UNCLASSIFIED / NON CLASSIFIÉ

TP 15505E

SIMRES Ambient Noise

Observed Differences in the Underwater Noise Soundscape Before and After Implementing the 2019 and 2020 Saturna Island Interim Sanctuary Zones

JASCO Applied Sciences (Canada) Ltd

10 December 2021

Prepared for:

Véronique Nolet and Laurence Lecavalier
Innovation Centre, Transport Canada
Contract T8156-17-0001/001/VAN

Authors:

Graham A. Warner
Toren S. Dofher
S. Bruce Martin

P001370-005 Task Authorization 4, Subtask 4
Document 002377
Version 3.0

NOTICES

Suggested citation:

Warner, G.A., T.S. Dofher, and S.B. Martin. 2021. SIMRES Ambient Noise: Observed Differences in the Underwater Noise Soundscape Before and After Implementing the 2019 and 2020 Saturna Island Interim Sanctuary Zones. Document 002377, Version 3.0. Technical report by JASCO Applied Sciences for Innovation Centre, Transport Canada.

The Innovation Centre (and the co-sponsoring agencies) does (do) not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

This report reflects the views of the authors (or the performing organization) and not necessarily those of the Innovation Centre of Transport Canada.

Un sommaire français se trouve avant la table des matières.

Transport Canada / Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No.	2. Project No.	3. Recipient's Catalogue No.
TP 15505E	B1BW	

4. Title and Subtitle	5. Publication Date
SIMRES Ambient Noise: Observed Differences in the Underwater Noise Soundscape Before and After Implementing the 2019 and 2020 Saturna Island Interim Sanctuary Zones	7 June 2021
	6. Performing Organization Document No.: Document 002377, Version 3.0

7. Author(s)	8. Transport Canada File No.
G.A. Warner, T.S. Dofher & S.B. Martin	RDIMS: 17614892

9. Performing Organization Name and Address	10. PWGSC File No.
JASCO Applied Sciences (Canada) Ltd. Suite 2305, 4464 Markham St. Victoria, BC V8Z 7X8 Canada	Contract T8156-17-0001/001/VAN
	11. PWGSC or Transport Canada Contract No.: P001370-005 Task Authorization 4, Subtask 4

12. Sponsoring Agency Name and Address	13. Type of Publication and Period Covered
Transport Canada, Innovation Centre Innovation Centre (IC) Place de Ville, Tower C 330 Sparks Street, 18th Floor Ottawa, Ontario K1A 0N5	Technical Report, 2020-2021
	14. Project Officer: Véronique Nolet and Laurence Lecavalier

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

SIMRES East Point and Monarch Head Hydroacoustic Measurements: Ambient Sound from February to December 2020

16. Abstract

Underwater ambient noise levels from recordings collected by the Saturna Island Marine Research and Education Society (SIMRES) at two locations in Boundary Pass were analyzed to compare differences in the underwater soundscape before and after implementing the 2019 and 2020 Saturna Island Interim Sanctuary Zones (ISZ). Several factors limited the interpretation of the results, including gaps in the acoustic data, calibration errors, non-acoustic system noise changes, uncertain large- and small-vessel presence, and current-induced flow noise. Given these limitations, the results were inconclusive with regard to documenting any real change in noise within the ISZ between years.

17. Key Words	18. Distribution Statement
Underwater sound	Limited number of copies available from the Innovation Centre

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
Unclassified	Unclassified	—	51	Shipping/ Handling

CI/IC 79-005
Rev. 96

Canada

Transport Canada / Transports Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. No de la publication de Transports Canada. TP 15505E	2. No de l'étude B1BW	3. No de catalogue du destinataire
4. Titre et sous-titre Bruit ambiant recueilli par la SIMRES : Différences observées dans l'environnement acoustique du bruit sous-marin avant et après la mise en œuvre des zones de refuge provisoires de l'île Saturna en 2019 et en 2020		5. Date de la publication 7 juin 2021 6. No de document de l'organisme exécutant Document 002377, Version 3.0
7. Auteur(s) G.A. Warner, T.S. Dofher et S.B. Martin		8. No de dossier - Transports Canada SGDDI : 17614892
9. Nom et adresse de l'organisme exécutant JASCO Applied Sciences (Canada) Ltd. Suite 2305, 4464 Markham St. Victoria, BC V8Z 7X8 Canada		10. No de dossier - TPSGC Contract T8156-17-0001/001/VAN 11. No de contrat - TPSGC ou Transports Canada P001370-005 Task Authorization 4, Subtask 4
12. Nom et adresse de l'organisme parrain Transport Canada Centre d'innovationC) Place de Ville, tour C 330, rue Sparks, 18e étage Ottawa (Ontario) K1A 0N5		13. Genre de publication et période visée Rapport Technique, 2020-2021 14. Agent de projet Véronique Nolet et Laurence Lecavalier

