, unless the ferry has a measured RNL reduction with speed reduction;

.3 spectral analysis may prove to be a useful post-construction or maintenance methodology to identify ship specific sources of noise peaks; and

.4 more design guidance should be developed for ferries, especially for noise mitigation above the 500 Hz frequency range, where there is minimal ship to ship difference in averaged frequency dependent RNL values.

15 Canada is also encouraged by the recent results from testing delivered jointly by the container shipping company Maersk and the Marine Physical Laboratory at the Scripps Institution of Oceanography. A hydrophone in the Santa Barbara Channel shipping lane off the coast of California has been monitored by Scripps since 2008. The device is used to make opportunistic recordings of ship transits, which are then linked to AIS in order to produce a noise profile specific to a ship and further develop the general catalogue of noise profiles by ship type.

16 Maersk has invested in ship design retrofits for 11 of its new panamax-size container ships for the purpose of improving fuel economy. Many of the retrofits were undertaken on the same areas of the ship known to be prominent sources of underwater noise, namely the propeller and hull. More specifically, the retrofits included a modification of the bulbous bow to reduce drag, a new propeller with four fins, and propeller boss cap fins to reduce cavitation.

17 The Scripps-monitored hydrophone was able to capture sufficient pre- and post-retrofit data for five of the Maersk container ships. The analysis of the data found that ship-source noise levels for the same ships after being retrofitted were typically six dB lower in the low frequency-band (8 – 100 Hz) and eight dB lower in the high frequency-band (100-1000 Hz). These significant noise reductions have been observed at lower operational speeds (<16 knots) and are largely attributed to these retrofits. The evidence suggests that widespread adoption of these mitigation measures by marine shipping has the potential to reduce noise, ocean basin wide.

18 The Maersk retrofits led to a 10 per cent improvement in fuel efficiency per containership, demonstrating the co-benefits of undertaking such changes. This improved efficiency supports air emissions reduction targets, including greenhouse gas emissions, and reduces operating costs. It is increasingly evident that, in general terms, optimal ship designs and operations can deliver a dual benefit of improved fuel efficiency and reduced environmental impact.

19 Importantly, these three studies are examples of how government, the private sector, and non-governmental organizations can work collaboratively to identify and implement innovative solutions that both benefit the private sector and help governments meet our collective environmental objectives[3]. In doing so, risk is reduced, resources are maximized, and positive relationships between all parties are fostered.

Future Work

20 Canada remains interested in advancing national and international scientific research and actions that can lead to underwater noise reductions through ship design and operations. To help advance this work, Canada is currently co-leading the development of a state of knowledge report on underwater noise in the Arctic through the Protection of the Arctic Marine Environment (PAME) working group of the Arctic Council. Canada also encourages Member States to take advantage of existing bilateral, regional and international opportunities to discuss anthropogenic underwater noise, including at the United Nations' Informal Consultative Process on Oceans and the Law of the Sea in June 2018.

21 Despite advances in the understanding of underwater noise and how the design and operation of a ship can contribute to it, knowledge gaps remain in our collective understanding of underwater noise from ships and how to effectively reduce or mitigate it. This challenge is made more complex by the various sources of noise in the marine environment and the wide variety of ship types, sizes, speeds and operational characteristics. Nevertheless, these gaps can be narrowed through research such as examining the noise benefits delivered by specific retrofits, including the ship characteristics that optimize its adoption, or undertaking a detailed examination of the relationship between ship noise and speed.

22 To help fill these gaps in knowledge and solutions, Canada will be seeking an output for this Committee at a later meeting that returns underwater noise to its agenda and which considers economically feasible actions that build on the Guidelines. At this time, Canada welcomes comments from Member States on this future request and invites Member States to collaborate with Canada in the development of this submission.

[3] Member States interested in learning more about Canada's research efforts on underwater noise from ships, or that are interested in collaborating on new projects are encouraged to send an email to Transport Canada's Mrs. Michelle Sanders at: <email address removed> Additional information and the final results of the Haro Strait ship slowdown trial are available by contacting Ms. Orla Robinson of Vancouver Fraser Port Authority at: <email address removed> Enquiries relating to the BC Ferries fleet testing can be sent to Mr. Greg Peterson of BC Ferries at: <email address removed> An overview of the Maersk retrofits and the Scripps findings are available by contacting Dr. Martin Gassmann of the Scripps Institution of Oceanography at: <email address removed>

Action requested of the Committee

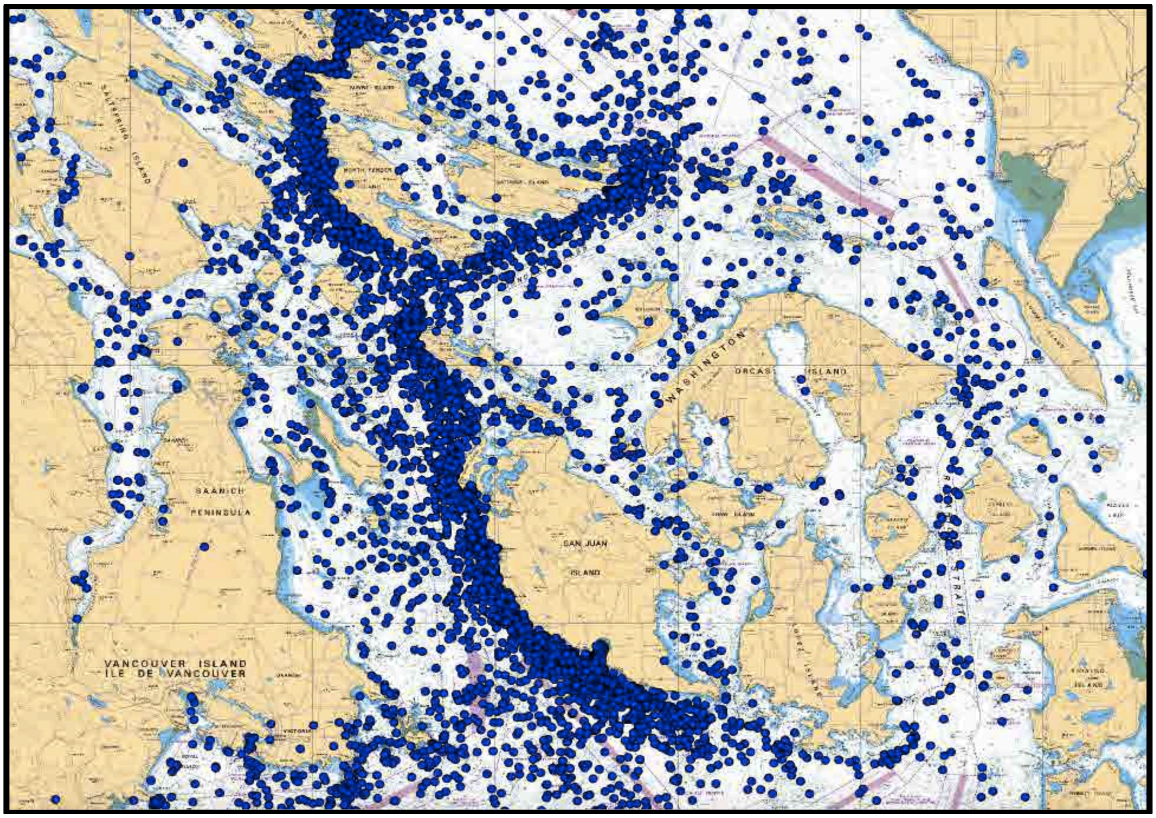
23 The Committee is invited to note the information in this document and take action as appropriate.

Appendix F

Greenwood Maritime Solutions Ltd.’s April 2018 report *Ship Noise Mitigation Risk Assessment*, commissioned by TC

Transports Canada Transport Canada

Ship Noise Mitigation Risk Assessment



Prepared for Transport Canada

This report reports on a high-level Risk Assessment of various measures to reduce ship-generated noise in the Salish Sea to mitigate impacts on Southern Resident Killer Whale Populations.

Prepared by Nigel Greenwood, MM, FRIN, FNI
Greenwood Maritime Solutions Ltd.

28 March 2018

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GREENWOOD MARITIME

Ship Noise Mitigation Risk Assessment

GMSL Report 02/2018
Version 1.3
19 April 2018

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TABLE OF CONTENTS

1. INTRODUCTION

1.1 Background

Many recent studies have highlighted the declining populations of Orcas in the Salish Sea. Both the Northeast Pacific Transient Killer Whales (NPTKW) and the Southern Resident Killer Whales (SRKW) are at risk, being defined as Threatened or Endangered in accordance with Canada Species at Risk Act.[1] One of the key factors thought to be impacting the foraging and reproductive habits of these marine mammals is the increasing volume, size and speed of shipping in the Salish Sea. Apart from the danger of physical interaction in the form of ship-whale strikes, the propagation of broadband noise from ships' engines, propellers and hull flow noise is believed to be disorienting and disrupting in areas of seasonal or habitual foraging. Accordingly, several initiatives have been launched in in recent years to identify ways in which ship-noise may be minimized.

One of the key initiatives to reduce ship-generated noise in the Salish Sea is a project of the Vancouver-Fraser Port Authority (VFPA) aimed at understanding and managing the impacts of shipping on at-risk whales in southern BC. The Enhancing Cetacean Habitat and Observation (ECHO) Program was stood up in 2014 and from 2016 has included input from a Vessel Operators Committee.[2] ECHO has undertaken a number of initiatives to examine the prospects of mitigating ship-noise. These have included studies to try to quantify the beneficial effects of ship-quieting through construction incentives, speed reductions and lateral displacement of traffic. JASCO Applied Sciences Ltd conducted a study in 2017 to identify regional noise contributors and characterize the overall underwater sound environment from traffic studies and related hydrophone records. This study concluded that, while small vessel traffic could not be quantified reliably, the major source of noise in Haro Strait (a key area of concern) was largely attributable to deep-sea shipping traffic.[3] Accordingly, VFPA conducted a voluntary vessel slow-down trial August-October 2017 to determine the level of noise reduction resulting from a transit speed of 11 knots (through the water).[4]

The Department of Fisheries and Oceans (DFO) also carried out an evaluation of the potential effectiveness of a number of measures to reduce ship noise.[5] This study was

[1] http://www.dfo-mpo.gc.ca/species-especes/profiles-profils/killerWhalesouth-PAC-NE-epaulardsud-eng.html, accessed 9 March 2018; http://laws-lois.justice.gc.ca/eng/acts/s-15.3/, accessed 9 March 2018
[2] VFPA, ECHO Program Annual Report 2016, https://www.portvancouver.com/wp-content/uploads/2017/01/ECHO-Program-Annual-Report-2016-FINAL.pdf, accessed 9 March 2018
[3] JASCO, Regional Ocean Noise Contributors Analysis, 2017, https://www.portvancouver.com/wp-content/uploads/2017/01/Regional-Ocean-Noise-Contributors.pdf, accessed 9 March 2017.
[4] VFPA, Vessel Slowdown Trial 2017, https://www.portvancouver.com/environment/water-land-wildlife/marine-mammals/echo-program/vessel-slowdown-trial-in-haro-strait/, accessed 9 March 2018
[5] DFO, Evaluation of Scientific Evidence to Inform the Probability of Effectiveness of Mitigation

completed through the Canadian Science Advisory Secretariat (CSAS) to provide science advice on the probability of effectiveness of both source-based and operations-based mitigation measures to reduce shipping noise. Among the possible measures proposed were:

- Vessel speed reductions
- Relocation of shipping lanes (lateral separation of source from SRKW)
- Changes in timing of traffic
- Changes in shipping practices
- Changes in ship design and retrofits to existing ships
- Redirection of traffic
- Changes in maintenance procedures (i.e.: hull cleaning)
- Operational responses to observed presence of SRKW (i.e.: slow-down and course alteration)
- Grouping vessels (i.e.: "convoy")
- Creating periods of quiescence (i.e.: alternating active/inactive shipping periods)

Subsequent to this DFO CSAS report, a workshop of the VFPA ECHO Program in October 2017 attempted to rank these options in terms of feasibility. Among the findings of this workshop was the need for greater clarity on the exact nature and proposed (practical) implementation of the measures and a more rigorous approach to analysis of the (navigational) safety risks inherent in the options.[6] Accordingly, Transport Canada asked for this Risk Assessment of the Ship Noise Mitigation Measures.

1.2 Task

The explicit task of this project is:

To assess and quantify the navigation safety risks, using the PRMM methodology, associated with introducing or implementing potential mitigation measures to address underwater vessel noise in the Salish Sea.[7]

1.3 Scope of Investigation

The project was initiated through discussions and Statement of Work development from August to December 2017, with contract award permitting commencement on 24 January 2018. With a remit to be complete before 31 March 2018, the scope of the project was very tightly focused on practical, navigational risks and not on economic, commercial or cultural impacts. The Risk Assessment acknowledged at the outset that a full range of impacts will have to be considered in due course, involving a wider representation of interested parties, and this was noted by Transport Canada as part of the following plan of action. For this project, however, the aim was to use the PRMM

Measure in Reducing Shipping-Related Noise Levels Received by Southern Resident Killer Whales, Science Advisory Report 2017/041, http://www.dfo-mpo.gc.ca/csas-sccs/Publications/SAR-AS/2017/2017_041-eng.html, accessed 9 March 2018

[6] ECHO Program Workshop, letter to DG Environmental Policy, Science Branch, Transport Canada, 19 October 2017

[7] Transport Canada T8080-170444 SOW – PRMM Project, by email 22 Dec 2017

process to examine purely navigational risk factors to identify which of the measures, if any, might be implemented with sufficiently low risk to warrant further examination and further engagement with various groups, communities, experts and stakeholders.

1.4 Measures to be Examined

The Statement of Work defined the Measures to be examined in four broad categories. Following discussion at the Orientation Session and further specification by TC, the list was resolved to the following discrete Measures:

1. Lateral Displacement:
    a. Protected area E in Haro Str: This takes into account traffic displacement as a consequence of a Whale Protection Zone (WPZ) as proposed by the Orca Relief Citizens' Alliance on San Juan Island;[8]
    b. SC route west of Haro Str lane: This proposes a small-craft route North-South on the west side of Haro Strait to displace small vessels from the habitual SRKW foraging area close to San Juan Island;
    c. SOA - Haro Str One-way: This proposes a Special Operating Area extending from Turn Point south to Beaumont Shoal, with rules precluding meeting traffic in Haro Strait, with the result of allowing greater lateral displacement of shipping from the San Juan Island shore;
    d. SJDF - Shift outbound N of SB: This proposes moving the outbound traffic at the mouth of the Strait of Juan de Fuca to go north of Swiftsure Bank, thus avoiding small craft and fishing vessels on the Bank;
    e. SJDF - Shift all lanes further S of SB: This proposes to move the whole TSS at the entrance to the SJDF south to provide greater separation from the small craft on Swiftsure Bank;[9]
    f. Shift SJDF TSS off Sooke to south: This proposes a shift of the TSS (or at least the outbound lane) further to the south between Race Rocks and Sooke to provide greater lateral separation from SRKW in this area.

2. Quiescence:
    a. Quiet Periods: This proposes in Haro Strait to alternate active shipping periods with quiet periods, say on 4-hour blocks, to provide noise respite for SRKW. This would require timing of arrivals and departures to meet these windows, or otherwise to hold vessels on Constance Bank or Boundary Pass pending the transit periods;
    b. Schedule transits: This proposes to group vessels in Haro Strait ("convoy") so as to have fewer periods of noise. This would require protocols (schedules, maximum numbers, minimal distance separations, common speed) to effect this, as well as limiting waits pending "critical mass";
    c. Manage transits: This proposes managing vessel transits in Haro Strait

[8] Orca Relief Citizens' Alliance, Petition to Establish a Whale Protection Zone, November 2016, http://www.orcarelief.org/regulatory-request/, accessed 9 March 2018
[9] It was noted that this is a regressive step towards where the TSS was prior to 2006. See the Federal Register on TSS changes, https://www.federalregister.gov/documents/2010/11/19/2010-29165/traffic-separation-schemes-in-the-strait-of-juan-de-fuca-and-its-approaches-in-puget-sound-and-its, accessed 9 Mar 18

around SRKW presence. This would require a verifiable alerting scheme for SRKW presence and holding arrangements at Constance Bank inbound or in port/Boundary Pass for outbound ships. Some provision for maximal wait times would have to be established;

   d. Tidal transits: This proposes to route ships with the tidal currents. Some provisions would have to be determined for the periodic recurrence of diurnal tides (only one in/out transit period per day) and for slow traffic unable to complete the transit in one half tidal cycle;

3. Redirection
   a. Redirection through Rosario: This proposes to route all inbound traffic through Rosario Strait. This would require such traffic be streamed through Port Angeles for Puget Sound Pilots and BC Pilots be embarked before Roberts Bank;
   b. Conditional redirection to Rosario: This proposes a rerouting through Rosario Strait conditional on the presence of SRKW in Haro Strait. This would require some verifiable alerting scheme for SRKW presence and more complex arrangements of pilot embarkation;
   c. One-way Rosario-Haro (I/O): This proposes that traffic be routed counter-clockwise through Rosario-Haro Straits. This is similar to 3a above but would require outbound traffic from Anacortes and lower Rosario Strait to travel the long-way-round to exit via Haro Strait.

4. Speed Reduction
   a. Fixed SP Limit in Haro: This proposes a fixed maximal speed limit for all traffic in Haro Strait, in the order of 10-12 knots. Different restraints might have to be devised for smaller vessels;
   b. Circumstantial SP Limit in Haro (SRKW): This proposes to limit speed depending on the presence of SRKW in Haro Strait. This would require some verifiable alerting scheme for SRKW presence, or otherwise be dependent on vessel operator lookout and response;
   c. Conditional SP Limit in Haro (Vessels): This proposes some speed limit conditional on each vessel's acoustic profile, which would go in hand with incentives for ship quieting in construction;
   d. Circumstantial SP Limit in SJDF: This proposes a speed limitation dependent on the sighting of SRKW in SJDF.

