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Evaluation of a Proposed Approach for Offsetting Increases in Underwater Noise from Marine Shipping Using Information on Southern Resident Killer Whales

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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LIST OF TERMS, ACRONYMS, AND ABBREVIATIONS

AIS: Automatic Identification System

AMAR: Autonomous Multichannel Acoustic Recorders

CEAA: Canadian Environmental Assessment Act

CER: Canada Energy Regulator

CSAS: Canadian Science Advisory Secretariat

CTD: Conductivity, Temperature, Depth profiles

COSEWIC: Committee on the Status of Endangered Wildlife in Canada

dB: Decibel

DFO: Fisheries and Oceans Canada

EBSA: Ecological or biological significant marine area

ECHO: Vancouver Fraser Port Authority’s Enhancing Cetacean Habitat and Observation Program

EU: European Union

FFA: Frequent Foraging Area

FFHPP: Fish and Fish Habitat Protection Program

GPS: Global Positioning System

Hz: Hertz

IMO: International Maritime Organization

ISZ: Interim sanctuary zone

IQR: Interquartile range measured from the 25^{th} to the 75^{th} percentile.

kHz: kiloHertz

Leq: Equivalent continuous sound level, also known as the time-average sound level.

m: metre

MMSI: Maritime Mobile Service Identity

NL : Noise level

PCAD: Population Consequence of Acoustic Disturbance

PCoD: Population Consequence of Disturbance

PSD: Power Spectral Density

RAM Range-dependent Acoustic Model

RL: Received level

rms: Root Mean Square

SARA: Species at Risk Act

SDT: summer deadweight tonnage

SEL: Sound Exposure Level

SL: Source Level

SOG: speed over ground

SPD: spectral probability density

SPL: Sound Pressure Level

SME: Subject Matter Experts

SRKW: Southern Resident Killer Whale

STW: Speed Through Water

TSS: Traffic separation scheme

TMX: Trans Mountain Expansion Project

ABSTRACT

Advice was requested from Department of Fisheries and Ocean Science in the evaluation of a proposed framework for offsetting that could be applied to project-related underwater noise additions. To do this, a theoretical test case using information from southern resident killer whales (*Orcinus orca*, SRKW) in and around the Salish Sea was reviewed by subject matter experts. Advice was sought on several aspects of the approach, including: the spatial and temporal boundaries of the framework; the measurement of project-related vessel noise additions and the efficacy of management measures relative to a baseline; the use of offset ratios or weighting factors to express aspects of habitat use by the focal species; and how offset credits would be calculated and exchanged. Conceptually, there was reasonable agreement among participants that an offsetting approach could be applied to address residual project-related vessel noise increases on marine mammal species if existing mitigations proved insufficient. However, neither the proposed offsetting framework, nor the demonstration of its use in the test case, were recommended by participants due to concerns regarding the amount of data needed, and the risks and uncertainties in applying it to offsetting. Generally, issues remained unresolved in how the concept may be implemented, particularly in regards to credit calculation and exchange, and in understanding the associated benefits of the offsetting approach to at-risk focal species. High levels of uncertainty and risk were also identified for this, especially in the derivation and use of weighting factors to recognise areas of greater importance or use by the focal species. Guiding principles of credit exchange were discussed, including the need to determine habitat equivalency between regions based on focal species data, to allow for a ‘like-for-like’ exchange. Substantial and essential improvements were suggested to support future considerations of this concept.

1. INTRODUCTION

Growth in the world's economies and the expansion of shipping routes have elevated underwater ambient sound levels (Andrew et al. 2002, Malakoff 2010, Frisk 2012). More than 80% of global trade uses a maritime route, with the number and size of vessels predicted to increase. Sound level increases are focused around shipping routes, and in shallow coastal waters around major ports, however additions, particularly into the lower frequencies, can extend over greater distances (Jasny 2005, NRC 2005, Hildebrand 2009, Frisk 2012, Gillespie 2016, Mikis-Olds and Nichols 2016).

As anthropogenic noise in oceanic soundscapes increases, so too does the impact on marine life, including marine mammals. Their sensitivity in the acoustic sense means that sound from human activity can result in negative physiological, psychophysiological, or behavioural outcomes. Life processes, such as navigation, foraging, mate attraction, predator avoidance, group coherence, and other social behaviours rely on the exchange of acoustic information (Nowacek et al. 2007, Weilgart 2007, Cure et al. 2013, Erbe et al. 2016). Interference with an individual's use of acoustics could impact their efficacy in these behaviours and, if prolonged, reduce their likelihood of survival, and possibly be a factor in the demise of a population (Weilgart 2007, Erbe et al. 2016). Acoustic masking of signals occurs when an external noise obscures a signal of interest, reducing the perceptibility and interpretation of biologically relevant sounds, and reducing the range over which an individual can send and receive acoustic signals (Clark et al. 2009, Hatch et al. 2012, Burnham and Vagle 2023a, Burnham et al. 2023). If the noise source exceeds certain levels of amplitude, auditory injury, or permanent or temporary changes in hearing capacity might result (Southall et al. 2007, 2008, 2019, 2021, NMFS 2018, 2024). Anthropogenic noise has been shown to cause morphological damage (e.g., Ketten et al. 1993), with vessel noise increasing physiological stress levels in whales (Wright et al. 2007, Rolland et al. 2012), alter swimming, diving and calling behaviours (e.g., Holt et al. 2009, 2011, Parks et al. 2007, Lusseau et al. 2009, Williams et al. 2014, Dahlheim and Castellote 2016, Gomez et al. 2016), and reduce fecundity (e.g., Villegas-Amtmann et al. 2015, 2017, Lacy et al. 2017). This is in addition to other potential responses that might be observed as a result of the physical presence of vessels (e.g., see Lusseau et al. 2009, Holt et al. 2021). The risk of impact is often estimated from the likelihood and severity of exposure to the noise, considering an animal's co-occurrence with the noise source (see Southall et al. 2007, 2019, 2021).

Elevated underwater sound levels are increasingly listed as a threat to population recovery, and the success and survival of at-risk species (Simmonds et al. 2004, Weilgart 2007). For southern resident killer whales (*Orcinus orca,* SRKW) acoustic disturbance, particularly from vessels, is listed as one of four key threats to population recovery and survival (DFO 2017a,b, 2021, Lacy et al. 2017, Raverty et al. 2019, Williams et al. 2024). It is thought to have implications for habitat quality (Williams et al. 2014), and on their ability to forage effectively (Sato et al. 2021). As a highly acoustic species, SRKW rely on the use of communicative, social calls and echolocation to navigate, maintain group cohesion, and find, capture, and share prey (Ford 1987, 1989, 1991, Riesch et al. 2006). First recognised as a distinct ecotype in 2003, they have been listed since then as endangered under the *Species at Risk Act* (SARA) due to small population numbers (SC 2002, c29). At the most recent count, the SRKW population was 74 individuals (January 2024, CWR 2024).

The SRKW range spans more than 2000 km from British Columbia (BC) to California, with sightings in BC predominantly on Swiftsure Bank, Juan de Fuca Strait, and the inland waters around southern Vancouver Island and northern Washington State, collectively known as the Salish Sea (Figure 1). They are most prevalent in this area during the early spring to fall months

(May-October, Olson et al. 2018, Thornton et al. 2022a, Shields 2023), following the migratory spawning routes of Chinook salmon (*Oncorhynchus tshawytscha*) stocks to the Fraser River (Hanson et al. 2010, 2021). There is substantial overlap between foraging locations of SRKW and areas of high vessel traffic (Cominelli et al. 2018), with commercial vessels transiting international shipping lanes to ports including Vancouver, Victoria, and Nanaimo in Canada, and Port Angeles, Tacoma, and Seattle in the United States (US; Figure 1). As reliance on shipping routes increases, so too has the demand on these ports in the Pacific northwest (WSP 2020).

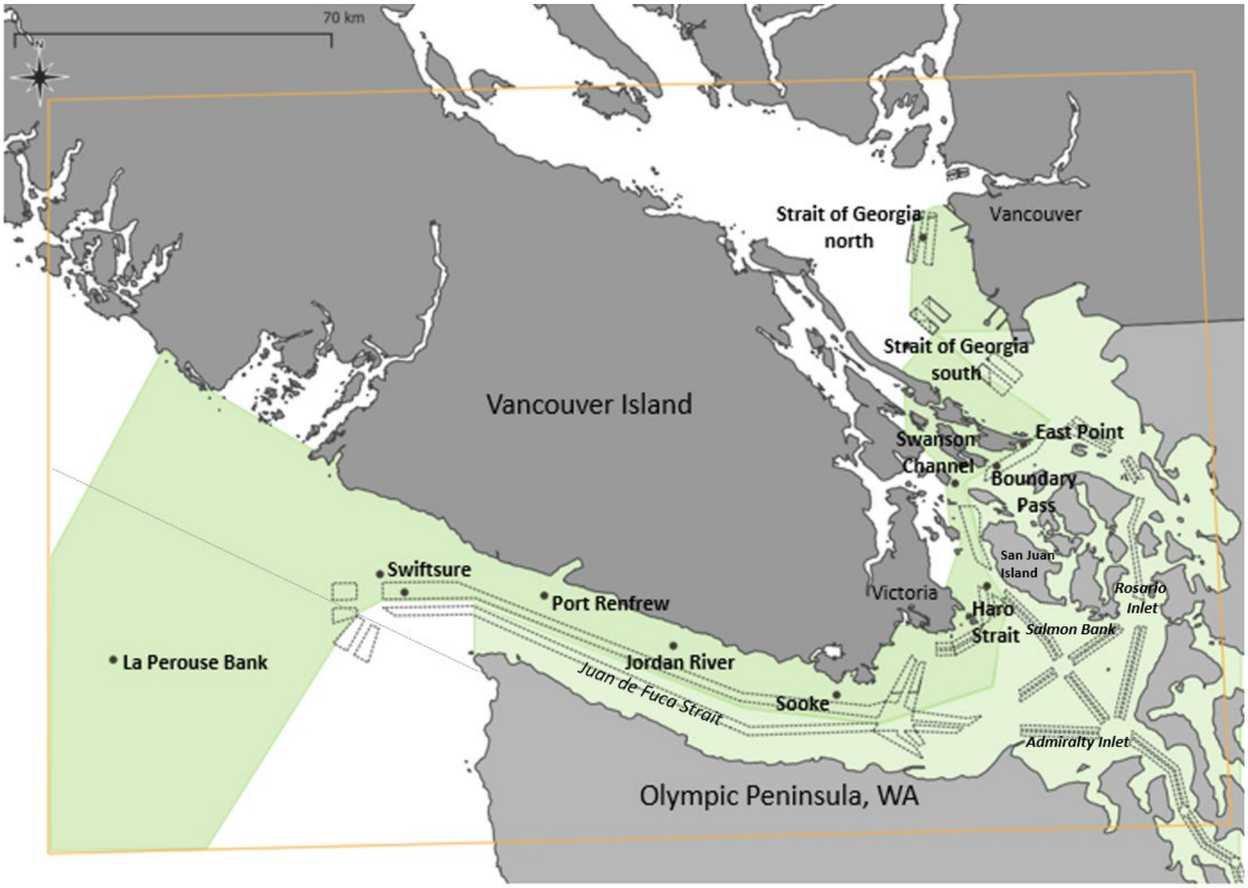

Figure 1. Swiftsure Bank and the Salish Sea. Indicated: full study area and acoustic model extent (yellow rectangle); mooring locations and names (black circles); international commercial shipping lanes (dashed lines); SRKW critical habitat (green shading).

Measures to reduce the underwater noise disturbance from vessels can be operational approaches, improving maintenance practices, or through quietening technologies at the source. Operational measures include those that change the way vessels are operated and used, or the areas they are present. They can include vessel slowdowns, changes in shipping lane configuration or rerouting transits away from important habitat, or in some cases complete exclusion from an area. Changes in vessel design can reduce the noise emissions at the source, including retrofitting, redesign, or increased maintenance (Veirs et al. 2021). Operational measures can be implemented on shorter time lines, and so are more frequently employed as management measures to mitigate vessel noise additions.

Noise offsetting has been suggested as an approach to guide management measures to lessen impacts of underwater vessel noise resulting from increased traffic from commercial development projects. The application of such an approach was assessed using information on

SRKW in waters in and around the Salish Sea, and the underwater additions from Trans Mountain Pipeline Expansion Project (TMX). The predicted increase in tanker transits resulting from TMX is approximately seven-fold, from five to thirty-four tankers each month calling to Westridge Marine terminal in Vancouver. There will also be an associated increase in tug and escort vessels to support these tanker transits through pilotage areas. The first tanker transits related to TMX in the Salish Sea were in May 2024.

Offsetting (described further below in Section 2) is increasingly being applied in environmental policy and remedial actions globally; however, this is the first use of the concept to address reduced acoustic habitat quality assumed to result from the noise additions from project-related vessel traffic to at-risk species. The aim of offsetting is ‘no-net loss’, where in this proposed use of offsetting this refers to as a no-net loss of acoustic habitat. It is assumed that management measures put in place to achieve no-net increase, or even a decrease, in vessel noise would achieve this through offsetting. Offsetting aims to address any residual impact or habitat loss following the application of mitigation measures. In this example, it would aim to address any remaining noise increases following the use of measures to reduce acoustic disturbance such as vessel slowdown and rerouting, and is only considered if measures have not been fully successful.

The work presented in this document builds on discussions of an initial workshop in December 2021, where subject matter experts (SMEs) were asked to critically evaluate the proposed approach and preliminary aspects of an offsetting framework. It also represents the outcomes of a Canadian Science Advisory Secretariat (CSAS) meeting, convening SMEs, March 12-14 2024. Advice was sought on the calculation and the principles guiding exchange of offset credits from participants of this meeting. Included in this was guidance on spatial and temporal aspects of the approach; the need for, and definition of sub-regions for credit exchange; identification of a baseline against which changes in sound levels from project-related vessels and offsetting management measures can be compared; and the use and calculation of offset ratios or weighting factors to represent habitat use and importance to SRKW, and establish habitat equivalency.

In this initial evaluation of the approach, the proposed theoretical offsetting framework was applied to a test-case. This considered underwater noise additions from TMX-related vessels, and evaluated how an offsetting approach may address the residual effects expected after project-specific mitigation actions have been applied. The approach addresses acoustic additions from project vessels only; it does not address any additions from construction or other noise sources related to the operational phases of the project. It is also concerned only with the changes in sound levels in the Salish Sea, and does not directly consider the behavioural or physiological implications of noise additions, or the repercussions that this might have on the focal species or other marine mammals in the region, including the potential increased risk of vessel strike. Also, at this preliminary stage, the offsetting approach is considered for the vessels for a single project on its own (i.e., TMX only), and not part of a cumulative effects framework to address project-related impacts. Further, the tested offset management measures do not represent how the Government of Canada (GoC) addressed TMX project-related noise; the test-case is a theoretical example of how an offset might work conceptually. The analysis focused on SRKW in the Salish Sea, although this area also represents important habitat for other marine mammal species (McMillian et al. 2022).

The data presented in this report are intended only to be a worked example of the application of information to the proposed framework, and present the recommendations of subject matter experts in the use of offsetting. The test case is used to represent the progress thus far in using the offset approach to address project-related underwater noise, and highlight areas where more work is need, especially when being considered for other species and/or regions. All analysis presented in this report for the test case, including figures and tables, are preliminary and intended for demonstration purposes of the proposed framework only. Amendments, modifications, and refinements are anticipated before they are finalised.

2. DEVELOPMENT OF AN OFFSETTING FRAMEWORK

Offsetting aims to address changes in habitat quality or destruction from anthropogenic activity, following the hierarchy of measures, whereby all efforts are made to prevent habitat or species impact as much as possible. In cases where this is not possible, measures to mitigate (reduce impact) are first trialed before considering measures to offset (counterbalance impact, Figure 2). Offsetting is, therefore, only pursued as an option when project impacts are unavoidable and residual effects remain after the application of mitigation measures (Gardner et al. 2013). Losses are countered by the improvement, creation, or restoration of additional suitable habitat in adjacent or nearby areas. Ultimately offsetting actions aim to achieve at least a no-net increase in loss of habitat, or a zero-sum impact on species by addressing any residual effects. Offsetting management actions must, therefore, exceed the project-specific mitigation measures. In the case of the proposed offsetting application being reviewed for the test case, offsetting would be used to achieve no-net change in the acoustic environment, or no underwater noise increases.

Offsetting actions achieve no-net habitat impact through lessening non-project effects in addition to project mitigation. This may be through the exchange of credits between areas where management measures have reduced project effects and those where residual noise additions remain. However, when forming an offsetting approach, it should also be considered whether there is intrinsic value to some areas that would prevent credits from these regions being traded. It may be that there are areas that provide unique habitat for vital behaviours or life history events for the focal species, for example weaning, that should be excluded from credit calculation and exchange, and only targeted for sound-level reductions. Also, an evaluation of the level of allowable and acceptable losses in a given habitat region, although balanced in the offsetting calculations, is needed (Ives and Bekessy 2015). An offset plan should include a description of the management measures intended to be used to counterbalance the residual effects on the habitat; outline how these measures will be implemented and monitored for effectiveness; present contingency measures that could be enacted if offset measures do not meet the no-net habitat loss target; and define the timeline of implementation and review. This includes a schedule of re-assessment and validation of the estimate of impacts, the efficacy of the offset measures taken, and updating the process of credit calculation and exchange as more data becomes available. Although offsetting as an approach has been applied to several conservation issues globally (e.g., Kiesecker et al. 2009. Palmer and Filoso 2009, Madsen et al. 2010), it has never been used to address underwater noise additions, or more specifically unavoidable additions from project-related vessel noise, and the reductions in marine mammal acoustic habitat quality that results from its elevation of noise levels in the soundscape. The development and application of an offsetting approach for use in this case is aided by existing policy and guidance documents, including the *Policy for Applying Measures to Offset Adverse Effects on Fish and Fish Habitat Under the Fisheries Act* (‘Offsetting Policy’, DFO 2019), with adaptations to better suit its intended use. The use of offsetting is only required when effects are unavoidable and project-specific mitigation measures do not fully address the noise additions.

No-net loss in acoustic habitat in the test case would be achieved through addressing the expected residual impacts of TMX-related vessel noise throughout the Salish Sea. It is worth noting that noise levels in the region prior to TMX were already thought to be at levels that affect SRKW recovery potential, with noise additions, specifically vessel noise, listed as one of their key threats (DFO 2018). However, the development of the offsetting approach for the test case seeks to solely counterbalance the effects from project-related vessel noise on an endangered species in areas of their critical habitat.

Actions to lessen the harassment or harm to species, or destruction of important habitat, should be undertaken using the best available science, and should be guided by a precautionary, ecosystem, or risk-based approach where appropriate. Offsetting is a potential approach that could be applied to address the predicted harassment or harm to SRKW, or destruction of important SRKW habitat in the Salish Sea, from new major projects.

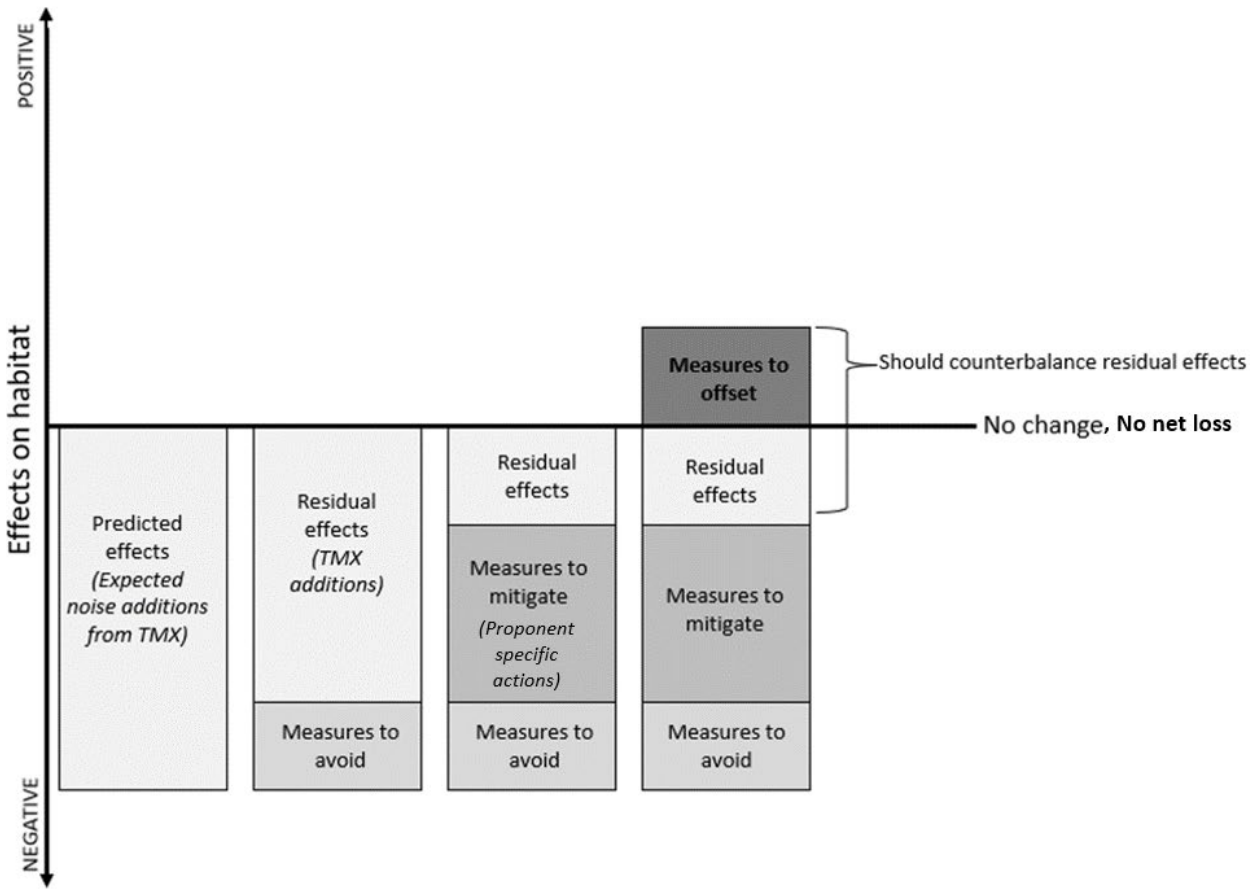

Figure 2. Conceptual diagram of the hierarchy of measures, adapted from the Offsetting Policy.

In its simplest form, offsetting allows areas that are more impacted to be balanced by areas that are less impacted, or have experienced a reduced impact as a result of offsetting management actions, so that there is no overall effect or loss of habitat resulting from a proposed project (Figure 3). Offsetting exceeds the direct mitigation of project-related or proponent-specific impacts, with the amount of offsetting required being proportional to the adverse effects not yet mitigated by other actions. It should also sufficiently account for any uncertainty in the efficacy of the measures implemented to avoid, mitigate, or offset the residual impacts from project-related activities, and the lag time between measures being implemented and the benefits being realised. As such, offsetting efforts often aim to reduce the effects of habitat loss in a way that exceeds what is needed to address only the residual habitat impacts through the management actions put in place. In the case of the proposed application to underwater noise, the offsetting needed would be at least proportional to the increases from project-related vessels that are not addressed by mitigation actions. Areas that have an elevated noise levels

(NL) resulting from TMX tankers and tugs (NL > Baseline, Figure 3) would be countered by reductions from offsetting management actions in adjacent regions (NL < Baseline, Figure 3). The amount of habitat with noise levels below baseline would at least meet, if not exceed the areas impacted by vessel noise. In this simplest form, it is assumed that all the habitat units are equally available and their importance is the same to the focal species. It does not account for habitat preference, site fidelity, or variables that make one habitat unit more important than another, for example the presence of prey resources. If habitat use is not uniform, then a weighting factor, or offset ratio, is used to address and express such disparities. This would allow for the credit calculations to express the importance of the habitat changes. In this way, losses of habitat in areas of higher importance are amplified, as are any gains or restorative actions due to successful offsetting. The amount of offsetting required in areas of increased importance to the focal species to counter habitat losses is therefore increased relative to the amount of habitat impacted. Credit calculations assume that the greatest benefit would be experienced by a species in areas of high use, and/or that support important behaviours such as foraging or weaning. In terms of the underwater noise application, this means that greater reductions would be needed in other areas to counterbalance noise increases in these more heavily-weighted areas.

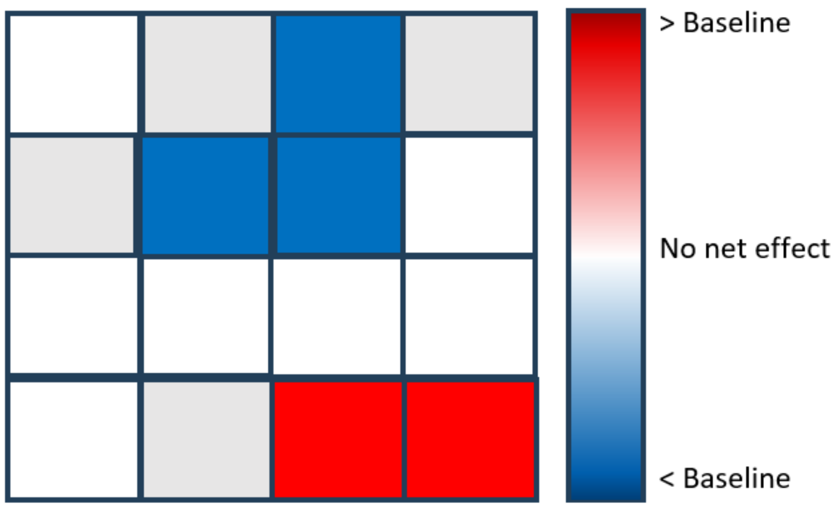

Figure 3. The theoretical concept of offsetting, where areas impacted more than a baseline amount are counterbalanced by those where impact is reduced to result in no net change.

Further, the use of these weighting factors helps guide the credit exchange between areas that show equivalency. This 'like-for-like' exchange is not just between areas of high-quality habitat to the focal species, but should be representative of the behaviours or life functions the habitat unit supports. In addition to weighting factors, an additional variable, a 'multiplier', may be used in the credit calculation to help account for uncertainty, including a means to express any margin of error that might have been carried through the credit calculations. Multipliers can be used to express risk, as a ratio between the impacted and compensated area; capture variability in the proposed approach (such as efficiency or compliance to mitigation measures); account for any lag in the application of measures or calculation in offset; or be used as a placeholder to be used for any other considerations needed when calculating no-net habitat loss.

The proposed offsetting framework developed by Fish and Fish Habitat Protection Program (FFHPP, the 'client') is data led, and may be iteratively updated and credit calculations completed at regular intervals to establish the effectiveness of measures to address project-related vessel noise (Figure 4). Review and reassessment of the parameters are expected if offsetting is furthered as a tool to address acoustic disturbance, and each step in the process adjusted as more data becomes available (Figure 4). Offsetting as a compensatory technique that might address negative impacts was introduced following the amendments to the *Fisheries Act* in 2012. In its application here, it seeks to establish the changes in the acoustic condition of the habitat as a result of project-related activities, but does not go so far as assessing how these changes may impact mortality/growth rates of a population, or fecundity and vital rates of individuals. An offsetting framework in previous applications has been used as part of assessing allowable harm, and in decision making processes in evaluating projects, works, undertakings or activities in areas used by SARA-listed aquatic species, although its use is still largely conceptual (see DFO 2022). Limitations in the application of this approach have been identified, including a lack of species-specific life history data on which to form the framework (DFO 2022). Uncertainties and knowledge gaps have been identified for each component of the framework. Applied to at-risk species, no additional measures of defensible criteria have been suggested in the implementation of extra measures or strategies to lessen these uncertainties (see DFO 2022).

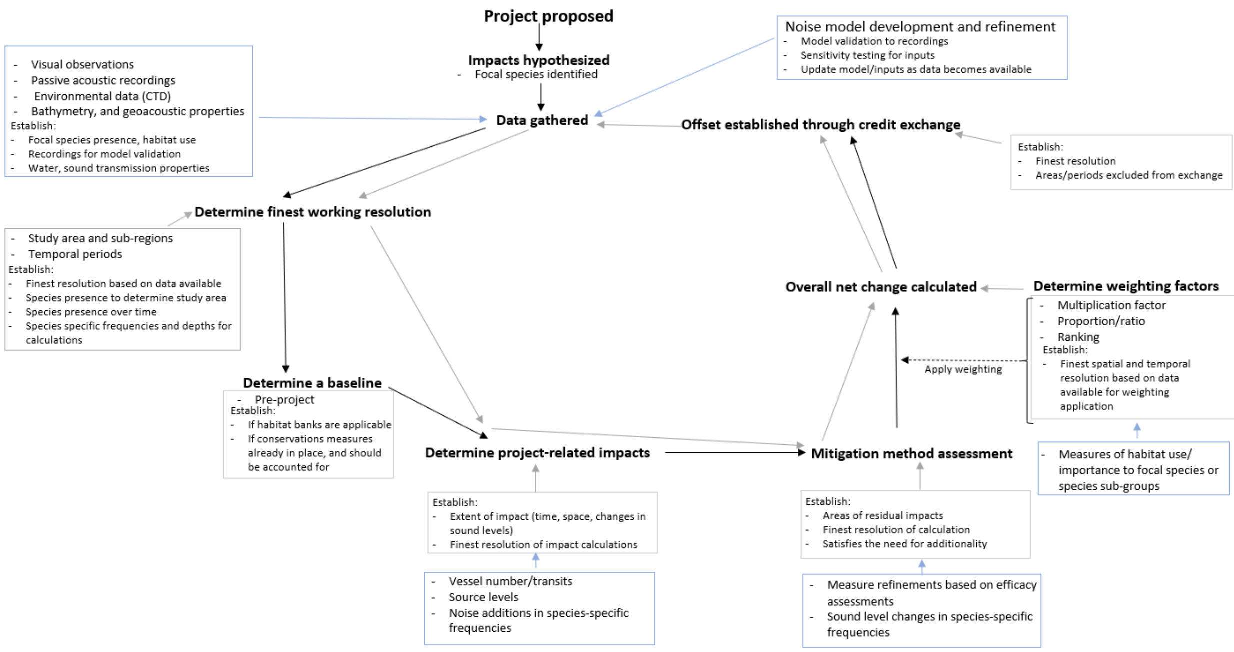

Figure 4. The proposed offsetting framework. Grey boxes and arrows represent aspects that would be considered every time the offset was calculated. Items in blue boxes list the updates that might be considered on each iteration of the calculation.

3. SRKW AND TMX TEST CASE OF THE OFFSET APPROACH

3.1. HISTORY OF TMX

Trans Mountain Corporation (owners and operators of the existing pipeline and proposed TMX project) submitted its application for a project certificate to the Canada Energy Regulator (CER, formerly the National Energy Board) in December 2013. The expansion (referred to throughout this document as TMX) would increase the capacity of the existing pipeline system nearly three-fold from 300,000 barrels per day to 890,000 barrels per day. Increased vessel transits would be needed to support this increase in oil outflow. The predicted increases in traffic, from five to 34 tankers per month would account for an increase of approximately 13.4% of the total traffic through Burrard Inlet and 5.5% through Juan de Fuca Strait (see Figure 1). Following the first approval of the TMX project in May 2016, the Government of Canada (GoC) committed to address the impact of additional TMX traffic and vessel-related noise on SRKW (DFO 2017a,b). This initial certificate was subject to 157 terms and conditions. Work to evaluate, develop, and implement measures that would aim for no-net increase in noise as a result of TMX-vessels began in 2016, with the GoC committing to more than mitigate the impacts on SRKW (NEB 2019).

A second, reconsideration hearing was held for TMX in 2018. Following this, CER concluded that TMX project-activities would contribute to other known effects already jeopardizing the reproductive success, survival and population recovery of SRKW. The CER concluded that operations were likely to result in significant adverse effects to SRKW. It also anticipated that Indigenous cultural use of the Salish Sea associated with SRKW would be impacted. Therefore, they recommended that the project be approved subject to 156 conditions and 16 recommendations, intended to mitigate or avoid these effects.

3.2. RECOMMENDATION 5 AND 6

Of the 156 conditions and 16 recommendations made by the CER, two recommendations (recommendations 5 and 6) specifically speak to the development of an offset program to address the foreseen increases in underwater noise and ship strike risk resulting from TMX-vessels. Recommendation 5 suggested the development of a program to offset both the increased underwater noise and strike risk posed to SARA-listed marine mammal and fish species due to project-related shipping, with periodic reporting on the efficacy of measures. Recommendation 6 further suggested the evaluation of specific measures to be considered as part of the offset program. Measures would be required to address needs outlined under section 79(2) of SARA and the *Canadian Environmental Assessment Act, 2012* (CEAA 2012) to consider and monitor the effects of project-related shipping. The development, implementation, and assessment of measures to avoid or reduce these effects under an adaptive management scheme was also required.