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Mesures hydroacoustiques de SIMRES à East Point et à Monarch Head : Niveaux sonores ambiants de février à décembre 2020

16. Résumé

Les niveaux de bruit ambiant sous-marin provenant d'enregistrements recueillis par la Saturna Island Marine Research and Education Society (SIMRES) à deux endroits dans le passage Boundary ont été analysés afin de comparer les différences dans l'environnement acoustique sous-marin avant et après la mise en œuvre des zones de refuge provisoires (ZRP) de l'île Saturna, de 2019 et 2020. Plusieurs facteurs ont limité l'interprétation des résultats, notamment les lacunes dans les données acoustiques, les erreurs d'étalonnage, les modifications du bruit des systèmes non acoustiques, la présence incertaine de grands et de petits navires et le bruit du flux induit par le courant. Compte tenu de ces limitations, les résultats n'ont pas été concluants en ce qui concerne la documentation d'un changement réel du bruit dans la ZRP entre les années

17. Mots clés Maritime – Bruits sous-marins	18. Diffusion Copie numérique.

19. Classification de sécurité (de cette publication) Non classifiée	20. Classification de sécurité (de cette page) Non classifiée	21. Déclassification (date) —	22. Nombre de pages 51	23. Prix Port et manutention

CI/IC 79-005
Rev. 96

Canada

EXECUTIVE SUMMARY

Transport Canada (TC) commissioned the analysis of underwater sound recordings acquired by the Saturna Island Marine Research and Education Society (SIMRES), to characterize differences in the underwater noise soundscape before and after implementation of the 2019 and 2020 Saturna Island Interim Sanctuary Zones. Two locations in Boundary Pass, south of Saturna Island, BC, were used for the analysis: Monarch Head and East Point. The SIMRES hydrophones are part of the BC Coast Hydrophone Network, which allow for scientific collaboration to monitor underwater soundscape and marine mammals. Boundary Pass is an important habitat for several marine species, including the endangered Southern Resident Killer Whale (SRKW). Much of the SRKW population have consistent and prolonged seasonal occupancy near heavily used shipping lanes. This environment is an important element of their habitat, but the proximity to shipping leads to their experiencing substantial levels of vessel noise that has the potential to disturb and mask sounds important to SRKW, such as transmitting and receiving their echolocation clicks and other vocalizations essential for navigating, foraging, and engaging cultural and social activities (DFO 2011). Transport Canada recognizes the need to monitor, examine and minimize underwater noise conditions to prevent physical disturbance in this critical habitat.

In 2019 and 2020, the Interim Order Respecting the Protection of Killer Whales (Orcinus orca) in the Waters of Southern British Columbia established three interim sanctuary zones (ISZ) to mitigate underwater noise and physical disturbance risks from vessels to killer whale populations. The three ISZ were located off the south-east end of Saturna Island, the south-west coast of Pender Island, and at Swiftsure Bank. This report focusses on acoustic recordings near the Saturna Island ISZ only, which was in effect from 1 Jun to 31 Oct 2019 and 1 Jun to 30 Nov 2020. During these periods, most vessels were banned from operating within the zone.

JASCO Applied Sciences analyzed underwater sound recordings from SIMRES's hydrophones off East Point, Saturna Island (within the sanctuaries) and at Monarch Head (near but outside the sanctuaries) acquired during the three-year period 2018–2020. The recordings at both sites were generally continuous from January 2018 to December 2020, but there were some data gaps due to power outages, and some calibration issues identified. It is noted that the SIMRES's hydrophones are primarily intended for detecting marine mammal calls, with noise characterization being a secondary goal. While some hydrophone calibration work was done, that was not performed consistently and the signal sensitivity is not monitored regularly for possible changes. This places some limitations on their use for the purposes of comparing noise levels between years. The data calibration and consistency issues were examined and the effects of occasional inconsistencies in sensitivity are discussed here.