1.5 Constraints/Restraints

To clarify the points made above and to limit discussion to relevant factors, the following Constraints and Restraints were developed in conjunction with TC and introduced to the participants at the Orientation Session 7 February 2018:

Constraints: This project ***is*** about:

- Hypothesizing in greater (operational) detail the proposed Measures
- Outlining the issues involved in implementing these Measures
- Determining the (operational) risk factors associated with the proposed Measures
- Determining if mitigations of such risk factors is required or possible (without eliminating benefits of the proposed Measures)

- Arriving at a qualitative Risk Assessment of implementing the proposed Measures

Restraints: This project ***is not*** about:

- Efficacy of the proposed Measures (science programmes are addressing this)
- Economic impact of potential Measures (subsequent TC initiatives will cover this)
- Collaborative mechanisms for addressing vessel traffic management (a separate TC project is addressing this)
- Consultation with interested coastal communities (future outreach and engagement will address this)

Great concern was expressed by some participants over the exclusion of coastal communities and diverse marine interest groups from the discussion, especially First Nations and Tribes on both sides of the border. The facilitators and TC project directors affirmed that this was not to discount the interests or perspective of potentially impacted communities but to focus the effort at this stage on the perspectives of those with deep nautical knowledge of the navigational challenges of major shipping in the study area. Furthermore, the output of the project is only to identify those potentially acceptable for further study and refinement, not to make a positive recommendation for implementation of any particular measure.

1.6 Qualifications of the Contractors

The lead author, RAdm Nigel Greenwood is a 37-year surface warfare officer of the Royal Canadian Navy (RCN), whose last jobs included responsibility for maritime defence of western Canada and search and rescue (SAR) for BC and the Yukon. He was a navigation specialist who conducted his naval pilotage training on the west coast and commanded a frigate in local waters for two years.

Captain William Devereaux is a 30-year veteran of the US Coast Guard, in which he held command of a cutter based in Alaska and also led the Puget Sound Vessel Traffic Services for three years. In this latter domain he has been intimately involved in the development of Standards of Care in traffic management and the negotiation of Traffic Separation Scheme changes.

Both RAdm Greenwood and Capt. Devereaux are qualified in Transport Canada's Pilotage Risk Management Methodology. They have recently collaborated in such projects as the Pacific Pilotage Authority's Pilotage Waivers Review.

2. METHODOLOGY

2.1 PRMM

This project was conducted in accordance with Transport Canada's Pilotage Risk Management Methodology.[10] This is a formulated approach to a workshop discussion of operational scenarios in a marine navigation setting. The process involves:

- Clarification of the purpose of the Risk Assessment (the "RA Question")
- Identification of risk scenarios
- Determination of contributory factors
- Determination of Probability and Consequence of various outcomes
- Calculation of Risk from Probability and Consequence
- Determination of possible risk mitigations
- Calculation of Residual Risk from mitigated Probability and Consequence
- Determination if the Residual Risk is acceptable

TP 13741E provides a standardized guidance table to Probability and Consequence levels across the domains of Human, Property, Vessels, Environmental and Reputation impacts. Each of these is defined in five broad levels, and RA team members are asked to use personal knowledge and professional judgment to determine what is the appropriate level (i.e. 1 to 5) of Probability and Consequence for each adverse outcome. Risk is calculated accordingly as Probability x Consequence to give a Risk figure out of 25. This is to be understood in this process as a relative, subjective assessment of risk for which the RA Team must determine if this is acceptable or not.

2.2 Orientation

An orientation session was conducted on 7 February 2018, two weeks after commencement of the project. Representation was requested from Government agencies, industry, and particularly pilotage authorities on both sides of the border. The intent of this session was to define the project, explain the process of the PRMM, and otherwise gather input to help situate the following work.

The table at Annex A indicates the participants in the RA. While every effort was made to ensure the participation at both the Orientation Session and the Risk Assessment Workshop, this was not possible for all attendees. The orientation session laid out the process and answered a number of questions, largely around issues defined by the Constraints and Restraints above.

2.3 Risk Assessment and Interviews

Following the Orientation, participants were sent a dropbox link on Monday 12 February, and subsequent emailings of the related files, giving access to the Orientation Brief, a

[10] TP 13741E (05/2010), PRMM handbook, http://publications.gc.ca/collections/collection_2010/tc/T29-70-2010-eng.pdf, accessed 9 March 2018

template Risk Assessment Table, and Instructions for Completion of the Risk Assessment. They were requested to complete the RA and return the table by 19 February in order to allow individual follow-up before the 1 March Risk Assessment Workshop.

The RA Template was returned by 13 participants, including the two facilitators and the TC Project Director. Six participants in the Orientation session declined to fill in the table on the basis of lack of specific nautical familiarity with the subject matter and geographical area. Of those who completed the RA, all were experienced mariners of different grades of command qualification, from Naval Command Qualification to Master Mariner to Senior Pilot. The average sea-time among this group was over 23 years, and familiarity with the Salish Sea was variously qualified but averaged “4” on a five point scale. The average time to complete the RA was 5.2 hours.

Follow-up interviews were conducted with 10 of the 13 respondents (i.e. excluding the consultants, all but one of the respondents) between 16 February and 27 February. The purpose of this interview was to collect the experiential data and to confirm or clarify responses. In some cases, the responses were inconsistent between Measures or between initial assessments and mitigated Probability/Consequence. Respondents were given the opportunity to explain their choices/assessments and to amend these if errors had been made. These interviews averaged between 30 and 60 minutes apiece.

Following the interviews, the results were combined to give a starting point for discussion at the RA Workshop on the 1st March. It should be noted that the figures were averaged to give a sense of the median position and the spread of opinion between the participants. What is presented as an average figure in the results is not a formal, statistical average of all participants for several reasons. First, it is firmly biased in the direction of the nautical practitioners’ views, as the other RA participants declined to venture an opinion on the specific risks. Secondly, the BCCP and PPA representatives elected to do the RA together, so their input was counted as one submission rather than four identical but independent submissions. And lastly, the full data sample was still very small and not appropriate for rigorous analysis. Nonetheless, the results very clearly indicated the direction of collective assessment, even if the variance between responses was very large in some instances.

2.4 Risk Assessment Workshop

The RA Workshop was conducted from 1000-1415 on 1 March at the offices of the Chamber of Shipping of BC. Fifteen participants attended the RA Workshop in person, while 3 others called-in. Of these 18, 14 (including the facilitators) had also attended the Orientation Session. Those present in person or attending by phone represented 11 of the RA responses.

The RA Workshop commenced with a Power-point Brief to refresh the purpose of the project and to share the results of the individual assessments. This brief is attached in Pdf form as Annex B, with amendments as suggested at the workshop.

3. DISCUSSION

Several items of information were presented at the workshop to answer questions raised in the Orientation Session and through individual interviews. These are covered below.

3.1 Presence of Killer Whales in the Salish Sea

A recurrent question was about the presence, location and prevalence of whales in the Salish Sea. It was related by several participants that whereas much concern had been raised about the SRKW in Haro Strait, the period of the VFPA's ECHO Program slow-down trial was notably light in SRKW presence. Doubt was expressed as to the driving imperative for mitigating measures.

Between the two sessions, the BC Cetaceans Sighting Network was approached for locating information on Killer Whales in the Salish Sea. This sighting data was provided with the caveat that this is raw sighting data and is not corrected for effort.[11] A plot of this data is included within Annex B. The data corrected for effort as in Figure 1 confirms that Haro Strait and Sooke are hot-spots of whale presence, although this plot does not as distinctly show that the presence is closely clustered to the San Juan Island west shore.

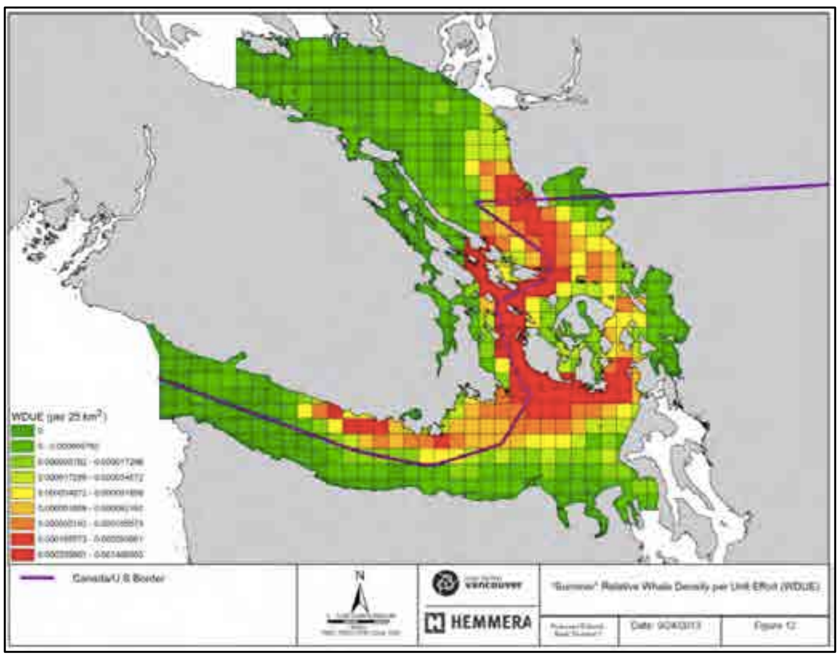

Figure 1. Summer Whale Density per Unit Effort (WDUE) in the Salish Sea[12]

The facilitators noted that the project is not tasked to verify the case for ship-noise mitigating measures, only to assess if they are acceptable from the standpoint of

[11] BC Cetaceans Sighting Network, http://wildwhales.org, data provided by email from Jessica Torode to Nigel Greenwood, 27 February 2018

[12] Courtesy of VFPA ECHO Program; SMRU Canada Ltd, Roberts Bank Terminal 2 Technical Data Report, Marine Mammal Habitat Use Studies, prepared for Port Metro Vancouver December 2014

navigational safety.

3.2 Traffic Patterns and Volume in the Salish Sea

The RA Team debated the volume and pattern of marine traffic in the Salish Sea. Of particular concern was the presence and tracks of pleasure craft, particularly in the summer months. A number of AIS heat-map plots were provided by the USCG, of which Figure 2 below is representative of the busiest months. The red parts of the plot indicate the areas of more frequent ferry traffic in the summer. These tracks are also augmented by heavier density of pleasure-craft, although many of these vessels will not be carrying or transmitting on AIS and so are not captured in this plot. Nonetheless, some of these tracks do include non-commercial traffic; those tracks from Sidney up through Dock Is, and the traffic along the west side of San Juan and Pender Islands are illustrative of this component of marine activity. Other than this, the separated lanes and nodes of the Traffic Separation Scheme are well-defined by this plot.

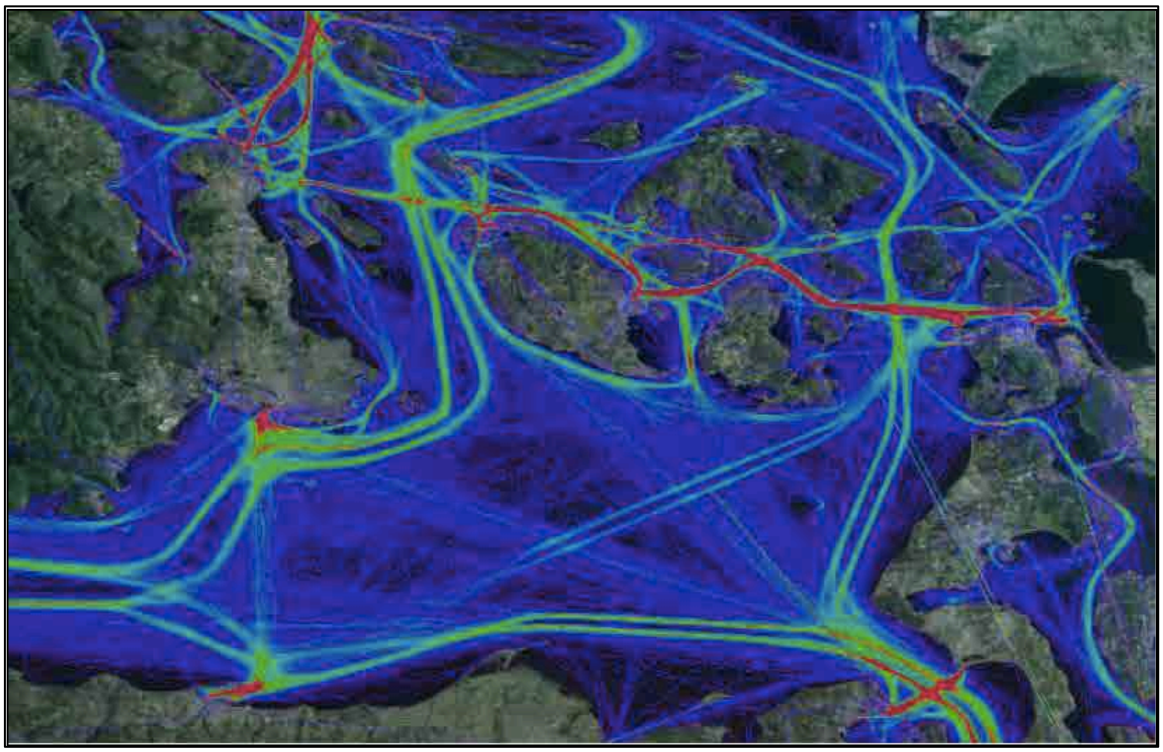

Figure 2. Traffic Patterns in the Salish Sea in August (USCG)[13]

There is no good estimate of pleasure craft density in Haro Strait. The JASCO report for VFPA on noise contributors in the Salish Sea[14] notes that the true volume of recreational vessels is greatly underestimated by the record of AIS tracks from such vessels, but that in two previous studies to physically confirm numbers in order to scale-up AIS densities

[13] Personal communication from Capt. L. Hail, USCG
[14] JASCO, Regional Ocean Noise Contributors Analysis, 2017, https://www.portvancouver.com/wp-content/uploads/2017/01/Regional-Ocean-Noise-Contributors.pdf, accessed 9 March 2017.

neither were satisfactory in establishing the overall size of the recreational fleet. The issue is of concern especially in Haro Strait, where one of the proposed measures (an exclusion zone along the San Juan Island shore) could force small traffic into closer proximity with deep-sea traffic. The facilitator's estimate of 25-30 recreational vessels at a time in Haro Strait was considered by more experienced members of the RA Team to be very low for good weather periods.

3.3 Marine Accident/Incident Statistics in the Salish Sea

Two lines of investigation were pursued to try to baseline marine incidents in the area under discussion. A database of all Marine Occurrences for the Pacific Region, 1997-2016, previously obtained from the Transportation Safety Board of Canada[15] was examined for incidents in the study area. A similar database of occurrences was obtained from the USCG covering the years 1992-2017.[16] These two data sets were not directly comparable as different accident/incident/occurrence definitions are used. However they do permit some generalizations of navigation safety experience in Haro and Rosario Straits.

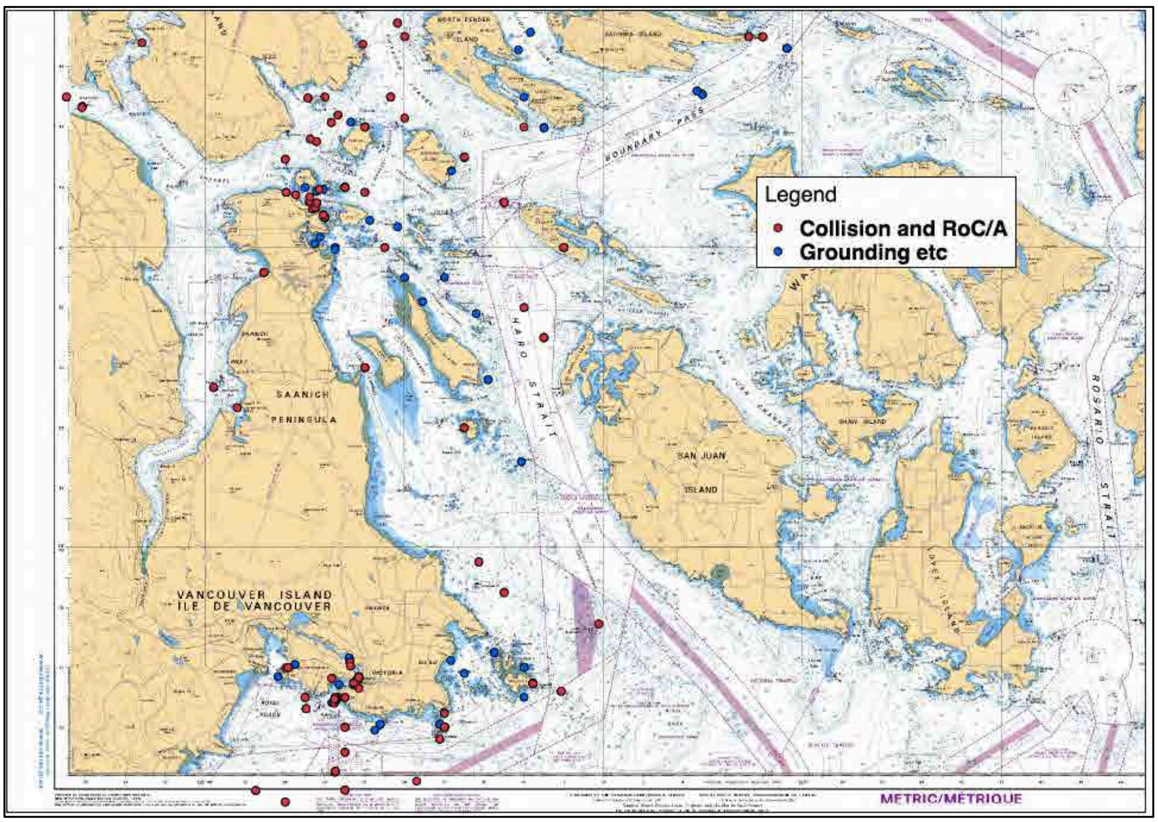

Figure 3. Plot of Collisions and Groundings (including Risks of Collisions, Grounding and Allisions) in Haro Strait, all vessels, 1997-2016

[15] TSB, Marine Occurrences 1997-2016, by personal communication from Olga Gordynska, 14 March 2017, for the Pacific Pilotage Authority Waivers Risk Assessment.
[16] Vessels Casualties list, USCG, personal communication from Capt Laird Hail via William Devereaux, 27 February 2018.