In providing recommendation 5, the CER noted that existing government initiatives “are intended to reduce cumulative effects on the whales and are designed to more than offset the impacts of project-related traffic including vessel noise and strikes.” They went on to say that "the Government of Canada will continue to build upon existing investments to address the impacts of the project, and additional measures will be developed and introduced as new information and results become available”. The commitment to this was reiterated, with the government stating continuing support to implement noise-related management measures to avoid or, where needed, mitigate project-related effects, and to monitor or adaptively implement measures that are consistent with recovery strategies and action plans of at-risk species. The CER recommended that measures undertaken to mitigate noise be applied to all appropriate vessels, and not just project-related vessels, as this would be needed to effectively offset impacts. They showed confidence that technically and economically feasible measures could be developed that would achieve offsetting based on evidence that was submitted in the reconsideration hearing.

The focus of this evaluation of the application of offsetting is SRKW, as a data-rich species. However, other marine mammals species in the Salish Sea include humpback (*Megaptera novaeangliae*), gray (*Eschrichtius robustus*), minke (*Balaenoptera acutorostrata*) and Bigg’s (transient) killer whales; harbour (*Phocoena phocoena*), and Dall’s porpoises (*Phocoenoides dalli*); harbour seals (*Phoca vitulina*); and Steller sea lions *(Eumetopias jubatus*), and Pacific white-sided dolphins (*Lagenorhynchus obliquidens)* (McMillian et al. 2022), which may also be impacted. Humpback and gray whales are listed as special concern and Bigg's killer whales as threatened under SARA (COSEWIC 2008, 2017, 2022). In addition, the Salish Sea encompasses rockfish protection areas, with yelloweye rockfish (*Sebastes ruberrimus*) listed as threatened under SARA (COSEWIC 2020). The application of the offsetting approach as a multi-species tool was considered in the review of the test case materials, but there was no resolution on how the framework would be applied in this instance. The pervasive nature of sound, travelling across sub-regions differently according to signal types and oceanography also means that effects on different species with distinct auditory capabilities needs quantifying. Data for each species would need to be incorporated into the offsetting approach. Therefore, the initial focus when considering recommendation 5 and the offsetting framework development remained on SRKW at this stage, with any reductions in noise levels presumed to benefit other species by increasing acoustic habitat quality.

3.3. GOC INITIATIVES

An Order in Council (PC 2018-1352, announced May 2019; Canada 2019) and explanatory note (Canada Gazette 2019) describe the potential and expected effects from TMX. It outlined suggested measures, and the recommendations from the CER to GoC to mitigate and offset these effects, including the additional underwater noise resulting from project-related vessels (recommendations 5 and 6). Funding from the Oceans Protection Plan (OPP) and the Whales Initiative (WI) have contributed to some of these efforts. Studies into the effectiveness of ongoing efforts intended to reduce cumulative effects, and more than offset the impacts of project-related traffic including vessel noise were suggested. The engagement of government departments in programs to address emissions, noise and disturbance from project-related shipping in SRKW critical habitat, as well as increasing marine safety and security measures including oil spill preparedness, was advised.

Several conservation measures have been initiated, including trialing voluntary measures for large commercial vessels in the Salish Sea. Voluntary slowdowns on Swiftsure Bank through Haro Strait and Boundary Pass, and a lateral displacement of tugs away from the Canadian coastline have been overseen by the Enhancing Cetacean Habitat and Observation (ECHO) Program. The Vancouver Fraser Port Authority launched the ECHO program in 2014, to better understand and reduce effects of shipping, recognizing that vessel activity in the region is increasing, and has the potential to impact at-risk whale species. Measures were first trialled in 2017, pre-dating GoC OPP and WI programs, with the voluntary measures enacted formalised through a non-binding conservation agreement with the GoC in 2019, and renewed again in 2024 for a further five years (Section 11, *SARA*). That agreement committed the parties to work together to quantifiably reduce threats, such as underwater noise, to SRKW from commercial ships. This would be through continued participation in programs such as the port authority-led ECHO Program. There was no specific mention of the TMX project or offsetting project noise additions within the agreement. The sites and maximum speeds selected for trials were chosen through advisory working groups, committees and stakeholder engagement, and have expanded since the first implementation. The initial slowdown trial was in Haro Strait (Figure 1), with sections of Boundary Pass added in 2019. In 2020, slowdown requests were initiated on Swiftsure Bank for outbound traffic, and from 2022 onwards the speed reduction request was expanded to both in- and out-bound transits. Efficacy of the measures and levels of participation are measured annually (see Vagle and Neves 2019, Vagle 2020, Burnham et al. 2021a, Burnham and Vagle 2023b, and ECHO annual reports. *In-situ* recordings comparing trial to control periods show that the measures have been successful in reducing vessel noise. In particular, slowdown measures through the inner waters of the Salish Sea have been seen to reduce sound levels (see Burnham et al. 2021a, Burnham and Vagle 2023b). The lateral displacement reduced the emissions per vessel transit (Vagle and Neves 2019, Vagle 2020, Burnham et al. 2021a, Burnham and Vagle 2023b), and may also have reduced the potential for vessel strike.

In addition, regulatory measures implemented by GoC include extended minimum vessel approach distances for all vessels including whale watching and recreational vessels, Interim Sanctuary Zones (ISZ), which exclude the passage of all vessels in SRKW foraging areas, and seasonal slowdown regions on Swiftsure Bank, targeted to fishing and recreational vessel traffic. Fisheries closures have also been introduced to increase prey stocks and decrease vessel noise in foraging areas (see Burnham and Moore 2023). The GoC has committed to monitor the effectiveness of the measures in place, and develop, implement, and adaptively manage measures as new information becomes available (Canada Gazette 2019).

To respond to recommendation 5, and fulfil a commitment to more than mitigate the acoustic impact of TMX-related vessels, the GoC evaluated the concept of offsetting to achieve a no-net increase in underwater noise. The increased vessel number related to TMX is expected to elevate ambient sound levels in the Salish Sea; however, it is hoped that reductions from offsetting measures will counter against these increases. For the approach to be applied successfully, first the additions of TMX must be characterised, and then there is a need to determine how project-related mitigation measures might reduce this impact. Outstanding noise additions would then be addressed through offsetting. Work to date has focused on the underwater noise and potential impacts on SRKW, with the government developing, implementing, and adaptively managing multiple components of the offset program.

3.4. WORKSHOP OUTCOMES

An Underwater Noise Credit Workshop convened SMEs from Fisheries and Oceans Canada in December 2021 to consider the merits and limitations of a noise offset program. This was the first consideration of the use of a quantitative credit-based approach to offset the impacts of vessel-related noise expected to result from the increased traffic through the Salish Sea as TMX becomes operational. In addition, comments from external peer-reviews on aspects of the work were sought. These were integrated into the offsetting framework presented at the CSAS review.

The SMEs agreed that credits could, in theory, be used to address the impact of underwater noise on SRKW communication and echolocation, and the potential masking of these signals. Metrics selected should address or be a proxy for this; however, there was no consensus on the candidate frequencies or metrics that the credits would be based on. The SMEs looked to previously published works for the definition of the communication and echolocation frequency ranges (see Heise et al. 2017, and then subsequent to the workshop Thornton et al. 2022b, Burnham et al. 2023, Burnham and Vagle 2023a), but suggested that a single aggregate metric could be appropriate, while also trying to address the offsets with a species-specific approach. It was acknowledged that this metric should focus on addressing noise-related impacts, and may not be appropriate in understanding behavioural or physiological implications of the changes in sound levels. The implications for communication and echolocation would be assessed as equally important to the whales. Frequency weighting of sound level changes, based on experimentally derived hearing sensitivity estimations of SRKW, were thought best to not be included in the credit calculations, as they may underestimate the impact of vessel noise in higher frequencies. Metrics such as sound pressure level (SPL), sound exposure level (SEL), and cumulative SEL were determined to be appropriate, calculated over a month as the minimum time scale for the frequencies or frequency ranges of interest. It was agreed that May to October would be the initial focus, when SRKW presence in the Salish Sea is greatest. Seasonal and annual variation could be considered in future iterations of the framework. Changes in ambient sound levels were thought best to be considered using L_{90} or L_{95}

exceedance levels, with metrics used needing to be able to capture both the transient nature of passing vessels and the more consistent additions from vessels in the shipping lanes. Indicators of physiological impact or behavioural responses were deemed to have too much variability and uncertainty in their interpretation to be included (see e.g., Wright et al. 2007, Gomez et al. 2016).

The uncertainty in application of the credit system was thought to be reduced by sub-dividing the study area. It was agreed that the sub-regions to be used for assigning and transferring credits should be based on knowledge of the ambient soundscape, drawing on past analysis of acoustic recordings and known sound transmission properties from the Salish Sea (previously described in Burnham et al. 2021b). Determining credits based on the vessel noise model resolution (on the scale of hundreds of meters) was not thought to be appropriate, with broader scale calculations considered better to account for movements of SRKW within the study area. The SMEs suggested that the assignment and transfer of credits should be done on spatial and temporal scales that are biologically relevant to SRKW, but the details of credit exchange were not discussed.

The use of weighting factors for conveying information on the importance of habitats was suggested as part of the offsetting calculations by the SMEs, considering variables such as: SRKW preferred habitat use, determined from the frequency of sighted occurrence or purely a presence-absence metric, and variations in natural sound levels. The dominant behavioural habitat use (e.g., foraging or traveling) of a sub-region was discussed as an option but ruled out by the SMEs as a modifier to the credit calculation due to uncertainty and the broad nature of the classification.

Following the workshop, and at the request of FFHPP the evaluation of offsetting was to focus on May-October, when SRKW are most present in the Salish Sea, and considered:

- Changes from baseline using the median or algorithmic mean (L_{eq})
- Changes in ambient noise using the L_{99} exceedance level
- Implications for SRKW acoustics using previously published frequencies for communication calls and echolocation
- Changes in sound levels in the upper water column only, integrating model results to 25 m
- The calculation and exchange of credits between sub-regions.

3.5. DATA NEEDS

Offset credit calculations and exchange should be based on field observations and, where needed, modelled results. Both offer their own contribution to aspects of the approach, and bring with them considerations about how the data can be applied. In the review of the offset approach where each data type could add to the offsetting calculation was considered, along with minimum data requirements (see Figure 4).

For the test case, the spatial extent of the analysis was bounded by 49.0°N, 125.5°W in the northwest, 49.0°N, 123.0°W in the northeast, 48.0°N, 125.5°W in the southwest and 48.0°N, 123.0°W in the southeast (Figure 1). This area encompassed regions of known use by SRKW in waters around Swiftsure Bank and in the Salish Sea (Olson et al. 2018, DFO 2021). It covered SRKW critical habitat in Juan de Fuca Strait, Haro Strait and Boundary Pass, the southern Gulf Islands and the southern portion of the Strait of Georgia. It also extended west to Swiftsure Bank and La Perouse Bank, and the surrounding canyons and bathymetric features that might characterize foraging areas (Figure 1). All credit calculations and offsetting analysis were limited to the months of May to October throughout; this period represents when SRKW are most present in the Salish Sea, and when most data are available on their presence, movements and behaviours.

3.5.1. Focal species data

Impact assessments must start by considering the presence of the focal species. Data is needed on their presence, time spent in the study area, and habitat use to understand the level and duration of exposure. Species presence data can be collected through dedicated surveys or opportunistic sighting collation. Systematic sampling can take the form of vessel-based or aerial surveys that are corrected for effort and sighting conditions. As well as location, data regarding whale numbers and behaviour can be collected, and information on residency time and return rate inferred if a mark-recapture study is undertaken through, for example, photo-identification methods. Passive acoustic recordings could also be used, where call presence becomes a proxy for physical whale presence, giving a minimal presence of the focal species over time within the detection range. Behavioural context of presence may be inferred in this case from the length of the calling period/call bouts that are recorded as well as clues from call type. Probabilistic statistics, predictive density surfaces, or animal movement models can then be used to generalise the results from line- or point-based surveys to the study area, expressing the likelihood that whales would be present in each region and how the habitat might be used (Hammond et al. 2021). If the whale presence data is collected through visual observations then it is typically limited to only daylight hours and periods where visibility allows accurate detection of individuals. Passive acoustic methods can extend the survey window in time, but generally have less spatial coverage, and it can be difficult to ascertain location or abundance of whales especially if using only one hydrophone. Used together, some of these gaps may be addressed, but the limitations and constraints of the extent to which the data can be generalised over time and/or space should be acknowledged.

The integration of information on habitat use in time, including behavioural context, time spent in the area, and the age- and gender-partitioning, if known, of animals present can help determine the distinctive features of the area and what might be the drivers of its use. In reference to the offsetting approach, this information helps in determining regions where the use of habitat might be equivalent, and identifying regions that may allow credit exchange. Higher resolution data, in time and/or space or the behaviours noted, can give greater detail on whale presence and movements through an area. However, taking a coarser perspective, such as determining foraging and non-foraging areas, or even common and frequent foraging areas over six months, as was done in the test case, aids in more areas being deemed similar in their importance to the focal species. Habitat use, and determining equivalency of use, where the same individuals could use areas for the same function at the same time for the same period of time, is important in the assignment of weighting factors that may express habitat importance and/or uniqueness, and guides the exchange of credits between similar regions.

In the case where multiple species are present, several approaches may be taken. A species of priority may be selected, as was done with the test case, to represent the species deemed at greatest risk. Alternatively, a species that best represents the other species may be used as an indicator species. The presence and use of habitat may be also expressed as a species diversity metric, with a means to express variability in time as well as in space.

3.5.1.1. SRKW in the Salish Sea

Southern resident killer whales were first recognized as a distinct population, and listed as endangered under SARA in 2003 (SC 2002, c29) due to small population numbers, which have fluctuated over the last forty years. Population numbers peaked at 98 individuals in 1995, followed by a decline to the current population of 74 individuals (as of January 2024, CWR

2024). The recovery strategy for SRKW was published in 2008, and has undergone a number of amendments since (DFO 2017a,b, 2018). The most recent update lists four main threats to the recovery and survival of the population: reduced prey availability, contamination from persistent organic pollutants, acoustic disturbance, specifically from vessels, and the risk of vessel strike (DFO 2017a,b, 2018, 2021, Raverty et al. 2019).

The acoustic repertoire of SRKW is generally considered to fit into two broad categories, either communication calls or echolocation ‘clicks’. The communication calls include whistles and burst-pulse calls, and typically fall in the 500 Hz to 15 kHz frequency range (Heise et al. 2017). Whistles (2-17 kHz, Ford 1989) and pulsed calls (1-15 kHz, Riesch et al. 2006) include lower frequency components (Miller and Bain 2000), whereas echolocation relies on the use of high-frequency to ultrasonic signals. These signals typically fall in the 15-100 kHz range (Heise et al. 2017), and allow the whale to receive information about its surroundings from the echo of its own projected signals. These signals have been described as bimodal (Au et al. 2004), with a lower peak at 20-30 kHz and a higher peak at 40-60 kHz. Interference and reduced effectiveness of these calls may result through acoustic masking following the introduction of anthropogenic noise into the soundscape (see Holt et al. 2009, 2011). There is concern that increased traffic loads transiting to and from the ports in the Salish Sea will elevate sound levels and result in increased stress and acoustic disturbance for SRKW, with this area found to have the highest ambient noise levels along the British Columbia coast (Erbe et al. 2012).

The productive waters of the Salish Sea host foraging areas for several marine mammal species, including SRKW. For the test case, the presence and prevalence of habitat use of SRKW was estimated using 12 years of encounter data collated from dedicated surveys (Noren et al. 2009, Holt et al. 2013, Olson et al. 2018, Thornton et al. 2022a) and sightings from whale watching operators. Thornton et al. (2022a) reviewed sightings and acoustic data collected over summer months, extending from May to October, to define areas where SRKW were most prevalent during this time. Time-stamped location data were collected, with duplication of sightings, or repeat sightings of the same whale group removed in post-processing (see Thornton et al. 2022a). Resighting was considered if observations were within 1 hour and/or 2 nautical miles (nm) (3.7 km) of each other. Sightings were effort-corrected by overlaying an effort grid over the study area, and the survey effort for each square expressed as a proportion of the total effort. To interpolate to an expected frequency of occurrence layer of the full study area, with values between sighting locations, a spatiotemporal model was applied using the number of SRKW sightings per unit of search effort for each unit area (see Watson et al. 2021). This was then expressed as the predicted intensity of occurrence at the 70 % confidence level, indicating regions most frequented by SRKW (Figure 5). A model output resolution of 885 m^2 was used.

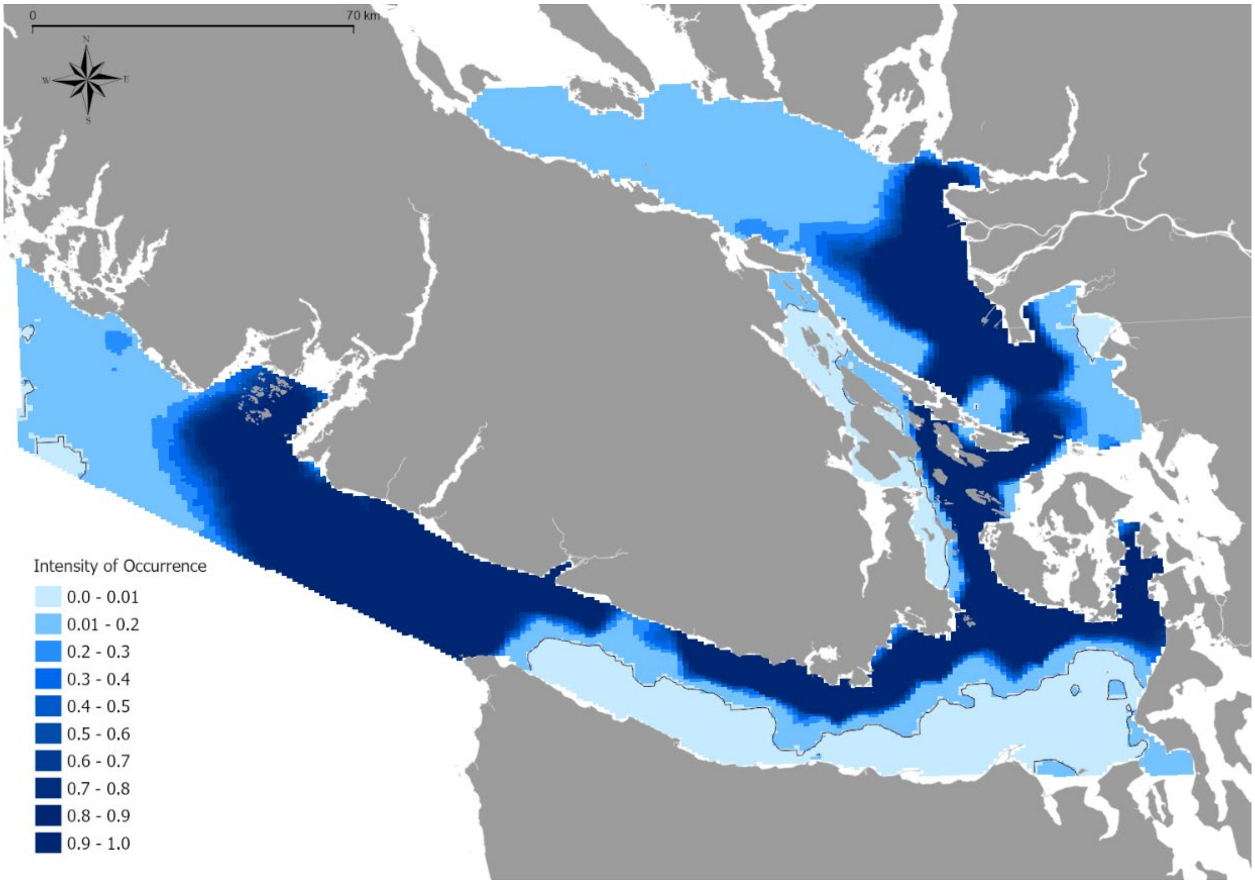

Figure 5. The cumulative spatial occurrence of SRKW from May to October indicates habitat preference within SRKW critical habitat. The probability of SRKW occurrence is denoted by the blue scale. Areas in white are outside the geographic extent of the model. Adapted from data from Thornton et al. (2022a).

Behavioural data from the surveys were also collated to identify predominant habitat use, with focus given to areas on Swiftsure Bank and Haro Strait (see Figure 1). These data were collected during vessel-based observations using either a focal follow or group behavioural survey protocol. Behavioural state categories included foraging, traveling, socializing and resting, and were documented every ten minutes via instantaneous scan sampling (Noren et al. 2009, Holt et al. 2013, Thornton et al. 2022a). A strong spatial correlation of traveling and foraging behaviour was indicated by the analysis, and these behaviours formed the binary response variable for the model, reducing the behavioural ethogram essentially to either foraging or non-foraging behaviours at a location. To extrapolate the observational data to Swiftsure Bank and Haro Strait regions, a Bayesian inference approach of integrated nested Laplace approximations was selected to estimate probability of foraging in space (see Stredulinsky et al. 2023, Figures 6-7). This helped identify foraging regions as either common (>25% likelihood, Figure 6) or frequent (>50% likelihood, Figure 7). The output resolution of this model was a projection at 200 m^2 resolution (Stredulinsky et al. 2023), with the data extent limited to areas on Swiftsure Bank and Haro Strait (Figures 5-6), which were already noted for increased SRKW presence and use for foraging (Olson et al. 2018, Hanson et al. 2010, 2021, Thornton et al. 2022a).

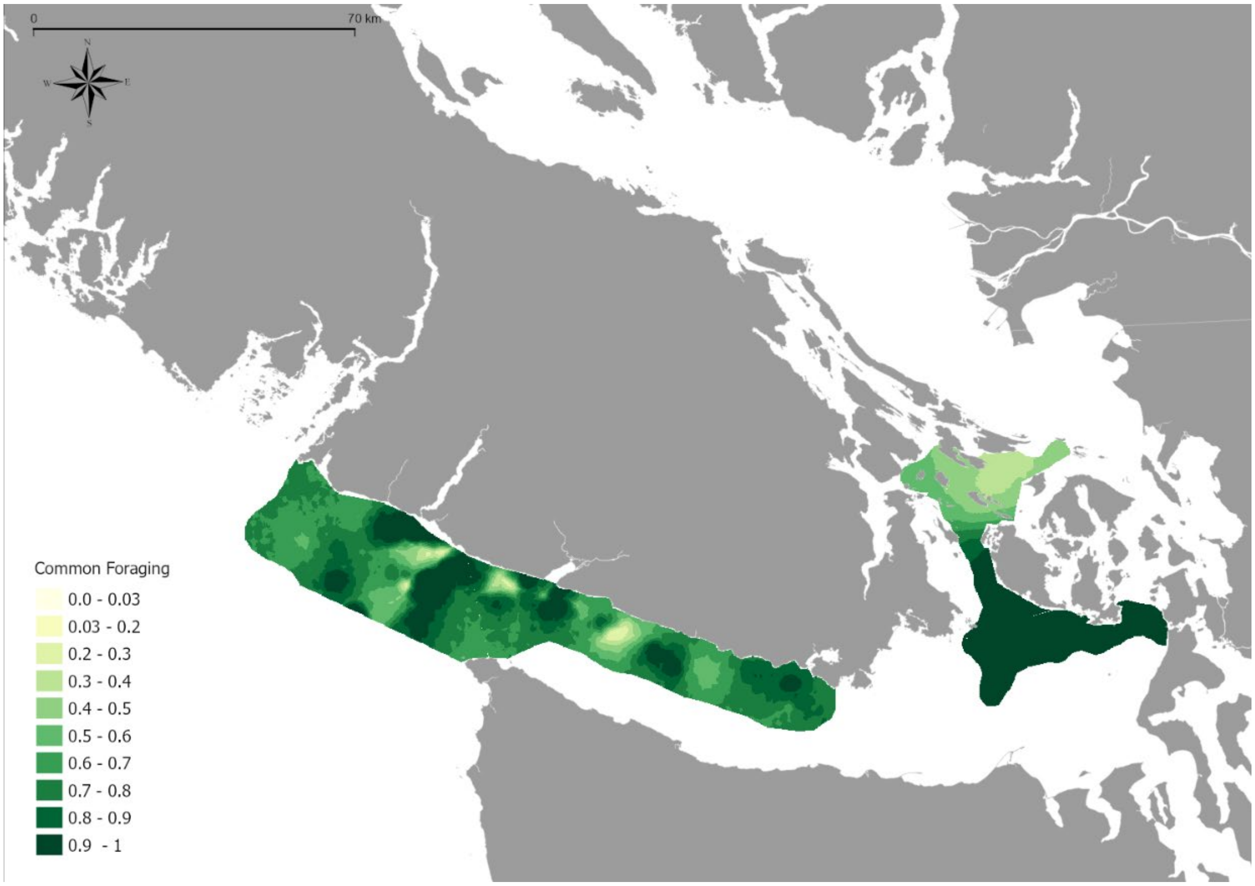

Figure 6. SRKW common foraging areas (CFAs) indicated from visual observations and classification of behaviour (see Stredulinsky et al. 2023). CFAs are predicted by the top-ranked spatiotemporal models for the Swiftsure Bank and Haro Strait regions. The probability of an area being a CFA (0.25 exceedance value) is indicated by the green scale. Areas in white are outside the geographic extent of the model. Adapted from Stredulinsky et al. (2023).

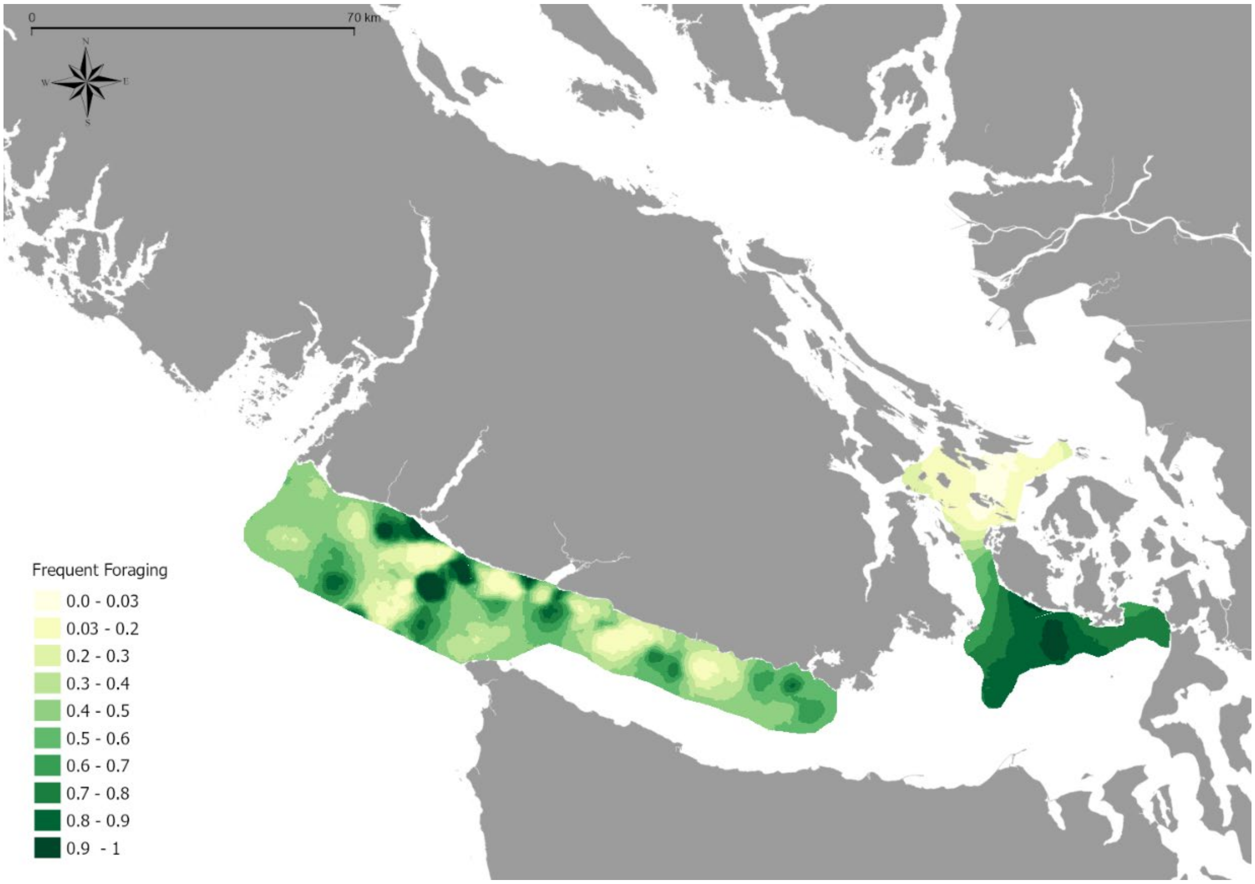

Figure 7. SRKW frequent foraging areas (FFAs) indicated from visual observations and classification of behaviour (see Stredulinsky et al. 2023). FFAs are predicted by the top-ranked spatiotemporal models for the Swiftsure Bank region and the Haro Strait regions. The probability of an area being an FFA (0.5 exceedance value) is indicated by the green scale. Areas in white are outside the geographic extent of the model. Adapted from Stredulinsky et al. (2023).

3.5.2. Passive acoustic monitoring

The use of passive acoustic recordings from the study area were instrumental in a number of aspects of the credit calculations. *In-situ* measures of the soundscape could help form a realistic baseline ambient sound level, from which project-related impacts and changes associated with mitigation measures can be assessed. These recordings could also aid in the understanding of noise sources and the variability in their presence, and therefore their contribution to the overall soundscape in time and space. They could also be used to add to knowledge of species' habitat use, if recordings are analysed for the presence of whale calls. Importantly, these recordings can also be used to validate and refine vessel noise models used to predict sound levels under differing vessel presence and density scenarios.

The choice of deployment locations is important as the recordings become reference points for the offset approach. Therefore, passive acoustic mooring sites should consider the project-activities and the habitat use of the focal species. Hydrophones may be deployed as a network, where each independent unit forms part of the acoustic monitoring of the area of interest, or as part of an array which may allow for localisation of a sound source. To best characterise the soundscape, the placement of recorders should consider the different topographical settings if present (e.g., coastal waters, bays, inlets, open ocean); water properties, especially if there is a significant freshwater input; vessel presence and density, including the type of vessels most frequently present (commercial and/or recreational); and proximity to ports or shipping lanes that might be sites of project-related noise. Understanding the pre-project soundscape, including patterns of natural and anthropogenic noise sources, and their contributions and variability in time and space, can further refine the estimate of project-related noise additions. Although not necessary in the estimation of credits throughout the study area if using a noise propagation model, *in-situ* recordings can be used to form the acoustic baseline to understand project-related impacts and to monitor effectiveness of measures to lessen noise additions. They may also be used to define study site sub-regions, or refinement of weighting factors if sound levels are used as a variable to represent habitat quality, or the focal species is known to use an area as aspects of its soundscape represents a noise requiem or acoustic anti-predation mechanism (e.g., Szabo and Duffus 2008, Burnham and Duffus 2020). If a model is being used, recordings are needed to validate its outputs, and can confirm changes seen in sound levels under different modeled scenarios for corresponding locations, times, conditions, and vessel presence.

For the test case, recordings that have been made at locations throughout the Salish Sea since early 2018 were used. Six moorings were initially deployed, at Swiftsure Bank, Port Renfrew, Jordan River, Sooke, Haro Strait and Boundary Pass, with then a recorder in Swanson Channel deployed in summer 2019, and two recorders in the Strait of Georgia in summer 2020 (Figure 1). The locations of these recorders were selected to represent areas commonly used by SRKW, as well as cover a range of topographic and sound field conditions, water properties and proximity to vessel transit routes (Figure 1). The data were collected using Autonomous Multichannel Acoustic Recorders (AMAR, G4) equipped with GeoSpectrum Technologies M36-100 hydrophones. These were mounted on small, quiet moorings manufactured by Oceanetic Measurement Ltd., which positioned the hydrophones approximately 2 m from the sea floor. Sampling rate was 256 kHz with 24-bit resolution, with data stored on internal SD memory cards as wav files. The recordings were made continuously, with only short breaks in data collection when the moorings were serviced approximately every 3-4 months. Once the data were recovered, custom Python scripts, modified from those used by Merchant et al. (2015), were used to post-process the wav files to generate 1 minute power spectral density in 1-Hz frequency bands using a 1 second Hanning window with 50% overlap and Welch’s averaging.

The soundscape data collected allowed minute-wise sound levels to be examined at frequencies or in frequency ranges of interest. The distribution of sound energy was also considered through power spectral density (PSD) curves. The data were also averaged to form 30-minute measures comparable to the vessel noise model, and examined hourly, daily, monthly, seasonally, and annually for patterns in the soundscape and dominant sound sources for the six longest-running moorings as part of the model validation process (also see Burnham et al. 2021b).

3.5.3. Underwater vessel noise propagation modelling

Underwater vessel noise propagation models are useful to estimate noise levels at any time or location in the study area, including at different depths through the water column, resulting from vessel presence. This can aid in estimating the noise levels that marine mammals may be subject to while diving and engaging in different behaviours, which contrasts to recordings from *in-situ* moorings which are limited to a single depth of recording. The use of models also allows the interpolation between recording locations to create soundscape layers using real or synthetic vessel presence and tracking data. It integrates the acoustic impacts of remote yet recurrent vessel activity that propagates through the area of interest. The use of vessel noise models also allows the examination of changes of sound levels through time, including forming predictions based on future scenarios and proposed projects, as with the test case example, or hindcast to estimate historic or pre-disturbance ambient levels. Scenarios may also include the manipulation of vessel data to understand how effective conservation measures might be before being enacted.

