Board of Pilotage Commissioners Tug Escort Rulemaking (Chapter 363-116 WAC)
State Environmental Policy Act Draft Environmental Impact Statement

Environmental Health: Noise Discipline Report

Washington State Board of Pilotage Commissioners

Washington State Department of Ecology

Olympia, WA

June 2025

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Acronyms and Abbreviations

ATB	articulated tug barge
AIS	Automatic Identification System
ARTEMIA	Acoustic Real-Time Exposure Model Incorporating Ambient
BLM	Bureau of Land Management
BMP	best management practice
BPC	Board of Pilotage Commissioners
CFR	Code of Federal Regulations
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CORI	Coastal Ocean Research Institute
CWR	Center for Whale Research
dB	decibel
DFO	Fisheries and Oceans Canada
DNR	Washington State Department of Natural Resources
DPS	Distinct Population Segment
Ecology	Washington Department of Ecology
EFH	Essential Fish Habitat
EIS	Environmental Impact Statement
ESA	Endangered Species Act
ESHB	Engrossed Substitute House Bill
FOR	functional and operational requirement
FR	Federal Register
HAPC	Habitat Area of Particular Concern
hp	horsepower
Hz	hertz
kHz	kilohertz
L_{eq}	average (equivalent continuous) noise level
L_5	highest (95th percentile) noise level, represents the sound pressure level that is exceeded 5 percent of the time
L_{50}	median (50th percentile) noise level, represents the sound pressure level that is exceeded 50 percent of the time

MMPA	Marine Mammal Protection Act
MPA	Marine Protected Area
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NWIFC	Northwest Indian Fisheries Commission
NWR	National Wildlife Refuge
OTSC	Oil Transportation Safety Committee
RCW	Revised Code of Washington
RPM	revolutions per minute
SEPA	State Environmental Policy Act
SPL	sound pressure level
SRKW	Southern Resident Killer Whale
USACE	U.S. Army Corps of Engineers
USCG	U.S. Coast Guard
USFWS	U.S. Fish and Wildlife Service
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife

Summary

This Discipline Report is produced by the Washington State Department of Ecology (Ecology) as part of the development of an Environmental Impact Statement (EIS) as required pursuant to the State Environmental Policy Act (SEPA).

The Board of Pilotage Commissioners (BPC), in consultation with Ecology, is conducting a rulemaking to amend Chapter 363-116 of the Washington Administrative Code (WAC), Pilotage Rules. The rulemaking will consider 2019 legislative changes made to Chapter 88.16 of the Revised Code of Washington (RCW) (Pilotage Act) through the passage of Engrossed Substitute House Bill (ESHB) 1578. The rules will be designed to achieve best achievable protection, as defined in RCW 88.46.010, and will be informed by other considerations in ESHB 1578. The BPC and Ecology determined that the rulemaking may have significant adverse impacts on the environment and are developing an EIS.

This Noise Discipline Report describes the existing conditions and potential impacts to noise resource resulting from the four rulemaking alternatives: No Action (Alternative A), Addition of Functional and Operational Requirements (FORs) (Alternative B), Expansion of Tug Escort Requirements (Alternative C), and Removal of Tug Escort Requirements (Alternative D). To compute underwater noise levels, a specialized underwater acoustic model was applied using forecast vessel traffic data for each alternative provided by Ecology. Results were prepared for two time periods, one in January (winter conditions) and the other in July (summer conditions). Acoustic source levels for different vessel categories were derived from a comprehensive review of existing vessel underwater radiated noise (URN) data sets and reports. Local water depths and environmental parameters that influence underwater sound propagation were accounted for by the model. The outputs included sound maps of average noise levels across the modeling area, and the metrics for the average (L_{eq}), median (L_{50}), and highest (L_5) noise levels were tabulated in three frequency bands: broadband sound pressure level (SPL) and Southern Resident killer whale (SRKW) communication and echolocation bands. The change in these metrics was also calculated for each alternative. See JASCO Applied Sciences' Technical Memorandum on Underwater Noise Modeling for details on the underwater noise modeling approaches used for this assessment.

The following noise-related objectives were analyzed in the assessment:

- What are the existing underwater sound levels at the key receptor locations (i.e., biologically significant areas)? How often are the National Marine Fisheries Service (NMFS) behavioral disturbance thresholds for marine mammals and fishes (120 and 150 dB broadband SPL, respectively) exceeded at these locations?
- How do existing tug escort operations contribute to these existing underwater noise conditions? Conversely, how would removal of the tug escort requirements change in noise levels?
- How would the proposed expansion of the tug escort requirements affect the underwater sound levels at the key receptor locations?
- What are the airborne operational noise impacts to human and wildlife receptors?

Significant and unavoidable noise impacts were identified under Alternatives A, B, and C. Table 1 summarizes the changes in escort tug activity under each alternative, the resulting impacts on noise, mitigation measures identified, and determinations of significance.

Table 1. Noise impact summary.

Change in Activity	Resulting Impact on Noise	Comparison to No Action Alternative	Mitigation	Significant and Unavoidable Adverse Impact?
Alternative A: No Action				
Continued operation of escort tugs throughout EIS Study Area.	Continued substantial contribution to underwater noise impacts at certain locations.	N/A	Adherence to laws (Endangered Species Act, Marine Mammal Protection Act), codes (requirements for minimum distances between vessels and whales, and vessel speed in proximity to whales), and Standards of Care and best management practices (participating in noise reduction programs).	**Yes**
	Continued airborne noise from escort tug engines, ventilation, whistles, etc.	N/A	Adherence to state noise standards and best practices to limit unnecessary and nighttime airborne noise.	No
Alternative B: Addition of Functional and Operational Requirements				
Continued operation of escort tugs throughout EIS Study Area.	Continued substantial contribution to underwater noise impacts at certain locations.	Same as for Alternative A.	Same as for Alternative A.	**Yes**
	Continued airborne noise from escort tug engines, ventilation, whistles, etc.	Same as for Alternative A.	Same as for Alternative A.	No

Change in Activity	Resulting Impact on Noise	Comparison to No Action Alternative	Mitigation	Significant and Unavoidable Adverse Impact?
Alternative C: Expansion of Tug Escort Requirements				
Increase in escort tug underway time (by 2.41%) and shift in escort tug commute and escort locations.	Continued substantial contribution to underwater noise impacts at certain locations.	Minor increase in underwater noise at certain locations.	Same as for Alternative A.	**Yes**
	Continued airborne noise from escort tug engines, ventilation, whistles, etc.	Minor increase in airborne noise at certain locations.	Same as for Alternative A.	No
Alternative D: Removal of Tug Escort Requirements				
Elimination of escort tug activity throughout EIS Study Area.	Substantial reduction in underwater noise at certain locations.	Substantial reduction in underwater noise at certain locations.	None.	No
	Eliminated airborne noise from escort tug engines, ventilation, whistles, etc.	Minor decrease in airborne noise in the EIS Study Area.	None.	No

1.0 Introduction

1.1 Background

The Board of Pilotage Commissioners (BPC), in consultation with the Washington Department of Ecology (Ecology), is conducting a rulemaking to amend Chapter 363-116 of the Washington Administrative Code (WAC), Pilotage Rules. The rulemaking will consider 2019 legislative changes made to Chapter 88.16 of the Revised Code of Washington (RCW) (Pilotage Act) through the passage of Engrossed Substitute House Bill (ESHB) 1578. The rules will be designed to achieve best achievable protection, as defined in RCW 88.46.010, and will be informed by other considerations in ESHB 1578.

The rulemaking will:

- Describe tug escort requirements for the following vessels (referred to as "target vessels" throughout this report) operating in the waters east of the line extending from Discovery Island light south to New Dungeness light and all points in the Puget Sound area:
  - Oil tankers of between 5,000 and 40,000 deadweight tons.
  - Articulated tug barges (ATBs) and towed waterborne vessels or barges greater than 5,000 deadweight tons that are designed to transport oil in bulk internal to the hull.
- Specify operational requirements for tug escorts, where they are required.
- Specify functionality requirements for tug escorts, where they are required.
- Consider the existing tug escort requirements applicable to Rosario Strait and connected waterways to the east, established in RCW 88.16.190(2)(a)(ii), including adjusting or suspending those requirements, as needed.
- Describe exemptions to tug escort requirements, including whether certain vessel types or geographic zones should be precluded from the escort requirements.
- Make other changes to clarify language and make any corrections needed.

> **Note:** Unless specified otherwise, the following terminology applies throughout this discipline report:
>
> - **"Tug escort"** refers to the act of a tug escorting a target vessel that is specifically affected by this rulemaking.
> - **"Escort tug"** refers to the tug that conducts escorts of target vessels. Underway time for an escort tug includes active escort time and time spent commuting to and from an escort job.

This rulemaking could potentially increase or decrease tug escort activity and the risk of oil spills in Puget Sound. The BPC and Ecology therefore determined that the rulemaking may have significant adverse impacts on the environment. The BPC and Ecology issued a Determination of Significance on February 22, 2023, which initiated development of an Environmental Impact Statement (EIS) as required under RCW 43.21C.030 (2)(c) pursuant to the State Environmental Policy Act (SEPA). At the same time, Ecology also issued a formal scoping notice as required through the SEPA process. Ecology conducted an EIS Scoping Meeting on March 21, 2023, to invite comments on the scope of the EIS and a comment period was open from February 22 through April 8, 2023.

The BPC and Ecology have agreed to act as co-lead agencies under SEPA and share lead agency responsibility for the EIS. The elements of the environment to be included in the EIS were preliminarily identified in the scoping notice. This Discipline Report serves as the detailed analysis of an element identified for inclusion in the EIS and will serve as supporting documentation to the EIS.

The BPC is conducting the rulemaking process concurrently with the EIS development and works closely with Ecology to coordinate the public involvement process. The rulemaking effort includes regular public involvement workshops that are designed to share information with stakeholders, Tribal government representatives, and the public. The BPC also appointed the Oil Transportation Safety Committee (OTSC) as an advisory committee of subject matter experts representing different areas like the regulated industry, Tribal governments, and environmental groups. The OTSC meets regularly to develop recommendations for the BPC, and the BPC makes the final decisions related to this rulemaking.

1.2 Rulemaking Alternatives

Through the rulemaking public involvement process, the BPC developed rulemaking alternatives for consideration in the EIS. The BPC has proposed four reasonable[1] rulemaking alternatives to be analyzed in the EIS. This Discipline Report analyzes the impacts associated with the four proposed rulemaking alternatives: No Action (Alternative A), Addition of Functional and Operational Requirements (FORs) (Alternative B), Expansion of Tug Escort Requirements (Alternative C), and Removal of Tug Escort Requirements (Alternative D). The proposed rulemaking alternatives are summarized below and are shown in Figure 1.

Alternative A. No Action. Under Alternative A, the existing tug escort regulations would continue in effect with no changes.

Alternative B. Addition of Functional and Operational Requirements. The existing tug escort regulations would continue with the addition that escort tugs operating under the rule would need to meet the following three functional and operational requirements:

1. Pre-escort conference: Prior to beginning the escort, the escort tug and the target vessel need to coordinate and discuss safety measures and other standard requirements.
2. Minimum horsepower: Escort tugs must meet minimum horsepower (hp) requirements based on the DWT of the escorted vessel:
    - Escort tugs must have 2,000 hp for vessels greater than 5,000 and less than 18,000 DWT
    - Escort tugs must have 3,000 hp for vessels equal to or greater than 18,000 DWT and less than 40, 000 DWT.
3. Propulsion specifications: To ensure sufficient propulsion, escort tugs must have a minimum of twin-screw propulsion.

Alternative C. Expansion of Tug Escort Requirements. This alternative would maintain the geographic scope of the current tug escort regulations and extend them to the northwest (see

[1] As defined in Chapter 197-11-786 WAC.

Figure 1 below). This alternative would add 28.9 square miles (74.9 square kilometers) to the existing geographic extent where tug escort requirements apply. The expansion area would be located at the northern boundary of the existing tug escort requirement. This alternative would include the above-mentioned three functional and operational requirements set forth under Alternative B.

Alternative D. Removal of Tug Escort Requirements. This alternative would remove the current tug escort requirement for the target vessels within the rulemaking boundaries.

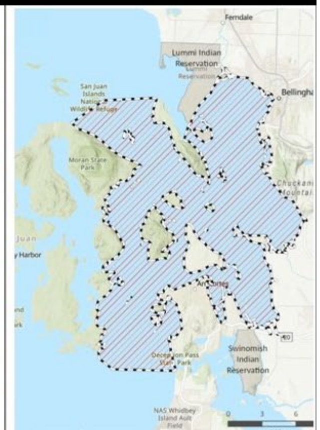
Alternative A (No Action)	Alternative B (Add FORs)	Alternative C (Expansion)	Alternative D (Removal)
			
No change to geographic scope of requirements	No change to geographic scope of requirements	Expand current requirements north to Patos Island	Remove requirements within current boundary
No change to existing functional and operational requirements (FORs)	Add pre-escort conference, minimum horsepower, and propulsion requirements	Add pre-escort conference, minimum horsepower, and propulsion requirements	N/A – tug escort requirements for target vessels are removed

Figure 1. Proposed rulemaking alternatives.

Under ESHB 1578, Ecology developed a model to simulate vessel traffic patterns and oil spill risk, including escort tug activity. The model was based on historical automatic identification system (AIS) data from 2015–2019 and was used to inform the 2023 Analysis of Tug Escorts for Tank Vessels. For the current EIS effort, Ecology used the model 1) to simulate the tracks of escort and assist[2] tug traffic, based on 2015–2019 historical AIS data, and 2) to simulate the current volumes of escort and assist tug traffic along these tracks while accounting for tug escort requirements that went into effect in 2020. Ecology also used the model to simulate tracks and volumes of target and non-target vessels based on 2015–2019 historical AIS data, specifically for use as inputs for the underwater noise modeling.

The model produced 1,000 annual simulations of escort and assist tug traffic. To represent current conditions and Alternative A, Ecology selected the simulation output with the highest

[2] Escort tugs are sometimes referred to as “escort/assist tugs” in this analysis because the same vessels typically perform both escorting and assisting work. Ecology used the model to simulate traffic for both escorting and assisting work; however, only escorting work would be affected by the rulemaking alternatives.

amount of escort tug traffic (i.e., the "worst case scenario") to ensure that the EIS does not undercount potential environmental impacts and to account for other potential near-term growth in vessel traffic (e.g., traffic from the Trans Mountain Expansion). For Alternative C, Ecology modified the Alternative A simulated traffic outputs to account for the proposed changes in tug escort requirements under that alternative. For Alternative D, activity associated with tug escort requirements was excluded from the underwater noise model inputs. Finally, Ecology adjusted the outputs for non-target vessels to account for recreational and fishing vessels that are not equipped with AIS.

The simulation outputs are used here to show the differences in underway time for escort tugs under Alternative A and Alternative C. Figure 2 and Figure 3 show the results of these simulations, compiled to indicate the total minutes per year (min per yr) of escort tug underway time within each one-square-kilometer grid cell. Figure 4 depicts the change in escort tug underway time between Alternatives A and C. Escort tug activity under Alternative B would not be expected to be meaningfully different than under Alternative A, while Alternative D would result in zero tug escorts. Refer to the Transportation: Vessel Traffic Discipline Report (Appendix B) for details regarding the vessels activity simulation methodology and results.

See Attachment A (JASCO's Technical Memorandum on the Underwater Acoustics Assessment) for additional details about how marine vessel activity was incorporated into the underwater noise model.

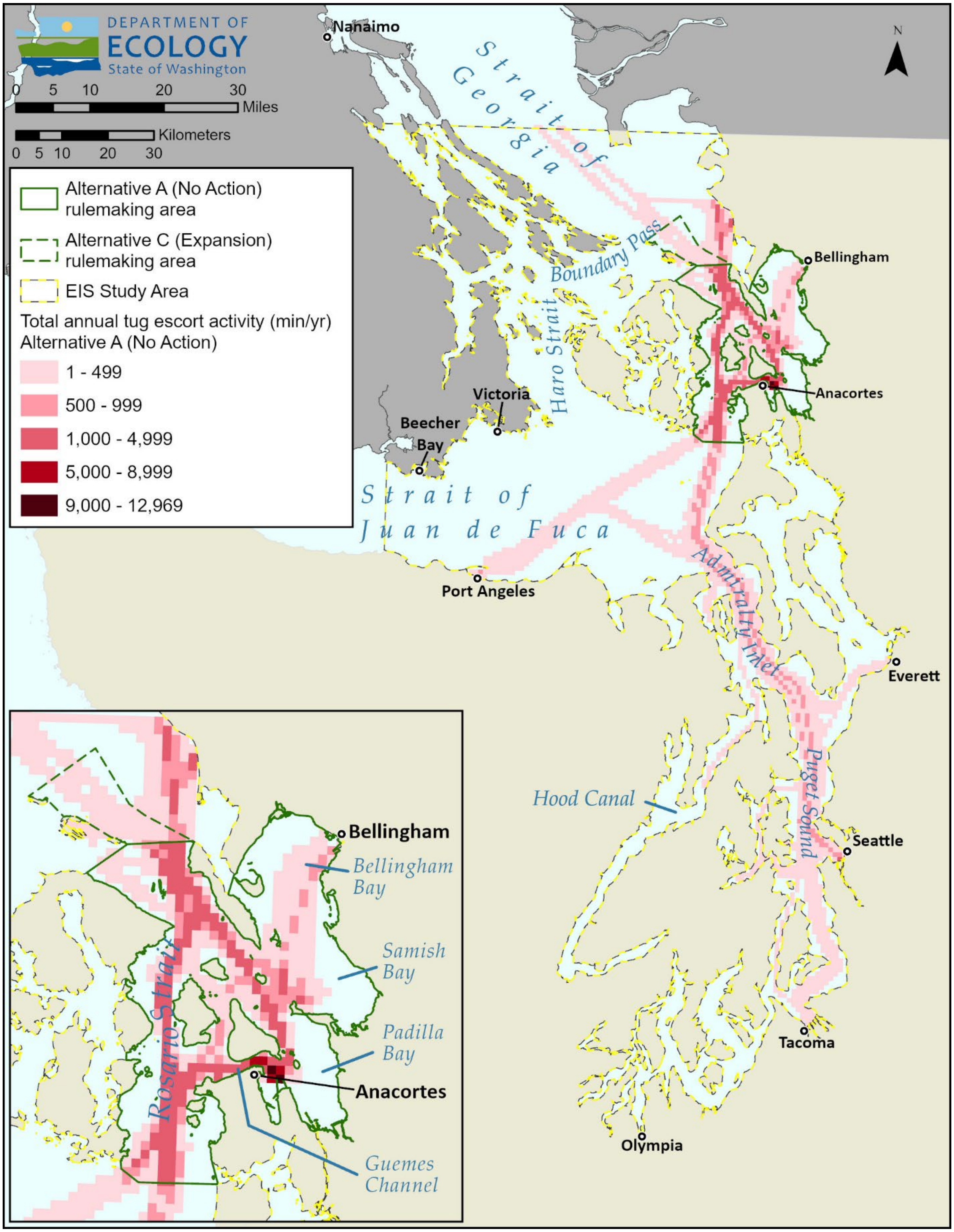


Figure 2. Simulated escort tug underway time under Alternative A.

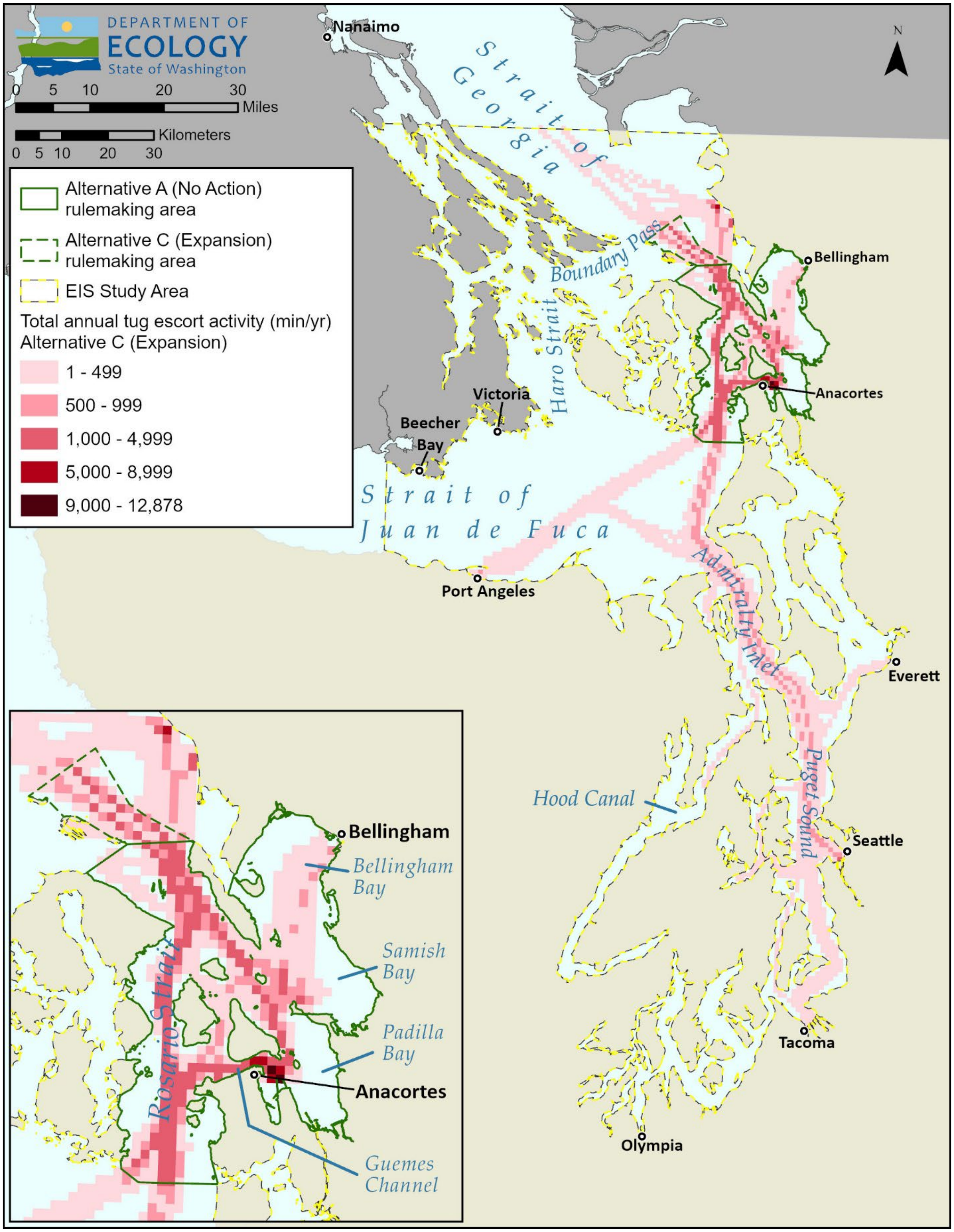


Figure 3. Simulated escort tug underway time under Alternative C.

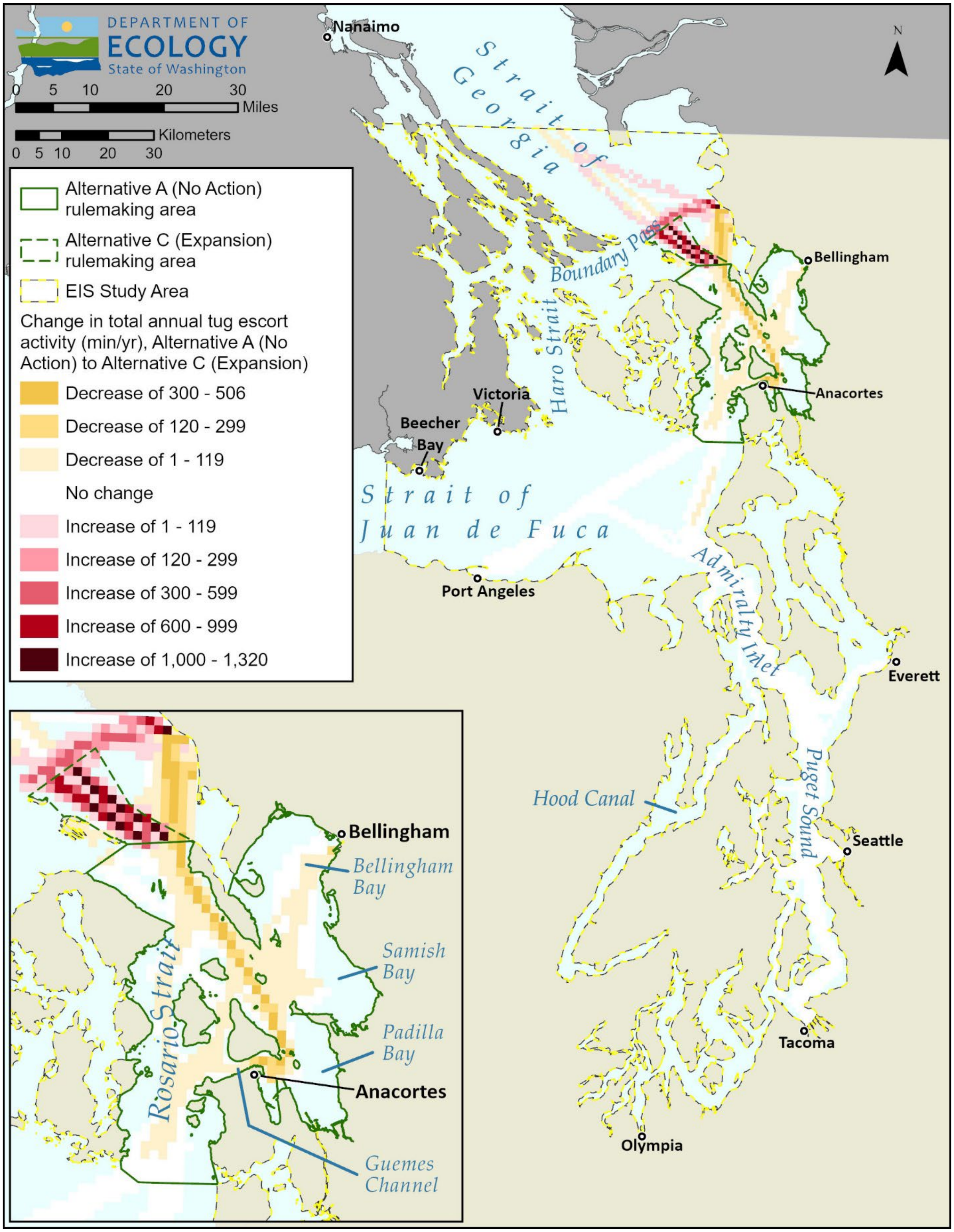


Figure 4. Simulated change in escort tug underway time between Alternative A and Alternative C. An additional accessible version of this map is available in Appendix M.

1.3 Resource Study Area

The EIS Study Area includes the rulemaking alternative boundaries and potential areas for escort tug commutes to and from the alternative boundaries. Specifically, the EIS Study Area includes all connected marine waters in the Salish Sea[3] network of coastal waterways (including Puget Sound), bounded to the north by the 49th Parallel and bounded to the west by a line extending across the Strait of Juan de Fuca from Pike Point to Tongue Point (see Figure 5). A smaller area was selected for the underwater noise modeling to optimize computation time and reduce storage requirements yet address the key objectives.

[3] The term "Salish Sea" is used here to describe the transboundary waters of the Strait of Juan de Fuca, the Puget Sound, and the Georgia Strait. The name for this waterbody was proposed in 1989 by a marine science professor at Western Washington University to emphasize the region as a single ecosystem. It has since been formally adopted by the Washington State Committee on Geographic Names (Chapter 237-990 WAC) and the British Columbia Geographical Names Office (BC Geographical Names, n.d.). It was named for the Coast Salish Tribes who live on or near the Salish Sea on both sides of the U.S.-Canadian border. However, the defined geographic boundary of the Salish Sea also extends into the lands and waters of Tribes that are not Coast Salish, including the Makah Tribe (Nuu-Chah-Nulth). We use the term "Salish Sea" in this analysis, but recognize the diversity of native peoples that have lived in and used these waters since time immemorial.

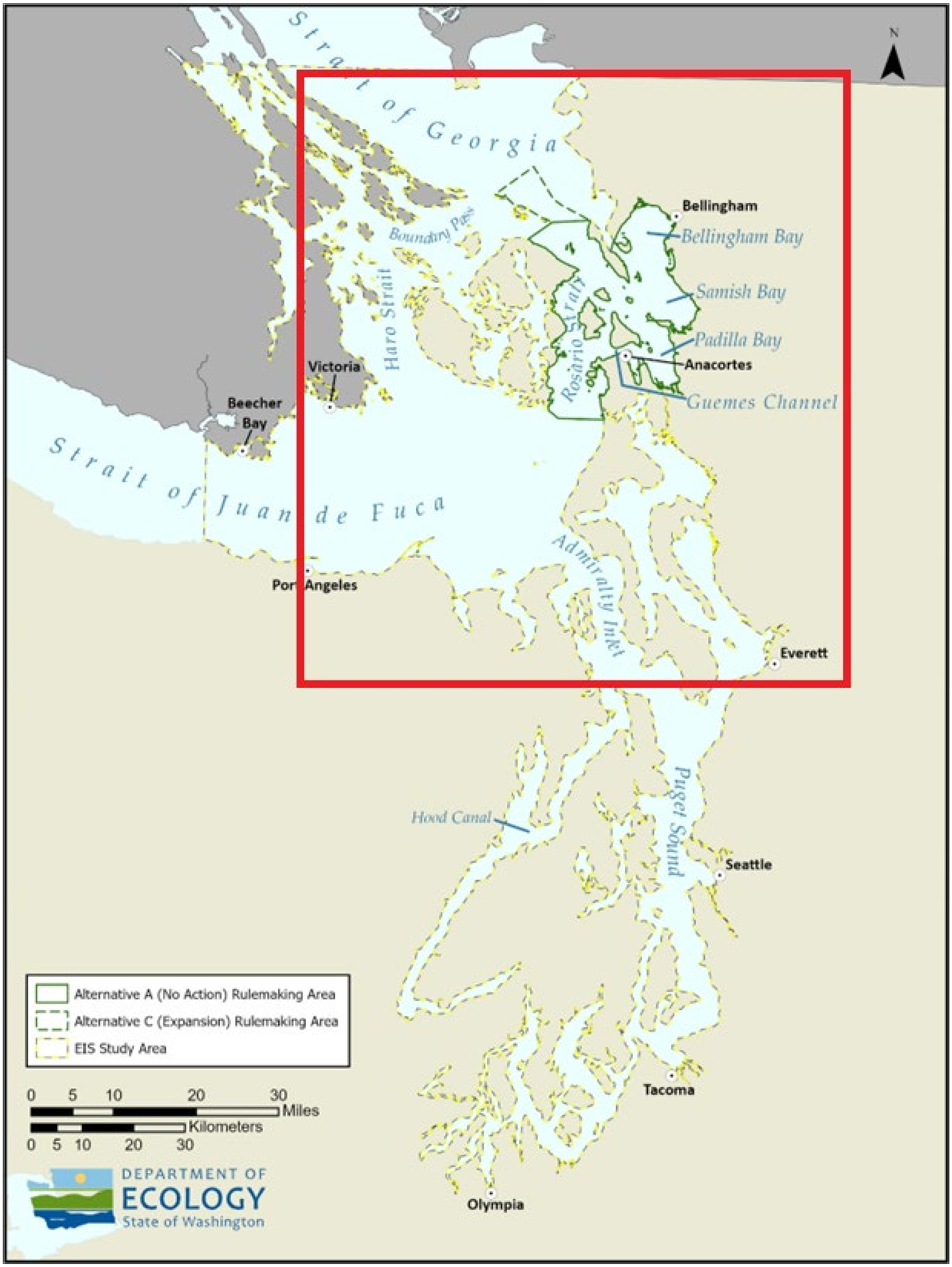


Figure 5. Boundary of the EIS Study Area with the underwater noise modeling area encompassed by the red box.

1.4 Resource Description

This Noise Discipline Report describes the existing noise in the EIS Study Area—focusing primarily on noise related to marine vessel activity—and evaluates the potential noise impacts as a result of each rulemaking alternative. The assessment focuses on the following sub-elements:

- Underwater noise assessment:
  - Marine mammals, including Southern Resident killer whale (SRKW) (*Orcinus orca*), Bigg's or transient killer whales, humpback whales, gray whales, minke whales, and harbor porpoise.
  - Finfish.
- Airborne operational noise impacts to human and wildlife receptors.

1.5 Regulatory Framework

Several federal and state laws, plans, and policies are applicable to noise in the EIS Study Area. Discussion of these laws, plans, and policies related to noise is intended to provide a framework for the overall regulatory context of the action but is not necessarily intended to imply applicability or compliance requirements for the four regulatory alternatives evaluated in the EIS.

Table 2 summarizes relevant federal and state laws, plans, and policies for noise.

Table 2. Relevant laws, plans, and policies related to noise.

Statute, Regulation, Policy	Description
Federal	
Endangered Species Act (ESA)	• Establishes the framework for the protection and conservation of threatened and endangered species and their habitats.
Marine Mammal Protection Act (MMPA)	• Establishes the framework to prevent the significant decline of marine mammal species and population stocks.
Protective Regulations for Killer Whales in the Northwest Region Under the Endangered Species Act and Marine Mammal Protection Act (76 Federal Register [FR] 20870)	• Establishes protections for killer whales against vessel encroachment by prohibiting vessels within 200 yards (183 meters) of killer whales and prohibiting vessels remaining in the path of whales in inland waters of Washington State, unless exempt.
Noise Control Act of 1972 (42 USC 4910)	• Sets a national policy to protect Americans from noise pollution that threatens their health or welfare; boosts federal coordination on noise control research and activities; establishes Federal noise emission standards; and informs the public about noise reduction strategies.

Statute, Regulation, Policy	Description
Inland Navigation Rules, Subpart D - Sound and Light Signals (33 Code of Federal Regulations [CFR] Part 83, Subpart D)	• Establishes the appropriate use of vessel "sound signals" (i.e., whistles, short blasts, and long blasts) for activity within U.S. inland waters.
Navigation Rules and Regulations handbook	• Establishes the "rules of the road" for vessel activity in inland and international waters, including regarding appropriate frequencies of vessel whistles.
Tribal	
N/A	
State	
Fish and Wildlife (RCW Title 77)	• Establishes state policies to preserve, protect, perpetuate, and manage fish and wildlife resources.
State Listed Species - Washington Administrative Code (WAC) Chapter 220-610-010, 220-200-100	• Identifies and classifies species in need of protection or management as state endangered, state threatened, or state sensitive; and defines the process for species listing, management, recovery, and delisting.
Executive Order 18-02, Southern Resident Killer Whale Recovery and Task Force	• Directs certain state agencies to take immediate action to aid in the recovery of SRKW populations and establishes the Southern Resident Killer Whale Task Force to identify, prioritize, and support the implementation of a long-term action plan to recover SRKW and address threats to SRKW.
Washington State Wildlife Action Plan	• Develops a comprehensive plan for conserving fish, wildlife, and natural habitats; provides a list of Species of Greatest Conservation Need for management purposes; and identifies threats to species and conservation actions and priorities.
RCW 79A.60.130	• Sets marine vessel noise standards and requires vessels to have mufflers.
WAC 173-60-040	• Implements a maximum permissible noise level. Does not apply to vessels.
Local	
San Juan County Municipal Code (Chapter 10.28 Article III, Operation of Vessels in Proximity to the Southern Resident Killer Whale)	• Requires vessel operators to adhere to measures that restrict the potential take of SRKW in San Juan County marine waters.

2.0 Methodology Summary

Ecology identified and reviewed scientific literature, technical reports, and data regarding existing noise within the EIS Study Area, focusing primarily on noise related to marine vessel activity. Ecology also reviewed Tribal and stakeholder input received from the scoping and workshop phases. During scoping, the public identified underwater noise, physical disturbances, and oil spill risks as primary concerns, with particular interest in how these factors affect marine mammals, specifically the SRKW population and SRKW extirpation risks. Scoping comments also expressed that fisheries studies should be considered (see Appendix F Plants and Animals Discipline Report for details). Additional noise-specific suggestions were put forward, including: examining differences in noise effects due to having two vessels present relative to one (addition of noise sources); considering similar studies which show that tugs contribute substantially to the local underwater soundscape; and looking into mitigation techniques, such as using hybrid vessels, slowing down, or moving traffic routes. These suggestions are addressed in this report.

Ecology reviewed available literature and data from previous studies and other technical sources associated with marine vessel activities to examine how different vessel categories contribute to the underwater soundscape in the EIS Study Area. Ecology also assessed the underwater noise distributions for several vessel activity simulations. These simulations estimated the existing annual spatial and temporal distribution for escort tugs, and how underway times and routes are modeled to change under the rulemaking alternatives (see Appendix B, Transportation: Vessel Traffic Discipline Report).

Ecology then identified seven biologically important locations that could be impacted by the proposed rulemaking and overlayed them with the escort tug density map to select certain locations for monitoring the sound levels under each alternative. High-resolution acoustic propagation modeling was performed to determine how existing marine vessels and escort tug operations affect the local soundscape, specifically at the identified biologically sensitive locations.

The model predicted some significant impacts based on the significance thresholds outlined in Table 3. Per WAC 197-11-794, significant “means a reasonable likelihood of more than a moderate adverse impact on environmental quality” and should rely on context (e.g., physical setting) and intensity (e.g., magnitude and duration of impact). Findings of significance were reported for each alternative, where identified.

Table 3. Significance thresholds for noise impacts.

Indicator	Significance Thresholds
Underwater sound levels exceeding the National Marine Fisheries Service (NMFS) acoustic disturbance thresholds	• Tug escort requirements contribute to at least a 10 percent increase in the area where received noise (ensonified area) is above the NMFS acoustic disturbance threshold compared to without tug escort requirements (Alternative D). • Tug escort requirements contribute to at least a 10 percent increase in the occurrence of periods during which received noise levels are above the NMFS acoustic disturbance thresholds compared to without tug escort requirements (Alternative D).
Highest and median underwater sound levels	• Tug escort requirements contribute to the highest received levels (95th percentile) increasing by greater than 3 decibels (dB) compared to without tug escort requirements (Alternative D). • Tug escort requirements contribute to the median received levels (50th percentile) increasing by greater than 3 dB compared to without tug escort requirements (Alternative D).
Airborne operational noise levels exceeding noise standards	• Reasonable likelihood of a chronic and recurring increase in the frequency, severity, and/or extent of noise standard exceedances in populated communities, due to source noise from escort tugs, compared to without tug escort requirements (Alternative D).

3.0 Technical Analysis and Results

This section describes the affected environment for noise within the EIS Study Area. It also describes the anticipated qualitative impacts on noise from the four alternatives: No Action (Alternative A), Addition of FORs (Alternative B), Expansion of Tug Escort Requirements (Alternative C), and Removal of Tug Escort Requirements (Alternative D). This section also identifies mitigation measures that could avoid, minimize, or reduce the potential impacts and determines if there would be significant and unavoidable adverse environmental impacts.

3.1 Affected Environment

The EIS Study Area for noise includes most of the connected network of marine waters in the Salish Sea (including Puget Sound), bounded to the north by the 49th Parallel and bounded to the west by a line extending across the Strait of Juan de Fuca from Pike Point to Tongue Point (see Figure 5). The Salish Sea is a geographic area encompassing land and water bodies of southern British Columbia, Canada, and northern Washington State. Major waters that make up the Salish Sea estuarine ecosystem include the Strait of Georgia, Strait of Juan de Fuca, and Puget Sound. Within these major waters are numerous straits, inlets, canals, and bays (Western Washington Institute, 2024).

The rulemaking areas include marine waters of San Juan, Skagit, and Whatcom counties, and a small portion of Island County, Washington. Specific waters include Bellingham Bay, Samish Bay, Rosario Strait, Thatcher Pass, Burrows Bay, and smaller areas such as Boat Harbor, Deepwater Bay, Strawberry Bay, Secret Harbor, and Cooks Cove.

Washington's marine waters support Tribal treaty fishing rights and cultural practices (see Appendix K Tribal Resources Discipline Report for further discussion). They are habitat for a vast array of species, are extensively used recreationally, and produce income from maritime sector economic activities. Vessels that utilize the EIS Study Area include recreational boats as well as large commercial vessels such as container ships, tank barges, ATBs, ferries, cruise ships, and commercial and factory fishing vessels. For the purposes of this analysis and consistent with previous analyses, Ecology is considering the escort tug population of this EIS to be the 18 escort tugs identified in Appendices P and Q of the 2021 Vessel Traffic Trend Study (BPC & Ecology, 2021). Ecology assumes that, while the fleet conducting tug escort activity may have changed since the 2021 study (and may continue to change), the fleet will remain generally similar in composition and characteristics (e.g., length) to those identified in the 2021 study. Ecology estimates that escort tug activity currently represents approximately 0.96 percent of the overall marine vessel activity with AIS in the EIS Study Area. See Appendix B Transportation: Vessel Traffic Discipline Report for details.

3.1.1 Overview of Marine Vessel Noise

The Salish Sea, including the EIS Study Area, is a high marine vessel traffic area for both commercial and recreational vessels (MacGillivray et al., 2024). Busy marine shipping routes pass through this area, including local and international shipping lanes to the Ports of Seattle, Tacoma, and Vancouver, British Columbia, as well as numerous passenger and cargo ferry routes, and several types of tugs. These inland waters are also popular for recreational and fishing vessels, as well as whale watching and other ecotourism traffic. Underwater noise, introduced into the environment by vessel traffic, can impact marine animals by disrupting their behavior, reducing their habitat quality, and limiting their ability to communicate and forage (Nowacek et al., 2007; Weilgart, 2007; Tyack, 2008; Joy et al., 2019).

A recent underwater noise study conducted in the Salish Sea (MacGillivray et al., 2024) evaluated sound level contributions from different categories of vessel traffic and compared them with the natural ambient background. The assessment found that, in general, the monthly average sound pressure level (SPL) from vessels exceeded ambient sound by more than 10 dB throughout most of the study area. The broadband frequency band contained the greatest excess of noise energy which can be attributed to the fact that underwater radiated noise (URN) emissions from large vessels are greatest at low frequencies (i.e., below 500 hertz [Hz]). Nonetheless, the excess level above ambient remained high in the SRKW frequency bands (detailed in Section 3.1.5), particularly near locations of concentrated vessel activity. These areas can be identified in the underwater soundscape maps produced for this study presented in Figure 6 and Attachment A. In the SRKW masking bands, exposure to sound levels 10 dB above ambient sound can have a substantial effect in reducing the available listening space for communication and echolocation, both important life functions for surviving in their habitat (Pine et al., 2018; Putland et al., 2017).

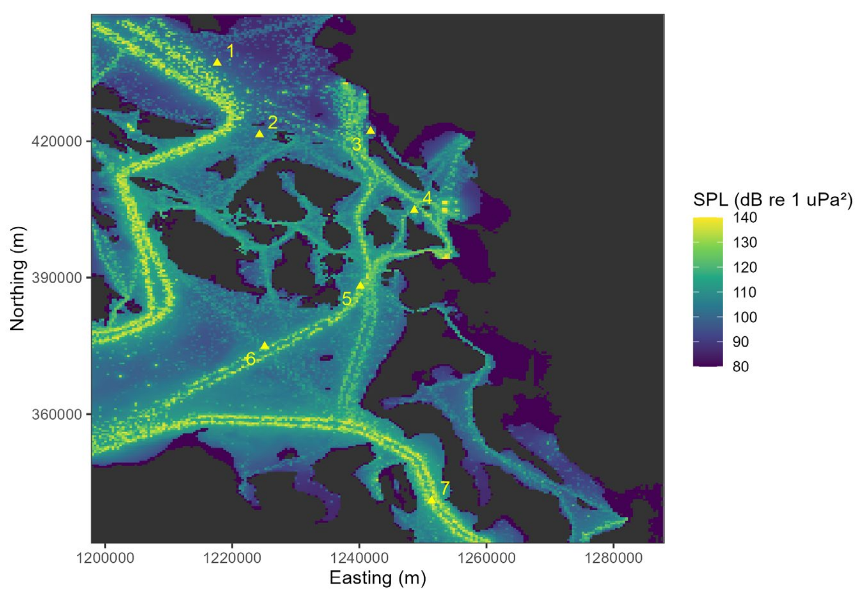


Figure 6. Equivalent continuous noise levels (L_{eq}) for summer in the broadband SPL for Alternative A. Key receptor locations (yellow triangles) are numbered on the map.