Both the Canadian and US datasets list a full range of occurrences from serious accidents to near-misses and temporary ship-board material or personnel casualties. Figure 3 shows the Canadian data in the Haro Strait – Boundary Pass area, limited to Collisions, Groundings and Strikings (Allisions) as well as reported risks of those outcomes. When filtered down to actual accidents in the principal study area (bounded by latitudes 48.33 to 48.83 degrees North and longitudes 117.05 to 123.33 degrees West), each list yields only 31-43 collisions, groundings and strikings over a 20-year period. This includes only 3 deep-sea ships on each side, with the majority of accidents being attributable to fishing vessels (15 and 8), tugs and tows (3 and 4), and passenger vessels (3 and 17). Examination of the Canadian accidents (not incidents, which cover near-misses) in Haro Strait itself reveals that none of these were deep-sea vessels in the last 20 years.

Canadian Marine Accidents in the Haro-Rosario Area 1997-2016																
Accident/ Year	1997	1998	1999	2000	2001	2002	2003	2004	2006	2007	2008	2009	2010	2014	2016	Grand Total
BOTTOM CONTACT				1		1									2	4
COLLISION														1		1
GROUNDING	1	1	2		2	1	1	2	1	1	3	2	1		2	20
STRIKING	3					1						1			1	6
Grand Total	4	1	2	1	2	3	1	2	1	1	3	3	1	1	5	31

Table 1. Canadian Accidents in the study area

US Marine Accidents in the Haro-Rosario Area 1997-2016																	
Accident/ Year	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Grand Total
COLLISION				1		1								1		1		4
GROUNDING	1	1	1	1	2		4		4	2	1	2	1	4	1		2	27
ALLISION		1	1		1	3		1					2	1		1	1	12
Grand Total	1	2	2	2	3	4	4	1	4	2	1	2	3	6	1	2	3	43

Table 2. US Accidents in the study area

This information is important for base-lining the Risk Assessment process. The number of accidents over the amount of time gives us data for Probability of accidents happening in the status quo scenario. The results of these accidents over time, gives us an idea of the consequences in the status quo scenario. Based upon the table in Annex B, page 29, this would result in a Probability of 4 and a Consequence of 2 for a Risk of 8. If every tenth accident resulted in a death, this would be 2 x 4 for a Risk Figure of 8 also. In this example, a Risk Figure of 8 fairly represents the combined risk of these two different outcomes.

4. RISK ASSESSMENT

4.1 Key Concerns

Throughout the RA, two principal concerns recurred. The first of these was the prospect of small craft being forced into interaction with deep-sea vessels. While the prospect of collisions and groundings by large ships was considered serious, it was deemed likely fatal if a small craft should be in collision with a deep-sea ship. The unpredictability of small craft movements and the inability of large vessels to make radical evasive manoeuvres makes for a possibly more serious outcome than possible interaction between major ships under pilotage and also participating in VTS.

The second concern was the likelihood of some scenarios creating circumstances where vessels not under pilotage would be forced to loiter This was considered to be a key risk factor in Measures which might require delays at the Victoria pilot station or redirection to the Port Angeles pilot station. On the Victoria side, Constance Bank is an area of periodic high tidal currents and is not conducive for ships to drift while awaiting pilots and clearance to proceed inbound. Room for waiting anchorages is limited at Royal Roads and the area south of the TSS at Constance Bank is a popular fishing area. Language limitations were also considered to be a potential contributor to misunderstood intentions of vessels having to manoeuvre before/after embarking/disembarking pilots. For this reason also, any changes to the major TSS “roundabout” at Race Rocks was considered to be especially risky.

In both these concerns, the speed of the deep-sea ship is a factor. On the side of higher speed, of course, the consequences are higher, as is the noise, which is what we want to reduce by requiring lower engine revs and thus speed-through-the water. On the side of low speeds, this is also a risk for large ships as they lose a measure of manoeuvrability at slower speeds. This is not an issue generally in benign conditions, but in some conditions of wind and tidal current the difference between 10-11 knots and normal speed for certain ships may be significant.

4.2 Baseline Risk Assessment – Status Quo Haro Strait

The RA started with a baseline assessment of the status-quo risk in Haro Strait. While there are other areas of concern in the project (i.e. Strait of Juan de Fuca, Rosario Strait, Constance Bank, Boundary Pass), the current Haro Strait situation was presented as representing the highest risk of these areas. It is an area of close passing traffic at Kelp Reef, a Special Operating Area to manage a blind turn at Turn Point, and occasionally dense crossing traffic at Spieden Channel.

The Haro Strait status-quo was presented as one of the examples in the RA Template, scored by the facilitators. Nonetheless, many of the RA Team scored this independently, returning Risk Figures between 3 and 10, with an average of 6.5. This was considered to be an “acceptable” level of risk as it is what is currently being managed without a driving imperative for additional mitigations. Some of the RA Team went the next stage of the RA process in any case, proposing various mitigations such as a rescue tug stationed at Bedwell Harbour, enforcement of traffic lanes and small craft separation from deep sea traffic, and improved education (for recreational mariners). With such mitigations applied the Risk Figure ranged from 3 to 8 with an average of 4.3. The variation in responses was fairly tight for this example, represented as a Standard Deviation of 1.9.[17] This step of mitigation was not treated consistently by the RA Team, and in any case it is the unmitigated situation in Haro Strait that should be our focus: this is the standard from which most of the Measures propose a departure in practice.

4.3 Relative Risk Assessment

It should be noted at this point the difference between the average "status-quo" Risk Assessment of 6.5 for Haro Strait determined by the RA Team and the Risk Figure of 8 determined from the record of accident probabilities in section 3.3. Due to the compressed timeline of the project, the RA Team did not have access to the accident record in determining either the probability or consequence of possible outcomes in their individual RA tables. They were asked to complete the table to the best of their ability based on professional experience and personal judgment. This baseline figure should be taken then not as a formal and precise expression of risk, but as a benchmark from which the resulting risk from proposed changes is notionally measured.

4.4 Average Risk Assessments

		Probability			Consequence			Risk			% Diff from Status Quo
	Measure	Highest	Lowest<>0	Mean<>0	Highest	Lowest	Mean	Highest	Lowest	Mean	
1	**0. Status Quo**										
2	0a. Current Operations in Haro Strait	2.0	1.0	1.6	5.0	3.0	3.9	10.0	3.0	6.5	0.00%
3	**1. Lateral Displacement**										
4	1a. Protected area E in Haro Str	4.0	1.0	2.8	5.0	3.0	3.8	16.0	3.0	11.1	69.41%
5	1b. SC route west of Haro Str lane	4.0	2.0	2.8	5.0	2.0	3.6	16.0	6.0	9.8	50.39%
6	1c. SOA - Haro Str One-way	5.0	1.0	2.9	5.0	3.0	4.0	25.0	3.0	12.2	85.88%
7	1d. SJDF - Shift outbound N of SB	4.0	1.0	2.6	5.0	3.0	4.1	20.0	3.0	11.0	68.24%
8	1e. SJDF - Shift all lanes further S of SB	3.0	1.0	2.5	5.0	1.0	3.8	15.0	1.0	9.8	50.59%
9	1f. Shift SJDF TSS off Sooke to south	4.0	2.0	2.8	5.0	3.0	3.9	20.0	6.0	11.2	70.59%
10	**2. Quiescence**										
11	2a.Quiet Periods	5.0	2.0	3.2	5.0	3.0	3.8	25.0	8.0	12.2	87.06%
12	2b. Schedule transits	5.0	3.0	3.6	5.0	3.0	3.9	25.0	9.0	14.3	118.82%
13	2c. Manage transits	5.0	3.0	3.7	5.0	3.0	3.9	25.0	9.0	14.6	123.53%
14	2d. Tidal transits	5.0	2.0	3.3	5.0	3.0	3.9	25.0	8.0	13.1	100.00%
15	**3. Redirection**										
16	3a. Redirection through Rosario	5.0	2.0	3.5	5.0	3.0	4.4	25.0	8.0	15.6	139.14%
17	3b. Conditional redirection to Rosario	4.0	1.0	3.2	5.0	3.0	4.4	20.0	3.0	14.3	118.82%
18	3c. One-way Rosario-Haro (I/O)	4.0	1.0	2.8	5.0	3.0	4.4	20.0	3.0	12.9	97.65%
19	**4. Speed Reduction**										
20	4a. Fixed SP Limit in Haro	3.0	2.0	2.5	5.0	3.0	4.0	15.0	6.0	10.3	57.65%
21	4b. Circumstantial SP Limit in Haro (SRKW)	3.0	2.0	2.6	5.0	3.0	4.0	15.0	6.0	10.6	62.35%
22	4c. Conditional SP Limit in Haro (Vessels)	3.0	2.0	2.4	5.0	3.0	4.0	15.0	6.0	9.6	47.06%
23	4d. Circumstantial SP Limit in SJDF	5.0	1.0	2.5	5.0	2.0	3.8	20.0	2.0	10.3	57.65%

Table 3. Initial Risk Assessments by Measure, from Individual RA Tables

The initial RA results from individual responses is shown in Table 3. Examination of this table indicates that the average risk by Measure ranges from 50% to 123% higher than the status quo, with risk figures of 9.8 to 15.6.

The question was posed to the RA Team: what is the maximum tolerable risk? There was no firm consensus or rationalized position on this, but in practice the RA Team

[17] The meaning of this is that the Average figure +/- the Standard Deviation represents 68.2% of the responses. As explained earlier, the sample size is not large for this kind of statistical treatment, so this is merely informative of the spread of values.

seemed to regard the Haro Strait status-quo as defining the (near) maximum tolerable risk. In the final analysis, only four Measures with a Mitigated Risk Figure greater than the status quo were deemed acceptable and only one of these was over 7.3.

It should be noted that the RA Team members proposed Probability and Consequence figures for each Measure and the Risk Figure was calculated from this. The Highest, Lowest and Median risks in Table 3 are as combined by the RA Team members individually and do not represent an overall Worst Probability x Worst Consequence match. The resulting Risk Figure thus required no separate judgement. The judgement of maximum acceptable risk, however, may have been influenced by the terminology in the scale at Table 4. This mirrors the PRMM scale for Consequence and has the upper-right/lower-left sets of six cells as the extremes of the scale. Other versions of this chart are not as graduated between green and red, with a broader yellow band in between Low and Extreme.

Probability

Consequence	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

Net Risk Scale	
Score =>15	**Extreme**
Score 10-15	**Very High**
Score 7-9	**High**
Score 4-6	**Medium**
Score <4	**Low**

Table 4. Net Risk Scale

It will be seen that in several measures the maximal probabilities and consequences are extreme at “5”. RA Team members were instructed to think of worst case outcomes possibly attributable to the implementation of proposed Measures and to rate these by Probability and Consequence. It is believed in some cases, they may have considered worst Probability and worst Consequence separately, without relating the probability directly to the consequence. This would in some cases have resulted in an exaggeration of the overall risk, as with the proposal of highest probability and highest consequence together (that is 5x5=25 = multiple deaths, massive environmental damage, material repairs in the greater than $10M and/or significant adverse publicity on a national scale ***every year***). Clearly, however, in very plausible outcomes the risk could be extreme with little opportunity for doubt: if just one collision between a deep-sea ship and a recreational boater in Haro Strait each three years resulted in a death and serious injuries, this would figure as 4 x 4 = 16, i.e. “Extreme.” Some of this uncertainty on the assessment could have been resolved with an interim step in which the RA Team devised an agreed set of outcomes for each Measure, but the timeline of the project and restricted focus did not permit this refinement.

4.5 Mitigations and Residual Risk

A large number of mitigations were proposed in the course of the individual risk assessments. These have been consolidated in a table by Measure at Annex C. The mitigations were not discussed in any detail as they are largely self-evident. In some cases, the mitigations were edited to be able to group like mitigations.

The mitigations fall into 8 broad categories:

1. CCG – those mitigations requiring some sort of enforcement of directions to shipping. This is noted as different from VTS as it is beyond traffic services per se, even though both VTS and enforcement are shared by CCG and TC.[18]
2. DFO – those mitigations requiring further scientific work or determination of whale presence.
3. Education – those mitigations suggesting a campaign of public awareness and amateur or professional training in navigation practices.
4. Pilots – those mitigations requiring amendments to pilotage practice, scheduling or regulation. These mitigations ranged from actions that could be managed by pilots themselves to sweeping changes to the pilotage scheme in the area.
5. TC – those mitigations suggesting changes in vessel equipment carriage or classification to serve the purposes of noise mitigation.
6. TSS – those mitigations requiring changes to the Traffic Separation Scheme. As Haro Strait and the Strait of Juan de Fuca are binational straits containing IMO-approved TSS, these measures presume a large effort in high-level negotiation and approval.
7. Tugs – those mitigations requiring either stand-by, escort or tethered tugs in various locations.
8. VTS – those mitigations requiring changes to the practice of Vessel Traffic Services in the area. This was is distinct from the on-water role of the CCG in enforcement or the communications services element of MCTS, and was the largest group of mitigations, ranging from geofencing to direct coordination of traffic. Some of the advisory mitigations related to VTS are within the current capability and mandate of VTS.

It will be seen from inspection of the table at Annex C that 4 to 12 mitigations were proposed collectively by the RA Team for each Measure. Some mitigations were proposed for unique Measures, while others were proposed for up to 9 Measures. The most common mitigations were, in order: rescue tugs on standby, geofencing (i.e. AIS tracking alarms on deviations of track or speed), and education of small craft operators. Most of the mitigations fell in the domain of VTS (24), followed by TSS (16) and Pilots (9). All of the proposed mitigations, with the possible exception of Rescue Tug on Standby, were oriented towards the reduction of Probability, not Consequence.

Once the mitigations were applied, the RA Team members assessed the Mitigated (or Residual) Risk as shown in Table 5. In most cases the assessment was due to a reduction in perceived Probability, although in a few isolated cases the Consequence was seen to drop also.[19] The Mean Mitigated Risk (apart from the Status Quo situation)

[18] In some cases in Canada such enforcement would be a police mandate (RCMP)
[19] An example of the difference would be such as this: against the risk of a tanker grounding in Haro Strait, the potential mitigation of a tethered escort tug would diminish Probability of this

ranges from marginally below the Mean Status Quo Risk to 76% higher than this baseline risk. Of the 18 Measures, 10 result in a Risk Figure of 8 or more. The standard deviation for these results ranged from 3.3 to 5.5, demonstrating a fairly wide variation of judgment in many cases.

It should be noted that the full range of mitigations was assembled from individual reponses. None of the RA Team members actually proposed or applied all of these Mitgations to their own risk assessments. It is possible that if the RA Team had considered and applied the full range of mitigations to the problem, the Mean Mitigated Risk would have been somewhat lower than the average of the individually-mitigated risks. Time available for the project and for this particular workshop did not permit this additional round of assessment.

		Mitigated Probability			Mitigated Consequence			Mitgated Risk				
	Measure	Highest	Lowest	Mean	Highest	Lowest	Mean	Highest	Lowest	Mean	Std Dev	% Diff from Status Quo
1	**0. Status Quo**											
2	0a. Current Operations in Haro Strait	2.0	1.0	1.1	5.0	3.0	3.9	8.0	3.0	4.3	1.9	
3	**1. Lateral Displacement**											
4	1a. Protected area E in Haro Str	3.0	1.0	1.8	5.0	3.0	3.9	12.0	3.0	7.2	3.7	10.26%
5	1b. SC route west of Haro Str lane	3.0	1.0	1.8	5.0	2.0	3.6	12.0	3.0	6.5	3.6	-0.70%
6	1c. SOA - Haro Str One-way	4.0	1.0	2.3	5.0	3.0	3.9	20.0	3.0	9.4	5.2	44.87%
7	1d. SJDF - Shift outbound N of SB	3.0	1.0	2.0	5.0	3.0	4.1	15.0	3.0	8.2	4.5	25.87%
8	1e. SJDF - Shift all lanes further S of SB	3.0	1.0	1.8	5.0	1.0	3.7	12.0	1.0	7.0	3.7	7.69%
9	1f. Shift SJDF TSS off Sooke to south	3.0	1.0	1.9	5.0	3.0	4.0	12.0	3.0	7.8	3.8	19.23%
10	**2. Quiescence**											
11	2a.Quiet Periods	4.0	1.0	2.1	5.0	3.0	3.8	20.0	3.0	8.2	5.2	25.64%
12	2b. Schedule transits	4.0	2.0	2.7	5.0	3.0	4.0	20.0	6.0	10.8	5.1	66.67%
13	2c. Manage transits	4.0	2.0	2.7	5.0	3.0	4.0	20.0	6.0	10.8	5.1	66.67%
14	2d. Tidal transits	4.0	1.0	2.4	5.0	3.0	3.9	20.0	3.0	9.8	5.4	50.00%
15	**3. Redirection**											
16	3a. Redirection through Rosario	4.0	2.0	2.5	5.0	3.0	4.4	16.0	6.0	11.2	5.5	72.03%
17	3b. Conditional redirection to Rosario	4.0	1.0	2.5	5.0	3.0	4.5	16.0	3.0	11.4	5.3	75.64%
18	3c. One-way Rosario-Haro (I/O)	4.0	1.0	2.3	5.0	3.0	4.4	16.0	3.0	10.2	5.2	56.41%
19	**4. Speed Reduction**											
20	4a. Fixed SP Limit in Haro	2.0	1.0	1.6	5.0	3.0	4.0	10.0	3.0	6.5	3.3	0.00%
21	4b. Circumstantial SP Limit in Haro (SRKW)	3.0	1.0	1.8	5.0	3.0	4.1	12.0	3.0	7.3	3.6	11.54%
22	4c. Conditional SP Limit in Haro (Vessels)	2.0	1.0	1.6	5.0	3.0	4.0	10.0	3.0	6.5	3.3	0.00%
23	4d. Circumstantial SP Limit in SJDF	5.0	1.0	2.1	5.0	2.0	3.8	20.0	2.0	8.3	5.5	26.92%

Table 5. Mitigated Risk Assessments, by Measure, from Individual RA Tables

4.6 Suitability for Further Examination

Following the review of the compilation of the individual Risk Assessments as presented above, the RA Team engaged in a discussion of which Measures could possibly warrant further examination or development. The question was initially phrased with a number of qualifiers: Given the range of responses, and recognizing the spread of assessed risk, and in consideration of the effort involved in implementing the various Measures to reduce ship-generated noise in the Salish Sea, are any of the Measures sufficiently close to acceptable risk levels as to warrant further examination?