Before applying to the credit calculations confidence in the model outputs should be established. Validation of model outputs, and the ability for them to represent sound levels from *in-situ* recordings for the same location, time, and frequencies has to be tested. The vessel noise model used for the Salish Sea test case was adapted from a Range-dependent Acoustic Model (RAM) developed by Aulanier et al. (2017). The model extent in the Salish Sea (see Figure 1) encompassed both the project-footprint and designated SRKW critical habitat, and captured areas SRKW are known to use. The domain covered waters in the Salish Sea and on Swiftsure Bank up to the 12-nautical mile territorial sea limit offshore and encompassed SRKW CH (Figure 1). This model used the Pade split-stepping method to solve the range-dependent parabolic equation for sound propagation in a cylindrical coordinate system on a vertical plane. The model used a high-resolution grid horizontally, and through the water column. The horizontal direction was divided into 120 vertical planes, equally distributed to achieve a full 360 degrees coverage around each vessel. The model integrated Automatic Identification System (AIS) data and vessel source levels, and theoretical sound propagation properties to estimate received levels throughout the study area. It was applied to a probabilistic framework to understand how sound levels differ under different scenarios. The model estimated the received noise levels (RL) every thirty minutes on a 440 m by 500 m grid at up to 20 depths from 0.5 m to the ocean floor, or a maximum depth of 500 m. Three depths were consistently compared throughout the analysis; 7.5 m to represent a typical upper water column swimming depth of SRKW, but below the typical source depth of commercial vessels; 50 m, a mid-water column water depth where salmonid prey are typically encountered, and 100 m, a maximum repeatable foraging diving depth (Baird et al. 2005, Wright et al. 2017, Tennessen et al. 2019a,b). The use of these depths is also consistent with other studies considering the acoustic impact on SRKW by commercial vessels (see Thornton et al. 2022b, Burnham et al. 2023).

Model outputs aid in the calculation of project-related impacts and offset credits: the predicted change in noise levels as a result of mitigation or offsetting measures, or of various scenarios of increased vessel traffic and associated noise can be quantified relative to a baseline (see Section 3.5).

3.5.3.1. Model inputs

Inputs to the model can be real and/or synthetic data. The sound levels are estimated through the use of data on the number and location of sources, in this case vessels, as well as the inclusion of data on environmental conditions and water properties to refine the propagation pathways. This can include bathymetry; sediment profiles and geoacoustic properties; sound speed profiles from salinity, conductivity and temperature (CTD) data; and frequency-dependent water absorption coefficients.

Inputs for the vessel noise model for the Salish Sea included AIS data to define the presence and movement of vessels in the model domain (Figure 1), and to detail the number of vessels per type that defines the level and frequency of noise emissions at the source (Table 1). Also included were variables to characterize sound speed and propagation pathways (Table 1). The assumptions made for the use of each input, and the relative sensitivity of the model output to each variable is described qualitatively in Table 1; a quantitative sensitivity analysis is ongoing.

Table 1. A list of vessel noise model and extrapolation inputs, the sources of the data, assumptions under which the data was applied and the sensitivity of the model to each of the inputs.

Model Input	Data Input	Source	Assumption	Model sensitivity
Bathymetry	15 s arc, 300 m resolution	Canadian Hydrographic Service, 2020	Interpolated to model grid	Low
Sediment data	Sediment type, on a 300m resolution	Haggarty et al. 2018	Sediment type approximated to different zones	High
Geoacoustic sediment properties	Low frequency (60-500 Hz) propagation of P and S waves	Hamilton 1980, Jensen et al. 2011	Properties tuned to for acoustic observations	High
Water properties	Temperature, salinity, wind data	Live Ocean model, SalishSeaCast model	Interpolated from hydrodynamic model grid to acoustic model grid	Medium
Water column properties	40 vertical layers	McDougall and Barker 2011	Variable layer thickness	Low
Acoustic transmission properties	Acoustic frequency dependent absorption for pH value of 8	Francois and Garrison 1982	Assumes constant pH	Low
Vessel source levels	Derived source levels, considering SOG	Veirs et al. 2016, Simard et al. 2016, MacGillivray and Li 2018	Assumes all vessels of the same type have the same SL	High
Vessel presence	Cleaned Automatic Identification System (AIS) vessel presence data. AIS Class A only	CCG	Assumes all vessels are accounted for	High

3.5.3.1.1. Vessel data

Vessel passage through the Salish Sea was quantified using AIS data collected by Canada Coast Guard terrestrial receivers (Table 1). The AIS data included vessel name, identification number, type, and location every 5-30 seconds. These data were cleaned and binned into 5-minute packages from which the pathway and speed of each vessel was interpolated. Vessels were classified into thirteen types:

1. Bulk carriers,
2. Container ships,
3. Ferries,
4. Fishing vessels,
5. Government/Research,

6. Naval vessels,
7. Passenger vessels,
8. Recreational vessels,
9. Tankers,
10. Tugs,
11. Vehicle carriers,
12. Registered whale watching vessels, and
13. Other, or vessels of unknown type.

The model inputs are only Class A AIS, which commercial vessels are required to carry. Class A transceivers are mandatory in Canada for vessels over 300 tonnes, excluding fishing vessels, and for passenger vessels for more than 12 passengers and exceeding 150 tons. Tow and escort vessels must also carry a Class A receiver. Smaller commercial vessels and recreational vessels are not required to carry Class A receivers, but may carry Class B transceivers by choice. These data were part of the AIS records, but were not used as a model input.

The transit speed of vessels was calculated as speed over ground (SOG) for each 5-minute bin using the distance between GPS locations and elapsed time. The data were cleaned to remove erroneous measures (e.g., SOG exceeding 30 knots or GPS position on land) as a quality control step. Missing data points were interpolated from neighboring time periods and locations, and missing vessel data added from online registries using the unique identification numbers of each vessel (Maritime Mobile Service Identity (MMSI) numbers or International Maritime Organisation (IMO) numbers).

Locational data points were aggregated for each vessel into trips based on data in successive time intervals. Source level (SL) inputs were those reported by MacGillivray and Li (2018), for each vessel type. Vessel travel speeds were accounted for by adjusting these SL using the linear relationship described by Veirs et al. (2016), whereby sound levels were increased by 0.93 dB/knot of increased speed over ground (or +1.8 dB per m/s). In cases where the vessel type was not reported in the AIS record, the source level was estimated using the relationship between ship speed and size characteristics and vessel noise outputs as described by Simard et al. (2016).

3.5.3.1.2. Environmental data

Realistic environmental data based on high resolution bathymetry, sediment composition, and water property data from the SalishSeaCast NEMO model (Sootiens et al. 2016, Sootiens and Allen 2017) were included in the RAM model to simulate quasi-3D (or 2.5D) sound propagation (Table 1). Bathymetric data was obtained from the Canadian Hydrographic Service (CHS 2020) and interpolated to give water depths for the study area with a 15-arc second spacing, or at approximately 300 m resolution (Haugerud 1999, Table 1). Sound speed profiles through the water column were calculated from CTD measures. *In-situ* data were collected at 3-4 monthly intervals, with these profiles complementing the SalishSeaCast CTD data (Sootiens et al. 2016, Sootiens and Allen 2017). These water properties were converted to sound speeds using the Intergovernmental Oceanographic Commission standard TEOS-10 (McDougall and Barker 2011, Table 1). The range dependency of the model was used to parameterize acoustic propagation in relation to bathymetry, profiles of properties through the water column, and the maximum propagation of each sound source. Frequency dependent absorption was accounted for by using the pH value of 8 from Francois and Garrison (1982). Propagation through unconsolidated ocean floor sediment was incorporated using values from Hamilton (1980) and

Jensen et al. (2011), using broad bottom-type classifications, characterising areas of either rock, sand, or silt and mud (Table 1).

3.5.3.2. Model outputs

Model outputs might be fine to coarse in resolution on both spatial and temporal scales. The granularity of the output of the acoustic models, and other modeled or collected data on animal presence and habitat use, defines the finest resolution to which project-effects can be estimated. Working at the finest scale possible removes subjectivity that might be inherent in sub-region definition, and may represent a more receiver- or animal-based assessment of change over the study area. However, the resolution of the outputs may not be biologically relevant to the focal species, and so aggregation to delineate areas based on average prey patch size, areas of density, home range, or travel distances or speeds of the focal species may be more appropriate when interpreting from the scale of the outputs. Also, typically the finer the resolution the more computationally complex and time consuming the model is to both run and interpret, so the output resolution may represent a balance of being ecologically meaningful while also producing results in a timely manner. Also, fine scale outputs may not be needed if the answer desired is the net change in sound levels over the home range of a species, for example. However, if considered on a finer scale, model outputs can highlight times or areas with the greatest noise additions from project-related vessels, or conversely the areas that see the greatest benefit from mitigation or offset measures.

The output sound levels of the Salish Sea vessel noise model were at 125 Hz every 30-minutes, and over a grid of area units approximately 440 m by 500 m at 20 vertical levels through the water column between 0.5 and 500 m. The resolution for the vertical layers in the near-surface waters was 1 m, whereas at the deepest depths it was 24 m. This gave an output of sound levels (SPL) as a function of time, t (30 minute intervals), depth d, and points on a horizontal grid (i,j), with the model output therefore defined as:

$$SPL(125Hz, t, i, j, d).$$

For the test case, the analysis was limited to May to October, as this is when SRKW are most prevalent in the study area, and the most is known about their movements and habitat use. The single median SPL value was derived from model outputs for this entire 6-month period to test the offsetting concept. Finer temporal resolutions were considered possible by participants, for example calculations on a monthly scale, but this would not be in line with the available data on SRKW presence and habitat use. Comparisons at depth were made, with depths selected referencing biologging data for killer whales to represent typical swimming and diving depths. Species relevant frequency ranges were used, extrapolating from the model output at 125 Hz to a communication call range (500 Hz to 15 kHz) and echolocation signals (15-100 kHz) (Burnham et al. 2023).

3.5.3.3. Model validation

Confidence in the model outputs, and its ability to accurately represent the sound levels in an area of interest are established through validation through the comparison to field measurements. Model refinement, to increase agreement between model outputs to *in-situ* measurements, will increase the accuracy in the interpretation of the model parameters. For the vessel noise model used for the test case in the Salish Sea, outputs were compared to SPL recorded at mooring locations. The evaluation between the model and *in-situ* values was therefore done for conditions as similar as possible; comparisons were made for median sound levels at 125 Hz (the model output) for the matching time period, using model outputs at the depth closest to that of the mooring deployment depths for six locations (Figure 8).

The comparison between the modelled data and the mooring recordings was made using a probabilistic framework and expressed as curves showing the disparity between the modelled and *in-situ* sound levels. The vessel noise model consistently under-predicted the SPL at each of the locations analyzed (Figure 8), and more so in enclosed waterways or areas with other acoustic barriers. These lower sound levels can be attributed to several possible reasons. The first is the lack of advanced three-dimensional physics (out-of-plane refraction) in the quasi-3D model being used to simulate the propagation of sound waves in the model domain. Also, although the comparison was made for periods where abiotic sound inputs from wind and wave were minimal, not all remote sound sources of offshore weather, commercial vessel noise (transiting or anchored), or recreational vessel presence were accounted for in the model, but would be captured in the recordings. The model does not yet fully capture all aspects of the soundscape. While the predictions made by the model for each scenario of project-related noise may be accurate, it is hard to know the full implications of future changes on vessel transits on the overall sound field. The comparison also highlighted the difference between sites and how commercial vessel noise impacted them (Figure 8). This may help guide management actions to areas most affected by the changes in vessel presence.

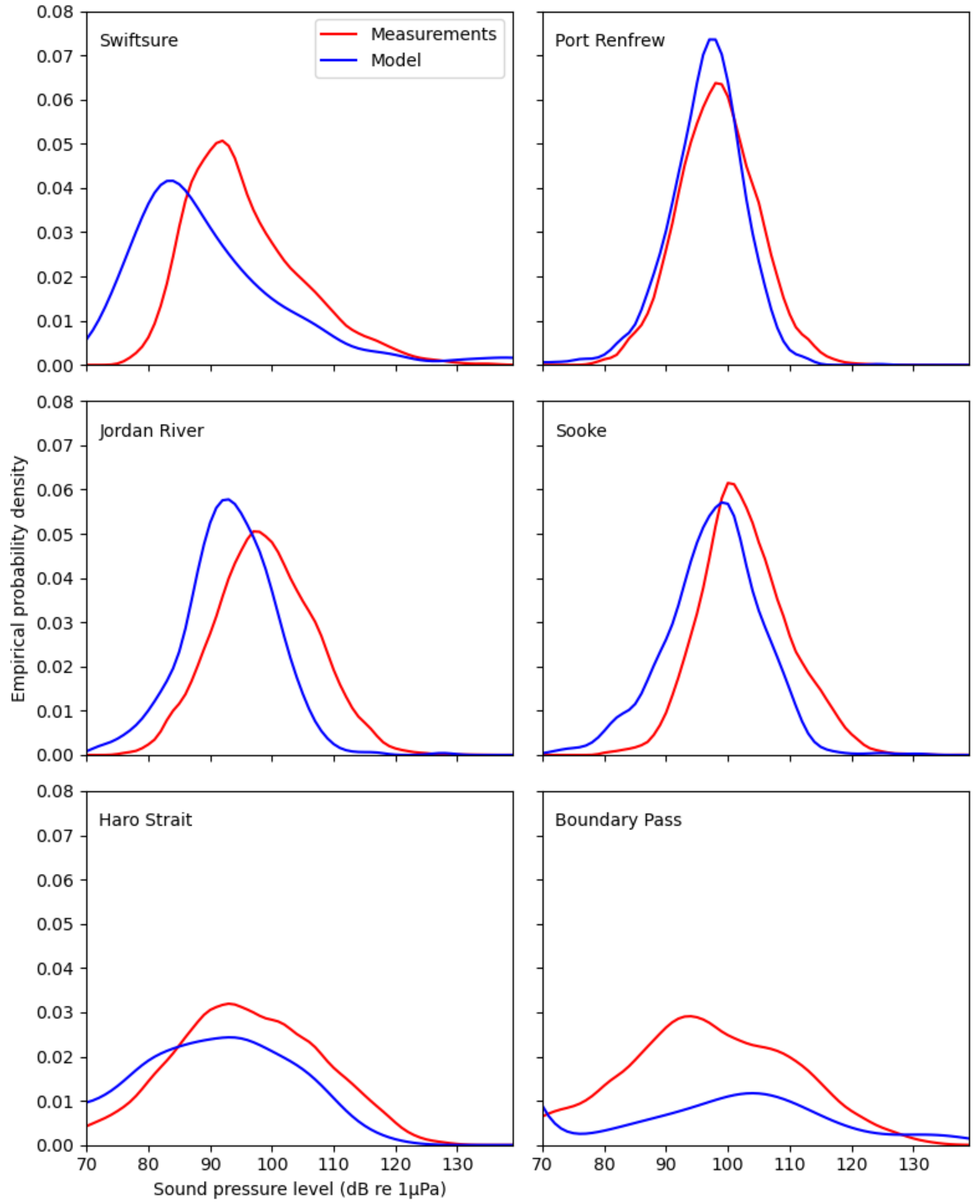

Figure 8. Comparison between the simulated model output (blue) and recorded SPL levels from moorings at Swiftsure Bank, Port Renfrew, Jordan River, Sooke, Haro Strait and Boundary Pass (red) for May 2018, expressed as an empirical probability density.

The disparities between the model outputs and the recordings perhaps highlight the current limitations of the model, the sound sources that are present in the Salish Sea that are not currently represented in the model, and the uncertainties of the sound transmission properties particularly around islands and in inlets and narrow waterways. Refinements of the model will work to address this, but a means to express the accuracy or confidence of the representation of recorded values at each location could be considered in the credit calculations. This could be expressed for each sub-region, or each area unit based on the proximity to the comparison locations.

3.5.3.3.1. *Model Uncertainty*

The greatest source of uncertainty, and the vessel noise model input with the greatest variability, was vessel source levels (SL) (Table 1, Simard et al. 2016). Inputs into the model were average measures made in the Salish Sea and reported in MacGillivray and Li (2018). Sensitivity analyses help determine the influence of each variable on the model outputs, and characterise how uncertainty in each of the input variables could alter outcomes as the outputs are used to calculate credits. Several factors in addition to speed, including vessel loading and draught, also influence the underwater noise emissions from vessels and are not yet accounted for in the model. A sensitivity analysis of vessel source level inputs is ongoing, and it is anticipated that the model inputs will become more refined as better data becomes available.

A better determination of TMX-vessels source levels is ongoing. Source levels of TMX-vessels will be determined using passive acoustic recordings and AIS data following the first sailings in May 2024, and when vessel names/MMSI numbers have been identified. These will then be integrated into the model, to determine the project-specific inputs more accurately. The spatial and temporal resolution of inputs of this model are greater than other proprietary models applied to the region for other similar noise level assessments (e.g., Matthews et al. 2018, Matthews and Groom 2021).

3.6. SPECIES-SPECIFIC SOUNDSCAPE CHANGES

Sounds can be expressed as pressure levels (SPL) measured in decibels (dB), as an exposure metric (SEL), or other means to express the sum change of exposure over acoustic frequency and time (Southall et al. 2007, Finneran 2015). For an exposure estimate the presence and residency of the focal species must be known, whereas SPL can be used without this. Throughout the test case the median sound levels of values from May to October were used. This did not follow the advice from the 2021 Underwater Noise Credit workshop, but is consistent with previous work on the implications of vessel noise on SRKW (see Thornton et al. 2022b, Burnham et al. 2023). Although the arithmetic mean (L_{eq}), suggested as a metric during the 2021 workshop, is a more sensitive measure to extreme sound sources, the median represents the sound levels that whales would more typically be subject to. Consensus was not reached by participants on the favoured metric, although it was stressed that the same measure needs to be used in all calculation consistently; therefore, the median SPL was used in all calculations throughout this specific exercise.

Changes in sound levels are key to the offsetting approach, first calculating the elevation in noise levels anticipated from project-related vessels, and then the changes seen as mitigation or offsetting measures are introduced. By definition, changes in sound level are established through comparison to a reference sound level or baseline. Considering the change from a baseline differs from the use of a predetermined noise threshold or noise exposure criteria for species. These have been described for broad species groups, where exceedance might initiate a stress response, behavioural change, or changes in hearing sensitivity and auditory physiology on either a temporary or permanent basis (e.g., see Southall et al. 2007, 2009, 2021, NMFS 2018). While potentially helpful in understanding the possible impact to an individual or population group, dose-response curves are not linear, with reactions highly context specific (Wright et al. 2023). These thresholds were not considered in this analysis as the offset concept does not attempt to address the mitigation of impacts, only to quantify the change in sound levels, with the assumption that a no-net increase in noise, or reduction in vessel noise would be beneficial for the focal species.

3.6.1. Acoustic frequencies of interest

Determining the acoustic frequency or frequency ranges of interest is critical in calculating the sound levels or metrics used to establish changes in sound levels from baseline. The frequencies and metrics used may be site- or species-specific, but must be consistent throughout all calculations.

Broadband measures capture the full spectrum of *in-situ* recordings or full range of model outputs. However, the definition of broadband may change based on recording equipment capabilities and/or the computational capacities of the modelling process and model refinements. This would be something to consider if it is anticipated that the offsetting approach was to be utilised as a long-term measure. The use of broadband measures is less species-targeted, and so makes no assumptions on the hearing ability or sensitivity ranges for the focal species. It may also be an appropriate singular measure that could be used in a multi-species scenario.

Refining frequency ranges of interest, and examining parts of the soundscape in more detail may help identify the source or sources of change in sound levels, confirming it to be project-related, and also suggest the species (if a multi-species approach is used) and/or behaviours with the potential of being most impacted by the noise input. Such a refinement could use classifications of low-, mid- and high-frequency ranges, or more source-specific frequency ranges described in the literature. For example, frequency ranges that represent emissions from commercial/project vessels could be used. This may be done referencing previous vessel noise studies, or international standards or metrics such as the EU Marine Strategy vessel noise ranges (EU Marine Strategy Framework Directive 2008). Other standardised measures such as decidecade (1/3 octave bands) or millidecade (1/1,000th of a decade) bands might also be examined. These frequency ranges would represent more of a change in the acoustic habitat, and not necessarily be species-specific.

Metrics that are more specific to the focal species might help estimate the potential impact, and represent changes in the soundscape that might be more relevant to the species of interest. The vocal range of the focal species may be used or, if known, the hearing range. These ranges, however, may not fully capture the full extent of noise that might elicit negative reactions, cause disturbance, physiological stress, or other negative implications. Nevertheless, they may help indicate which part of the acoustic repertoire might be most sensitive to effects from project-related noise and be suggestive of the connotations for the focal species.

For the SRKW test case frequency ranges representative of their communication calls and echolocation signals were used. Previous work on potential masking effects used the candidate range of 1-40 kHz for communication calls, parameterised by Holt and colleagues (2009, 2011, 2013) and 50 kHz to represent echolocation (Au et al. 2004, Burnham et al. 2023). However, for offsetting calculations a more conservative approach was taken, using broader frequency ranges to represent the SRKW calling repertoire. Therefore, for communication the range 500 Hz to 15 kHz was used and echolocation signals were described by the range 15-100 kHz, as suggested by Heise et al. (2017). These broader ranges also go some way to addressing the uncertainty in how well the vocal repertoire represents the frequencies that could result in physiological, behavioural, or acoustic calling changes for SRKW, and may better represent the full hearing range described for killer whales (Miller 2002, 2006). An aggregate measure of change, combining the communication and echolocation ranges (500 Hz to 100 kHz) was also considered. This allowed the change over the full SRKW repertoire to be considered without bias to either signal type, with both ranges weighted equally in the calculation.

3.6.1.1. Extrapolation to species-specific frequencies

To be able to take a more species-relevant perspective on the sound level changes caused by the TMX-vessel traffic, and mitigation or offset of these additions, the outputs of the model at 125 Hz were extrapolated to represent the SRKW communication call range (500 Hz to 15 kHz) and echolocation signalling range (15-100 kHz). Sound levels in these ranges were extrapolated using the frequency-dependent source level curve of tankers, reported by MacGillvray and Li (2018, Figure 9). This average monopole source curve was formed from a number of vessels making numerous passages at different speeds over a hydrophone. The curve from tankers was used to be more project-relevant, recognizing variability among vessels exists.

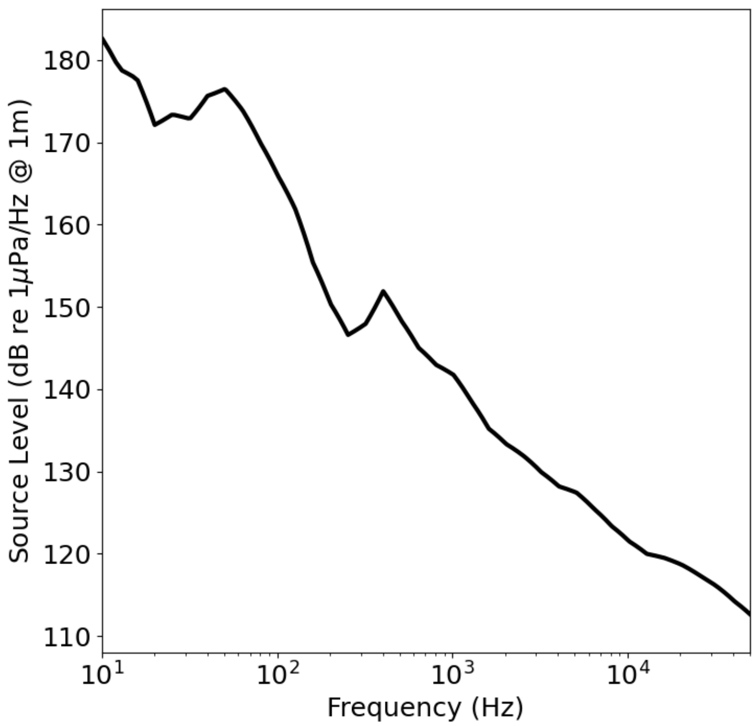

Figure 9. Average monopole source level (SL) of tankers transiting the Salish Sea taken from multiple transits. Adapted from MacGillvray and Li (2018). The curve is used for the interpolation of the model output at 125 Hz to SRKW communication (500 Hz to 15 kHz) and echolocation (15-100 kHz) range.

Using the curve that maps source level by frequency, a correction factor was developed between the model output at 125 Hz and the frequencies in the ranges of interest. The correction factor for each model output was defined as $dSL(125Hz - f)$, where f represents each 1-Hz frequency band within either the communication or echolocation range.

A term was also included into the extrapolation to account for frequency-dependent absorption of the higher frequencies in the water column. This correction factor was expressed as $\alpha(f)$ (dB/m), and was incorporated into the extrapolation, so that the model output became:

$$SPL(f, i, j, d) = SPL(125Hz, i, j, d) - dSL(125Hz - f) - \alpha(f) \cdot R_{SL}(i, j) \quad (1)$$

where $R_{SL}(i, j)$ is the range between each grid point (i, j) and the nearest location in the shipping lane (Figure 10), as it was assumed the noise was primarily emitted from commercial vessels (the model inputs) travelling in the shipping lane (also see Burnham et al. 2023). For higher frequencies, especially those in the echolocation range, the significant frequency-dependent absorption meant that the vessel noise additions were focused in the shipping lanes, with little of the noise from these vessels extending into other areas.

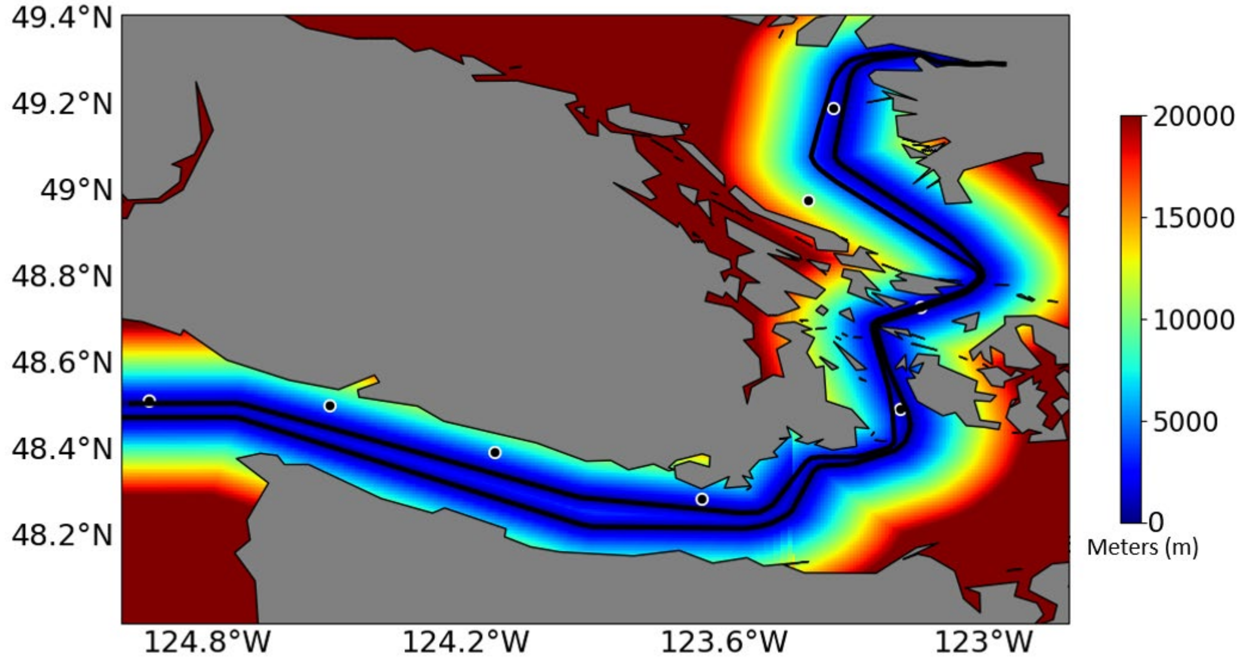

Figure 10. Map showing the ranges to the nearest shipping lane (R_{SL}) at each model grid point, used to calculate range and frequency dependent absorption when extrapolating from 125 Hz to higher frequencies of interest. See Burnham et al. 2023.

Consideration was given to the depth or depths (d) over which to compare model outputs. Discussions at the 2021 workshop suggested that integrating over the top 25 m of the water column would represent the sound levels experienced by SRKW as they transited the Salish Sea, as typical swimming and diving depths while traveling are captured in the upper water column (Wright et al. 2017, Tennessen et al. 2019a,b). However, this would include the sound source depth, would assume equal use of these upper water depths by SRKW, and would not represent deeper diving depths for foraging. Instead, the sound levels at 7.5 m, 50 m and 100 m were determined to represent a typical swimming/traveling depth, the depth where prey is first encountered and the typical Chinook salmon swimming depth (43.4 m; Wright et al. 2017), and a maximum repeatable foraging diving depth of SRKW recorded by bio-logging sensors respectively (Wright et al. 2017, Tennessen et al. 2019a,b). This is consistent with previous work on noise impacts to SRKW in the Salish Sea by Burnham et al. (2023).

Therefore, the calculation for the communication range for every 30-minute model output at each area unit (pixel) in the model domain became:

$$SPL((500-15000), i, j, (7.5, 50, 100)) = SPL((500-15000), i, j, (7.5, 50, 100)) - dSL((500-15000)-f) - \alpha(f) \cdot R_{SL}(i,j) \qquad (2)$$

and the echolocation range:

$$SPL((15000-100000), i, j, (7.5, 50, 100)) = SPL((15000-100000), i, j, (7.5, 50, 100)) - dSL((15000-100000)-f) - \alpha(f) \cdot R_{SL}(i,j) \qquad (3)$$

For this initial consideration of a possible offsetting approach for the SRKW-Salish Sea example, the median SPL values of equations (2) and (3) over the six-month period from May to

October were calculated and used in subsequent steps of the analysis. The median was selected to be a representative measure of the soundscape that SRKW would experience at least 50% of the time. Other metrics may be considered, and useful to evaluate: the mean sound level (L_{eq}) is frequently used, but is sensitive to extreme additions. Changes in the periods of highest (e.g., L_5) or lowest (e.g., L_{95}) or background sound levels may also be worth considering, but the median was used to be precautionary for the test case example.

3.7. DEFINING THE STUDY AREA EXTENT AND SUB-REGIONS

3.7.1. Study area

In DFO's Offsetting Policy, the 'service area' is that which encompasses the project area, and the full area of the conservation or mitigation/offsetting actions and the habitat bank, if that is being used (DFO 2019). The analysis and development of the approach would be defined by the constraints and scale of this area. However, in discussions about the application of the offsetting concept to the impact of project-related vessel noise on at-risk species, the participants strongly felt that this definition was inadequate as it allowed the inclusion of areas with no impacts or offsetting benefits for the focal species. Instead, the meeting participants conveyed that the study area extent should be defined exclusively by the presence of the focal species in time and space, and not by where elevated noise levels related to a project are expected to occur. It was therefore considered that data on the presence of the species of interest was decisive in the developments of the offset approach, and without it, the approach could not be considered. Impact to SRKW, for example, could not be determined without knowing their presence and habitat use, and therefore their exposure in terms of noise level and duration.

In the test case, the definition of the study area for credit exchange was not fully guided by this agreed principle, instead including SRKW critical habitat and areas of possible presence in addition to areas of known use by referencing historic sighting data (Figures 5 and 11, see Section 3.2.1, Thornton et al. 2022a). The area considered for offsetting also encapsulated foraging habitat and areas where SRKW are seen annually (Olson et al. 2018, Thornton et al. 2022a), while being broad enough to capture the changes in movement patterns in recent years (see Hanson et al. 2021, Shields 2023). However, the study area extended beyond where SRKW were predicted to occur when data were aggregated over the 6 months of May to October at the 70% confidence level, as it corresponded to the entire modelled area and thus, included zones where predicted probability of SRKW occurrence was nil (Figure 11). For situations where the offsetting approach is being trialed on a species that is not as data rich as SRKW, or habitat use not as well defined, the extent of the study area may be more extensive than the space that captures direct sightings. This may be precautionary, but such an approach incurs major caveats, which could bias weighting factors (see Section 3.4.2), but may better capture the full extent of a species movements.

3.7.2. Statiotemporal scales

The spatial and temporal scales used in developing the approach define the resolution by which credits are calculated and exchanged, and the granularity by which weighting can be applied. It was suggested that each component of the offsetting approach should be incorporated at the finest resolution that the data would allow. If the offset is observation driven, resolution would be defined by the space and time that data were collected. If the offset calculations rely more on modelled data, the resolution would be defined by the output resolution (data grid/ pixel size) of the model used. However, using the resolution of model outputs may not be as ecologically relevant, or species-based as other means. The test case showed how the resolution of model outputs may be achieved, but also considered the use of sub-regions. These may be used when data is more limited, or available on coarser scales.

Depth dependency of the spatial presence and habitat use of SRKW was not considered by participants during the review of the test case. Initial calculations presented to participants were derived from noise levels determined through the integration of model outputs over 0.5-25 m depth. Following comments made by participants, revised calculations and model outputs from the three SRKW-representative depths were considered (7.5, 50 and 100m respectively) (Baird et al. 2005, Wright et al. 2017, Tennessen et al. 2019a,b). Credit calculation and comparisons of model outputs for scenarios were only made at the same depth (i.e., results from 7.5 m baseline compared to model results for project impact, and management actions at 7.5 m only, not to 50 or 100 m). If the temporal resolution of data allows, the sub-regions could be adjusted through time to be more reflective of habitat use. If known, behaviours at depth could be incorporated into this, but these finer scale appreciations of behaviour exceed the data available for this first test.