Due to the prevalence of underwater noise from Salish Sea vessel traffic and its overlap with SRKW critical habitat, voluntary vessel slowdown programs have been implemented in three separate locations in the region (Swiftsure Bank, Haro Strait and Boundary Pass, and Puget Sound) (Matei et al., 2024; Port of Vancouver, 2024). Studies have shown that noise levels decrease substantially during the slowdown periods with underwater SPL reductions by up to 3 dB (Joy et al., 2019; Matei et al., 2024; Port of Vancouver, 2024), which is equivalent to a 50 percent reduction in sound intensity due to decibels being on a logarithmic scale.

The current rulemaking proposes changes to escort tug traffic, and a recent local study (Matei et al., 2024) conducted in Puget Sound revealed that tug traffic can contribute up to approximately 19 percent to the overall underwater noise budget in the area. (MacGillivray et al., 2024) had consistent findings, with tugs ranked the second and third highest contributing vessel category in the SRKW communication and echolocation bands, respectively, in the Salish Sea.

While underwater noise is a primary ecological concern, marine vessel activity also contributes to airborne noise levels. Marine vessel airborne noise primarily comes from the propulsion and auxiliary engines, with other on-vessel sources including exhaust, ventilation systems, and occasional whistle use (e.g., foghorns). Whistles are generally used to communicate with other nearby vessels, announce vessel anchoring or presence while navigating in restricted visibility conditions (e.g., fog), or to signal an onboard emergency.

Vessel parameters, such as size and load, can influence airborne noise emissions. Typically, larger vessels produce more noise, as they require larger engines that also produce lower frequency sound waves that travel farther than high frequency waves (Physics Lab, 2025). Therefore, larger vessels may be audible to more distant receptors as compared to smaller vessels. Engine load further influences noise levels, as ships carrying or pulling heavier loads require more power and therefore produce more engine noise.

Vessels also contribute to airborne noise levels when in port and stationary. Repair and maintenance, loading and unloading cargo, and idling add to noise levels in ports.

Numerous factors influence the propagation and human perception of noise. The surrounding environment, such as topography, atmospheric conditions (e.g., temperature, humidity, wind), and even vegetation coverage (Gaudon et al., 2022; Hamer, 2019) can influence where and how far sound travels. Water bodies can act as “hard” surfaces for airborne noise, meaning they do not absorb sound well, resulting in noise reaching longer distances compared to noise travelling across noise-absorbent soft soils.

The noise contribution from an escort tug is dependent on whether it is actively escorting a target vessel or transiting on its own. Under Alternatives A (No Action) and C (Expansion), tugs are actively escorting for approximately 37–39 percent of their underway time and are commuting alone for the remaining 61–63 percent of underway time. Since noise is additive (on a logarithmic scale, due to noise being measured in decibels), there would be higher sound levels associated with escorting activities where more than one vessel is present, compared to a vessel on its own.

To better understand the existing underwater soundscape in the EIS Study Area, JASCO Applied Sciences (JASCO) conducted underwater acoustic noise modeling as discussed in Section 3.1.5 (Assessment of Current Underwater Noise Impacts from Marine Vessels).

3.1.2 Wildlife Noise Receptors

Many marine wildlife species that are found in the EIS Study Area are sensitive to underwater noise. Marine mammals are particularly sensitive to underwater noise due to their use of sound for vital life functions, which underwater noise can negatively affect. An overview of the species present in the area is given below, with a focus on their spatial and temporal distribution throughout the EIS Study Area. See the Plants and Animals Discipline Report (Appendix F) for detailed biological information and corresponding regulatory status on the marine life species present in the EIS Study Area.

The SRKW, with a current population of only 73 individuals, is an important species that utilizes the EIS Study Area (Center for Whale Research, 2024; Orca Conservancy, 2024). This distinct population of killer whales has been listed under the ESA as endangered (DOC, 2005) with three factors believed to be related to their decline: food availability, contaminant loads, and vessel and noise interactions (Krahn et al., 2002; Lacy et al., 2017; Shields et al., 2018). The SRKW population is protected under the ESA and MMPA in the United States, and the Species at Risk Act (SARA) in Canada. SRKW critical habitat spans much of the southern Salish Sea, due to the important salmon foraging grounds in this area, and overlaps with nearly the entire EIS Study Area. This killer whale ecotype relies on both passive listening as well as echolocation for communication, navigation, and finding food (Holt, 2008). Their presence is documented year-round, with a peak historically in spring and summer which has now shifted later in the year to summer and fall, coinciding with the abundance trends of their preferred prey, the Fraser River chinook salmon (Ettinger et al., 2022; Shields et al., 2024). SRKW presence in fall and winter in the Salish Sea has remained consistent or even increased in recent years (Shields et al., 2024).

The other population of killer whales that frequents the EIS Study Area is the Bigg’s or transient killer whales, whose population has had a significant increase in presence over the past 15 years (Shields et al., 2018, 2024). This population’s local distribution is more widespread than SRKW (Shields et al., 2024). Bigg’s killer whales also rely on the use of sound for important life functions, but they are less vocal and use passive listening to a greater extent than echolocation for foraging than SRKW (Ford et al., 2013) since they prey on marine mammals (Ford et al., 2013; Shields et al., 2018) whose hearing range overlaps with killer whale vocalizations. The peak occurrence for Bigg’s killer whales in the Salish Sea was historically in late summer but now spans half the year, from April through to September (Shields et al., 2024).

Other whale species that frequent the area are humpback, gray, and minke whales. The number of humpback and gray whale sightings in the Salish Sea has increased substantially over the last decade, while minke sightings have remained stable or decreased slightly (Olson et al., 2018; Shields et al., 2024). Recent studies (Olson et al., 2018; Shields et al., 2024) have identified each species’ current local presence and spatial distribution.

Harbor porpoises are another marine mammal species present in the Salish Sea with increased sightings in recent years (Anderson et al., 2023). Their distribution is relatively widespread but has localized concentrations in the waters south of Victoria, B.C., Boundary Pass, and southern Rosario Strait (Anderson et al., 2023).

Finfish (e.g., herring, salmon, etc.) present in the EIS Study Area are sensitive to underwater noise and are wildlife noise receptors. Approximately 200 species of finfish inhabit the waters throughout Puget Sound (Ruckelshaus & McClure, 2007). Critical habitat for five fish species can be found in the EIS Study Area, and nearly the entire EIS Study Area has been designated as Essential Fish Habitat (EFH) for Groundfish and Coastal Pelagic Species (NOAA Fisheries, 2020).

Birds are also wildlife noise receptors. While all birds could be affected by airborne noise, diving seabirds are also sensitive to underwater noise. Over 170 bird species utilize the Salish Sea marine ecosystem. While diving seabirds could be found in the waters throughout the EIS Study Area while foraging, marine birds in general tend to select nearshore habitats with limited disturbances for foraging and resting. Certain parts of the EIS Study Area, such as the San Juan Islands National Wildlife Refuge, have been designated as protected areas to preserve and provide important habitat specifically for birds.

See the Plants and Animals Discipline Report (Appendix F) for additional details regarding wildlife species present in the EIS Study Area.

3.1.3 Wildlife Noise Assessment Studies and Effects Criteria

Underwater sound from ships has, until recently, received lower interest than sound produced by louder sources such as seismic surveys and pile driving. However, ships are present over a much larger fraction of the world's oceans and vessel traffic more often overlaps with areas, such as the southern Salish Sea, with critical habitat of endangered species. There has been an increase in ship noise in many areas due to the increase in marine vessel traffic (McKenna et al., 2012). The waters within the EIS Study Area are biologically rich and diverse, as discussed in Appendix F Plants and Animals Discipline report. However, they also serve as major shipping corridors for commercial vessels and contain popular recreational and fishing areas. As awareness of anthropogenic noise and its potential to have negative impacts on wildlife increases, numerous studies have been conducted to better understand these effects—notably, on SRKW, due to their extremely vulnerable population status.

Several recent reports have confirmed negative impacts from vessels and their noise on SRKW. It was found that noise from vessels significantly impacted the communication and echolocation abilities of SRKW (Burnham & Moore, 2023), with a greater reduction in echolocation range during daylight hours and on weekends due to increases in recreational vessel traffic (DFO, 2021). Studies have also shown that SRKW significantly increased the sound level and duration of their calls in the presence of boats (Foote et al., 2004; Holt et al., 2009). This indicates that acoustic masking by boat noise affects the ability of these animals to communicate and it can be inferred that their communication and echolocation spaces are reduced. Furthermore, vessel noise has been shown to reduce the amount of time spent foraging, particularly in female SRKW (Tennessen et al., 2024). This can have even greater detrimental effects on the population given the important reproductive implications of females being impacted. Tennessen et al. (2024) also revealed that male SRKW have reduced success in attempted prey captures, and that high levels of noise (received SPL ≥110 dB re 1 μPa^2 in the

15–45 kilohertz [kHz] frequency band)[1] decreased dive depth and success during deep dives, likely reducing the capture of adult Chinook salmon.

A study by Fournet et al. (2018) found that humpback whales decreased their calling rate in the presence of vessel noise, regardless of the overall ambient noise level. Additionally, Sprogis et al. (2020) used vessel playback experiments to compare the impact of low and high levels of noise on humpback whales. They found that humpback whale mothers decreased their resting time by 30 percent, doubled their respiration rate, and increased their swim speed by 37 percent in response to the high level of noise playbacks (172 dB re 1 μPa^2 m^2 SPL low frequency-weighted source level). These behavioral changes not only affect the animals' physical demands, but could potentially have wider population effects due to alterations in mothering as well as mating behaviors, such as decreased calling and male singing rates shown in other studies (Fournet et al., 2018; Miller et al., 2000).

There are comparatively fewer noise impact studies for other marine wildlife species found in the EIS Study Area. However, studies on gray whale responses showed that vessel noise may result in displacement from prime habitat (Moore & Clarke, 2002) or impaired communication among individuals, which may compromise vital social interactions (Burnham & Duffus, 2019), including those essential for reproduction (Dahlheim & Castellote, 2016).

Because many marine animals rely on acoustic cues for survival, NMFS has established acoustic thresholds representing underwater noise levels at which the behavior of marine wildlife would be expected to be disturbed (NOAA Fisheries, 2023a, 2023b). These thresholds vary depending on the type of wildlife exposed to the noise as marine species have different hearing ranges and susceptibilities to hearing damage and behavioral disturbances (NOAA Fisheries, 2023a, 2023b). The NMFS marine mammal and finfish behavioral acoustic disturbance thresholds have been established as 120 dB broadband SPL and 150 dB broadband SPL, respectively, for continuous noise sources (NOAA Fisheries, 2023a, 2023b).

3.1.4 Human Noise Receptors

Human receptors for airborne escort tug noise include those in populated communities along the shoreline within the EIS Study Area. Communities that may perceive escort tug noise include Tacoma, Seattle, Everett, Port Townsend, Port Angeles, Anacortes, Bellingham, and Neptune Beach. Tribal communities are also sensitive noise receptors of note, particularly those located along the shoreline near major shipping lanes, such as the Lummi Nation and the Suquamish Tribe. People on other marine vessels, such as those used for fishing or recreation, could also be exposed to escort tug noise. Refer to Appendix I Recreation Discipline Report for information on recreational areas of interest.

[1] "dB re 1 μPa^2" is a common unit for measuring underwater sound levels. 'dB' stands for decibel, which is a unit of measure used to express the ratio of one value of a power quantity to another on a logarithmic scale. It is especially suited to quantify variables with a large dynamic range. '1 µPa' is the typical reference value for underwater sound level computations. When expressed as μPa^2 m^2 this refers to source levels referenced at 1 m from the source (Robin & Plante, 2022; ISO, 2017).

3.1.5 Assessment of Current Underwater Noise Impacts from Marine Vessels

In order to better understand the existing underwater soundscape in the EIS Study Area and assess potential underwater noise impacts from marine vessels (including escort tugs) under existing conditions and the proposed rulemaking alternatives, Ecology entered contract with JASCO to conduct underwater noise modeling. This subsection summarizes the modeling methodology and the results of the analysis for existing conditions (as represented by the results for Alternative A).

Underwater Noise Modeling Methodology

The JASCO applied a specialized underwater acoustic ship noise model to assess escort tug and other vessel noise. The ship noise model takes into account the Ecology-supplied simulated vessel tracks in 10-minute timesteps over the course of a week to compute estimated existing sound levels. The model predicts how escort tug traffic contributes to the soundscape (Figure 7 and Table 4). Additionally, changes in noise levels over time and under each alternative were investigated. The model incorporates all vessel categories present in the dataset, each with their unique source signature defined using an accurate source level formula that accounts for vessel category, size, and speed (MacGillivray et al., 2022). The overall sound field is determined by all acoustic sources present, incorporating their respective acoustic frequency distributions and corresponding levels. Refer to Attachment A for more details about the modeling approach.

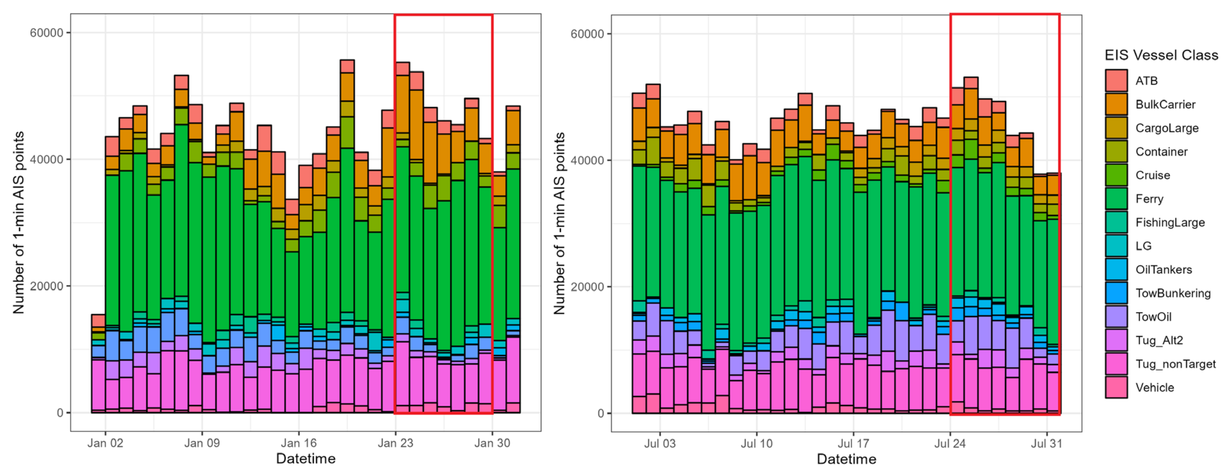


Figure 7. Daily density values for vessels with AIS (measured in number of 1 min vessel track points) in January (left) and July (right) 2022 for Alternative A: No Action. The weeks modeled are highlighted by the red box.

Table 4. Ten vessel categories used for the classification of all vessel traffic in the track datasets.

Category Name	Description
Cargo Vessels at Anchorage	Bulk Carriers, Container Ships, General Cargo Ships, Tankers, or Vehicle Carriers at anchor
Bulk Carriers	Cargo vessels that carry bulk cargo
Container Ships	Cargo vessels that carry shipping containers
Fishing	Fishing vessels, including commercial and indigenous fishing vessels, but excluding personal recreational fishing boats
Tankers	Cargo vessels transporting oil or large amounts of fluid
Passenger	Vessels with a purpose of carrying passengers that do not fit in other categories, such as cruise ships and water taxis
Recreational	Personal watercrafts
Ferry	Ferry vessels including roll-on roll-off vessels that carry passengers (ro-ro passenger) or cargo (ro-ro cargo)
Tugs and Tug-and-barge Combos	Tugs with or without associated barges, ATB, tow bunkering, tow oil tugs
Vehicle Carriers	Cargo vessels that transport vehicles

The underwater noise model focused on seven wildlife noise receptor locations. JASCO identified these receptors by conducting a literature review to determine areas of high importance to local marine wildlife, and more specifically to marine mammals due to their use of sound for vital life functions that could be negatively affected by underwater noise. To identify locations of high importance to SRKW, JASCO reviewed the most recent studies on SRKW distribution in the Salish Sea (Olson et al., 2018; DFO, 2021; Shields et al., 2024) that highlighted areas of high occurrence, which were overlayed with the affected escort tug traffic routes to determine areas of potential impact. Because humpback, gray, and minke whales also utilize the EIS Study Area and/or are also highly sighted marine mammal species in the Salish Sea, it is important to consider noise effects from the rulemaking on these species of baleen whale as well. Therefore, JASCO also examined areas utilized by humpback, gray, and minke whales (Olson et al., 2018; Shields et al., 2024). These areas of high biological importance were then overlayed with the Ecology-provided dataset of simulated escort tug activity to narrow the selection to a set of receptor locations that could be exposed to noise from escort tugs under existing conditions and/or one of the rulemaking alternatives. The seven selected wildlife receptor locations are shown in Figure 8 and described in Table 5.

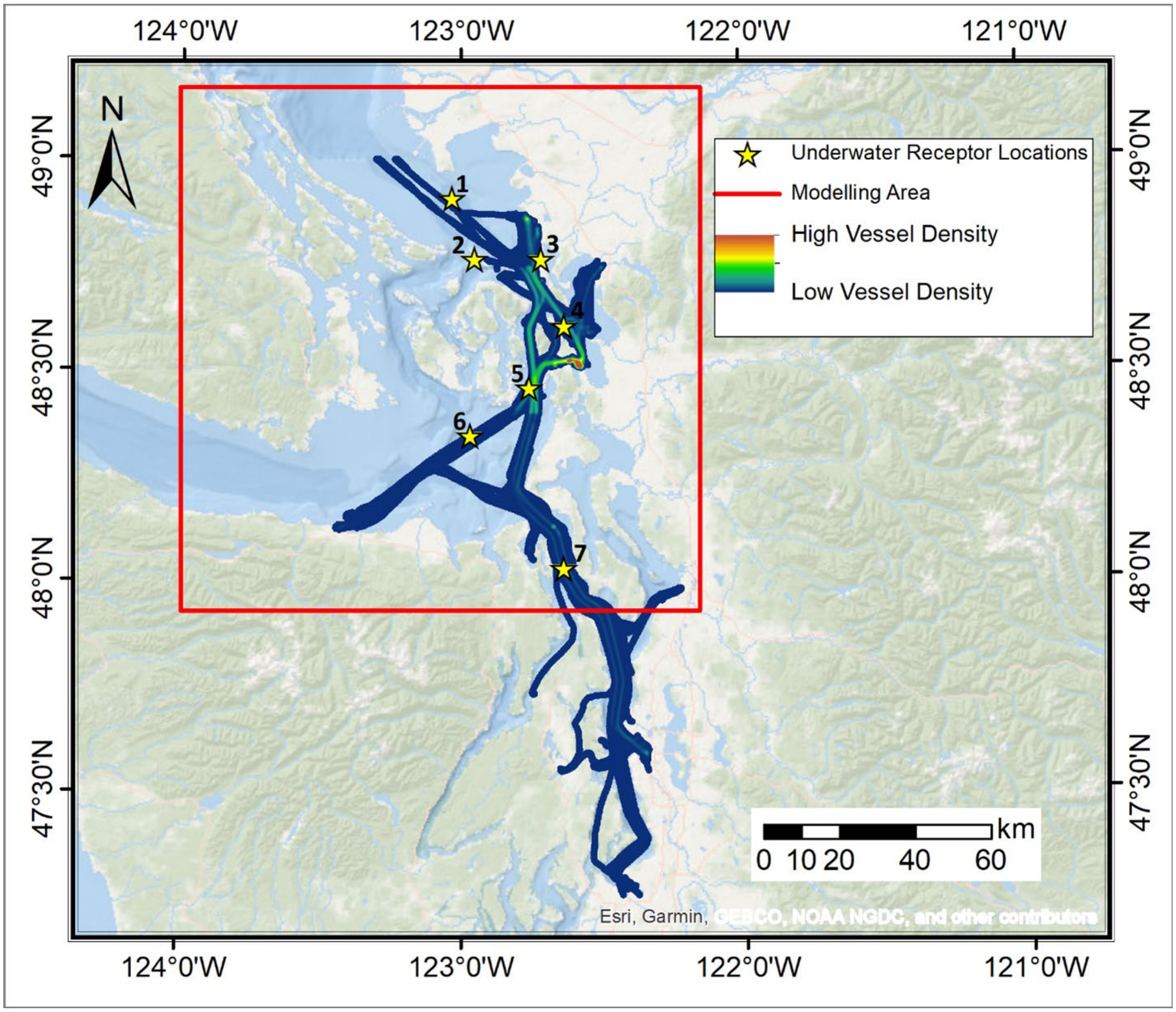


Figure 8. Map of modeling area with key acoustic receptor locations and density tracks of the escort tugs affected by the rulemaking.

Table 5. Key underwater noise receptor locations and rationale for their selection.

Key Receptor Location	Rationale for Selection
1 – Strait of Georgia	Near proposed expansion area and an area of intensive SRKW activity[a]
2 – Boundary Pass	Near proposed expansion area and an area frequented by SRKW,[a] humpback whales[b] and harbor porpoises[c]
3 – Lummi Bay	Near proposed expansion area
4 – Anacortes	Close to a moderate amount of target tug traffic and an area frequented by SRKW[a,d] and harbor porpoises[c]
5 – Rosario Strait	Close to a moderate amount of target tug traffic and an area frequented by SRKW,[a,d] gray whales[e] and harbor porpoises[c]
6 – Haro Strait	An area of intensive SRKW activity,[a,d] humpback whales[b] and minke whales[e]
7 – Puget Sound	Close to current target tug route and an area frequented by SRKW,[d] humpback, and gray whales[b]

Source: a – (DFO, 2021), b – (Olson et al., 2024), c – (Anderson et al., 2023), d – (Olson et al., 2018), e – (Shields et al., 2024)

Underwater acoustic modeling of vessel noise was then performed to characterize existing noise levels at these seven receptor locations and to investigate the changes under the escort tug rulemaking alternatives. This noise assessment used the NMFS behavioral acoustic disturbance threshold for marine mammals (120 dB broadband SPL) and fish (150 dB broadband SPL) for continuous sources (NMFS, 2024).

Underwater noise calculations were carried out using JASCO's Acoustic Real-Time Exposure Model Incorporating Ambient (ARTEMIA). The ARTEMIA is an underwater soundscape prediction and mapping model that accurately simulates underwater sound levels generated by large ensembles of marine sources that can be moving (e.g., such as vessels, geophysical surveys, and ambient sound) over large geographic areas. The model combines input data from several different sources, described below, to predict marine environmental noise originating from ship traffic and ambient sources. The frequency range of the sound mapping calculations was 10–63,000 Hz, in decidecade frequency bands.[1]

Key inputs to the ARTEMIA model included a georeferenced database describing environmental features influencing sound propagation, vessel source density maps, and time-dependent wind and rain data. From these inputs, ARTEMIA used numerical sound propagation models to produce digital maps of SPL data versus easting, northing, frequency, and depth for the study area (Figure 9).

[1] A frequency band whose bandwidth is equal to one decidecade, which is one tenth of a decade or approximately one third of an octave, and for this reason sometimes referred to as a 1/3 octave (ISO, 2017).

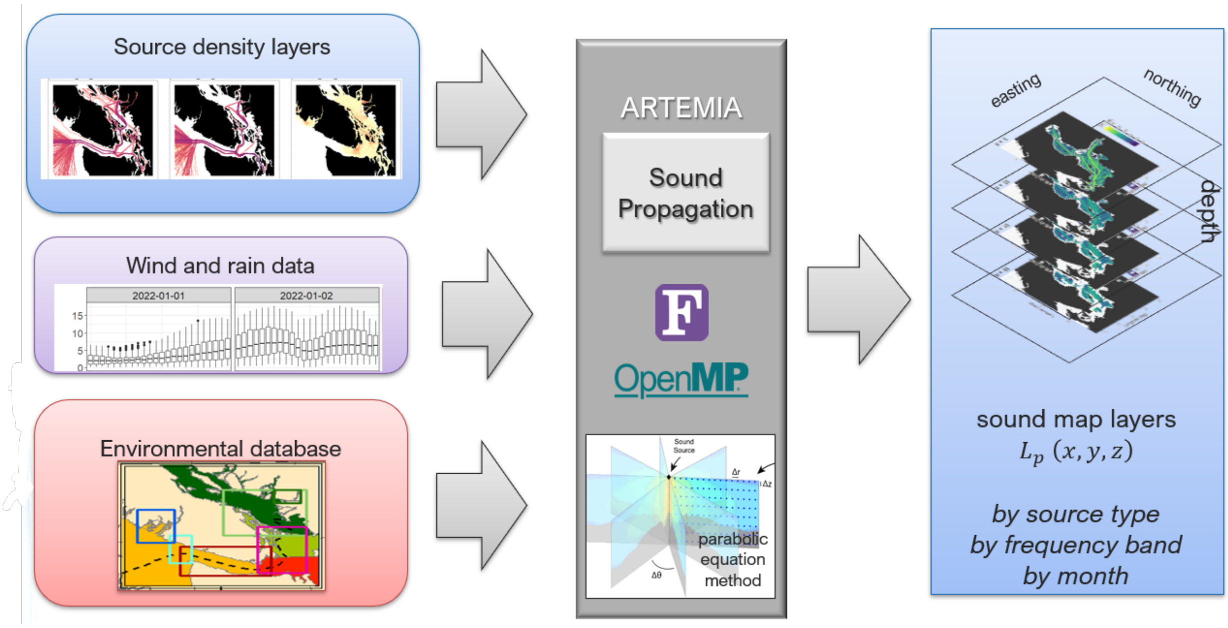


Figure 9. Flowchart of JASCO's Acoustic Real-Time Exposure Model Incorporating Ambient (ARTEMIA) model.

Sound maps generated using ARTEMIA were analyzed in terms of the following three frequency bands that were identified by an expert working group convened by the Coastal Ocean Research Institute (CORI) (Heise et al., 2017) as being particularly relevant to the acoustic quality of SRKW habitat:

1. Broadband (nominally 10–100,000 Hz; limited to 10–63,000 Hz for this study), for evaluating behavioral or physiological impacts.
2. Communication band (500–15,000 Hz), for evaluating effects of noise on communication masking.
3. Echolocation band (nominally 15,000–100,000 Hz; limited to 15,000–63,000 Hz for this study), for evaluating effects of noise on echolocation masking.

These frequency bands cover the range of overlap between vessel noise and SRKW hearing sensitivity, as shown in Figure 10.

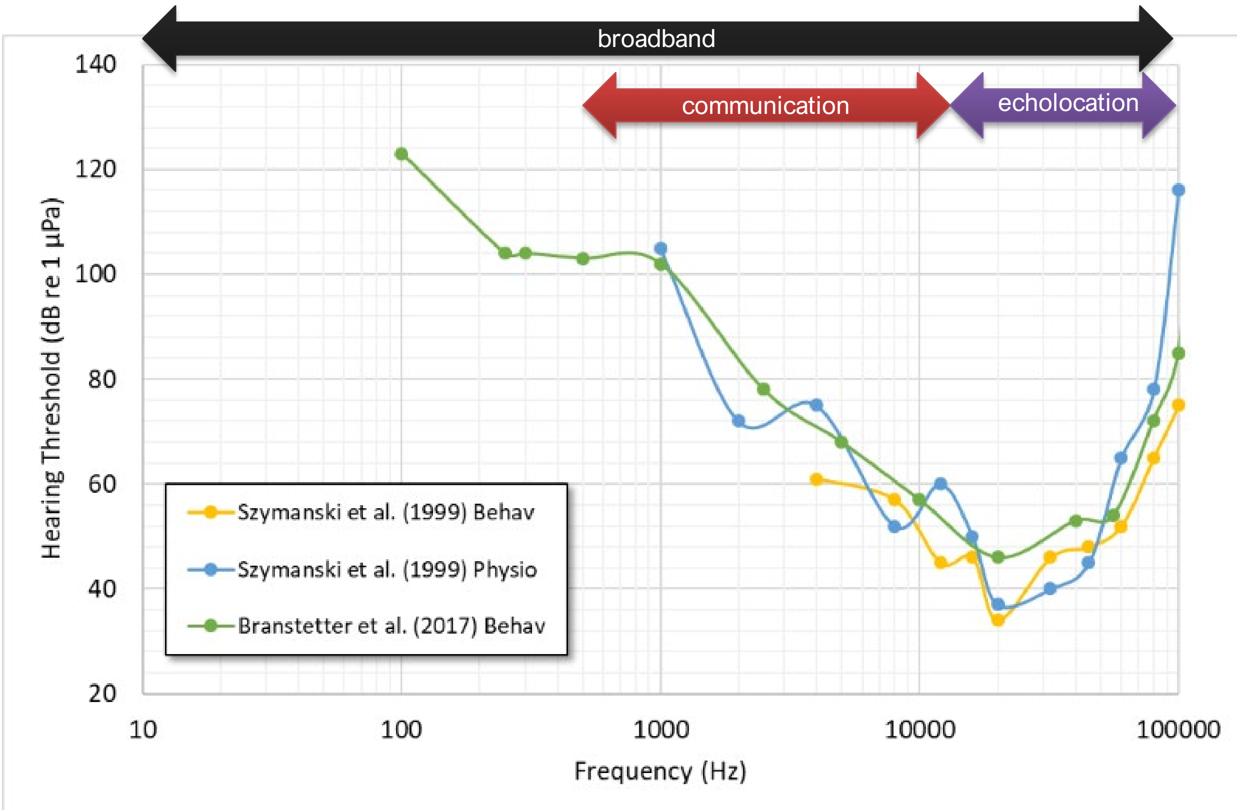


Figure 10. Killer whale audiogram data (i.e., hearing threshold versus frequency) (Szymanski et al., 1999; Branstetter et al., 2017). The range of the Coastal Ocean Research Institute (CORI) broadband, communication, and echolocation bands are indicated by the plot annotations.

In this analysis, the SPL was computed in the three CORI bands by summing the decidecade frequency band sound maps from ARTEMIA within the corresponding frequency ranges (with appropriate weighting at the band edges). Summation of the broadband and SRKW echolocation bands was limited to the maximum modeled band frequency of 63,000 Hz. Neglecting bands above 63,000 Hz was not expected to affect the results, as these bands generally contribute comparatively little sound energy to the marine soundscape, due to the strong effect of seawater absorption on sound propagation at high frequencies.

The model was run for one week of vessel traffic data in the summer (July) and in winter (January) to compute estimated existing sound levels.

Results (Existing Conditions, With and Without Tug Escorts)

The underwater noise modeling assessment suggests that noise levels at all seven biologically important locations periodically exceed the NMFS acoustic disturbance threshold for marine mammals (120 dB SPL) under existing vessel traffic conditions. A few of the locations (four in winter and three in summer) also had exceedances above the 150 dB (SPL) threshold for finfish. Exceedances of this noise threshold are more frequent near congested ports and shipping lanes; for example, the most frequent noise level exceedances occurred in Puget Sound for approximately 1,326 minutes total per week in the summer (i.e., 13 percent of the time).

More specifically, the underwater noise modeling revealed the following key findings, addressing the study's key objectives:

- The SPL at all seven receptor locations occasionally reached the NMFS 120 dB broadband SPL behavioral disturbance threshold for marine mammals under the existing vessel traffic conditions during both seasons. At four of the seven modeled locations, these exceedances are over 10 percent more frequent with tug escort requirements (Alternative A) compared to without them (Alternative D).
  - Note: Similar trends would be expected if the modeling were to use a threshold of 110 dB SPL in the SRKW echolocation band, as highlighted by Tennessen et al. (2024) to be of particular relevance when examining potential impact on foraging. However, the threshold is anticipated to be exceeded less often than the 120 dB SPL broadband threshold since the echolocation band encompasses a smaller frequency range that does not include predominant ship noise frequencies, and therefore contains less acoustic energy. This suggests that using the 120 dB SPL broadband threshold results is a more environmentally conservative analysis because it identifies more instances where vessel underwater noise could be affecting marine mammal behavior.
- The highest existing median sound levels were observed on the Strait of Georgia receptor in winter and the Puget Sound receptor in summer (in the broadband frequency band). We suspect that the highest median noise levels observed in the Strait of Georgia during winter are due to higher vessel traffic density, particularly bulk carriers, at that location. Interestingly, the largest difference between winter and summer was observed at the Puget Sound receptor, with higher sound levels experienced in summer likely attributed to an increase in recreational and cruise ship vessel traffic.
- The modeling revealed that existing escort tug operations (those affected by the rulemaking) have a fairly substantial contribution to the local soundscape at certain locations. Under current conditions (Alternative A), tug escort requirements account for an increase in the median and highest noise levels of up to 1.7 and 2.8 dB broadband SPL, respectively, compared to without tug escort requirements (Alternative D). These increases occurred at locations with high escort tug underway time density, i.e., Rosario Strait. However, the increase attributable to current tug escort requirements was less than 0.5 dB SPL for most other modeled locations and time periods.
- Under existing vessel traffic conditions, the NMFS behavioral disturbance threshold for finfish (150 dB broadband SPL) was reached at three locations in summer and four in winter; although some sites had very few exceedances (i.e., 1-5 minutes per week). Two of these locations had fewer exceedances when escort tugs were removed (Alternative D).
  - The noise model used a receiver depth of 10 meters due to the particular focus on marine mammals, specifically SRKW. Therefore, an animal at a greater water depth than 10 meters would experience lower sound levels due to the increased

distance between the source (vessel) and the receiver (animal). In other words, there would be fewer or no exceedances of the 150 dB SPL threshold for animals closer to the seafloor. Finfish of greatest concern in the EIS Study Area (i.e., those with special conservation statuses at greatest risk of impacts from the rulemaking), particularly salmonids, typically inhabit waters much deeper than 10 meters during most of the year (Arostegui et al., 2017; Smith et al., 2015).[1] Therefore, finfish of concern would likely be exposed to fewer exceedances of the finfish behavioral threshold than the model indicates.

- However, there would be more exceedances if a lower threshold value was to be considered, such as 123 dB SPL or 140 dB, as shown by van der Knaap et al. (2022) to instill a reaction in herring and salmon, respectively.

Tables 6 and 7 present the median (L_{50}) and highest (L_5) noise levels, respectively, under existing conditions for the three frequency bands of interest and two seasons examined, and the change in noise levels when tug escort requirements were removed from the model. Table 8 and Table 9 present the total number of minutes per week where the received broadband SPL is above the NMFS acoustic disturbance thresholds for marine mammals (120 dB SPL) and finfish (150 dB SPL), with and without tug escort requirements. Tables 10 and 11 present the average area ensonified above 120 dB and 150 dB broadband SPL, respectively, with and without tug escort requirements. Collectively, these results serve to illustrate the noise contribution from escort tugs under existing conditions. See Attachment A for all modeling details and results.

[1] Salmonids may possibly be found at depths less than 10 meters during the spring. However, the model runs were specifically based on winter and summer data (seasonal vessel, wind, rain, and temperature data) and may therefore not be representative of noise impacts during the spring. Other finfish of conservation concern were not considered closely in this noise analysis because they are expected to inhabit depths much deeper than 10 meters (e.g., bocaccio, eulachon, green sturgeon, yelloweye rockfish) or to inhabit shallow, nearshore areas where little tug escort activity occurs (e.g., bull trout, steelhead) (Hayes et al., 2011; Moser et al., 2016; NOAA Fisheries, 2024; Pietsch & Orr, 2015; Puget Sound Partnership and WDFW, 2011).

Table 6. Modeled median noise levels under existing conditions, with and without tug escort requirements.

Key Receptor Location		Broadband (0.01–63 kHz)		SRKW Communication Band (0.5–16 kHz)		SRKW Echolocation Band (16–63 kHz)	
		Winter	Summer	Winter	Summer	Winter	Summer
Median noise level (L_{50}, dB re 1 μPa^2), existing conditions with tug escort reqs. (Alt. A)							
1	Strait of Georgia	100.8	89.4	99.0	87.5	77.2	79.3
2	Boundary Pass	92.9	92.6	91.6	90.9	78.3	81.1
3	Lummi Bay	94.2	88.1	93.4	86.6	77.8	79.4
4	Anacortes	98.2	92.5	95.6	90.5	78.9	80.7
5	Rosario Strait	94.2	96.8	93.2	95.7	80.6	82.0
6	Haro Strait	94.0	94.0	92.7	92.7	79.6	82.0
7	Puget Sound	89.8	105.1	88.4	103.5	78.3	81.0
Change in median noise level (L_{50}, dB re 1 μPa^2) without tug escort reqs. (Alt. D)							
1	Strait of Georgia	-0.2	0	-0.2	0	0	0
2	Boundary Pass	-0.1	0	-0.1	0	0	0
3	Lummi Bay	-0.2	-0.1	-0.3	0	-0.1	0
4	Anacortes	-0.3	-0.3	-0.1	-0.3	0	0
5	Rosario Strait	-0.9	-1.7	-1.1	-1.9	-0.2	-0.3
6	Haro Strait	-0.2	-0.3	-0.3	-0.4	0	0
7	Puget Sound	-0.1	-0.8	-0.1	-0.9	0	-0.2

Table 7. Modeled highest noise levels under existing conditions, with and without tug escort requirements.

Key Receptor Location		Broadband (0.01–63 kHz)		SRKW Communication Band (0.5–16 kHz)		SRKW Echolocation Band (16–63 kHz)	
		Winter	Summer	Winter	Summer	Winter	Summer
Highest noise level (L_5, dB re 1 μPa^2), existing conditions with tug escort reqs. (Alt. A)							
1	Strait of Georgia	118.9	105.2	117.0	100.1	90.0	84.3
2	Boundary Pass	112.3	107.9	110.1	104.3	89.3	85.2
3	Lummi Bay	116.8	92.6	116.3	90.5	90.2	83.1
4	Anacortes	115.3	111.7	114.5	110.1	90.5	92.1
5	Rosario Strait	123.3	120.5	120.5	117.9	99.1	97.1
6	Haro Strait	119.2	115.8	115.5	112.8	91.3	90.0
7	Puget Sound	124.5	125.3	118.8	119.2	97.1	99.7
Change in highest noise level (L_5, dB re 1 μPa^2) without tug escort reqs. (Alt. D)							
1	Strait of Georgia	0	0	0	0	0	0
2	Boundary Pass	0	0	-0.1	0	0	0
3	Lummi Bay	-0.2	-0.4	-0.4	0	-0.1	0
4	Anacortes	-1.2	-1	-1.7	-1	-0.1	-0.5
5	Rosario Strait	-0.8	-2.8	-1	-2.5	-1.5	-2.6
6	Haro Strait	0	-0.2	0	-0.3	0	-0.3
7	Puget Sound	0	-0.1	0	-0.4	0	-0.1

Table 8. Modeled number of minutes (per week) above the 120 dB SPL threshold under existing conditions, with and without tug escort requirements.

Key Receptor Location		Winter		Summer	
		With Tug Escorts (Alt. A)	Without Tug Escorts (Alt. D)	With Tug Escorts (Alt. A)	Without Tug Escorts (Alt. D)
1	Strait of Georgia	366	366	3	3
2	Boundary Pass	15	15	42	42
3	Lummi Bay	134	119	4	4
4	Anacortes	162	126	210	192
5	Rosario Strait	926	782	604	483
6	Haro Strait	498	498	293	277
7	Puget Sound	1,144	1,133	1,326	1,220

Table 9. Modeled number of minutes (per week) above the 150 dB SPL threshold under existing conditions, with and without tug escort requirements.

Key Receptor Location		Winter		Summer	
		With Tug Escorts (Alt. A)	Without Tug Escorts (Alt. D)	With Tug Escorts (Alt. A)	Without Tug Escorts (Alt. D)
1	Strait of Georgia	0	0	0	0
2	Boundary Pass	0	0	0	0
3	Lummi Bay	0	0	0	0
4	Anacortes	1	0	0	0
5	Rosario Strait	5	4	15	12
6	Haro Strait	1	1	1	0
7	Puget Sound	26	26	35	35

Table 10. Modeled average total area ensonified above the 120 dB SPL threshold under existing conditions, with and without tug escort requirements.

Scenario	Area Ensonified Above 120 dB (SPL) (km^2)	
	Winter	Summer
With Tug Escorts (Alt. A)	118.4	80.7
Without Tug Escorts (Alt. D)	116.2	78.0

Table 11. Modeled average total area ensonified above the 150 dB threshold under existing conditions, with and without tug escort requirements.

Scenario	Area Ensonified Above 150 dB (SPL) (km^2)	
	Winter	Summer
With Tug Escorts (Alt. A)	1.5	1.2
Without Tug Escorts (Alt. D)	1.5	1.2

3.1.6 Assessment of Current Airborne Operational Noise Impacts from Escort Tugs

While underway, escort tugs produce continuous airborne noise from their propulsion and auxiliary engines, exhaust, and ventilation systems. As noted in Section 3.1.1 (Overview of Marine Vessel Noise), the generation and perception of noise are influenced by factors including engine size, load, and whether the escort tug is operating alone or with a target vessel. Escort tug propulsion engines range from approximately 2,000 hp to 10,000 hp, which are significantly smaller than the engines used on oil tankers and emit noise in higher frequency ranges that generally are less perceptible over long distances. Engine sizes and noise frequency ranges from escort tug engines are expected to be generally comparable to those for the engines on ATBs and tugs towing oil barges. Other than when they are actively escorting or assisting a target vessel, escort tugs are almost exclusively running “light” with minimal load on the engine, and thus produce less noise than the engines that are propelling or towing the target vessel.

For tugs that are actively escorting a target vessel—which, as noted in Section 3.1.1 (Overview of Marine Vessel Noise), represents approximately 37–39 percent of escort tug underway time—the ability to perceive noise specifically from the escort tug can depend on the positioning of the escort tug relative to the engines that are propelling or towing the target vessel. For example, when escorting a tank barge (which has a separate tug that is towing the barge), the escort tug may be positioned hundreds of feet behind the towing tug. Humans along the shoreline may therefore be able to distinguish the noise from these two separate sources. However, while escorting a tanker ship or ATB, the engines are closer together and their noise may not be individually distinguishable to distant receptors.

Escort tugs also produce intermittent noise from whistles or bells in certain circumstances, such as when maneuvering near other vessels, leaving a dock or berth, or operating in areas where visibility is limited (e.g., due to night, fog, or visual obstructions). Per the U.S. Coast Guard (USCG) and Puget Sound Harbor Safety Committee, marine vessel operators should limit unnecessary and nighttime noise (Puget Sound Harbor Safety Committee, 2023; USCG, 2016). Where feasible, vessel operators generally rely on radio communications, rather than whistles, to coordinate vessel movements and reduce unnecessary noise impacts. Ecology expects that escort tugs would rarely need to use whistles while actively escorting, as the target vessel would typically be responsible for any necessary whistle use.

Routine maintenance and repair activities can also be a source of noise while escort tugs are anchored. While some potentially noisy maintenance and repair activity may occur while the tug is on the water, most of it likely occurs while the tugs are out of service and on land in a shipyard. Ecology estimates that a typical escort tug is out of service for approximately 30 days per year (Captain Jeff Slesinger, OTSC Tug Industry Representative, personal communication, October 10, 2024), a portion of which would be to perform maintenance and repair activities.

Escort tug activity primarily occurs far enough from the shoreline that routine escort tug activity is generally not expected to meaningfully influence perceived noise levels in shoreline communities within the EIS Study Area. Approximately half (306,074 minutes per year) of existing escort tug activity takes place within 1 mile of the shoreline, approximately 37 percent (114,237 minutes per year) of which is during the escorting phase when noise from the escort tug is less likely to be individually perceptible. Only a subset of this represents activity within 1 mile of populated areas. However, as noted in Section 3.1.1 (Overview of Marine Vessel Noise), other factors such as topography, atmospheric conditions, and vegetation coverage can influence noise propagation.

Noise from escort tugs has the potential to contribute to wildlife impacts by causing birds to flush from nesting, foraging, or resting areas. However, as discussed in the Plants and Animals Discipline Report (Appendix F), escort tugs rarely operate in close proximity to shoreline habitats.

3.2 Alternative A: No Action

3.2.1 Impacts from Implementation

Alternative A represents the most likely future conditions if we make no changes to existing tug escort requirements for target vessels. Tug escort requirements for target vessels would remain in place in the current rulemaking area as established by RCW 88.16.190(2)(a)(ii).