Sound levels were analyzed and presented in standard formats for both sites in accompanying technical reports (Dolman et al. 2020, Dofher and Warner 2021). Those reports contained results in decade frequency bands that are commonly used for underwater soundscape analysis but they are not specifically designed for SRKW

acoustic masking analysis. In this report, sound levels were also analyzed in frequency bands relevant for killer whale communication and echolocation as defined by an independent technical working group (Heise et al. 2017). In an attempt to isolate and identify possible effects of implementing the ISZ on sound levels, the analysis performed here omitted time periods that may have been modified or contaminated by other confounding factors such as high wind speeds and large-vessel traffic. The analysis also focussed on daytime (7 am to 7 pm) measurements between June and October of the three years because most traffic in the ISZ is small vessels that operate primarily during daylight hours and the ISZ was in effect only over these summer months. Large-vessel traffic was assessed using Automatic Identification System (AIS) data and an automated large-ship acoustic detector. Small-vessel traffic could not be reliably determined because not all small vessels broadcast AIS messages.

A modelling study showed a very small decrease in mean sound level (0.2 dB broadband) from implementing the Saturna Island ISZ (Matthews and Grooms 2020). Identifying such a small decrease with measurements is extremely difficult even with high-quality data for several reasons. First, natural variability of ambient noise levels from weather-related sounds often leads to variations of levels by several decibels and year-to-year weather differences will lead to differences in underwater noise levels. Noise from vessel traffic outside the ISZ can propagate into the zone, also leading to variations of several decibels. Water currents lead to vibrations of hydrophones that produces non-acoustic noise that varies with the tides, and hydrophone systems that are not accurately calibrated have limited accuracy, so comparing their levels between years or even between deployments in the same year is not always possible.

After applying filtering to exclude high wind periods, large vessel presence exclusion, and temporal filtering criteria, the measured sound levels in 2019 and 2020, when the sanctuaries were in effect, were found to be higher at least in some frequency bands than measured in 2018, before the sanctuary was implemented. This increase is obviously the opposite of what was expected, but we attribute the finding to natural noise variability, non-acoustic noise from currents, and hydrophone accuracy issues as explained above. The measurements here were further confounded by some data dropouts during the months the ISZ was in place. Some electronic noise and recording system sensitivity changes also reduced the data available for comparison between years. Our overall interpretation of these results is that they are inconclusive with regard to documenting any real change in noise within the ISZ between years.

Accurately measuring the effect of the sanctuaries would require more highly calibrated and consistent acoustic monitoring systems, together with a careful monitoring of confounding noise sources. The ISZ is in an environment with very high tidal currents. Substantial improvement in acoustic data quality could be achieved through installation of hydrophone flow shields and/or specialized hydrophone supports. A study of noise savings could combine other monitoring methods with acoustic data. For example, the measurements here would have benefitted from simultaneous monitoring for small vessel presence using video, radar, or lidar. Our understanding is that SIMRES has recently implemented a video system that might be used for combined studies in the future. Non-acoustic noise from tidal currents is a significant confounding factor in the SIMRES acoustic data. The current speed at the hydrophone locations likely is not predicted well by tide models because of complex eddies that form around East Point and Monarch Head. A current meter deployed near each hydrophone site would be highly beneficial to allow determination of periods of high currents, which could then be filtered out to reduce the effect of this noise.

SOMMAIRE

Transports Canada (TC) a commandé l'analyse d'enregistrements sonores sous-marins acquis par la Saturna Island Marine Research and Education Society (SIMRES), afin de caractériser les différences dans l'environnement acoustique du bruit sous-marin avant et après la mise en œuvre des zones de refuge provisoires de l'île Saturna, de 2019 et 2020. Deux endroits dans le passage Boundary, au sud de l'île Saturna, en Colombie-Britannique, ont été utilisés pour l'analyse : Monarch Head et East Point. Les hydrophones de la SIMRES font partie du BC Coast Hydrophone Network, qui permet une collaboration scientifique pour surveiller l'environnement acoustique sous-marin et les mammifères marins. Le passage Boundary est un habitat important pour plusieurs espèces marines, y compris l'épaulard résident du Sud (ERS), en voie de disparition. Une grande partie de la population des ERS côtoie de manière saisonnière, constante et prolongée des voies de navigation très achalandées. Cet environnement est un élément important de leur habitat, mais la proximité de la navigation les expose à des niveaux substantiels de bruit provenant de navires qui peuvent perturber et masquer les sons importants pour l'ERS, tels que la transmission et la réception de ses clics d'écholocalisation et d'autres vocalisations essentielles pour la navigation, la recherche de nourriture et les activités culturelles et sociales (DFO 2011). Transports Canada reconnaît la nécessité de surveiller, d'examiner et de minimiser les conditions de bruit sous-marin afin d'éviter les perturbations physiques dans cet habitat essentiel.