Among the qualifiers was the issue of implementation effort. While it was not the mandate of this project to consider the impact to industry of implementing these

outcome, whereas a potential mitigation of improved oil spill response would reduce the Consequence of such an outcome.

Measures, nor the cost in administrative effort to negotiate regulatory and procedural changes, the issues surrounding implementation were used to gauge the relative difficulty of effecting each of the Measures. RA Team members were asked to indicate what were the key issues, and then to rank the difficulty on an ascending scale from 1 to 5, ranging from days/$10K to years/$10M+. The collated, paraphrased and grouped Implementation Issues are tabulated in Annex E by Measure. The leading issues for implementation are Consultation (with various groups, covering all Measures), Bi-national Agreement (14), Coast Pilot/Sailing Directions Updates (12), Procedures Changes and VTS Staff Training (11), Supply Chain Disruptions (8), and IMO TSS Approval (6). Individual Measures had from 7 to 12 issues associated with implementation, not all mentioned by each RA Team member. The net assessment of implementation effort suggests that at least 10 of the Measures would require "Extensive" (months/$100K+) effort or greater.

The discussion of Measures warranting further investigation was impeded by the complexity of the qualified question, and the difficulty of hypothesizing a risk appreciation encompassing all of the variously proposed risk mitigations that may or may not lead to a further-diminished residual risk. Accordingly, after review and discussion of the Measures, the question was put simply to the RA Team by Measure:

"Does this Measure warrant further examination?"

The results of this poll are presented with the Mitigated Risk and Implementation Scores in Table 6 below.

The Measures deemed ***acceptable*** for further examination, towards possible implementation are:

1a – the Whale Protection Zone in east Haro Strait;
1b – the small craft route up the west side of Haro Strait;
1e – the shift of the TSS further south at Swiftsure Bank (SJDF entrance); and
4a-4d – all the Speed Reduction options for Haro Strait and SJDF

The Measures deemed ***unacceptable*** for further examination and development are:

1c – extending the Turn Point SOA practices to all of Haro Strait;
1d – shifting the outbound lane at the SJDF entrance north of Swiftsure Bank;
1f – shifting the SJDF TSS south off Sooke;
2a-2d – all of the Quiescence options; and
33-3c – all of the Redirection options through Rosario Strait.

	Measure	Mitgated Risk				Implementation			Examine Further?
		Highest	Lowest	Mean	Std Dev	Highest	Lowest	Mean	1=Y; 0=N
1	**0. Status Quo**								
2	0a. Current Operations in Haro Strait	8.0	3.0	4.3	1.9	2.0	1.0	1.2	1
3	**1. Lateral Displacement**								
4	1a. Protected area E in Haro Str	12.0	3.0	7.2	3.7	5.0	1.0	2.8	1
5	1b. SC route west of Haro Str lane	12.0	3.0	6.5	3.6	4.0	1.0	2.7	1
6	1c. SOA - Haro Str One-way	20.0	3.0	9.4	5.2	5.0	2.0	3.5	0
7	1d. SJDF - Shift outbound N of SB	15.0	3.0	8.2	4.5	5.0	2.0	3.8	0
8	1e. SJDF - Shift all lanes further S of SB	12.0	1.0	7.0	3.7	5.0	3.0	4.0	1
9	1f. Shift SJDF TSS off Sooke to south	12.0	3.0	7.8	3.8	5.0	3.0	4.0	0
10	**2. Quiescence**								
11	2a.Quiet Periods	20.0	3.0	8.2	5.2	5.0	2.0	2.9	0
12	2b. Schedule transits	20.0	6.0	10.8	5.1	5.0	3.0	3.6	0
13	2c. Manage transits	20.0	6.0	10.8	5.1	5.0	2.0	3.6	0
14	2d. Tidal transits	20.0	3.0	9.8	5.4	5.0	2.0	3.5	0
15	**3. Redirection**								
16	3a. Redirection through Rosario	16.0	6.0	11.2	5.5	5.0	4.0	4.7	0
17	3b. Conditional redirection to Rosario	16.0	3.0	11.4	5.3	5.0	2.0	4.3	0
18	3c. One-way Rosario-Haro (I/O)	16.0	3.0	10.2	5.2	5.0	2.0	4.3	0
19	**4. Speed Reduction**								
20	4a. Fixed SP Limit in Haro	10.0	3.0	6.5	3.3	5.0	1.0	2.7	1
21	4b. Circumstantial SP Limit in Haro (SRKW)	12.0	3.0	7.3	3.6	5.0	2.0	2.9	1
22	4c. Conditional SP Limit in Haro (Vessels)	10.0	3.0	6.5	3.3	5.0	2.0	3.3	1
23	4d. Circumstantial SP Limit in SJDF	20.0	2.0	8.3	5.5	5.0	2.0	3.0	1

Table 6. Mitigated Risk Results and Implementation Scores

It will be noted from inspection of Table 6 that all of the acceptable Measures except one have mean Risk Figures of 7.3 or less, demonstrating some flexibility from the (unmitigated) Status-Quo mean of 6.5. All of the unacceptable Measures except three have mean Risk Figures of 9.4 or above. The exceptions in each case have Risk Figures between 7.8 (unacceptable) and 8.3 (acceptable); that is, there is an overlapping band of Risk Figures in this range where the decision of whether to further examine Measures was not solely determined by the Residual Risk Figure. These cases are shaded yellow in the right hand column of Table 6. This suggests that the “tolerable risk level” could be generalized to be in the order of 8, and that other factors (scope of required mitigations, implementation difficulties) may have influenced the outcome in the range of Risk Figures from 7.8 to 8.3. It may be that a more focused and comprehensive consideration of mitigations could result in further shifts of risk assessment in these cases, or perhaps others also.

It should also be noted that the Yes-No vote related above was not in all cases much more than a simple majority; in a few cases the vote was very close, with some RA Team members abstaining. However, in all the cases where the vote was within 2 votes of changing the result, these are shown here as “Yes” votes. The “No” votes were all more definite judgments in this process. Nonetheless, in the opinion of the facilitators, it might be possible upon review and refinement of the Measures, that some Risk Assessments would shift and result in a positive vote. Measure 1f – Shifting TSS South at Sooke – is the one refusal that overlaps acceptable Risk Figures and thus might be suitable for re-evaluation notwithstanding the vote result. It is believed that this Measure’s result was heavily influenced by the dislike of disturbing the Race Rocks roundabout, so that the Measure might have been acceptable if an alternate solution could achieve the lateral separation objective without this negative change.

5. INTERPRETATION OF RESULTS

This was a high level risk assessment with a tight timeline, so some qualification of the results are appropriate. First, it should be acknowledged that the RA Team members gave generously of their time and that the time spent doing the “homework” was greatly appreciated as helping to advance the project to completion in a short time. In retrospect the RA Process could have benefitted from an additional round of examination, but the timeline did not permit this. However, within the restricted mandate of the project, it is considered that the result fairly represents the collective experience of nautical professionals regarding the risk of the proposed noise-reduction Measures. Several specific qualifications are outlined below.

5.1 Imprecision in Specification of Measures

The specific Measures to be assessed were defined only loosely, in the sheet of instructions provided with the RA Table as “homework” for the RA Team. This was sufficient for the generality of the result achieved here, but further elaboration and precision would be required to do a proper “Implementation” assessment.

5.2 Imprecision of Outcomes/Factors Examination

The Risk Assessment conducted here was based on generalized risk scenarios related to each Measure. For greater confidence in the results, a standardized set of specific outcomes for each Measure would have to be developed and used by each RA Team member. This would resolve any doubt as to the combination of Probabilities and Consequences of different outcomes.

5.3 Variation in Results

The variation of Mitigated Risk Factors is a positive outcome in demonstrating a range of perspectives on the suggested Measures. The down-side of this is that it leaves doubt as to the actual risks involved and the true threshold of risk tolerance. A three-stage PRMM could have resolved some of this by providing greater definition in the Measures, Outcomes and also providing some prior orientation in the recorded frequency of accidents in the study area. This might have set a better baseline of common appreciation from which to gauge the degree of risk increases subsequent to hypothetical Measures implementation. In addition, a more extended process would also permit a more robust discussion of available mitigations and subsequent application of a standardized set to get a more consistent Residual Risk.

5.4 Effort for Implementation

Clearly, many of the issues for implementation would require considerable effort. The need for consultation is paramount and must include a wide variety of stakeholders. The fact that only a limited and focused representation was invited at this RA does not reflect ignorance of other interested parties but only the restricted scope of this preliminary process. Apart from this, the RA Team identified a generous range of implementation issues which should form a solid basis for further examination. Certain members of the RA Team with personal experience also cautioned that the effort of redrawing IMO-approved Traffic Separation Schemes is not to be under-estimated.

5.5 Political Non-Starters

Among the Measures rejected by the RA Team were all of the suggestions of redirecting traffic through Rosario Strait. These Measures rated highest on both the Residual Risk calculation and also on the Implementation Difficulty scale. The suggestion calls for longer redirection of Canadian-bound traffic from a bi-national strait to US internal waters, with implications of more complex pilotage arrangements, tighter navigation, displacement of the problem from one area to another, and possibly lack of routing clarity for ships arriving at the Race Rocks TSS junction. All of this spells unacceptable risk. Furthermore, these Measures involve the United States accepting significant risk to solve a problem for which other, simpler measures exist. In the end, apart from the RA, this was felt to be a political non-starter.

6. FUTURE STEPS

This Risk Assessment was a preliminary step toward identification and sorting of potential measures to reduce ship-noise impacts on the SRKW. A number of Measures have been examined and judged acceptable for further consideration. This judgement has been on the basis of navigational safety, informed also by the potential difficulty of implementation. Others have been rejected on similar grounds.

In further consideration of the possible implementation of ship-noise reduction measures in the Salish Sea, the following is recommended:

a. That the process allow ample timelines to engage appropriate representation;
b. That a wider representation allow a broad-based risk appreciation including economic impacts and social/cultural factors;
c. That the RA process include an interim step to better define Measures with navigational precision and details of implementation practices;
d. That DFO provide representatives to better clarify the relative benefits of modified Measures; and
e. That detailed accident records be used to provide an accurate assessment of current risk profiles.

7. REFERENCES

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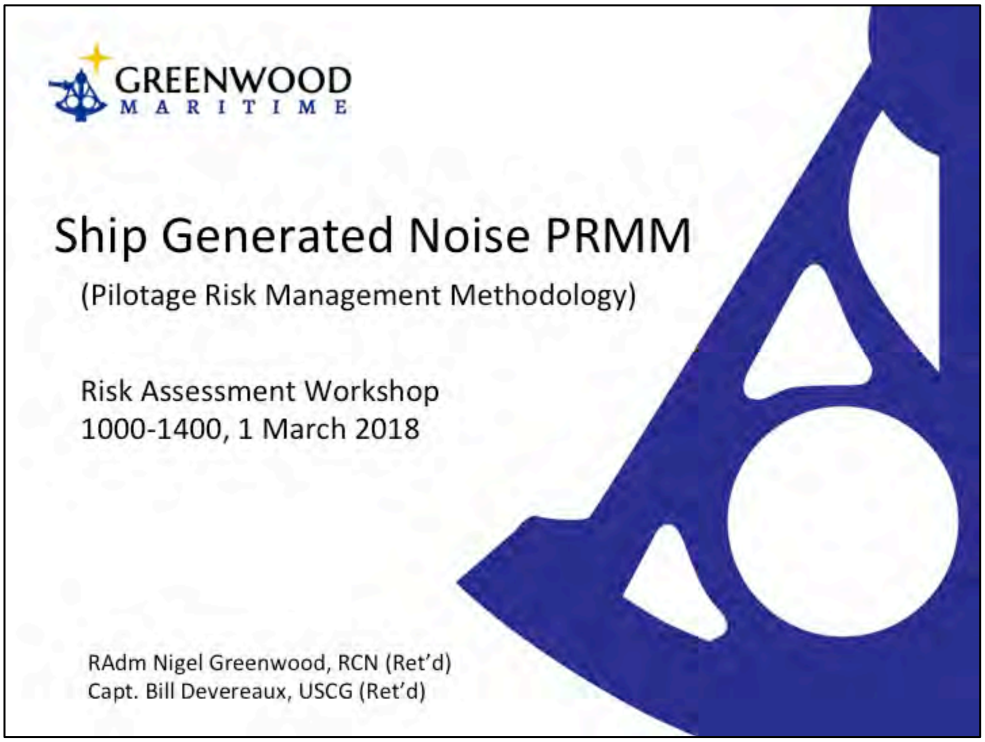
ANNEX A. PARTICPANTS

Name	Org	Phone	Email	7 Feb	1 Mar
Nigel Greenwood	Greenwood Maritime			Y	Y
Bill Devereaux	Devereaux Consulting			Y	Y
Sol Kohlhaas	Andeavor			Y	by phone
Robin Stewart	BC Coast Pilots			Y	
Roy Haakonson	BC Coast Pilots			Y	Y
Paul Devries	BC Coast Pilots			Y	Y
Kent Reid	Canadian Coast Guard			Y	Y
Art Statham	Canadian Coast Guard			Y	Y
Robert Lewis-Manning	Chamber of Shippin of BC			Y	Y
Greg Wirtz	CLIA			Y	
Donna Spalding	CLIA				Y
Phillip Nelson	Council of Marine Carriers			Y	Y
Paulo Ehkebus	Pacific Pilotage			Y	
Eric Von Brandenfels	Puget Sound Pilots			Y	
Ivan Carlson	Puget Sound Pilots				Y
Jostein Kalvoy	Puget Sound Pilots			Y	
Scott Galloway	SFC				
Bill McKinstry	SFC			by phone	
Chad Allen	SFC				by phone
Sonia Simard	SFC				by phone
Khushru Irani	Transport Canada			Y	Y
Marie-Helene Roy*	Transport Canada			by phone	Y
Jeff Pelton	Transport Canada			Y	Y
Laird Hail	U.S. Coast Guard			Y	Y
Krista Trounce	VFPA			Y	Y

<contact information removed>

ANNEX B. WORKSHOP BRIEF



Project Objective:

To describe and assess, using the PRMM methodology, the *navigation* safety risks and issues associated with implementing potential measures to mitigate impacts on SRKW populations in the Salish Sea

Proposed "Measures"

1. ***Lateral displacement of vessel traffic through regulation, guidelines or the redesign traffic separation schemes***
2. ***Creation of periods of quiescence accomplished directly or through clustering of vessel transits***
3. ***The re-direction of some vessel traffic through alternate routes (Rosario Strait)***
4. ***Reducing vessel speed***

**defined in greater detail later*

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CAVEATs:

This project is ***not*** about:

1. Efficacy of the proposed Measures (science programmes are addressing this)
2. Economic impact of potential Measures (subsequent TC initiatives will cover this)
3. Collaborative mechanisms for addressing vessel traffic management (a separate TC project is addressing this)
4. Consultation with interested coastal communities (future outreach and engagement will address this)

This project ***is*** about:

1. Hypothesizing in greater (operational) detail the proposed Measures
2. Outlining the issues involved in implementing these Measures
3. Determining the (operational) risk factors associated with the proposed Measures
4. Determining if mitigations of such risk factors is required or possible (without eliminating benefits of the proposed Measures)
5. Arriving at a qualitative Risk Assessment of implementing the proposed Measures