3.7.2.1. Sub-regions

Sub-divisions of the study area may be used in the calculation and exchange of credits in the offsetting approach. The test case presented two options of sub-region use. The first draws on the observed or predicted presence and behavioural data of SRKW in the Salish Sea, with regions determined by the level of occurrence of whales, and the occurrence of foraging (detailed in Section 3.2.1 and below). The second means to sub-divide the Salish Sea used known soundscape patterns, and differing ambient sound levels (Figure 14, Burnham et al. 2021b). This means of sub-division may help understand the potential impacts of changes in soundscape to the focal species. Regions of differing bathymetry, or sound transmission properties may represent a different habitat use context or ambient conditions, which may also influence behaviours. These sub-regions, in part, also corresponded to the sub-divisions outlined in the CER recommendations. However, preference was shown throughout the review for the first means of sub-division, driven by species presence data. One criticism in the formation of the sub-regions used in the test case was that the boundaries were not modified to exclude areas of predicted SRKW absence (see below; Figure 11), and that a sensitivity analysis would aid in establishing if the divisions were well placed or if presence and use within each sub-region showed too much variability.

It was concluded that sub-divisions should be based on focal species data, using data indicative of their presence, and ideally recurrence of presence or relative densities. Behavioural context of habitat use could be integrated in this, or be used alone, to identify key locations, for example foraging areas, migratory corridors, or breeding grounds, to the finest resolution possible. To allow for exchange between regions, there should be multiple locales where the same or similar behaviour or habitat use by the focal species occurs. Only if these data are lacking, or spatiotemporally limited, should alternative ways to sub-divide the study area be considered.

Deriving sub-regions by the presence and/or behavioural use of the area by the focal species requires extensive data on their spatiotemporal occurrence in the study area and its context. This can be acquired through systematic surveys (vessel, air, or shore-based), opportunistic sighting reports or data from platforms of opportunity, biologging data, or data from passive acoustic monitoring where the presence of calls outlines the minimal presence of the species, and context perhaps gained from call type. It may also draw on historic data such as previously reported presence or habitat use, including whaling catch records. Data from multiple years should be considered to be able to form an idea of consistent or recurring patterns. Knowing how regions within the study area are used by the focal species aids in determining the equivalency to each other, which helps to set sub-region extent, determine their weighting, and the ability to exchange credits that are like-for-like. Additional criteria that can be used to determine the boundaries of the sub-regions may be the presence of designated critical habitat, data on the movement of the focal species through the area, including travel distance or home ranges, residency patterns, or the context of use or life history event that the area supports. Data that might be indicative of behaviours, such as prey data to represent potential for foraging, might also be considered. A multispecies approach, where the offset is considered for more than one species simultaneously, may sub-divide the study area through common boundaries in species presence or habitat use, or divisions may, for example, aggregate more productive regions into sub-regions. This may be guided by bathymetry, knowing that topographic complexity and underwater or habitat features (e.g., submarine canyons, rocky reefs with kelp beds) can aggregate prey species. Divisions may also be based on a species diversity index, for example.

There are several key aspects that should be considered when defining the sub-regions, as they influence the offsetting calculations. One central aspect is that the application of weighting factors is not mutually exclusive to the formation of sub-regions, and together define the credits available for offset. It was stressed throughout the review of the test case that extreme care should be taken in sub-region definition because of how highly influential this is in the calculation of offset credits and determination of equivalency between regions to allow for credit exchange. Ensuring homogeneity in importance or characteristics within each sub-region is particularly crucial. For instance, if an important habitat feature represents only a small portion of the defined sub-region, or there is a lot of variability in this feature across the sub-region, there will be a dilution effect of habitat value, which may potentially lead to insufficient consideration when used in an offsetting context.

Other considerations in defining the study area and sub-regions may include the ability of a jurisdiction to have an impact in all regions of a study area. The test case is a good example, where the outputs of the model display sound levels in the US and Canada in its outputs, however the GoC does not influence the measures that might be enforced outside of Canadian waters. Although outputs in just Canadian waters may be isolated using the model, not including data from US waters in the modeling would misrepresent the level of traffic present. The model outputs from the vessel noise and habitat use models extended into US waters, and the modeled scenarios assumed that vessels traveling in those waters (i.e., in the inbound shipping lane) followed the measures as described. However, when moving from the theoretical to the actual application of the offset concept, the ability to prescribe conservation actions in other economic or political regions may need to be considered. In the case of SRKW in the Salish Sea, the feasibility and likelihood of measures being matched in both US and Canadian waters should be considered and held in mind when designing measures for offsetting noise impacts, and the different uptake of measures perhaps taken into account in the offsetting calculations.

Although sub-division of the study area may be designed adequately to support exchange of offset credits, some sub-regions may be of too high an ecological value to the focal species to be included in credit exchange. These areas may be a focus for offset measures with the aim of only reducing sound levels, and represent locations in the study area that are unique in their setting or what they provide to the focal species, or areas where critical life stages are undertaken, such as weaning. It may be that as part of the designation of sub-regions ‘quiet areas’ or requiems are outlined, or areas assigned as those that should only experience a noise reduction. These areas may also be those where pre-project conservation measures are in place, for example designated ‘safety zones’, or exclusion or conservation areas that are designed with the species protection in mind.

Sub-regions in the test case were first defined using effort-corrected sighting and focal follow data Figures 5-7, Section 3.2.1). Collation of these datasets and model outputs resulted in eight sub-regions (Figure 11). Boundaries were placed at transitions between areas that showed different levels of presence (Figure 5), and/or that delineated key foraging areas from areas where foraging was not noted, or those outside of the foraging model extent (Figures 6-7). However, boundaries were not adjusted to exclude areas of predicted absence of SRKW, as discussed in the test case review, and thus have likely increased heterogeneity in habitat importance values in some of the sub-regions.

The sub-region definitions were held constant through the six months that the offset approach was considered (May-October), with no adjustment of sub-regions made through time for this example application to represent whale movement. This may be reconsidered, however, in the case that the offsetting for SRKW in the Salish Sea was extended to also cover the winter period to better reflect changes in densities, number of whales and their spatial movements for that period, or is adjusted so that calculations are made on finer temporal scales.

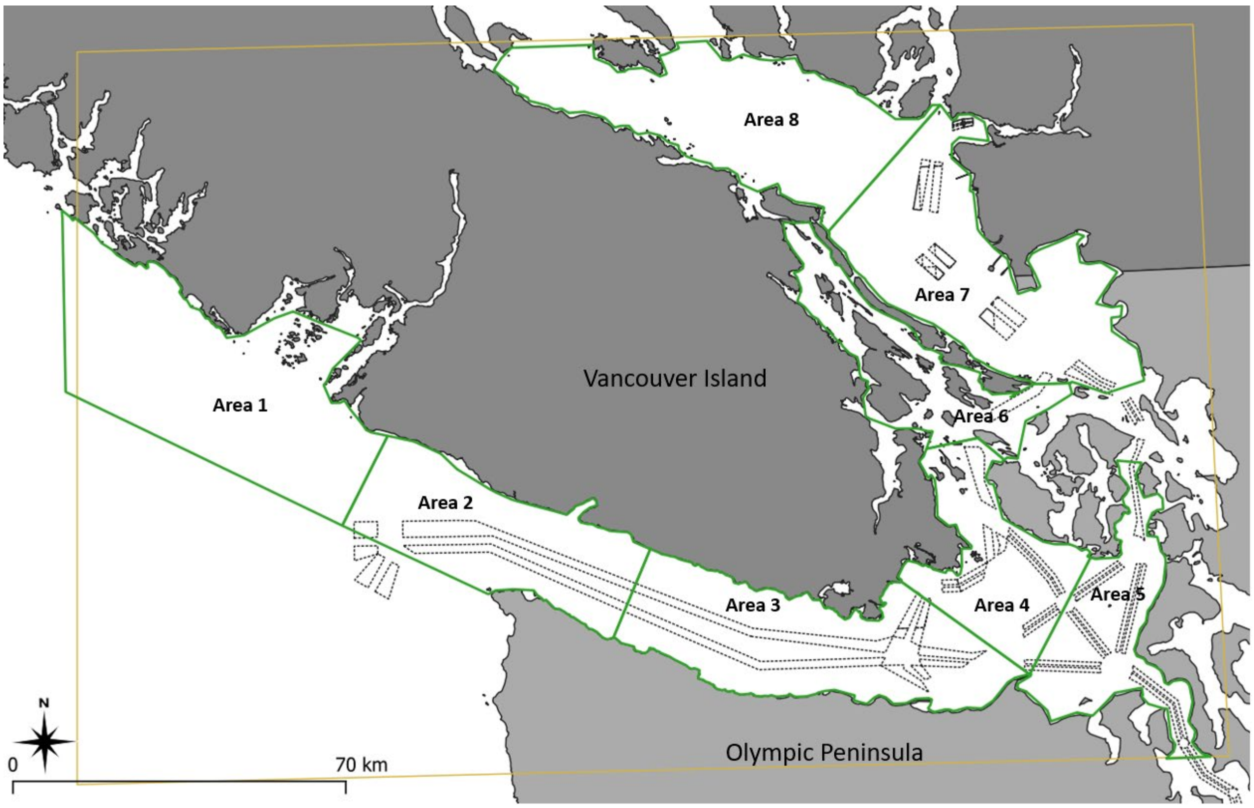

Figure 11. The eight defined behavioural sub-regions, outlined in green. Area 1: La Perouse, Area 2: Swiftsure Bank, Area 3: Juan de Fuca Strait, Area 4: Haro Strait, Area 5: Admiralty Inlet, Area 6: the Gulf Islands, Area 7: South Strait of Georgia, Area 8: North Strait of Georgia. The yellow rectangle represents the full study area, from which Automatic Identification System (AIS) data were examined. Area 1 distance from shore limit is 12 nm. The shipping lanes are indicated by dashed lines.

Behavioural sub-region descriptions by area:

Area 1: La Perouse Bank

This area exhibited a moderate frequency of occurrence of SRKW in summer months in the eastern extent.

Area 2: Swiftsure Bank

This area encapsulated the habitat use of Swiftsure Bank and adjacent waters, and emphasizes the importance of this area as a key foraging location for SRKW. The sub-division between this area and Area 1 aligns with the distinction of the frequency of foraging behaviours observed near Swiftsure Bank compared to La Perouse Bank and areas to the north (Stredulinsky et al. 2023).

Area 3: Juan de Fuca Strait

In this area visual and acoustic data indicate that SRKW travel parallel to the shore, and exhibit reduced foraging behaviours in comparison to adjacent areas (Thornton et al. 2022a).

Area 4: Haro Strait

This area captures the higher relative occurrence of SRKW in the vicinity of Victoria, BC and throughout Haro Strait. It also encompasses the areas of common and frequent foraging on the southern and western side of San Juan Island, including Salmon Bank (see Figure 1).

Area 5: Admiralty Inlet

Except for a portion of Rosario Strait to the north, this area exhibits low SRKW frequency of occurrence, and has not been identified as a significant foraging area for the months of May to October.

Area 6: Gulf Islands

Within this sub-region, SRKW occur more frequently in the southern Gulf Islands and Boundary Pass than in the northern waters. No foraging areas are indicated by the current model (Stredulinsky et al. 2023), but historic data indicate that the western side of Pender Island and the waters near Saturna Island support SRKW foraging behaviour (Heimlich-Boran 1988, Hoelzel 1993).

Area 7: South Strait of Georgia

This area covers areas of elevated SRKW occurrence associated with the Fraser River. No foraging areas are indicated, as this area falls outside the behavioural study boundary (Stredulinsky et al. 2023).

Area 8: North Strait of Georgia

For the months of May to October, the frequency of occurrence of SRKW in these waters is low. This area also falls outside the behavioural study boundary.

An alternative approach, where the study area was divided based on the soundscape characteristics of the Salish Sea, was also considered for comparison to the behavioural sub-regions. If *in-situ* soundscape recordings are not available, then modelled surfaces or proxies could be used, drawing on AIS or vessel density data or the mapping of the position or proximity of anthropogenic sound sources. This mechanism of study area division draws on aspects of the environment, is less species-centric, but may be useful for situations when species data is not extensive, or the divisions are trying to account for more than one species. Alternative data sources for a more environmentally-derived sub-division approach may be bathymetry, water depth, sediment composition or other charted features that may be influential to the way the focal species uses the area.

In the test case, the approach to divide the study area using soundscape characteristics used passive acoustic data described in Section 3.2.2. Sound levels in frequency ranges that represented aspects of different inputs were considered, including vessel metrics (63-Hz and 125-Hz 1/3 octave bands, 100 Hz to 1,000 Hz), wind noise (a 1-kHz band centered around 8 kHz), rain and smaller vessel noise (1-kHz band centered around 20 kHz), as well as broadband (10 Hz to 100 kHz) sound levels. To make reference to SRKW, sound levels in their communication (500 Hz-15 kHz) and echolocation (15-100 kHz, Heise et al. 2017) band were also included in the analysis. Several aspects of the soundscape were considered when setting the sub-region boundaries, including spatiotemporal patterns in noise levels, baseline ambient levels, the dominant sources of noise in time and space, and the patterns of sound transmission properties (Burnham et al. 2021b).

Sound levels were considered on a minute-wise resolution, examining the distribution of sound energy through the broadband range through power spectral density (PSD) curves. Background ambient noise levels at each location were considered using the L_{99} exceedance level. This was considered to have minimal to no wind, wave or vessel additions. This highlighted similarities between locations, particularly those in the Strait of Juan de Fuca (Port Renfrew and Jordan River) and Haro Strait and Boundary Pass (Figure 12, taken from Vagle et al. 2021).

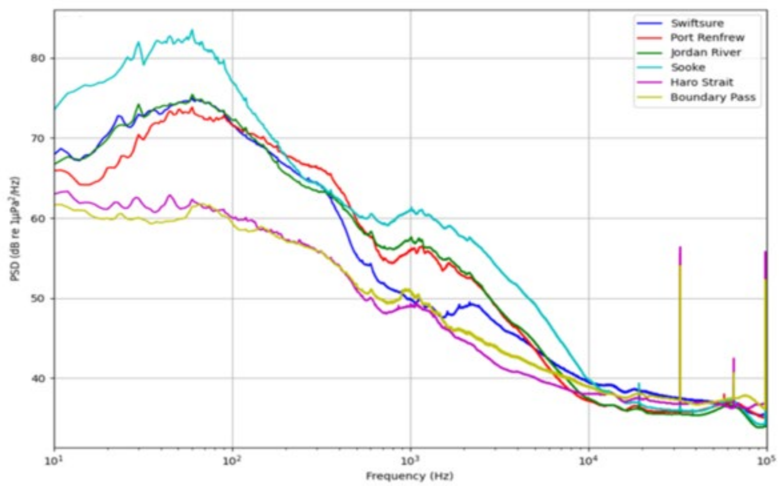

Figure 12. The L_{99} exceedance levels for ambient noise levels of each site aggregated over May to September for 2018-2020. Taken from Vagle et al. (2021).

Empirical probability curves were also considered to describe the distribution of noise in the broadband range and the vessel metrics of 63-Hz and 125-Hz 1/3 octave bands, with indications of the upper (L_5) and lower (L_{95}) and median (L_{50}) noise levels. These vessel metrics represent the commercial vessel component of the soundscape. The L_5 exceedance level represents acute additions only present 5% of the recording time, and L_{95} represents the ambient noise level. Again, clustering in the distributions was seen when comparing mooring sites, similar to those from the PSD curves (Figure 13, taken from Burnham et al. 2021b).

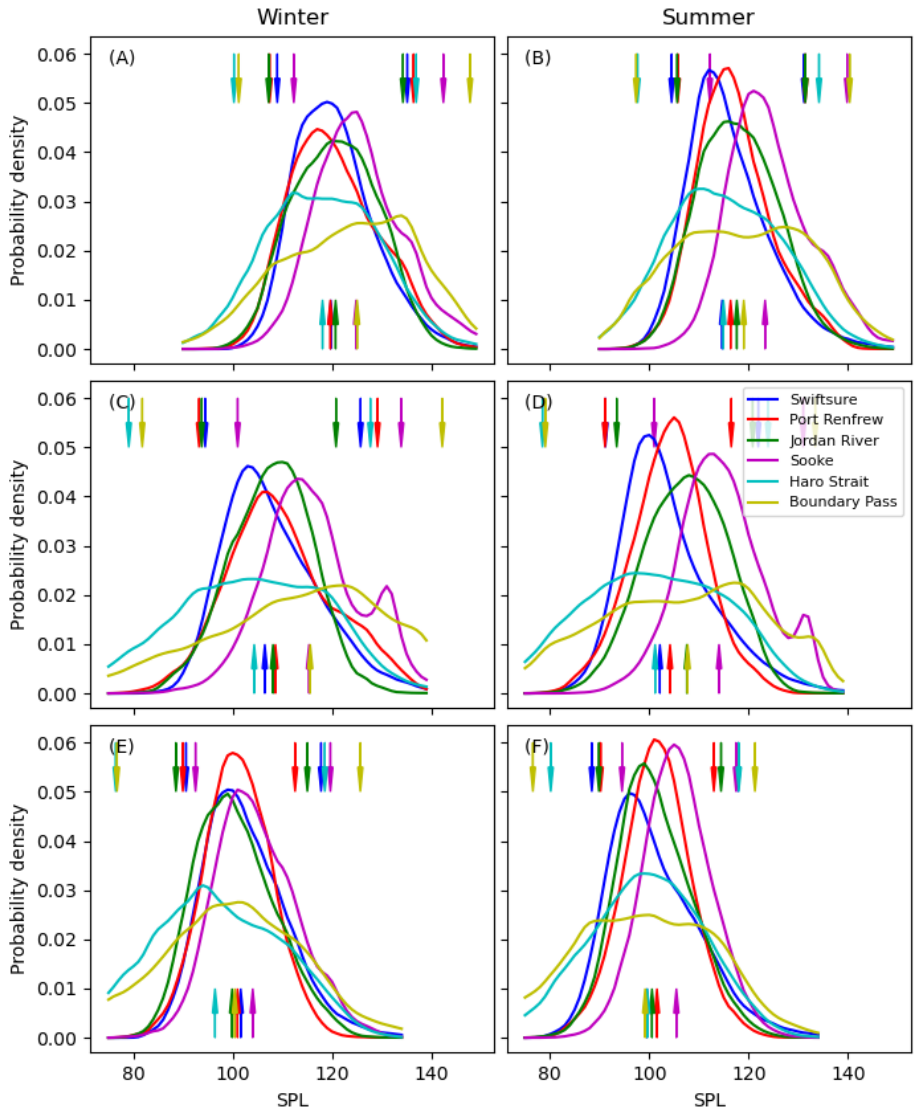

Figure 13. Empirical probability densities of noise levels in 10-100,000 Hz band (A,B), the 63-Hz 1/3 octave band (C,D) and the 125-Hz 1/3 octave band (E,F) for the winter and summer periods in 2019. Downward arrows are L_{95} and L_5 and upward arrows are the corresponding L_{50} levels. Taken from Burnham et al. (2021b).

The soundscape analysis resulted in six sub-regions being defined for the Salish Sea (Figure 14). The areas aggregated the moorings with similarities in their recordings, drawing on patterns in both natural and anthropogenic noise in the soundscape.

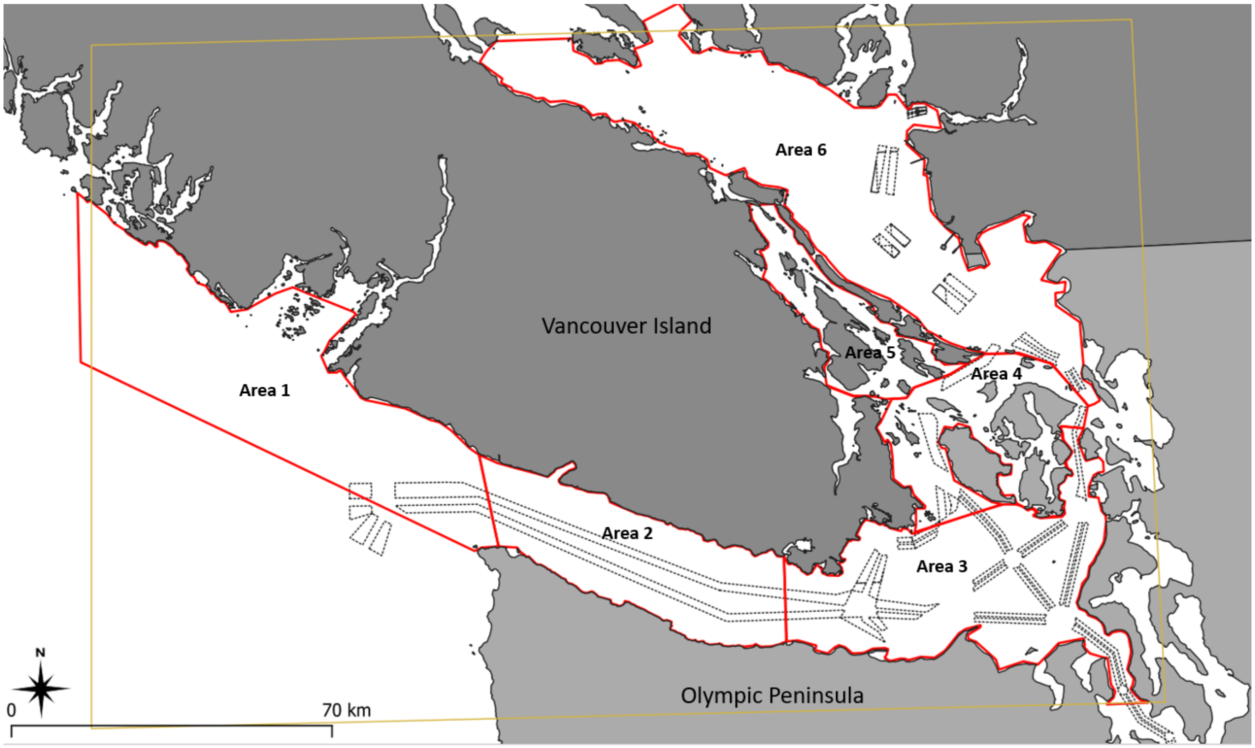

Figure 14. The six defined ambient soundscape areas, indicated by red outlines. Area 1: Swiftsure Bank, Area 2: Juan de Fuca Strait west, Area 3: Juan de Fuca Strait east, Area 4: Haro Strait-Boundary Pass, Area 5: the Gulf Islands, Area 6: Strait of Georgia. The yellow rectangle represents the full study area, from which Automatic Identification System (AIS) data were examined. Area 1 distance from shore limit is 12 nm. The shipping lanes are indicated by dashed lines.

Soundscape sub-region descriptions by area:

Area 1: Swiftsure Bank

Swiftsure Bank sound levels are consistently elevated compared to other areas; it is a site of mixing and water movement, and is subject to both local and more distant/offshore wind and wave effects, as well as commercial traffic.

Area 2: Juan de Fuca West

The soundscape in this area is influenced in the low frequencies by shipping lanes, and the presence of small vessel traffic especially in the summer. Ocean swell from the mouth of Juan de Fuca Strait can influence the soundscape as far as Jordan River, but dissipates eastward from there.

Area 3: Juan de Fuca East

The recordings made by the Sooke mooring characterized this area (see Figures 1, 12-14). The PSD analysis showed peaks in both the lower- and higher- frequencies that were not present in other neighbouring moorings (Figures 12-13, Vagle et al. 2021). A localized wind effect seen from the SalishSeaCast model in the summer months also makes the sound field in this area distinct. The soundscape here represents an amalgam of outer and inner Strait meteorological and oceanographic conditions and vessel presence (Burnham et al. 2021b).

Area 4: Boundary Pass-Haro Strait

Vessel noise was acute and intermittent in this area, with additions made to otherwise relatively quiet soundscapes in the absence of vessels. This area showed the lowest baseline soundscape conditions in the Salish Sea due to the waterways being more protected. (Figure 12, Vagle et al. 2021).

Area 5: Gulf Islands

This area was determined from recordings from Swanson Channel and East Point on Saturna Island. The presence of smaller, recreational vessels was elevated particularly during the summer. Ferry traffic was consistent, and increased in summer, and deep-sea passages occur in shipping lanes.

Area 6: Strait of Georgia

Wind and wave noise additions are consistent through this area. Vessel traffic, including frequent ferry transits also characterizes the sound fields in this area.

3.7.2.2. Model raster-based division

If the resolution of data are sufficient, the concept of sub-regions can be disregarded, and a finer resolution of study area sub-division could be used. This would be most easily applied when model outputs are used in the calculation of credits. In this case the sub-divisions, or sub-regions, would be at the scale of the model outputs. If multiple model outputs are being used together, as they were for the test case, the finest resolution that reconciled the outputs of each of the models would be used. For the test case the area units on which calculations could be based would be a reconciling between the acoustic model and the species presence and/or foraging model outputs as a grid covering the entire study area. This resolution would be carried through to each step of the calculations, being used for the calculation of both the change in sound levels and application of weighting factors. This would then create a pixel-by-pixel analysis, whereby credit calculation and exchange would be theoretically possible between each of the grid squares. This was not shown as part of the test case review, but was suggested for future refinements of the offsetting approach.

3.8. DEFINING AN ACOUSTIC BASELINE

An acoustic baseline is needed to assess the impact of project-related vessels, and the success of management or offset actions. It sets the reference point from which to calculate credit based on project-related effects or noise reductions due to measures being implemented, with the overall target of no-net increase in noise levels. An acoustic baseline could be calculated from recordings or modeled from real data inputs.

Consensus was not reached with regards to the proposed choice of baseline year for the test case. There was agreement that the baseline should be a period prior to project-related operations, and pre-date any project-related inputs to the soundscape. There was also agreement that the baseline should be a time that precedes the implementation of any project-specific mitigation or offsetting measures. This was thought to be consistent with the guidelines in DFOs Offsetting Policy (DFO 2019) and the principle of additionality (IUCN 2016). Any management measures that are in place in the study area prior to, and not directly related to, project activities should be considered part of the baseline, and any measures intended to address project-related noise be in addition to these. This is to ensure that the baseline is a realistic representation of pre-project sound levels in the study area, and that offsetting measures go beyond any changes the existing actions make.

In the initial work presented to participants, AIS data from 2015 was input into the vessel noise model to form an acoustic baseline. No *in-situ* recordings were available for this period and so the baseline was formed solely from model outputs. Baseline median sound levels were considered for the SRKW communication call and echolocation signal frequency ranges at depths of 7.5, 50, and 100 m for May to October using AIS data from 2015 (Figure 15-16). This reference pre-dates the CER board consideration of the TMX project, and the recommendations made by the board. It is following the CER decision that the GoC increased the efforts and investments into mitigation actions. The use of 2015 as a baseline is in line with the GoC position of their advancing measures to form regional actions to address threats to SRKW and incremental noise increases in the Salish Sea through programs such as the Ocean Protection Plan and Whales Initiative (see Canada Gazette 2019). This includes investment into actions such as the voluntary measures overseen by the ECHO program and those regulated by Transport Canada (TC).

Some participants felt, however, that a baseline closer in time to vessels sailing would be more appropriate. A later baseline, proposed to be a year after 2018, would address concerns of participants of a baseline formed solely from modelled outputs, without the ability to verify through comparison to field recordings. Outputs for a baseline using data following 2018 could be verified by empirical data from at least six locations through the Salish Sea. Data from 2022 was suggested during the review, as this would be representative to the seasonal measures in place by ECHO and GoC for the years directly preceding the initiation of TMX project-vessel transits that began in May 2024. These measures would need to be accounted for in the baseline as existing actions in place that could impact sound levels. The divergent views were acknowledged, however in the test case presented 2015 remained the baseline year. This was used to form a conceptual reference point from which the offsetting approach was applied and credit calculations trialed. It demonstrated how the project-related impacts and management and offsetting measures could be estimated theoretically (Figure 15-16), where *in-situ* data might be lacking.

The AIS data showed approximately 300 more AIS-equipped commercial vessel transits in 2022 compared to 2015 (<1 vessel per day extra). This increase is unlikely to have altered the acoustic 2015 baseline substantially, especially when derived from minimum ambient levels. The possible change in the soundscape from non-AIS vessels was, however, not considered. Some consideration was also given to whether the baseline should be more dynamic in nature than that presented in the test case with the reference year being reconsidered and potentially updated on each iteration of the offset calculations. This could be, for example, annually or seasonally. Any update would be based on evidence from *in-situ* recordings and/or modeled results (see Figure 4). If relying solely on model outputs, the baseline could be updated through input variables and/or the use of a correction factor or estimated growth projections for commercial vessel presence. Moreover, the revised baseline could take into account changes in the number and composition of vessels present and/or the environmental conditions and the changes in sound speed profiles that this might precipitate. This would go some way to address changes in vessel presence predicted for the Salish Sea, outside of the TMX additions, and the need to address climate change raised by some participants. The integration and schedule of refinements to the proposed offsetting framework (see Figure 4) was not discussed specifically, only to agree that inputs should be updated as more data becomes available. The inclusion of aspects relating to changes in vessel presence and/or habitat use and sound speed profiles resulting from climate change were mentioned as one example of this, however how these variables would be included, and if it would make the credit calculations more scientifically robust was not ascertained.

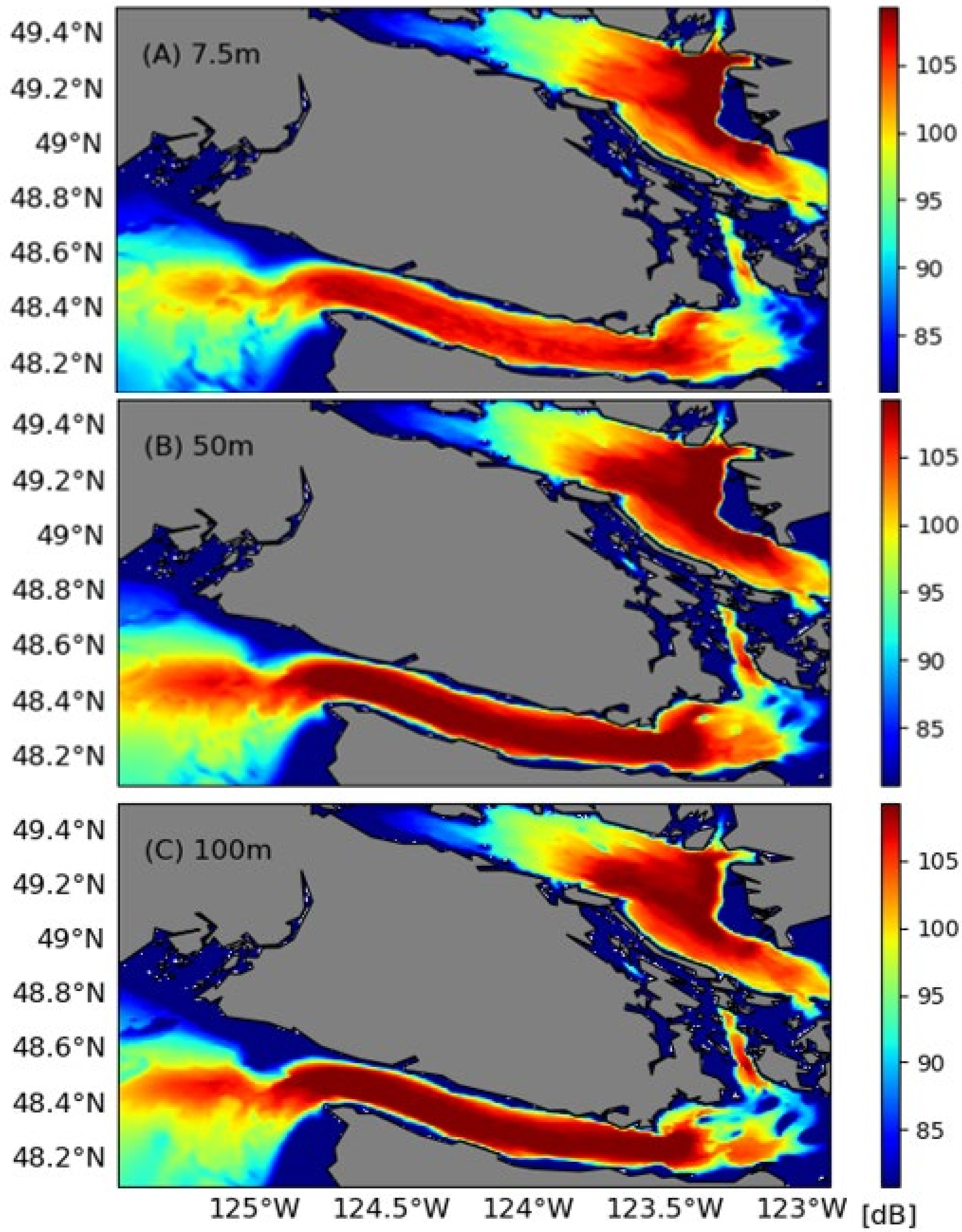

Figure 15. Modelled median noise levels in the SRKW communication calling range (500 Hz to 15 kHz) using Automatic Identification System (AIS) data from May-October 2015 at (A) 7.5 m, (B) 50 m, and (C) 100 m.