As discussed above in Section 3.1.5 (Assessment of Current Underwater Noise Impacts from Marine Vessels), escort tugs would continue to have potential impacts related to underwater noise, and no additional impacts would occur under Alternative A. When evaluating impacts on SRKW specifically, due to their low population numbers, the death of just one animal would represent a population decline of approximately 1.4 percent and would further reduce population health by limiting genetic diversity (Williams et al., 2024). Any potential continued underwater noise impacts for marine mammals, and SRKW in particular, therefore merits careful assessment.

Ecology's underwater noise modeling indicates that existing sound pressure levels at all seven biologically important receptor locations periodically exceed the NMFS marine mammal behavioral disturbance acoustic threshold (i.e., 120 dB broadband SPL). The modeling also revealed that existing escort tug operations have a fairly substantial contribution to the local soundscape at some of these modeled locations, particularly Rosario Strait, Anacortes, and Lummi Bay.

The intensity, duration, and frequency of underwater noise impacts depend on the location and the time of year. The contribution of escort tugs to these noise threshold exceedances at the Rosario Strait location is approximately 18 percent and 25 percent higher in winter and summer, respectively, with tug escort requirements compared to conditions with no tug escort requirements (Alternative D). At the Anacortes location, the duration of exceedances, with tug escort requirements, is 29 percent higher in winter compared to conditions with no tug escort requirements. Lastly, at Lummi Bay, an increase (13 percent) in the duration of the threshold exceedances was observed in winter only when tug escort requirements are present compared to conditions with no tug escort requirements. This portion of underwater noise is attributable to the tug escort requirements, which would continue under Alternative A.

Since noise levels exceed the behavioral threshold for marine mammals in areas of high biological importance, underwater noise from continued tug escort requirements under Alternative A would have the potential to result in negative impacts on marine mammals at those locations. Numerous species of marine mammals frequent those locations, particularly SRKW, Bigg's killer whales, humpback and gray whales. Some possible impacts from continued underwater noise could include displacement of marine mammals; alteration of calling rates, intensities, or other forms of communication; effects on foraging behavior and orientation; stress; and/or physical injury in extreme cases.

Additionally, underwater noise could also negatively affect the behavior of finfish and diving marine birds. The NMFS behavioral disturbance acoustic threshold for finfish (i.e., 150 dB broadband SPL) was exceeded briefly at two locations, i.e., Rosario Strait and Puget Sound. Only Rosario Strait had noise contribution from escort tugs, with a 25 percent increase in threshold exceedances with tug escort requirements in both seasons compared to conditions with no tug escort requirements. Two other locations, Anacortes and Haro Strait, had only one minute of exceedance time above the threshold. It should be taken into consideration that the noise model used a receiver depth of 10 meters due to the particular focus on marine mammals, specifically SRKW. Therefore, an animal at a greater water depth than 10 meters would experience lower sound levels due to the increased distance between the source (vessel) and the receiver (animal). In other words, there would be fewer or no exceedances of the thresholds for animals closer to the seafloor.

While sound levels infrequently exceeded the NMFS finfish behavioral threshold, recent research (Ogurek et al., 2024; van der Knaap et al., 2022) indicates that there could still be potential for behavioral impacts to finfish, particularly where fish 'hotspots' overlap with high vessel traffic areas (e.g., Puget Sound). Additionally, there may be updates to the NMFS finfish threshold in the future to lower it (S. Nedelec pers. comm.) as numerous studies (Picciulin et al., 2010; Simpson et al., 2016; Nedelec et al., 2017; van der Knaap et al., 2022; Ogurek et al., 2024) have shown behavioral changes as well as impacts to survival in finfish from boat noise and at much lower levels (i.e., 123–140 dB broadband SPL) than 150 dB SPL.

As mentioned below in Section 3.2.2 (Mitigation Measures), escort tugs would continue to adhere to regulations regarding minimum distances to marine mammals, slowdown requirements, and noise reduction best management practices (BMPs) when safe and appropriate to do so. Refer to Appendix F Plants and Animals Discipline Report for more details on overall impacts to wildlife.

Climate change is expected to have minimal effect on the impacts caused by underwater noise. An increase in atmospheric carbon dioxide has the potential lead to increased ocean acidity, reducing the absorption of high frequency sound. This could lead to longer distance propagation of the higher frequency component of ship noise, but it could also increase the distances over which animals are able to communicate and echolocate.

Lastly, under Alternative A, escort tugs would continue to emit airborne noise as discussed in Section 3.1.6 (Assessment of Current Airborne Operational Noise Impacts from Escort Tugs). Shoreline communities, particularly those near ports and docks used by target vessels, may continue to hear occasional noise from escort tugs.

3.2.2 Proposed Mitigation Measures

Implementation of the required and/or recommended mitigation measures described in this subsection would further reduce the potential for noise-related impacts under Alternative A.

Required Mitigation (Rulemaking or Other Existing Regulations)

Escort tugs are required to adhere to all applicable federal requirements regarding vessel traffic safety and navigation within the established traffic separation scheme and under the vessel traffic service. Escort tugs are also required to adhere to all applicable requirements regarding airborne noise, including the noise standards established under RCW 79A.60.130.

Recommended Mitigation Measures

There are both federal (76 FR 20870) and state (RCW 77.15.740) requirements to maintain a certain distance from killer whales; 200 yards under federal regulations and 1,000 yards under state regulations. The state regulations also include vessel speed requirements. These measures help reduce noise and vessel disturbance-related impacts to marine mammals, as described in Section 1.5 (Regulatory Framework) and in the Plants and Animals Discipline Report (Appendix F). At both the federal and state levels, these requirements have an exemption for vessels operating in conjunction with the vessel traffic service, which includes escort tugs and target vessels. Ecology encourages tugs and target vessels to comply with these distance and speed regulations where safe and feasible to do so. Ecology also recommends that the Puget Sound Harbor Safety Committee consider developing a Standard of Care for escort tugs that encourages them to maintain 1,000-yard distance from killer whales where safe and feasible to do so.

Recommended noise-specific mitigation measures include vessel slowdowns, when safe and appropriate to do so. Several studies have shown that noise levels substantially decrease during vessel traffic slowdowns (Joy et al., 2019; Matei et al., 2024; Port of Vancouver, 2024). Two separate voluntary slowdown programs reduced underwater sound intensity levels by up to 50 percent, or 3 dB by slowing large commercial vessel traffic to 11 or 14.5 knots, depending on the vessel type (Matei et al., 2024; Port of Vancouver, 2024). Specifically for tugs, a comprehensive study on tug noise levels revealed that main engine revolutions per minute (RPM) was the only design parameter that has a strong correlation with source level (MacGillivray et al., 2022). Ecology recommends that escort tugs continue their participation in voluntary slowdowns aimed at reducing noise and disturbance impacts to marine mammals, including those led by the ECHO Program and Quiet Sound.

The PSHSC Standard of Care on tanker escorts recommends that in Rosario Strait, escort speed should not exceed ten knots. Ecology recommends that the PSHSC extend this SOC to the escort of target vessels and that escort tugs and target vessels continue to reduce speed to reduce underwater noise impacts.

Additionally, the use of battery-electric or hybrid-electric vessels may help reduce vessel noise levels. The Trans Mountain Expansion is using escort tugs with a hybrid electric engine which allows the tugs to operate on a single thruster, reducing underwater noise as well as emissions and fuel consumption. While operating in this hybrid mode, the tugs travel at much slower speeds (Transmountain, 2021). There is also a fully electric harbor tug operating at the Port of San Diego (Crowley’s eWolf) (Crowley, 2024). While this tug may be effective for assist work in the Port of San Diego, the technological readiness for deployment of electric tugs for escort work in the Salish Sea is not yet in place. Harbor tugs are designed to control larger vessels at slow speeds while escort tugs need to be able to control their escorted vessels at higher speeds. Additionally, the range of the eWolf (Crowley, 2022), up to two assist jobs in the Port of San Diego with minimal charging, likely would not work in the context of the Salish Sea where escort jobs are typically much longer. Ecology recommends that escort tug companies consider a transition to hybrid electric and eventually electric tugs, when the cost and technology make this feasible, in order to further reduce underwater noise impacts of their operation.

The displacement of vessel traffic routes away from biologically sensitive locations could result in substantial reductions in noise levels (Vagle & Neves, 2019; Burnham & Vagle, 2023). The ECHO Program has run a voluntary lateral displacement initiative for several years within the Canadian inshore area of Juan de Fuca Strait shifting traffic away from sensitive SRKW foraging areas. These trials showed a broadband underwater noise reduction between 4 and 7 dB SPL, mainly due to the increase in distance of tugs and barges to the key SRKW area (Burnham & Vagle, 2023; Port of Vancouver, 2024). Any new proposed voluntary lateral displacement trials would require participation and approval from the USCG, a careful analysis of potential risks, consultation with Tribes to assess potential interactions with treaty fishing, and coordination with relevant stakeholder and industry interests. Unlike the Strait of Juan de Fuca, much of the EIS Study Area has more restricted waterways and narrower shipping lanes, so displacement within existing shipping lanes may be less feasible.

Refer to the Plants and Animals Discipline report (Appendix F) for a comprehensive list of mitigation measures to reduce impacts to marine mammals.

For airborne noise, Ecology recommends that escort tug operators follow best practices to limit unnecessary and nighttime airborne noise consistent with guidelines from the USCG and Puget Sound Harbor Safety Committee (Puget Sound Harbor Safety Committee, 2023; USCG, 2016).

3.2.3 Significant and Unavoidable Adverse Impacts

Alternative A would result in significant and adverse noise impacts in the EIS Study Area due to the substantial contribution to underwater noise from tug escort requirements. As discussed in Section 3.2.1 (Impacts), Ecology's underwater noise modeling indicates that tug escort requirements in Alternative A do make a significant contribution to underwater noise in certain modeled biologically important areas—specifically, Rosario, Anacortes, and Lummi in winter and Rosario in summer. Tug escort requirements in Alternative A cause the NMFS 120 dB marine mammal behavioral disturbance to be exceeded at least 10 percent more frequently at these locations than without the current tug escort requirements.

Tug escort requirements under Alternative A also cause the NMFS 150 dB SPL finfish behavioral disturbance threshold to be exceeded over 10 percent more frequently in certain areas. However, the counts of these exceedances (both with and without tug escort requirements) are very low. For example, the 25 percent increase at Rosario Strait in summer under Alternative A represents an increase of only three minutes per week (0.03 percent of the week). Further, while the noise model is based on a receiver depth of 10 meters, most finfish of concern are found at greater depths. Therefore, the underwater noise from tug escort requirements under Alternative A is not expected to result in meaningful exceedances of the threshold at the depths where finfish of concern are likely to be found and thus is not expected to result in significant impacts on finfish.

Lastly, regarding airborne noise, continued tug escort requirements under Alternative A would not be expected to result in a chronic or recurring increase in the frequency, severity, and/or extent of airborne noise standard exceedances in populated communities. Therefore, Alternative A would not result in significant and adverse impacts related to airborne noise in the EIS Study Area.

3.3 Alternative B: Addition of Functional and Operational Requirements

3.3.1 Impacts from Implementation

Alternative B adds functional and operational requirements intended to increase safety and formalize existing best practices. It makes no change to the geographic boundaries described in Alternative A. The additional functional and operational requirements include 1) minimum either 2,000 or 3,000 hp requirements for the escort tugs based on the DWT of the escorted vessel, 2) minimum of twin-screw propulsion, and 3) a pre-escort conference between the tug and the escorted vessel.

Of the 18 tugs identified in the 2021 Vessel Traffic Trend Study (BPC & Ecology, 2021) as performing target vessel escort work, two are between 2,000 and 3,000 hp. Ecology reviewed the data used in this report and found that the escort tugs between 2,000 and 3,000 hp were only escorting target vessels under 18,000 DWT. The horsepower requirement codifies existing industry practices and ensures that tugs have sufficient power to intervene to prevent a drift grounding (and potential subsequent spill). Additionally, all 18 of the identified tugs meet the minimum twin screw propulsion requirement. These two requirements reflect today's industry practices and are therefore unlikely to result in changes to the distribution of escort tugs and their associated impacts. The FORs are intended to increase safety and formalize existing best practices.

The addition of FORs would not be anticipated to have any meaningful changes in underwater or airborne noise levels compared to Alternative A, since all escort tugs in the existing fleet already meet the proposed horsepower and propulsion requirements.

Refer to the Plants and Animals Discipline Report (Appendix F) for more details on overall impacts to wildlife.

3.3.2 Mitigation Measures

No additional mitigation measures than those included for Alternative A in Section 3.2.2 (Mitigation Measures) have been identified for Alternative B. The FORs are not expected to change the underwater noise impacts over those described in Alternative A. Escort tugs would be required to adhere to existing federal vessel traffic safety requirements and state noise standards. Ecology recommends that escort tugs continue to participate in PSHSC Standards of Care, voluntary underwater noise reduction measures, maintain distance from killer whales where safe to do so, and consider transitions to hybrid electric vessels when feasible to do so. We also recommend that the PSHSC consider extending and/or creating new Standards of Care as described in Section 3.2.2.

3.3.3 Significant and Unavoidable Adverse Impacts

As stated in Section 3.3.1 (Impacts), the addition of the FORs would not be anticipated to have any meaningful changes in underwater or airborne noise levels compared to Alternative A. However, similarly to Alternative A, Alternative B would result in significant and unavoidable adverse impacts to marine mammals in the EIS Study Area due to the substantial contribution to underwater noise from tug escort requirements. See details under Section 3.2.3 (Significant and Unavoidable Adverse Impacts) for Alternative A.

3.4 Alternative C: Expansion of Tug Escort Requirements

3.4.1 Impacts from Implementation

Alternative C maintains the tug escort requirements outlined in Alternative A and expands them northwest towards Patos Island. Alternative C would result in a 2.41 percent increase in escort tug underway time. The net increase in escort tug underway time would occur primarily within and near the expansion area (i.e., in the Strait of Georgia and the Strait of Georgia South Zones). Escort tug underway time in the rest of the EIS Study Area would decrease slightly or remain the same (see Figure 4). Alternative C also includes the FORs included in Alternative B. The FORs are not expected to have an impact on noise levels and locations, relative to Alternative A.

Ecology also modeled predicted changes in underwater noise at the seven selected biologically important locations under Alternative C. The results of the noise modeling showed that the expansion of the tug escort requirements would minimally change the underwater sound levels at most modeled locations when compared to Alternative A (Table 12 and Table 13). Alternative C would also not result in additional exceedances of the NMFS 120 dB SPL and 150 dB SPL behavioral disturbance acoustic thresholds as compared to existing conditions (Table 14 and Table 15). Specifically, median and highest noise levels at only two locations (Boundary Pass and Lummi Bay), which are adjacent to the expansion area, increased slightly, and only in winter. The relative increase observed in winter, which is not present in the summer, is attributed to higher noise levels from recreational vessel traffic that mask the smaller changes in noise produced by expanded tug escort requirements. This small increase would result in no additional threshold exceedances and only very minor changes in the average ensonified area, where the received sound would be above 120 dB SPL.

Since noise levels under Alternative C reach the marine mammal and finfish behavioral disturbance acoustic thresholds, there is potential for the noise to have negative impacts on marine mammals and fish, as discussed in Section 3.2 (Alternative A: No Action), with some additional negligible to minimal impacts on marine mammals, finfish, and diving birds within and near the rulemaking expansion area.

Refer to the Plants and Animals Discipline Report (Appendix F) for more details on overall impacts to wildlife.

Table 12. Change in modeled median noise levels from Alternative A to Alternative C.

Key Receptor Location		Broadband (0.01–63 kHz)		SRKW Communication Band (0.5–16 kHz)		SRKW Echolocation Band (16–63 kHz)	
		Winter	Summer	Winter	Summer	Winter	Summer
Median noise level (L_{50}, dB re 1 μPa^2), Alternative A							
1	Strait of Georgia	100.8	89.4	99.0	87.5	77.2	79.3
2	Boundary Pass	92.9	92.6	91.6	90.9	78.3	81.1
3	Lummi Bay	94.2	88.1	93.4	86.6	77.8	79.4
4	Anacortes	98.2	92.5	95.6	90.5	78.9	80.7
5	Rosario Strait	94.2	96.8	93.2	95.7	80.6	82.0
6	Haro Strait	94.0	94.0	92.7	92.7	79.6	82.0
7	Puget Sound	89.8	105.1	88.4	103.5	78.3	81.0
Change in median noise level (L_{50}, dB re 1 μPa^2) from Alternative A to Alternative C							
1	Strait of Georgia	0	0	-0.1	0	0	0
2	Boundary Pass	0	0	0.1	0	0	0
3	Lummi Bay	0.6	0	0.3	0	0	0
4	Anacortes	0	-0.1	0	-0.1	0	0
5	Rosario Strait	0	0	0	0	0	0
6	Haro Strait	0	0	0	0	0	0
7	Puget Sound	0	0	0	0	0	0

Table 13. Change in modeled highest noise levels from Alternative A to Alternative C.

Key Receiver Location		Broadband (0.01–63 kHz)		SRKW Communication Band (0.5–16 kHz)		SRKW Echolocation Band (16–63 kHz)	
		Winter	Summer	Winter	Summer	Winter	Summer
Highest noise level (L_5, dB re 1 µPa^2), Alternative A							
1	Strait of Georgia	118.9	105.2	117.0	100.1	90.0	84.3
2	Boundary Pass	112.3	107.9	110.1	104.3	89.3	85.2
3	Lummi Bay	116.8	92.6	116.3	90.5	90.2	83.1
4	Anacortes	115.3	111.7	114.5	110.1	90.5	92.1
5	Rosario Strait	123.3	120.5	120.5	117.9	99.1	97.1
6	Haro Strait	119.2	115.8	115.5	112.8	91.3	90.0
7	Puget Sound	124.5	125.3	118.8	119.2	97.1	99.7
Change in highest noise level (L_5, dB re 1 µPa^2) from Alternative A to Alternative C							
1	Strait of Georgia	0	0	0	0	0	0
2	Boundary Pass	0.4	0	0.3	0	0	0
3	Lummi Bay	0	-0.1	-0.1	0	0	0
4	Anacortes	0	-0.2	0	0	0	0
5	Rosario Strait	0	0	0	0	0	0
6	Haro Strait	0	0	0	0	0	0
7	Puget Sound	0	0	0	0	0	0

Table 14. Modeled number of minutes (per week) above the 120 dB SPL threshold under Alternative A and Alternative C.

Key Receptor Location		Winter		Summer	
		Alternative A	Alternative C	Alternative A	Alternative C
1	Strait of Georgia	366	366	3	3
2	Boundary Pass	15	15	42	42
3	Lummi Bay	134	134	4	4
4	Anacortes	162	162	210	210
5	Rosario Strait	926	926	604	604
6	Haro Strait	498	498	293	293
7	Puget Sound	1,144	1,144	1,326	1,326

Table 15. Modeled number of minutes (per week) above the 150 dB SPL threshold under Alternative A and Alternative C.

Key Receptor Location		Winter		Summer	
		Alternative A	Alternative C	Alternative A	Alternative C
1	Strait of Georgia	0	0	0	0
2	Boundary Pass	0	0	0	0
3	Lummi Bay	0	0	0	0
4	Anacortes	1	1	0	0
5	Rosario Strait	5	5	15	15
6	Haro Strait	1	1	1	1
7	Puget Sound	26	26	35	35

Table 16. Modeled average total area ensonified above the 120 dB SPL threshold under Alternative A and Alternative C.

Scenario	Area Ensonified Above 120 dB SPL (km^2)	
	Winter	Summer
Alternative A	118.4	80.7
Alternative C	118.6	80.6

Table 17. Modeled average total area ensonified above the 150 dB SPL threshold under Alternative A and Alternative C.

Scenario	Area Ensonified Above 150 dB SPL (km^2)	
	Winter	Summer
Alternative A	1.5	1.2
Alternative C	1.5	1.2

Lastly, under Alternative C, the changes in escort tug activity described above could result in additional perceptible airborne noise impacts to shoreline communities located near the rulemaking expansion area, especially near Cherry Point. However, the majority of the increase in escort tug activity would take place far from the shoreline (i.e., within the expanded rulemaking area), and escort tug activity near certain communities (e.g., Anacortes, Neptune Beach) would decrease under Alternative C.

3.4.2 Mitigation Measures

Mitigation measures for Alternative C are largely the same as those included for Alternative A (Section 3.2.2). Escort tugs would be required to adhere to existing federal vessel traffic safety requirements and state noise standards. Ecology recommends that escort tugs continue to participate in PSHSC Standards of Care, voluntary underwater noise reduction measures, maintain distance from killer whales where safe to do so, and consider transitions to hybrid electric vessels when feasible to do so. We also recommend that the PSHSC consider extending and/or creating new Standards of Care as described in Section 3.2.2.

Specifically for Alternative C, our recommendation to extend the Tanker Escort Standard of Care includes both extending the overall applicability and speed recommendations to the escort of target vessels, and including the expansion area.

3.4.3 Significant and Unavoidable Adverse Impacts

The expansion of tug escort requirements under Alternative C would result in significant and unavoidable adverse impacts to marine mammals in the EIS Study Area due to the substantial contribution to underwater noise attributable to tug escort requirements , which would be the same as those discussed in Section 3.2.3 (Significant and Unavoidable Adverse Impacts) for Alternative A.

The expansion of tug escort requirements would not be expected to result in a chronic or recurring increase in the frequency, severity, and/or extent of airborne noise standard exceedances in populated communities. Therefore, Alternative C would not result in significant and adverse impacts related to airborne noise in the EIS Study Area.

3.5 Alternative D: Removal of Tug Escort Requirements

3.5.1 Impacts from Implementation

Alternative D removes the existing tug escort requirements for target vessels, eliminating escort tug activity associated with this proposed rule. Target vessel movement would be unaffected by this Alternative. We can reasonably assume that most or all of the 18 identified escort tugs would remain within the EIS Study Area but shift to other assisting and/or escort work for larger vessels. While the individual *tugs* may continue to contribute to underwater noise across the EIS Study Area, those impacts are unrelated to this rulemaking and are not considered. Our analysis for Alternative D focuses on the change in underwater noise associated with the removal of tug escort requirements for target vessels in the current rulemaking area.

We estimate that Alternative D reduces total AIS vessel traffic underway time by 0.96 percent. The reduction of escort tug vessel traffic would result in less vessel traffic in shipping lanes and, thus, corresponding underwater noise. As discussed in Sections 3.1.5 (Assessment of Current Underwater Noise Impacts from Marine Vessels) and 3.2 (Alternative A: No Action), the existing tug escort requirements (Alternative A) contribute a substantial amount to underwater noise, with potential impacts to marine mammals and finfish at some modeled locations in the EIS Study Area, specifically Rosario Strait, Anacortes, and Lummi Bay. Therefore, a substantial improvement in the underwater soundscape at those three locations would be possible due to the reduced exceedances of the NMFS marine mammal behavioral disturbance acoustic threshold. See the “without tug escorts” portions of Tables 6 to 11 for the model outputs for Alternative D.

The underwater noise model predicted changes in median noise levels at all seven biologically sensitive receptor locations under Alternative D, either during one or both seasons. The results of the noise modeling showed that median noise levels are expected to decrease at certain modeled times and locations (notably Rosario Strait and Puget Sound), including fewer and/or shorter exceedances of the 120 dB SPL NMFS marine mammal behavioral threshold in some of these modeled locations. For example, Alternative D would decrease exceedances at the Rosario Strait modeled location by 18 percent and 25 percent in the winter and summer, respectively. At the Anacortes modeled location, Alternative D would decrease exceedances by 29 percent in the winter. Alternative D would also be expected to reduce exceedances near the Lummi Bay modeled location in the winter by 13 percent. Alternative D would also reduce exceedances of the 150 dB SPL NMFS finfish behavioral acoustic threshold at Rosario Strait (winter and summer), Haro Strait (summer), and Anacortes (winter).

The removal of escort tug requirements for target vessels would reduce noise-related impacts in the areas highlighted above, resulting in benefits to important animal resources such as through reduced risk of noise-related injury and stress; expanded area use; and improved communication, orientation, foraging, mating, and defense.

Refer to the Plants and Animals Discipline Report (Appendix F) for more details on overall impacts to wildlife.

Lastly, under Alternative D, elimination of the tug escort requirement would eliminate airborne noise contributions from escort tugs. However, because these existing noise impacts are not substantial, improvements in airborne noise levels would not be expected to be significant.

3.5.2 Mitigation Measures

No mitigation measures have been identified for Alternative D.

3.5.3 Significant and Unavoidable Adverse Impacts

Alternative D would result in reductions in the amount of time that underwater noise exceeds the 120 dB SPL and 150 dB SPL thresholds at some biologically sensitive locations. This reduction in noise would result in benefits for marine mammals, finfish, marine birds, and other noise-sensitive marine wildlife due to a substantial (> 10 percent) decrease in the time when noise levels exceed the acoustic thresholds at certain locations (i.e., Rosario Strait, Anacortes and Lummi Bay). Due to the reduction in underwater and airborne noise, Alternative D would not result in significant and unavoidable adverse noise impacts.

4.0 References

33 CFR Chapter I Subchapter D - International Navigation Rules. (2025). Retrieved March 19, 2025, from https://www.ecfr.gov/current/title-33/chapter-I/subchapter-D

Anderson, D., Shuster, L., Elliser, C. R., MacIver, K., Gless, E. J., Krieger, J., & Hall, A. (2023). Harbor Porpoise Aggregations in the Salish Sea. *Oceans, 4*(3), 269–285. https://doi.org/10.3390/oceans4030019

Arostegui, M. C., Essington, T. E., & Quinn, T. P. (2017). Interpreting vertical movement behavior with holistic examination of depth distribution: A novel method reveals cryptic diel activity patterns of Chinook salmon in the Salish Sea. *Animal Biotelemetry*, *5*(1), 2. https://doi.org/10.1186/s40317-016-0116-5

BPC, & Ecology. (2021). *Synopsis of Changing Vessel Trends: Reducing Threats to Southern Resident Killer Whales by Improving the Safety of Oil Transportation* (No. ESHB 1578). https://nebula.wsimg.com/17056ac82adb868022291ad1d8dae1b9?AccessKeyId=F86D0A1E7A0091C2061F&disposition=0&alloworigin=1

Branstetter, B. K., St. Leger, J., Acton, D., Stewart, J., Houser, D., Finneran, J. J., & Jenkins, K. (2017). Killer whale (Orcinus orca) behavioral audiograms. *Journal of the Acoustical Society of America*, *141*(4), 2387–2398. https://doi.org/10.1121/1.4979116.

Burnham, & Duffus, D. (2019). Gray Whale Calling Response to Altered Soundscapes Driven by Whale Watching Activities in a Foraging Area. *Journal of Ocean Technology, 14*(3), 84–106.

Burnham, R., & Moore, K. (2023). *Implications of Fisheries Closures on the Soundscape in areas used by Southern Resident Killer Whales (SRKW)* (No. 3535; Canadian Technical Report of Fisheries and Aquatic Sciences, p. 69). https://publications.gc.ca/collections/collection_2023/mpo-dfo/Fs97-6-3535-eng.pdf

Burnham, R., & Vagle, S. (2023). *Changes in sound field levels of the Salish Sea resulting from trials of vessel slowdown, lateral displacement and exclusion from Interim Sanctuary Zones in 2021* (No. 3528; Canadian Technical Report of Fisheries and Aquatic Sciences, p. 72). https://publications.gc.ca/collections/collection_2023/mpo-dfo/Fs97-6-3528-eng.pdf

Center for Whale Research. (2024). *Southern Resident Orca (SRKW) Population*. https://www.whaleresearch.com/orca-population

Crowley. (2022). *Electric Ship Assist Tug*. https://www.crowley.com/wp-content/uploads/sites/7/2022/07/22-THS-08240-eWolf-NoVendors.pdf

Crowley. (2024, January 24). *Crowley Accepts Delivery of eWolf, the First Fully Electric Tugboat in the U.S*. https://www.crowley.com/news-and-media/press-releases/crowley-accepts-delivery-of-ewolf-the-first-fully-electric-tugboat-in-the-u-s/

Dahlheim, M., & Castellote, M. (2016). Changes in the acoustic behavior of gray whales Eschrichtius robustus in response to noise. *Endangered Species Research, 31*, 227–242. https://doi.org/10.3354/esr00759

DFO. (2021). *Identification of Areas for Mitigation of Vessel-related Threats to Survival and Recovery for Southern Resident Killer Whales* (No. 2021/025). Fisheries and Oceans Canada. https://waves-vagues.dfo-mpo.gc.ca/library-bibliotheque/40979817.pdf

DoC. 2005. 50 CFR 224: Endangered and Threatened Wildlife and Plants: Endangered Status for Southern Resident Killer Whales. *Federal Register 70*(222): 69903–69912. https://www.federalregister.gov/d/05-22859.

Ettinger, A. K., Harvey, C. J., Emmons, C., Hanson, M. B., Ward, E. J., Olson, J. K., & Samhouri, J. (2022). Shifting phenology of an endangered apex predator mirrors changes in its favored prey. *Endangered Species Research, 48*, 211–223. https://doi.org/10.3354/esr01192

Exec. Order No. 18-02., Southern Resident Killer Whale Recovery and Task Force. https://governor.wa.gov/sites/default/files/exe_order/eo_18-02_1.pdf

Foote, A. D., Osborne, R. W., & Rus Hoelzel, A. (2004). Whale-call response to masking boat noise. *Nature, 428*, 910. https://doi.org/10.1038/428910a

Ford, J. K. B., Durban, J. W., Ellis, G. M., Towers, J. R., Pilkington, J. F., Barrett-Lennard, L. G., & Andrews, R. D. (2013). New insights into the northward migration route of gray whales between Vancouver Island, British Columbia, and southeastern Alaska. *Marine Mammal Science*, *29*(2), 325–337. https://doi.org/10.1111/j.1748-7692.2012.00572.x

Fournet, M., Matthews, L., Gabriele, C., Haver, S., Mellinger, D., & Klinck, H. (2018). Humpback whales Megaptera novaeangliae alter calling behavior in response to natural sounds and vessel noise. *Marine Ecology Progress Series, 607*, 251–268. https://doi.org/10.3354/meps12784

Gaudon, J. M., McTavish, M. J., Hamberg, J., Cray, H. A., & Murphy, S. D. (2022). Noise attenuation varies by interactions of land cover and season in an urban/peri-urban landscape. *Urban Ecosystems*, *25*(3), 811–818. https://doi.org/10.1007/s11252-021-01194-4

Hamer, A. (2019, August 1). *Here's Why Sound Carries Farther on Cold Days*. Discovery. https://www.discovery.com/science/Sound-Carries-Farther-Cold-Days

Hayes, M. C., Rubin, S. P., Reisenbichler, R. R., Goetz, F. A., Jeanes, E., & McBride, A. (2011). Marine Habitat Use by Anadromous Bull Trout from the Skagit River, Washington. *Marine and Coastal Fisheries*, *3*(1), 394–410. https://doi.org/10.1080/19425120.2011.640893

Heise, K., Barrett-Lennard, L., Chapman, R., Dakin, T., Erbe, C., Hannay, D., Merchent, N., Pilkington, J., Thorton, S., Tollit, D., Vagle, S., Veirs, S., Vergara, V., Wood, J., Wright, B., & Yurk, H. (2017). *Proposed Metrics for the Management of Underwater Noise for Southern Resident Killer Whales* (Coastal Ocean Report Series, pp. 1–29). Coastal Ocean Research Institute. 10.25317/CORI20172

Holt, M. M. (2008). *Sound Exposure and Southern Resident Killer Whales (Orcinus orca): A Review of Current Knowledge and Data Gaps* (NOAA Technical Memorandum No. NMFS-NWFSC-89). NMFS.

Holt, M. M., Noren, D. P., Veirs, V., Emmons, C. K., & Veirs, S. (2009). Speaking up: Killer whales (Orcinus orca) increase their call amplitude in response to vessel noise. *Journal of the Acoustical Society of America, 125*(1), EL27–EL32. https://doi.org/10.1121/1.3040028

ISO. (2017). *ISO 18405:2017. Underwater acoustics—Terminology*. https://www.iso.org/obp/ui/en/#!iso:std:62406:en

Joy, R., Tollit, D., Wood, J., MacGillivray, A., Li, Z., Trounce, K., & Robinson, O. (2019). Potential Benefits of Vessel Slowdowns on Endangered Southern Resident Killer Whales. *Frontiers in Marine Science, 6*. https://doi.org/10.3389/fmars.2019.00344

Krahn, M. M., Wade, P. M., Kalinowski, S. T., Dahlheim, M. E., Taylor, B. L., Hanson, M. B., Ylitalo, G. M., Angliss, R. P., Stein, J. E., & Waples, R. S. (2002). *Status Review of Southern Resident Killer Whales (Orcinus orca) under the Endangered Species Act* (NOAA Technical Memorandum No. NMFS-NWFSC-54). NMFS.

Lacy, R. C., Williams, R., Ashe, E., Balcomb III, K. C., Brent, L. J. N., Clark, C. W., Croft, D. P., Giles, D. A., MacDuffee, M., & Paquet, P. C. (2017). Evaluating anthropogenic threats to endangered killer whales to inform effective recovery plans. *Scientific Reports, 7*(1), 14119. https://doi.org/10.1038/s41598-017-14471-0

MacGillivray, A. O., Ainsworth, L. M., Zhao, J., Dolman, J. N., Hannay, D. E., Frouin-Mouy, H., Trounce, K. B., & White, D. A. (2022). A functional regression analysis of vessel source level measurements from the Enhancing Cetacean Habitat and Observation (ECHO) database. *Journal of the Acoustical Society of America, 152*(3), 1547–1563. https://doi.org/10.1121/10.0013747

MacGillivray, A. O., Stothart, F. M. C., Li, Z., Grooms, C. H., & Zykov, M. M. (2024). *Regional 2022 Ocean Noise Contributors in Southern Resident Killer Whale Habitat: Update to the ECHO Study on Regional 2015 Ocean Noise Contributors* (No. Document 03382, Version 2.2.). JASCO Applied Sciences for Innovation Centre of Transport Canada. https://open-science.canada.ca/items/5f0c36ba-5a78-4511-a7ca-c8361edcfaf1

Matei, M., Charish, R., Quinn, M., Wilder, F., Tabbutt, S., & Wood, J. D. (2024). *Quiet Sound Vessel Slowdown 2023*. SMRU Consulting for Quiet Sound.

McKenna, M. F., Ross, D., Wiggins, S. M., & Hildebrand, J. A. (2012). Underwater radiated noise from modern commercial ships. *Journal of the Acoustical Society of America, 131*(1), 92–103. https://doi.org/10.1121/1.3664100

Miller, P. J. O., Biassoni, N., Samuels, A., & Tyack, P. L. (2000). Whale songs lengthen in response to sonar. *Nature, 405*(6789), 903–903. https://doi.org/10.1038/35016148

Moore, S. E., & Clarke, J. T. (2002). Potential impact of offshore human activities on gray whales (Eschrichtius robustus). *Journal of Cetacean Research and Management, 4*(1), 19–25. https://doi.org/10.47536/jcrm.v4i1.863

Moser, M. L., Israel, J. A., Neuman, M., Lindley, S. T., Erickson, D. L., McCovey, B. W., & Klimley, A. P. (2016). Biology and life history of Green Sturgeon (Acipenser medirostris Ayres, 1854): State of the science. *Journal of Applied Ichthyology, 32*, 67–86. https://doi.org/10.1111/jai.13238

Nedelec, S. L., Radford, A. N., Pearl, L., Nedelec, B., McCormick, M. I., Meekan, M. G., & Simpson, S. D. (2017). Motorboat noise impacts parental behaviour and offspring survival in a reef fish. *Proceedings of the Royal Society B, 284*, 20170143. https://doi.org/10.1098/rspb.2017.0143

NMFS. (2024). *National Marine Fisheries Service: Summary of Marine Mammal Protection Act Acoustic Thresholds* (p. 7). https://www.fisheries.noaa.gov/s3/2024-10/MM-Acoustic-Thresholds-OCT2024-508-secure-OPR1.pdf

NOAA Fisheries. (2020, June 24). *Habitat Areas of Particular Concern within Essential Fish Habitat (Southeast)*. NOAA. https://www.fisheries.noaa.gov/southeast/habitat-conservation/habitat-areas-particular-concern-within-essential-fish-habitat

NOAA Fisheries. (2023a, January). *National Marine Fisheries Service: Summary of Endangered Species Act Acoustic Thresholds (Marine Mammals, Fishes, and Sea Turtles)*. https://www.fisheries.noaa.gov/s3/2023-02/ESA%20all%20species%20threshold%20summary_508_OPR1.pdf

NOAA Fisheries. (2023b, February). *National Marine Fisheries Service: Summary of Marine Mammal Protection Act Acoustic Thresholds*. https://www.fisheries.noaa.gov/s3/2023-02/MMAcousticThresholds_secureFEB2023_OPR1.pdf

NOAA Fisheries. (2024, June 10). *Eulachon*. NOAA. https://www.fisheries.noaa.gov/species/eulachon

Nowacek, D. P., Thorne, L. H., Johnston, D. W., & Tyack, P. L. (2007). Responses of cetaceans to anthropogenic noise. *Mammal Review, 37*(2), 81–115. https://doi.org/10.1111/j.1365-2907.2007.00104.x

Ogurek, S. D.-L., Halliday, W. D., Woods, M. B., Brown, N., Balshine, S., & Juanes, F. (2024). Boat noise impedes vocalizations of wild plainfin midshipman fish. *Marine Pollution Bulletin, 203*, 116412. https://doi.org/10.1016/j.marpolbul.2024.116412

Olson, J. K., Larson, S. E., Robertson, F. C., Miller, H., Morrigan, A., Berta, S., & Calambokidis, J. (2024). Utilizing long-term opportunistic sightings records to document spatio-temporal shifts in mysticete presence and use in the Central Salish Sea. *Frontiers in Conservation Science, 5*, 1401838. https://doi.org/10.3389/fcosc.2024.1401838

Olson, J. K., Wood, J., Osborne, R. W., Barrett-Lennard, L., & Larson, S. (2018). Sightings of southern resident killer whales in the Salish Sea 1976-2014: The importance of a long-term opportunistic dataset. *Endangered Species Research, 37*, 105–118. https://doi.org/10.3354/esr00918

Orca Conservancy. (2024, November 23). *Remembering L128*. https://www.orcaconservancy.org/blog/remembering-l128

Physics Lab. (2025). *Introduction to Sound*. https://www.physicslab.org/DocumentPrint.aspx?doctype=3&filename=WavesSound_IntroSound.xml

Picciulin, M., Sebastianutto, L., Codarin, A., Farina, A., & Ferrero, E. A. (2010). In situ behavioural responses to boat noise exposure of Gobius cruentatus (Gmelin, 1789; fam. Gobiidae) and Chromis chromis (Linnaeus, 1758; fam. Pomacentridae) living in a marine protected area. *Journal of Experimental Marine Biology and Ecology, 386*, 125–132. https://doi.org/10.1016/j.jembe.2010.02.012

Pietsch, T. W., & Orr, J. W. (2015). *Fishes of the Salish Sea: A compilation and distributional analysis*. https://www.eopugetsound.org/sites/default/files/features/resources/FishesoftheSalishSea_Pietsch_and_Orr.pdf

Pine, M. K., Hannay, D. E., Insley, S. J., Halliday, W. D., & Juanes, F. (2018). Assessing vessel slowdown as an option for reducing acoustic masking for Arctic cod in the western Canadian Arctic [Meeting abstract]. *Journal of the Acoustical Society of America, 144*(3). https://doi.org/10.1121/1.5067412

Port of Vancouver. (2024). *2023 Annual Report: Enhancing Cetacean Habitat and Observation (ECHO) Program*. Port of Vancouver. https://www.portvancouver.com/sites/default/files/2024-08/2023-ECHO-Program-annual-report-2.pdf

Puget Sound Harbor Safety Committee. (2023, January). *Puget Sound Harbor Safety Plan*. https://marexps.com/wp-content/uploads/2023/06/Puget-Sound-Harbor-Safety-Plan-WEBSITE-DOC-1.pdf

Puget Sound Partnership and WDFW. (2011). *Puget Sound Steelhead Foundations: A Primer for Recovery Planning*. https://wdfw.wa.gov/sites/default/files/publications/01512/wdfw01512.pdf

Putland, R. L., Merchant, N. D., Farcas, A., & Radford, C. A. (2017). Vessel noise cuts down communication space for vocalizing fish and marine mammals. *Global Change Biology, 24*(4), 1708–1721. https://doi.org/10.1111/gcb.13996

Robin, O., & Plante, C. (2022). An illustrated tutorial for logarithmic scales and decibels in acoustics. *Journal of the Acoustical Society of America, 152*(2), 2880–2892. https://doi.org/10.1121/10.0015144

Ruckelshaus, M. H., & McClure, M. M. (2007). *Sound Science: Synthesizing Ecological and Socioeconomic Information about the Puget Sound Ecosystem.*

San Juan County Code § 10.28.III. (2007). Operation of Vessels in Proximity to the Southern Resident Killer Whale., San Juan County Code (2007). https://www.codepublishing.com/WA/SanJuanCounty/html/SanJuanCounty10/SanJuanCounty1028.html

Shields, M. W., Hysong-Shimazu, S., Shields, J. C., & Woodruff, J. (2018). Increased presence of mammal-eating killer whales in the Salish Sea with implications for predator-prey dynamics. *PeerJ, 6*, e6062. https://doi.org/10.7717/peerj.6062

Shields, M. W., Moore, R. M., Filipovic, T. B., Gless, E. J., & Krieger, J. W. (2024). *Whale presence trends in Haro Strait and Boundary Pass 2017-2023*. Contract Report for the Vancouver Fraser Port Authority.

Simpson, S. D., Radford, A. N., Nedelec, S. L., & McCormick, M. I. (2016). Anthropogenic noise increases fish mortality by predation. *Nature Communications, 7*(1), 10544. https://doi.org/10.1038/ncomms10544

Smith, J., Fresh, K., Kagley, A., & Quinn, T. (2015). Ultrasonic telemetry reveals seasonal variation in depth distribution and diel vertical migrations of sub-adult Chinook and coho salmon in Puget Sound. *Marine Ecology Progress Series, 532*, 227–242. https://doi.org/10.3354/meps11360

Sprogis, K. R., Videsen, S., & Madsen, P. T. (2020). Vessel noise levels drive behavioural responses of humpback whales with implications for whale-watching. *eLife, 9*, e56760.

Szymanski, M. D., Bain, D. E., Kiehl, K., Pennington, S., Wong, S., & Henry, K. R. (1999). Killer whale (Orcinus orca) hearing: Auditory brainstem response and behavioral audiograms. *Journal of the Acoustical Society of America, 106*(2), 1134–1141. https://doi.org/10.1121/1.427121

Tennessen, J. B., Holt, M. M., Wright, B. M., Hanson, M. B., Emmons, C. K., Giles, D. A., Hogan, J. T., Thornton, S. J., & Deecke, V. B. (2024). Males miss and females forgo: Auditory masking from vessel noise impairs foraging efficiency and success in killer whales. *Global Change Biology, 30*(9), e17490. https://doi.org/10.1111/gcb.17490

Transmountain. (2021, November). *Tug Fact Sheet*. https://www.kotug.com/wp-content/uploads/291121_KOTUG_TM_fact-sheet.pdf

Tyack, P. L. (2008). Implications for marine mammals of large-scale changes in the marine acoustic environment. *Journal of Mammalogy, 89*(3), 549–558. https://doi.org/10.1644/07-MAMM-S-307R.1

USCG. (2016, December 23). *Marine Safety Information Bulletin 003-16*.