**** A lot of this project is necessarily "hypothetical" as not all the science is complete***

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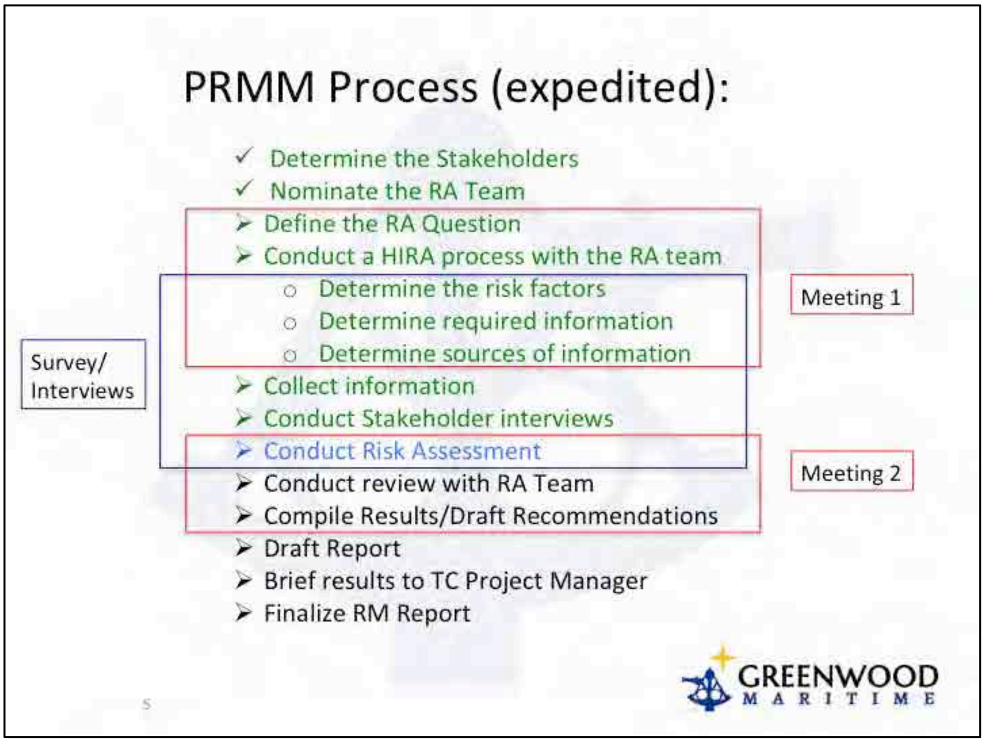
PRMM Process (expedited):
✓ Determine the Stakeholders
✓ Nominate the RA Team
➢ Define the RA Question
➢ Conduct a HIRA process with the RA team
○ Determine the risk factors
○ Determine required information
○ Determine sources of information
➢ Collect information
➢ Conduct Stakeholder interviews
➢ Conduct Risk Assessment
➢ Conduct review with RA Team
➢ Compile Results/Draft Recommendations
➢ Draft Report
➢ Brief results to TC Project Manager
➢ Finalize RM Report
Survey/ Interviews
Meeting 1
Meeting 2
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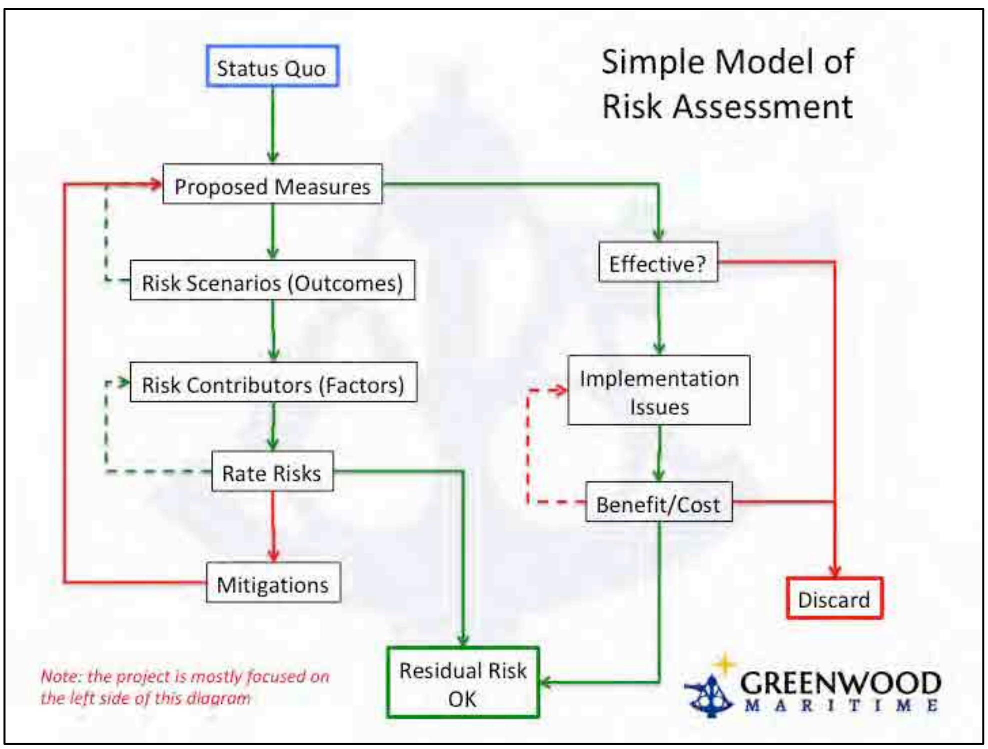
5


Simple Model of Risk Assessment
Status Quo
Proposed Measures
Risk Scenarios (Outcomes)
Risk Contributors (Factors)
Rate Risks
Mitigations
Residual Risk OK
Effective?
Implementation Issues
Benefit/Cost
Discard
Note: the project is mostly focused on the left side of this diagram
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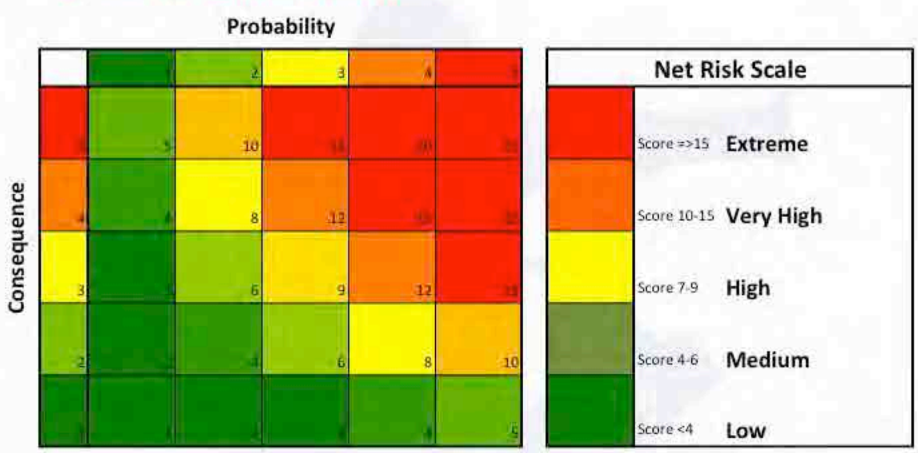
Hazard Identification and Risk Assessment (to discuss)

Net Risk Scale:

◆ *what is a tolerable level of risk?*



e.g.: 9 = some people with long-term injuries, once every 10 years;
10 = incidence of multiple deaths incident at intervals of more than 10 years
12 = incidence of single death/multiple injuries, once every 10 years

Standard Criteria of Probability and Consequence

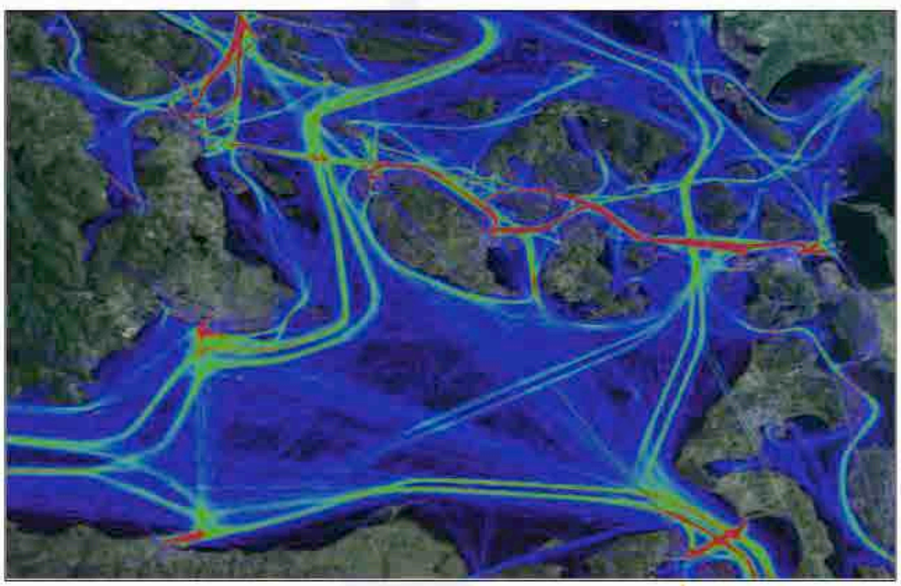
PROBABILITY	
5 Highly Probable	[illegible]
4 Probable	Expected that the event will occur [illegible] over a period of three years
3 Possible	The event could occur over a period of 10 years
2 Unlikely	It is not expected that the event will occur over a period 10 years
1 Improbable	[illegible]

	CONSEQUENCE/SEVERITY				
	Human	Property	Vessel(s)	Environmental	Reputation
5 Extreme	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4 Very High	[illegible]	Damage to facilities is such that operations cease for up to one month or financial loss of $5 - $10 million	Vessel sustains damage significant enough to result in towing to dry dock and loss of operations of up to one month	[illegible] medium term harm to the environment (i.e. damage lasts up to one month)	[illegible]
3 High	Some people with serious long term injury and multiple minor injuries.	Damage to facilities is such that the operations cease for up to two weeks or financial loss of $1 - $5 million.	Vessel sustains significant damage with dry docking and loss of operations for two weeks.	Incident causes medium term harm to environment (i.e. damage lasts up to two weeks).	Intermittent adverse national media coverage.
2 Medium	One person with serious long-term injury. Some minor injuries	Damage to facilities cause operations to cease for up to one week or financial impact of $500,000 - $1 million.	Vessel sustains damage resulting in loss of operations for one week.	Incident causes short term harm to the environment (i.e. damage lasts no longer than one week).	Sustained front page adverse local media coverage. Board and Ottawa receive complaints from CS and Major Clients.
1 Low	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Ref: PRMM Manual
TP 13741E, 2010

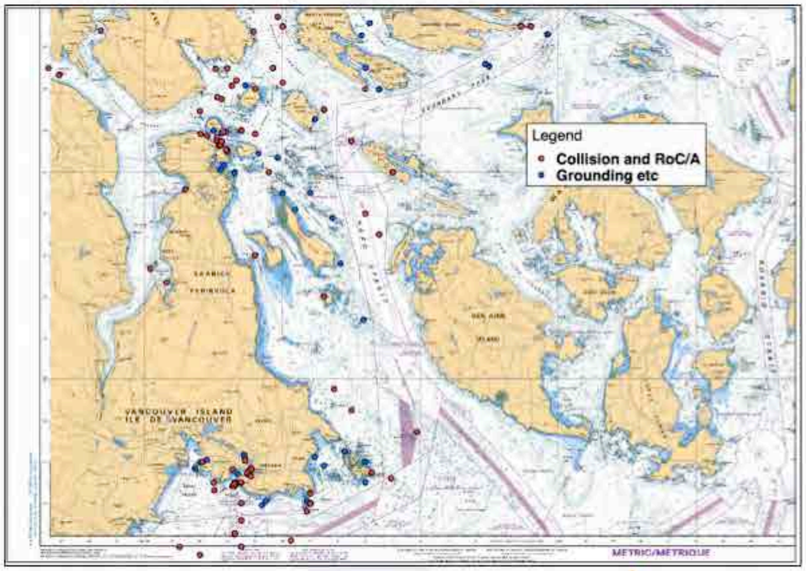
9

Traffic Patterns (Aug)



(courtesy USCG)

TSB Canada Incidents/Accidents 1997-2016



This plot show Collisions and Risks of Collisions and Allisions, Grounding and Risks of Groundings, Touching Bottom etc

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Probability Benchmarking

Geographical Filter:
48.33N < Lat > 48.83N
122.67W < Long > 123.33W
(Haro, Boundary, Rosario)

US Stats 1992-2017

498 Incidents
52 Allisions, Collisions, Groundings (11 FV, 17 PV, 1 SV, 9 T, 3 MV)
MV: 3/25 years = 0.12/yr ~ "3" on Probability Table (once every 10 yr)
FV: 11/25 years = 0.44/yr ~ "4" on Probability Table (once every 3 yr)
FV/PV/SV/T Collision/Grounding: 28/25 years = 1.12/yr ~ "5" on Prob Table (once per yr)

Cdn Stats 1997-2016

166 Incidents
31 Allisions, Collisions, Groundings (15 FV, 3 PV, 0 SV, 3T&B, 5 MV)
MV: 5/20 years = 0.25/yr ~ "3" on Probability Table (at least once in 10 yr)
FV: 15/20 years = 0.75/yr ~ "4" on Probability Table (once every 3 yr)
FV/PV/SV/T Collision/Grounding: 21/20 years = 1.1/yr ~ "5" on Prob Table (once every 3 yr)

*** Note this includes "Risk of Grounding", etc*

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Risk Benchmarking: Linking of Prob and Conseq

Say Probability of MV (deep sea) grounding ~ 0.12/yr ~ "3" on Prob table

- This is 3 over 25 years
- Say #1/3 grounded with minor fuel spill from bunkers
  - ~ 0.04/yr ~ "1-2" on Prob table, "3-5" on Conseq table,
  - Risk = "3-10"
- Say #2/3 grounded with no damage, 1 serious pers injury
  - ~ 0.04/yr ~ "1-2" on Prob table, "2" on Conseq table,
  - Risk = "2-4"

Say Probability of FV grounding ~ 0.44/yr ~ "4" on Prob table

- This is 11 over 25 years
- Say 8 ground with no damage, minor injuries
  - ~ 0.32/yr ~ "3-4" on Prob table, "1" on Conseq table
  - Risk = "3-4"
- Say 1 grounds with minor fuel spill, loss of life
  - ~ 0.04/yr ~ "1-2" on Prob table, "4" on Conseq table
  - Risk = "4-8"

Result: Greatest hypothetical risk is "8-10" ~ "High-Very High"

Ground truth in Haro Strait: no Deep Sea groundings reported in last 20 years

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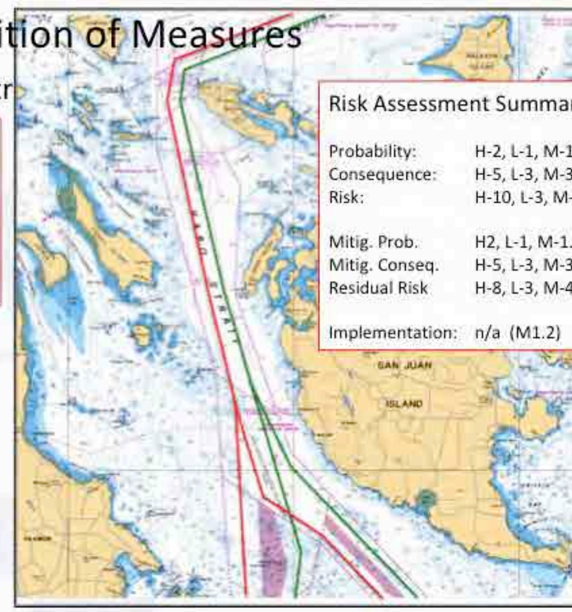
Refinement/Definition of Measures

(0) Status Quo – Haro Str

- two-way traffic
- SOA at Turn Point
- Confluence at Beaumont Sh
- Cooperative VTS CanUS
- Mixed deep-sea/coastal/ recreational traffic



Risk Assessment Summary:

Probability:	H-2, L-1, M-1.6
Consequence:	H-5, L-3, M-3.9
Risk:	H-10, L-3, M-6.5
Mitig. Prob.	H2, L-1, M-1.1
Mitig. Conseq.	H-5, L-3, M-3.9
Residual Risk	H-8, L-3, M-4.3
Implementation:	n/a (M1.2)

Risk Scenarios:

- Small traffic crossing/ merging with deep sea
- Grounding at Kelp Rf
- Collision at Turn Pt

Risk Factors:

- ◆ Weather
- ◆ Currents
- ◆ Proximity to shore
- ◆ Proximity of other ships

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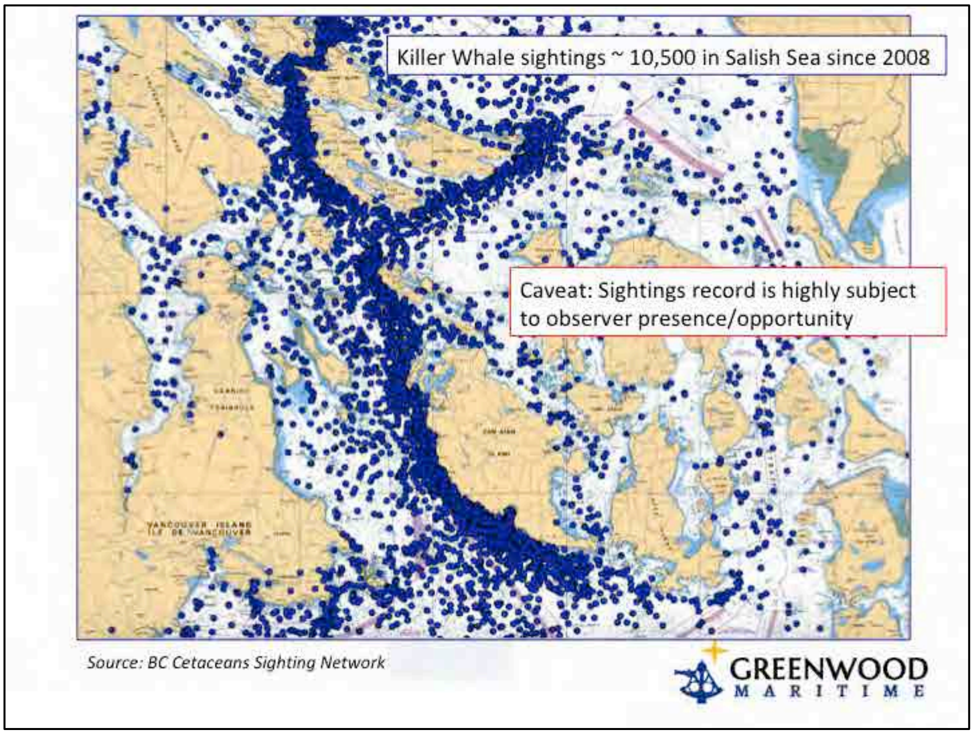
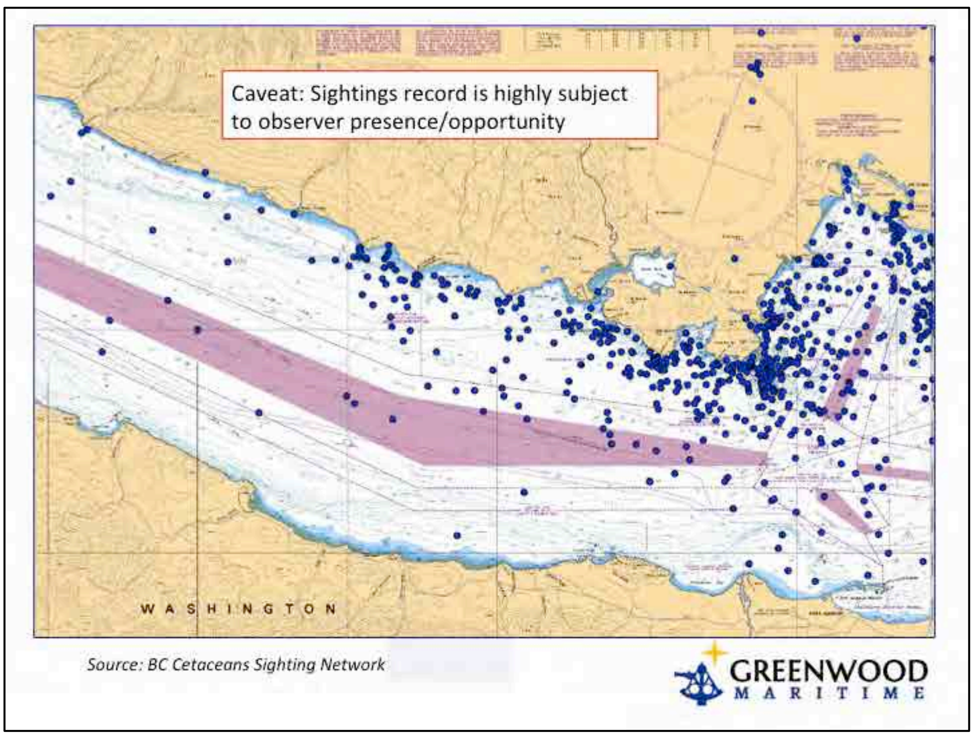