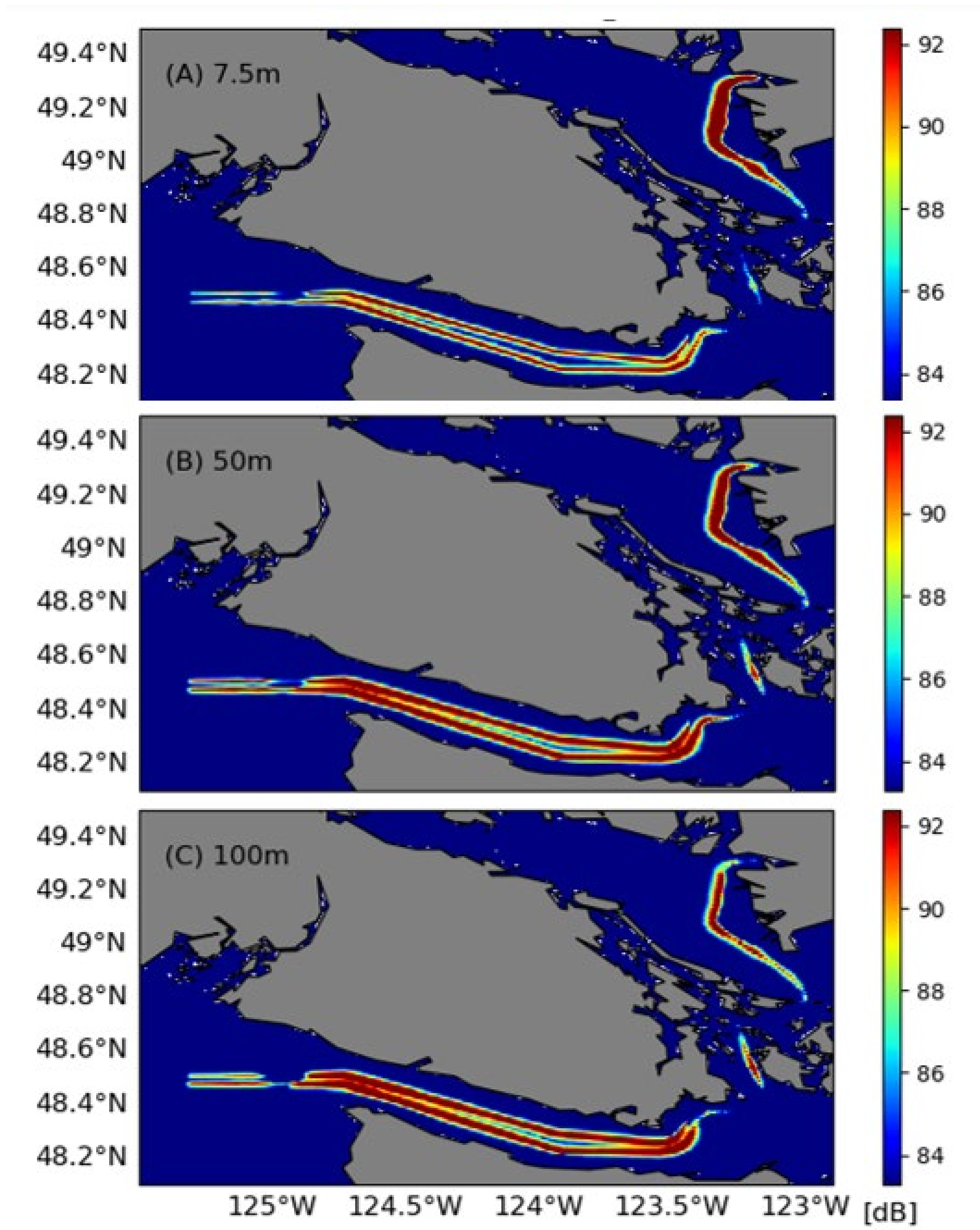

Figure 16. Modelled median noise levels in the SRKW echolocation signal range (15-100 kHz) using Automatic Identification System (AIS) data from May-October 2015 at (A) 7.5 m, (B) 50 m, and (C) 100 m.

The concept of habitat banking was raised during the review of the test case material. It was introduced as part of the discussions of the most appropriate baseline, and how to account for pre-existing measures in the study area that may not be specifically targeted to the project that is being offset. According to the '*Interim policy for establishing fish habitat banks to support the administration of the Fisheries Act and the Species at Risk Act'*, fish habitat banking is a formalized approach for a proponent to create offset measures (i.e., conservation projects) for their own future use in advance of applying for a Fisheries Act authorization (DFO 2021). 'Habitat credits' are accrued that could be put towards offsetting by conservation actions that are in place prior to the project and/or are mitigations that are not project specific. If habitat credits are accrued in this way, credits may become part of a ‘habitat bank’, although this has not been described for use following positive acoustic habitat actions. The habitat bank and credit system should be formally established and be voluntary on both sides, preventing one entity from ‘using’ credits from a habitat bank built up by another entity, without their consent and/or payment (DFO 2021).

Reductions in ambient soundscape levels have been noted as a result of the measures currently in place seasonally in the Salish Sea, quantified by comparing sound levels in July to October during trial periods to control periods (see Vagle and Neves 2019, Vagle 2020, Burnham et al. 2021a, Burnham and Vagle 2023a). As such, the reductions in sound level could contribute to habitat credits to be used in the TMX-offsetting. These credits must be established with sufficient proximity and equivalency to the habitat areas being impacted for exchange to occur, with agreement also needed on the value of each ‘habitat credit’, its unit of measure and rate of exchange.

In the test case example, the voluntary vessel speed reductions enabled under the ECHO program since 2017 may be considered to form a habitat bank. The pivotal point in the discussions of the applicability of this was establishing the of intent of the Vancouver Fraser Port Authority and their partners at the time the ECHO project was conceptualized, to determine whether or not the principle common to biodiversity offsetting, which is to provide new conservation benefits that would not otherwise have occurred, was actually met. Some felt that the vessel speed reductions put in place under the ECHO program were not intended specifically to offset noise from TMX, whereas other disagreed. Therefore, the concept of habitat banks was not furthered for the test case, and dismissed by many participants despite it being one means to account for existing measures in place if a later (post 2018) baseline was furthered in the offsetting calculations.

3.8.1. Minimum ambient

Ambient soundscape levels are influenced by both abiotic and anthropogenic sounds sources. To better understand the additions from project-related vessels, without external soundscape contributions, the additions were estimated in reference to an ‘ideal’ baseline, using minimum ambient sound levels. Under minimum ambient conditions, it is assumed that acoustic disturbance and masking effects for marine species are absent as the soundscape is void of noise from vessels, or wind and waves, and the range over which communication and echolocation can occur is at its maximum (see Burnham et al. 2023). Therefore, calculating the additions from this level represent the greatest change in sound levels predicted and is a precautionary approach to estimating the effect of TMX vessels.

For the test case, the minimum ambient level was derived from recordings made in the Salish Sea from the six longest running moorings (Swiftsure Bank, Port Renfrew, Jordan River, Sooke, Haro Strait, and Boundary Pass, Figure 1). Sound levels at the L_{99} exceedance level for May to October for 2018-2020 were considered (Figures 12, 17). This exceedance level was thought to represent the background ambient noise level when Beaufort Sea State was zero, without wind or wave noise. Sites that might be influenced by offshore wind and remote shipping (Swiftsure Bank and Port Renfrew) were excluded from the definition of minimum ambient. Summer values were used as environmental influence on ambient noise levels is at its least at this time (Burnham et al. 2021b), and the use of acoustic data from May to October is consistent with the time period used for other analyses conducted as part of the offset evaluation. Haro Strait and Boundary Pass were the quietest sites when not influenced by the acute input of direct vessel passages; an aggregate of the L_{99} exceedance levels at these sites was therefore used to form the minimum ambient (Figure 20). The differences between values at each of the mooring locations in the frequencies used for communication and echolocation ranges were minimal (Figure 17), and so the minimum ambient values were applied globally, across the study area without refinement.

The modelled noise field in this analysis, NL', can therefore be described as:

$$NL'(f,i,j,d) = NL(f,i,j,d) \qquad for\ NL(f,i,j,d) \geq NL_0(f) \qquad (4)$$

$$NL'(f,i,j,d) = NL_0(f) \qquad for\ NL(f,i,j,d) \leq NL_0(f) \qquad (5)$$

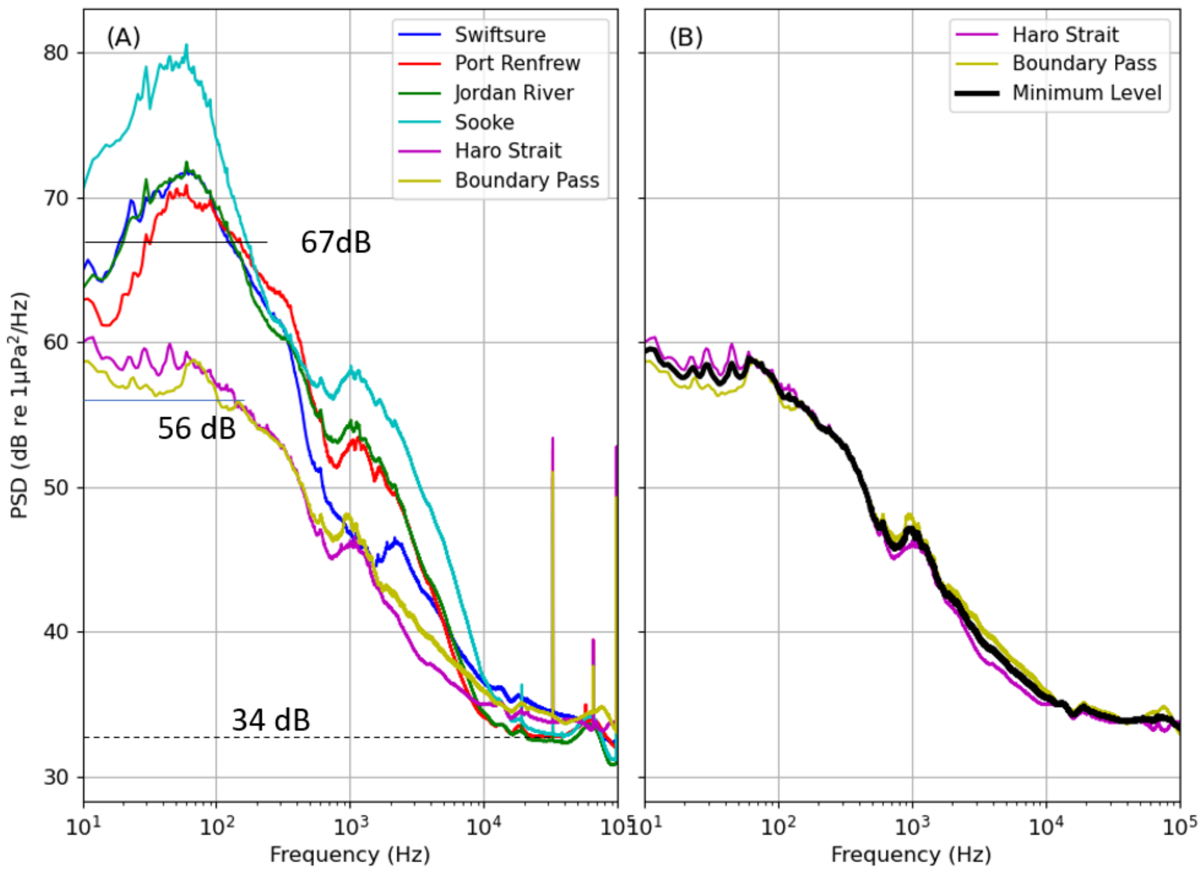

Figure 17. Power Spectral Density (PSD) curve for L_{99} exceedance levels for six of the mooring locations aggregating data from May-October 2018-2020. The minimum ambient sound level (black line) was formed from averaging Haro Strait and Boundary Pass. Dashed line represents the level derived for the echolocation candidate frequency of 50 kHz (34 dB).

The baseline, and minimum ambient level, can be applied to the whole study area, as they were for the test case, or more localised or area-specific values could be used. These areas may be equivalent to the defined sub-regions, or may be an aggregation of several sub-regions into zones. The application of a more regional approach would be based on observed or estimated similarities in sound levels and transmission properties of regions, and distinctions between areas.

3.9. CALCULATING CHANGE FROM BASELINE

All changes in sound levels were expressed relative to the 2015 pre-project baseline for this conceptual example of the proposed offsetting framework. The changes in the soundscape were characterised using the median sound levels in the SRKW communication and echolocation ranges, as well as an aggregate metric that encompassed their full repertoire range (0.5-100 kHz). Impact regions were defined using changes from minimum ambient values from baseline, where wind and other vessel additions were at their lowest. Synthetic data were created to represent scenarios of TMX vessel presence (baseline + TMX tankers and tugs) and the proposed offset management vessel slowdown measure (baseline – 100% slowdown of full transit).

3.9.1. Noise additions from project-related vessels

The vessel noise model estimated noise levels for the expected increase in tanker traffic to and from Vancouver as a result of the TMX project. Prior to project-related traffic increases being fully realised, the tanker traffic related to TMX operations transited the route from Vancouver to La Perouse Bank roughly once a week. When the new pipeline is operational, this will increase to approximately 1 tanker per day leaving the Burrard Inlet loading site and transiting the study area. This 7-fold increase scenario was simulated by creating an adapted synthetic AIS record from data from 2015 as the baseline year (Figure 18-19, Table 2). The timing of these transits was randomised as specific scheduling of the vessels is unknown.

Tankers with a summer deadweight tonnage (SDT) of 40,000 tonnes or more, and carrying liquids in excess of 6,000 tonnes through Haro Strait and Boundary Pass require escort tugs. For outbound transits the escort begins about 2 nautical miles north of East Point on Saturna Island to approximately Race Rocks. These necessary escorts were part of the simulated data created for the TMX-vessel scenario. The total noise level, including the TMX vessels in addition to baseline (Figures 18-19) and the location of vessel noise additions (Figures 20-21) were estimated in SRKW communication and echolocation ranges.

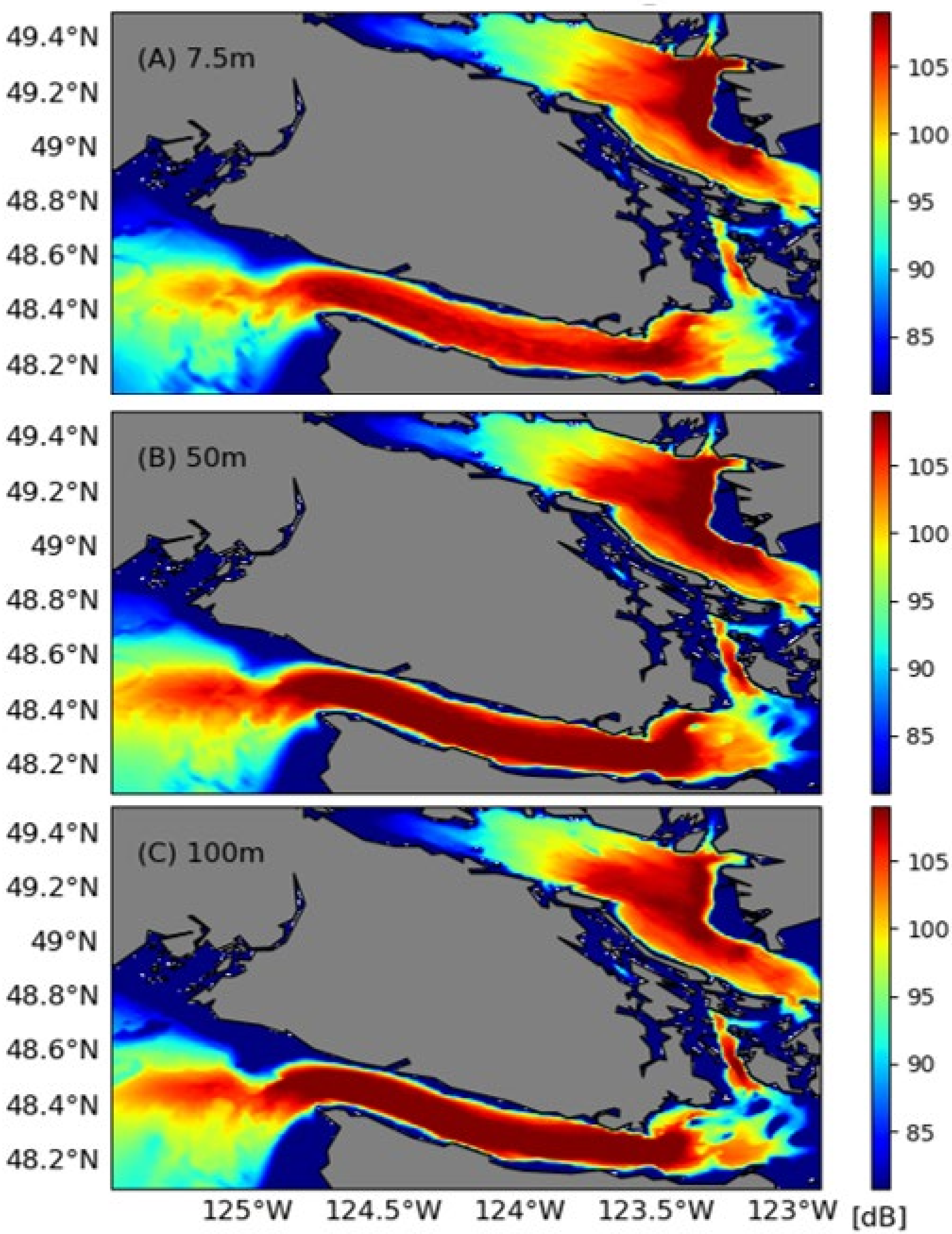

Figure 18. Modelled median noise levels (in dB) in the SRKW communication calling range (500 Hz to 15 kHz) using synthetic Automatic Identification System (AIS) data from May-October 2015 adjusted to include predicted TMX tanker and tug transits at (A) 7.5 m, (B) 50 m, and (C) 100 m.

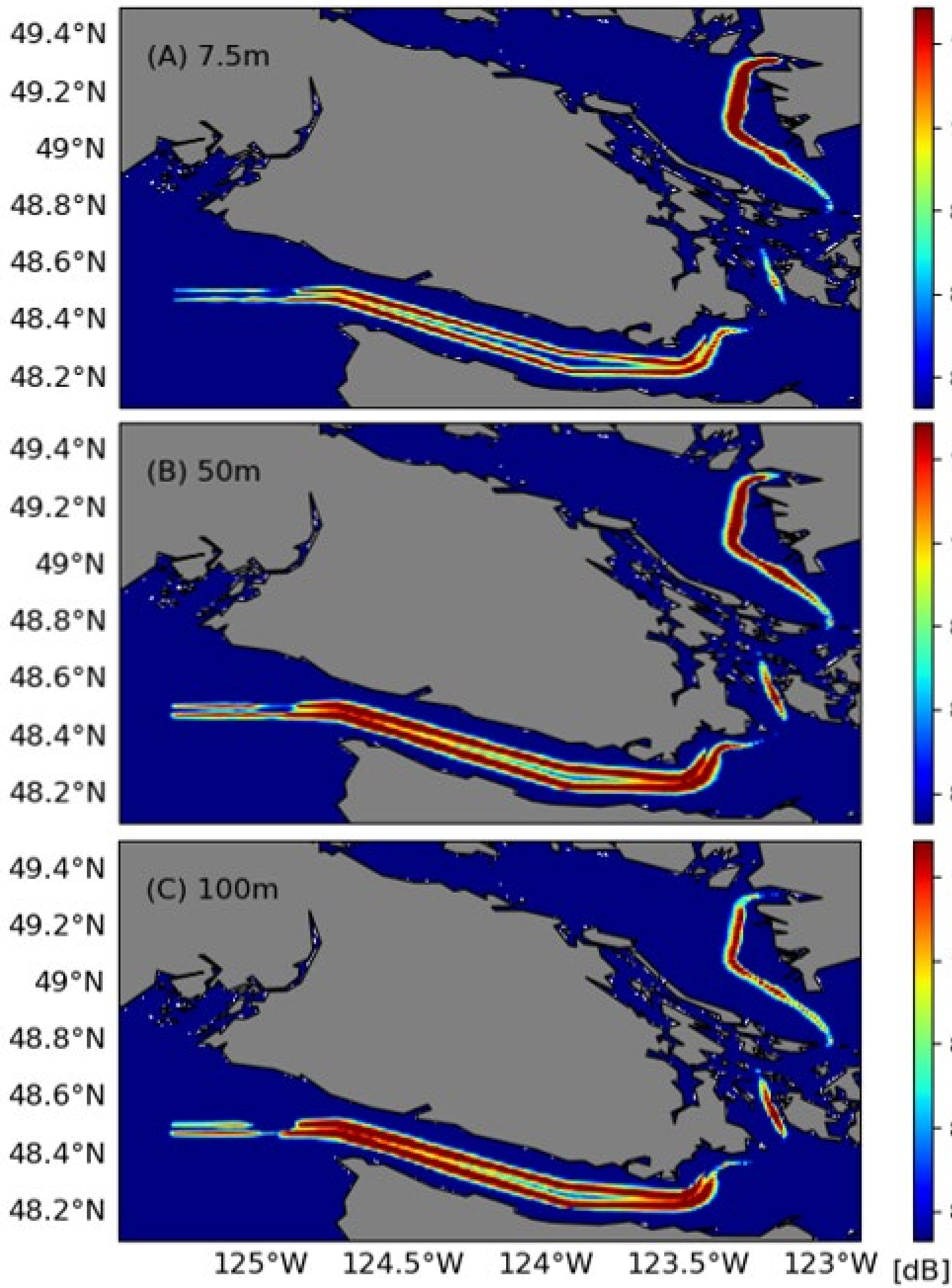

Figure 19. Modelled median noise levels (in dB) in the SRKW echolocation calling range (15 to 100 kHz) using synthetic Automatic Identification System (AIS) data from May-October 2015 adjusted to include predicted TMX tanker and tug transits at (A) 7.5 m, (B) 50 m, and (C) 100 m.

For both the SRKW communication and echolocation frequency ranges, sound levels were greatest in and near the shipping lanes. The spatial extent of elevated sound levels was greater for the low- to mid-frequencies of communication calls (Figures 18-19), encompassing most of Juan de Fuca, Haro and Georgia Straits (Figure 18). Little difference was seen between the depths considered although the model indicated that 50 m showed the most elevated sound levels (Figures 18-19).

3.9.2. Describing areas of impact

Areas of impact were those predicted to experience an increase in sound levels from minimum ambient; this was visualised for the test case by considering elevated sound levels in the SRKW communication and echolocation frequency ranges resulting from the presence of TMX vessels (Figure 20-21). The change in noise levels were expressed as an increase in decibels (dB) calculated using the median noise levels for May to October. Noise additions were focused in areas around the shipping lanes and in shallower waters, defining the acoustic footprint of TMX-vessels in the study area (Figures 18-21).

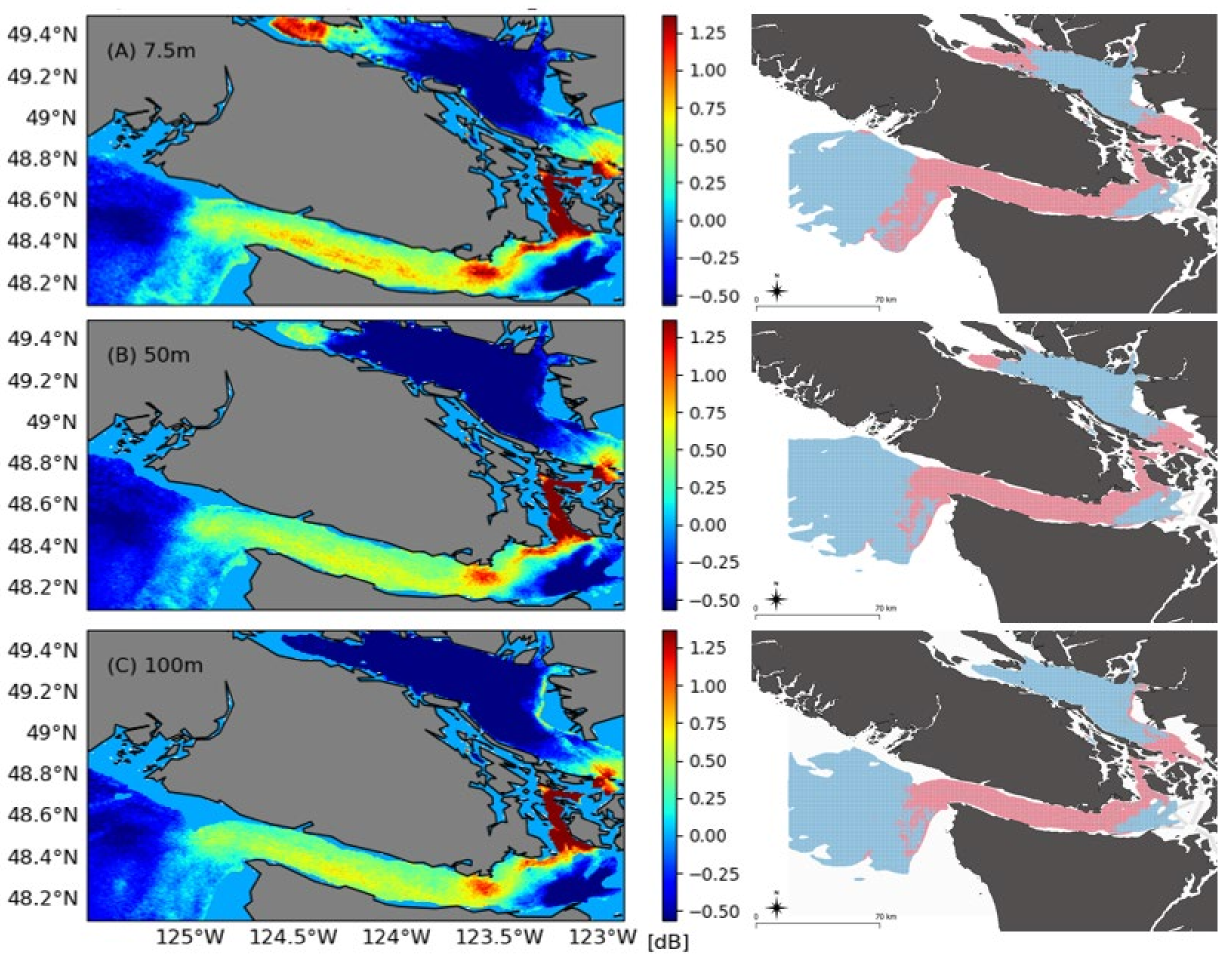

Figure 20. LEFT: Modelled median noise level changes (in dB) in the SRKW communication calling range (500 Hz to 15 kHz) from baseline to the scenario using synthetic Automatic Identification System (AIS) data from May-October 2015 adjusted to include predicted TMX tanker and tug transits RIGHT: Highlighting changes as a binary output, where red= increased sound levels and blue = no change due to the presence of TMX traffic at (A) 7.5 m, (B) 50 m, and (C) 100 m.

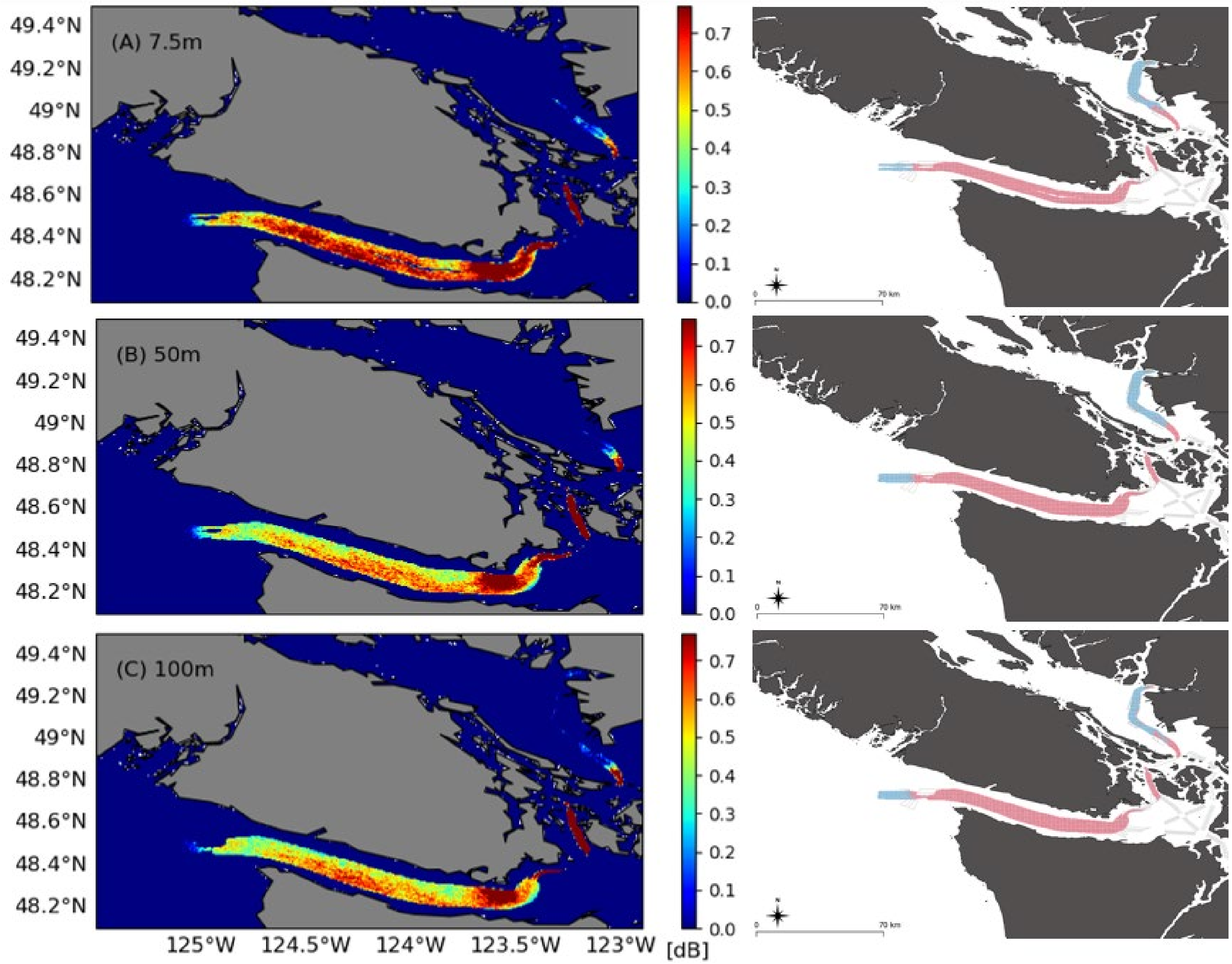

Figure 21. LEFT: Modelled median noise level changes (in dB) in the SRKW echolocation signal range (15 to 100 kHz) from baseline to the scenario using synthetic Automatic Identification System (AIS) data from May-October 2015 adjusted to include predicted TMX tanker and tug transits RIGHT: Highlighting changes as a binary output, where red= increased sound levels and blue = no change sound levels due to the presence of TMX traffic at (A) 7.5 m, (B) 50 m, and (C) 100 m.

Additions were present through Juan de Fuca Strait, Haro Strait and at the southern end of the Strait of Georgia in both the SRKW communication and echolocation frequencies. These additions were greatest around Sooke and through Haro Strait (Figures 20-21). No reference to focal species data was made, and so impact is not determined by the number of individuals exposed to the noise relative to the population (e.g., Wood et al. 2012, Lawson and Lesage 2013), but simply indicates an elevation in sound levels.

3.10. CHANGES IN SOUND LEVELS FROM OFFSET MEASURES

Management measures employed to address project-related vessel noise additions and offset any residual effects should be well-understood, carefully selected based on the best science available, technologically feasible, and result in measurable benefits with a high likelihood of success. To offset, measures must be applied more broadly than mitigating only project-related impacts.

To be able to meet a no-net noise increase objective, the measures must result in reductions equivalent to or exceeding the incremental noise increases from TMX. This could be achieved by reducing vessel noise levels in the study area generally, with measures extending further than project vessels. Under the principle of additionality, the measures should also exceed any management measures that may be in place in the study area prior to the project initiation, and that are not directly attributed to solely lessening the impact of the project. This principle ensures that the management measures imposed for the offset outweigh any reductions that would have occurred otherwise, without further intervention. The concept of additionality in offsetting is to put in place measures that are project-specific, and that will have habitat gains that exceed those that would be obtained solely under a 'business as usual' scenario (Gross et al. 2016).

The proposed management action for offsetting presented in the test case, was a slowing of all commercial Class A AIS vessels in the study area to 10 knots for their full transit. It should be noted that limitations in the implementation of the proposed offsetting actions were not accounted for, and that there may be feasibility issues or caveats in the application of these measures if they were to be implemented and not just considered theoretically. This proposed management scenario exceeds any measure currently in place or previously trialled in the Salish Sea, with a larger spatial extent than the current slowdown zones and a greater requested speed reduction. The reduction of speed to 10 knots is, however, consistent with measures in place to lessen acoustic disturbance and ship-strike risk for at-risk species in other regions.