Vagle, S., & Neves, M. (2019). *Evaluation of the effects on underwater noise levels from shifting vessel traffic away from Southern Resident Killer Whale foraging areas in the Strait of Juan de Fuca in 2018* (No. 329; Canadian Technical Report of Hydrography and Ocean Sciences). https://publications.gc.ca/collections/collection_2019/mpo-dfo/Fs97-18-329-eng.pdf

van der Knaap, I., Ashe, E., Hannay, D., Bergman, A. G., Nielsen, K. A., Lo, C. F., & Williams, R. (2022). Behavioural responses of wild Pacific salmon and herring to boat noise. *Marine Pollution Bulletin, 174*, 113257. https://doi.org/10.1016/j.marpolbul.2021.113257

Wash. Admin. Code § 173-60-040. (2003), Maximum permissible environmental noise levels. Washington Administrative Code. https://app.leg.wa.gov/WAC/default.aspx?cite=173-60-040

Wash. Admin. Code § 197-11-786. (2003), Reasonable alternative Washington Administrative Code. https://app.leg.wa.gov/WAC/default.aspx?cite=197-11-786

Wash. Admin. Code § 197-11-794. (2003), Significant. Washington Administrative Code. https://app.leg.wa.gov/WAC/default.aspx?cite=197-11-794

Wash. Admin. Code § 220-200-100. (2023), Wildlife classified as protected shall not be hunted or fished. Washington Administrative Code. https://app.leg.wa.gov/WAC/default.aspx?cite=220-200-100

Wash. Admin. Code § 220-610-010. (2023), Wildlife classified as endangered species. Washington Administrative Code. https://app.leg.wa.gov/WAC/default.aspx?cite=220-610-010

Wash. Admin. Code Chapter 237-990. (2017), APPENDIX—DETERMINATION OF GEOGRAPHIC NAMES Washington Administrative Code. https://app.leg.wa.gov/wac/default.aspx?cite=237-990

Wash. Admin. Code Chapter 363-116. (2024), Pilotage Rules. Washington Administrative Code. https://app.leg.wa.gov/wac/default.aspx?cite=363-116

Wash. Rev. Code § 43.21C.030. (2010), Guidelines for state agencies, local governments—Statements—Reports—Advice—Information. Revised Code of Washington. https://app.leg.wa.gov/rcw/default.aspx?cite=43.21C.030

Wash. Rev. Code § 77.15.740 (2019), Protection of southern resident orca whales—Unlawful activities—Penalty. (Effective until January 1, 2025.) Revised Code of Washington. https://app.leg.wa.gov/rcw/default.aspx?cite=77.15.740

Wash. Rev. Code § 79A.60.130. (1993), Muffler or underwater exhaust system required—Exemptions—Enforcement—Penalty. Revised Code of Washington. https://app.leg.wa.gov/rcw/default.aspx?cite=79A.60.130

Wash. Rev. Code § 88.16.190. (2019), Oil tankers—Restricted waters—Requirements. Revised Code of Washington. https://app.leg.wa.gov/RCW/default.aspx?cite=88.16.190

Wash. Rev. Code § 88.46.010. (2015), Definitions Revised Code of Washington. https://app.leg.wa.gov/RCW/default.aspx?cite=88.46.010

Wash. Rev. Code Chapter 88.16. (2019), Pilotage Act. Revised Code of Washington. https://app.leg.wa.gov/rcw/default.aspx?cite=88.16

Wash. Rev. Code Title 77., Fish and Wildlife. Revised Code of Washington. https://app.leg.wa.gov/rcw/default.aspx?cite=77

Weilgart, L. S. (2007). The impacts of anthropogenic ocean noise on cetaceans and implications for management. *Canadian Journal of Zoology, 85*(11), 1091–1116. https://doi.org/10.1139/Z07-101

Western Washington Institute. (2024). *The Salish Sea & Surrounding Basin*. Western Washington Institute. https://salishsea.wwu.edu/salish-sea-surrounding-basin

Williams, R., Lacy, R. C., Ashe, E., Barrett-Lennard, L., Brown, T. M., Gaydos, J. K., Gulland, F., MacDuffee, M., Nelson, B. W., Nielsen, K. A., Nollens, H., Raverty, S., Reiss, S., Ross, P. S., Collins, M. S., Stimmelmayr, R., & Paquet, P. (2024). Warning sign of an accelerating decline in critically endangered killer whales (Orcinus orca). *Communications Earth & Environment, 5*(1), 1–9. https://doi.org/10.1038/s43247-024-01327-5

Attachment A: JASCO's Technical Memorandum on the Underwater Acoustics Assessment

Tug Escort Rulemaking: Underwater Noise Modeling

Technical Memorandum

JASCO Applied Sciences (Canada) Ltd

June 2025

Submitted to:

Patrick Goodwin
Eastern Research Group, Inc.
Contracting Agreement Number 4564.00.001/2

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JASCO Project Number P001905-001
Document 03619
Version 5.0

Suggested citation:

Wladichuk, J.L. and J.N. Dolman. 2025. Escort Tug Rulemaking: Underwater Noise Modeling: Technical Memorandum. Document 03619, Version 5.0. Technical report by JASCO Applied Sciences for Eastern Research Group, Inc.

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Executive Summary

The Salish Sea and Puget Sound are important habitat areas for Southern Resident killer whales (SRKW) and many other species of marine mammals. Busy marine shipping routes also pass through these areas, including local and international shipping lanes to the Ports of Seattle, Tacoma, and Vancouver British Columbia and others, as well as numerous passenger and cargo ferry routes. These inland waters are also popular for recreational and fishing vessels, as well as tug and ecotourism traffic. Underwater noise from vessels can have widespread impacts on marine animals by disrupting their behaviour, reducing their habitat quality, and limiting their ability to communicate and forage.

Underwater noise is one of the priority elements of the tug escort rulemaking Environmental Impact Statement (EIS). This technical memorandum presents the details of an underwater noise modeling assessment to compute existing noise levels and predicted changes due to changes in tug escort requirements under the proposed rulemaking alternatives. This report includes the modeling objectives, overview of the alternatives, details of the model and inputs, the results in a number of formats (graphs of noise level vs. time, sound maps, and tabulated values), and the key findings. The assessment examined noise levels at identified biologically-important receptor locations and aimed to address the following questions:

1. What are the existing underwater sound levels at the key receptor locations (i.e., biologically significant areas)?
2. How do existing tug escort operations contribute to these existing conditions?
3. How does the proposed expansion of the tug escort requirements affect the underwater sound levels at the key receptor locations?
4. What are the changes in noise levels at the key receptor locations due to the removal of the tug escort requirements?
5. Where and how often are the National Marine Fisheries Service (NMFS) behavioral disturbance thresholds (120 and 150 dB broadband sound pressure level (SPL) for marine mammals and finfish, respectively) exceeded, and how does this change between the alternatives?

To answer these questions, a state-of-the-art acoustic model (JASCO's ARTEMIA) was used to create weekly-average sound maps for the alternatives and received noise levels with time at each receptor. The model used vessel traffic data for each alternative provided by the Department of Ecology for January and July 2022. Source levels for the different vessel categories were derived from a comprehensive review of vessel underwater radiated noise (URN) data sets and reports collected by the VFPA-led ECHO Program, Transport Canada, and JASCO since 2015.

The results were analyzed in three frequency bands, specified by an expert working group (Heise et al. 2017) for their special relevance to the acoustic quality of SRKW habitat:

1. Broadband (10–63,000 Hz), for evaluating behavioural or physiological impacts.
2. Communication band (500–15,000 Hz), for evaluating effects of noise on communication masking.
3. Echolocation band (15,000–63,000 Hz), for evaluating effects of noise on echolocation masking.

The analysis revealed that noise levels at all of the seven biologically-important receptor locations periodically exceeded the NMFS 120 dB acoustic disturbance behavorial threshold for marine mammals under existing vessel traffic conditions during both seasons modeled. Additionally, three to four of the locations (depending on the season) occasionally exceeded the 150 dB finfish acoustic disturbance threshold, though this occurred much less frequently than the 120 dB threshold exceedances.

The occurrence and duration of exceedances above both the 120 and 150 dB thresholds under Alternative C were identical to those under Alternative A. Some locations (four for the 120 dB threshold and two for the 150 dB threshold) had fewer and/or shorter exceedances under Alternative D (removal of tug escort requirements). Existing tug escort operations (those affected by the rulemaking) have a fairly substantial contribution to the local soundscape depending on the location as determined by the model. Median noise levels increased at all of the receptor locations, although minimally at some (0.1 to 0.3 dB) but substantially at others (up to 1.7 dB) with high tug density, i.e., southern Rosario Strait.

The expansion of the tug escort requirements was modeled to have minimal effect on underwater sound levels at the key receptor locations. The median and highest broadband noise levels increased by a maximum of 0.6 and 0.4 dB, respectively, at the closest receptors to the expansion area, i.e., Lummi and Boundary Pass, and only in the winter. The lack of effect in summer is likely attributed to higher noise levels from recreational vessel traffic that mask the smaller changes in noise produced by the presence of escort tugs. The NMFS behavioral thresholds are not exceeded more often under Alternative C than under the existing conditions (Alternative A).

1. Introduction

This report presents the underwater noise assessment as part of the tug escort[1] rulemaking Environmental Impact Statement (EIS). Underwater noise pollution, introduced into the environment by vessel traffic, can have widespread impacts on marine animals by disrupting their behaviour, reducing their habitat quality, and limiting their ability to communicate and forage (Nowacek et al. 2007; Weilgart 2007; Tyack 2008; Joy et al. 2019). The endangered Southern Resident killer whale (SRKW) population is protected under the Endangered Species Act (ESA) in the United States of America, and its critical habitat overlaps with the EIS Study Area. To examine the potential impacts on SRKW and other local marine mammal species, sound levels were computed at biologically-significant locations within the EIS study area for the following four rulemaking alternatives:

- Alternative A: Alternative A represents the most likely future conditions if no changes are made to existing tug escort requirements for target vessels. Tug escort requirements for target vessels would remain in place in the current rulemaking area as established by RCW 88.16.190(2)(a)(ii). Alternative A maintains tug escort[1] requirements for laden tank barges and articulated tug barges (ATBs) over 5,000 deadweight tonnage (DWT) and oil tankers between 5,000 and 40,000 DWT, hereafter referred to as the target vessels, in Rosario Strait and connected waters east. This is the no action alternative and the current requirement in statute.
- Alternative B: Alternative B adds functional and operational requirements (FORs) intended to increase safety and formalize existing best practices. It makes no change to the geographic boundaries of the RCW 88.16.190(2)(a)(ii) or the vessels to which it applies. These FORs include a pre-escort conference, minimum horsepower, and propulsion specifications.
- Alternative C: Alternative C maintains the tug escort requirements outlined in Alternative A and expands them northwest towards Patos Island. Alternative C would result in a 2.41 percent increase in escort tug underway time. The net increase in escort tug underway time would occur primarily within and near the expansion area (i.e., in the Strait of Georgia and the Strait of Georgia South Zones), while escort tug underway time in the rest of the EIS Study Area would decrease slightly or remain the same (see Figure 6). Alternative C also includes the FORs outlined in Alternative B.
- Alternative D: Alternative D removes the existing tug escort requirements for target vessels within the rulemaking area, eliminating escort tug underway time associated with this proposed rule. It is reasonable to assume that most or all of the 18 identified escort tugs would remain within the EIS Study Area but shift to other assisting and/or escort work for larger vessels. While the individual tugs may continue to contribute to underwater noise impacts, they would be unrelated to this rulemaking and are not considered here.

[1] [1]Unless specified otherwise, the terms “escort tug” and “tug escort” refer to the subset of overall tug escort activity or underway time for target vessels that are specifically affected by this rulemaking. Unless otherwise noted, the following meanings apply: “Tug escort” refers to the act of a tug escorting a target vessel that is specifically affected by this rulemaking. “Escort tug” refers to the tug that conducts escorts of target vessels. Underway time for an escort tug includes active escort time and time spent commuting to and from an escort job.

JASCO's ARTEMIA model was used to compute sound levels (broadband, SRKW communication, and echolocation bands) for each alternative to create average sound level maps, and to compute noise level variations with time. This model accounts for individual ship locations and movements through the study area to calculate area-wide noise levels in 10-minute time steps and locally around each receptor location in 1-minute time steps. It was applied to address the following objectives:

1. What are the existing underwater sound levels at the key receptor locations (i.e., biologically significant areas)?
2. How do existing tug escort operations contribute to these existing conditions?
3. How does the proposed expansion of the tug escort requirements affect the underwater sound levels at the key receptor locations?
4. What are the changes in noise levels at the key receptor locations due to the removal of the tug escort requirements?
5. Where and how often is the National Marine Fisheries Service (NMFS) behavioral disturbance thresholds (120 dB and 150 dB broadband SPL for marine mammals and finfish, respectively) exceeded and how does this change between the alternatives?

This report presents the methodology and assumptions that were associated with the modeling. Section 2 presents the details of the model and input data sets. Section 3 presents the results of the modeling and Section 4 summarizes the key findings and important notes for the interpretation of the results.

2. Methods

2.1. Model Area and Noise Receptor Locations

The underwater noise model area covered a slightly smaller region than the EIS study area to reduce computational time and storage requirements yet still address the study objectives. For example, the affected tug traffic density was consistent throughout the main waterways of Puget Sound (Figure 1), thus extrapolation of the results from the northern portion (near receptor #7) is reasonable.

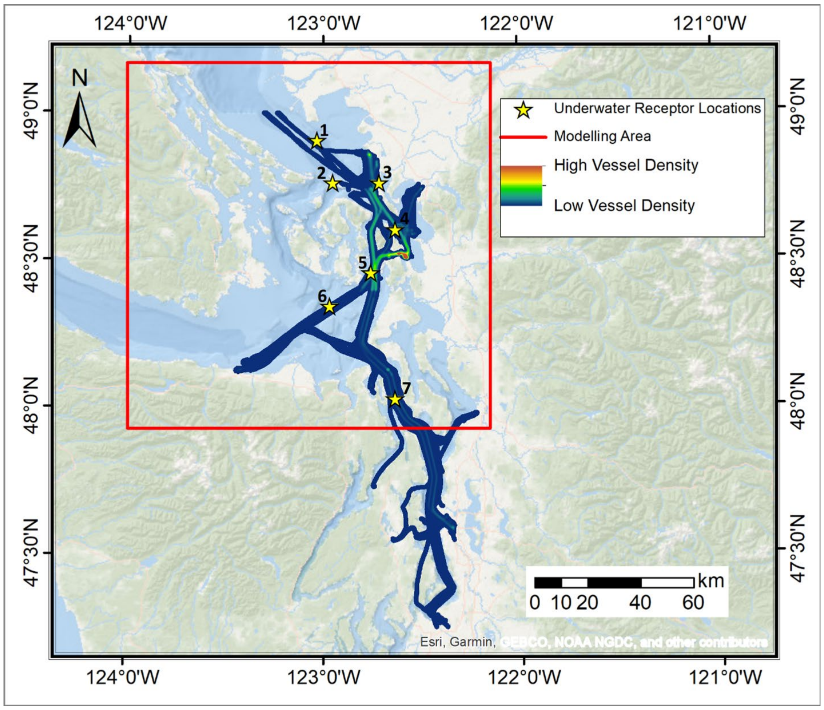


Figure 1. Map of modeling area with key acoustic receptor locations with density tracks of the escort tugs affected by the rulemaking.

Table 1. Key underwater noise receptor locations and rationale for their selection.

Key receptor location	Rationale for selection
1 – SoG	Near proposed expansion area and a SRKW hotspot[3]
2 – Boundary	Near proposed expansion area and an area frequented by SRKW[3], humpback whales[2] and harbor porpoises[4]
3 – Lummi	Near proposed expansion area
4 – Anacortes	Close to a moderate amount of target tug traffic and an area frequented by SRKW[1,3] and harbor porpoises[4]
5 – Rosario	Close to a moderate amount of target tug traffic and an area frequented by SRKW[1,3] and harbor porpoises[4]
6 – Haro	A hotspot for SRKW[1,3] and humpback whales[2]
7 – Puget	Close to current target tug route and an area frequented by SRKW[1], humpback, and gray whales[2]

[1] (Olson et al. 2018), [2] (Olson et al. 2024), [3] (DFO 2021), [4] (Anderson et al. 2023)

2.2. ARTEMIA Model Overview

Underwater noise calculations were carried out using JASCO's Acoustic Real-Time Exposure Model Incorporating Ambient (ARTEMIA). ARTEMIA is an underwater soundscape prediction and mapping model that accurately simulates underwater sound levels generated by large ensembles of marine sources (e.g., such as vessels, geophysical surveys, and ambient sound) over large geographic areas. The model combines input data from several different sources, described below, to predict marine environmental noise originating from ship traffic and ambient sources. All sound map calculations were performed in a BC Albers easting (x) and northing (y) coordinate system (code EPSG:3005). The frequency range of the sound mapping calculations was 10–63,000 Hz, in decidecade (i.e., standard one-third-octave) frequency bands.

Key inputs to the ARTEMIA model included a georeferenced database describing environmental features influencing sound propagation (see Section 2.7), vessel source density maps (see Section 2.4), and time-dependent wind and rain data (see Section 2.7.4). From these inputs, ARTEMIA used numerical sound propagation models to produce digital maps of sound pressure level (SPL) data versus easting, northing, frequency, and depth for the study area (Figure 2).

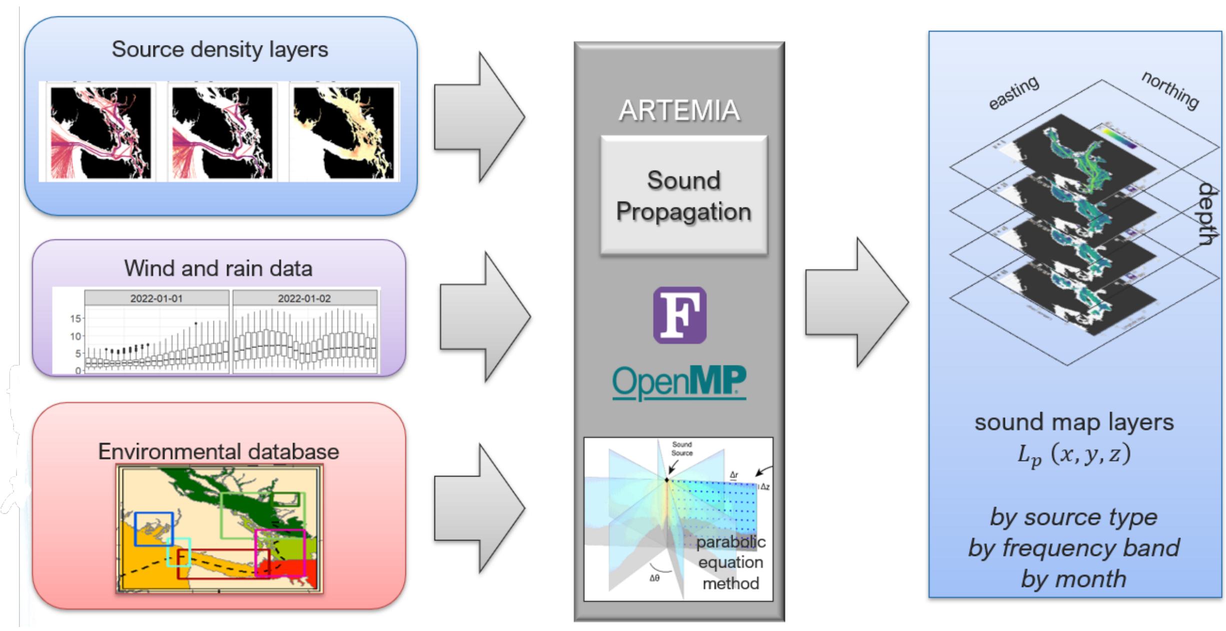


Figure 2. Flowchart of JASCO's Acoustic Real-Time Exposure Model Incorporating Ambient (ARTEMIA) model.

For this study, ARTEMIA was configured to compute sound propagation using the split-step parabolic-equation method, which is a fast and accurate method for calculating underwater wave propagation. In ARTEMIA, the time-dependent aspect of the soundscape is handled by running the model in the track mode, which computes time-dependent sound level maps from vessel tracks and meteorological data. This was used to calculate ship noise and ambient sound calculations through the study area to compute area-wide noise levels in 10-minute time steps and locally around each receptor location in 1-minute time steps.

ARTEMIA takes advantage of Open Multi-Processing (OpenMP) parallelization technology to accelerate propagation modeling calculations using multi-core CPU architectures. Sound fields for the present study were calculated using a High Performance Computing (HPC) cluster. Parallel model runs were executed on multiple HPC nodes, with 40–96 processor cores per node, to accelerate the model calculations.

2.3. CORI SRKW Frequency Bands

Sound maps generated using ARTEMIA were analyzed in terms of the following three frequency bands that were identified by an expert working group convened by the Coastal Ocean Research Institute (CORI) (Heise et al. 2017) as being particularly relevant to the acoustic quality of SRKW habitat:

1. Broadband (nominally 10–100,000 Hz; limited to 10–63,000 Hz for this study), for evaluating behavioural or physiological impacts.
2. Communication band (500–15,000 Hz), for evaluating effects of noise on communication masking.
3. Echolocation band (nominally 15,000–100,000 Hz; limited to 15,000–63,000 Hz for this study), for evaluating effects of noise on echolocation masking.

These frequency bands cover the range of overlap between vessel noise and SRKW hearing sensitivity, as shown in Figure 3.

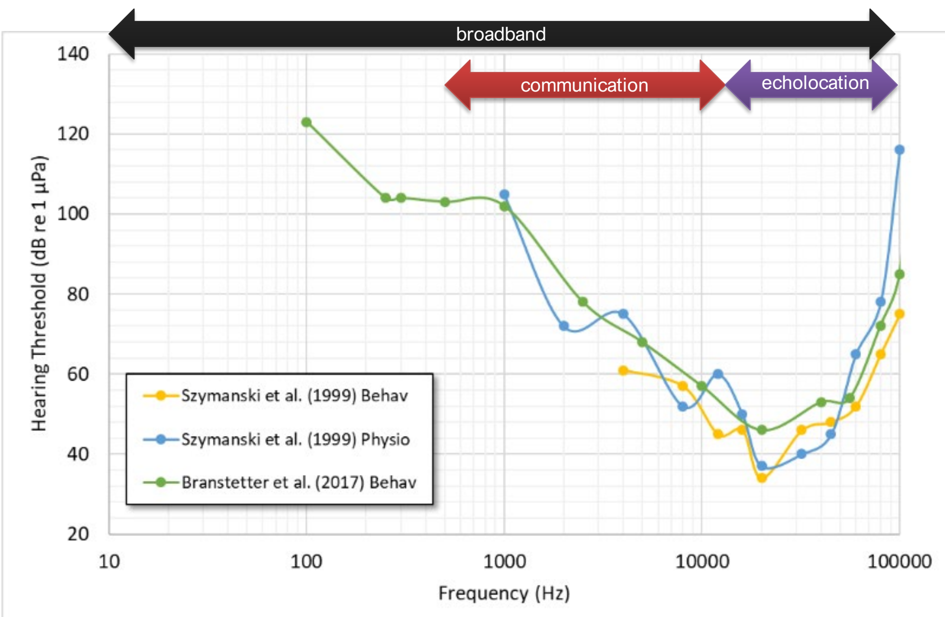


Figure 3. Killer whale audiogram data (i.e., hearing threshold versus frequency) (Szymanski et al. 1999; Branstetter et al. 2017). The range of the Coastal Ocean Research Institute (CORI) broadband, communication and echolocation bands are indicated by the plot annotations.

SPL in the three CORI bands were computed by summing the decidecade sound maps from ARTEMIA within the corresponding frequency ranges (with appropriate weighting at the band edges). Summation of the broadband and SRKW echolocation bands was limited to the maximum modeled decidecade band frequency of 63,000 Hz. Neglecting bands above 63,000 Hz was not expected to affect the results, as these bands generally contribute comparatively little sound energy to the marine soundscape due to the strong effect of seawater absorption on sound propagation at high frequency.

2.4. Vessel Traffic Dataset

Vessel traffic datasets for each alternative were provided by the Department of Ecology, and are thus consistent across other aspects of the EIS. Ecology developed a model to simulate vessel traffic patterns and oil spill risk, including escort tug activity. The model was based on historical automatic identification system (AIS) data from 2015–2019 and was used to inform the 2023 Analysis of Tug Escorts for Tank Vessels. For the current EIS effort, Ecology used the model 1) to simulate the tracks of escort and assist tug traffic, and 2) to simulate the current volumes of escort and assist tug traffic along these tracks while accounting for tug escort requirements that went into effect in 2020. Ecology also used the model to simulate tracks and volumes of target and non-target vessels, specifically for use as inputs for the underwater noise modeling.

The model produced 1,000 annual simulations of escort and assist tug traffic. To represent current conditions and Alternative A, Ecology selected the simulation output with the highest amount of escort tug traffic (i.e., the "worst case scenario") to ensure that the EIS does not undercount potential environmental impacts and to account for other potential near-term growth in vessel traffic (e.g., traffic from the Trans Mountain Expansion). For Alternative C, Ecology modified the Alternative A simulated traffic outputs to account for the proposed changes in tug escort requirements under that alternative. For Alternative D, escort tug underway time associated with this rule was excluded from the underwater noise model inputs. Finally, JASCO adjusted the outputs for non-target vessels to account for recreational and fishing vessels that are not equipped with AIS.

JASCO compared the Department of Ecology-provided datasets with AIS data downloaded from the National Oceanic and Atmospheric Administration (NOAA) Marine Cadastre website, which revealed comparable numbers of vessel transits and density. Table 2 summarizes how the escort tug underway time differs between the alternatives.

Table 2. Description of the escort tug underway time associated with the proposed rulemaking for each alternative.

Alternative	Description
A – No action	Ecology-provided escort tug activity data representing (simulated) existing traffic conditions.
B - FORs	Assumed identical to Alternative A; did not model.
C - Expansion	Ecology-provided escort tug activity data representing simulated activity under the expansion, corresponding to an increase in escort tug activity in the Strait of Georgia and Strait of Georgia South; minor or no changes in escort tug activity throughout the rest of the EIS study area;
D - Removal	Elimination of the existing escort tug activity in the EIS study area.

One full week of simulated vessel transits in winter and one full week in summer were selected for this assessment to capture seasonal variations in vessel traffic (Figure 4). These weeks were chosen in January and July to represent the respective winter and summer season. The provided traffic data were relatively consistent throughout the modeled months.

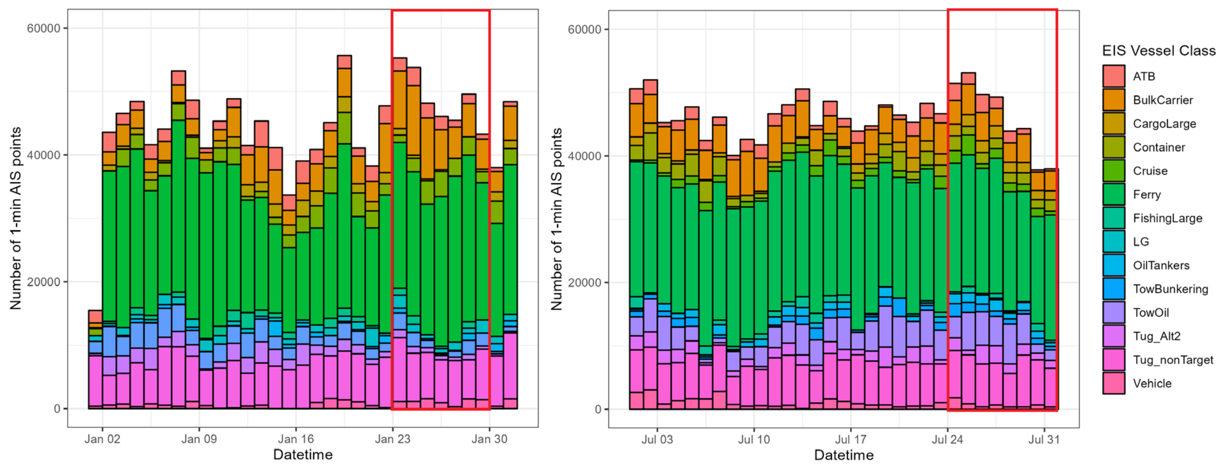


Figure 4. Daily density values for vessels with AIS (measured in number of 1 min vessel track points) in January (left) and July (right) for Alternative A. The weeks modeled are highlighted by the red box.

Recreational and fishing vessels frequently do not carry AIS transponders or sometimes use shorter range AIS transponders so their messages are not always received and logged at sparsely distributed AIS monitoring stations. As such, the simulated traffic dataset provided by the Department of Ecology is not necessarily reflective of all vessel traffic present in the area. Adjustments to account for missing recreational and fishing vessel traffic are described in Section 2.5. Track data for recreational vessels, fishing vessels and anchored vessels were acquired through NOAA's Marine Cadastre website.

All vessels were categorized as one of ten types of vessels (Table 3) to assign source levels, as detailed in Section 2.6.

Table 3. The ten vessel categories used for the classification of all vessel traffic in the track datasets.

Category name	Description
Cargo Vessels at Anchorage	Bulk Carriers, Container Ships, General Cargo Ships, Tankers, or Vehicle Carriers at anchor
Bulk Carriers	Cargo vessels that carry bulk cargo
Container Ships	Cargo vessels that carry shipping containers
Fishing	Fishing vessels, including commercial and indigenous fishing vessels, but excluding personal recreational fishing boats
Tankers	Cargo vessels transporting oil or large amounts of fluid
Passenger	Vessels with a purpose of carrying passengers that do not fit in other categories, such as cruise ships and water taxis
Recreational	Personal watercrafts
Ferry	Ferry vessels including roll-on roll-off vessels that carry passengers (ro-ro passenger) or cargo (ro-ro cargo)
Tugs and Tug-and-barge Combos	Tugs with or without associated barges, ATB, tow bunkering, tow oil tugs
Vehicle Carriers	Cargo vessels that transport vehicles

2.5. Non-AIS Scaling Factors

AIS is a radio broadcasting system used to track and identify vessels for navigational safety. Requirements for vessels to carry AIS vary depending on the vessel type/size and local regulations. It was assumed that only the fishing and recreational vessel categories include a significant percentage of vessels that do not broadcast AIS (Serra-Sogas et al. 2021). The AIS tracks for these categories were scaled to correct for missed traffic records, as discussed in the study by Serra-Sogas et al. (2021) that compared aerial survey vessel identifications with corresponding AIS records. Serra-Sogas et al. (2021) estimated average non-AIS percentage at between 85 and 87 percent for these vessels categories. However, AIS use by these vessel categories has likely increased since the data collection in 2016 and 2017; thus, it was projected that approximately 75 percent of fishing and recreational vessels do not broadcast AIS and are not accounted for in the Department of Ecology or NOAA vessel activity datasets. A scaling factor of four was therefore applied to the corresponding fishing and recreational vessel data downloaded from the NOAA Marine Cadastre website to account for these non-AIS vessels.

2.6. Vessel Source Levels

Source levels for the ten different vessels categories were derived from a comprehensive review of vessel underwater radiated noise (URN) data sets and reports collected by the ECHO Program, Transport Canada (TC), and JASCO since 2015 (Table 4). Supplement B provides more details about the source level data sets used to represent URN for different types of vessels for this assessment.

In the acoustic model, AIS vessels in each category were assigned source levels based on their type classification, length (l), speed (v), and draft (d). The general form of the frequency-dependent source levels in the model was a power law formula, adapted from MacGillivray et al. (2022):

$$L_S(f) = L_{S,\mathrm{ref}}(f) + \beta_v(f)\log_{10}\frac{v}{v_{\mathrm{ref}}} + \beta_l(f)\log_{10}\frac{l}{l_{\mathrm{ref}}} + \beta_d(f)\log_{10}\frac{d}{d_{\mathrm{ref}}} \quad \mathrm{dB} \qquad (1)$$

where:

- f is the decidecade band centre frequency (Hz), from 10 to 50,000 Hz;
- $\beta_v(f)$, $\beta_l(f)$, and $\beta_d(f)$ are frequency-dependent scaling factors for speed, length, and draft (taken to be zero if source levels for the specified vessel type do not scale with a given parameter); and
- $L_{S,\mathrm{ref}}(f)$ is a reference source level versus frequency curve (dB re 1 µPa²m²), for a specified vessel type, at speed v_{ref}, length l_{ref}, and draft d_{ref}.

For certain vessel categories, reference source levels were produced based on subdivision by additional factors due to additional information on how the vessel noise emissions changed under specific circumstances. These additional factors included subdivisions based on vessel size used for cargo and passenger vessels, subdivisions based on year of build (YOB) used for roll-on roll-off (ro-ro) ferries, and subdivisions based on different speed ranges used for ecotourism vessels. For the purposes of this analysis and consistency with previous analyses, the escort tug population considered are the eighteen escort tugs identified in Appendices P and Q of the 2021 Vessel Traffic Trend Study (BPC and Ecology 2021).

While the fleet conducting tug escort activity may have changed since the 2021 study (and may continue to change), the fleet will remain generally similar in composition and characteristics (e.g., length) to those identified in the 2021 study. Therefore, to compute average sound levels for this assessment, the source level for the affected escort tug vessel traffic was not scaled for vessel length and instead used a single length corresponding to the 75th percentile of the lengths of those eighteen escort tugs. The reference source level curves for the different vessel types are shown in Supplement B.

The time-stamped vessel position and source level data were used to calculate spatial grids (i.e., raster maps) of frequency-dependent source density per unit area for the study area.

Table 4. Summary of data sources and scaling relationships used for assigning source levels to different vessel categories.

Vessel category	Data sources	Speed scaling ($\beta_v \neq 0$)	Size or YOB sub-categories [1]	Length scaling ($\beta_l \neq 0$)	Draft scaling ($\beta_d \neq 0$)
Bulk carriers Container ships General cargo Oil tankers Other tankers Passenger Tugs and tug-and-barge combos Vehicle carriers	ECHO functional regression model (MacGillivray et al. 2022)[3] ECHO database (passenger vessels under 100 m only)[4]	Yes	Yes	Yes	Yes
Fishing Government Miscellaneous Recreational	ECHO database (TC Boundary Pass ULS, 2019–2023)[4] ECHO 2017 slowdown trial report (naval vessels only; MacGillivray and Li 2018)[4]	Yes	No	Yes	No
Ferry	ECHO measurements for ferry operators (MacGillivray and Li 2016; MacGillivray et al. 2017; Frouin-Mouy et al. 2020; Dolman et al. 2021)[5]	Yes	Yes	No	No
Cargo vessels at anchorage	ECHO Burrard Inlet Measurements(Harris et al. 2022)[6]	No	No	No	No
Ecotourism	ECHO Whale Watch and Small Vessel URN Study (Wladichuk et al. 2018)[7]	By speed bin[2]	No	No	No

[1] Indicates whether vessels in this category were assigned different reference source level curves based on their size or year of build (YOB).
[2] Ecotourism vessels were assigned one of three source level profiles based on their AIS-reported speed over ground (<10, 10–20, and >20 knots).

2.7. Environmental Description

Sound propagation in the ocean depends on the seawater and seabed environmental parameters. These include water column temperature and salinity profiles, water depth, and geoacoustic properties of the seabed, including sediment type (e.g., sand, silt, and bedrock) and the corresponding thickness of each sediment layer. Details on each of these and the corresponding data sources are provided in the sub-sections below.

2.7.1. Bathymetry

The bathymetry (depth contours) within the modeled region was represented using a 20 m resolution BC Albers grid (code EPSG:3005). These data were synthesized from multiple sources, including the NOAA digital elevation model (NGDC 2013), charts from the Canadian Hydrographic Service, and the SRTM15+ (v7.0) global bathymetry grid, which offers a 30 arc-second grid covering the entire globe (Rodríguez et al. 2005). The compilation underwent re-gridding via minimum curvature techniques to account for different resolutions of input data.

2.7.2. Sound speed profiles

In temperate regions, the seasonal variations in oceanic temperature and salinity profiles significantly impact the speed of sound depth profile, leading to acoustic refraction effects. To capture these variations, representative sound speed profiles (SSP) for January and July were derived using temperature and salinity data from Fisheries and Oceans Canada (Water Properties Group 2019) and the US Naval Oceanographic Office's Generalized Digital Environmental Model V 3.0 (GDEM; 1990; Carnes 2009). The acoustic models applied here use these profiles to evaluate refractive effects.

2.7.3. Seabed geoacoustics

The geoacoustic characteristics of the seafloor play a crucial role in determining the propagation of sound waves through the water column, particularly in shallow water where the seabed interacts strongly with the propagating acoustic field. The primary mechanism for sound attenuation in shallow water (less than approximately 200 m) is the reflection and absorption of sound energy at the seabed (Urick 1983). The seabed geoacoustic properties within the modeled area were compiled by integrating results of geoacoustic inversion analyses based on acoustic measurements and consulting relevant scientific literature (Hamilton 1980; Erbe, MacGillivray, and Williams 2012; JASCO 2015; Matthews et al. 2018; Ramsey and Warner 2021). These results were used to define and assign three geoacoustic zones, representing different properties of the seafloor as inputs to the acoustic model (Table 5).

Table 5. Seabed profiles for the geoacoustic zones. Parameter values vary linearly within each depth range.

Depth below seafloor (m)	Material	Density (g/cm^3)	Compressional wave		Shear wave	
			Speed (m/s)	Attenuation (dB/λ)	Speed (m/s)	Attenuation (dB/λ)
Zone A						
0–100	Clayey-silt	1.54	1502–1602	0.61	125.0	2.2
>100	Bedrock	1.90	2275	0.10		
Zone B and Zone C						
0–50	Sand-silt-clay	1.80	1541–1591	0.72	250.0	1.2
>50	Bedrock	1.90	2275	0.10		
Zone D						
0–50	Silt	1.64	1558–1608	0.83	250	3.4
>50	Bedrock	1.90	2275	0.10		

2.7.4. Wind and rain data

The acoustic model predicts ambient sound energy caused by wind and rain interacting with the sea surface. These effects lead to baseline noise levels even in the absence of ship traffic.

To model sound due to wind and rain, meteorological data were retrieved from the Copernicus ERA5 reanalysis data set. The ERA5 is a global reanalysis data set, comprised of over 200 variables, containing data from 1940 to the present day, with a spatial resolution of 0.25 ° × 0.25 ° and a temporal resolution of 1 h. Grids of precipitation rate, temperature at sea surface, and wind speed at 10 m were retrieved for January and July 2022. The retrieved grids were processed into 144 virtual weather stations, each with a continuum of wind speed, temperature, and precipitation.

The resulting data set for each station then went through several checks to ensure completeness, and accuracy of the data products produced. Statistics of the processed weather data indicate that both wind and precipitation rate are significantly greater in winter (January) than in summer (July) across the study area (plots in Appendix A.4).

3. Results

The underwater noise results are presented in a number of formats, including temporal plots showing sound pressure level (SPL) vs time at each receptor location (Section 3.1), soundscape maps (Section 3.2) and tabulated levels and differences between alternatives at each receptor location (Section 3.3).

3.1. SPL vs Time

Broadband SPL versus time at receptor location #2 (Boundary Pass) for Alternatives A and C is shown in Figure 5 and receptor location #5 (Rosario) for Alternatives A and D in Figure 6. These locations are presented here as the model predicted greater differences between the Alternatives at those receptors. The plots for all the other receptor locations are found in Supplement C.

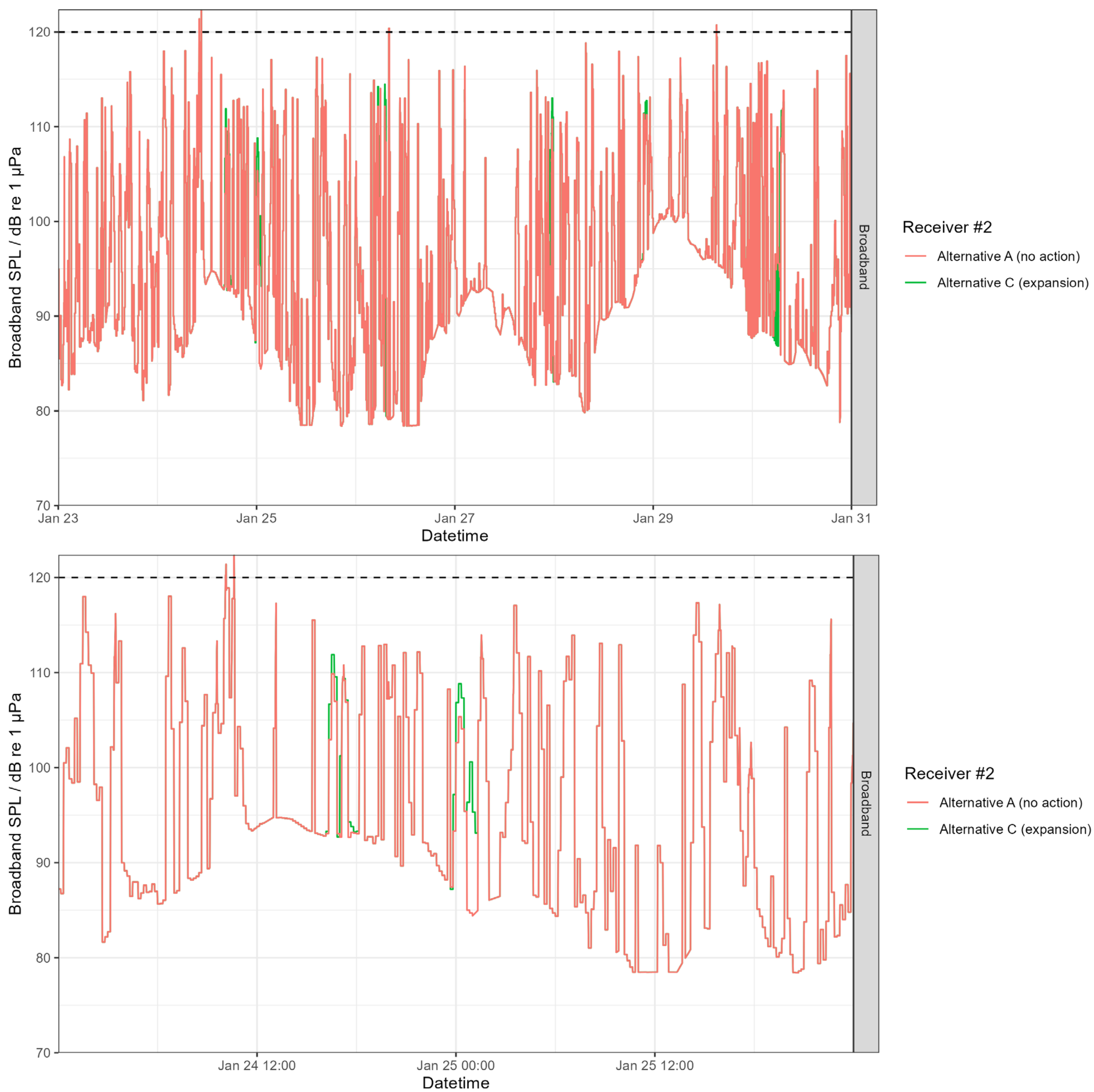
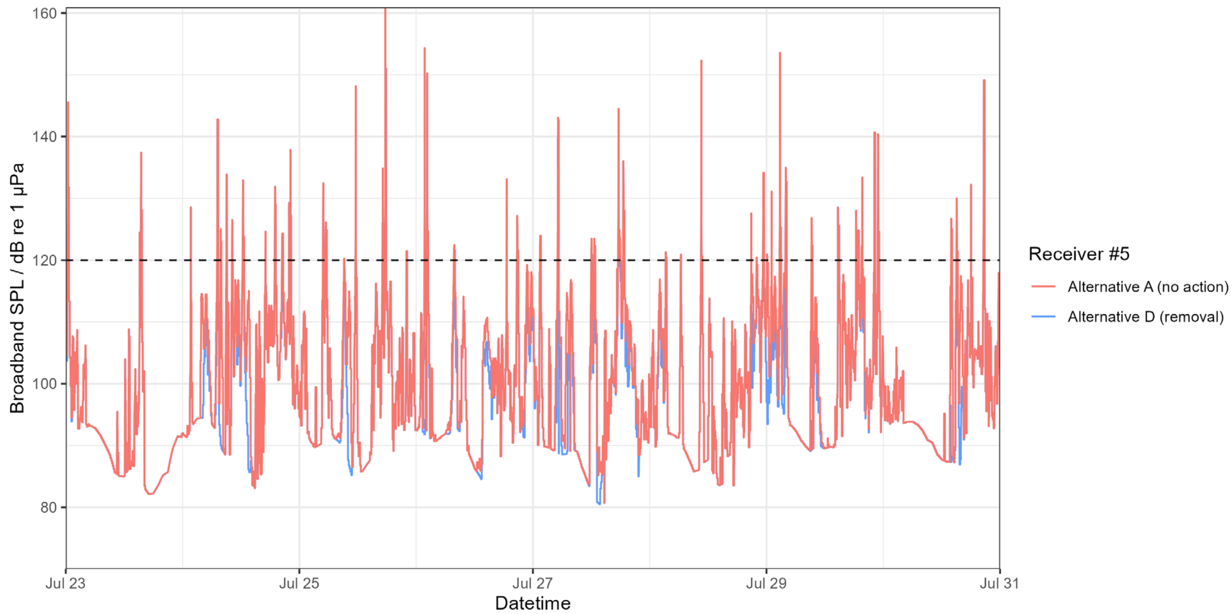


Figure 5. Broadband (10 Hz to 63 kHz) received sound pressure level (SPL) for Alternative A (red) and Alternative C (green) with time (one week – top plot, 48 hrs – bottom plot) at receptor location #2 (Boundary Pass) adjacent to the expansion area. The NMFS 120 dB marine mammal disturbance threshold is represented by the bold dashed line. The spikes in SPL indicate vessel transits past the receptor location. No increase in the exceedance of the 120 dB threshold due to the expansion (green) is observed; however, there are some periods of elevated levels which are more apparent in the close-up graph on the bottom. These increases can be due to a closer approach of an actively escorted target vessel as seen just past 00:00 on Jan 25 or an additional transit from an escort tug on its own, as seen

just following this event.