En 2019 et 2020, l'Arrêté d'urgence concernant la protection des épaulards (Orcinus orca) dans les eaux du sud de la Colombie-Britannique a établi trois zones de refuge provisoires (ZRP) pour atténuer les risques de bruit sous-marin et de perturbation physique des navires pour les populations d'épaulards. Ces trois ZRP étaient situées à l'extrémité sud-est de l'île Saturna, au large de la côte sud-ouest de l'île Pender et sur le banc Swiftsure. Ce rapport, qui était en vigueur du 1er juin au 31 octobre 2019 et du 1er juin au 30 novembre 2020, est axé uniquement sur les enregistrements acoustiques à proximité de la ZRP de l'île Saturna. Pendant ces périodes, la navigation dans cette zone était interdite à la plupart des navires.

JASCO Applied Sciences a analysé les enregistrements sonores sous-marins des hydrophones de la SIMRES au large d'East Point, sur l'île Saturna (à l'intérieur des refuges) et à Monarch Head (à proximité, mais à l'extérieur des refuges) acquis au cours de la période de trois ans de 2018 à 2020. Les enregistrements aux deux endroits ont été généralement continus de janvier 2018 à décembre 2020, mais il y a eu quelques lacunes dans les données en raison de pannes de courant et parce que certains problèmes d'étalonnage ont été relevés. Il convient de noter que les hydrophones de la SIMRES sont principalement destinés à la détection des vocalises de mammifères marins, l'interprétation du bruit étant un objectif secondaire. Bien que certains travaux d'étalonnage des hydrophones aient été effectués, ils n'ont pas été effectués de manière cohérente et la sensibilité du signal n'est pas surveillée régulièrement pour détecter d'éventuels changements. Cela impose certaines limites à leur utilisation à des fins de comparaison des niveaux de bruit entre les années. Les problèmes d'étalonnage et de

cohérence des données ont été examinés et les effets des incohérences occasionnelles de sensibilité sont discutés ici.

Les niveaux sonores ont été analysés et présentés dans des formats standard pour les deux endroits dans les rapports techniques d'accompagnement (Dolman et al. 2020, Dofher and Warner 2021). Ces rapports contenaient des résultats dans des bandes de fréquences décennales couramment utilisées pour l'analyse de l'environnement acoustique sous-marin, mais ils ne sont pas spécifiquement conçus pour l'analyse du masquage acoustique de l'ERS. Dans ce rapport, les niveaux sonores ont également été analysés dans les bandes de fréquences pertinentes pour la communication et l'écholocalisation des épaulards, telles que définies par un groupe de travail technique indépendant. (Heise et al. 2017). Dans une tentative d'isoler et de déterminer les effets possibles de la mise en œuvre de la ZRP sur les niveaux sonores, l'analyse effectuée ici a omis les périodes de temps qui peuvent avoir été modifiées ou contaminées par d'autres facteurs de confusion tels que la vitesse élevée du vent et le trafic de grands navires. L'analyse portait également sur les mesures diurnes (de 7 h à 19 h) entre juin et octobre des trois années, car la majorité du trafic dans la ZRP est constitué de petits navires qui naviguent principalement pendant les heures de clarté et la ZRP n'était en vigueur que pendant ces mois d'été. Le trafic des grands navires a été évalué à l'aide des données du système d'identification automatique (SIA) et d'un détecteur acoustique automatisé pour les grands navires. Le trafic des petits navires n'a pas pu être déterminé de manière fiable, car certains petits navires ne diffusent pas de messages à l'aide du SIA.