3.10.1. All vessels slowdown: proposed conceptual offset scenario

The vessel noise model was used to assess the possible noise reductions as a result of management actions throughout the whole study area. This was modelled in response to comments received from participants in the first review of the working research document at the CSAS meeting in March 2024. The input vessel data for the slowdown trial were synthesised through manipulation of real AIS data transmissions from 2015 to allow a consistent comparison to the modelled baseline. Synthetic data was created for the proposed conceptual slowdown scenario, where 100% of vessels were slowed to travel at 10 knots for their full transit through the Salish Sea, and for every passage for the time period of this analysis (May-October). The model allowed testing of the offsetting approach and its potential to reduce noise throughout the study area. For each vessel transit each five-minute data point on a vessel's track was evaluated against the target speed using speed over ground (SOG) calculated from the distance travelled over the time elapsed in the AIS data. If the vessel speed was at or below 10 knots the vessel transit data remained unchanged. If the speed exceeded 10 knots it was adjusted. When vessels were not traveling at the target speed, the time taken to travel the distance between each of the 5-minute locations at slowdown speed was calculated. The time stamp in the AIS data was adjusted in the synthetic data to reflect the additional time that would be needed to travel the distance at 10 knots rather than the speed calculated from the AIS data. This data manipulation was applied to both out- and in-bound traffic traveling throughout the Salish Sea. All vessels transiting in the model domain were modelled as traveling at 10 knots. When exiting ports such as Vancouver, their speed was allowed to increase to, but not exceed, 10 knots. Escort vessels, specifically tugs traveling with tankers, were slowed in accordance with any actions taken on their escorted vessel to match speed and direction. Escort vessels were defined as those traveling within 200 m of a vessel where an escort would be necessary, and at a directional heading that differed no more than 10º, and a speed that differed no more than 3 knots for at least two consecutive 5-minute data points.

Reductions in noise levels were seen throughout the shipping lane areas, with reductions exceeding 4 dB in SRKW communication frequencies and 2 dB in the echolocation frequency range (Figures 22-23). Areas of greatest sound reduction were in the Strait of Georgia for both

SRKW communication and echolocation ranges. Shallow water areas were also highlighted for the communication call range as areas of sound level reductions (Figure 21). In the echolocation frequency range, areas in the shipping lanes in Juan de Fuca Strait also showed strong reductions in noise levels (Figure 22). Increases in sound levels in parts of Haro Strait and Boundary Pass are thought to be a result of more vessels being present in these areas at the same time, with the slowdown aggregating vessels (Figures 22-23).

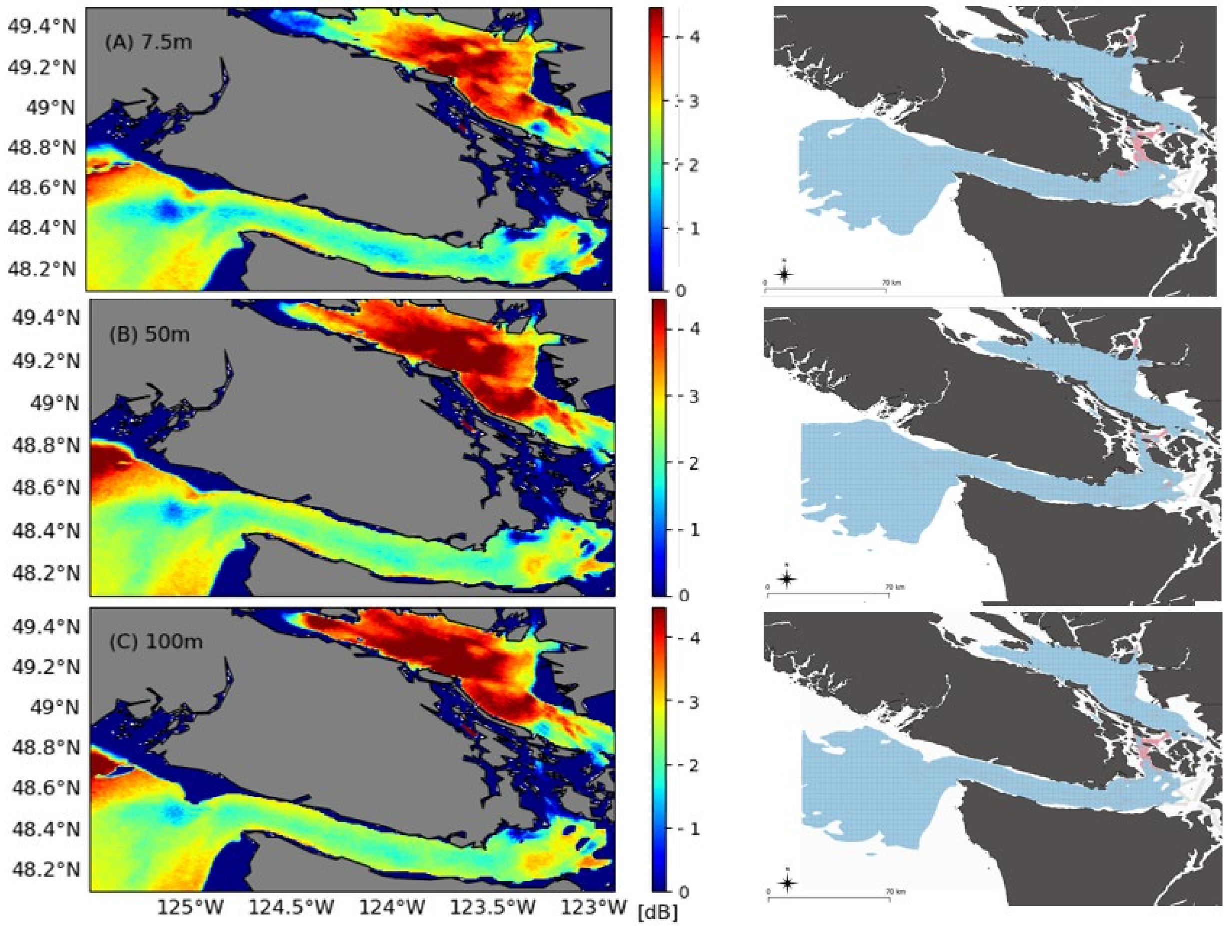

Figure 22. LEFT: Modelled median noise level changes (in dB) in the SRKW communication call range (500 Hz to 15 kHz) from baseline from May-October 2015 and the 100% slowdown scenario with all commercial vessels traveling at 10 knots. RIGHT: Highlighting changes as a binary output, where red = increased sound levels and blue = decreased sound levels due to the presence of TMX traffic at (A) 7.5 m, (B) 50 m, and (C) 100 m.

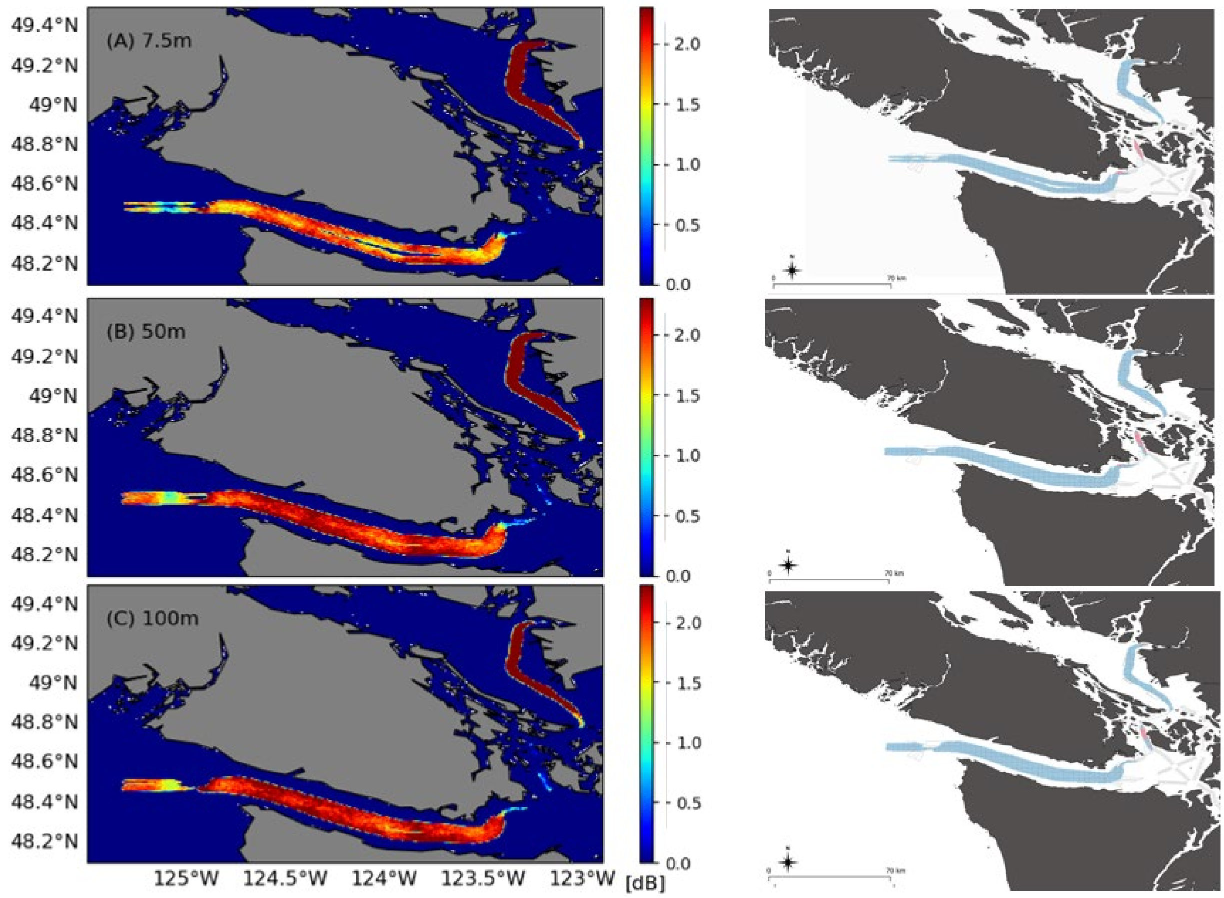

Figure 23. LEFT: Modelled median noise level changes (in dB) in the SRKW echolocation signal range (15 to 100 kHz) from baseline from May-October 2015 and the 100% slowdown scenario with all commercial vessels traveling at 10 knots. RIGHT: Highlighting changes as a binary output, where red = increased sound levels and blue = decreased sound levels due to the presence of TMX traffic at (A) 7.5 m, (B) 50 m, and (C) 100 m.

3.10.1.1. Feasibility

The conceptual management scenario modelled participation of the slowdown at 100%, however several reasons may factor into whether a vessel operator would comply to a speed reduction request. The financial, operational, and potential supply chain implications of reducing vessel transit speeds have been documented (e.g., see Maloni et al. 2013, Hanafiah et al. 2021). For vessels in the Salish Sea, the proposed slowdown will not only increase transit time and delay port arrival, but the number of onboard pilots needed to oversee the passage of each vessel through the pilotage area would increase as transit time would exceed one 8-hour shift. A BC coast pilot is compulsory for commercial vessels over 350 gross tonnes and pleasure craft over 500 gross tonnes coming in or out of port. There may also be an increased cost in fuel if the vessel attempts to make up time elsewhere on its transit.

In areas of high current, strong tidal influence, or increased water turbulence, reduced maneuverability at slower speeds is often cited as a safety concern (see MacGillivray et al. 2019). Maximum participation and navigational safety were seen to converge when asking vessels to travel at speeds no greater than 11 knots in the current slowdown trials for the Salish Sea (see MacGillivray et al. 2019). Concern was expressed that slowing further, to speeds less than 10 knots, would create more economic and safety issues for industry, lessening participation. A multiplier (discussed further in Section 3.8.3) could be used to express the realistic participation levels in the scenario presented. Other measures to reduce noise inputs in the Salish Sea and SRKW habitat may be modeled in the future, including quieter design or other technological approaches.

3.11. CREDIT CALCULATION AND EXCHANGE

If an offset credit approach is to be undertaken, the value and units of credit exchange must be established. Credits must be defensible and use replicable measures of exchange. This may be based on a metric or unit of habitat area, or amount of habitat created, restored, or enhanced. For the test case this could be represented by a change in sound levels in decibels (dB). It could also be a metric of change towards a reference sound level or the target of no-net increase in noise. Credit exchange requires shared equivalency between sub-regions, which may take into account the habitat use and benefit of each locale to the focal species, and consider that this use may differ with life stage, gender, and type.

Zero-sum or no-net change goals for offsetting mean that credit calculation and exchange affords full compensation of residual habitat losses. For the test case, this means determining how much vessel noise should be reduced generally to account for the additions from TMX-vessels.

Offsetting the impact of TMX-related noise for the test case would be countering the residual additions to the soundscape with credits from areas where the slowdown scenario reduced noise levels. It was argued by participants that this exchange should only occur in regions where SRKW are present. To visualise these areas of residuals and offset credits, the scenario of baseline plus TMX tankers and tugs with the 100% slowdown of vessels to 10 knots was run. As with Figures 21 and 22, areas of impact and reduction were visualised (Figure 24). Where sound additions still occurred was coloured red, and where overall sound levels were reduced was coloured blue. Overlaid was the predicted occurrence of SRKW at the 70% confidence level (also see Figure 5). What should be noted is that Figure 24 only shows the location of the noise residuals and reductions, and does not give any indication of the amount of change from the baseline (in dB). The offset calculations would take this into account when calculating and exchanging credits.

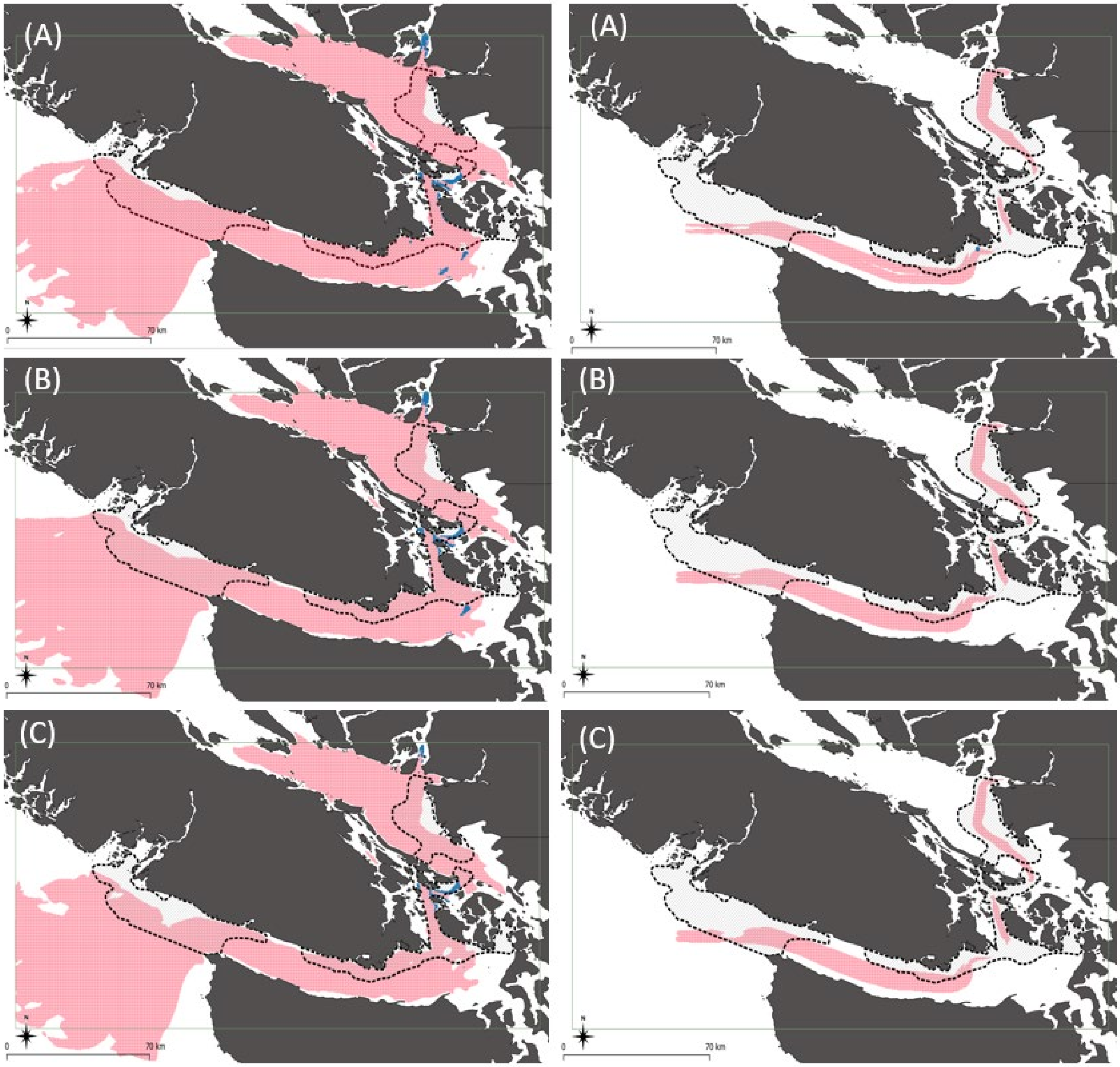

Figure 24. A visualisation of where residual noise increases and decreases occur relative to baseline for the scenario of (Baseline + TMX-vessels) + slowdown all vessels to 10 knots. Red = sound level increases; blue = sound level decreases; black dash line and grey hatching = SRKW predicted occurrence at 70% confidence level; yellow rectangle = vessel noise model extent. LEFT: SRKW communication frequency range; RIGHT:SRKW echolocation range; A = 7.5 m depth; B = 50 m depth; C = 100 m depth. Preliminary example for demonstration purposes only, not finalised results.

The calculation of credits for exchange is outlined by using Equations 1-12 to represent the change in sound levels. The credits can be further modified through weighting factors or offset ratios as habitat value metrics and multipliers. The credit calculation and exchange should have rules and counterfactuals by which net outcomes are evaluated (Quetier and Lavorel 2012, Bull et al. 2013, 2014, 2016, Gibbons et al. 2015). Participants discussed whether there would be some degree of allowable deviation while still concluding offsetting had been successful in achieving no-net noise increase, but no conclusions was met.

Ultimately, the test case highlighted major deficiencies in the proposed framework and was unsuccessful in demonstrating a sound approach to how credits might be calculated and exchanged, and the outcome of the offset process applied to TMX. Although participants thought offsetting was a promising measure to explore, at this point in development of the concept, the use of offset credits was rejected. The suggestions made and the discussions held during the review may, however, lead to improvements and support future considerations of the approach, and so are outlined below in Sections 3.8.2 and 3.8.3.

3.11.1. Sound level change

The excess noise associated with increased vessel activity, such as TMX, or reductions in noise due to mitigation and offsetting measures, NL_E, in the SRKW communication and echolocation frequency ranges, were calculated from extrapolations from the model output at 125 Hz for each of the sub-regions.

For communication, this was:

$$NL_E(500-15000Hz) = 10\, log_{10} \frac{\sum_{ij}(nl_M(500-15000Hz,i,j)}{\sum_{i,j} nl_B(500-15000Hz,i,j)} \quad (6)$$

and echolocation:

$$NL_E(15-100kHz) = 10\ \ log_{10} \frac{\sum_{ij}(nl_M(15-100kHz,i,j)}{\sum_{i,j} nl_B(15-100kHz,i,j)} \quad (7)$$

where the summations are over all model grid points within a given sub-region, and:

$$nl_M\ \ = 10^{**}\,(\frac{RL_M}{10})$$

$$nl_B\ \ = 10^{**}\ (\frac{RL_B}{10})$$

are the linear representations of noise excess or reduction, and baseline model outputs, respectively. Calculating it in this way, using equations (6) and (7), the excess or reduced noise becomes independent of the size of each sub-region. This allows for the possibility of easier credit exchange between regions, regardless of their size/shape relative to each other, as the calculation of each credit unit shows equivalency.

If considered at the resolution of the model output, the correction of expressing the change of sound levels as a function of the number of grid points in a sub-region would not be necessary. In this case the change in sound levels would be expressed for each grid point independently. However, the function to make values equivalent may be retained in the calculation when reconciling calculation of change in sound levels with weighting factors. For the test case, this would be done to resolve the outputs from the vessel noise model with the habitat use and behavioural models used to calculate weighting factors, if calculations were done on the finer resolution of model outputs and not for sub-regions.

The overall SRKW relevant excess or reduced noise for each sub-region was calculated as a single metric (‘Combined’ Tables 2-8) by combining the two metrics for SRKW communication and echolocation, (6) and (7), into one, NL_E, which can be expressed as:

$$NL_E = 10\, log_{10}\, (10^{**}\, 10\, log_{10}\, (10^{**}(NL_E\, (NL_E\ \ 10\, log_{10}(10 ** \, (\frac{NL_E(500-15000Hz)}{10}) +$$

$$(10^{**}(NL_E\, (NL_E(10 **\, (\frac{NL_E(15-100kHz)}{10}) \quad (8)$$

As a worked example using test case data, the change in sound pressure levels between baseline and the TMX tankers and tugs scenario was calculated for each of the sub-regions, using the behavioural (Table 2a) and acoustic (Table 2b) sub-divisions. This is the first step in the offset credit calculation. For this conceptual application of the proposed framework, the calculations were made using 2015 as the baseline year and modified 2015 AIS data for the scenarios (values from Figures 15, 18-19, 22-23). For each sub-region, the proportion that would experience elevated noise levels is indicated, and the increase/decrease in median sound levels in decibels (dB) calculated (Table 2).

Table 2a. Proportion of behaviourally derived sub-regions elevated from baseline by TMX tanker and tugs (Impact, %) and median excess noise within a given sub-region (in dB) calculated from 2015 data at depths 7, 50, and 100 m for communication (500 Hz to 15 kHz) and echolocation (15-100 kHz) frequency ranges, and an aggregated metric of the two ('Combined').

Sub-region	Impact (%)			Increase (dB)		
	7 m	50 m	100 m	7 m	50 m	100 m
La Perouse Bank						
Communication	11.0	0.0	0.0	-0.3	-0.4	-0.3
Echolocation	0.0	0.0	0.0	0.0	0.0	0.0
Combined	-	-	-	-0.2	-0.3	0.2
Swiftsure Bank						
Communication	73.9	72.3	65.4	0.5	0.4	0.4
Echolocation	30.0	43.0	41.9	0.4	0.4	0.4
Combined	-	-	-	0.5	0.4	0.4
Juan de Fuca						
Communication	78.3	78.3	78.3	0.6	0.5	0.5
Echolocation	34.2	43.0	41.9	0.6	0.6	0.5
Combined	-	-	-	0.6	0.5	0.5
Haro Strait						
Communication	45.6	47.6	43.0	0.9	0.7	1.0
Echolocation	7.9	12.1	9.2	0.3	0.5	0.5
Combined	-	-	-	0.8	0.7	0.9
Admiralty Inlet						
Communication	2.4	2.9	0.6	-0.1	-0.2	-0.2
Echolocation	0.0	0.0	0.0	0.0	0.0	0.0
Combined	-	-	-	0.0	-0.1	-0.1
Gulf Islands						
Communication	4.2	4.2	4.2	1.2	1.4	1.4
Echolocation	0.0	0.0	0.0	0.0	0.0	0.0
Combined	-	-	-	0.9	1.1	1.1
South Strait of Georgia						
Communication	28.2	18.0	22.2	-0.4	-0.5	-0.5
Echolocation	4.7	3.0	4.9	-0.2	-0.2	-0.0
Combined	-	-	-	-0.4	-0.6	-0.5
North Strait of Georgia						
Communication	11.0	11.0	0.6	-0.7	-1.1	-1.1
Echolocation	0.0	0.0	0.0	0.0	0.0	0.0
Combined	-	-	-	-0.7	-1.1	-1.1

Sub-region	Impact (%)			Increase (dB)		
	7 m	50 m	100 m	7 m	50 m	100 m
SALISH SEA TOTAL						
Communication	-	-	-	0.0	0.0	0.1
Echolocation	-	-	-	0.2	0.2	0.3
Combined	-	-	-	0.0	0.0	0.1

Table 2b. Proportion of soundscape derived sub-regions elevated from baseline by TMX tanker and tugs (Impact, %) and median excess noise within a given sub-region (in dB) calculated from 2015 data at depths 7, 50, 100 m for communication (500 Hz to 15 kHz) and echolocation (15-100 kHz) frequency ranges, and an aggregated metric of the two ('Combined').

Sub-region	Impact (%)			Increase (dB)		
	7 m	50 m	100 m	7 m	50 m	100 m
Swiftsure Bank						
Communication	15.8	14.8	12.7	0.3	0.3	0.3
Echolocation	5.2	6.7	5.9	0.1	0.1	0.1
Combined	-	-	-	0.3	0.3	0.3
Western Juan de Fuca						
Communication	83.9	83.9	83.9	0.6	0.5	0.5
Echolocation	41.6	50.1	50.1	0.5	0.5	0.5
Combined	-	-	-	0.6	0.5	0.5
Eastern Juan de Fuca						
Communication	34.1	33.6	32.1	0.5	0.4	0.5
Echolocation	10.7	13.4	11.8	0.4	0.4	0.4
Combined	-	-	-	0.5	0.4	0.5
Haro-Boundary						
Communication	50.4	50.4	50.4	2.2	2.0	2.0
Echolocation	0.1	3.4	5.1	0.4	0.7	0.7
Combined	-	-	-	2.0	2.0	1.9
Gulf Islands						
Communication	2.0	2.0	2.0	0.5	0.6	0.6
Echolocation	0.0	0.0	0.0	0.0	0.0	0.0
Combined	-	-	-	0.3	0.4	0.4
Strait of Georgia						
Communication	14.7	9.4	12.3	-0.5	-0.7	-0.7
Echolocation	2.4	1.5	2.2	-0.2	-0.2	-0.1
Combined	-	-	-	-0.5	-0.7	-0.7
SALISH SEA TOTAL						
Communication	-	-	-	0.0	0.0	0.1
Echolocation	-	-	-	0.2	0.2	0.3
Combined	-	-	-	0.0	0.0	0.1

Similar calculations were completed to quantify the change in noise levels resulting from the vessel slowdown scenario proposed as the offset management measure. The change in sound pressure levels resulting from slowing all vessels to 10 knots on their full transit was calculated for the sub-regions defined behaviourally (Table 3a) and using soundscape data (Table 3b). Again, as a conceptual demonstration of the calculation of credits, the figures given are median changes from the 2015 baseline year and using modified 2015 AIS data for the slowdown scenario. The proportion of each sub-region that would experience a reduction in sound levels is given. Also indicated, using asterisks, are the areas that would also show increases in sound levels, presumably from aggregating vessels into one area of the sub-division (Table 3).

Table 3a. Proportion of behaviourally derived sub-regions where sound levels were reduced from baseline by the slowdown measure (Impact, %). Sub-regions also experiencing increases are indicated by an asterisk (*). The change in median sound level within a given sub-region (in dB) was calculated from 2015 data at depths 7, 50, and 100 m for communication (500 Hz to 15 kHz) and echolocation (15-100 kHz) frequency ranges, and an aggregated metric of the two ('Combined').

Sub-region	Impact (%)			Mitigation change (dB)		
	7 m	50 m	100 m	7 m	50 m	100 m
La Perouse Bank						
Communication	39.3	44.2	31.6	-2.1	-2.7	-2.4
Echolocation	0.0	0.0	0.0	0.0	0.0	0.0
Combined	-	-	-	-1.2	-1.8	-1.4
Swiftsure Bank						
Communication	84.5	83.5	72.7	-2.0	-2.2	-2.2
Echolocation	30.0	36.5	33.2	-1.2	-1.6	-1.7
Combined	-	-	-	-2.0	-2.2	-2.2
Juan de Fuca						
Communication	87.1	87.1	87.1	-2.0	-2.1	-2.2
Echolocation	34.2	43.0	41.9	-1.2	-1.7	-1.7
Combined	-	-	-	-2.0	-2.1	-2.1
Haro Strait						
Communication	63.6*	65.3*	65.3*	-0.7	-1.0	-0.9
Echolocation	5.1*	4.5*	4.3*	0.0	0.0	0.0
Combined	-	-	-	-0.7	-1.0	-0.9
Admiralty Inlet						
Communication	9.3	12.1	7.1	-0.7	-1.1	-0.9
Echolocation	0.0	0.0	0.0	0.0	0.0	0.0
Combined	-	-	-	-0.3	-0.5	-0.4
Gulf Islands						
Communication	4.2*	4.2*	4.2*	-0.5	-0.4	-0.4
Echolocation	0.0	0.1	0.1	0.0	0.0	0.0
Combined	-	-	-	-0.3	-0.3	-0.3
South Strait of Georgia						
Communication	70.5	70.5	70.5	-3.4	-3.6	-3.5
Echolocation	17.6	18.1	14.8	-2.0	-1.7	-1.0
Combined	-	-	-	-3.3	-3.6	-3.5
North Strait of Georgia						
Communication	89.2	89.2	89.2	-3.8	-4.4	-3.5
Echolocation	0.0	0.0	0.0	0.0	0.0	0.0
Combined	-	-	-	-3.7	-4.3	-4.3
SALISH SEA TOTAL						
Communication	-	-	-	-2.7	-2.7	-2.7
Echolocation	-	-	-	-0.9	-1.1	-1.0

Sub-region	Impact (%)			Mitigation change (dB)		
	7 m	50 m	100 m	7 m	50 m	100 m
Combined	-	-	-	-2.6	-2.7	-2.6

Table 3b. Proportion of soundscape derived sub-regions where sound levels were reduced from baseline by the slowdown measure (Impact, %). Sub-regions also experiencing increases are indicated by an asterisk (*). The change in median sound level within a given sub-region (in dB) was calculated from 2015 data at depths 7, 50, and 100 m for communication (500 Hz to 15 kHz) and echolocation (15-100 kHz) frequency ranges, and an aggregated metric of the two ('Combined').

Sub-region	Impact (%)			Mitigation change (dB)		
	7 m	50 m	100 m	7 m	50 m	100 m
Swiftsure Bank						
Communication	50.9	55.3	40.6	-1.9	-2.1	-2.1
Echolocation	5.3	6.7	5.9	-0.2	-0.5	-0.6
Combined	-	-	-	-1.7	-2.0	-2.0
Western Juan de Fuca						
Communication	89.1	89.1	89.1	-2.0	-2.2	-2.2
Echolocation	41.6	50.1	50.1	-1.4	-1.8	-1.9
Combined	-	-	-	-2.0	-2.2	-2.2
Eastern Juan de Fuca						
Communication	57.1*	57.1*	57.1*	-1.9	-2.1	-2.1
Echolocation	10.9*	13.4	11.8	-0.6	-0.9	-0.9
Combined	-	-	-	-1.8	-2.0	-2.1
Haro-Boundary						
Communication	21.5*	21.5*	21.5*	0.4	0.2	0.0
Echolocation	1.0*	3.4*	5.1*	0.1	0.1	0.0
Combined	-	-	-	0.4	0.2	0.1
Gulf Islands						
Communication	0.012*	0.012*	0.012*	-0.5	-0.7	-0.9
Echolocation	0.0	0.0	0.0	0.0	0.0	0.0
Combined	-	-	-	-0.2	-0.4	-0.5
Strait of Georgia						
Communication	83.5	83.5	78.9	-3.4	-3.8	-0.9
Echolocation	9.6	9.6	9.6	-1.4	-1.1	-0.6
Combined	-	-	-	-3.4	-3.7	-3.7
SALISH SEA TOTAL						
Communication	-	-	-	-2.7	-2.7	-2.7
Echolocation	-	-	-	-0.9	-1.1	-1.0
Combined	-	-	-	-2.6	-2.7	-2.6

The next step in the credit calculation is to establish the overall change in sound levels per sub-region, and ascertaining whether the reductions from management measures (Table 3) have addressed the noise increases (Table 2) from project-related vessels. The overall change was calculated for each sub-region, either behaviourally (Table 4a) or acoustically (Table 4b) defined, as well as the full study area (Table 4). The resulting change in sound level, in decibels, is carried forward to the next step of credit calculations. Considering the changes at the sub-region level identifies the areas that would most benefit from the slowdown measure to counter the TMX-noise additions. At the study site level, a Salish Sea-wide change in sound levels is given, in principle weighing any areas of increase with the reductions resulting from the proposed full slowdown of all vessels to 10 knots. The calculations on each scale considered the sound level change in the SRKW communication and echolocation frequency ranges, as well as the ‘combined’ metric, and for each representative SRKW diving depth (Table 4). This helps to determine which aspect of their ethology would be potentially most impacted by the soundscape changes.

Table 4a. The overall average change in sound level for each pixel of sub-regions (in dB) calculated from 2015 data at depths 7.5, 50, and 100 m for communication (500 Hz to 15 kHz) and echolocation (15-100 kHz) frequency ranges and an aggregated metric of the two (‘Combined’) for sub-regions defined from whale presence and behaviour data for baseline plus TMX tanker and tug traffic, with 100% slowdown of commercial vessels. Negative values indicate an overall decrease, whereas positive values indicate an overall increase in noise levels.