Killer Whale sightings ~ 10,500 in Salish Sea since 2008
Caveat: Sightings record is highly subject to observer presence/opportunity
Source: BC Cetaceans Sighting Network
GREENWOOD MARITIME


Caveat: Sightings record is highly subject to observer presence/opportunity
WASHINGTON
Source: BC Cetaceans Sighting Network
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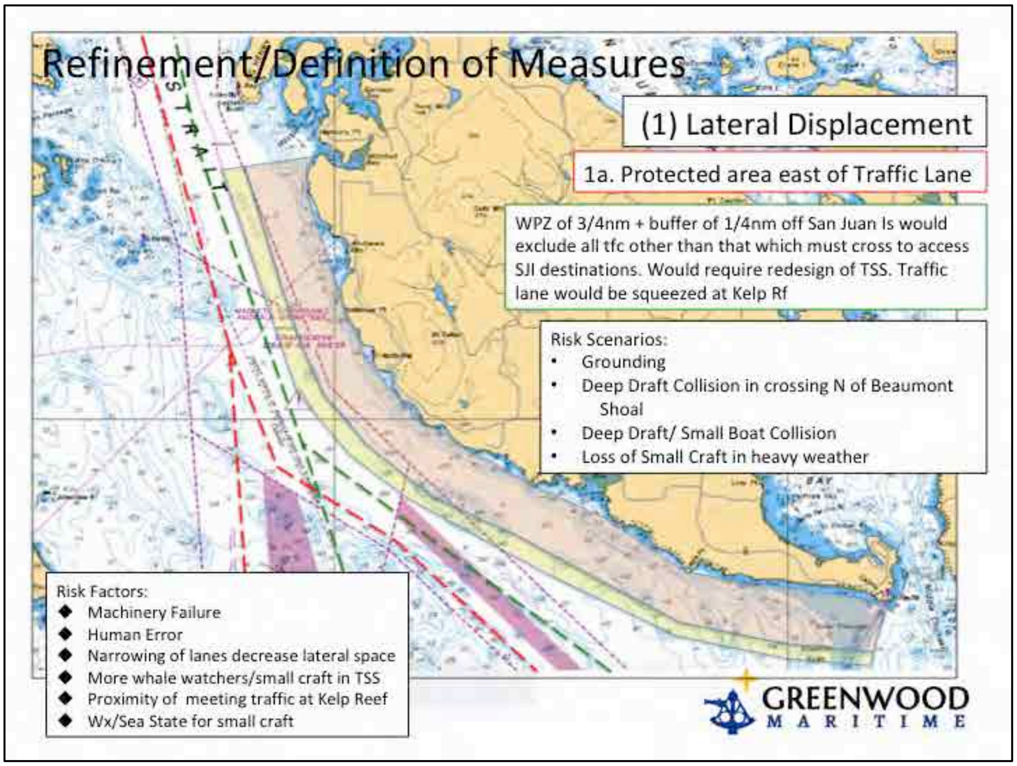


Mitigations: [Measure 1A WPZ east of Traffic Lane]

- ✓ Rescue Tug [on standby]
- ✓ Enforcement of traffic lanes
- ✓ Improved Geofencing Techniques
- ✓ Dedicated VTS sector
- ✓ Smaller WPZ (less impact on TSS)
- ✓ Prevent deep draft meeting at Kelp Reef
- ✓ Securite Broadcasts
- ✓ Wx exceptions for protected area
- ✓ Education program
- ✓ Escort Tugs
- ✓ Speed Reductions

Implementation Issues:

- ✧ Getting LE presence
- ✧ Bi-national agreement
- ✧ TSS IMO approval
- ✧ Industry Consultation
- ✧ ID/Comms with small craft
- ✧ Availability/Cost of Rescue Tug
- ✧ Education of small craft operators
- ✧ Flexibility of WPZ
- ✧ Local consultation [?]

Risk Assessment Summary:

Probability:	H-4, L-1, M-2.8
Consequence:	H-5, L-3, M-3.8
Risk:	H-16, L-3, M-11.1
Mitig. Prob.	H-3, L-1, M-1.8
Mitig. Conseq.	H-5, L-3, M-3.9
Residual Risk	H-12, L-3, M-7.2
Implementation:	H-5, L-1, M-2.8

Discussion:

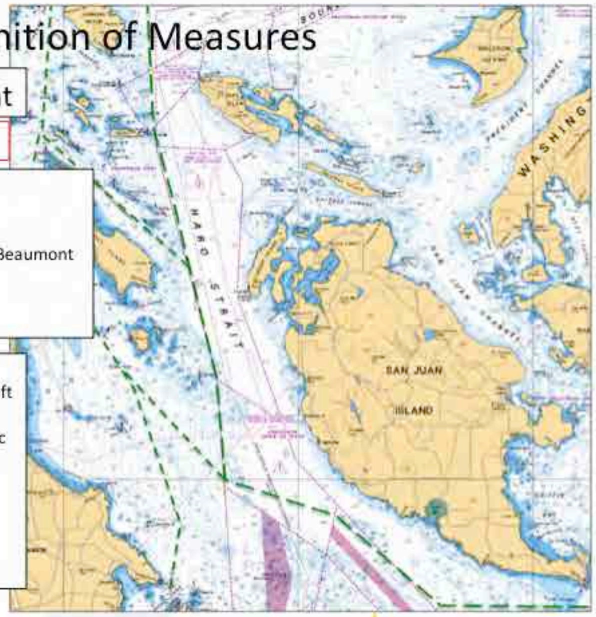
- ❑ Difference in Conseq due small/deep-sea impacts?
- ❑ Mitigation: Prob, Conseq, or both?
- ❑ …?

GREENWOOD MARITIME

Refinement/Definition of Measures

(1) Lateral Displacement

1b. SC route west of traffic lane



Risk Scenarios:
- Deep Sea Collisions at Kelp Reef
- Groundings (especially small craft)
- Deep Draft Collision in crossing N of Beaumont
- Deep Draft/ Small Craft Collision
- Collisions between Small Craft
- Loss of tow

Risk Factors:
- ◆ Proximity of deep draft and small craft
- ◆ Crossing of small craft
- ◆ Increased small boat density of traffic
- ◆ Human Error
- ◆ Machinery Failure
- ◆ Bottom contact with tow lines
- ◆ Area too small for sailing vessels
- ◆ Reduced visibility
- ◆ Closer to shoals for small craft

GREENWOOD MARITIME

Mitigations: [Measure 1B Small craft route west of Traffic Lane]
- ✓ Better design of TSS
- ✓ Enforcement of traffic lanes
- ✓ Improved Geofencing Techniques
- ✓ Dedicated VTS sector
- ✓ Encourage small craft to cross at BS
- ✓ One-way traffic
- ✓ Only light tugs required to use route
- ✓ Require only pleasure craft and naval vessels use this measure
- ✓ Mandatory AIS carriage for small craft
- ✓ Education program
- ✓ Prohibit sailing in area
- ✓ Complete surveys and channel design process
- ✓ Provide better tide and current predictions

Implementation Issues:
- ✧ Getting LE presence
- ✧ Bi-national agreement
- ✧ TSS IMO approval
- ✧ Industry Consultation
- ✧ Regulatory change process
- ✧ Challenge of redirecting vessels when not following
- ✧ Education of small craft operators
- ✧ Noise and other issues with coastal communities

Risk Assessment Summary:

Probability:	L-2, H-4, M-2.8
Consequence:	L-2, H-5, M2.6
Risk:	L-6, H-16, M9.8
Mitig. Prob.	L-1, H-3, M1.8
Mitig. Conseq.	L-2, H5, M2.6
Residual Risk	L-3, H-12, M6.5
Implementation:	L-1, H-4, M2.7

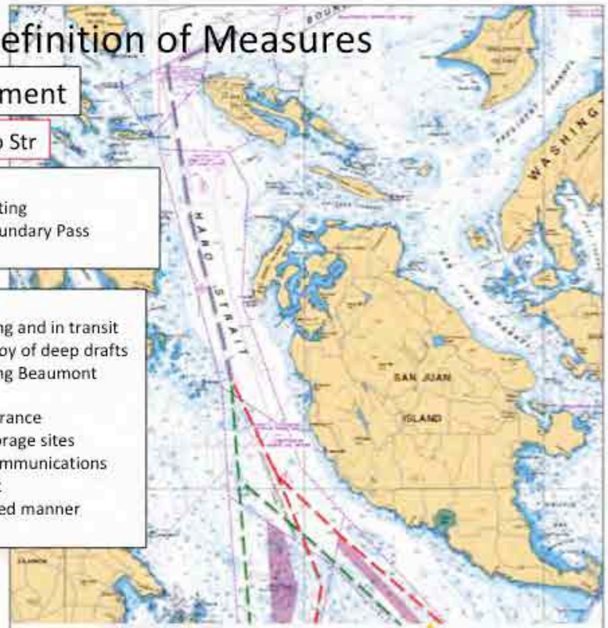
Discussion:
- ❑
- ❑

GREENWOOD MARITIME

Refinement/Definition of Measures

(1) Lateral Displacement

1c. One-way traffic in Haro Str



Risk Scenarios:
- Traffic compression while waiting
- Collisions at Constance Bk, Boundary Pass
- Collisions in Haro Str

Risk Factors:
- Proximity of deep draft holding and in transit
- Crossing of small craft in convoy of deep drafts
- Crossing situations approaching Beaumont
- Machinery Failure
- Vessels loitering awaiting clearance
- Congestion at overused anchorage sites
- Language Barriers/Unclear Communications
- Closer to shoals for small craft
- Vessel navigation in unexpected manner
- Wx, Tide, Currents

GREENWOOD MARITIME

Mitigations: [Measure 1C One-way traffic in Haro]
- ✓ Better design of TSS at Beaumont
- ✓ SOA mgmt of vsls to prevent meeting at Kelp Reef
- ✓ Early notification of one-way restrictions
- ✓ Strict coordination of S & N bound vessels
- ✓ Encourage small craft to cross at BS
- ✓ Increase VTS comms about SOA and meeting situations
- ✓ Increase coord of Brotchie and VFPA terminals for SOA arrival
- ✓ Redesign TSS to reflect SOA procedures
- ✓ Tug Availability
- ✓ Require pilots for vessels loitering for clearance

Implementation Issues:
- Industry acceptance of increased pilotage time & costs
- TSS IMO approval
- Scheduling of pilotage transfers
- Warning inbound traffic to time arrivals
- Redesign of TS in a CVTS system
- Increased coordination of scheduling industry
- SOP changes and VTS staff training
- Updates to guidance in Coast Pilot, Sailing Directions, Charts, etc.

Risk Assessment Summary:

Probability:	L-1, H-5, M-2.9
Consequence:	L-3, H-5, M-4.0
Risk:	L-3, H-25, M-12.2
Mitig. Prob.	L-1, H-4, M-2.3
Mitig. Conseq.	L-3, H-5, M-3.9
Residual Risk	L-3, H-20, M-9.4
Implementation:	L-2, H-5, M-3.5

Discussion:
- ❑
- ❑

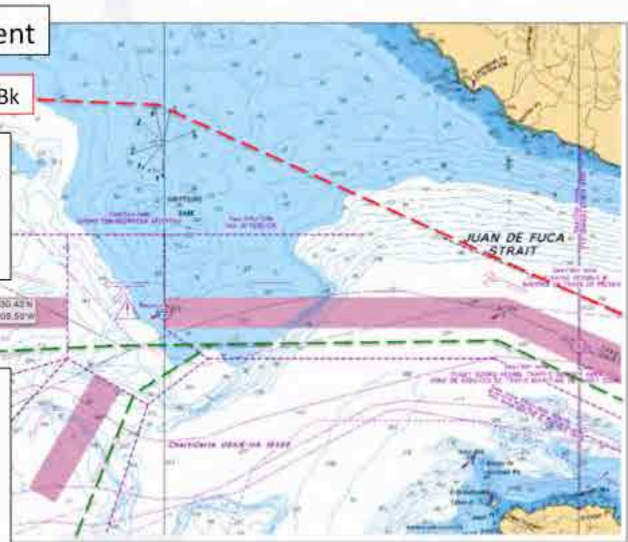
GREENWOOD MARITIME

Refinement/Definition of Measures

(1) Lateral Displacement

1d. Outbound N of Swiftsure Bk

Risk Scenarios:
- Collision deep draft/coastal traffic or fishing vsl
- Groundings deep draft N of SB
- Collision deep draft/Tug
- Deep Draft/ Small Craft Collision



Risk Factors:
- Proximity of deep draft w/fishing and coastal traffic
- Proximity to land
- Reduced Visibility
- Language Barriers/No pilots
- Unidentified small craft
- Human Error
- Mechanical Failure
- More crossing situations for exiting southbound vsls

Mitigations: [Measure 1D Outbound lane N of SB at Buoy J]
- ✓ Extra surveillance – identifying fishing vsl locations
- ✓ Inshore traffic lanes
- ✓ Slow speed over SB
- ✓ Improved nav equipment for fishing vsls
- ✓ Expand compulsory pilotage
- ✓ Education
- ✓ Assist tug at SJDF

Implementation Issues:
- ✓ Bi-national agreement
- ✓ TSS IMO approval
- ✓ Agreement of coastal communities/ fishermen
- ✓ Getting word out of changes
- ✓ Consultation with First Nations/U.S. Tribes
- ✓ Additional monitoring
- ✓ Coordination with coastal communities
- ✓ Unintended impacts to marine life

Risk Assessment Summary:

Probability:	L-1, H-4, M-2.6
Consequence:	L-3, H-5, M-4.1
Risk:	L-3, H-20, M-11.0
Mitig. Prob.	L-1, H-3, M-2.0
Mitig. Conseq.	L-3, H-5, M-4.1
Residual Risk	L-3, H-15, M-8.2
Implementation:	L-2, H-5, M-2.8

Discussion:
- ❑
- ❑

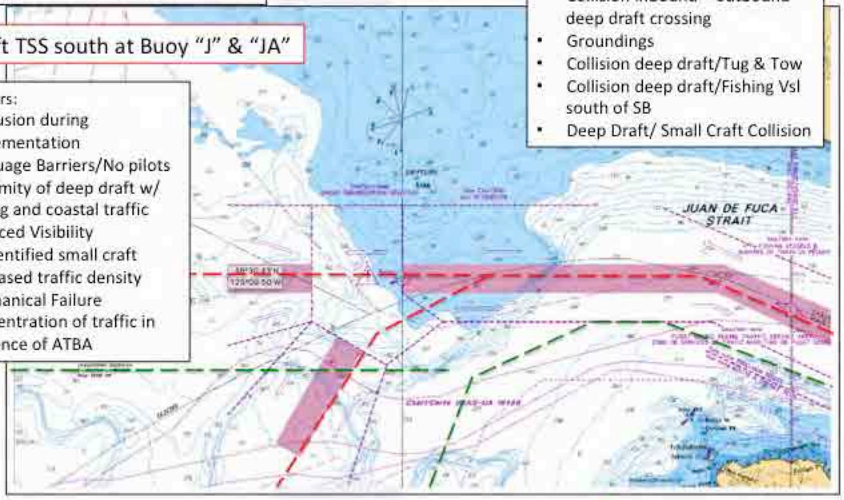
Refinement/Definition of Measures

(1) Lateral Displacement

1e. Shift TSS south at Buoy "J" & "JA"

Risk Scenarios:
- Collision inbound – outbound deep draft crossing
- Groundings
- Collision deep draft/Tug & Tow
- Collision deep draft/Fishing Vsl south of SB
- Deep Draft/ Small Craft Collision

Risk Factors:
- Confusion during implementation
- Language Barriers/No pilots
- Proximity of deep draft w/ fishing and coastal traffic
- Reduced Visibility
- Unidentified small craft
- Increased traffic density
- Mechanical Failure
- Concentration of traffic in presence of ATBA