Une étude de modélisation a montré une très faible diminution du niveau sonore moyen (0,2 dB à large bande) à la suite de l'établissement de la ZRP de l'île Saturna (Matthews and Grooms 2020). Il est extrêmement difficile de relever une si petite diminution à l'aide de mesures, même avec des données de haute qualité, et ce pour plusieurs raisons. Premièrement, la variabilité naturelle des niveaux de bruit ambiant provenant des sons liés aux conditions météorologiques entraîne souvent des variations de niveaux de plusieurs décibels et les différences météorologiques d'une année à l'autre entraîneront des différences dans les niveaux de bruit sous-marin. Le bruit du trafic maritime à l'extérieur de la ZRP peut se propager dans la zone, entraînant également des variations de plusieurs décibels. Les courants d'eau entraînent des vibrations des hydrophones qui produisent un bruit non acoustique qui varie selon les marées, et les systèmes d'hydrophones qui ne sont pas étalonnés avec exactitude offrent une précision limitée, il n'est donc pas toujours possible de comparer leurs niveaux entre les années ou même entre les déploiements de la même année.

Après avoir appliqué un filtrage pour exclure les périodes de vents forts, une exclusion de la présence de grands navires et des critères de filtrage temporel, les niveaux sonores mesurés en 2019 et 2020, lorsque les refuges étaient en vigueur, se sont avérés plus élevés, au moins dans certaines bandes de fréquences, que ceux mesurés en 2018, avant l'établissement du refuge. Cette augmentation est évidemment à l'opposé de ce qui était attendu, mais nous attribuons le résultat à la variabilité naturelle du bruit, au bruit non acoustique des courants et aux problèmes de précision des hydrophones, comme expliqué ci-dessus. Les mesures ici ont été en outre brouillées par quelques abandons de données pendant les mois où la ZRP était en place. Certains changements de sensibilité au bruit électronique et au système d'enregistrement ont également réduit les données disponibles pour la comparaison entre les années. Notre interprétation globale de ces résultats est qu'ils ne sont pas concluants en ce qui concerne la documentation d'un changement réel du bruit dans la ZRP entre les années.

Mesurer avec précision l'effet des refuges nécessiterait des systèmes de surveillance acoustique mieux étalonnés et plus cohérents, ainsi qu'une surveillance attentive des sources de bruit portant à confusion. La ZRP est dans un environnement avec des courants de marée très élevés. Une amélioration substantielle de la qualité des données acoustiques pourrait être obtenue grâce à l'installation de dispositifs pour réduire le bruit d'écoulement et/ou de supports spécialisés pour hydrophones. Une étude des économies de bruit pourrait combiner d'autres méthodes de surveillance avec des données acoustiques. Par exemple, les mesures effectuées ici auraient bénéficié d'une surveillance simultanée de la présence de petits navires à l'aide d'une vidéo, d'un radar ou d'un lidar. Nous comprenons que la SIMRES a récemment mis en œuvre un système vidéo qui pourrait être utilisé pour des études combinées à l'avenir. Le bruit non acoustique des courants de marée est un facteur de confusion important dans les données acoustiques de la SIMRES. La vitesse du courant aux emplacements des hydrophones n'est probablement pas bien prédite par les modèles de marée en raison des tourbillons complexes qui se forment autour d'East Point et de Monarch Head. Un courantomètre déployé à proximité de chaque emplacement d'hydrophone serait très utile pour permettre de déterminer les périodes de forts courants, qui pourraient ensuite être filtrés pour réduire l'effet de ce bruit.

CONTENTS

FIGURES

TABLES

GLOSSARY OF ABBREVIATIONS, ACRONYMS, SYMBOLS, AND SPECIAL TERMS

ambient noise

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

background noise

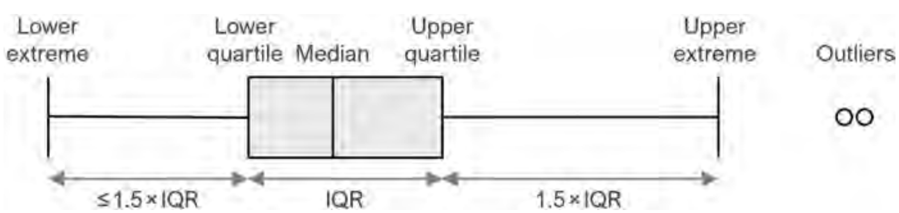
Total of all sources of interference in a system used for the production, detection, measurement, or recording of a signal, independent of the presence of the signal (ANSI S1.1-1994 (R2004)). Ambient noise detected, measured, or recorded with a signal is part of the background noise.