Sub-region	Overall change (dB)		
	7.5 m	50 m	100 m
La Perouse Bank			
Communication	-1.8	-2.2	-2.1
Echolocation	0.0	0.0	0.0
Combined	-1.0	-1.5	-1.2
Swiftsure Bank			
Communication	-2.6	-2.6	-2.7
Echolocation	-1.6	-2.1	-2.1
Combined	-2.5	-2.6	-2.7
Juan de Fuca			
Communication	-2.6	-2.6	-2.7
Echolocation	-1.8	-2.2	-2.2
Combined	-2.6	-2.6	-2.7
Haro Strait			
Communication	-1.6	-1.8	-1.9
Echolocation	-0.3	-0.5	-0.5
Combined	-1.5	-1.7	-1.8
Admiralty Inlet			
Communication	-0.5	-0.9	-0.7
Echolocation	0.0	0.0	0.0
Combined	-0.2	-0.4	-0.3
Gulf Islands			
Communication	-1.7	-1.8	-1.8
Echolocation	0.0	0.0	0.0
Combined	-1.2	-1.4	-1.4
South Strait of Georgia			
Communication	-3.0	-3.0	-2.9
Echolocation	-1.7	-1.5	-1.0
Combined	-2.9	-3.0	-2.9
North Strait of Georgia			
Communication	-3.1	-3.2	-3.2
Echolocation	0.0	0.0	0.0
Combined	-3.0	-3.1	-3.1

Sub-region	Overall change (dB)		
	7.5 m	50 m	100 m
SALISH SEA TOTAL			
Communication	-2.7	-2.7	-2.7
Echolocation	-1.1	-1.4	-1.3
Combined	-2.7	-2.7	-2.7

Table 4b. The overall average change in sound level for each pixel of sub-regions (in dB) calculated from 2015 data at depths 7.5, 50, and 100 m for communication (500 Hz to 15 kHz) and echolocation (15-100 kHz) frequency ranges and an aggregated metric of the two ('Combined') for sub-regions defined soundscape data for baseline plus TMX tanker and tug traffic, with 100% slowdown of commercial vessels. Negative values indicate an overall decrease, whereas positive values indicate an overall increase in noise levels.

Sub-region	Overall change (dB)		
	7.5 m	50 m	100 m
Swiftsure Bank			
Communication	-1.9	-2.1	-2.1
Echolocation	-0.3	-0.7	-0.7
Combined	-2.0	-2.3	-2.4
Western Juan de Fuca			
Communication	-2.0	-2.2	-2.2
Echolocation	-1.9	-2.3	-2.3
Combined	-2.6	-2.7	-2.7
Eastern Juan de Fuca			
Communication	-1.9	-2.1	-2.1
Echolocation	-0.9	-1.4	-1.3
Combined	-2.4	-2.5	-2.6
Haro-Boundary			
Communication	0.4	0.2	0.0
Echolocation	-0.3	-0.6	-0.7
Combined	-1.6	-1.8	-1.9
Gulf Islands			
Communication	-0.5	-0.7	-0.9
Echolocation	0.0	0.0	0.0
Combined	-0.5	-0.8	-0.9
Strait of Georgia			
Communication	-3.5	-3.8	-3.8
Echolocation	-1.2	-1.0	-0.6
Combined	-2.9	-3.0	-3.0
SALISH SEA TOTAL			
Communication	-2.7	-2.7	-2.7
Echolocation	-1.1	-1.4	-1.3
Combined	-3.0	-3.0	-3.0

For this worked example of the test case using 2015 data, an overall decrease in noise levels was achieved from the proposed slowdown management measures in the Salish Sea, for all frequency ranges and at all depths (Table 4). Therefore, the proposed offset measures more than countered the predicted increases from TMX-related vessel noise additions in this case. On a sub-region scale, only the Haro-Boundary sub-region defined using soundscape data would be expected to have an overall increase in noise levels at the median level in the SRKW communication frequency range from TMX vessels despite the offset measure (Table 4b). This was not apparent for the similar Haro Strait sub-region using whale presence and behavioural data (Table 4a). The mechanism used to create sub-division therefore made no difference to the overall study area change, but individual regions may have differing overall results. This is important to consider further, especially given that Haro Strait has been identified as an important area for SRKW foraging and is an area of high occurrence (Figures 5-7).

Participants questioned this approach to credit calculation for exchange as it assumed that decibels are of equal value regardless of magnitude of change, i.e., a 3 dB increase in a sub-region would be considered equivalent to a 1 dB increase in each of three sub-regions, and the decibel reduction would be treated equally regardless of the starting sound level. However, dB are expressed on a logarithmic scale where a 3 dB change roughly means a doubling in noise level. In addition, impacts are dose-dependent and were shown to increase non-linearly in killer whales (Williams et al. 2006). How to resolve these issues in credit calculations were not discussed as part of the test case review. The translation from quantifying the change in sound level numerically, to offset credits as a mechanism to interpret potential effect or impact on the focal species as a metric that would be biologically meaningful was a source of discord for the participants, who thought that this was not achieved by the proposed offsetting framework as it was presented.

3.11.2. Developing species-specific offset weighting factors (β)

A large number of variables can affect animal distribution and behaviour. The use of weighting factors allows the recognition that regions within the study area may be used differently by the focal species, and that their presence, distribution and habitat use is not uniform across space or time. Although considered in the calculation of sound level change, the time spent at different depths, and the behavioural context of that time, was not accounted for in the calculation of the weighting factors. The amount of this nuanced data is limited, and would be complex to try and capture accurately within the offset credit calculations. For the test case, weighting factors are based on interpretation of diving behaviours from surface-based observations only.

When assessing noise impacts to a species, these are also key components to understanding loss of habitat quality. The use of weighting factors allows the changes in sound levels in each sub-region or area unit, depending on the resolution of the credit calculations, to be weighted differently and in a way that reflects relative importance to the focal species. This may include, but not be limited to: the relative presence/frequency of occurrence, behavioural context of use, relative metric representing the sensitivity of the animals or population group that use the area, hearing sensitivity of the focal species, or a metric that represents a behavioural or energetic cost to any animal subject to noise in that area. Habitat quality may also be used as means to weight regions; indicators representing physical, chemical, or biological attributes may be used to assess ecosystem health or value to the focal species. Weighting factors could be based on data that shows predictability in presence, a known and well characterised behavioural use of the area, or variables including known abundance and variability in prey reserves if foraging areas are present and are being used as a metric. Weighting is used to express where the introduction of noise would be most detrimental for the focal species, or conversely, where greater benefits may be seen if noise levels were reduced. The weighting could also express the population sub-structuring or habitat use of the study area. This could include, for example, if regions are predominantly used by weaning cow-calf pairs, or if gender structuring is apparent. This may be important if stress responses differ between genders, with potential implications on energy intake or expenditure, or fecundity. If no strong patterns of movement through the study area or population sub-structure are evident then all members of the focal species would be considered to have equal exposure to the impacts.

For a multispecies application, the weighting may represent the number of species that might be impacted by project-related vessel noise, or benefit from offset measures. This could include something akin to a species diversity index, or a measure that expresses the biological importance of the habitat, including if it is designated as critical for one or more of the species considered in the offset.

These indicators of habitat importance should be measurable, and defendable in the way that they are applied. Indicators of the variables being used should have the ability to be re-measured or updated as new data become available and/or more is learnt about focal species responses (see Figure 4). They could be expressed as an absolute value, a proportion or ratio, represented by a value between 0-1, or a ranking. The values typically represent a spatial matrix of features/landscape patches; however, the offset weighting could also be altered for different time periods that it is being applied to, for example representing a seasonal habitat use pattern of the focal species.

Areas that are deemed more important, through presence, contextual use or other designation, may be weighted more heavily without necessarily following a linear incrementation of importance. For example, foraging regions may be more heavily weighted than an area where travelling behaviours are dominant, or where the focal species demonstrates behaviours that are less sensitive to ambient noise changes and acoustic disruption. Alternative variables to consider to be used as weighting factors may include a means to quantify the impact on the population when in a certain region, perhaps looking to quantify the altered energetic needs, or the reduction in feeding or foraging opportunities, fecundity or social interactions. For example, outcomes from a Population Consequences of Disturbance (PCoD, New et al. 2013) model or Population Consequences of Acoustic Disturbance models (PCAD, New et al. 2014) were suggested, recognizing, however, there are few examples of fully parameterised PCoD or PCAD frameworks drawing on data for specific species. A metric to represent potential acoustic disturbance or impact, based on expected or predicted changes in soundscape amplitude and frequency, and referencing the auditory threshold of the focal species, may also be considered, although was not encouraged.

For the SRKW test case, weighting factors, β, drew on effort-corrected observations (outlined in Section 3.2.1, see Figure 5). Probabilistic spatiotemporal modelling techniques allowed for interpolated surfaces that represented the predicted frequency of occurrence of SRKW aggregated for May to October at the 70% confidence level (Figure 5, Watson et al. 2021, Thornton et al. 2022a). This resulted in a weighting factor representing the number of SRKW sightings per unit of search effort expressed on a scale of 0-1 (Figure 5). Behaviour data from individual and group focused observations were used to identify common and frequent foraging areas (see Section 3.2.1, Figures 6-7). The incorporation of behaviour into the spatial descriptions of presence would identify areas and times where the risk of disturbance is elevated. For the test case, the potential for foraging behaviours to be impacted was expressed inherently in the calculation of the weighting factor. Behavioural data, as described in Section 3.2.1, was used to develop spatiotemporal models to estimate the relative probability of SRKW foraging. However, this was spatially limited, with the data extending only to areas on Swiftsure Bank, Juan de Fuca Strait and Haro Strait (Figures 5-6). Areas where foraging probability would exceed 0.50 were labelled as frequent foraging areas (FFA), and areas where foraging probability exceeded 0.25 were referred to as common foraging areas (CFA, see Section 3.2.1). Both were considered for use as a weighting factor, expressed on a scale of 0-1

(Figures 6-7). The mean value of units within the sub-areas were calculated as the sum of the value within the sub-region by the total number of units (see Figure 25).

It was agreed during the review that these variables were appropriate measures for the weighting factor, and would give insight into the habitat use of SRKW. However, the calculation and application of the weighting factors were discussed at length, as well as how to best express relative importance, and the variability and uncertainty in the values used to represent a sub-region. The best scale of the weighting factors was discussed, as well as whether aspects of habitat (e.g., designation of critical habitat) or being precautionary weighting allocations (e.g., indicating all areas where the focal species could be present) should be considered in their calculation.

When developing offsetting weighting factors, there are numerous methodologies for the measurement of losses and gains that can be considered (Kangas et al, 2021). As the chosen calculation method can strongly influence the outcome, the selection of approach should consider the resolution of available data and evaluate trade-offs between the simplicity of calculation and ecological robustness. Concerns were raised about the approach taken to calculate the weighting factors proposed in the test case (see below). In particular giving a base value of one to indicate critical habitat presence was questioned. For the test case, critical habitat designation and the modeling extent were almost synonymous. Participants argued that it was difficult to ascertain areas where whales were absent or those that were deemed less important with the use of this base value. In addition, issues were raised in the application of some data for weighting, namely the designation of foraging areas, that was only available to limited regions of the study area, and not throughout. Full consensus was not reached given the concerns expressed while reviewing how weighting factors were applied to the test case. It was acknowledged that the use and calculation of weighting factors would likely have species- and situation-specific elements to its determination for each application of offsetting under the proposed framework. The calculation of weighting factors when using more than one variable was also a source of great discussion, with participants suggesting a multiplicative approach rather than the additive approach be considered for use in the test case. Care in using these factors was stressed throughout, especially as they pertain to calculating credits and determining areas that may exchange credits. Also discussed was the additional use of metrics that would indicate the variability or distribution of values within a sub-region if an average or aggregate measure of some kind is used.

3.11.2.1. Allocation of weighting factors in the test case

For the test case example, the additive approach was selected to develop weighting factors, $\beta(p)$ for study area sub-regions, p, using values of probability of occurrence, and refined by the likelihood of foraging to occur in a given area (Table 5). The weighting factor assignment was designed to balance the predicted frequency of occurrence with the identified habitat use for those areas that were covered by the behavioural model (Figures 24-25).

For the test case calculations, each area unit (pixel) was assigned a baseline value of one to account for the value of areas within critical habitat for SRKW. Values representing occurrence and the probability of foraging were then added to produce an overall habitat value on a scale of 1-4 (Figure 24). The values from the frequency of occurrence layer represented the proportion of 1,000 model runs with an intensity of exceedance greater than 70% on a scale of zero to one. The frequent and common foraging area layers represented the proportion of 1,000 model runs where the likelihood of foraging was greater than 0.25 (common foraging) or 0.50 (frequent foraging) on a scale between zero and one for each layer. However, the extent of the behavioural model results was limited to areas on Swiftsure Bank, Juan de Fuca Strait, and Haro Strait, and so it was only for locations that fell within the bounds of the foraging model that this additional weighting was allocated. The common and frequent foraging layer values were then combined, to give a value between zero and two. This was then added to the critical habitat and frequency of occurrence layer values to create a final habitat layer composed of pixel values ranging from one to four. Sub-region values were expressed as the sum of all the pixels at the resolution of the model output divided by the number of pixels in that region (see Figure 25, Table 5). A value of one for a pixel would indicate the designation of critical habitat, but little sighting data to confirm use of the area by SRKW, whereas a value of four would represent that habitat unit representing a frequent foraging area where SRKW are often sighted that is captured by the critical habitat designation. Values between one and four would represent the relative frequency of occurrence and likelihood of foraging, if known for that area (see Figure 26 for weighting scenarios, and Figure 27 for weighting values). It is this means of calculating weighting factors that was given as part of the step-wise example of credit calculation and followed for the test case; however, some participants found this summation method conceptually flawed and offered suggestions of alternative means of calculation during the review. The demonstration of weighting calculation (Figure 25) and example scenarios (Figure 26) are included for clarity. However, without a means to represent which areas were within the behavioural model extent, for lower to mid-range weighting factors it would be difficult to determine if the value is most representative of whale presence or whether it forms important foraging habitat.

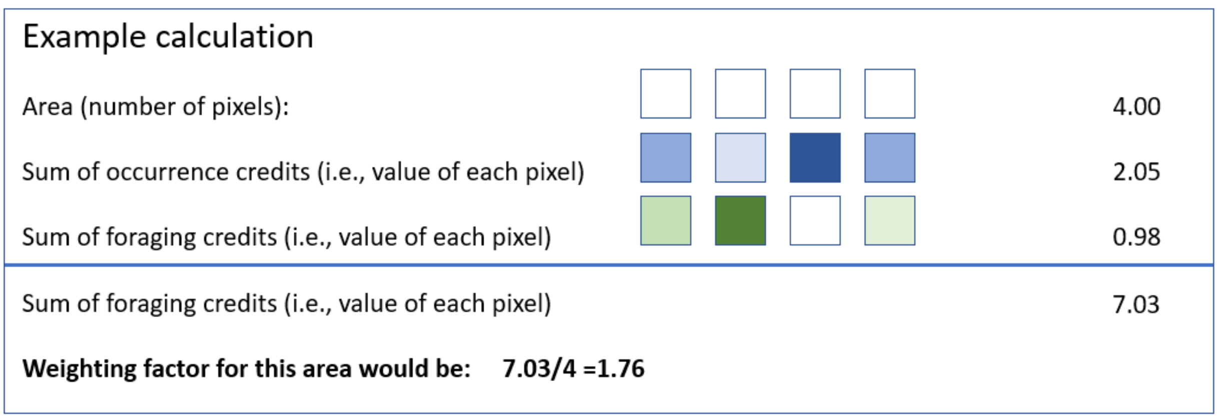

Figure 25. An example of the calculation of weighting for a region of 4 area units to demonstrate how offsets were determined and applied when calculating credits.

PIXEL VALUE SCENARIOS	OCCURRENCE		FORAGING		AREA		WEIGHTING
Location where probability of occurrence and foraging is zero, or outside the model boundaries	0	+	0	+	1	=	1
Location of maximum probability of occurrence and maximum probability of foraging	1	+	2	+	1	=	4
Location of maximum probability of occurrence and either no data or zero probability of foraging	1	+	0	+	1	=	2
Location of maximum probability of foraging but low probability of occurrence	0.1	+	2	+	1	=	3.1
Location where there is a positive value for the probability of occurrence and foraging	.5	+	1	+	1	=	2.5

Figure 26. Example scenarios in calculating the weighting of each area unit to demonstrate how offsets may be calculated and applied when calculating credits. This demonstrates the use of the additive approach to weighting factor calculations. Participants suggested a multiplicative approach may be more appropriate.

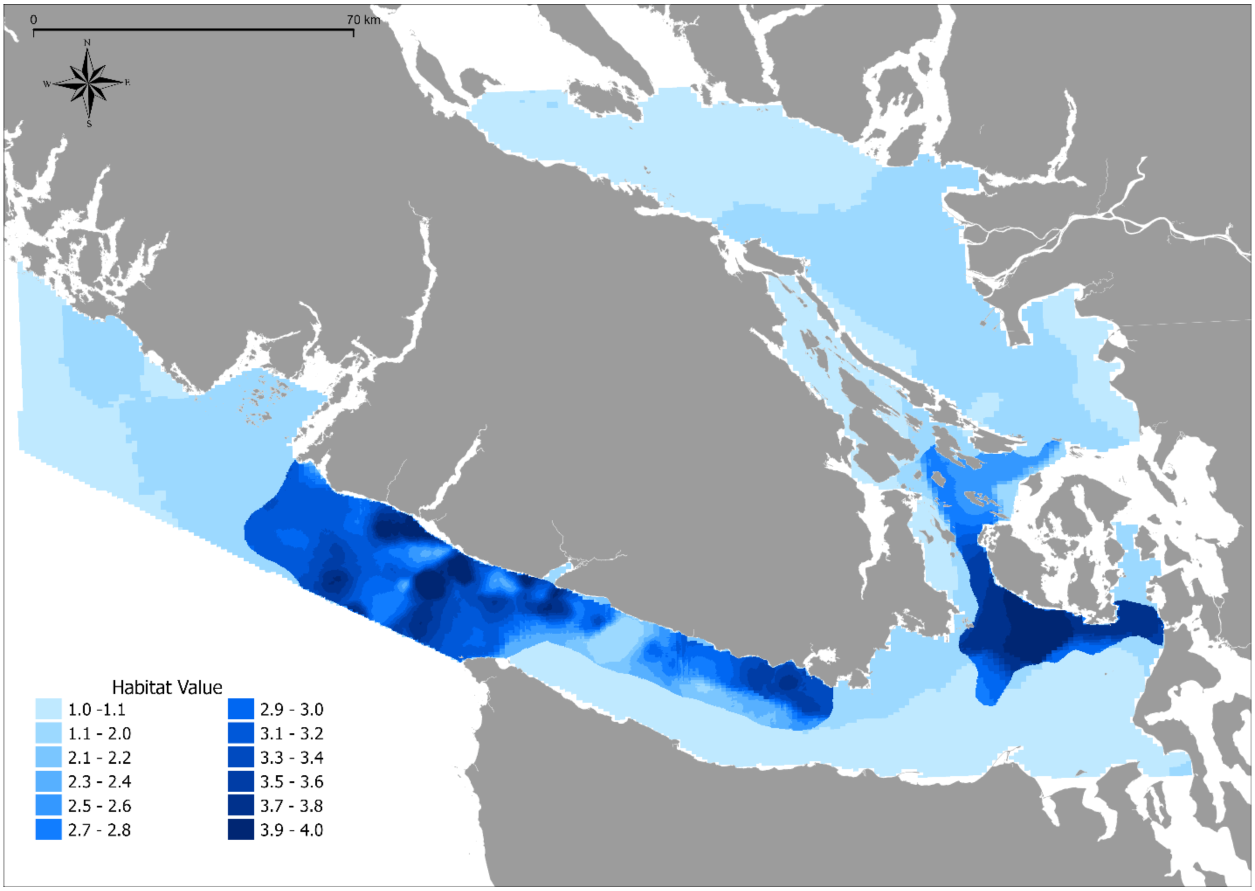

Figure 27. Weighting factors determined using both SRKW frequency of occurrence and behavioural data.

Through discussions the participants decided that a multiplicative approach may be a more scientifically sound means of calculating the weighting factors, especially when they are derived from multiple variables, as they were for the test case. When multiple variables are being used to express habitat value, or distinctive features of the area, it cannot always be assumed that the variables would be additive in nature, as it was in the worked example.

Multiplication would lead to much smaller weighing factors within the credit calculations, but may be a more accurate representation of the value of the habitat. It may also result in values of or close to zero in weighting. Also, it was highly encouraged for the base value of one representing the designation of critical habitat be removed, allowing for a value of zero for areas where no whales were predicted to occur at the 70% confidence level. However, this would limit offsetting to habitats that are currently in use by the population and would allow for degradation of areas that may have historical importance, or may be necessary to meet the future needs as resources change, or population growth occurs. This may, therefore, need to be one of many things that would be considered for each iterative calculation of credits (see Figure 4).

Another suggestion when incorporating multiple factors, especially those that may be mismatched in their spatial or temporal coverage, as was the case in the test case, may be to use a coding system whereby, for example, a value of predicted frequency of occurrence and then a letter or symbol to represent habitat use, in this case the presence of foraging areas, would be implemented. This would not only help determine the contribution of each variable when deciphering habitat equivalence, but would, in the example of the test case, show more clearly where there was data available in the behavioural model, and where the bounds of this model were exceeded. This may then be translated into a value or ranking; however it was not determined how such a coding system would be incorporated into the credit calculation.

3.11.2.2. Allocation of weighting factors to sub-regions

It was agreed that the weighting factors should be applied at the finest resolution possible; however, this may be on the sub-region level. A comparison was made to consider the influence of how the study area is sub-divided, comparing the behavioural and acoustic sub-region definitions (Table 5, Figure 28). This demonstrated the differences that arise given the differing placement of sub-divisions, and how variability in the values within a sub-region can influence the overall credit value. The weighting factors were calculated using the additive approach (see Figures 25-27), rather than the multiplicative approach suggested during the review. However, the process of including weighting factors into the offset credit calculations would be the same irrespective of how the factors were calculated.

Table 5. Weighting factors, β, sub-regions (A) derived from SRKW presence and behavioural data ('behavioural') and (B) soundscape data, considering frequency of occurrence raster values (Occurrence), or the refinement with the inclusion of foraging area presence (Occurrence and Foraging). In this example, weighting factors were estimated using an additive approach and not the more scientifically sound multiplicative approach.

Sub-region	Weighting factors, β	
	Occurrence	Occurrence and Foraging
(A) Behavioural		
La Perouse Bank	1.43	1.60
Swiftsure Bank	1.78	2.86
Juan de Fuca	1.26	1.66
Haro Strait	1.57	2.38
Admiralty Inlet	1.23	1.47
Gulf Islands	1.38	1.58
South Strait of Georgia	1.60	1.60
North Strait of Georgia	1.08	1.08
(B) Soundscape		
Swiftsure Bank	1.57	2.00
Western Juan de Fuca	1.36	2.08
Eastern Juan de Fuca	1.32	1.68
Haro-Boundary	1.69	2.34
Gulf Islands	1.24	1.35
Strait of Georgia	1.35	1.35

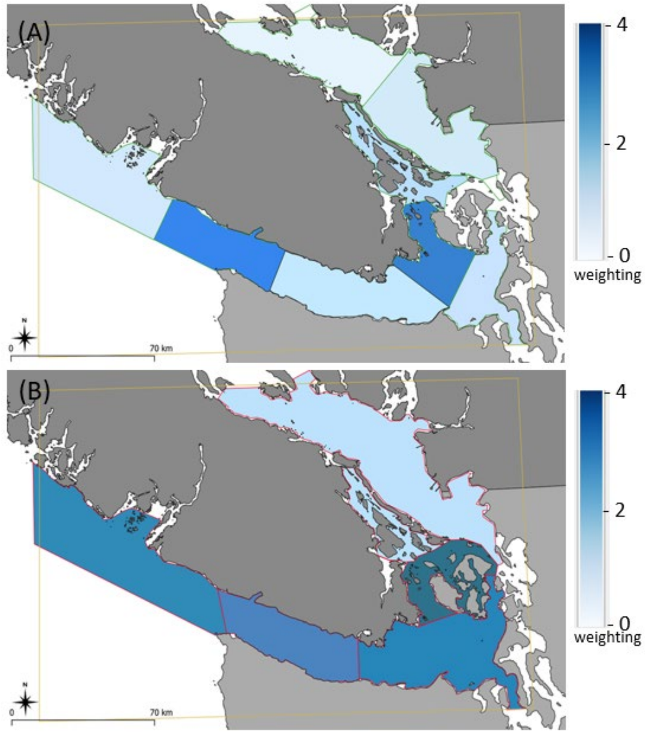

Figure 28. Comparison between the average weighting factor values calculated using an additive rather than a multiplicative approach, when using (A) SRKW data (occurrence and behavioural outputs) sub-region and (B) soundscape derived sub-regions.

The soundscape sub-regions were typically larger, and generally had a greater weighting value, and showed less distinction in overall weighting between regions than those derived from the behavioural data (Table 5, Figure 28). This theoretical example shows how sensitive weighting values can be to the effect of dilution. It also clearly depicts the limited extent of the behavioural model, where there are inputs for Haro Strait, Juan de Fuca Strait, and Swiftsure Bank only, which have greater weighting factors, particularly evident in Figure 28A. However, it is still unclear for the areas that are assigned the lower value weighting factors whether that results from a low whale presence, little likelihood of foraging, both of these factors, or if the area is ranked lower because of the paucity of data in that region. While in the test case, areas with no predicted occurrence were included in the offset study area, following participant discussions, it was agreed that areas where whales are absent should be excluded. Greater indication of model extent in using foraging data to calculate weighting factors, or exclusion of areas not captured in the model output, should also be considered.

For the test case, frequency of occurrence did not distinguish between pods or population sub-groups of SRKW. However, sighting data have indicated that there are pod-specific distributions and space-use patterns (Hauser et al. 2007, Shields 2023). Population sub-structuring or differences in site fidelity patterns might mean that a portion of the focal species population might be disproportionately impacted by project-related activities (DeFur et al. 2007, Bonnell et al. 2022). In the case of SRKW in the test case, it has been suggested that this variable exposure to risk factors could contribute to differing relative contributions to population trends including mortality rates (Hauser et al. 2007). Where possible inclusion in the weighting factor to represent population sub-structuring, if present, was encouraged, but the mechanism to do so was not discussed.

3.11.2.3. Expressing variability in sub-region weighting values

When calculating single value weighting factors to contribute to offset calculations and exchange on a sub-region level, it is typical to use the mean or median, as was used for the test case. In seeing the uncertainties that this can result in, it was suggested that, in addition to this value, a kurtosis calculation or similar should be included to convey the distribution of values within the sub-region and how well they are represented by the singular value. A value representing the level of confidence might also be included if, for example, weighting was being expressed as a predictive value of habitat use. Metrics such as kurtosis, skew, confidence intervals or other values of statistical power, were suggested to express variability and/or confidence in the weighting factor being used. They are also an expression of uncertainty as well as excess risk as it pertains to the proportion of the focal species that may still feel undesirable effects of project-related activities. Acceptable ranges or deviations in these values that would still allow areas to be deemed equivalent was not agreed upon, but should be determined prior to offsetting calculations being made. For the test case, the values of kurtosis and skew were calculated (Tables 6-7). Skew addresses the distribution of the data relative to a normal curve around the peak and the value of the median compared to the mean. It represents a measure of the asymmetry around a peak value, with zero being symmetrical. Values should ideally be between -1 and 1. Positive values have a left-hand skew, with a longer tail of values to the left. In this case the mean and median values are always positive, and the mean is greater than the median. The opposite is true for a negative value that has a right-handed skew, and the median is the larger value. Kurtosis represents the spread of the data around a peak, and whether it is a sharp rise and decline (leptokurtic), normally distributed (mesokurtic), or flat (platykurtic).

A kurtosis value less than 3 typically represents a platykurtic distribution, suggesting that outliers are infrequent. A mesokurtic distribution has no extreme values and outliers are rare. Finally a leptokurtic distribution, with a value above 3, is more strongly peaked around the mean value, with heavier tails in the data distribution, and so a higher likelihood of outliers. In the test case example, higher values of kurtosis would be expected for the sub-regions defined by using whale presence and behavioural data than the soundscape sub-regions, and this was generally true. Skew values would be expected to be lower, which was also generally the case for regions that covered similar areas (Tables 6-7).

Table 6. Skew and kurtosis values for sub-regions (A) derived from SRKW presence and behavioural data ('behavioural') and (B) soundscape data, considering frequency of occurrence raster values (Figure 5).

Sub-region	Max.	Mean	Median	St. Dev.	Skew	Kurtosis
(A) Behavioural						
La Perouse Bank	2.00	1.43	1.22	0.39	0.42	1.42
Swiftsure Bank	2.00	1.78	2.00	0.38	-1.37	3.04
Juan de Fuca	2.00	1.26	1.01	0.40	1.13	2.44
Haro Strait	2.00	1.57	1.89	0.46	-0.27	1.19
Admiralty Inlet	2.00	1.23	1.01	0.39	1.27	2.78
Gulf Islands	2.00	1.38	1.05	0.45	0.53	1.40
South Strait of Georgia	2.00	1.60	1.74	0.40	-0.32	1.37
North Strait of Georgia	1.85	1.08	1.05	0.08	2.76	12.75
(B) Soundscape						
Swiftsure Bank	2.00	1.57	1.69	0.42	-0.16	1.19

Sub-region	Max.	Mean	Median	St. Dev.	Skew	Kurtosis
Western Juan de Fuca	2.00	1.36	1.06	0.43	0.62	1.54
Eastern Juan de Fuca	2.00	1.32	1.02	0.43	0.77	1.72
Haro-Boundary	2.00	1.70	2.00	0.42	-0.85	1.89
Gulf Islands	2.00	1.24	1.01	0.39	1.25	2.71
Strait of Georgia	2.00	1.35	1.10	0.39	0.82	1.89

Table 7. Skew and kurtosis values for sub-regions (A) derived from SRKW presence and behavioural data ('behavioural') and (B) soundscape data, considering frequency of occurrence raster values with the refinement with the inclusion of foraging area presence (Figures 5-7).

Sub-region	Max.	Mean	Median	St. Dev.	Skew	Kurtosis
(A) Behavioural						
La Perouse Bank	3.40	1.60	1.22	0.70	1.27	3.33
Swiftsure Bank	4.00	2.86	3.05	0.84	-1.11	3.47
Juan de Fuca	3.79	1.66	1.02	0.84	0.89	2.39
Haro Strait	3.93	2.38	2.00	1.15	0.03	1.35
Admiralty Inlet	3.75	1.47	1.01	0.88	1.76	4.57
Gulf Islands	2.74	1.58	1.09	0.64	0.48	1.55
South Strait of Georgia	2.63	1.60	1.74	0.40	-0.31	1.38
North Strait of Georgia	1.85	1.08	1.05	0.08	2.76	12.67
(B) Soundscape						
Swiftsure Bank	4.00	2.00	1.71	0.96	0.52	1.71
Western Juan de Fuca	3.93	2.08	2.20	0.94	0.07	1.55
Eastern Juan de Fuca	3.93	1.68	1.02	0.99	1.23	2.97
Haro-Boundary	3.91	2.34	2.46	0.92	0.03	1.94
Gulf Islands	2.71	1.35	1.02	0.53	1.29	3.18
Strait of Georgia	2.63	1.35	1.10	0.39	0.82	1.90

In all cases minimum values were 1, as this value was assigned without additional input from the whale presence (Figure 5) or foraging data (Figure 6-7) to each area unit/pixel to represent the designation of critical habitat, defined as the habitat necessary for survival or recovery of an at-risk population. Differences between the values in Table 6 to Table 7 are indicative of the inclusion of the foraging data, and weighting value derived using behavioural data, compared to those regions that were outside the bounds of this model. Swiftsure Bank, Juan de Fuca, and Haro Strait regions had the greatest maximum weighting values, indicating their importance to SRKW, but also highlighting the impact of including weighting from the behavioural data for those regions (Table 7). Skew values were typically within the acceptable -2 to 2 range, with predominantly positive values (left-handed skew). Those with negative values may be influenced by areas that have very high frequency of occurrence values within the sub-region relative to the mean (Tables 6-7). Very little skew was evident in the values for western Juan de Fuca and Haro-Boundary sub-regions when using both presence and behavioural data (Table 7), suggesting that although the sub-regions were defined using acoustic properties, the borders were well placed to capture similar values in SRKW use. The greater the kurtosis value the more focused the data around the peak, suggesting that the mean value is a true representative of the data within the sub-region as it is defined, and that the region's boundaries do indeed capture areas that are of similar use by SRKW, as defined by the weighting factor.

This is well demonstrated by the value for the northern Strait of Georgia sub-region defined using presence data (Tables 6-7). Lesser, or even platykurtic kurtosis values suggest more variation in the values of presence (Table 6) or presence and foraging (Table 7) within the sub-region. This would be expected more for the soundscape-defined sub-regions, although the lowest kurtosis values were seen for Haro Strait, the Gulf Islands and the southern Strait of Georgia using the sub-regions defined by SRKW presence and behavioural data (Tables 6-7). These areas showed low kurtosis values centred on the mean, indicating variability in the mean value calculated for the sub-region, and that there are pixels that are much more valuable than the mean, and others much less valuable captured within.