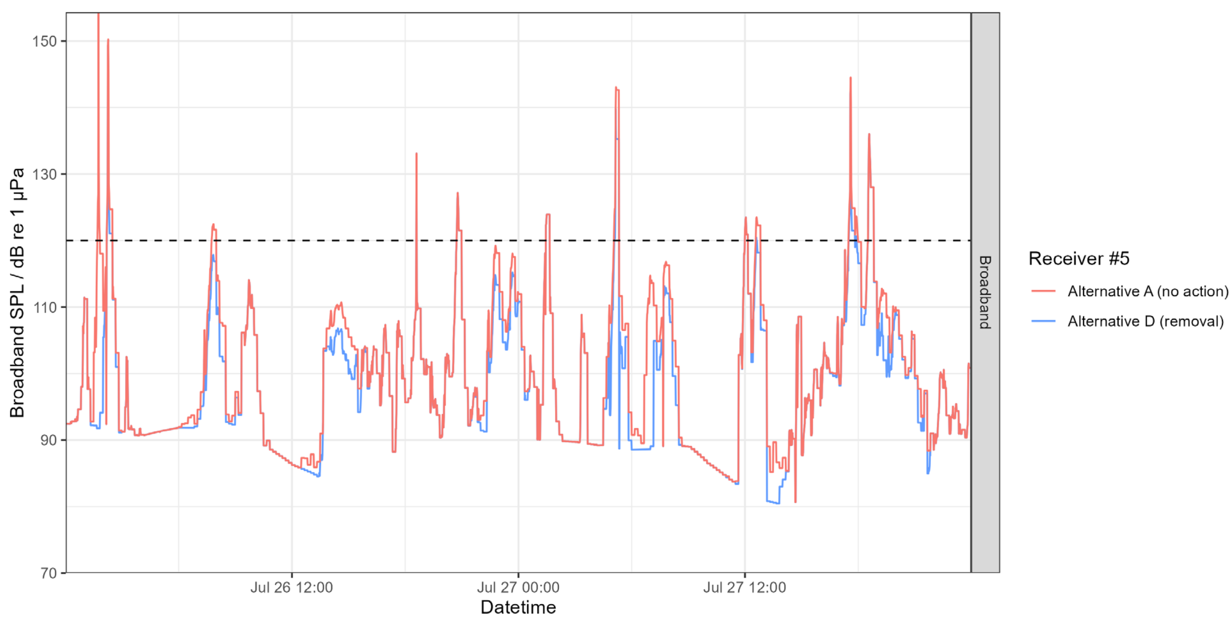


Figure 6. Broadband (10 Hz to 63 kHz) received sound pressure level (SPL) for Alternative A (red) and Alternative D – removal (blue) with time (one week – top plot, 48 hrs – bottom plot) at key receptor location #5 (Rosario) that has high escort tug traffic. The NMFS 120 dB marine mammal disturbance threshold is represented by the bold dashed line. There are reductions in SPL due to the removal of the escort tug requirement (blue), which vary in level depending on the proximity of the tug to the receptor as well as whether the transit included two vessels or one (i.e., escort tug alone). These differences are more apparent in the close-up graph on the bottom.

3.2. Soundscape Maps

This section presents soundscape maps for the equivalent continuous noise levels (L_{eq}), also known as the time-average sound level, in each of the three frequency bands of interest (broadband, SRKW communication, and echolocation bands) for the two seasons. Alternative A is presented in Figure 7 below; the other alternatives are presented in Supplement D.

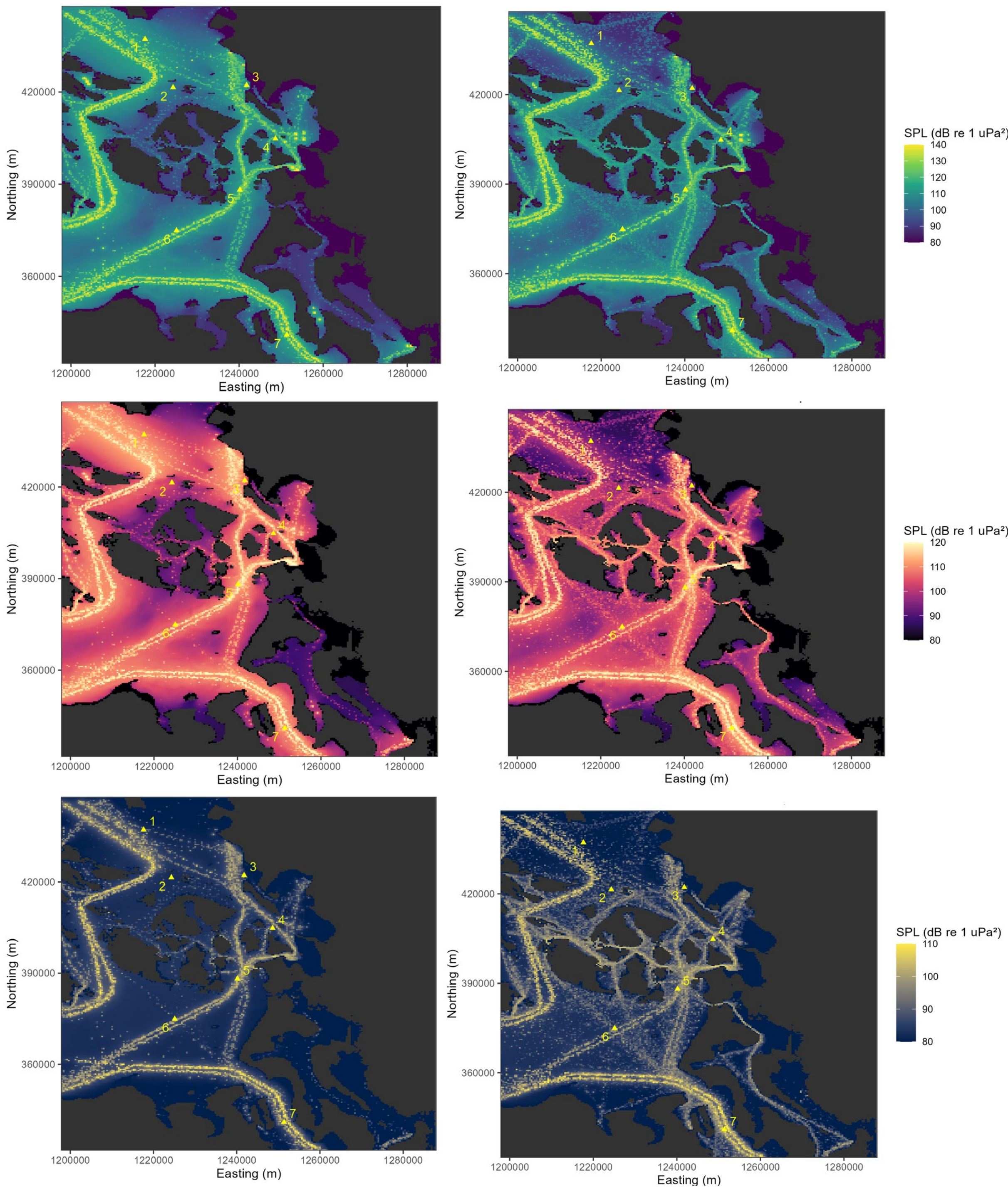


Figure 7. Equivalent continuous noise levels (L_{eq}) for winter (left) and summer (right) in the broadband (top), Southern Resident killer whale (SRKW) communication band (middle), and SRKW echolocation band (bottom) for Alternative A. Key receptor locations (yellow triangles) are numbered on each map. Note the difference in scales between the three frequency bands.

3.3. Tabulated Sound Levels

Tables 6 and 7 below present the median (L_{50}) and highest (L_5) values, respectively, for Alternative A and the difference with Alternatives C and D for the three frequency bands and two seasons examined. A corresponding table for the equivalent continuous noise levels (L_{eq}) is found in Supplement E.

Table 6. Median noise levels (L_{50}; dB re 1 µPa) for Alternative A (top section) and the differences with Alternative C and D (bottom sections) in the broadband, Southern Resident killer whale (SRKW) communication band, and SRKW echolocation band at the key receptor locations.

Key receptor location		Broadband (0.01 to 63 kHz)		Communication band (0.5 to 16 kHz)		Echolocation band (16 to 63 kHz)	
		Winter	Summer	Winter	Summer	Winter	Summer
Median noise level (L_{50}, dB re 1 µPa^2), existing conditions with tug escorts (Alt. A)							
1	SoG	100.8	89.4	99.0	87.5	77.2	79.3
2	Boundary Pass	92.9	92.6	91.6	90.9	78.3	81.1
3	Lummi	94.2	88.1	93.4	86.6	77.8	79.4
4	Anacortes	98.2	92.5	95.6	90.5	78.9	80.7
5	Rosario	94.2	96.8	93.2	95.7	80.6	82.0
6	Haro	94.0	94.0	92.7	92.7	79.6	82.0
7	Puget	89.8	105.1	88.4	103.5	78.3	81.0
Change in median noise level (L_{50}, dB re 1 µPa^2) with expansion (from Alt. A to Alt.C)							
1	SoG	0	0	-0.1	0	0	0
2	Boundary Pass	0	0	0.1	0	0	0
3	Lummi	0.6	0	0.3	0	0	0
4	Anacortes	0	-0.1	0	-0.1	0	0
5	Rosario	0	0	0	0	0	0
6	Haro	0	0	0	0	0	0
7	Puget	0	0	0	0	0	0
Change in median noise level (L_{50}, dB re 1 µPa^2) without tug escorts (from Alt. A to Alt. D)							
1	SoG	-0.2	0	-0.2	0	0	0
2	Boundary Pass	-0.1	0	-0.1	0	0	0
3	Lummi	-0.2	-0.1	-0.3	0	-0.1	0
4	Anacortes	-0.3	-0.3	-0.1	-0.3	0	0
5	Rosario	-0.9	-1.7	-1.1	-1.9	-0.2	-0.3
6	Haro	-0.2	-0.3	-0.3	-0.4	0	0
7	Puget	-0.1	-0.8	-0.1	-0.9	0	-0.2

Table 7. Highest noise levels (L_5; dB re 1 µPa) for Alternative A (top section) and the differences with Alternative C and D (bottom sections) in the broadband, Southern Resident killer whale (SRKW) communication band, and SRKW echolocation band at the key receptor locations.

Key receptor location		Broadband (0.01 to 63 kHz)		Communication band (0.5 to 16 kHz)		Echolocation band (16 to 63 kHz)	
		Winter	Summer	Winter	Summer	Winter	Summer
HIghest noise level (L_5, dB re 1 µPa^2), existing conditions with tug escorts (Alt. A)							
1	SoG	118.9	105.2	117.0	100.1	90.0	84.3
2	Boundary Pass	112.3	107.9	110.1	104.3	89.3	85.2
3	Lummi	116.8	92.6	116.3	90.5	90.2	83.1
4	Anacortes	115.3	111.7	114.5	110.1	90.5	92.1
5	Rosario	123.3	120.5	120.5	117.9	99.1	97.1
6	Haro	119.2	115.8	115.5	112.8	91.3	90.0
7	Puget	124.5	125.3	118.8	119.2	97.1	99.7
Change in highest noise level (L_5, dB re 1 µPa^2) with expansion (from Alt. A to Alt.C)							
1	SoG	0	0	0	0	0	0
2	Boundary Pass	0.4	0	0.3	0	0	0
3	Lummi	0	-0.1	-0.1	0	0	0
4	Anacortes	0	-0.2	0	0	0	0
5	Rosario	0	0	0	0	0	0
6	Haro	0	0	0	0	0	0
7	Puget	0	0	0	0	0	0
Change in highest noise level (L_5, dB re 1 µPa^2) without tug escorts (from Alt. A to Alt. D)							
1	SoG	0	0	0	0	0	0
2	Boundary Pass	0	0	-0.1	0	0	0
3	Lummi	-0.2	-0.4	-0.4	0	-0.1	0
4	Anacortes	-1.2	-1	-1.7	-1	-0.1	-0.5
5	Rosario	-0.8	-2.8	-1	-2.5	-1.5	-2.6
6	Haro	0	-0.2	0	-0.3	0	-0.3
7	Puget	0	-0.1	0	-0.4	0	-0.1

The number of 1-min time steps where the received broadband SPL is above 120 dB and 150 dB were summed for the week at each receptor location under each alternative (Tables 8 and 9 for the 120 dB threshold exceedances for winter and summer, respectively and Tables 10 and 11 for the 150 dB threshold exceedances for winter and summer, respectively).

Table 8. Winter: number of minutes (per week) above the 120 dB threshold at each receptor location under each alternative and percent increase from Alternative D.

Alternative	Duration of noise levels exceeding 120 dB (min/week) (Δ % from Alt. D)						
	1 – SoG	2 – Boundary	3 – Lummi	4 – Anacortes	5 – Rosario	6 – Haro	7 – Puget
A – No action	366 (0%)	15 (0%)	134 (13%)	162 (29%)	926 (18%)	498 (0%)	1144 (1%)
C – Expansion	366 (0%)	15 (0%)	134 (13%)	162 (29%)	926 (18%)	498 (0%)	1144 (1%)
D – Removal	366	15	119	126	782	498	1133

Table 9. Summer: number of minutes (per week) above the 120 dB threshold at each receptor location under each alternative and percent increase from Alternative D.

Alternative	Duration of noise levels exceeding 120 dB (min/week) (Δ % from Alt. D)						
	1 – SoG	2 – Boundary	3 – Lummi	4 – Anacortes	5 – Rosario	6 – Haro	7 – Puget
A – No action	3 (0%)	42 (0%)	4 (0%)	210 (9%)	604 (25%)	293 (6%)	1326 (9%)
C – Expansion	3 (0%)	42 (0%)	4 (0%)	210 (9%)	604 (25%)	293 (6%)	1326 (9%)
D – Removal	3	42	4	192	483	277	1220

Table 10. Winter: number of minutes (per week) above the 150 dB threshold at each receptor location under each alternative and percent increase from Alternative D.

Alternative	Duration of noise levels exceeding 150 dB (min/week) (Δ % from Alt. D)						
	1 – SoG	2 – Boundary	3 – Lummi	4 – Anacortes	5 – Rosario	6 – Haro	7 – Puget
A – No action	0	0	0	1 (100%)	5 (25%)	1 (0%)	26 (0%)
C – Expansion	0	0	0	1 (100%)	5 (25%)	1 (0%)	26 (0%)
D – Removal	0	0	0	0	4	1	26

Table 11. Summer: number of minutes (per week) above the 150 dB threshold at each receptor location under each alternative and percent increase from Alternative D.

Alternative	Duration of noise levels exceeding 150 dB (min/week) (Δ % from Alt. D)						
	1 – SoG	2 – Boundary	3 – Lummi	4 – Anacortes	5 – Rosario	6 – Haro	7 – Puget
A – No action	0	0	0	0	15 (25%)	1 (100%)	35 (0%)
C – Expansion	0	0	0	0	15 (25%)	1 (100%)	35 (0%)
D – Removal	0	0	0	0	12	0	35

The average area ensonified above 120 dB and 150 dB broadband SPL for the weeks modeled under each alternative are provided in Table 12 and 13 below.

Table 12. Average total area ensonified above the 120 dB threshold for each alternative and percent increase from Alternative D.

Alternative	Area ensonified above 120 dB (km^2) (Δ % from Alt. D)	
	Winter	Summer
A – No action	118.4 (2%)	80.7 (4%)
C – Expansion	118.6 (2%)	80.6 (3%)
D – Removal	116.2	78.0

Table 13. Average total area ensonified above the 150 dB threshold for each alternative and percent increase from Alternative D.

Alternative	Area ensonified above 150 dB (km^2) (Δ % from Alt. D)	
	Winter	Summer
A – No action	1.5 (0%)	1.2 (0%)
C – Expansion	1.5 (0%)	1.2 (0%)
D – Removal	1.5	1.2

4. Conclusions

The underwater noise modeling assessment of the tug escort requirement alternatives revealed the following key findings, addressing the study's objective questions:

- The SPL at all seven receptor locations periodically exceeded the NMFS 120 dB broadband SPL behavorial disturbance threshold for marine mammals under the existing vessel traffic conditions (Alternative A) during both seasons modeled. The levels at four locations in winter and three in summer also periodically exceeded the 150 dB acoustic disturbance threshold for finfish, but much less frequently than the 120 dB threshold. It should be taken into consideration that the noise model used a receiver depth of 10 meters due to the particular focus on marine mammals, specifically SRKW. Therefore, an animal at a greater water depth than 10 meters would experience lower sound levels due to the increased distance between the source (vessel) and the receiver (animal). In other words, there would be fewer or no exceedances of the thresholds for animals closer to the seafloor.
- The occurrence and duration of exceedances above both the 120 and 150 dB thresholds under Alternative C were identical to those under Alternative A. Some locations (four in both winter and summer for the 120 dB threshold and two in both seasons for the 150 dB threshold) had fewer and/or shorter exceedances under Alternative D.
- Similar trends would be expected for a threshold of 110 dB in the SRKW echolocation band, as highlighted by Tennessen et al. (2024) to be of particular relevance when examining potential impact on foraging by SRKW. However, the threshold is anticipated to be exceeded less often than the 120 dB broadband threshold (Figure C-29 in Appendix C.3) since the echolocation band encompasses a smaller frequency range, and therefore contains less acoustic energy. This suggests that using the 120 dB broadband threshold results in a more ecologically conservative analysis for this type of noise.
- The highest existing (Alternative A) median sound levels were observed on the Strait of Georgia receptor in winter and the Puget Sound receptor in summer (in the broadband frequency band). Interestingly, the largest difference between winter and summer was observed at the Puget Sound receptor, with higher sound levels experienced in summer.
- The modeling revealed that existing tug escort requirements (those affected by the rulemaking) have a fairly substantial contribution to the local soundscape at particular locations. Under current conditions (Alternative A), tug escort requirements account for an increase in the median and highest noise levels of up to 1.7 and 2.8 dB broadband SPL, respectively, compared to without tug escort requirements (Alternative D). These increases occurred at locations with high escort tug underway time density, i.e., Rosario Strait. However the increase attributable to current tug escort requirements was less than 0.5 dB SPL for most other modeled locations and time periods.
- Adherence to the functional and operational requirements (FORs), which includes pre-escort conference, minimum horsepower, and propulsion specifications, is not expected to change the noise levels. Based on a review of historical AIS data, Ecology found that the horsepower requirement codifies existing industry practices for tug horsepower and size of target vessel. The propulsion specification also codifies the existing conditions of escort tugs in the region. The OTSC identified that all 18 tugs identified in the 2021 Vessel Traffic Trend Study (Ecology and BPC 2021) currently have twin screw propulsion or better. The pre-escort conference will not change noise levels.

- The expansion of the tug escort requirements (Alternative C) was modeled to have minimal effect on underwater sound levels at the key receptor locations. The median and highest broadband noise levels increased by a maximum of 0.6 and 0.4 dB, respectively relative to Alternative A, at the closest receptors to the expansion area, i.e., Lummi and Boundary Pass. Both NMFS behavioral thresholds are not exceeded more often with the expansion than under the existing conditions.
- Median noise levels decreased at all of the receptor locations, in either one season or both, due to the removal of the curent tug escort requirements (Alternative D), and the amount of time spent above the two NMFS behavioral thresholds decreased at four of the seven locations for the 120 dB threshold (marine mammals) and two of the seven locations for the 150 dB threshold (finfish).

A few limitations or assumptions were made that could affect accuracy or relevancy of the assessment results. The percentage of non-AIS vessel traffic was approximated from 7–9 year old data and while some scaling for expected changes was made, there is uncertainty in the scaling parameter used to estimate real fishing vessel and recreational vessel densities. The source level for the anchored vessels is from measurements of one vessel and may not be representative of a typical vessel at anchor. The simulation of vessel traffic represented just one week of winter and one week of real vessel traffic data; some variability of traffic occurs between different weeks but it is expected that the variability will not lead to substantial differences from the results predicted here.

Acknowledgements

The authors would like to acknowledge the ECHO Program for use of the vessel URN source level database.

Glossary of Acoustics Terms

Unless otherwise stated in an entry, these definitions are consistent with ISO 18405 (2017).

Italicized text indicates related terms that might be in this glossary. Underlined text indicates clickable links to related terms in this glossary

1/3-octave

One third of an *octave*. A 1/3-octave is approximately equal to one *decidecade* (1/3 oct ≈ 1.003 ddec).

1/3-octave-band

Frequency band whose *bandwidth* is one *1/3 octave*. The bandwidth of a 1/3-octave-band increases with increasing centre frequency.

90 % sound pressure level (90 % SPL)

The *sound pressure level* calculated over the *90 % energy time window* of a pulse. Unit: *decibel (dB).*

absorption

The conversion of *sound* energy to heat energy. Specifically, the reduction of *sound pressure* amplitude due to particle motion energy converting to heat in the propagation medium.

acoustic noise

Sound that interferes with an acoustic process.

ambient sound

Sound that would be present in the absence of a specified activity (ISO 18405: 2017). It is usually a composite of sound from many sources near and far, e.g., shipping vessels, seismic activity, precipitation, sea ice movement, wave action, and biological activity.

annotation

Within a spectrogram, a labelled selection of a time interval and *frequency* range as created during *manual analysis*.

attenuation

The gradual loss of acoustic energy from *absorption* and scattering as *sound* propagates through a medium. Attenuation depends on *frequency*—higher frequency sounds are attenuated faster than lower frequency sounds.

audiogram

A graph or table of *hearing threshold* as a function of *frequency* that describes the hearing sensitivity of an animal over its hearing range.

background noise

Combination of *ambient sound, acoustic self-noise,* and, where applicable, sonar reverberation (ISO 18405: 2017) that is detected, measured, or recorded with a signal.

bandwidth

A range within a continuous band of frequencies. Unit: *hertz (Hz)*.

broadband level

The total *level* measured over a specified *frequency* range. If the frequency range is unspecified, the term refers to the entire measured frequency range.

cetacean

Member of the order Cetacea. Cetaceans are aquatic mammals and include whales, dolphins, and porpoises.

compressional wave

A mechanical vibration wave in which the direction of particle motion is parallel to the direction of propagation. Also called a longitudinal wave. In seismology/geophysics, it's called a primary wave or P-wave. *Shear waves* in the seabed can be converted to compressional waves in water at the water-seabed interface.

conductivity-temperature-depth (CTD)

Measurement data of the ocean's conductivity, temperature, and depth; used to compute *sound speed profiles* and salinity.

continuous sound

A *sound* whose *sound pressure level* remains above the *background noise* during the observation period and may gradually vary in intensity with time, e.g., sound from a marine vessel.

decade

Logarithmic *frequency* interval whose upper bound is ten times larger than its lower bound (ISO 80000-3 2006). For example, one decade up from 1000 Hz is 10,000 Hz, and one decade down is 100 Hz.

decibel (dB)

Unit of *level* used to express the ratio of one value of a power quantity to another on a logarithmic scale. Especially suited to quantify variables with a large dynamic range.

decidecade

One tenth of a *decade*. Approximately equal to one third of an octave (1 ddec ≈ 0.3322 oct), and for this reason sometimes referred to as a *1/3 octave*.

decidecade band

Frequency band whose *bandwidth* is one *decidecade*. The bandwidth of a decidecade band increases with increasing centre frequency.

energy source level

A property of a *sound* source equal to the *sound exposure level* measured in the *far field* plus the *propagation loss* from the acoustic centre of the source to the receiver position. Unit: *decibel (dB). Reference value*: 1 $\mu Pa^2\,m^2\,s$.

energy spectral density level

The *level* ($L_{E,f}$) of the *energy spectral density* (E_f) in a stated *frequency* band and time window. Defined as: $L_{E,f}$ = 10log10($E_f/E_{f,0}$). Unit: *decibel (dB).* As with energy spectral density, energy spectral density level can be expressed in terms of various field variables (e.g., *sound pressure, sound particle displacement*). The *reference value* ($E_{f,0}$) for energy spectral density level depends on the nature of the field variable.

energy spectral density source level

A property of a *sound* source equal to the *energy spectral density level* of the *sound pressure* measured in the *far field* plus the *propagation loss* from the acoustic centre of the source to the receiver position. Unit: *decibel (dB)*. *Reference value*: 1 μPa^2 m^2 s/Hz.

ensonified

Exposed to *sound*.

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.

hearing threshold

For a given species or *functional hearing group*, the *sound level* for a given signal that is barely audible (i.e., that would be barely audible for a given individual in the presence of specified *background noise* during a specific percentage of experimental trials).

hertz (Hz)

Unit of *frequency* defined as one cycle per second. Often expressed in multiples such as kilohertz (1 kHz = 1000 Hz).

hydrophone

An underwater *sound pressure* transducer. A passive electronic device for recording or listening to underwater *sound*.

hydrostatic pressure

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).

isopleth

A line drawn on a map through all points having the same value of some specified quantity (e.g., sound pressure level isopleth).

knot (kn)

Unit of vessel speed equal to 1 nautical mile per hour.

level

A measure of a quantity expressed as the logarithm of the ratio of the quantity to a specified *reference value* of that quantity. For example, a value of *sound pressure level* with reference to 1 μPa^2 can be written in the form *x* dB re 1 μPa^2.

masking

Obscuring of *sounds* of interest by other sounds at similar frequencies.

median

The 50th percentile of a statistical distribution.

mysticete

Member of the Mysticeti, a suborder of *cetaceans*. Also known as baleen whales, mysticetes have baleen plates (rather than teeth) that they use to filter food from water (or from sediment as for grey whales). This group includes rorquals (Balaenopteridae, such as blue, fin, humpback, and minke whales), right and bowhead whales (Balaenidae), and grey whales (Eschrichtius robustus).

***N* percent exceedance level**

The *sound level* exceeded *N* % of the time during a specified time interval. See also percentile level.

non-impulsive sound

Sound that is not an *impulsive sound*. Not necessarily a *continuous sound*.

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.

odontocete

Member of Odontoceti, a suborder of *cetaceans*. These whales, dolphins, and porpoises have teeth (rather than baleen plates). Their skulls are mostly asymmetric, an adaptation for their echolocation. This group includes sperm whales, killer whales, belugas, narwhals, dolphins, and porpoises.

parabolic equation method

A computationally efficient solution to the acoustic wave equation that is used to model *propagation loss*. The parabolic equation approximation omits effects of backscattered *sound* (which are negligible for most ocean-acoustic propagation problems), simplifying the computation of propagation loss.

percentile level

The *sound level* not exceeded *N* % of the time during a specified time interval. The *N*th percentile level is equal to the (100−*N*) % exceedance level. See also N percent exceedance level.

permanent threshold shift (PTS)

An irreversible loss of hearing sensitivity caused by excessive noise exposure. Considered auditory injury. Compare with *temporary threshold shift*.

propagation loss (PL)

Difference between a *source level* (SL) and the level at a specified location, PL(x) = SL − L(x). Unit: decibel (dB). See also transmission loss.

radiated noise level (RNL)

A *source level* that has been calculated assuming *sound pressure* decays geometrically with distance from the source, with no influence of the sea-surface or seabed. Often used to quantify source levels of vessels or industrial operations from measurements.

received level

The *level* of a given field variable measured (or that would be measured) at a given location.

reference value

Standard value of a quantity used for calculating underwater *sound level*. The reference value depends on the quantity for which the level is being calculated:

Quantity	Reference value
Sound pressure	${p_0}^2$ = 1 μPa² or p_0 = 1 μPa
Sound exposure	E_0 = 1 μPa² s
Sound particle displacement	${\delta_0}^2$ = 1 pm²
Sound particle velocity	${u_0}^2$ = 1 nm²/s²
Sound particle acceleration	${a_0}^2$ = 1 μm²/s⁴

sound

A time-varying disturbance in the pressure, stress, or material displacement of a medium propagated by local compression and expansion of the medium. In common meaning, a form of energy that propagates through media (e.g., water, air, ground) as pressure waves.

sound intensity

Product of the *sound pressure* and the *sound particle velocity* (ISO 18405: 2017). The magnitude of the sound intensity is the *sound* energy flowing through a unit area perpendicular to the direction of propagation per unit time. Unit: watt per meter squared (W/m²). Symbol: I.

sound pressure

The contribution to total pressure caused by the action of *sound* (ISO 18405: 2017). Unit: pascal (Pa). Symbol: p.

sound pressure level (SPL), rms sound pressure level

The *level* (L_p) of the time-mean-square *sound pressure* (p^2_{rms}) in a stated *frequency* band and time window: L_p = 10log$_{10}$(p^2_{rms}/p^2_0) = 20log$_{10}$(p_{rms}/p_0), where rms is the abbreviation for root-mean-square. Unit: *decibel (dB)*. *Reference value* (p^2_0) for *sound* in water: 1 μPa². SPL can also be expressed in terms of the root-mean-square (rms) with a *reference value* of p_0 = 1 μPa. The two definitions are equivalent.

sound speed profile

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

soundscape

The characterization of the *ambient sound* in terms of its spatial, temporal, and *frequency* attributes, and the types of sources contributing to the *sound* field (ISO 18405: 2017).

source level (SL)

A property of a *sound* source equal to the *sound pressure level* measured in the *far field* plus the propagation loss from the acoustic centre of the source to the receiver position. Unit: *decibel (dB)*. *Reference value*: 1 μPa^2 m^2.

spectrogram

A visual representation of acoustic amplitude over time and frequency. A spectrogram's resolution in the time and frequency domains should generally be stated as it determines the information content of the representation.

spectrum

Distribution of acoustic signal content over *frequency*, where the signal's content is represented by its power, energy, mean-square *sound pressure*, or *sound exposure*.

temporary threshold shift (TTS)

Reversible loss of hearing sensitivity caused by noise exposure. Compare with *permanent threshold shift*.

transmission loss (TL)

The difference between a specified level at one location and that at a different location: TL(x_1,x_2) = $L(x_1) - L(x_2)$ (ISO 18405: 2017). Unit: *decibel (dB)*. See also propagation loss.

unweighted

Term indicating that no *frequency-weighting function* is applied.

wavelength

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

Literature Cited

Ainslie, Michael A. 2010. *Principles of Sonar Performance Modeling*. Praxis Books. Berlin: Springer. https://doi.org/10.1007/978-3-540-87662-5.

Ainslie, Michael A., Chris H. Harrison, and Mario Zampolli. 2011. “An Analytical Solution for Signal Background and Signal to Background Ratio for a Low Frequency Active Sonar in a Pekerisch Waveguide Satisfying Lambert’s Rule.” In , 491–98. Kos, Greece. https://www.uaconferences.org/docs/Past_proceedings/UAM2011_Proceedings.pdf.

Ainslie, Michael A., S. Bruce Martin, Krista B. Trounce, David E. Hannay, Justin M. Eickmeier, Terry J. Deveau, Klaus Lucke, Alexander O. MacGillivray, Veronique Nolet, and Pablo Borys. 2022. “International Harmonization of Procedures for Measuring and Analyzing of Vessel Underwater Radiated Noise.” *Marine Pollution Bulletin* 174:113124. https://doi.org/10.1016/j.marpolbul.2021.113124.

Anderson, Dave, Laurie Shuster, Cindy R. Elliser, Katrina MacIver, Erin John Gless, Johannes Krieger, and Anna Hall. 2023. “Harbor Porpoise Aggregations in the Salish Sea.” *Oceans* 4:269–85. https://doi.org/10.3390/oceans4030019.

BPC] Washington State Board of Pilotage Commissioners and ECY] Washington State Department of Ecology. 2021. “Synopsis of Changing Vessel Trends: ESHB 1578 – Reducing Threats to Southern Resident Killer Whales by Improving the Safety of Oil Transportation.”

Branstetter, Brian K., Judy St. Leger, Doug Acton, John Stewart, Dorian S. Houser, James J. Finneran, and Keith Jenkins. 2017. “Killer Whale (Orcinus Orca) Behavioral Audiograms.” *Journal of the Acoustical Society of America* 141 (4): 2387–98. https://doi.org/10.1121/1.4979116.

Carnes, Michael R. 2009. “Description and Evaluation of GDEM-V 3.0.” US Naval Research Laboratory, Stennis Space Center, MS. NRL Memorandum Report 7330-09-9165. https://apps.dtic.mil/dtic/tr/fulltext/u2/a494306.pdf.

Chapman, N. Ross, and J. W. Cornish. 1993. “Wind Dependence of Deep Ocean Ambient Noise at Low Frequencies.” *Journal of the Acoustical Society of America* 93 (2): 782–89. https://doi.org/10.1121/1.405440.

Collins, Michael D. 1993a. “A Split-Step Padé Solution for the Parabolic Equation Method.” *Journal of the Acoustical Society of America* 93 (4): 1736–42. https://doi.org/10.1121/1.406739.

———. 1993b. “The Adiabatic Mode Parabolic Equation.” *Journal of the Acoustical Society of America* 94 (4): 2269–78. https://doi.org/10.1121/1.407498.

Collins, Michael D., R. J. Cederberg, David B. King, and Stanley Chin-Bing. 1996. “Comparison of Algorithms for Solving Parabolic Wave Equations.” *Journal of the Acoustical Society of America* 100 (1): 178–82. https://doi.org/10.1121/1.415921.

DFO] Fisheries and Oceans Canada (Pacific Region). 2021. “Identification of Areas for Mitigation of Vessel-Related Threats to Survival and Recovery for Southern Resident Killer Whales.” Canadian Science Advisory Secretariat Science Advisory Report 2021/025.

Dolman, Joshua N., Alexander O. MacGillivray, Zizheng Li, and Connor H. Grooms. 2021. “Underwater Noise Measurements of Seaspan Ferries Hybrid Electric Vessels: Task 1 Technical Report.” Technical report by JASCO Applied Sciences for Vancouver Fraser Port Authority ECHO Program.

Ecology, and BPC. 2021. “Synopsis of Changing Vessel Traffic Trends.” Washington State Department of Ecology, Washington State Board of Pilotage Commissioners. https://nebula.wsimg.com/17056ac82adb868022291ad1d8dae1b9?AccessKeyId=F86D0A1E7A0091C2061F&disposition=0&alloworigin=1.

Erbe, Christine, Alexander O. MacGillivray, and Rob Williams. 2012. “Mapping Cumulative Noise from Shipping to Inform Marine Spatial Planning.” *Journal of the Acoustical Society of America* 132 (5): EL423–28. https://doi.org/10.1121/1.4758779.

Frouin-Mouy, Héloïse. 2017. “BC Ferries Vessel Underwater Radiated Noise Measurements in Swanson Channel: Vessel Noise Analysis.” Technical report by JASCO Applied Sciences for British Columbia Ferry Services Inc.

Frouin-Mouy, Héloïse, Joshua N. Dolman, Alexander O. MacGillivray, and C. Eric Lumsden. 2020. “Underwater Noise Measurements of Four BC Ferries Vessels: Including Hull Coating Analysis for Queen of Oak Bay.” Technical report by JASCO Applied Sciences for Vancouver Fraser Port Authority ECHO Program.

Hamilton, Edwin L. 1980. “Geoacoustic Modeling of the Sea Floor.” *Journal of the Acoustical Society of America* 68 (5): 1313–40. https://doi.org/10.1121/1.385100.

Hannay, David E., Alexander O. MacGillivray, Héloïse Frouin-Mouy, Zizheng Li, Federica Pace, Jennifer L. Wladichuk, and Zahra Alavizadeh. 2019. “Study of Quiet-Ship Certifications: Analysis Using the ECHO Ship Noise Database.” Technical report by JASCO Applied Sciences for Transport Canada.

Harris, A., K. Palmer, Jason D. Wood, and Dominic J. Tollit. 2022. “Burrard Inlet Underwater Noise Characterization: 2021 Final Report.” Report by SMRU Consulting NA for Vancouver Fraser Port Authority and Tsleil-Waututh Nation.

Heise, Kathy A., Lance G. Barrett-Lennard, Ross Chapman, Tom Dakin, Christine Erbe, David E. Hannay, Nathan D. Merchant, et al. 2017. “Proposed Metrics for the Management of Underwater Noise for Southern Resident Killer Whales.” Coastal Ocean Report Series. Vancouver, BC, Canada: Report for the Coastal Ocean Research Institute. © Ocean Wise 2017. https://doi.org/10.25317/CORI20172.

[ISO] International Organization for Standardization. 2006. “ISO 80000-3:2006. Quantities and Units — Part 3: Space and Time.” https://www.iso.org/standard/31888.html.

———. 2017. “ISO 18405:2017. Underwater Acoustics — Terminology.” Geneva. https://www.iso.org/obp/ui/en/#!iso:std:62406:en.

JASCO. 2015. “Underwater Acoustic Measurements in Haro Strait and Strait of Georgia: Transmission Loss, Vessel Source Levels, and Ambient Measurements. Appendix A in Hemmera and SMRU. Roberts Bank Terminal 2 Technical Data Report: Ship Sound Signature Analysis Study.” Report by JASCO for Port Metro Vancouver.

Jensen, Finn B., William A. Kuperman, Michael B. Porter, and Henrik Schmidt. 2011. *Computational Ocean Acoustics*. 2nd ed. AIP Series in Modern Acoustics and Signal Processing. New York: AIP Press - Springer. https://doi.org/10.1007/978-1-4419-8678-8.

Joy, Ruth, Dominic J. Tollit, Jason D. Wood, Alexander O. MacGillivray, Zizheng Li, Krista B. Trounce, and Orla Robinson. 2019. “Potential Benefits of Vessel Slowdowns on Endangered Southern Resident Killer Whales.” *Frontiers in Marine Science* 6:344. https://doi.org/10.3389/fmars.2019.00344.

Kuperman, William A., and M. C. Ferla. 1985. “A Shallow Water Experiment to Determine the Source Spectrum Level of Wind-generated Noise.” *Journal of the Acoustical Society of America* 77 (6): 2067–73. https://doi.org/10.1121/1.391781.

MacGillivray, Alexander O., Laurie M. Ainsworth, Joanna Zhao, Joshua N. Dolman, David E. Hannay, Héloïse Frouin-Mouy, Krista B. Trounce, and Derek A. White. 2022. "A Functional Regression Analysis of Vessel Source Level Measurements from the Enhancing Cetacean Habitat and Observation (ECHO) Database." *Journal of the Acoustical Society of America* 152 (3): 1547–63. https://doi.org/10.1121/10.0013747.

MacGillivray, Alexander O., Héloïse Frouin-Mouy, and Jorge E. Quijano. 2017. "BC Ferries Vessel Noise Analysis: Vessel Noise Analysis for Customers of Port of Vancouver." Technical report by JASCO Applied Sciences for Vancouver Fraser Port Authority ECHO Program.

MacGillivray, Alexander O., David E. Hannay, and Heloise Frouin-Mouy. 2019. "A Multivariate Analysis of Vessel Source Levels from the Enhancing Cetacean Habitat Observation (ECHO) Ship Noise Database [Meeting Abstract]." *Journal of the Acoustical Society of America* 146:3060–61. https://doi.org/10.1121/1.5137621.

MacGillivray, Alexander O., and Christ A. F. de Jong. 2021. "A Reference Spectrum Model for Estimating Source Levels of Marine Shipping Based on Automated Identification System Data." *Journal of Marine Science and Engineering* 9 (4): 369. https://doi.org/10.3390/jmse9040369.

MacGillivray, Alexander O., and Zizheng Li. 2016. "Seaspan Ferries Vessel Noise Analysis." Technical report by JASCO Applied Sciences for Vancouver Fraser Port Authority (VFPA).

———. 2018. "Vessel Noise Measurements from the ECHO Slowdown Trial: Final Report." Technical Report by JASCO Applied Sciences for Vancouver Fraser Port Authority ECHO Program.

MacGillivray, Alexander O., S. Bruce Martin, Michael A. Ainslie, Joshua N. Dolman, Zizheng Li, and Graham A. Warner. 2023. "Measuring Vessel Underwater Radiated Noise in Shallow Water." *Journal of the Acoustical Society of America* 153 (3): 1506–24. https://doi.org/10.1121/10.0017433.

MacGillivray, Alexander O., Michael A. Wood, Zizheng Li, Ainsley S. Allen, and David E. Hannay. 2017. "Regional Ocean Noise Contributors Analysis: Enhancing Cetacean Habitat and Observation Program." Technical report by JASCO Applied Sciences for Vancouver Fraser Port Authority (VFPA). https://www.portvancouver.com/wp-content/uploads/2017/01/Regional-Ocean-Noise-Contributors.pdf.

Matthews, Marie-Noël R., Zahra Alavizadeh, David E. Hannay, Loren Horwich, and Héloïse Frouin-Mouy. 2018. "Assessment of Vessel Noise within the Southern Resident Killer Whale Critical Habitat: Final Report." Technical report by JASCO Applied Sciences for the Innovation Centre, Transport Canada/Government of Canada. © (2018) Transport Canada.

Murchy, Kelsie A., Svein Vagle, and Francis Juanes. 2022. "Anchored Bulk Carriers Have Substantial Impacts on the Underwater Soundscape in Cowichan Bay, British Columbia." *Marine Pollution Bulletin* 182:113921. https://doi.org/10.1016/j.marpolbul.2022.113921.

[NGDC] National Geophysical Data Center. 2013. "High Resolution NOAA Digital Elevation Model." *U.S. Coastal Relief Model (CRM)*. National Oceanic and Atmospheric Administration, US Department of Commerce. https://www.ngdc.noaa.gov/redirects/dem-portal.html.

Nowacek, Douglas P., Lesley H. Thorne, David W. Johnston, and Peter L. Tyack. 2007. "Responses of Cetaceans to Anthropogenic Noise." *Mammal Review* 37 (2): 81–115. https://doi.org/10.1111/j.1365-2907.2007.00104.x.

Olson, Jennifer K., Shawn E. Larson, F. C. Robertson, H. Miller, A. Morrigan, Susan A. Berta, and John Calambokidis. 2024. "Utilizing Long-Term Opportunistic Sightings Records to Document Spatio-Temporal Shifts in Mysticete Presence and Use in the Central Salish Sea." *Frontiers in Conservation Science* 5:1401838. https://doi.org/10.3389/fcosc.2024.1401838.

Olson, Jennifer K., Jason D. Wood, Richard W. Osborne, Lance G. Barrett-Lennard, and Shawn Larson. 2018. "Sightings of Southern Resident Killer Whales in the Salish Sea 1976–2014: The Importance of a Long-Term Opportunistic Dataset." *Endangered Species Research* 37:105–18. https://doi.org/10.3354/esr00918.

Ramsey, Elizabeth H., and Graham A. Warner. 2021. "Hydroacoustic Modelling of Vessel Noise: Port of Prince Rupert and Surrounding Waters." Technical report by JASCO Applied Sciences for Prince Rupert Port Authority.

Rodríguez, Ernesto, C. S. Morris, Y. J. E. Belz, Elaine C. Chapin, Jan M. Martin, Willaim H. Daffer, and Scott Hensley. 2005. "An Assessment of the SRTM Topographic Products." Pasadena, CA, USA: Jet Propulsion Laboratory.

Ross, Donald. 1987. *Mechanics of Underwater Noise*. Peninsula Publishing.

Scrimger, Joseph A., Donald J. Evans, and Wayman Yee. 1989. "Underwater Noise Due to Rain—Open Ocean Measurements." *Journal of the Acoustical Society of America* 85 (2): 726–31. https://doi.org/10.1121/1.397598.