bandwidth

The range of frequencies over which a sound occurs. Broadband refers to a source that produces sound over a broad range of frequencies (e.g., seismic airguns, vessels) whereas narrowband sources produce sounds over a narrow frequency range (e.g., sonar) (ANSI/ASA S1.13-2005 (R2010)).

box-and-whisker plot

A plot that illustrates the centre, spread, and overall range of data from a visual 5-number summary. The box is the interquartile range (IQR), which shows the middle 50% of the data—from the lower quartile (25th percentile) to the upper quartile (75th percentiles). The line inside the box is the median (50th percentile). The whiskers show the lower and upper extremes excluding outliers, which are data points that fall more than 1.5 × IQR beyond the upper and lower quartiles.



broadband sound level

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

decade

Logarithmic frequency interval whose upper bound is ten times larger than its lower bound (ISO 2006).

decidecade

One tenth of a decade (ISO 2017). Note: An alternative name for decidecade (symbol ddec) is “one-tenth decade”. A decidecade is approximately equal to one third of an octave (1 ddec ≈ 0.3322 oct) and for this reason is sometimes referred to as a “one-third octave”.

decidecade band

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

decibel (dB)

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

frequency

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

Global Positioning System (GPS)

A satellite based navigation system providing accurate worldwide location and time information.

hertz (Hz)

A unit of frequency defined as one cycle per second.

hydrophone

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

mean-square sound pressure spectral density

Distribution as a function of frequency of the mean-square sound pressure per unit bandwidth (usually 1 Hz) of a sound having a continuous spectrum (ANSI S1.1-1994 (R2004)). Unit: $\mu Pa^2/Hz$.

median

The 50th percentile of a statistical distribution.

percentile level, exceedance

The sound level exceeded n % of the time during a measurement.

power spectrum density

Generic term, formally defined as power in W/Hz, but sometimes loosely used to refer to the spectral density of other parameters such as square pressure or time-integrated square pressure.

pressure, acoustic

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

pressure, hydrostatic

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

rms

root-mean-square.

sound

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

sound pressure level (SPL)

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

For sound in water, the reference sound pressure is one micropascal (p_0 = 1 μPa) and the unit for SPL is dB re 1 μPa^2:

$$L_p = 10\log_{10}(p^2/p_0^2) = 20\log_{10}(p/p_0)$$

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

spectral density level

The decibel level ($10 \cdot \log_{10}$) of the spectral density of a given parameter such as SPL or SEL, for which the units are dB re 1 μPa^2/Hz and dB re 1 μPa^2·s/Hz, respectively.

spectrogram

A visual representation of acoustic amplitude compared with time and frequency.

spectrum

An acoustic signal represented in terms of its power, energy, mean-square sound pressure, or sound exposure distribution with frequency.

1. INTRODUCTION

Transport Canada (TC) commissioned JASCO Applied Sciences (JASCO) to analyze underwater sound recordings acquired by the Saturna Island Marine Research and Education Society (SIMRES) to characterize differences in the underwater noise soundscape before and after implementation of the 2019 and 2020 Saturna Island Interim Sanctuary Zones. Two locations in Boundary Pass, south of Saturna Island, BC, were used for analysis: Monarch Head and East Point. The SIMRES hydrophones are part of the BC Coast Hydrophone Network, which allow for scientific collaboration to monitor underwater soundscape and marine mammals. Boundary Pass is an important habitat for several marine species, including the endangered Southern Resident Killer Whale (SRKW). Much of the SRKW population have consistent and prolonged seasonal occupancy near heavily used shipping lanes. This environment is an important element of their habitat; however, they experience substantial levels of vessel noise here that has the potential to disturb and mask important sounds, such as echolocation clicks and other vocalizations essential for navigating, foraging, and engaging cultural and social activities (DFO 2011). Transport Canada recognizes the need to examine underwater noise conditions and prevent physical disturbance in this critical habitat.