A cautious approach was encouraged when applying the weighting factors, with a means to express uncertainty and variability in the values used stressed throughout the review. This would bring more transparency to the credit calculation process, and would show where greater data might aid in the certainty in credit estimation and application as part of the approach. Through discussions, it was concluded that the weighting factor calculations had insufficient behavioural data to support them in the way that they are currently being applied in the test case. However, the inclusion of a value such as kurtosis (Tables 6-7) or measure of confidence was highly encouraged.

3.11.2.4. Hot-spots and corridors

The use of weighting factors helps in determining ‘hot spot’ regions of importance or increased use by the focal species. However, in outlining these areas it is also important to understand the connectivity of these regions and how they form an integral habitat. This means using observational data to identify the presence of transit corridors between areas of greater use, perhaps using a metric to represent connectivity or spatial auto-correlation between habitats as an additional weighting factor, to show how the focal species may commute between areas of concentrated presence, or regions where a particular behaviour dominates. A temporal component may be a necessary inclusion here, or some other means to recognise that these areas may be used on a periodic basis, and that movements may be highly directional. This level of detail surpasses the data available for the test case, and would be very resource intensive in its collection. However, its consideration and inclusion into offsetting calculations was encouraged by participants.

3.11.3. Application of offset weighting factors (β) to credit calculations

The weighting factor, β(p), for each sub-region, p, (Table 5), combined with the excess or reduction in noise associated with added shipping or offset management measures (Equations (6) and (7), Table 4) were used to calculate comparable, and therefore tradeable, weighted offset credits φ(p) for each sub-region in the study area.

For communication:

$$\varphi(500 - 15000Hz) = \beta \times \left(1 - \frac{\sum_{i,j} nl_M(500{-}15000Hz)}{\sum_{i,j} nl_B(500{-}15000Hz)}\right) \qquad (9)$$

and echolocation:

$$\varphi(15 - 100kHz) = \beta \times \left(1 - \frac{\sum_{i,j} nl_M(15{-}100kHz)}{\sum_{i,j} nl_B(15{-}100kHz)}\right) \qquad (10)$$

and for the combined metric:

$$\varphi(0.5 - 100kHz) = \beta \times \left(1 - \frac{\sum_{i,j} nl_M(500{-}15000Hz)}{\sum_{i,j} nl_B(500{-}15000Hz)} * \frac{\sum_{i,j} nl_M(15{-}100kHz)}{\sum_{i,j} nl_B(15{-}100kHz)}\right) \qquad (11)$$

The weighting factor calculated (Table 5) was applied to each depth without modification (Table 8). The calculated change for communication and echolocation frequencies with offset could indicate which signalling type might be most impacted in each sub-region. The 'Combined' metric represented the change in their full repertoire, and was used following conclusions made by SMEs in the 2021 Workshop and further discussions with the FFHPP. It allowed a ranking of the areas most impacted by TMX, and still in need of offsetting, using a single metric while still incorporating the species-relevant frequencies. The values in Table 8 represent the credits gained or in deficit for each sub-region, using the SRKW presence and behavioural (Table 8a) or soundscape data (Table 8b) to define them. In using the weighting factors (Table 5) to modify the calculated sound level changes (Table 4) the values become unitless. For exchange, the credits were assumed to each be equal in worth which may not be an appropriate assumption in a noise (dB) offsetting context. The number of credits per sub-region could be used to rank areas where SRKW would experience the most acoustic disturbance. Only the soundscape data derived Haro-Boundary sub-region demonstrated overall noise additions following management measures (Table 4b), which carried forward in the calculations as a credit deficit (Table 8b) rather than surplus. Comparing this to the results for the similar area defined using behavioural data indicates how important the definition of sub-region could be to credit calculations.

The Salish Sea totals are the sum of the credits for each sub-region for the frequency range and depth stated, indicating the overall effectiveness of the slowdown measures in addressing the additions from TMX-vessels for the study area as a whole.

Table 8a. Weighted offsets, or 'credits' φ, for sub-regions derived from SRKW presence and behavioural data, considering frequency of occurrence raster values (Occurrence), or the refinement with the inclusion of foraging area presence (Occurrence and Foraging) at depths 7.5, 50, and 100 m for communication (500 Hz to 15 kHz) and echolocation (15-100 Hz) frequency ranges and an aggregated metric of the two ('Combined'). Negative values indicate an overall credit deficit, whereas positive values indicate an overall credit surplus. Credits determined from additions from TMX-vessel noise and reductions from slowdown scenario of all commercial vessels transiting the study area at 10 knots.

Sub-region	Occurrence			Occurrence and Foraging		
	7.5 m	50 m	100 m	7.5 m	50 m	100 m
La Perouse Bank						
Communication	0.49	0.57	0.55	0.54	0.64	0.61
Echolocation	0.00	0.00	0.00	0.00	0.00	0.00
Combined	0.29	0.42	0.35	0.33	0.47	0.39
Swiftsure Bank						
Communication	0.80	0.80	0.82	1.29	1.29	1.32
Echolocation	0.55	0.68	0.68	0.88	1.10	1.10
Combined	0.78	0.80	0.82	1.25	1.29	1.32
Juan de Fuca						
Communication	0.57	0.57	0.58	0.75	0.75	0.77
Echolocation	0.43	0.50	0.50	0.56	0.66	0.66
Combined	9.57	0.57	0.58	0.75	0.75	0.77
Haro Strait						
Communication	0.48	0.53	0.56	0.73	0.81	0.84
Echolocation	0.10	0.17	0.17	0.16	0.26	0.26
Combined	0.46	0.51	0.53	0.70	0.77	0.81
Admiralty Inlet						
Communication	0.13	0.23	0.18	0.16	0.28	0.22

Sub-region	Occurrence			Occurrence and Foraging		
	7.5 m	50 m	100 m	7.5 m	50 m	100 m
Echolocation	0.00	0.00	0.00	0.00	0.00	0.00
Combined	0.06	0.11	0.08	0.07	0.13	0.10
Gulf Islands						
Communication	0.45	0.47	0.47	0.51	0.54	0.54
Echolocation	0.00	0.00	0.00	0.00	0.00	0.00
Combined	0.33	0.38	0.38	0.38	0.44	0.44
South Strait of Georgia						
Communication	0.80	0.80	0.78	0.80	0.80	0.78
Echolocation	0.52	0.47	0.33	0.52	0.47	0.33
Combined	0.78	0.80	0.78	0.78	0.80	0.78
North Strait of Georgia						
Communication	0.55	0.56	0.56	0.55	0.56	0.56
Echolocation	0.00	0.00	0.00	0.00	0.00	0.00
Combined	0.54	0.55	0.55	0.55	0.55	0.55
SALISH SEA TOTAL						
Communication	4.27	4.53	4.51	5.33	5.65	5.65
Echolocation	1.60	1.82	1.68	2.12	2.48	2.34
Combined	3.81	4.13	4.08	4.79	5.19	5.15

Table 8b. Weighted offsets, or 'credits' φ, for sub-regions derived from soundscape data, considering frequency of occurrence raster values (Occurrence), or the refinement with the inclusion of foraging area presence (Occurrence and Foraging) at depths 7.5, 50, and 100 m for communication (500 Hz to 15 kHz) and echolocation (15-100 Hz) frequency ranges and an aggregated metric of the two ('Combined'). Negative values indicate an overall credit deficit, whereas positive values indicate an overall credit surplus. Credits determined from additions from TMX-vessel noise and reductions from slowdown scenario of all commercial vessels transiting the study area at 10 knots.

Sub-region	Occurrence			Occurrence and Foraging		
	7.5 m	50 m	100 m	7.5 m	50 m	100 m
Swiftsure Bank						
Communication	0.56	0.60	0.60	0.71	0.77	0.77
Echolocation	0.10	0.23	0.23	0.13	0.30	0.30
Combined	0.58	0.65	0.67	0.74	0.82	0.85
Western Juan de Fuca						
Communication	0.50	0.54	0.54	0.77	0.83	0.83
Echolocation	0.48	0.56	0.56	0.74	0.86	0.86
Combined	0.61	0.63	0.63	0.94	0.96	0.96
Eastern Juan de Fuca						
Communication	0.47	0.51	0.51	0.60	0.64	0.64
Echolocation	0.25	0.36	0.34	0.31	0.46	0.43
Combined	0.56	0.58	0.59	0.71	0.74	0.76
Haro-Boundary						
Communication	-0.16	-0.08	0.00	-0.23	-0.11	0.00
Echolocation	0.11	0.22	0.25	0.16	0.30	0.35

Sub-region	Occurrence			Occurrence and Foraging		
	7.5 m	50 m	100 m	7.5 m	50 m	100 m
Combined	0.52	0.57	0.60	0.72	0.79	0.83
Gulf Islands						
Communication	0.13	0.18	0.23	0.15	0.20	0.25
Echolocation	0.00	0.00	0.00	0.00	0.00	0.00
Combined	0.13	0.21	0.23	0.15	0.23	0.25
Strait of Georgia						
Communication	0.75	0.79	0.79	0.75	0.79	0.79
Echolocation	0.33	0.28	0.17	0.33	0.28	0.17
Combined	0.66	0.67	0.67	0.66	0.67	0.67
SALISH SEA TOTAL						
Communication	2.24	2.54	2.67	2.74	3.12	3.28
Echolocation	1.27	1.65	1.56	1.67	2.20	2.11
Combined	3.07	3.31	3.40	3.91	4.22	4.32

Overall, in all frequency ranges, at all depths considered, there were no-net noise additions (Table 4), which resulted in a general surplus of credits (Salish Sea Total, Table 8). For each case the number of credits was greater for the calculations using the sub-regions defined by SRKW presence and behaviour (Table 8a), but this may be a result of the calculations being on 8 sub-regions compared to 6 for the soundscape-derived sub-divisions.

It should be highlighted that the calculation of these offset credits was done purely to indicate the process and application of the proposed framework. There are flaws in the methods that were indicated by participants during the review, and aspects of the credit calculations that participants felt were problematic, that would need to be addressed before furthering the approach. The inclusion of values and use of test case data, rather than solely presenting the theoretical concept, helps better demonstrate the sensitivities in the calculations to aspects such as temporal and spatial scale, including sub-region definition, weighting factor inclusion and calculation, and the frequency ranges and depths of interest. This may not have been obvious without parameterisation of the proposed framework, and working through the test case using SRKW data. The issues highlighted by the worked example led to participants rejecting the calculation and weighting of offset credits in the form presented.

3.11.4. Use of a multiplier

In addition to weighting factors, the use of a multiplier was suggested during the review of the test case. This would represent the ratio between the negatively impacted and compensated habitat, or be representative of a risk factor/uncertainty in achieving the offset (Dunford et al. 2004, Bruggeman et al. 2005, Moilanen et al. 2009, Laitila et al. 2014). The gains of offsetting are estimated relative to a ‘business-as-usual’ scenario, where no project-specific mitigation measures are in place, and can be multifaceted, and is thought to help better express habitat value (Laitila et al. 2014). The use of a multiplier is thought to allow broader conservation objectives to be assessed, as well as reducing the data uncertainties and risk of unsuccessful offsetting. It can be used to account for temporal issues in offset initiation, and allow nuanced credit exchange (Moilanen et al. 2009, McKenney and Kiesecker 2010, Brownlie and Botha 2012, Maron et al. 2012, Bull et al. 2016). Daw et al. (2015) also suggest that multipliers might be used to discern between the trading of credits and their worth, and distinguish between credits that are ‘sacred’, which might be related to species success, biodiversity metrics, or habitat quality, and those that are 'secular', for example based more on economics or resource use. Multipliers may be a means to express uncertainties in the credit calculation, or capture variability in, for example, participation in the mitigation measures, the feasibility or ease of application of offsetting management measures, disparities between desired development and conservation outcomes, the use of habitat banks, or any lag between the project-related impacts and the offsetting activities (Laitila et al. 2014, Bull et al. 2016). Accounting for uncertainty, or many interacting factors, in a no-net habitat loss offsetting application would increase the multiplier (Moilanen et al. 2009, Pouzols et al. 2012, Pilgrim et al. 2013, Laitila et al. 2014). They may be used to address concerns or unknowns, or used as a means to express confidence in the data applied to credit calculation. For example, the use of discounting multipliers, which weights offsetting actions from proximal times or locations more heavily than those that are more distant, or conservation outcome multipliers which are designed to reflect measures taken to meet conservation targets.

Additional factors may be included in the formulation of the multiplier to express if the loss of habitat is complete or partial, or if including time-based factors, such as the rate/immediacy or permanence of the loss might be expressed (Laitila et al. 2014). If it was agreed that the exchange of credits through time was feasible, the multiplier could be used to express the delay between the impact and the compensation, whereby, for example, future gains were valued less than immediate gains (e.g., time discounting: Laibson 1997, Green and Myerson 2004, Moilanen et al. 2009), and realising that it may not be able to account fully for all the lost habitat (e.g., Moilanen et al. 2009, Maron et al. 2010). Another temporal aspect of multiplier use may express the duration of the effect of offsetting activities (e.g., Dargusch et al. 2010, McKenny and Kiesecker 2010, van Oosterzee et al. 2012). However, there was little discussion in the review of the concept of offsetting in time rather than space or how a multiplier would be best applied. Many obstacles were identified in the exchange of credits spatially, and many more unknowns were foreseen when trying to apply the proposed framework to an exchange through time. Not least, that the data available and used in the test case would not be in a resolution fine enough that would allow for exchange through time (minimum temporal resolution of frequency of occurrence of SRKW is monthly, see Thornton et al. 2022a). The calculations also only account for the change in sound levels and not altered noise exposure times. As such, it has not been included into the credit calculations for the test case.

3.12. EXCHANGE OF OFFSET CREDITS

Credits are earned when management or offset measures achieve or surpass a reduction in sound levels relative to baseline. Through the review of the test case, the discussions focused on the exchange of credits between spatial regions. The exchange of credits was considered for horizontal space only, as consideration of sound level change at different depths was not part of the original review. Also, discussions of temporal credit exchange were given little time, with a high degree of discomfort from the participants for this proposed application of the offsetting approach. Much of the discussion was given to exchanges between sub-regions, although it was agreed that the credit calculation and exchange process should be completed on the finest scale allowable with the data available.

The guiding principles for credit exchange were discussed, with participants stressing that credit exchange should be between areas that are equivalent to give a 'like-for-like' exchange. Practically, this would involve exchange between areas with similar weighting functions (and thus habitat values), or decreasing noise in areas with higher weightings than areas of increase. However, there was no resolution over how big a range of weightings could still be considered as 'like' each other. Also, the definition of equivalency and how this would allow for like-for-like exchange between area units, at any resolution credits were calculated, was not agreed upon.

Comparability in the use and importance of the habitat to the focal species is required for credit exchange, but the criteria for biological equivalency was not established. Equivalency should also take into account any features that are distinct to an area, that may be influential to the habitat use of the focal species. For the test case as it is currently presented, this may mean that exchange might only be possible between those areas identified as foraging areas to other foraging areas, and perhaps more specifically, areas of common and frequent foraging only with areas of a similar level of use. A hierarchical exchange was suggested, whereby, for example, credits for areas identified for foraging could be used to offset residual effects in areas of predominantly travelling behaviours, but not reciprocated from travelling to foraging areas. For this approach to be implemented, however, it would need to be possible to objectively determine that these areas differed in their importance to the focal species, and that indeed an area supporting one type of behavioural context was of lesser importance to the species than another.

Discussions expressed equivalency as area units, including sub-regions, that could be used by the same segment of the population for the same purpose during the same time period that is currently recorded. This may mean not only taking into account the contextual use of an area, but also the number of animals using the area, the section of the population they represent (e.g., same SRKW pods), and their residency time. To be able to exchange credits it is assumed that areas (sub-regions, area units/pixels) would demonstrate equivalency. Situations in which this may not be the case, or that the resolution of weighting factor designation is so fine where absolute equivalence is not achieved were not discussed. Mentioned, but not fully considered, was if areas of equivalency should be assessed for their ability to withstand the assumed extra stress of additional use, if animals were to relocate from one region to another, and how this assessment may be done. It was also suggested that an understanding not just of habitat use, but also connectivity and movement between habitat patches, is needed to fully assess equivalency.

The finer the resolution in space and/or time that the credit calculations are calculated, the more receiver-based the application of the offset approach becomes, which was deemed a benefit. Responses by focal species to changes in sound levels would likely be on these finer spatiotemporal scales (meters to kilometers/ minutes to hours), rather than the aggregated sub-region areas and 6 month time scale presented for the test case. This underlined the suggestion that sub-region definition, weighting factor application, and therefore overall credit calculation should be done at the finest granularity possible. However, care should be taken that the scale used be biologically meaningful for the focal species.

Weighting factors should help determine the habitat of equal quality to the focal species and guide the like-for-like exchange in credits. It was stressed that careful consideration should be given to the credit currency in the development of the approach, determining which measures would be used as weighting factors when calculating credit that will allow for a like-for-like exchange. However, as the test case was discussed, many limitations and uncertainties in the data needed to define habitat equivalency were identified. In general it was thought that the data applied to the test case for SRKW was not rigorous or exhaustive enough to be able to accurately determine area equivalency. Ultimately, this was one of the factors that led to a rejection of the offsetting approach.

The rate of exchange and proximity limits of exchange were also not determined. It may be, given the weighting factor of a region, for example, that the ratio of area units exchanged may not be 1:1. Although there was consensus that exchange should be between equivalent areas, need for these areas to be within a certain spatial proximity was not discussed. Exchange between areas and/or times that are more proximal may be more favourable than those that are more distant. Allowances in the span of space and time, and area equivalency or behavioural context were not discussed and so permissible deviations were not defined at this time.

3.12.1. Test case results

Credit deficits and surpluses were established for the SRKW communication and echolocation ranges as well as a combined metric (Table 8). Although not specifically discussed, it is presumed that within the like-for-like credit exchange definition, credits can only be exchanged within and not between each of these frequency ranges, and only in horizontal (between sub-regions/habitat units at the same water depth) and not vertical space (between water depths). However, too many uncertainties were identified to confidently further any concept of credit exchange under the offsetting approach at this time.

The test case presented two options of area sub-division which allowed for credit exchange between sub-regions. The use of SRKW presence and behavioural data was the preferred means to define the sub-regions, rather than the use of soundscape data. However, the final sub-region definitions were not agreed upon in terms of where divisions should be placed. Refinements were suggested as part of the test case review. The comparison highlighted the sensitivity of the credit calculation to the definition of sub-regions, with dilution of weighting factors dependent on the sub-region definition a great topic of discussion during the review.

Information on the frequency of occurrence of SRKW and presence of foraging regions were determined to be appropriate weighting factor variables, but how weighting factors should be calculated, applied, and used to guide exchange was not decided upon during the review, and was a source of great uncertainty and discomfort. Participants felt that the means to calculate the weighting factors presented in the test case should be adjusted, and the multiplicative approach evaluated as a first step.

It was agreed that the change in noise levels and application of weighting factors should be calculated on the finest possible scale and, where possible, the use of sub-regions should be eliminated. However, how that might impact the credit calculation, and identification of areas of equivalency was not discussed. It is possible that the finer the resolution the greater the variability between area units, and so the harder the ability to identify regions that are used in the same way by SRKW.

The test case represented the application of data to a theoretical concept and proposed offsetting framework. The SRKW-Salish Sea example demonstrated the use of extensive data and the best available science for an at-risk species to the offsetting concept. However, the data available is only sufficient for calculations for offsetting for the period of May to October; the winter period of November to April has much greater unknowns in terms of presence and habitat use of SRKW. The winter is considered data-poor and currently lacks the minimum data needed to apply the offsetting concept, as determined during the review process.

The greatest sources of uncertainty in the credit calculations for the test case came from the use of models. The vessel noise model showed discrepancies when compared to the *in-situ* data (Figure 8), likely because the source levels of vessels were not captured accurately enough in the model inputs, and not all vessel noise sources in the recordings were represented in the input AIS data. Great variability has been shown in source levels for vessels of the same type (see Simard et al. 2016), with ongoing testing to understand how this impacts the model outputs. The calculations in the SRKW communication and echolocation frequencies used values extrapolated from the low-frequency output of the current vessel noise model. The technique used to extrapolate from the low-frequency output to higher frequencies thought to be more pertinent to SRKW may also introduce uncertainty. Improvements to the model are underway for direct modelling in the higher frequencies. Much of the study area was not within the modelling domain for determining foraging areas; the values determined only pertained to regions in Haro Strait and on Swiftsure Bank (Figures 6-7). Also, this data is limited to the summer period. Additional behavioural data or measures that can be used as a proxy for foraging, for example metrics of prey abundance, may be valuable as the offsetting framework is further developed.

The aim of applying the offsetting concept to the test case data was two-fold: to understand how a framework of this kind could be parameterised and used as a conservation measure; and to initiate the development of a more generalised framework that might have wider application to at-risk species subject to project-related vessel noise. However, it became evident through the review that significant refinement would be needed for a noise offset framework to be robust and scientifically defensible.

3.12.2. Other considerations

In discussing the wider applications of an offsetting framework, the case of a multi-species application was considered; however, there was no resolution about how the potential impacts on more than one at-risk species might be addressed concurrently using the approach outlined in the test case. Other SARA-listed species are noted to use the Salish Sea during the summer months in addition to SRKW. These include humpback and gray whales; harbour and Dall's porpoise; and Pacific white-sided dolphins as well as other killer whale ecotypes (McMillian et al. 2022). Although it was agreed that reducing noise levels would be beneficial to all these species generally, in that it increases acoustic habitat quality, it may be difficult to reconcile the different frequencies that would need to be examined to account for these species together, and combine data in a way that the offset would be beneficial to all. If the offsetting approach was to be applied to a multi-species setting, then the credits calculated for exchange may not be equivalent between species. The 'service area' or habitat use of the study area may differ between species, and therefore credit calculation and habitat equivalency may differ.

Future-proofing the offset approach was also discussed. For example, the inclusion of variables or multipliers that would address changes in habitat conditions and sound speed profiles resulting from climate change and altered environmental conditions was suggested. How this would be achieved, and what aspects might be integrated into the credit calculations was, however, not determined. A sensitivity analysis could help determine the input parameters that are most influential to the model results, and how variation in environmental inputs, or uncertainty in their values, would impact model outputs. This would help determine the model dependency on these variables, and the extent to which their input is reflected in the model output. A sensitivity analysis might also help determine the consequences of changes in the input variables, and may be a means to understand the robustness of the model under different oceanographic conditions that represent climate change scenarios.

How success will be defined and reported on when using offsetting measures needs to be better characterised. This includes a schedule and timelines for calculations, and review of the approach (see Figure 4). The rate at which data inputs would be revised, or new data integrated as it becomes available, should also be specified. At these monitoring milestones the efficacy of offsetting management measures will be determined and updates considered, as well as any corrective actions or additional measures that might be needed to be introduced if credit exchange has not met the offset target of no-net increase in noise. In the DFO Offsetting Policy a performance target is suggested, which states a specific value or range which should also be able to take into account variability in the habitat quality indicators or weighting factors used. It should be confirmed through this monitoring process and credit re-evaluation that measures are providing the intended benefits to habitat quality and focal species. Performance targets may not be achieved because of poor design, implementation, or compliance to measures, or because of variability or uncertainty factoring into the credit calculations.

3.13. THE APPLICATION OF OFFSETTING

There was agreement that, conceptually, the offsetting approach could be a means to address project-related noise increases for at-risk cetacean species. Such a framework may be a useful tool to understand where additional measures may be needed to mitigate or offset negative effects; however, the calculation is data intensive. One of the main issues in offsetting use, highlighted by the test case, includes the availability and application of the information needed for the credit calculations. The identified risk and uncertainties in the data needs and implementation led to a high degree of discomfort in the application of offsetting as a conservation tool.

Discussions by participants when reviewing the test case centered on how data that would be applied to the offsetting concept should stress the importance and biological relevance of changes in soundscape to the focal species. However, the uncertainties and limitations in the empirical and/or modelled data available to guide credit calculation were highlighted throughout, with the risks of using this data in the credit calculation and exchange consistently emphasised. Data needs proved to be intensive, with the application to species and/or locations that are data limited was highly discouraged. The minimal data requirements to explore the offsetting approach for an at-risk species was not determined, although it was expressed several times that data on focal species presence would be needed at the very least. This, however, would likely not suffice for robust offsetting calculations. Discomfort in how data would be applied to the credit calculations and exchange led to the overall rejection of offsetting as presented via the test case. Main contributors to this were the lack of sufficient data that could be put towards reliably determining sub-regions and weighting functions, even for a data-rich species and periods like that demonstrated in the test case. The uncertainties of SRKW habitat use in lower use areas of critical habitat, and in areas that extended past predictive model domains added to this.

Some discussion was given to the robustness of the model and how inputs could be used to ‘future-proof’ the predictions. This focused on having realistic climate change predictions in the model inputs, in addition to the high resolution environmental data inputs, that would account for climatic changes if the model were to be used for future predictions. In particular, it was suggested that changes in sound speed and propagation due to changes in water temperature and salinity should be accounted for by inclusion into the model.

It has been suggested, particularly for SARA listed species, that the magnitude of habitat offsetting should be much higher than the allowable habitat impacts. Part of the analysis of the offsetting approach is considering the allowable harm and the level of uncertainty that is acceptable to progress with its application. Offsetting involves allowing habitat losses and/or species impacts at one place and/or time for improvements in another. As such, it has also been suggested that a limit or cap on the allowable impact be enforced, especially for species in decline or with unknown status and/or in areas known to be important to the focal species. This would be in place even if the overall credit calculation reaches or betters the no-net noise increase/ habitat loss goal. The consideration of noise thresholds, or levels where behavioural or physiological responses are known to occur could be incorporated, for example, for species for which these are available. These reference levels are, however, typically generic and applied to broad species groups (low-,mid-, high-frequency users; odontocetes, mysticetes, sirenians, and phocid or otariid pinnipeds; NMFS 2018) and may do little in helping prevent harm. Yet, the comparison to representative species-specific sound levels may still be useful. It was mentioned through the review that the level of change in sound of the equivalent number of dB may be perceived differently by the focal species depending on the initial noise levels (i.e., a change from 92 dB to 90 dB is not the same as 132 dB to 130 dB, despite both being a reduction of 2 dB). As such, noise reductions in regions that are already relatively quiet may not have the same impact overall to the focal species than a reduction in an area more heavily impacted by project noise. A minimum sound level threshold might be considered in this case, where further reductions of noise from this level would have little to no meaningful impact on the at-risk species. Identifying the quieter regions where this threshold may apply might also help focus offsetting actions to regions where they might be most impactful.

There was also concern that in applying an offsetting approach the key tenets of the mitigation hierarchy would be compromised. There was reservations, for example, that efforts would not be given to first prevent an impact or then implementing mitigation measures before using the offset as a last resort (Gardner et al. 2013), or that the application of offsetting would appear like measures are being taken with the effectiveness of these measures not yet fully characterised. Participants warned that implementation of offsetting without significant refinements may lead to a false sense of security in addressing and achieving conservation goals for at-risk species.

The assessment of the application of an offsetting approach should be made on a case-by-case, species-by-species basis, prior to any residual impacts being realised. A lack of data might limit the quantitative nature of this assessment, as would the estimation of the allowable harm in areas under the approach, and the predicted species response. The framework for the approach as described for the test case (see Figure 4) was not designed to be prescriptive, but to assist in the decision-making process of whether offsetting would be beneficial to a species, and help develop the concept and its application for each specific species and setting considered. As described, the use of the approach does not evaluate the effectiveness of mitigation or offset measures in supporting the continuation or recovery of an at-risk species; determine species impacts or the potential for acoustic or behavioural disturbance; identify physiological implications to individuals or populations from altered energetic outputs; or make any assessment of cumulative effects. However, overlaying the regions of impact (Figure 21) and mitigation/offset (Figure 22) can show where measures directly address project-related additions. The application of weighting factors to the impact or offset regions, rather than sub-regions, could determine further the level of disturbance that might be experienced by SRKW and refine of the estimate of the level of impact of the TMX project vessels.

3.13.1. Outcomes

While there was agreement amongst participants that an offsetting approach might be possible conceptually, the inability to realise the conceptual framework as presented for the relatively data-rich SRKW due to multiple knowledge gaps suggests it would be premature to implement such an approach for any species at this time. Offsetting represents the third phase in the mitigation hierarchy, whereby project-related impacts should first be avoided, or mitigated before offsetting is considered to address any residual effects (Gardner et al. 2013). The use of offsetting to address underwater noise is unprecedented, and the application of test case data to understand how this concept might be used to address residual project-related vessel noise was complex. It was increasingly realised through the review that the data required for successful implementation would need to be extensive, and that it was lacking in some areas even for the test case. As a result of the intensity of information needed, the approach was not recommended for data-poor settings, with minimum requirements not definitively established at this time. Also, the uncertainties and risks in the implementation of data to the approach at this time may outweigh any of the potential benefits, and are an obstacle for the approach to be considered further. There are several assumptions underlying the approach that, at the current time, several participants felt there was not sufficient evidence to confirm, not least that the reduction of project-related vessel noise will indeed benefit the focal species. Significant monitoring would also be needed to evaluate the outcomes of the offsetting approach and its function long term to aid the focal species.

It was appreciated by participants that there is likely no standard approach; an offsetting framework, when developed, should be flexible enough to allow for the incorporation of additional information as it becomes available (see Figure 4), and yet specific to each species and/or area that it is applied to. A review of the use of offsetting and its application to at-risk species showed that its effectiveness was uncertain, with concerns that the implementation of the framework might lead to a false sense of security in achieving conservation goals, undermine recovery efforts, or reduce the rigor and effort put to other stages of the mitigation hierarchy (DFO 2022). Through the review of the test case, challenges and methodological concerns in the effectiveness of the approach as a management tool were raised. While aspects of the protocol in calculating offset credits may inform noise reduction measures, and be an aid in identifying the successful implementation and where measures were most effective, additional work is needed before furthering the approach. As it is, it could be used as one of the tools that help to understand the effectiveness of the actions taken to lessen underwater noise, but the uncertainties were thought to be too great for it to successfully address residual effects.

There are no standard metrics or criteria to estimate the impacts of elevated sound exposure in the long term, or estimate the proportion of the focal species subject to project-related noise and how that might translate into population-wide health effects including reduced reproductive success or survival. The offsetting approach as presented here only accounts for changes in noise level and does not address the implications of the behavioural changes, signal masking, stress, or morphological responses that may occur as a result of the changes in the soundscape and noise exposure. Currently, impact and harm of the focal species, including disturbance, injury, or even potential mortality, do not factor into the offsetting framework.

As it is framed presently, the approach has limited means to consider the context of exposures, and so will struggle to truly characterise impact (Gomez et al. 2016, Wright et al. 2023). Also, as is currently presented for the test case, it is likely that the impact on SRKW would be underestimated as a result of uncertainties in the data, or where observations have been applied to the impact estimate without incorporating natural variation (e.g., Wobeser 1994, Wright and Kyhn 2014).

For more thorough impact assessments, a number of knowledge gaps need to be filled, not least: hearing capabilities, and the frequencies that species are sensitive to; trends of occurrence and habitat use in space and time of the focal species through observational and/or acoustic data; the impact of vessel noise on behaviours; potential link between noise emissions and vessel-strike or entanglement; cumulative impacts of project-related activities and/or other noise sources, perhaps part of an impact mapping (Merchant et al. 2018) or probabilistic (Aulanier et al. 2017) approach; tolerance to noise impacts and the implications of acoustic stress on a species. Increased work for characterising baseline or impact studies prior to new project activities commencing would also be beneficial (Wright and Kyhn 2014).

Each application of the offsetting approach will have its own unique considerations, and the precautions needed in the application of the data available to credit calculations and the acceptable risks given the uncertainties. The offsetting approach is one of few that combines several datasets, including animal presence, habitat use data, movement models, *in-situ* or modelled sound level data, as well as potentially environmental or prey abundance data. However, taking the approach from one that helps mitigate noise to one that helps understand impact is still problematic. There are still many gaps in knowledge in each one of these aspects for many at-risk species, as well as a lack of understanding of the biological implication of soundscape changes on cetaceans (Wright 2014, Williams et al. 2020, Marotte et al. 2022). Therefore, the limitations, assumptions, sources of uncertainty, and risk in assigning data to the approach were consistently highlighted in its review. Greater confidence in the use of offsetting will come from using the best available data, at its lowest resolution possible to parameterise the credit calculations, but caveated with associated measures of uncertainty or representations of variability.

4. CONCLUSION

The potential of offsetting as a means to counter project-related impacts was recognised by participants in the review of the proposed framework, and more specifically in the test case example. However, it was agreed that the limitations and uncertainties detailed in this document were cause of great concern for the participants that concluded that the application of an offsetting approach to underwater project-related noise would be premature at this time. Conceptually the steps taken in the proposed framework were sound, however many concerns in the implementation were expressed due to the amount of information and assumptions required. This ultimately hindered the furthering of the offsetting approach. Participants were not comfortable with the use of offsets to counterbalance habitat loss or species impacts in one area with a noise reduction from measures implemented in another. Several shortcomings in the credit calculations were also raised. No consensus about the use of the approach was reached, although many useful suggestions for future consideration were made.

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