Serra-Sogas, Norma, Patrick D. O'Hara, Kim Pearce, Leh Smallshaw, and Rosaline Canessa. 2021. "Using Aerial Surveys to Fill Gaps in AIS Vessel Traffic Data to Inform Threat Assessments, Vessel Management and Planning." *Marine Policy* 133. https://doi.org/10.1016/j.marpol.2021.104765.

Szymanski, Michael D., David E. Bain, Kent Kiehl, Scott Pennington, Scott Wong, and Kenneth R. Henry. 1999. "Killer Whale (Orcinus Orca) Hearing: Auditory Brainstem Response and Behavioral Audiograms." *Journal of the Acoustical Society of America* 106 (2): 1134–41. https://doi.org/10.1121/1.427121.

Teague, William J., Michael J. Carron, and Patrick J. Hogan. 1990. "A Comparison between the Generalized Digital Environmental Model and Levitus Climatologies." *Journal of Geophysical Research* 95 (C5): 7167–83. https://doi.org/10.1029/JC095iC05p07167.

Tennessen, Jennifer B., Marla M. Holt, Brianna M. Wright, M. Bradley Hanson, Candice K. Emmons, Deborah A. Giles, Jeffrey T. Hogan, Sheila J. Thornton, and Volker B. Deecke. 2024. "Males Miss and Females Forgo: Auditory Masking from Vessel Noise Impairs Foraging Efficiency and Success in Killer Whales." *Global Change Biology* 30 (9): e17490. https://doi.org/10.1111/gcb.17490.

Tyack, Peter L. 2008. "Implications for Marine Mammals of Large-Scale Changes in the Marine Acoustic Environment." *Journal of Mammalogy* 89 (3): 549–58. https://doi.org/10.1644/07-MAMM-S-307R.1.

Urick, Robert J. 1983. *Principles of Underwater Sound*. 3rd ed. New York, London: McGraw-Hill.

Water Properties Group. 2019. "Water Properties." Sidney, BC, Canada: Fisheries and Oceans Canada, Institute of Ocean Sciences. https://www.waterproperties.ca/data/.

Weilgart, Linda S. 2007. "The Impacts of Anthropogenic Ocean Noise on Cetaceans and Implications for Management." *Canadian Journal of Zoology* 85 (11): 1091–1116. https://doi.org/10.1139/Z07-101.

Wladichuk, Jennifer L., David E. Hannay, Alexander O. MacGillivray, and Zizheng Li. 2018. "Whale Watch and Small Vessel Underwater Noise Measurements Study: Final Report." Technical report by JASCO Applied Sciences for Vancouver Fraser Port Authority ECHO Program. https://apps.neb-one.gc.ca/REGDOCS/File/Download/3724167.

Zhang, Z. Y., and C. T. Tindle. 1995. "Improved Equivalent Fluid Approximations for a Low Shear Speed Ocean Bottom." *Journal of the Acoustical Society of America* 98 (6): 3391–96. https://doi.org/10.1121/1.413789.

Supplement A. ARTEMIA Model

A.1. CRAM Sound Propagation Model

Propagation loss was calculated in ARTEMIA using the CRAM (Complex-density Range-dependent Acoustic Model) wave equation model. CRAM computes acoustic propagation via a wide-angle split-step Padé parabolic equation (PE) solution to the acoustic wave equation (Collins 1993a). The parabolic equation method has been extensively benchmarked and is widely employed in the underwater acoustics community (Collins et al. 1996). CRAM accounts for the additional bottom loss resulting from partial conversion of incident compressional waves to shear waves at the seabed and sub-bottom interfaces. It also includes wave attenuation in all layers. Input parameters to CRAM include the sound speed profile as a function of depth, bathymetry versus range profiles, and geoacoustic profiles describing the stratified acoustic properties of the seabed. All input parameters are fully range dependent. CRAM is based on the RAMGEO1.5 source code and includes the following enhancements over the original version:

- Simulation of bottom loss from an elastic seabed using the complex-density equivalent fluid approximation (Zhang and Tindle 1995).
- Inclusion of seawater attenuation using the frequency-dependent Horton-Thorp-Urick formula (equation 1.47 in Jensen et al. 2011).
- Consideration of the Earth’s curvature using Tappert’s effective sound speed (Collins 1993b).
- Variable range step for enhanced short-range accuracy.
- Adaptive vertical grid for faster field calculations.
- Thread safety, dynamic memory allocation, and several bug fixes.

ARTEMIA calculates propagation loss in three dimensions by running CRAM along two-dimensional (2-D) vertical planes radiating from the source and covering a 360° angular swath, an approach commonly referred to as *N*×2D. These vertical planes are separated by an angular step size of $\Delta\theta$, yielding $N = 360°/\Delta\theta$ radials (Figure A-1). The current study employed a $\Delta\theta$ value of 10°. The parameters of CRAM's computational grid were frequency dependent. An optimal set of computational parameters for the study area was determined through convergence testing (Table A-1).

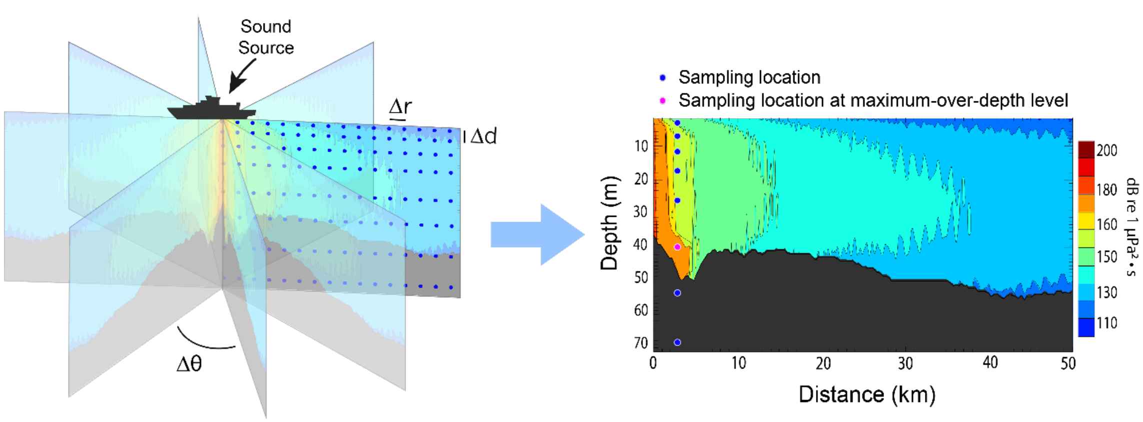


Figure A-1. The *N*×2-D modeling in ARTEMIA, with propagation loss for each radial computed using CRAM.

Table A-1. Frequency dependent parameters of the CRAM computational grid used in the current study. Parameters are as follows: decidecade frequency band range f (Hz), number of Padé terms N_p, coarse range step Δr (m), fine range step Δr_{fine} (m), maximum range of fine range step r_{fine} (m), depth increment Δz (m), depth of sponge layer below seabed z_{abs} (m), thickness of sponge layer h_{abs} (m), attenuation gradient in sponge layer α'_{abs} (dB/λ/m). The reference sound speed for the PE operator was 1500 m/s.

f	N_p	Δr	Δr_{fine}	r_{fine}	Δz	z_{abs}	h_{abs}	α'_{abs}
10–16	3	50	10	5000	2	234	704	0.1
20–31.5	3	50	10	5000	2	119	357	0.1
40–63.1	3	50	10	5000	2	60	178	0.1
80–125	3	50	10	5000	2	50	150	0.1
150–250	3	50	10	5000	1.2	50	150	0.1
315–500	3	50	10	5000	0.6	50	150	0.1
630–1000	4	50	10	5000	0.3	50	150	0.1

The PE method has several advantages that make it well suited to modeling low-frequency sound propagation. These include explicit range dependence of bathymetry and environmental properties, arbitrary vertical stratification of sound speed profile in the water column, arbitrary stratification of geoacoustic properties in the seabed, and computational efficiency at low-to-intermediate frequencies dominated by vessel URN. Furthermore, the complex-density PE implemented by CRAM can accurately simulate elastic seabed properties for most common seabed sediments, which increases the accuracy of long-range PL calculations at continental shelf locations. Disadvantages of the PE method limit its usefulness at higher frequencies: these include a quadratic increase in computational effort with increasing frequency and difficulty incorporating reflection losses due to rough interfaces at the surface and seabed.

For the current study, CRAM was used to calculate propagation loss for 21 decidecade frequency bands from 10–1000 Hz. Propagation loss above 1000 Hz was extrapolated from the CRAM PL at 1000 Hz using the Horton-Thorp-Urick seawater absorption formula:

$$N_{PL}(f > 1000\text{ Hz}) = N_{PL}(1000\,Hz) + (\alpha(f) - \alpha(1000\,Hz)) \times r \ \text{ dB},$$

where N_{PL} is the propagation loss (dB), f is the sound frequency (Hz), $\alpha(f)$ is the frequency-dependent absorption coefficient (dB/m), and r is the slant-range between the source and receiver points (m).

A.2. Areic Source Density Calculation

Georeferenced layers of gridded source density data are used to quantity the sound energy originating from different categories of vessel, for a specified area, time, and frequency band. These source density layers are calculated from ship source level and track data (see Sections 2.6 and 2.4). This post-processing is implemented using the *Navsrcmap* software tool written in the Fortran programming language. The tool takes as input vessel track data in the form of Comma Separated Value (CSV) files containing the following columns:

- Date (UTC),
- Time (UTC),
- Unique source ID (e.g., IMO or MMSI number),
- Unique track/journey ID,

- Vessel type code,
- Vessel easting (m),
- Vessel northing (m),
- Source depth (m), and
- Vessel source levels in decidecade bands from 10 to 50,000 Hz.

The *Navsrcmap* tool outputs raster files of georeferenced source density grids, by vessel type and frequency band. Source density is represented in terms of the areic[2] source factor (ASF; symbol $F_{S,A}$; units of Pa^2), which is defined as the mean vessel source factor per unit area within a single grid cell. The ASF within each layer is adjusted to a reference source depth, to facilitate the sound propagation modeling.

The algorithm employed by the *Navsrcmap* tool for calculating the ASF grids from the vessel track data is as follows. Before calculating source density, source levels from the track data are adjusted to a reference source depth (d_s') following the formulae described in MacGillivray and de Jong (2021):

$$L_s'(d_s') = L_s(d_s) + \Delta_L(d_s') - \Delta_L(d_s)\,, \qquad \text{(A-1)}$$

where the L_s is the source level (decibels) from the track data and Δ_L is a frequency-dependent adjustment factor (Ainslie et al. 2022):

$$\Delta_L(d) = -10\log_{10}\left(2 - \frac{\sin(2k_2 d\sin(\alpha)) - \sin(2k_1 d\sin(\alpha))}{k_2 d\sin(\alpha) - k_1 d\sin(\alpha)}\right)\,\mathrm{dB}\,. \qquad \text{(A-2)}$$

In this formula, α is a representative grazing angle and k_1 and k_2 are the wavenumbers corresponding to the lower and upper decidecade frequency band limits:

$$k_1 = \frac{2\pi f}{c} \times 10^{-0.05} \text{ and}$$

$$k_2 = \frac{2\pi f}{c} \times 10^{0.05}\,,$$

where f is frequency and c is the speed of sound in water (Figure A-2). An appropriate reference source depth value is chosen according to the mean source depth value for a specified vessel category (a typical value of d_s' is in the 1–6 m range). The source depth adjustment is averaged over three grazing angles (15°, 30°, and 45°).

[2] Meaning "per unit area", following the nomenclature employed in Ainslie (2010).

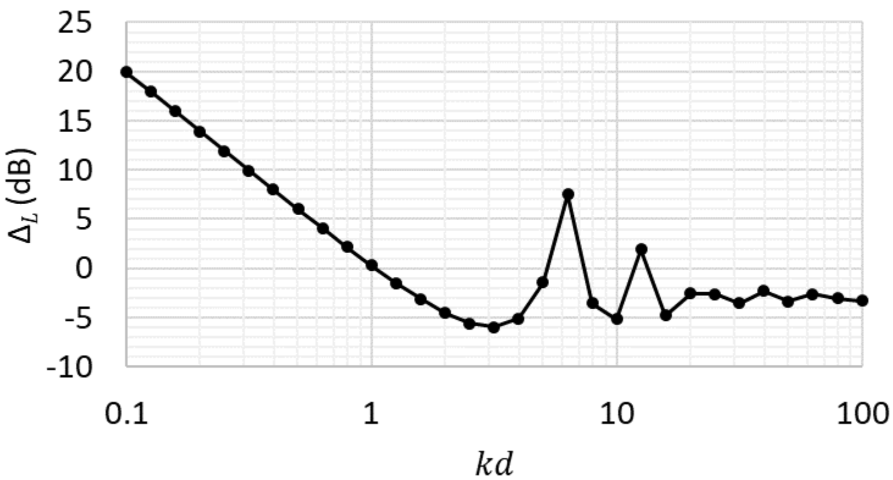


Figure A-2. The source depth adjustment factor, $\Delta_L(d)$, versus the product of wavenumber and source depth (kd), computed for an $\alpha = 30°$ grazing angle. The symbols show decidecade band values. The wavenumber is equal to the ratio of the angular frequency to the speed of sound ($k = \frac{2\pi f}{c}$).

The first step in computing the source density is to calculate the energy source factor ($F_{S,e}$) on a regular easting (x) and northing (y) grid. The grid coordinate system is defined as follows:

$$x_j = x_1 + (j-1)\Delta x \quad j = 1 \dots M_x \tag{A-3}$$

$$y_j = y_1 + (k-1)\Delta y \quad k = 1 \dots M_y \tag{A-4}$$

where Δx is the easting increment, Δy is the northing increment, and the centre of each grid cell is at coordinates (x_j, y_k). The gridded energy source factor is calculated by integrating the depth-adjusted source level over time (t) whenever a vessel track is within a grid cell:

$$F_{S,e}(x_j, y_k) = \int_{t_a}^{t_b} F_s(t)dt \quad \text{where} \quad F_s(t) = 10^{L_S'(t)/(10\ \text{dB})} \tag{A-5}$$

where t_a and t_b are the times when the vessel enters and leaves the grid cell, respectively. The integrand is evaluated numerically in *Navsrcmap* using trapezoidal rule integration.

The final step is to compute grids of source density, versus easting and northing, by vessel category. Given the energy source factor, the areic source factor ($F_{S,A}$) is calculated by dividing the energy source factor by the area of each grid cell and the total time (T):

$$F_{S,A}(x_j, y_k) = \frac{F_{S,e}(x_j, y_k)}{T\Delta x\Delta y}. \tag{A-6}$$

For visualization purposes, the ASF data can be represented as areic source level (ASL; symbol $L_{S,A}$) data by converting to decibels.

A.3. Average SPL Calculations

To produce soundscape maps, ARTEMIA computes the three-dimensional (3-D) propagation loss (PL; symbol N_p) from each source point using a cylindrical coordinate system in range (r), azimuth (ϑ), and depth (z). Propagation loss is modeled within two-dimensional (2-D) vertical planes aligned along radials covering a 360° swath from the source, an approach commonly referred to as N×2-D. These vertical radial planes are separated by an angular step size of $\Delta\theta$, yielding $M_\theta = (360°)/\Delta\theta$ number of planes (Figure A-3). The PL radials are thus sampled on a discrete grid:

$$\mathrm{r_i} = (\mathrm{i}-1)\Delta\mathrm{r} \quad \mathrm{i} = 1 \ldots \mathrm{M_r} \tag{A-7}$$

$$\theta_\mathrm{j} = (\mathrm{j}-1)\Delta\theta \quad \mathrm{j} = 1 \ldots \mathrm{M_\theta} \tag{A-8}$$

where the radial and angular increments (i.e., Δr and $\Delta\theta$) are selected through convergence testing to satisfy the scale and distance requirements for sound mapping in each region. Values of $\Delta r = 50$ m and $\Delta\theta = 10°$ were used for the present study. Bathymetry, sound speed, and geoacoustic profiles for each azimuth are sampled along radial lines extending from the source. The cylindrical PL coordinate system is then resampled to the coordinate reference system for calculating spatial sound maps.

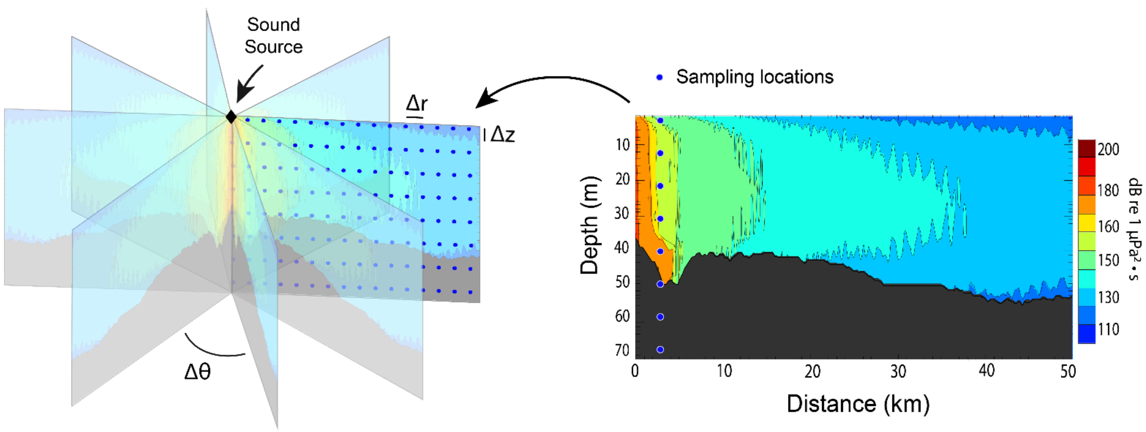


Figure A-3. The cylindrical coordinate system used for computing propagation loss in ARTEMIA.

ARTEMIA can calculate spatial maps using either projected or geographic coordinates. A projected BC Albers coordinate reference system (i.e., easting and northing) is used for the current project. ARTEMIA places the receiver points for the sound maps on a regular easting, northing, and depth grid. The easting and northing increments (Δx and Δy, respectively) are taken to be the same for both the source and receiver grids.

For each source grid point (x_j, y_k), the mean-square sound pressure at the surrounding receiver points is computed from the product of the areic source factor, the source cell area, and the mean propagation factor within the receiver cell, as follows:

$$\mathrm{p^2(x, y, z_r; x_j, y_k)} = \Delta\mathrm{x}\Delta\mathrm{y} \times \mathrm{F_{S,e}(x_j, y_k)} \times \bar{\mathrm{F}}_\mathrm{p,A}\mathrm{(x, y, z_r)} \tag{A-9}$$

where the mean propagation factor is calculated numerically at a discrete set of ${M_\mu}^2$ sampling points within a box of size $\Delta x \times \Delta y$ centred around the receiver at depth z_r (Figure A-4):

$$\bar{\mathrm{F}}_\mathrm{p,A}\mathrm{(x, y, z_r)} = \frac{1}{\mathrm{M_\mu^2}} \sum_{\mathrm{i}=1}^{\mathrm{M_\mu}} \sum_{\mathrm{j}=1}^{\mathrm{M_\mu}} \mathrm{F_p}\left(\mathrm{x} + \Delta\mathrm{x}\left(\frac{\mathrm{i}}{\mathrm{M_\mu}+1} - \frac{1}{2}\right), \mathrm{y} + \Delta\mathrm{y}\left(\frac{\mathrm{j}}{\mathrm{M_\mu}+1} - \frac{1}{2}\right), \mathrm{z_r}\right) \tag{A-10}$$

and the propagation factor F_p is calculated from PL according to ISO 18405 (2017):

$$\mathrm{F_p(x, y, z_r)} = \mathrm{r_0^{-2}} 10^{-\mathrm{N_{PL}(x,y,z_r)}/(10\ \mathrm{dB})} \tag{A-11}$$

where r_0 is the standard reference distance of 1 m. The use of the mean propagation factor ($\bar{F}_{p,A}$) for calculating the SPL in the receiver cell reflects the fact that vessels are approximated as a spatially distributed (i.e., areic sheet) source when running ARTEMIA in density mode.

The appropriate number of averaging points (i.e., as determined by M_μ) depends on the spatial resolution of the computation grid and may be determined through convergence testing. For the current study, a value of M_μ= 9 is used when the source and receiver are in the same grid cell and M_μ= 3 when they are in different grid cells.

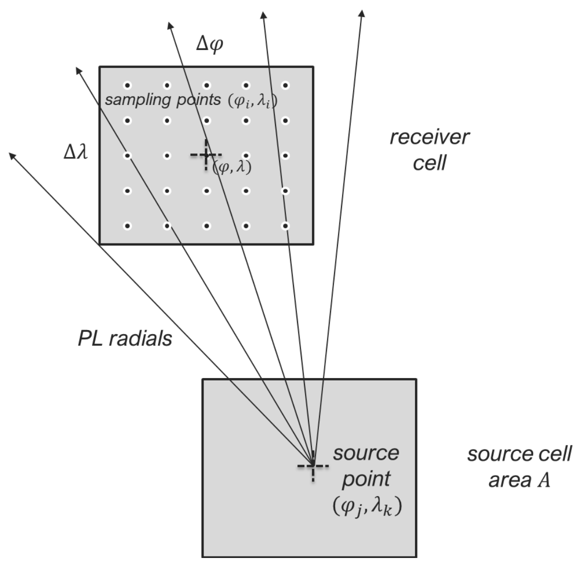


Figure A-4. Plan-view diagram showing geometry for calculation of mean propagation factor in each receiver grid cell. Averaging of the propagation factor is performed at M_μ^2 sampling points, as illustrated by the dots in the receiver cell.

Because PL is computed in cylindrical coordinates (r, θ), it is necessary to perform a transformation from cylindrical to projected coordinates when computing the mean propagation factor:

$$F_p(x, y) \rightarrow F_p\big(r(x, y), \theta(x, y)\big) . \tag{A-12}$$

This transformation is accomplished through bilinear interpolation of the propagation factor in r and θ. Finally, the total SPL at each receiver point is computed as the decibel level of the sum of the mean square pressure from all source cells:

$$L_p(x, y, z_r) = 10 \log_{10}\left(p_0^{-2} \sum_{j=1}^{M_\varphi} \sum_{k=1}^{M_\lambda} p^2(x, y, z_r; x_j, y_k)\right) \text{ dB} . \tag{A-13}$$

Because sound levels in the ocean depend on receiver depth, sound field calculations were performed at a total of 10 regularly spaced receiver depths between 10 and 190 m:

$$z_r(i) = z_1 + (i - 1)\Delta z \quad \text{where } i = 1 \ldots M_z \tag{A-14}$$

where z_1 = 10 m, Δz = 20 m, and M_z = 10. The main output of the ARTEMIA model consisted of raster files of georeferenced SPL versus depth, by vessel type and frequency band.

A.4. WRASP Ambient Sound Model

The Wind and Rain Ambient Sound Propagation (WRASP) model comprises an empirical source model (Scrimger, Evans, and Yee 1989; Ainslie 2010; Ainslie, Harrison, and Zampolli 2011) based on measurements (Kuperman and Ferla 1985) and an energy flux propagation model. WRASP is dependent on frequency, windspeed, rainfall rate, water sound speed, water depth, seafloor geoacoustic properties, and receiver depth. The model assumes a uniform distribution of surface sources and accounts for scattering off a rough sea surface. Figure A-5 shows the source spectrum for different wind speeds and rainfall rates. WRASP is implemented in ARTEMIS at each grid cell using the local environmental properties. For each snapshot, wind speed and rainfall rates were interpolated from the ten nearest synthetic weather stations to each grid cell using inverse distance weighting. WRASP has been validated using measurements from Chapman and Cornish (1993).

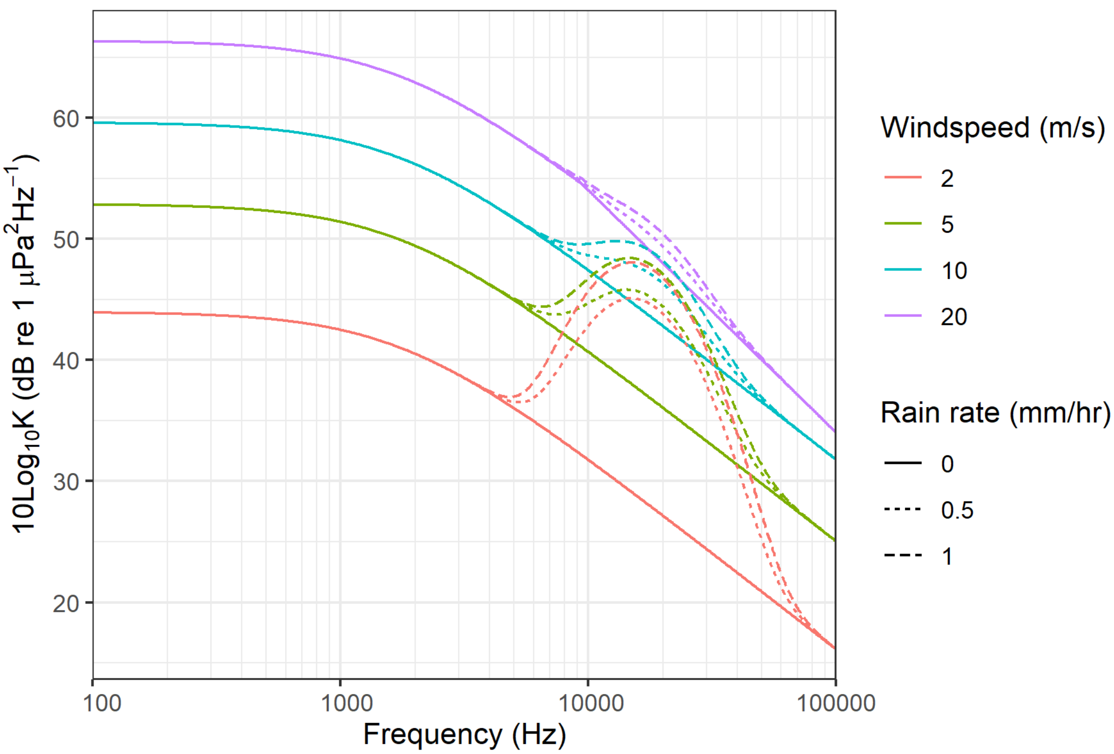


Figure A-5. Wind and rain noise areic dipole source spectrum level versus frequency used in the Wind and Rain Ambient Sound Propagation (WRASP) model.

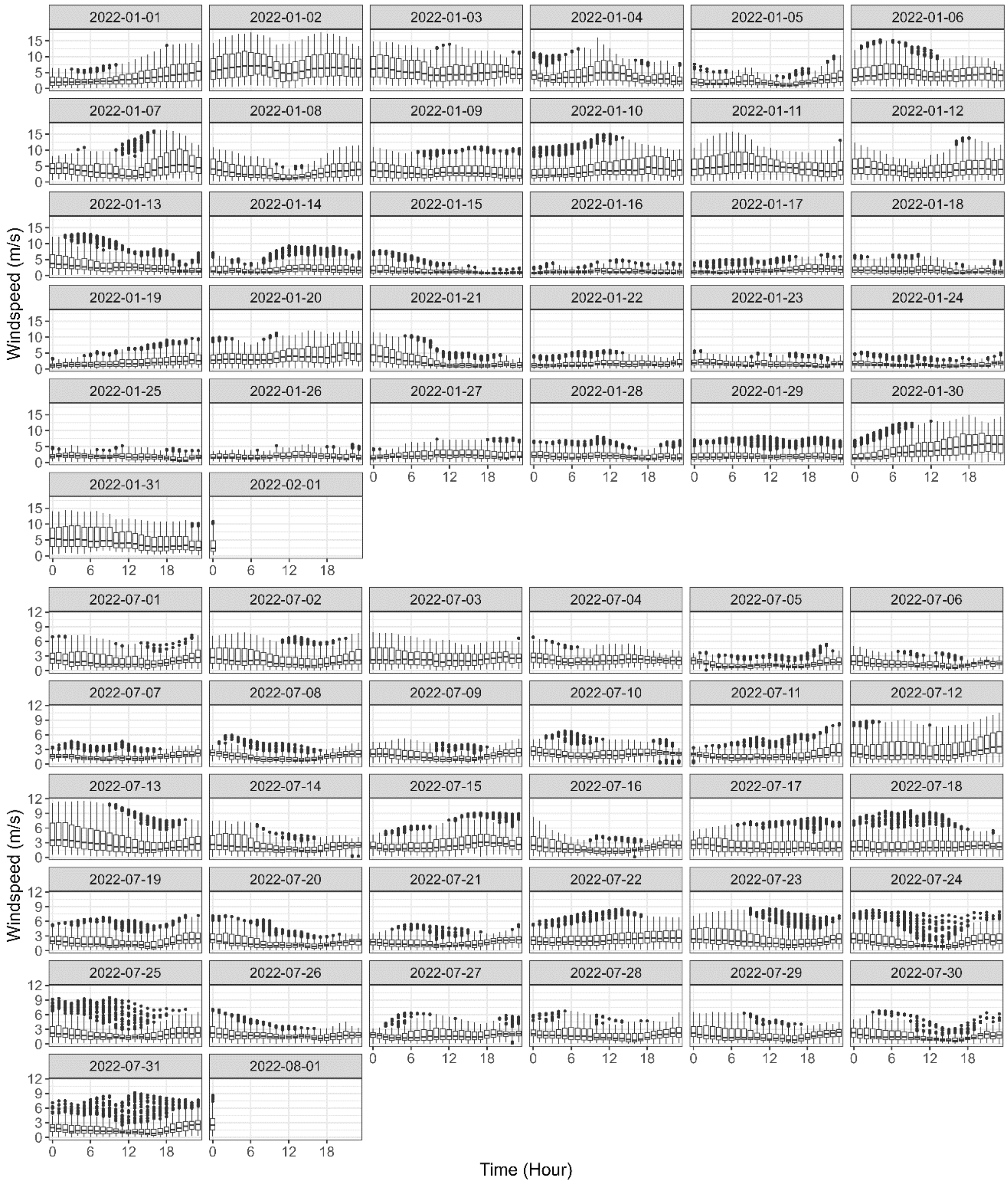


Figure A-6. Boxplots of hourly wind speed (in m/s) including data from all 144 stations in the modeling area for (top) January and (bottom) July 2022. The scales differ between the top and bottom plots.

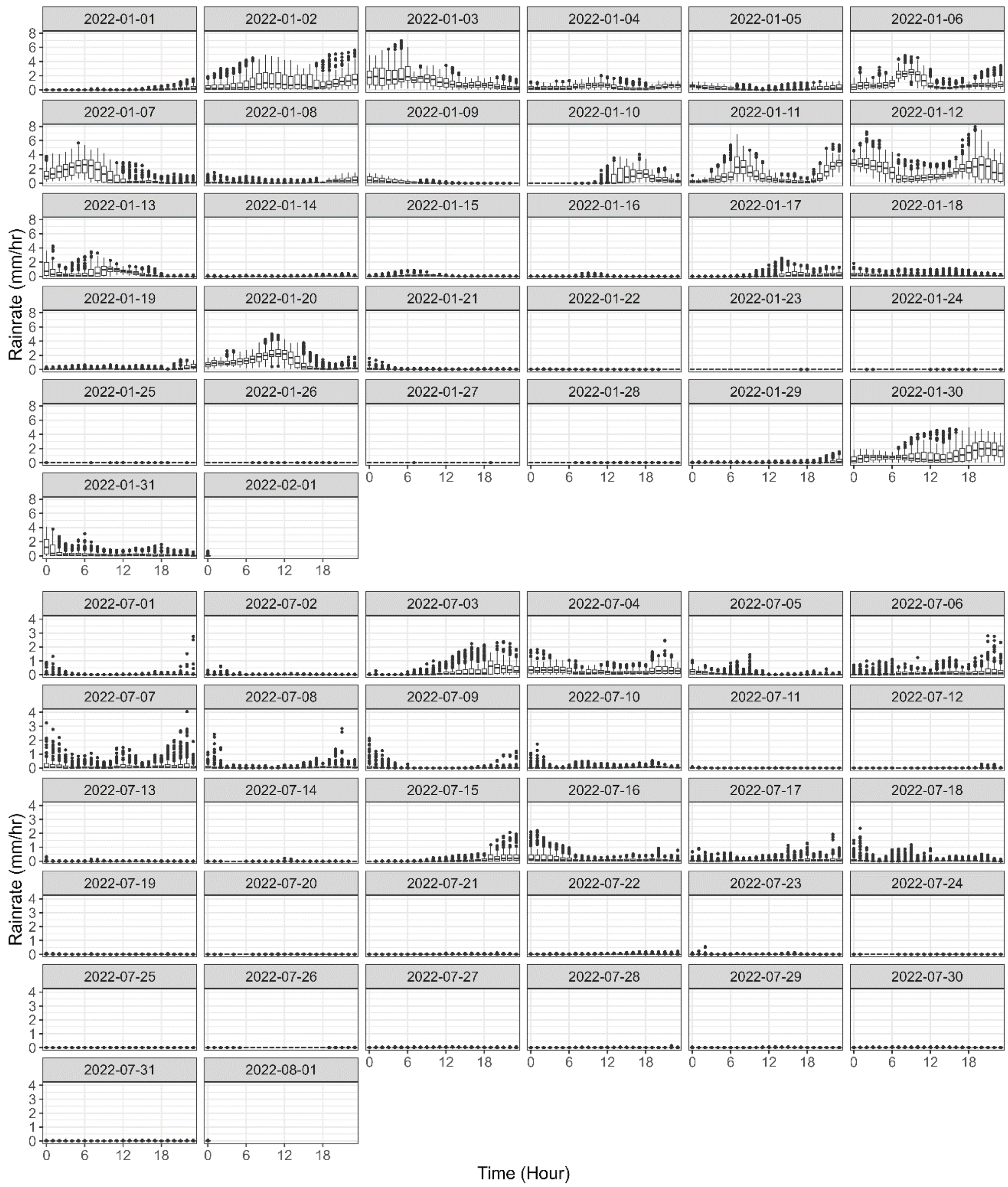


Figure A-7. Boxplots of hourly rain rate (in mm/h) including data from all 144 stations in the modeling area for (top) January and (bottom) July 2022. The scales differ between the top and bottom plots.

Supplement B. Reference Source Levels

B.1. Large commercial Cargo Vessels and Tugs

Source level parameters (i.e., for Equation 1) for bulk carriers, container ships, general cargo vessels, tankers, tankers, passenger vessels (over 100 m), and tugs were defined according to the ECHO functional regression model (MacGillivray et al. 2022). This is a statistical model for predicting source levels for six types of commercial vessels that involves nine operational and design parameters. This model was developed based on an intensive analysis of an ensemble of approximately 10,000 individual URN measurements from the ECHO data set. Vessel design parameters not included in AIS (including design speed, vessel age, engine RPM, and engine power) were fixed to their average values by creating reference source level curves for up to three size subdivisions per vessel class (Figure B-1).

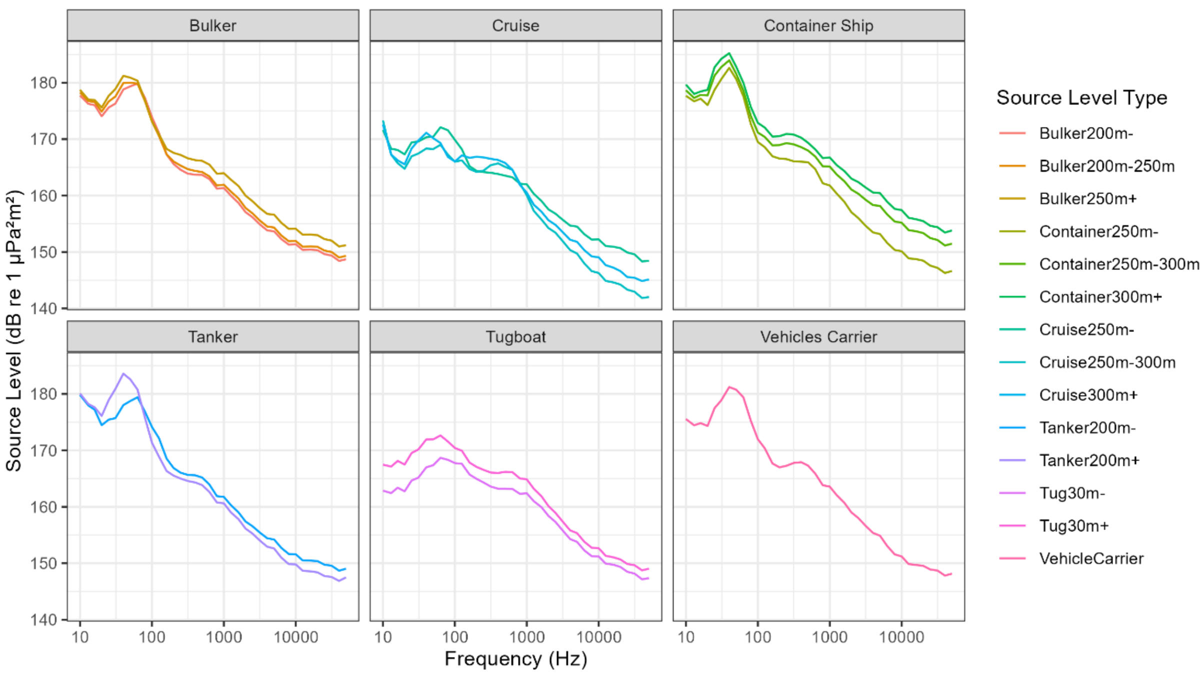


Figure B-1. Reference source level curves versus decidecade band frequency for bulk carriers, container ships, general cargo vessels, tankers, passenger vessels (over 100 m), and tugs. General cargo vessel source levels were identical to bulk carrier source levels. Size subdivisions were defined according to vessel length. A single subdivision was used for vehicle carriers since all vessels of this class are approximately the same size in the ECHO database.

B.2. Fishing, Government, Recreational, Miscellaneous, and Small Passenger Vessels

Source level parameters for fishing, government, miscellaneous, recreational vessels, small passenger vessels (under 100 m), and high-speed passenger ferries were derived specifically for this study by performing a multi-variable regression analysis on URN measurements collected from the ECHO database during 2019–2023 (Figure B-2). The regression analysis followed the methodology of an earlier TC study (Hannay et al. 2019; MacGillivray, Hannay, and Frouin-Mouy 2019), and it was used to derive reference source levels and frequency-dependent scaling coefficients for speed and length. No draft scaling was applied to these types of vessels (i.e., $\beta_d(f) = 0$) as their draft was not reliably reported by AIS. Source levels for fishing vessels included a notable spike in the 40 kHz decidecade band that corresponded to fisheries sonars. Separate source levels were derived for naval vessels, as they are currently excluded from the ECHO data set due to security restrictions. Average decidecade band source levels for naval vessels were instead obtained from measurements collected during the 2017 ECHO slowdown trial in Haro Strait (MacGillivray and Li 2018).

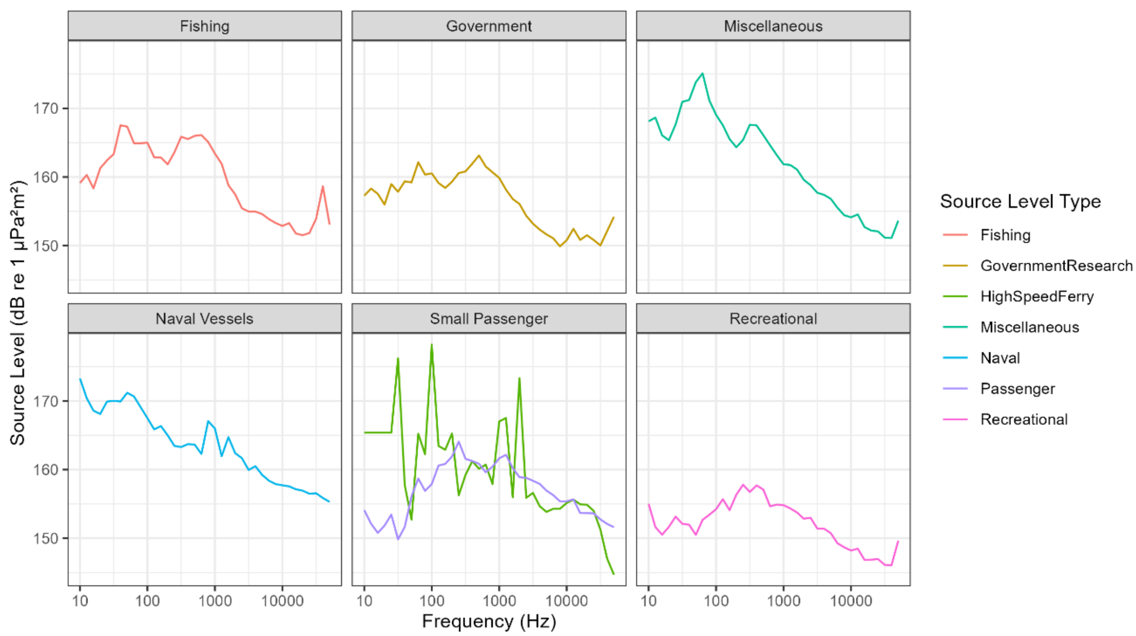


Figure B-2. Reference source level curves versus decidecade band frequency fishing, government, miscellaneous, naval, small passenger, and recreational vessels.

B.3. Ro-ro Ferries

Source levels for ro-ro ferries were collected from several previous JASCO studies carried out for ECHO and TC (MacGillivray and Li 2016; Frouin-Mouy 2017; MacGillivray, Frouin-Mouy, and Quijano 2017; Frouin-Mouy et al. 2020; Dolman et al. 2021). A detailed review of URN data from these reports suggested that differences in source level curves for ro-ro ferries were mainly associated with two factors: year of build and size. Thus, reference source levels were assigned to individual vessels based on these two factors (Figure B-3). Source level subdivisions for ro-ro passenger ferries were defined for large (>120 m length) and intermediate (<120 m length) size vessels and for vessels built before and after 2005. Source level subdivisions for ro-ro cargo ferries were defined for vessels built before and after 2005. Size subdivisions were not applied to ro-ro cargo vessels since their size was determined by year of build. Source level versus speed trends were quite variable for ro-ro ferries, due to widespread use of controllable pitch propulsion, so this category was simplified by assuming a nominal value of $\beta_v = 60$ for all vessels (Ross 1987).

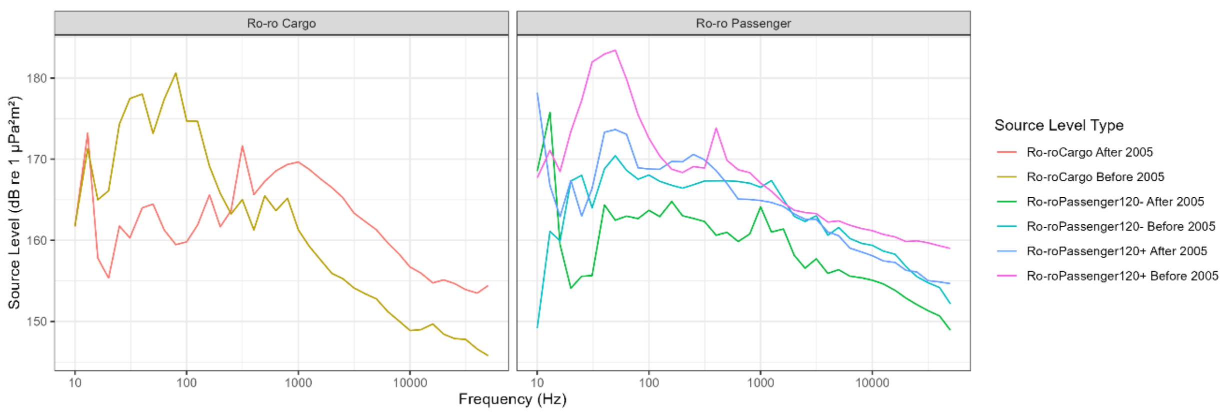


Figure B-3. Reference source levels for (left) ro-ro cargo and (right) ro-ro passenger ferries.

B.4. Anchored Cargo Vessels

Compared to the other vessel categories, limited source level data were available for anchored cargo vessels. Source levels for this category were derived from measurements of a single anchored bulk carrier in Burrard Inlet, collected by SMRU Consulting for the VFPA-led ECHO Program in partnership with the Tseil-Waututh Nation (Harris et al. 2022). Radiated noise level data shared by the study authors were converted to source levels (Figure B-4) using the seabed critical angle method for shallow water URN measurement, developed during the TC MMP2 project (MacGillivray et al. 2023). Additional SPL measurements from anchored bulk carriers were collected in Cowichan Bay by Murchy et al. (2022), but correspondence with the authors confirmed that this data set did not include source level measurements. As source levels for anchored cargo vessels were based on a very limited data set, no attempt was made to vary them according to vessel size or type in the acoustic model.