Mitigations: [Measure 1E Shift TSS south at Buoys J and JA]
- ✓ Notice to Shipping
- ✓ Careful tracking and Advisory by VTS
- ✓ Expand compulsory pilotage
- ✓ Extra surveillance by VTS
- ✓ Study impact to other marine life
- ✓ Provide better tide and current predictions

Implementation Issues:
- Bi-national agreement
- TSS IMO approval
- Consultation with First Nations/U.S. Tribes
- Consultation with ABTA agency
- Careful redesign of TSS
- Agreement of coastal communities/ fishermen
- Establishing additional monitoring
- Awareness of new system
- Unintended impacts to marine life

Risk Assessment Summary:

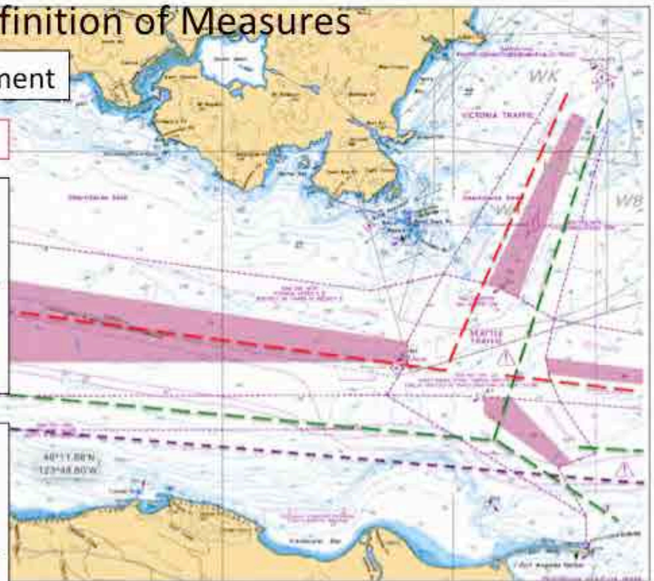
Probability:	L-1, H-3, M-2.5
Consequence:	L-1, H-5, M-3.8
Risk:	L-1, H-15, M-9.8
Mitig. Prob.	L-1, H-3, M-1.8
Mitig. Conseq.	L-1, H-5, M-3.7
Residual Risk	L-1, H-12, M-7.0
Implementation:	L-3, H-5, M-4.0

Discussion:
- ❑
- ❑

Refinement/Definition of Measures

(1) Lateral Displacement

1f. Shift TSS south at Sooke



Risk Scenarios:
- Collision inbound – outbound deep draft crossing
- Groundings
- Collision deep draft/Tug & Tow
- Collision deep draft/Fishing Vsl south of SB
- Deep Draft/ Small Craft Collision

Risk Factors:
- Confusion during implementation
- Unidentified small craft
- Language Barriers/No pilot
- Cutting corners to make transit window
- Close Proximity to coastal traffic
- Human Error
- Vessels closer to shore in south

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Mitigations: [Measure 1F Shift TSS south at Sooke]
- ✓ Public awareness campaign
- ✓ Notice to Shipping
- ✓ VTS Advisory
- ✓ Tug Availability
- ✓ Do not change TSS at Race Rock roundabout
- ✓ Extend compulsory pilotage
- ✓ Move outbound TSS south, but decrease Separation Zone to maintain same inshore lane to south
- ✓ Discontinue Recommended 2-way route south of lanes
- ✓ Work out agreement with FN/Tribal fishing vessels to provide VTS with their location
- ✓ Contingency routing of deep drafts during FN/Tribal fishery openings

Implementation Issues:
- Bi-national agreement
- TSS IMO approval
- Consultation with FN/U.S. Tribes
- Agreement of coastal communities
- Careful redesign of TSS
- Possible Geofencing
- Additional monitoring

Risk Assessment Summary:

Probability:	L-2, H-4, M-2.8
Consequence:	L-3, H-5, M-3.9
Risk:	L-6, H-20, M-11.2
Mitig. Prob.	L-1, H-3, M-1.9
Mitig. Conseq.	L-3, H-5, M-4.0
Residual Risk	L-3, H-12, M-7.8
Implementation:	L-3, H-5, M-4.0

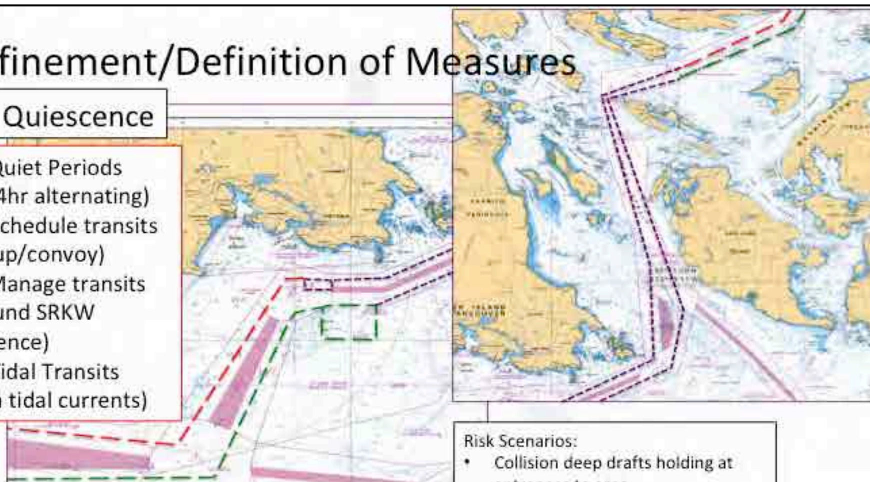
Discussion:
- ❑
- ❑

GREENWOOD MARITIME

Refinement/Definition of Measures

(2) Quiescence

2a. Quiet Periods (eg: 4hr alternating)
2b. Schedule transits (group/convoy)
2c. Manage transits (around SRKW presence)
2d. Tidal Transits (with tidal currents)



Risk Scenarios:
- Collision deep drafts holding at entrances to area
- Collision deep draft, small craft
- Collision deep drafts meeting in Haro Strait
- Grounding
- Allision w/vessel at anchor

Risk Factors:
- Loitering unpredictable vessels w/crossing potential
- Increased traffic density
- Required distance between vessels not maintained
- Close proximity of traffic and overused anchorages
- Abundance of unregulated small craft
- Loitering vessels outside compulsory pilotage
- Language Barriers
- Cutting corners to make transit window
- Unexpected change of plan when SRKW detected

GREENWOOD MARITIME

Mitigations: [Measure 2A Alt Quiet Periods]
- ✓ Time arrival at pilot station/Boundary to minimize loitering
- ✓ Keep1 nm distance separation of deep draft
- ✓ Enhance VTS monitoring
- ✓ Education of small craft operators
- ✓ Tug Availability
- ✓ Pilot Availability
- ✓ Additional mgmt. to avoid use of anchorages
- ✓ Manage arrival times at sea, not in SJDF
- ✓ Develop pilot procedure for awaiting clearance
- ✓ Require pilots on board vessels awaiting clearance
- ✓ Agreement to proceed in close proximity to other vessels at common speed

Implementation Issues:
- Bi-national agreement
- Notice to Shipping
- Consultation with PPA
- Coordination with Ports for departure times
- Pilotage availability – may need two
- Supply chain disruption
- SOP/VTS staff training
- Coast Pilot/Sailing Directions updates

Risk Assessment Summary:

Probability:	L-2, H-5, M-3.2
Consequence:	L-3, H-5, M-3.8
Risk:	L-8, H-25, M-12.2
Mitig. Prob.	L-1, H-4, M-2.1
Mitig. Conseq.	L-3, H-5, M-3.8
Residual Risk	L-3, H-20, M-8.2
Implementation:	L-2, H-5, M-2.9

Discussion:
- ☐ Very wide range of risk assessment
- ☐

GREENWOOD MARITIME

Mitigations: [Measure 2B Schedule, ,convoy]

- ✓ Time arrival at pilot station/Boundary to minimize loitering
- ✓ Keep1 nm distance separation of deep draft
- ✓ Enhance VTS monitoring
- ✓ Education of small craft operators
- ✓ Tug Availability
- ✓ Pilot Availability
- ✓ Additional mgmt. to avoid use of anchorages
- ✓ Manage arrival times at sea, not in SJDF
- ✓ Develop pilot procedure for awaiting clearance
- ✓ Require pilots on board vessels awaiting clearance

Implementation Issues:

- ✧ Bi-national agreement
- ✧ Notice to Shipping
- ✧ Consultation with PPA
- ✧ Coordination with Ports for departure times
- ✧ Pilotage availability – may need two
- ✧ Supply chain disruption
- ✧ SOP/VTS staff training
- ✧ Coast Pilot/Sailing Directions updates
- ✧ Grouping dissimilar ships to maintain transit group
- ✧ Industry negotiation

Risk Assessment Summary:

Probability:	L-3, H-5, M-3.6
Consequence:	L-3, H-5, M-3.9
Risk:	L-9, H-20, M-14.3
Mitig. Prob.	L-2, H-4, M-2.7
Mitig. Conseq.	L-3, H-5, M-4.0
Residual Risk	L-6, H-20, M-10.8
Implementation:	L-3, H-5, M-3.6

Discussion:

- ❑ Avg consequence higher after mitigation?
- ❑

Mitigations: [Measure 2C Manage ,around SRKW]

- ✓ Allow ships to spread out at best speed after delay
- ✓ Get whale info to vessels as early as possible
- ✓ Enhance VTS monitoring
- ✓ Geofencing Techniques
- ✓ Dedicated VTS sector
- ✓ Education of small craft operators
- ✓ Tug Availability
- ✓ Pilot Availability
- ✓ Additional mgmt. to avoid use of anchorages
- ✓ Require pilots on board vessels awaiting clearance
- ✓ Deep Draft crew training

Implementation Issues:

- ✧ Negotiate process with industry
- ✧ Determine maximum wait times
- ✧ Find verifiable process for spotting SRKW – decision to suspend traffic
- ✧ Engagement with PPA
- ✧ Supply chain disruption
- ✧ Industry support
- ✧ Resource Availability needed in bunched times
- ✧ SOP/VTS staff training
- ✧ Coast Pilot/Sailing Directions updates

Risk Assessment Summary:

Probability:	L-3, H-5, M-3.7
Consequence:	L-3, H-5, M-3.9
Risk:	L-9, H-25, M-14.6
Mitig. Prob.	L-2, H-4, M-2.7
Mitig. Conseq.	L-3, H-5, M-4.0
Residual Risk	L-6, H-20, M-10.8
Implementation:	L-2, H-5, M-3.6

Discussion:

- ❑ Avg consequence higher after mitigation?
- ❑

Mitigations: [Measure 2D Tidal transits]

- ✓ Allow ships to spread out at best speed after delay
- ✓ Enhance VTS monitoring
- ✓ Geofencing Techniques
- ✓ Dedicated VTS sector
- ✓ Education of small craft operators
- ✓ Tug Availability
- ✓ Pilot Availability
- ✓ Additional mgmt. to avoid use of anchorages
- ✓ Require pilots on board vessels awaiting clearance
- ✓ Deep Draft crew training

Implementation Issues:

- ✧ Negotiate process with industry
- ✧ Determine maximum wait times
- ✧ Find verifiable process for spotting SRKW – decision to suspend traffic
- ✧ Engagement with PPA
- ✧ Supply chain disruption
- ✧ Industry support
- ✧ Resource Availability needed in bunched times
- ✧ SOP/VTS staff training
- ✧ Coast Pilot/Sailing Directions updates

Risk Assessment Summary:

Probability:	L-2, H-5, M-2.3
Consequence:	L-3, H-5, M-3.9
Risk:	L-8, H-25, M-13.1
Mitig. Prob.	L-1, H-4, M-2.4
Mitig. Conseq.	L-3, H-5, M-3.9
Residual Risk	L-3, H-20, M-9.8
Implementation:	L-2, H-5, M-3.5

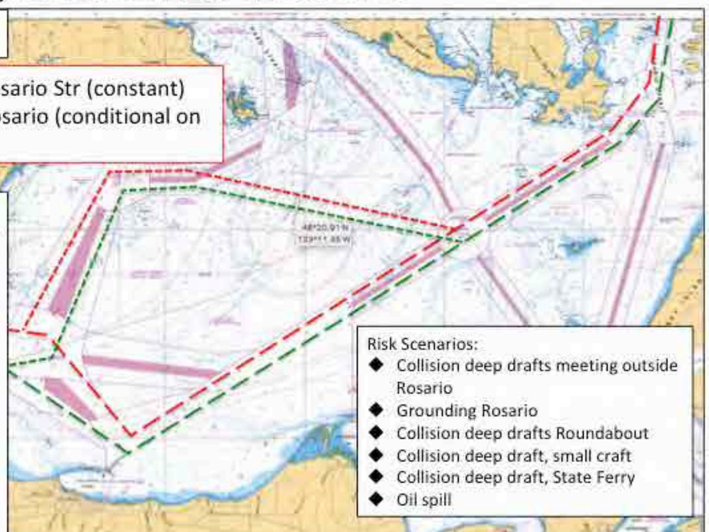
Discussion:

- ❑
- ❑

Refinement/Definition of Measures

(3) Redirection

3a. Redirection to Rosario Str (constant)
3b. Redirection to Rosario (conditional on SRKW in Haro)



Risk Factors:

- Increase traffic density at PA pilot station/ Rosario
- Rosario more complex w/more traffic
- Confusion over redirection
- Rosario not suitable for 2-way traffic
- Proximity to land
- Abundance of unregulated small craft
- Significant potential crossing situations as part of existing scheme
- Strong currents

Risk Scenarios:

- Collision deep drafts meeting outside Rosario
- Grounding Rosario
- Collision deep drafts Roundabout
- Collision deep draft, small craft
- Collision deep draft, State Ferry
- Oil spill

Mitigations: [Measure 3A Constant Redirection]
- ✓ Mgmt of meeting situations by VTS – holding ships back at Hein Bank
- ✓ Geofencing techniques
- ✓ Dedicated VTS sector
- ✓ Tethered or Escort tugs for all deep draft
- ✓ Active VTS directive of GO/NO Go Rosario
- ✓ Education of small craft operators
- ✓ Law Enforcement presence

Implementation Issues:
- ✧ Bi-national agreement
- ✧ U.S. agreement to accept Canadian traffic
- ✧ Pilot demand on PSP
- ✧ Pilot exchange at Roberts Bank
- ✧ Possible violation of Canadian commitment to UNCLOS
- ✧ Possible violation of U.S. regulations
- ✧ Restricting vessels in right to innocent passage
- ✧ Industry consultation
- ✧ U.S. Tribes consultation
- ✧ Consultation with environmental groups
- ✧ Negotiate process with industry
- ✧ SOP/VTS staff training
- ✧ Coast Pilot/Sailing Directions updates

Risk Assessment Summary:

Probability:	L-2, H-5, M-3.5
Consequence:	L-3, H-5, M-4.4
Risk:	L-8, H-25, M-15.6
Mitig. Prob.	L-2, H-4, M-2.5
Mitig. Conseq.	L-3, H-5, M-4.4
Residual Risk	L-6, H-16, M-11.2
Implementation:	L-4, H-5, M-4.7

Discussion:
- ❑ Highest risk, residual risk, and implementation effort
- ❑

Mitigations: [Measure 3B , redirection if SRKW present]
- ✓ PSP to board at Victoria if vessel is redirected
- ✓ Geofencing techniques
- ✓ Dedicated VTS sector
- ✓ Tethered or Escort tugs for all deep draft
- ✓ Active VTS directive of GO/NO Go Rosario
- ✓ Education of small craft operators
- ✓ Law Enforcement presence
- ✓ Reliable system to get max warning time of presence of SRKW
- ✓ If in Victoria area before whales sighted should be allowed to continue.