In 2019 and 2020, the Interim Order Respecting the Protection of Killer Whales in the Waters of Southern British Columbia established three interim sanctuary zones (ISZ) to mitigate underwater noise and physical disturbance risks from vessels to killer whale populations. The three zones included: off the south-east end of Saturna Island, the south-west coast of Pender Island, and at Swiftsure Bank. This report focusses on acoustic recordings near the Saturna Island ISZ only. The Saturna ISZ were in effect from 1 Jun to 31 Oct 2019 and 1 Jun to 30 Nov 2020. During these periods, most vessels were banned from operating within these areas. The zones were relatively near shore and outside the International Shipping Lanes, so most of the affected traffic is smaller vessels such as recreational and fishing vessels.

To assess the change in sound levels due to the implementation of sanctuary zones, we analyzed underwater sound recordings from SIMRES's hydrophones at East Point (within the sanctuaries) and at Monarch Head (near but outside the sanctuaries). The recordings at both sites were generally continuous from January 2018 to December 2020, but some data gaps and calibration issues were identified. Figure 1 shows a map of the Saturna Interim Sanctuary Zone (ISZ), the locations of the two hydrophones and their detection range, and two nearby weather stations.

Sound levels recorded by both hydrophones were analyzed and presented in standard formats for both sites in accompanying technical reports (Dolman et al. 2020, Dofher and Warner 2021). Those reports contained results in decade frequency bands that are commonly used for underwater soundscape analysis and are relevant to different species of marine mammals. A previous analysis compared the sound levels from 2019 to those from 2018 to assess the effect of the 2019 sanctuary (Warner 2020). The study found some decreases in sound levels in 2019 compared to in 2018 but recommended that other cofounding factors be taken into account, including correct calibration information, system noise quantification, AIS data for large-vessel presence, acoustic vessel detector results, and water current speeds in order to ensure sound level differences could be confidently attributed to implementation of the 2019 ISZ. The present report builds on that study by including recent analysis of 2020 recordings from SIMRES and applies an updated method to assess the possible effects from the interim sanctuary zones on sound levels at both sites.