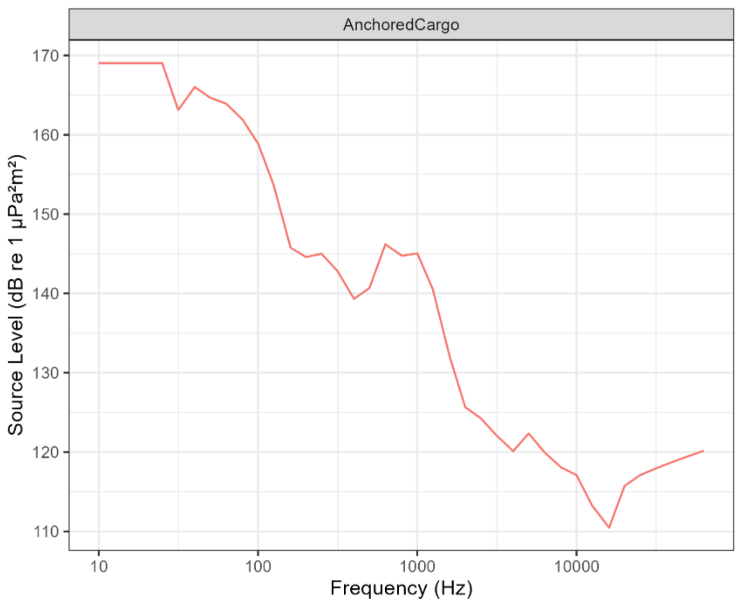


Figure B-4. Source levels for anchored cargo vessels.

B.5. Ecotourism Vessels

Source levels for ecotourism vessels were derived from a 2017 study carried out by ECHO and DFO that performed controlled source level measurements for 20 volunteer vessels (Wladichuk et al. 2018). This study showed that URN profiles of ecotourism vessels are highly variable, due to their large variety of hull and propulsion designs. Furthermore, speeds of ecotourism vessels vary significantly, depending on whether they are engaged in whale watching (nominally 5 knots) or transiting between locations (nominally 20–30 knots). To capture this range of variability in the model, this source level data set for ecotourism vessels category was binned and averaged within three speed ranges (0–10, 10–20, and >20 knots). Ecotourism vessels in the model were assigned one of these three reference source level curves, depending on their speed reported over AIS (Figure B-5).

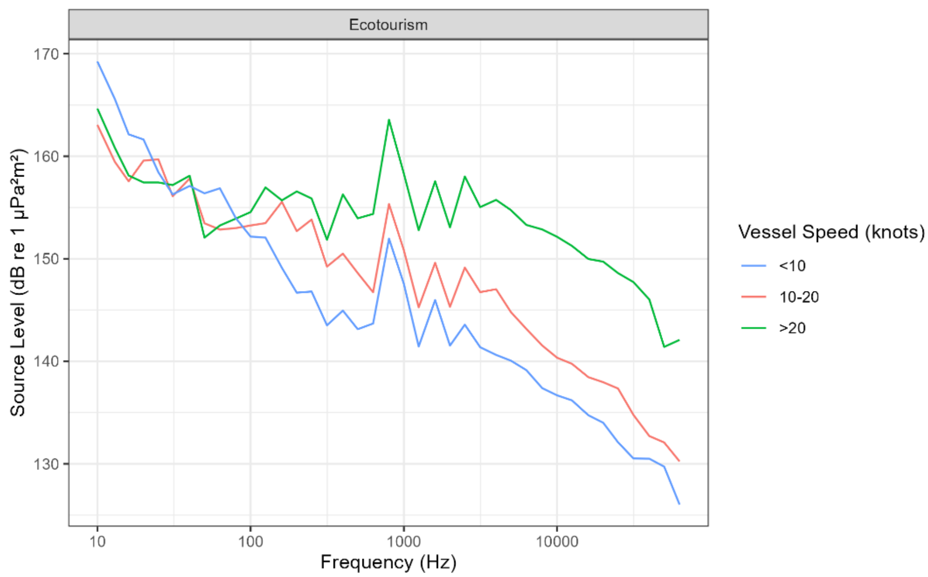


Figure B-5. Reference source levels for ecotourism vessels.

Supplement C. SPL vs time plots

C.1. Alternative A vs Alternative C

C.1.1. Winter

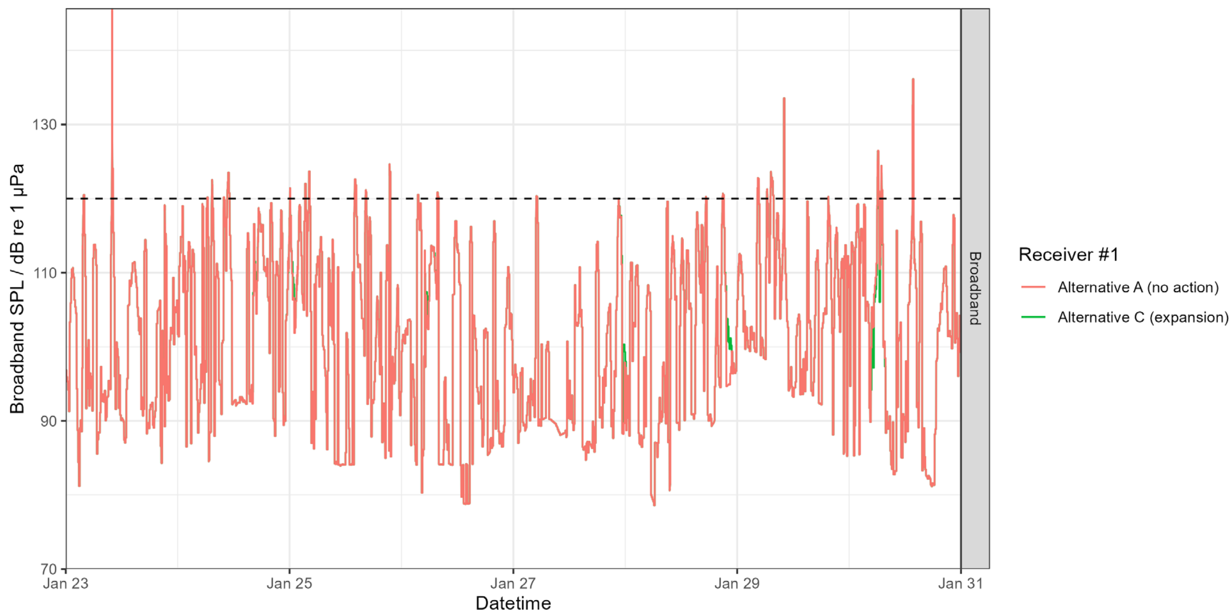


Figure C-1. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative C (green) with time (one week) at key receptor location #1.

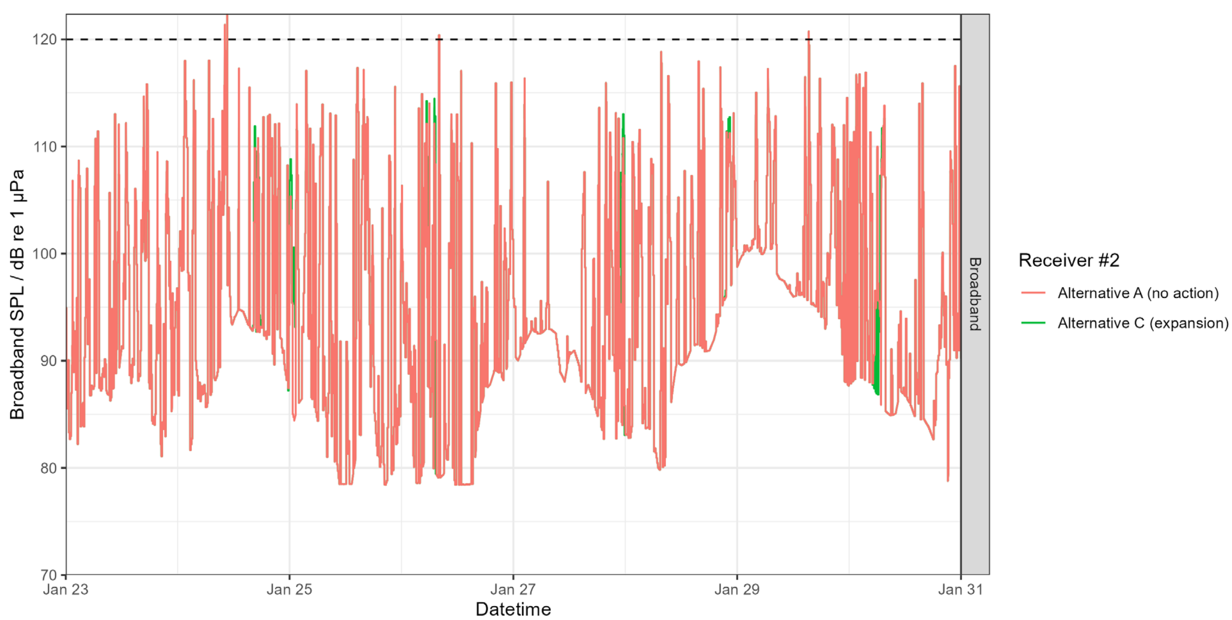


Figure C-2. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative C (green) with time (one week) at key receptor location #2.

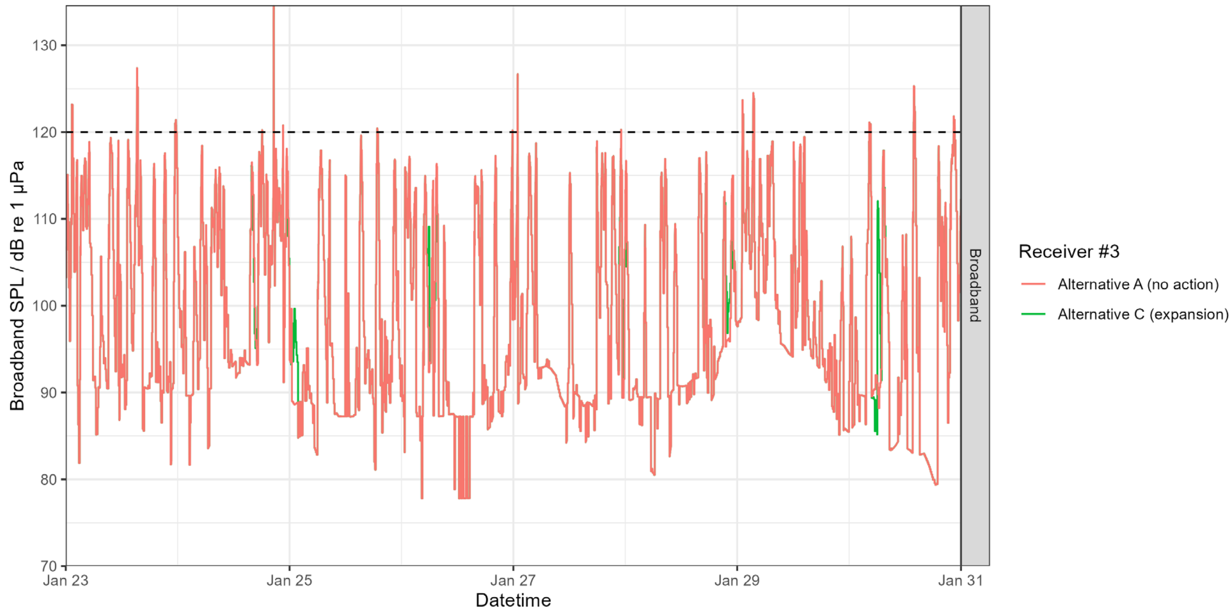


Figure C-3. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative C (green) with time (one week) at key receptor location #3.

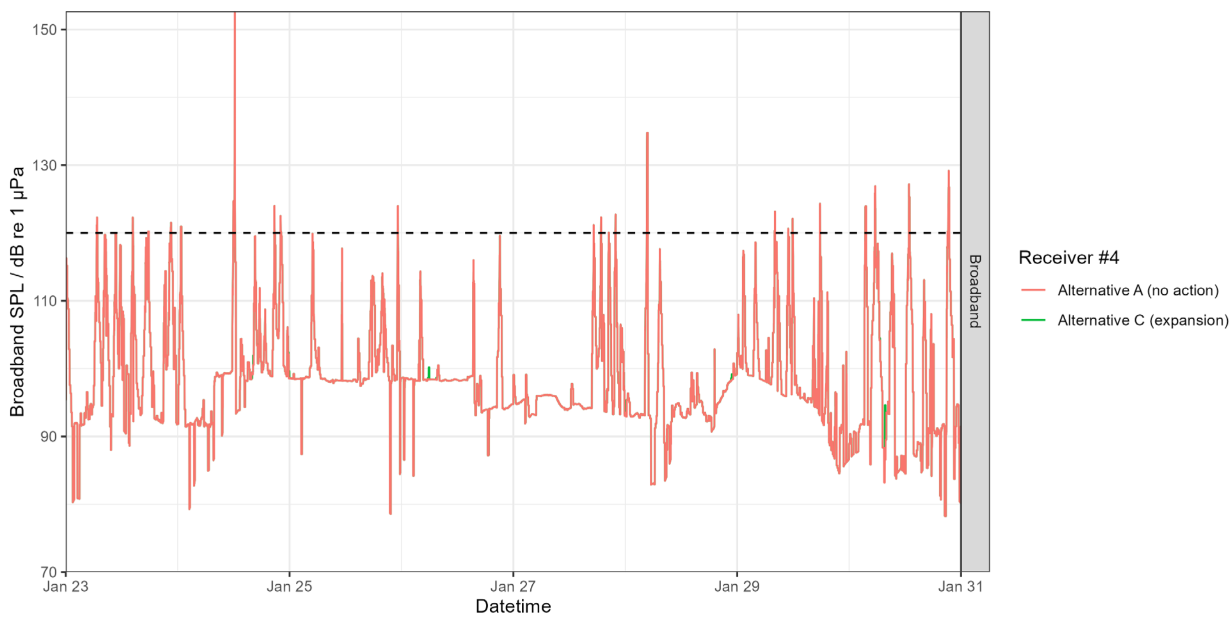


Figure C-4. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative C (green) with time (one week) at key receptor location #4.

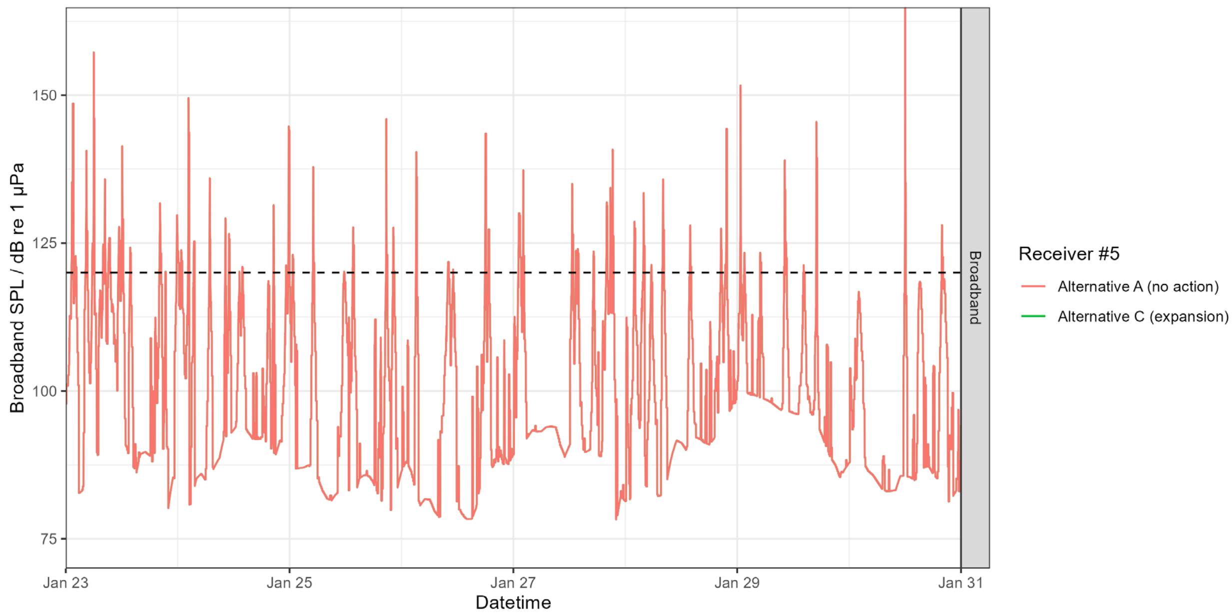


Figure C-5. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative C (green) with time (one week) at key receptor location #5.

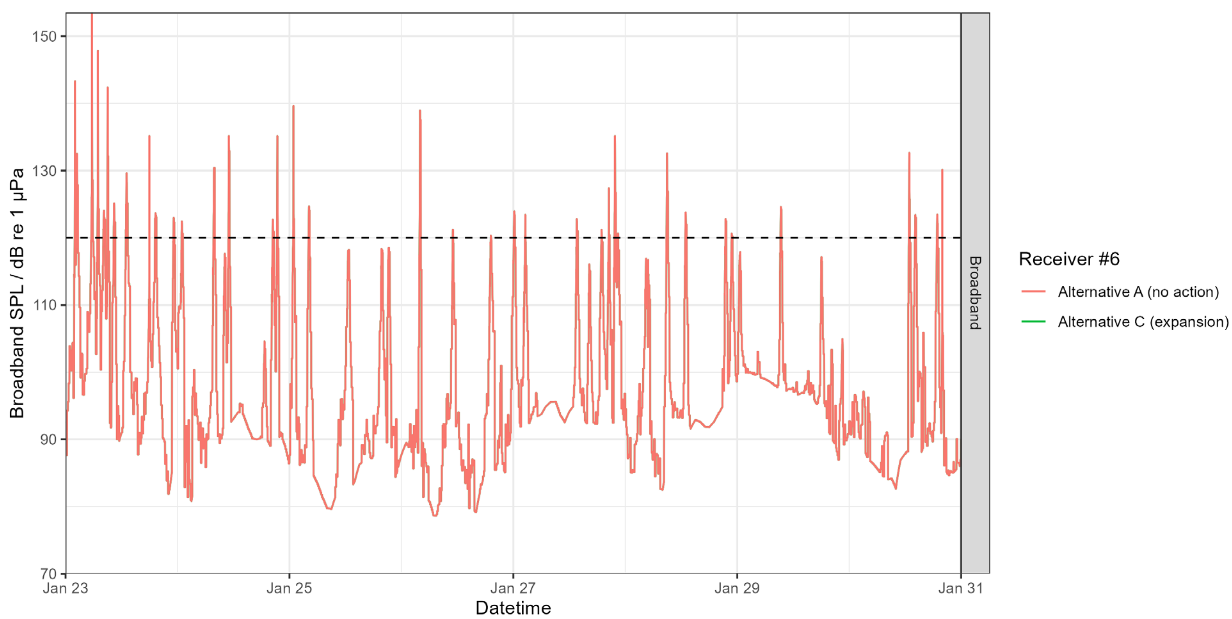


Figure C-6. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative C (green) with time (one week) at key receptor location #6.

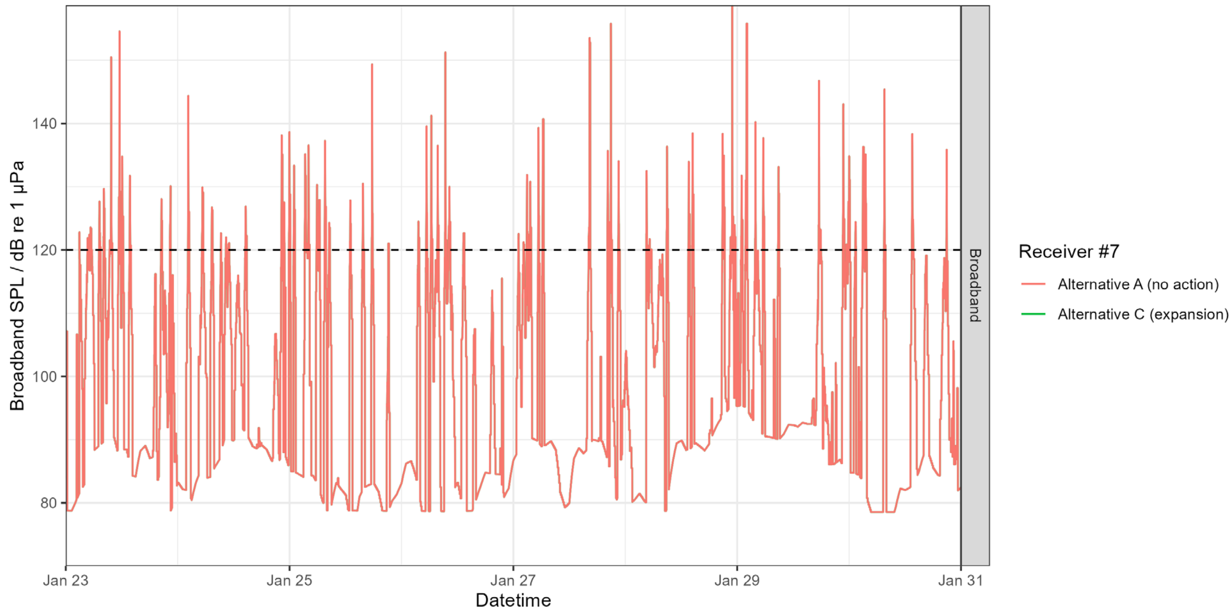


Figure C-7. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative C (green) with time (one week) at key receptor location #7.

C.1.2. Summer

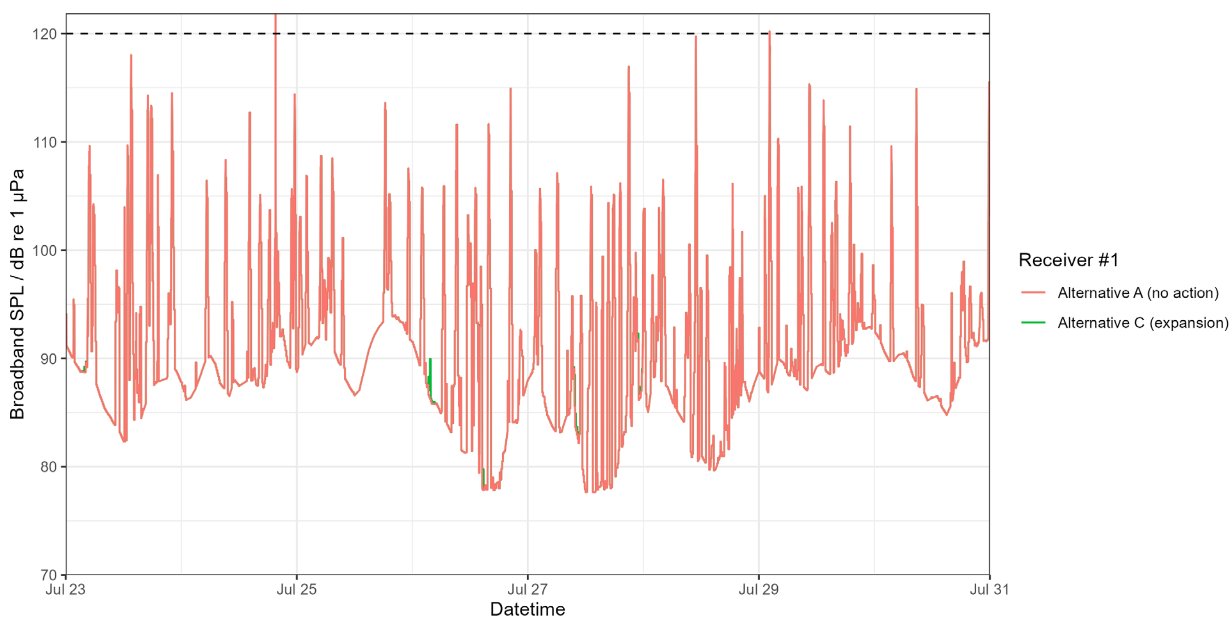


Figure C-8. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative C (green) with time (one week) at key receptor location #1.

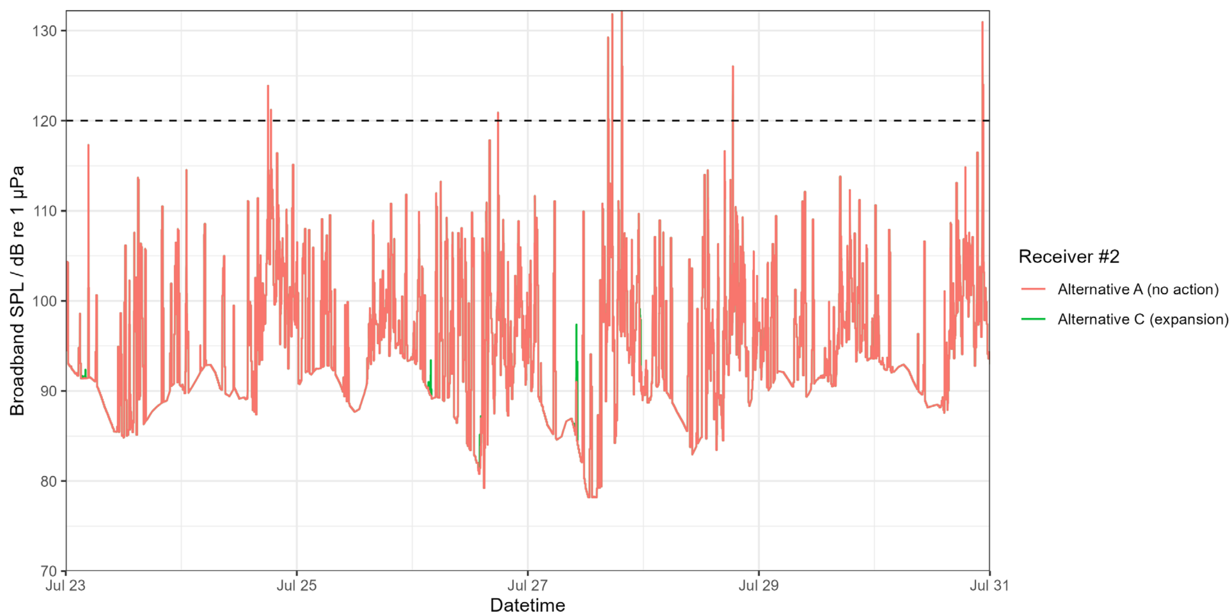


Figure C-9. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative C (green) with time (one week) at key receptor location #2.

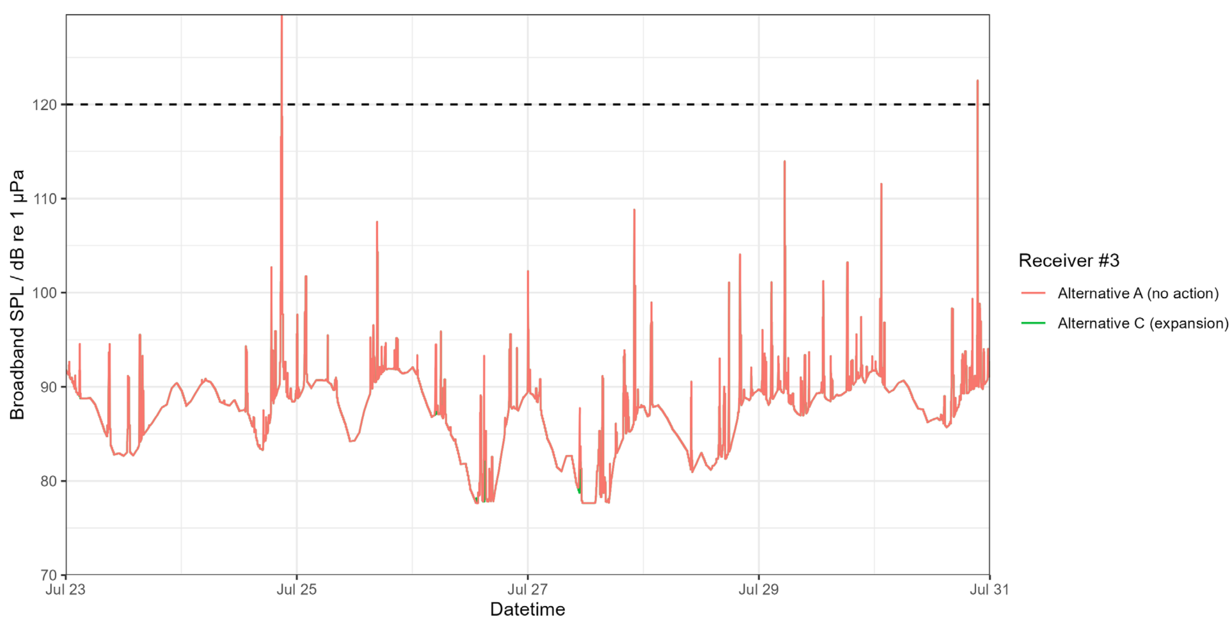


Figure C-10. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative C (green) with time (one week) at key receptor location #3.

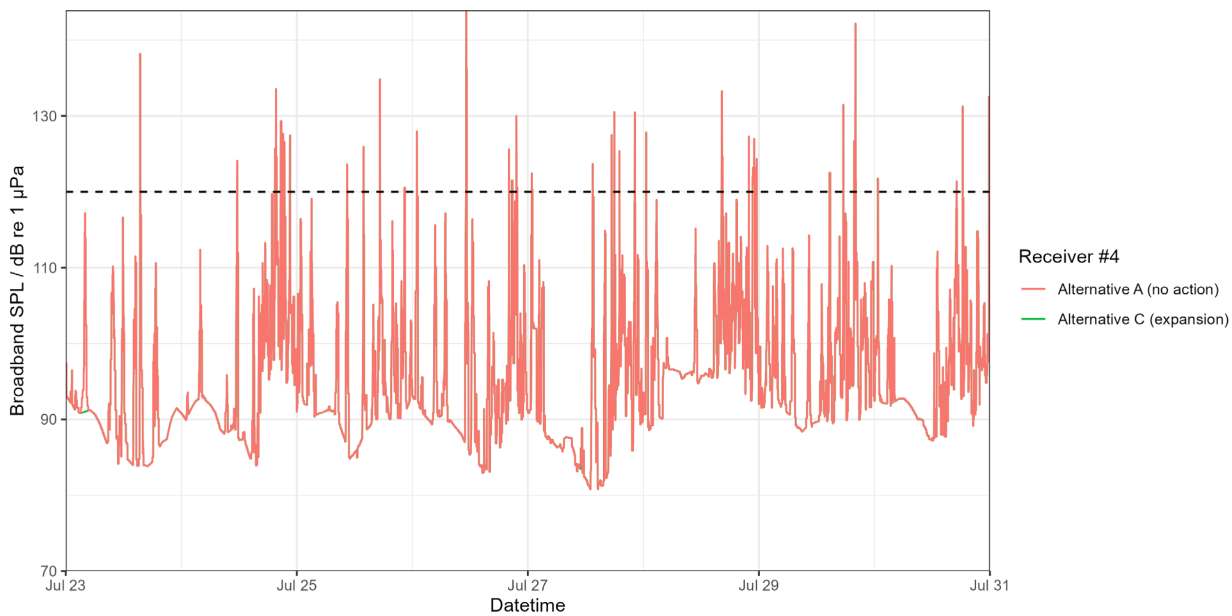


Figure C-11. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative C (green) with time (one week) at key receptor location #4.

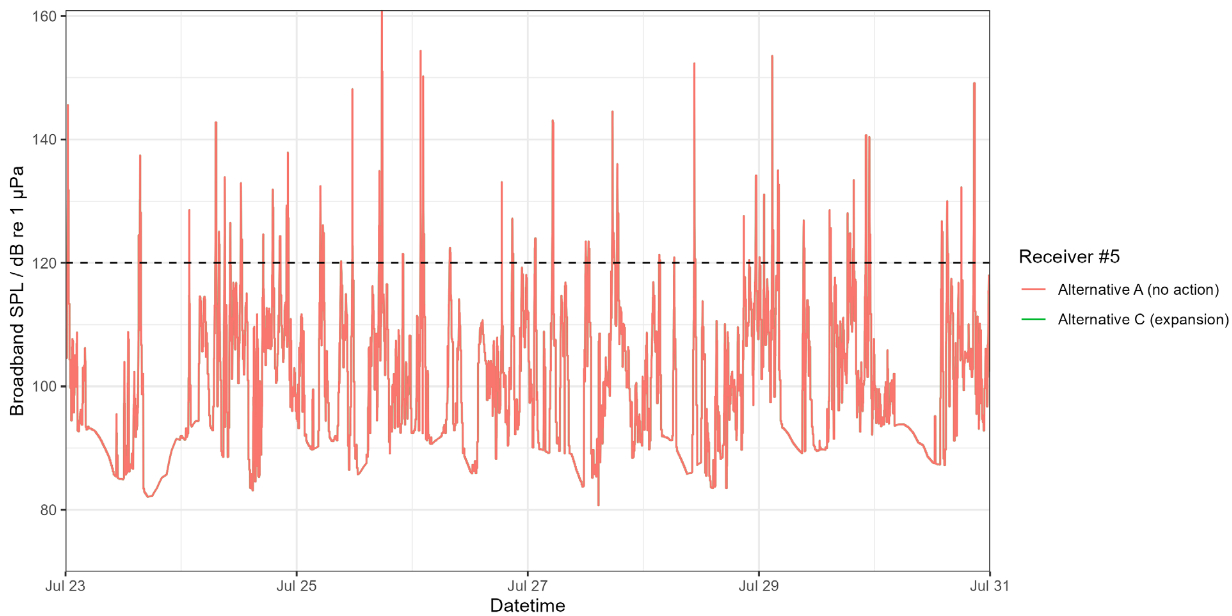


Figure C-12. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative C (green) with time (one week) at key receptor location #5.

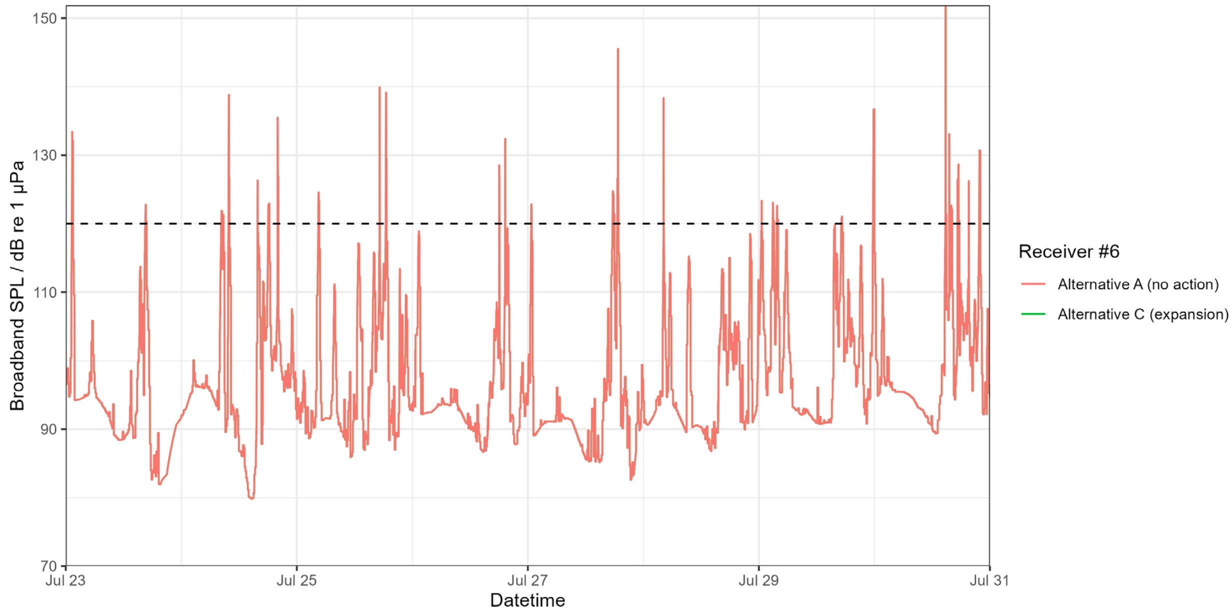


Figure C-13. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative C (green) with time (one week) at key receptor location #6.

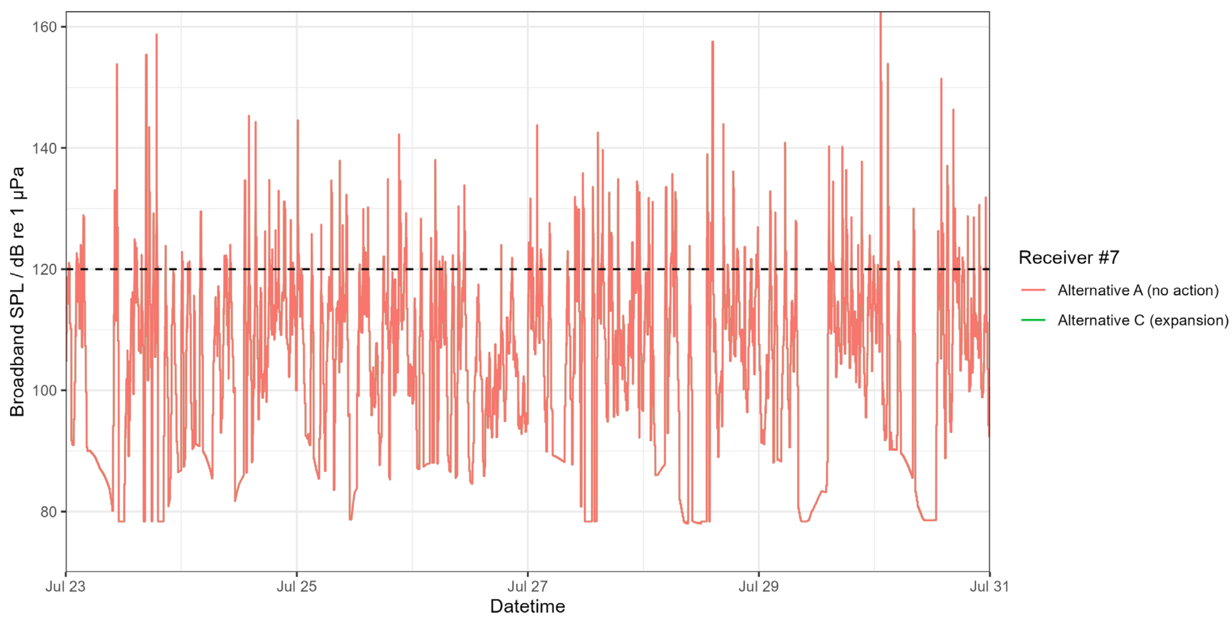


Figure C-14. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative C (green) with time (one week) at key receptor location #7.

C.2. Alternative A vs Alternative D

C.2.1. Winter

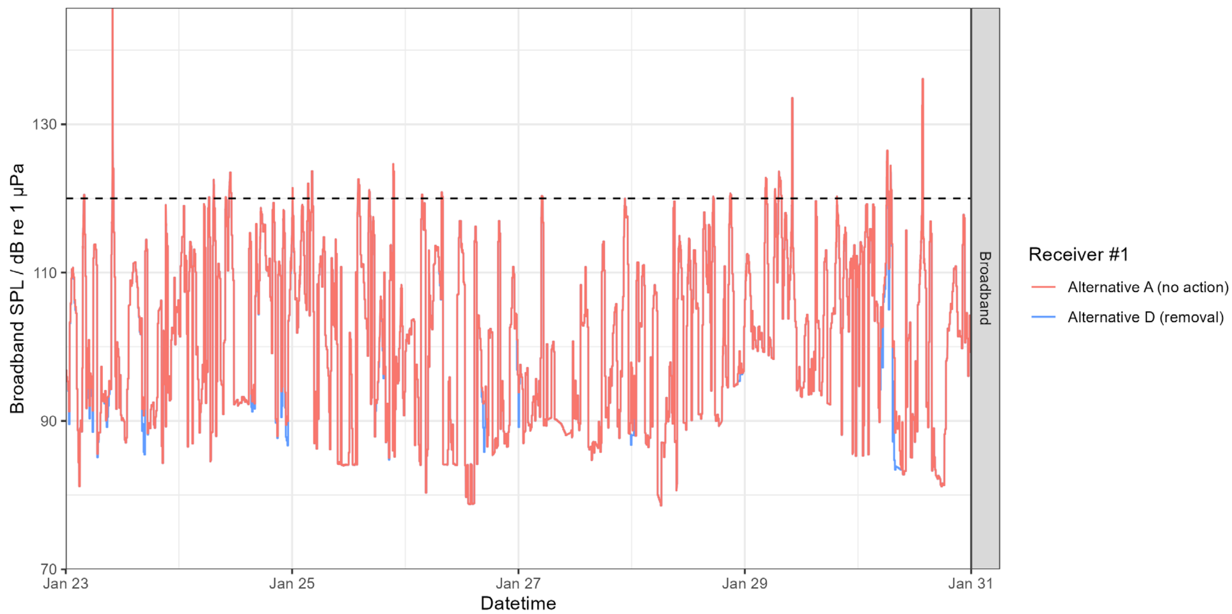


Figure C-15. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative D – removal (blue) with time (one week) at key receptor location #1.

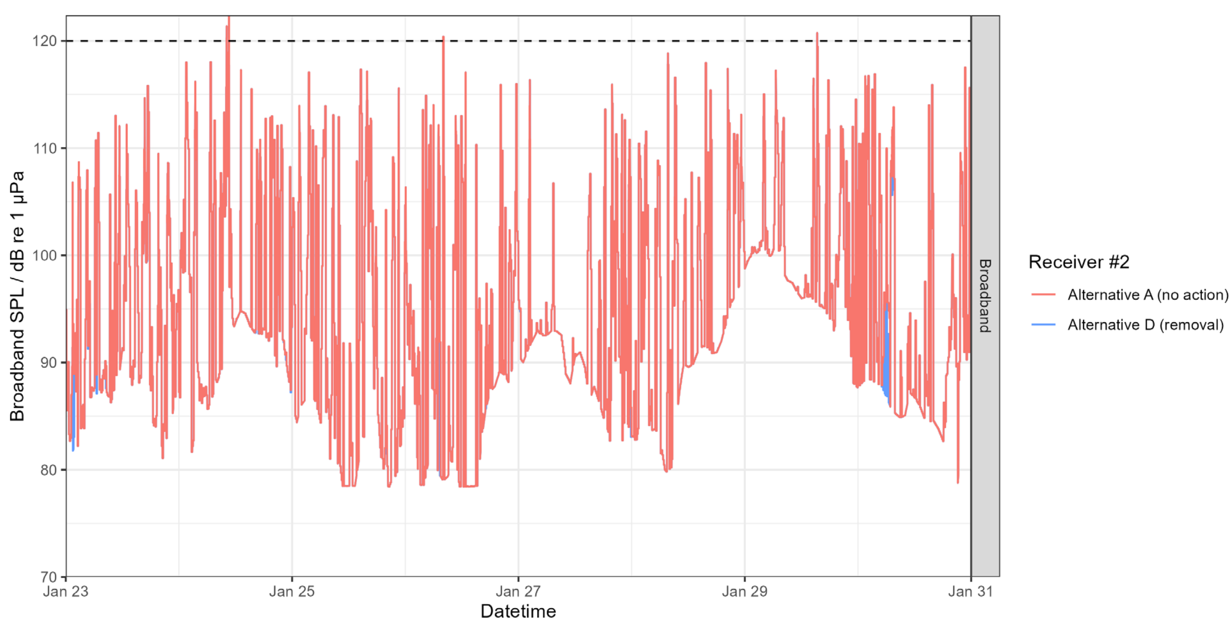


Figure C-16. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative D – removal (blue) with time (one week) at key receptor location #2.