Implementation Issues:
- ✧ Bi-national agreement
- ✧ U.S. agreement to accept Canadian traffic
- ✧ Pilot demand on PSP
- ✧ Pilot exchange at Roberts Bank
- ✧ Process for VTS advance notice of redirection
- ✧ Possible violation of U.S. regulations
- ✧ Restricting vessels in right of innocent passage
- ✧ Industry consultation
- ✧ U.S. Tribes consultation
- ✧ Consultation with environmental groups
- ✧ Negotiate process with industry
- ✧ SOP/VTS staff training
- ✧ Coast Pilot/Sailing Directions updates

Risk Assessment Summary:

Probability:	L-1, H-4, M-3.2
Consequence:	L-3, H-5, M-4.4
Risk:	L-3, H-20, M-14.3
Mitig. Prob.	L-1, H-4, M-2.5
Mitig. Conseq.	L-3, H-5, M-4.5
Residual Risk	L-3, H-16, M-11.4
Implementation:	L-2, H-4, M-4.3

Discussion:
- ❑
- ❑

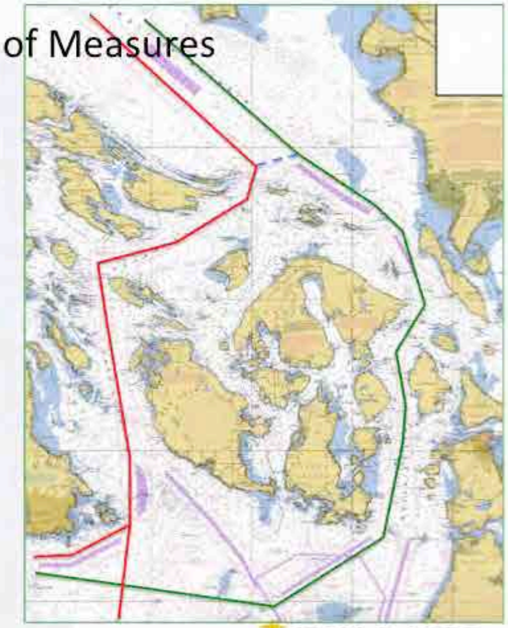
Refinement/Definition of Measures

(3) Redirection

3c. One way traffic CCW Rosario-Haro

Risk Scenarios:
- Collision deep drafts N of Patos Island
- Collision deep drafts crossing traffic West of New Dungeness
- Grounding Rosario/ Alden Bank
- Grounding Haro
- Collision deep draft, small craft
- Collision deep draft, State Ferry
- Oil spill

Risk Factors:
- Increase traffic density Rosario
- Increase tanker traffic in Rosario
- Increased crossing traffic at Patos
- Increased crossing traffic from Discovery Isl to PA pilot station
- Proximity to land
- Confusion over redirection
- Abundance of unregulated small craft
- Vessel separation requirements with a ferry crossing will be difficult with increased traffic
- Strong currents



GREENWOOD MARITIME

Mitigations: [Measure 3C One Way CCW Rosario-Haro]
- ✓ Geofencing techniques
- ✓ Dedicated VTS sector
- ✓ Tethered or Escort tugs for all deep draft
- ✓ Education of small craft operators
- ✓ Law Enforcement presence

Implementation Issues:
- Bi-national agreement
- U.S. agreement to accept Canadian traffic
- Pilot demand on PSP
- Pilot exchange at Roberts Bank
- Possible violation of Canadian commitment to UNCLOS
- Possible violation of U.S. regulations
- Industry consultation
- U.S. Tribes consultation
- Consultation with environmental groups
- SOP/VTS staff training
- Coast Pilot/Sailing Directions updates

Risk Assessment Summary:

Probability:	L-1, H-4, M-2.8
Consequence:	L-3, H-5, M-4.4
Risk:	L-3, H-20, M-12.9
Mitig. Prob.	L-1, H-4, M-2.3
Mitig. Conseq.	L-3, H-5, M-4.4
Residual Risk	L-3, H-16, M-10.2
Implementation:	L-2, H-5, M-4.3

Discussion:
- ❑
- ❑

GREENWOOD MARITIME

Refinement/Definition of Measures

(4) Speed Reduction

4a. Fixed Speed Reduction
4b. Circumstantial Sp Reduction
4c. Conditional (by Ship) Sp Reduction
4d. Circumstantial Sp Reduction in SJDF

Risk Factors:

- Limitation of ship control at slow speed in strong current
- Proximity to land
- Abundance of unregulated small craft
- Significant potential crossing situations
- Additional risk for some vessels restricted in maneuvering and alterations due to speed.
- Increase fatigue for pilot/crew
- Loss of situational awareness due to fatigue
- Human error
- Mechanical Failure
- Traffic congestion
- Inability to match speed – challenge maintaining safe CPA due to environmentals and vsl draft
- Extreme wx
- Commercial pressure

Risk Scenarios:

- Collision deep drafts in Haro
- Grounding in Haro
- Hard strike at berth making up time
- Collision deep drafts in Haro
- Grounding in Haro
- Collision [in Haro] due to awkward overtaking situations
- Collision/Grounding in SJDF

Mitigations: [Measure 4A Fixed Max Sp in Haro]

- ✓ Do not require speed of less than 10kts
- ✓ Mandatory double pilots
- ✓ Allow exceptions for safety situations
- ✓ Use Rosario

Implementation Issues:

- Bi-national agreement
- Industry agreement
- Regulation changes
- Implementation by pilots/MCTS
- Impact on industry and commerce, pilotage time requirements
- Compliance and Enforcement
- Delays to industry, loss of turn at anchor, scheduling difficulties, pilotage costs, late penalties
- If no whales, why slow down
- Inequity of delay across vessel type
- Consultation with FN/U.S. Tribes
- SOP/VTS staff training [for monitoring?]
- Coast Pilot/Sailing Directions updates

Risk Assessment Summary:

Probability:	L-2, H-3, M-2.5
Consequence:	L-3, H-5, M-4.0
Risk:	L-6, H-15, M-10.3
Mitig. Prob.	L-1, H-2, M-1.6
Mitig. Conseq.	L-3, H-4, M-4.0
Residual Risk	L-3, H-10, M-6.5
Implementation:	L-1, H-5, M-2.7

Discussion:

- ❑
- ❑

GREENWOOD MARITIME

Mitigations: [Measure 4B Circumstantial Sp Reduction when SRKW present]
- ✓ Do not require speed of less than 10kts
- ✓ Mandatory double pilots
- ✓ Allow exceptions for safety situations
- ✓ Use Rosario

Implementation Issues:
- Verifiable process for sighting SRKW
- Bi-national agreement
- Industry agreement
- Regulation changes
- Implementation by pilots/MCTS
- Impact on industry and commerce, pilotage time requirements
- Compliance and Enforcement
- Delays to industry, loss of turn at anchor, scheduling difficulties, pilotage costs, late penalties
- Inequity of delay across vessel type
- Consultation with FN/U.S. Tribes
- SOP/VTS staff training [for monitoring?]
- Coast Pilot/Sailing Directions updates

Risk Assessment Summary:

Probability:	L-2, H-3, M-2.6
Consequence:	L-3, H-5, M-4.0
Risk:	L-6, H-15, M-10.6
Mitig. Prob.	L-1, H-3, M-1.8
Mitig. Conseq.	L-3, H-5, M-4.1
Residual Risk	L-3, H-12, M-7.3
Implementation:	L-2, H-5, M-2.9

Discussion:
- ❑
- ❑

GREENWOOD MARITIME

Mitigations: [Measure 4C Sp Reduction Conditional by Vessel]
- ✓ Speed determined by ship characteristics
- ✓ Mandatory double pilots
- ✓ Allow exceptions for safety situations
- ✓ Use Rosario

Implementation Issues:
- Determination of ship by ship requirements
- Consistency in definition and application
- Enforcement process
- Larger vessels may need escort tug due to slow speeds
- Bi-national agreement
- Impact on industry and commerce, pilotage time requirements
- Compliance and Enforcement
- Delays to industry, loss of turn at anchor, scheduling difficulties, pilotage costs, late penalties
- Need to seek fairness across unequal playing field in requirements
- Consultation with FN/U.S. Tribes
- SOP/VTS staff training
- Coast Pilot/Sailing Directions updates

Risk Assessment Summary:

Probability:	L-2, H-3, M-2.4
Consequence:	L-3, H-5, M-4.0
Risk:	L-6, H-15, M-9.6
Mitig. Prob.	L-1, H-2, M-1.6
Mitig. Conseq.	L-3, H-5, M-4.0
Residual Risk	L-3, H-10, M-6.5
Implementation:	L-2, H-5, M-3.3

Discussion:
- ❑
- ❑

GREENWOOD MARITIME

Mitigations: [Measure 4D Sp Reduction in SJDF with SRKW presence]
- ✓ Do not require speed of less than 10kts
- ✓ VTS to provide locations of fishing vessels to deep draft
- ✓ Expand compulsory pilotage
- ✓ Allow exceptions for safety situations

Implementation Issues:
- Definition of areas
- Look-out or notification of SRKW
- Method of detecting if SRKW present
- Bi-national agreement
- Awareness of new system to foreign vessels
- Geofencing techniques
- Compliance and Enforcement
- SOP/VTS staff training [for monitoring?]
- Coast Pilot/Sailing Directions updates

Risk Assessment Summary:

Probability:	L-1, H-5, M-2.5
Consequence:	L-2, H-5, M-3.8
Risk:	L-2, H-20, M-10.3
Mitig. Prob.	L-1, H-5, M-2.1
Mitig. Conseq.	L-2, H-5, M-2.8
Residual Risk	L-2, H-20, M-8.3
Implementation:	L-2, H-5, M-3.0

Discussion:
- ❑ Very wide variance in risk assessment
- ❑

GREENWOOD MARITIME

Other Concerns?

- What have we missed and need to include within this Risk Assessment?

GREENWOOD MARITIME

ANNEX C. RA MITIGATIONS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Measure	**0. Status Quo**	0a. Current Operations in Haro Strait	**1. Lateral Displacement**	1a. Protected area E in Haro Str	1b. SC route west of Haro Str lane	1c. SOA - Haro Str One-way	1d. SJDF - Shift outbound N of SB	1e. SJDF - Shift all lanes further S of SB	1f. Shift SJDF TSS off Sooke to south	**2. Quiescence**	2a Quiet Periods	2b. Schedule transits	2c. Manage transits	2d. Tidal transits	**3. Redirection**	3a. Redirection through Rosario	3b. Conditional redirection to Rosario	3c. One-way Rosario-Haro (I/O)	**4. Speed Reduction**	4a. Fixed SP Limit in Haro	4b. Circumstantial SP Limit in Haro (SRKW)	4c. Conditional SP Limit in Haro (Vessels)	4d. Circumstantial SP Limit in SJDF	
Mitigation																								
1 CCG - Law Enforcement presence		1														1	1	1						4
2 CCG - Notice to Shipping								1	1															2
3 DFO - Provide better tide and current prediction					1			1																2
4 DFO - Reliable system to get max warning time of presence of SRKW													1				1							2
5 DFO - Study impact to other marine life								1																1
6 Education - general		1		1	1		1																	4
7 Education - Encourage small craft to cross at BS					1	1																		2
8 Education - Public awareness campaign									1															1
9 Education - Small craft operators											1	1	1	1		1	1	1						7
10 Education -Deep Draft crew training													1	1										2
11 Pilots - Develop pilot procedure for awaiting clearance											1	1												2
12 Pilots - Expand compulsory pilotage							1	1	1														1	4
13 Pilots - Keep 1 nm distance separation of deep draft											1	1												2
14 Pilots - Mandatory double pilots																				1	1	1		3
15 Pilots - Pilot Availability (i.e. scheduling)											1	1	1	1										4
16 Pilots - Prevent deep draft meeting at Kelp Reef				1																				1
17 Pilots - Puget Sound Pilots to board at Victoria if vessel is redirected																	1							1
18 Pilots - Require pilots for vessels loitering for clearance						1					1	1	1	1										5
19 Pilots - Securite Broadcasts				1																				1
20 Pilots - SOA mgmt of vsls to prevent meeting at Kelp Reef						1																		1
21 TC - Improved nav equipment for fishing vsls							1																	1
22 TC - Mandatory AIS carriage for small craft					1																			1
23 TC - Speed determined by ship characteristics																						1		1
24 TSS - Better design of TSS					1	1																		2
25 TSS - Complete surveys and channel design process					1																			1
26 TSS - Discontinue Recommended 2-way route south of lanes									1															1
27 TSS - Do not change TSS at Race Rock roundabout									1															1
28 TSS - Inshore traffic lanes							1																	1
29 TSS - Move outbound TSS south, but decrease Separation Zone									1															1
30 TSS - One-way traffic					1																			1
31 TSS - Prohibit sailing in area					1																			1
32 TSS - Redesign TSS to reflect SOA procedures						1																		1
33 TSS - Require only pleasure craft, naval vessels, light tugs					1																			1
34 TSS - Separation of SC		1																						1
35 TSS - Slow speed over SB							1																	1

Measure	0. Status Quo	0a. Current Operations in Haro Strait	1. Lateral Displacement	1a. Protected area E in Haro Str	1b. SC route west of Haro Str lane	1c. SOA - Haro Str One-way	1d. SJDF - Shift outbound N of SB	1e. SJDF - Shift all lanes further S of SB	1f. Shift SJDF TSS off Sooke to south	2. Quiescence	2a.Quiet Periods	2b. Schedule transits	2c. Manage transits	2d. Tidal transits	3. Redirection	3a. Redirection through Rosario	3b. Conditional redirection to Rosario	3c. One-way Rosario-Haro (I/O)	4. Speed Reduction	4a. Fixed SP Limit in Haro	4b. Circumstantial SP Limit in Haro (SRKW)	4c. Conditional SP Limit in Haro (Vessels)	4d. Circumstantial SP Limit in SJDF	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Mitigation																								
36 TSS - Smaller WPZ (less impact on TSS)				1																				1
37 TSS - Speed Reductions				1																				1
38 TSS - Use Rosario																				1	1	1		3
39 TSS - Wx exceptions for protected area				1																				1
40 Tugs - Rescue tug on standby		1		1		1	1		1		1	1	1	1										9
41 Tugs - Tethered or Escort tugs for all deep draft				1												1	1	1						4
42 VTS - Active VTS directive of GO/NO Go Rosario																1	1							2
43 VTS - Additional mgmt. to avoid use of anchorages											1	1	1	1										4
44 VTS - Advise location of FN/Tribal fishing vessels									1															1
45 VTS - Agreement to proceed in close proximity to other vessels at common speed											1													1
46 VTS - Allow exceptions for safety situations																				1	1	1	1	4
47 VTS - Allow ships to spread out at best speed after delay													1	1										2
48 VTS - Contingency routing of deep drafts during FN/Tribal fishery openings									1															1
49 VTS - Dedicated VTS sector				1	1								1	1		1	1	1						7
50 VTS - Do not require speed of less than 10kts																				1	1		1	3
51 VTS - Early notification of one-way restrictions						1																		1
52 VTS - Enforcement of traffic lanes		1		1	1	1																		4
53 VTS - Enhance VTS monitoring											1	1	1	1										4
54 VTS - Extra surveillance by VTS								1																1
55 VTS - Extra surveillance identifying fishing vsl locations							1																	1
56 VTS - Geofencing		1		1	1								1	1		1	1	1						8
57 VTS - If in Victoria area before whales sighted should be allowed to continue.																	1							1
58 VTS - Improved VTS		1																						1
59 VTS - Increase coord of Brotchie and VFPA terminals for SOA arrival						1																		1
60 VTS - Increase VTS comms about SOA and meeting situations						1																		1
61 VTS - Manage arrival times at sea, not in SJDF, to minimize loitering											1	1												2
62 VTS - Mgmt of meeting situations by VTS Ð holding ships back at Hein Bank																1								1
63 VTS - Provide locations of fishing vessels to deep draft																							1	1
64 VTS - Strict coordination of S & N bound vessels						1																		1
65 VTS -Careful tracking and Advisory by VTS								1	1															2
		9		15	17	17	14	14	19		21	21	24	24		23	26	23		24	25	26	27	

GREENWOOD MARITIME

ANNEX D. IMPLEMENTATION ISSUES

	Implementation Issues	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
		0. Status Quo	0a. Current Operations in Haro Strait	**1. Lateral Displacement**	1a. Protected area E in Haro Str	1b. SC route west of Haro Str lane	1c. SOA - Haro Str One-way	1d. SJDF - Shift outbound N of SB	1e. SJDF - Shift all lanes further S of SB	1f. Shift SJDF TSS off Sooke to south	**2. Quiescence**	2a.Quiet Periods	2b. Schedule transits	2c. Manage transits	2d. Tidal transits	**3. Redirection**	3a. Redirection through Rosario	3b. Conditional redirection to Rosario	3c. One-way Rosario-Haro (I/O)	**4. Speed Reduction**	4a. Fixed SP Limit in Haro	4b. Circumstantial SP Limit in Haro (SRKW)	4c. Conditional SP Limit in Haro (Vessels)	4d. Circumstantial SP Limit in SJDF	
1	Additional monitoring							1		1															2
2	Availability/Cost of Rescue Tug				1																				1
3	Awareness of new system							1	1															1	3
4	Bi-national agreement				1	1		1	1	1		1	1				1	1	1		1	1	1	1	14
5	Careful redesign of TSS								1	1															2
6	Challenge of redirecting vessels when not following					1																			1
7	Coast Pilot/Sailing Directions updates						1					1	1	1	1		1	1	1		1	1	1	1	12
8	Compliance and Enforcement																				1	1	1	1	4
9	Consistency in definition and application																						1	1	2
10	Consultation and agreement with industry				1	1							1	1	1		1	1	1		1	1			10
11	Consultation with ABTA agency								1																1
12	Consultation with coastal communities				1			1	1	1															4
13	Consultation with environmental groups																1	1	1						3
14	Consultation with First Nations/U.S. Tribes							1	1	1							1	1	1		1	1	1		9
15	Consultation with PPA											1	1	1	1										4
16	Coordination with Ports for departure times											1	1												2
17	Delays to industry, supply chain disruption, etc						1					1	1	1	1						1	1	1		8
18	Determination of ship by ship requirements																						1		1
19	Determine maximum wait times													1	1										2
20	Education of small craft operators				1	1																			2
21	Enforcement process				1	1																	1		3
22	Establishing additional monitoring								1																1
23	Flexibility of WPZ				1																				1
24	Geofencing techniques									1														1	2
25	Grouping dissimilar ships to maintain transit group												1												1
26	ID/Comms with small craft				1																				1
27	Implementation by pilots/MCTS																				1	1			2
28	Inequity of delay across vessel type																				1	1	1		3
29	Larger vessels may need escort tug due to slow speeds																						1		1
30	Noise and other issues with coastal communities					1																			1
31	Notice to Shipping											1	1												2
32	Pilot demand on PSP																1	1	1						3
33	Pilot exchange at Roberts Bank																1	1	1						3
34	Pilotage availability						1					1	1	1	1										5
35	Possible violation of Canadian commitment to UNCLOS																1		1						2
36	Possible violation of U.S. regulations																1	1	1						3
37	Process for VTS advance notice of redirection																	1							1
38	Redesign of TSS in a CVTS system						1																		1
39	Regulation changes													1							1	1			3
40	Regulatory change process					1																			1
41	Restricting vessels in right of innocent passage																1	1							2
42	SOP changes and VTS staff training						1					1	1	1	1		1	1	1		1	1		1	11
43	TSS IMO approval				1	1	1	1	1	1															6
44	U.S. agreement to accept Canadian traffic																1	1	1						3
45	Unintended impacts to marine life							1	1																2
46	Verifiable process for spotting SRKW													1	1						1	1		1	5
47	Warning inbound traffic to time arrivals						1																		1
		0	0	0	9	8	7	7	9	7	0	8	10	9	8	0	12	12	11	0	11	11	10	8	