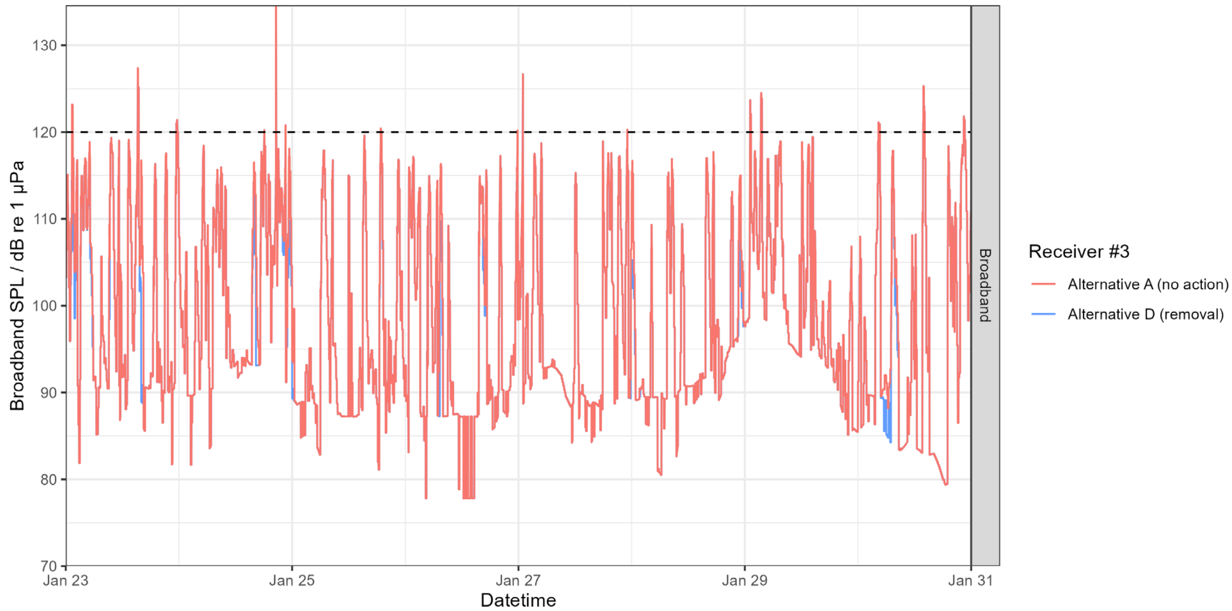


Figure C-17. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative D – removal (blue) with time (one week) at key receptor location #3.

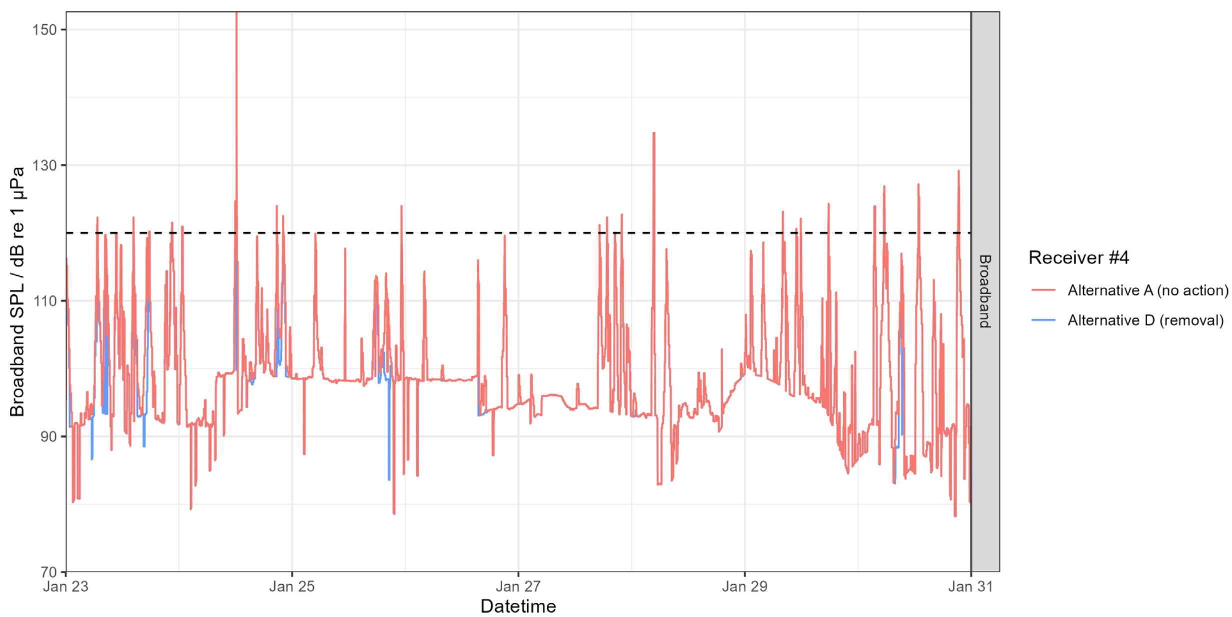


Figure C-18. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative D – removal (blue) with time (one week) at key receptor location #4.

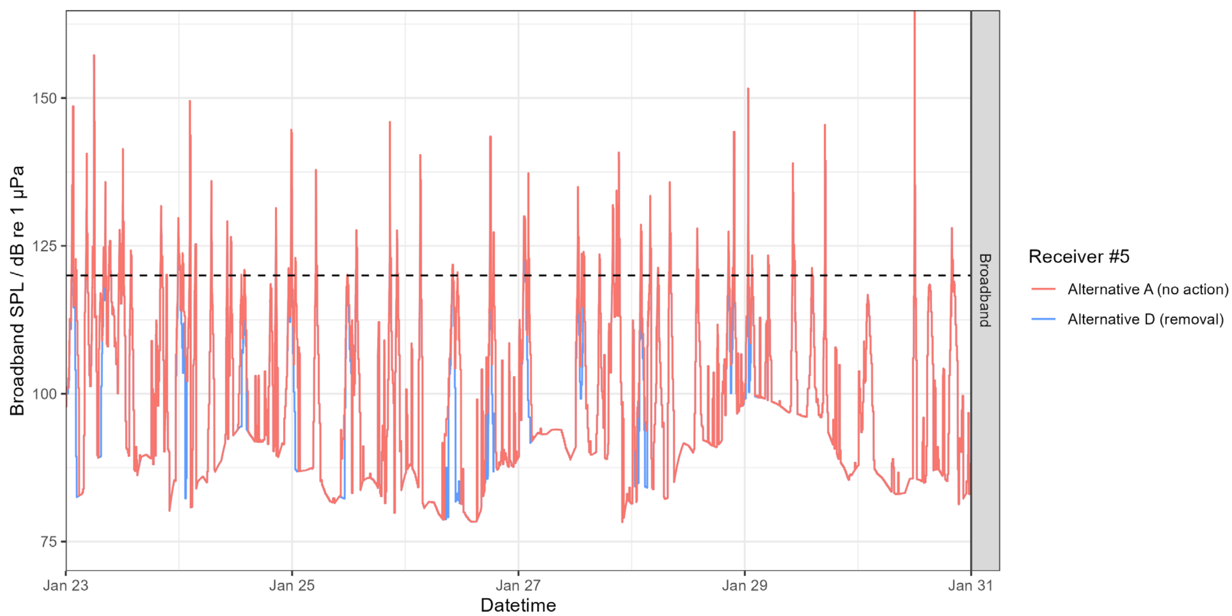


Figure C-19. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative D – removal (blue) with time (one week) at key receptor location #5.

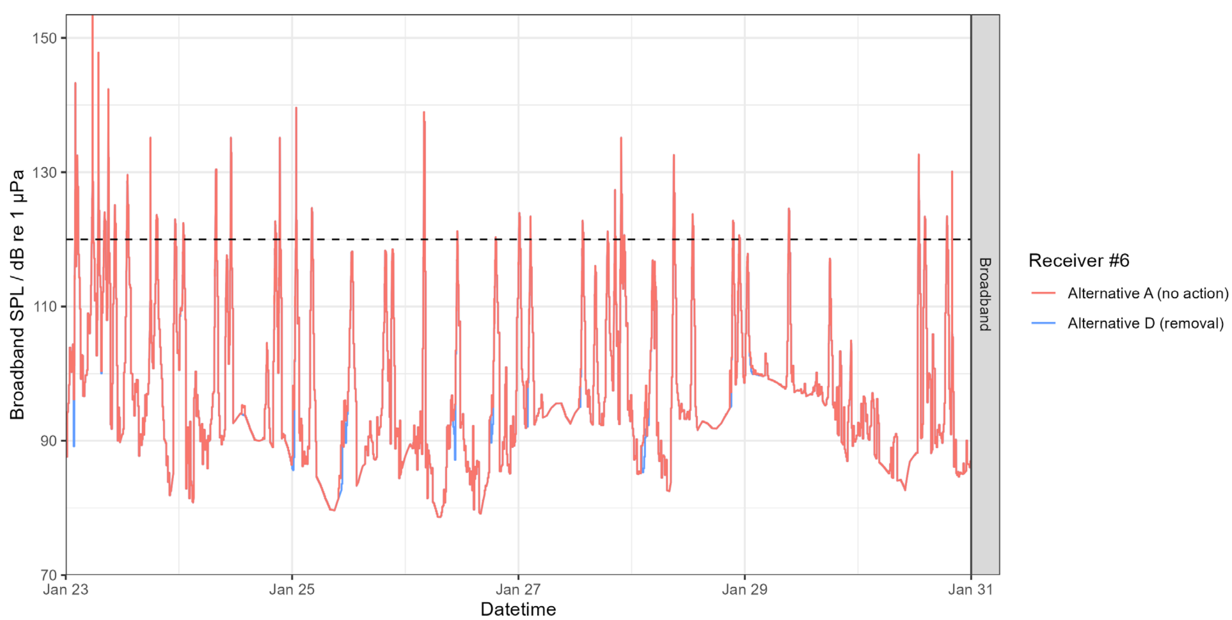


Figure C-20. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative D – removal (blue) with time (one week) at key receptor location #6.

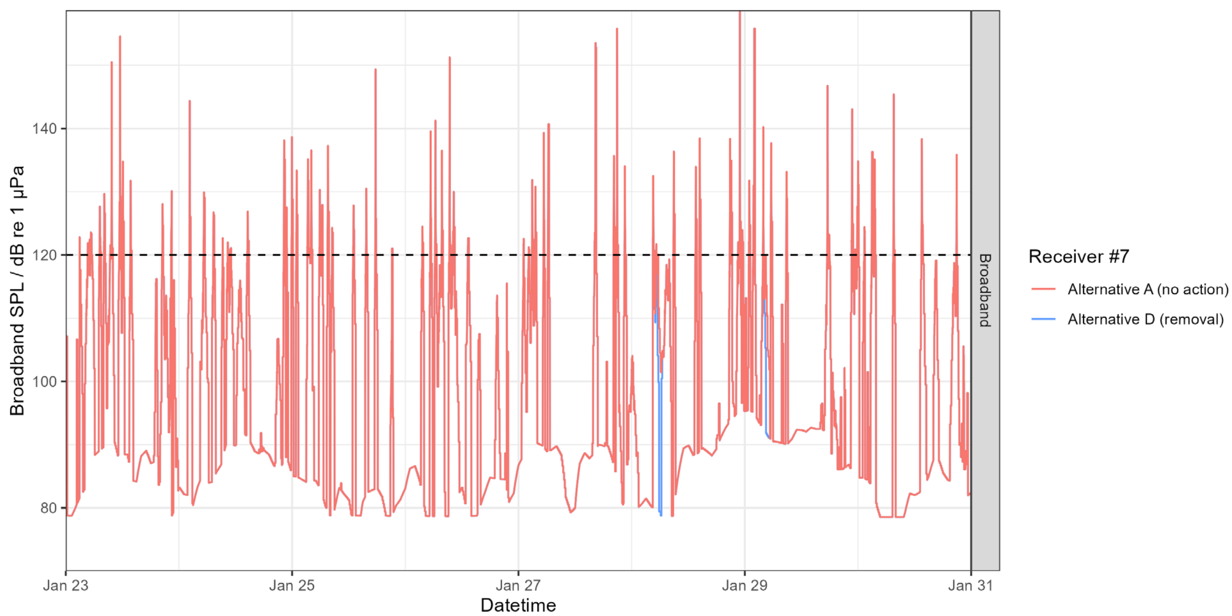


Figure C-21. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative D – removal (blue) with time (one week) at key receptor location #7.

C.2.2. Summer

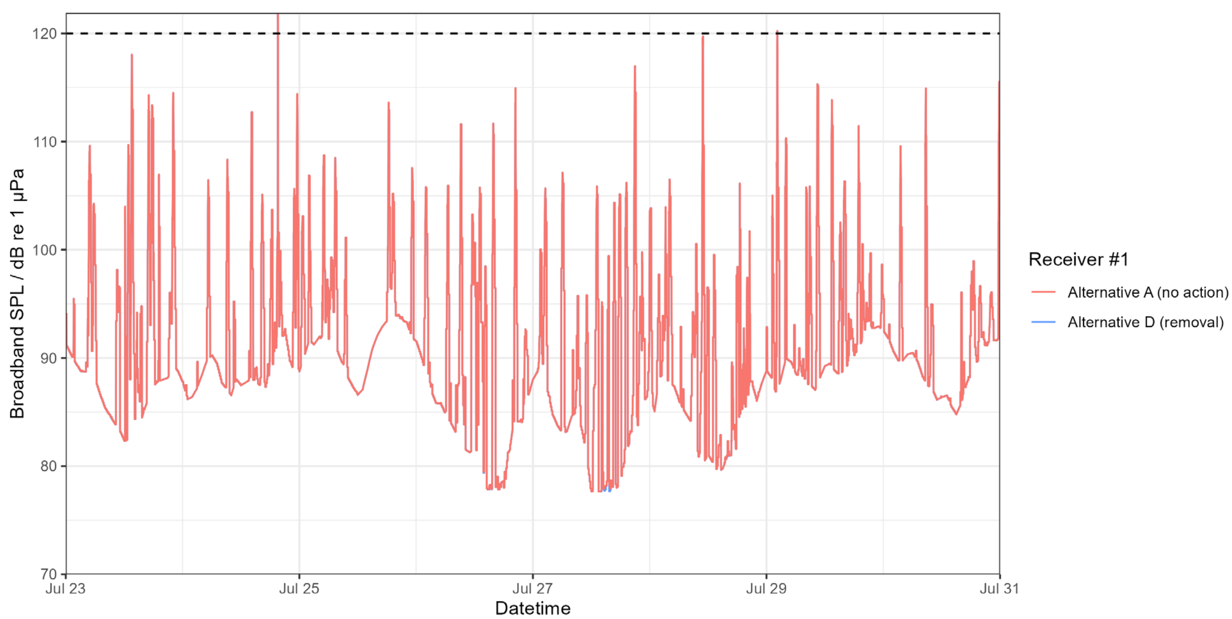


Figure C-22. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative D – removal (blue) with time (one week) at key receptor location #1.

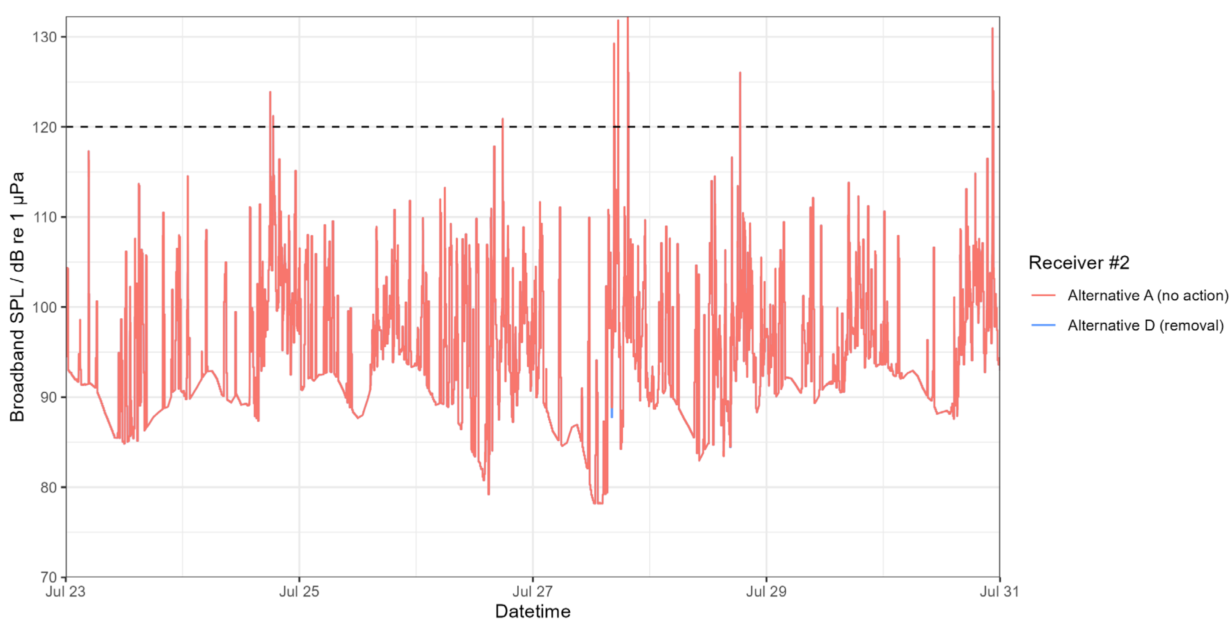


Figure C-23. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative D – removal (blue) with time (one week) at key receptor location #2.

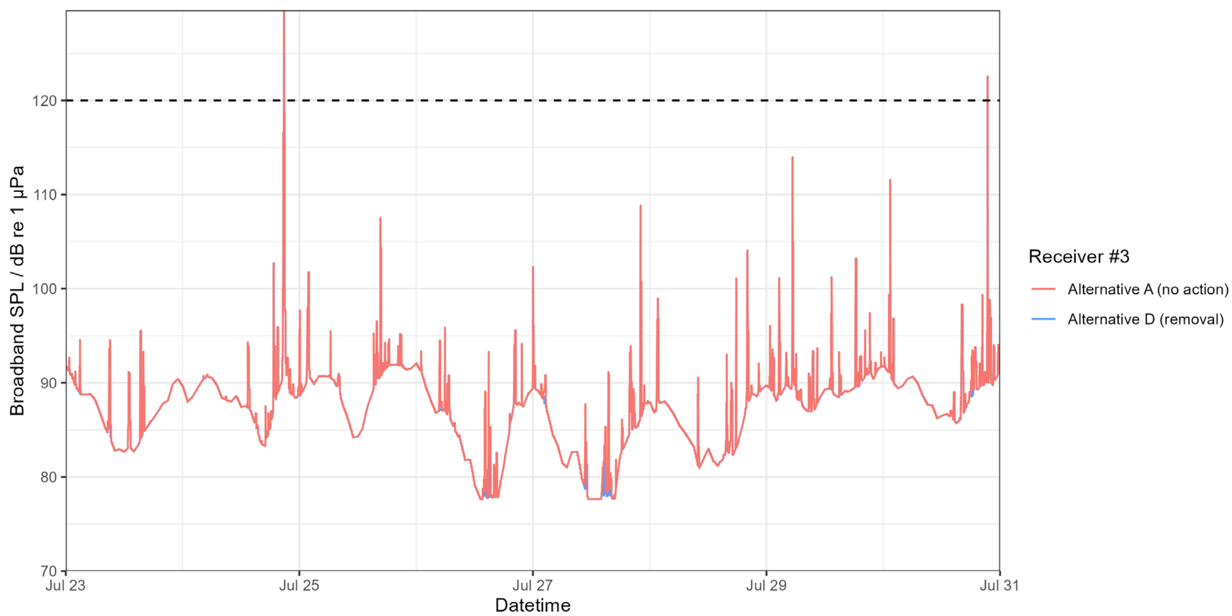


Figure C-24. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative D – removal (blue) with time (one week) at key receptor location #3.

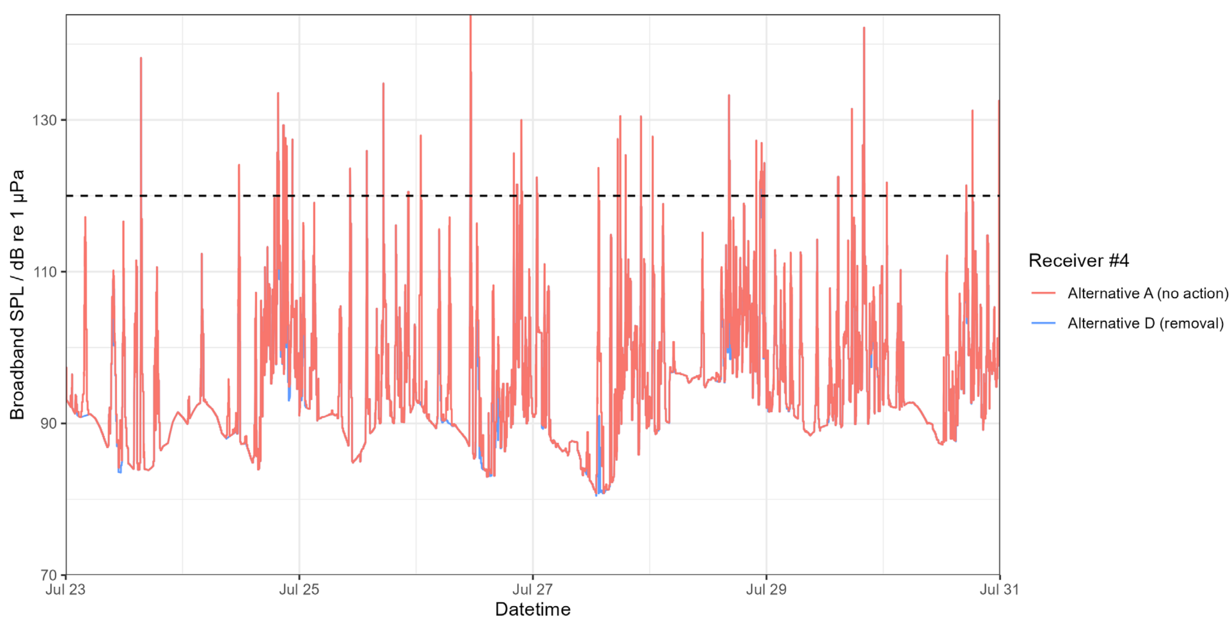


Figure C-25. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative D – removal (blue) with time (one week) at key receptor location #4.

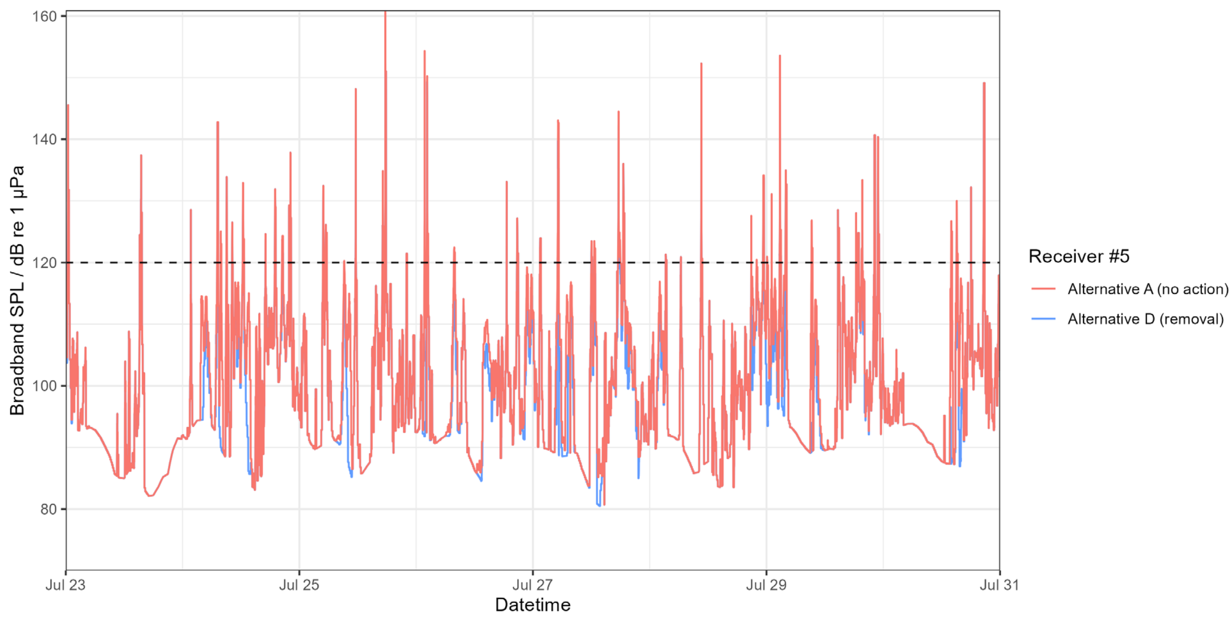


Figure C-26. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative D – removal (blue) with time (one week) at key receptor location #5.

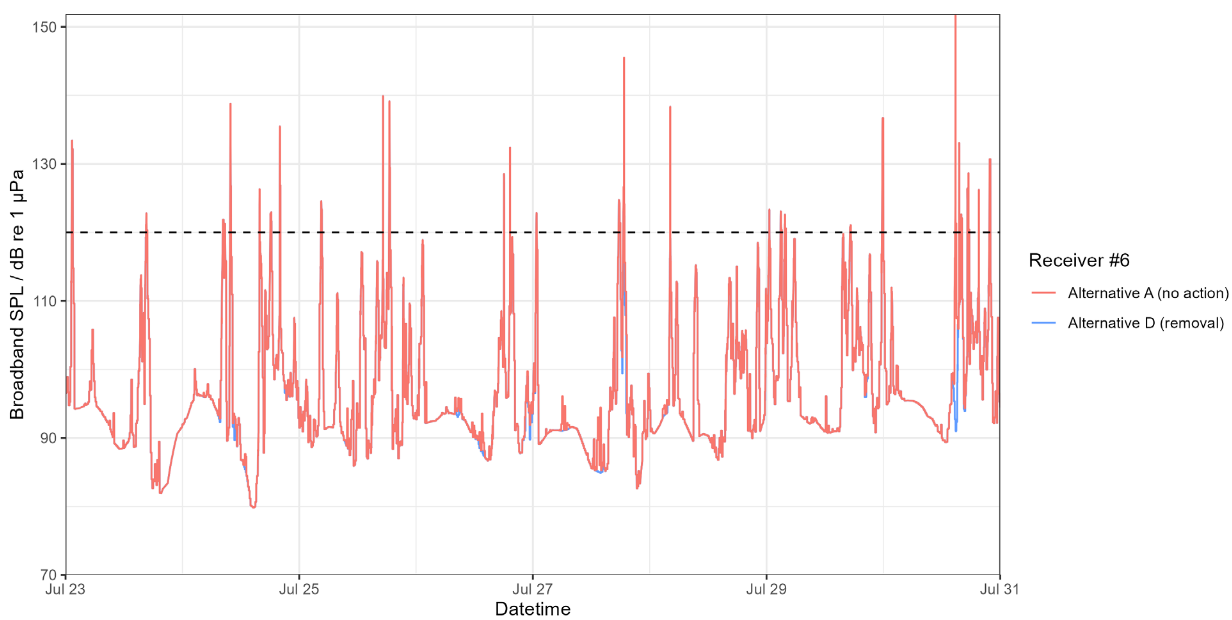


Figure C-27. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative D – removal (blue) with time (one week) at key receptor location #6.

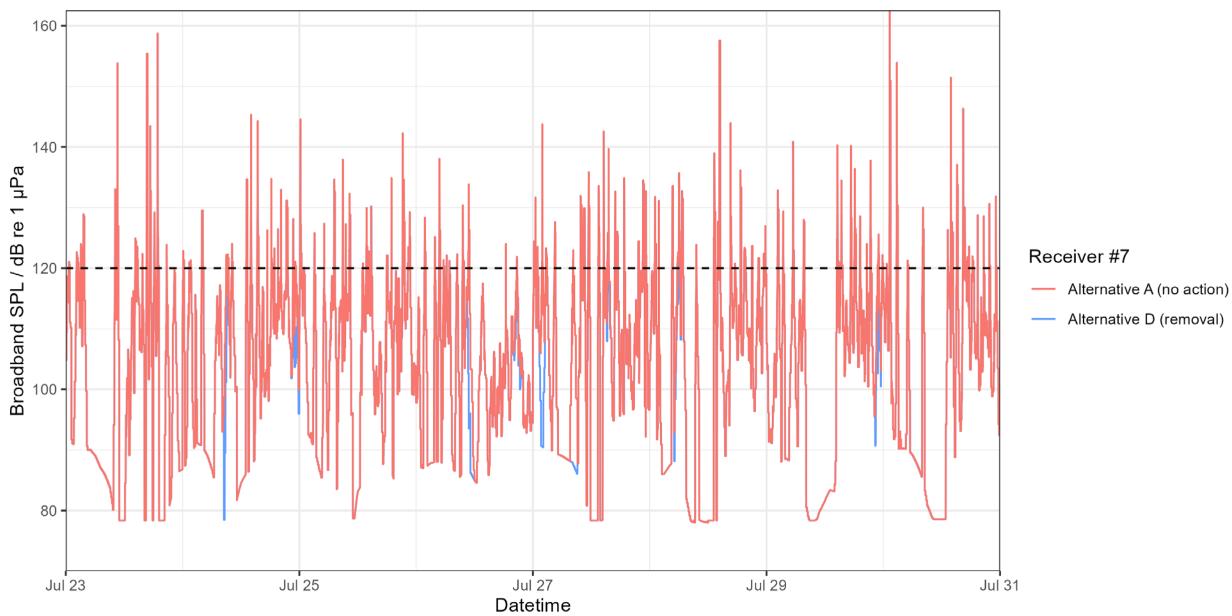


Figure C-28. Broadband received SPL (10 Hz to 63 kHz) for Alternative A (red) and Alternative D – removal (blue) with time (one week) at key receptor location #7.

C.3. SRKW Echolocation Band SPL vs time

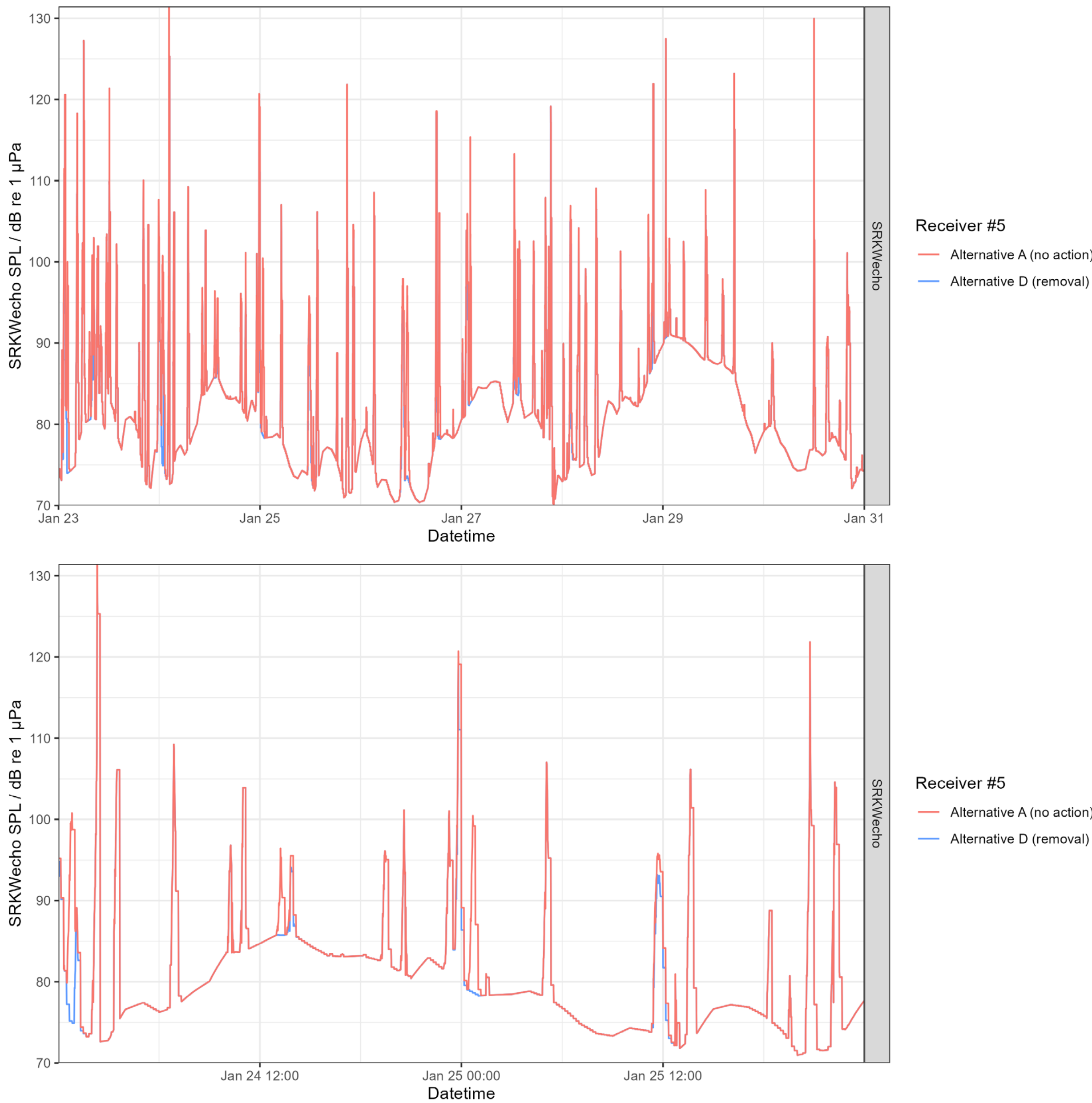


Figure C-29. SRKW echolocation band (15 to 63 kHz) received SPL for Alternative A (red) and Alternative D – removal (blue) with time (one week – top plot, 48 hrs – bottom plot) at key receptor location #5 in southern Rosario Strait. The levels exceed 110 dB much less frequently than the 120 dB broadband threshold is exceeded as shown in Figure C-19.

Supplement D. Soundscape Maps for Alternatives C and D

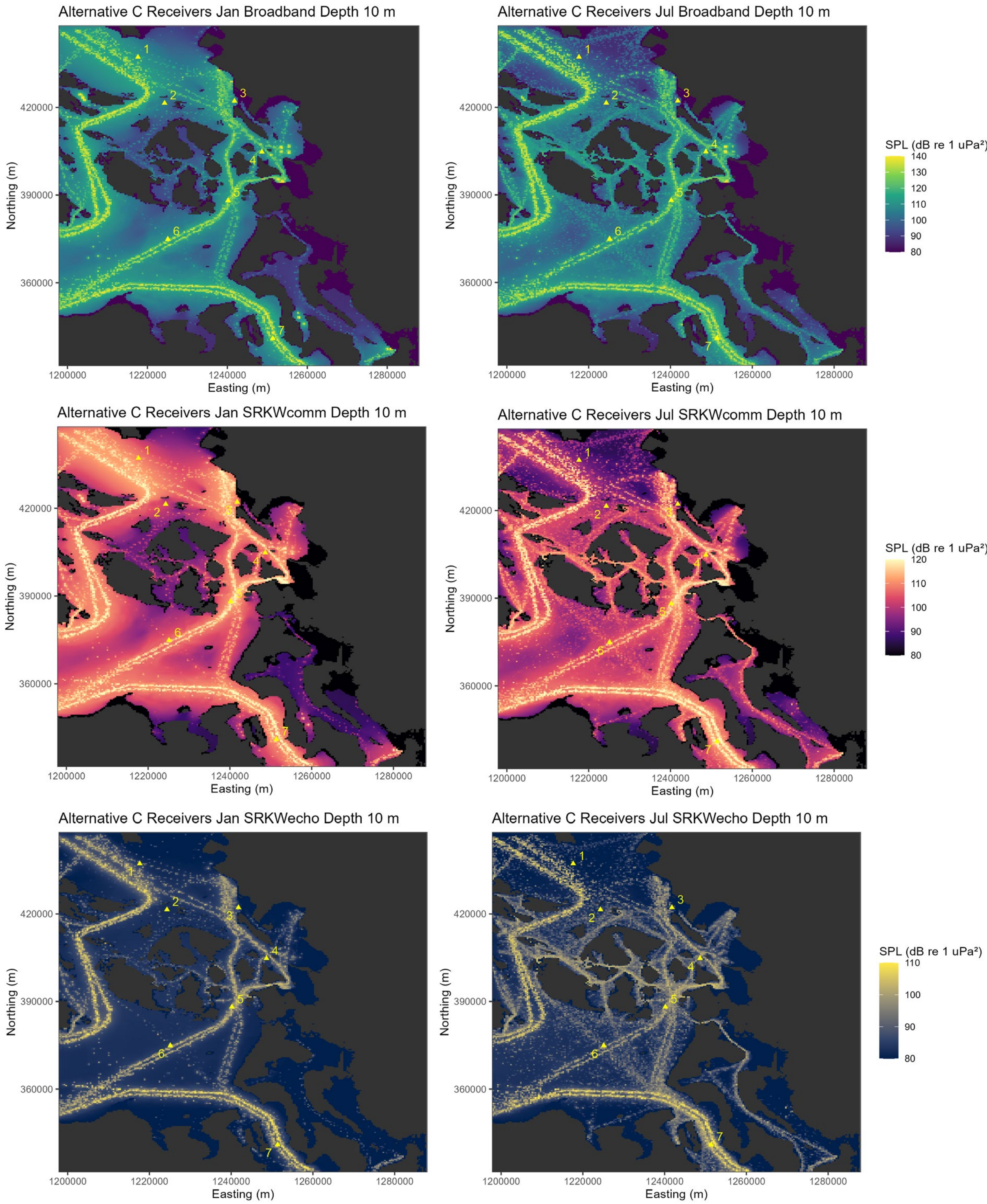


Figure D-1. Equivalent continuous noise levels (L_{eq}) for winter (left) and summer (right) in the broadband, Southern Resident killer whale (SRKW) communication band, and SRKW echolocation band for Alternative C. Key receptor locations (yellow triangles) are numbered on each map. Note the difference in scales between the three frequency bands.

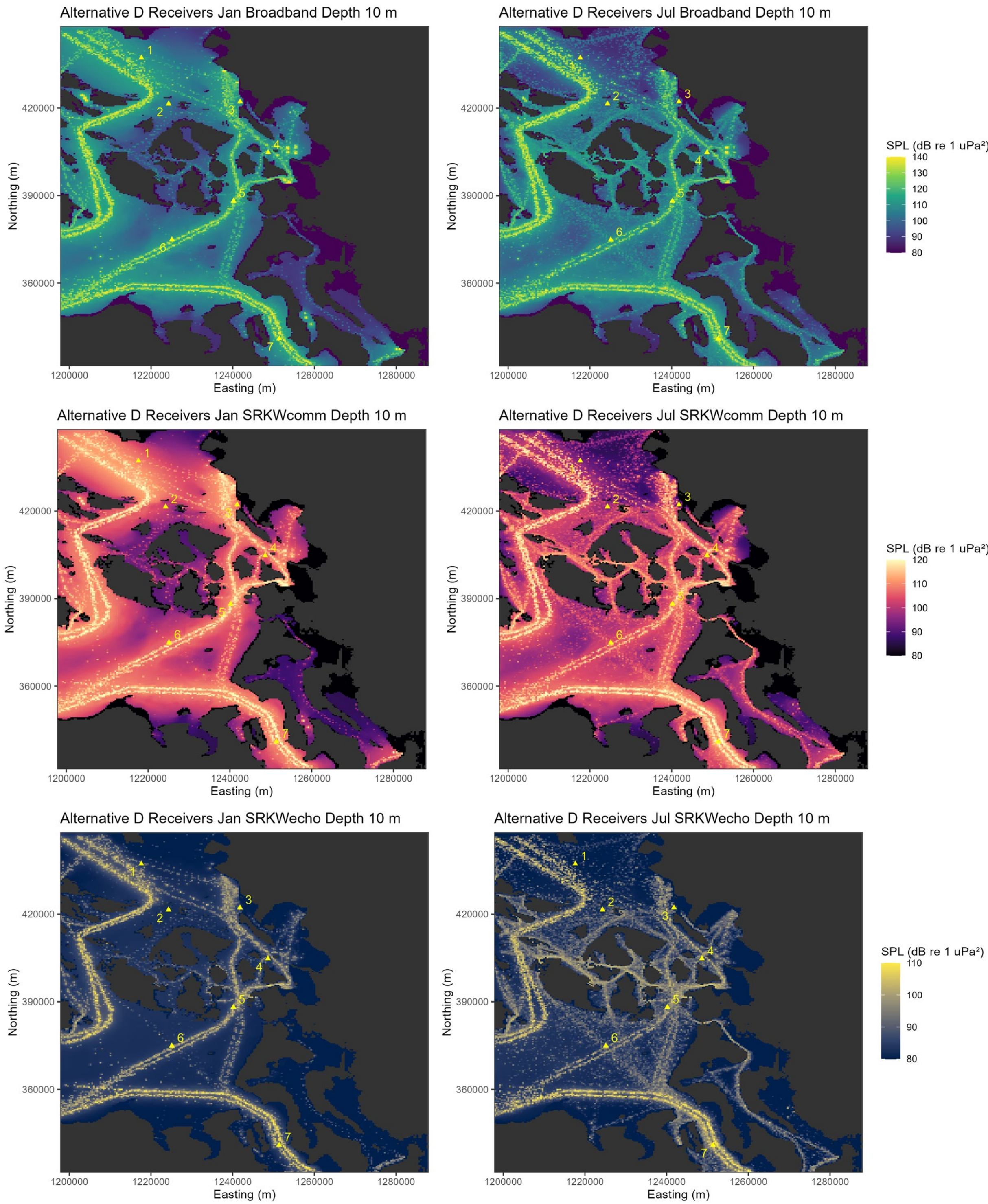


Figure D-2. Equivalent continuous noise levels (L_{eq}) for winter (left) and summer (right) in the broadband, Southern Resident killer whale (SRKW) communication band, and SRKW echolocation band for Alternative D. Key receptor locations (yellow triangles) are numbered on each map. Note the difference in scales between the three frequency bands.

Supplement E. Tabulated L_{eq} Sound Levels

Table E-1 below presents the equivalent continuous noise levels (L_{eq}) values for Alternative A and the difference with Alternatives C and D for the three frequency bands of interest and two seasons examined. Corresponding tables for L_{50} and L_{5} are found in Section 3.3.

Table E-1. Equivalent continuous noise levels (L_{eq}; dB re 1 µPa) for Alternative A (top section) and the difference with Alternative C and D (bottom sections) in the broadband, Southern Resident killer whale (SRKW) communication band, and SRKW echolocation band at the key receptor locations.

Key receptor location		Broadband (0.01 to 63 kHz)		Communication band (0.5 to 16 kHz)		Echolocation band (16 to 63 kHz)	
		Winter	Summer	Winter	Summer	Winter	Summer
Equivalent continuous noise level (L_{eq}, dB re 1 µPa^2), existing conditions with tug escorts (Alt. A)							
1	SoG	113.5	99.4	109.9	95.2	87.4	80.5
2	Boundary Pass	105.1	104.3	102.9	100.3	82.5	88.1
3	Lummi	109.6	94.9	108.9	90.8	86.4	81.7
4	Anacortes	114.2	112.1	109.1	108.7	90.2	94.4
5	Rosario	127.9	126.7	117.8	116.1	101.4	99.5
6	Haro	117.6	115.7	110.2	108.7	92.6	93.3
7	Puget	128.8	131.1	115.0	116.6	98.1	101.8
Change in equivalent continuous noise level (L_{eq}, dB re 1 µPa^2) with expansion (from Alt. A to Alt.C)							
1	SoG	0	0	0	0	0	0
2	Boundary Pass	0.1	0	0.2	0	0	0
3	Lummi	-0.1	0	-0.1	0	0	0
4	Anacortes	0	0	0	0	0	0
5	Rosario	0	0	0	0	0	0
6	Haro	0	0	0	0	0	0
7	Puget	0	0	0	0	0	0
Change in equivalent continuous noise level (L_{eq}, dB re 1 µPa^2) without tug escorts (from Alt. A to Alt. D)							
1	SoG	0	0	0	0	0	0
2	Boundary Pass	0	0	0	0	0	0
3	Lummi	-0.3	0	-0.3	0	-0.2	0
4	Anacortes	-4.9	-0.2	-2.4	-0.3	-3.9	-0.1
5	Rosario	-0.3	-0.7	-0.7	-1.7	-0.4	-1.4
6	Haro	0	-2.6	0	-2	0	-1.3
7	Puget	0	0	0	-0.2	0	-0.1