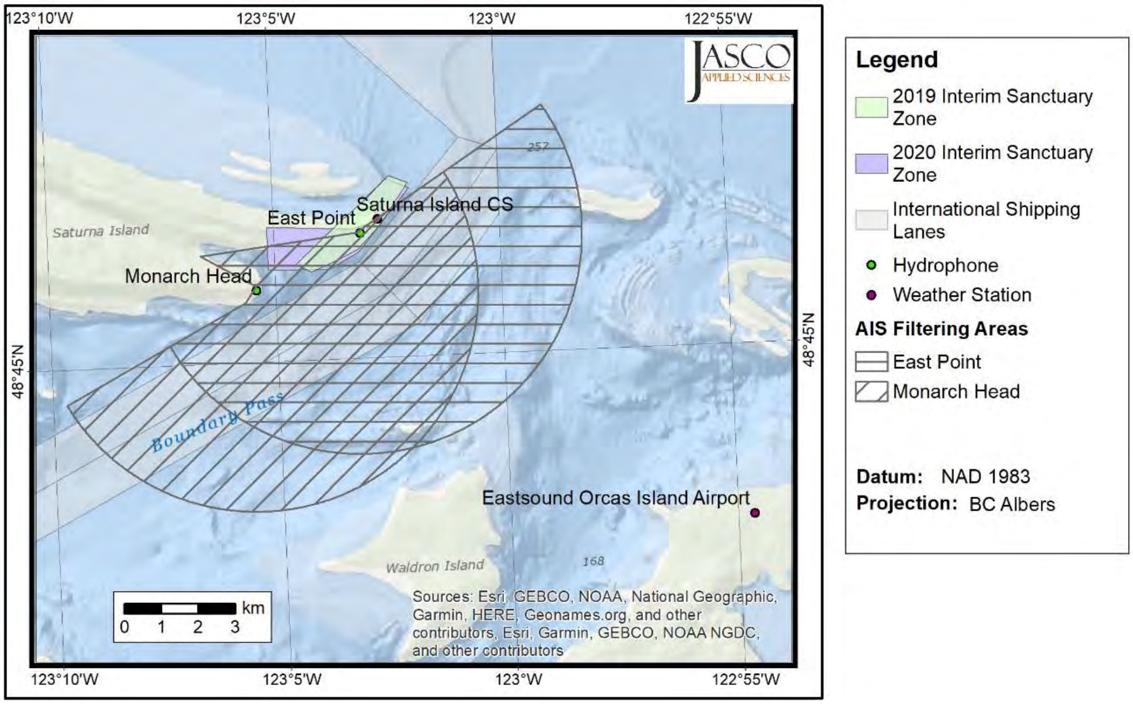


Figure 1. Map of the 2019 and 2020 Saturna Interim Sanctuary Zone (ISZ) and the locations of the hydrophones with their detection range. The map also shows the locations of nearby weather stations and the Automatic Identification System (AIS) filtering areas (described in Section 2.3).

2. METHODS

2.1. Acoustic Data

Acoustic data were collected by SIMRES using icListen hydrophones deployed close to shore at East Point and Monarch Head. The hydrophones were deployed at approximate 20 m depth. SIMRES's hydrophone data collected in 2018 and 2019 were previously processed and reported (Warner 2020). Those results (sound levels versus time) are considered in the present report along with new results obtained by similar processing of SIMRES's 2020 data. Table 1 lists the stations, icListen serial numbers, and details for each deployment over the analysis period, and Figure 2 shows the hydrophone sensitivity versus frequency curves for each hydrophone serial number and deployment. The sensitivity curves were obtained from independent calibrations performed by the hydrophone manufacturer and provided to JASCO by SIMRES. The hydrophone at East Point was changed in October 2020 because a new 2--channel system was deployed, and the hydrophone at Monarch Head was deployed in May 2020 to replace a system that was damaged by underwater boulder movement.

The 2018 and 2019 calibration information was originally provided only to a maximum frequency of ~25 kHz, while the acoustic data were sampled at 128 kHz and contained sound measurements up to the Nyquist frequency (64 kHz). The calibration values between 25 kHz and 64 kHz were therefore unknown during the original processing. The approach taken then was to extend the calibration value at 25 kHz through to 64 kHz (Figure 2). That assumption was not validated and consequently we cautioned the accuracy of reported levels at frequencies above 25 kHz. JASCO has since obtained more information on the high-frequency sensitivity of these hydrophones (Appendix A) and has performed additional investigation of the sensitivity curves used for the 2018 and 2019 data analysis. The result of the investigation was that the sensitivities for the 2018 and 2019 deployments should have been similar to those used for the 2020-02 East Point and 2020 Monarch Head deployments. Data for 2018 and 2019 could not be reprocessed in time for inclusion in this report with the updated calibration information. Results in this report for 2018 and 2019 are from the original data processing study (Warner 2020) which used the sensitivity curves shown in Figure 2 with results not accurate in the 10–10000 Hz and 25–64 kHz frequency ranges.

No calibration information was received for hydrophone icListen 2096 at the time of analysis and it was assumed to have the same sensitivity as the 2018-01 deployment for icListen 1283. Since analysis, we now understand the sensitivity curve used was incorrect (see previous paragraph) and have received calibration information for this hydrophone (Appendix A) that could be used for updating the results. Table 1 lists the deployments for which inaccurate calibrations were used for analysis and how sound levels were affected.

Table 1. Stations, icListen serial numbers, and deployment details for the 2018–2020 period.

Station	icListen serial number	Deployment name	Recording period	Calibration used for analysis
East Point	1283	2018-01	January 2018 to December 2019	Inaccurate. Reported levels are ~6 dB too high in the 10–10000 Hz range, 0–6 dB too high in the 10–20 kHz range, and 2–3 dB too high in the 25–64 kHz range.
	1283	2020-02	February to October 2020	Accurate
	2096	2020-10	October to December 2020	Inaccurate. Reported levels are ~6 dB too high in the 10–10000 Hz range, 0–6 dB too high in the 10–20 kHz range, and 2–3 dB too high in the 25–64 kHz range.
Monarch Head	1289	2018-01	January 2018 to December 2019	Inaccurate. Reported levels are ~6 dB too high in the 10–4000 Hz range, 0–6 dB too high in the 4–10 kHz range, and 2–3 dB too high in the 25–64 kHz range.
	1289	2020-01	February to March 2020	Accurate
	1289	2020-12	December 2020	Accurate
	1376	2020-05	May to December 2020	Accurate

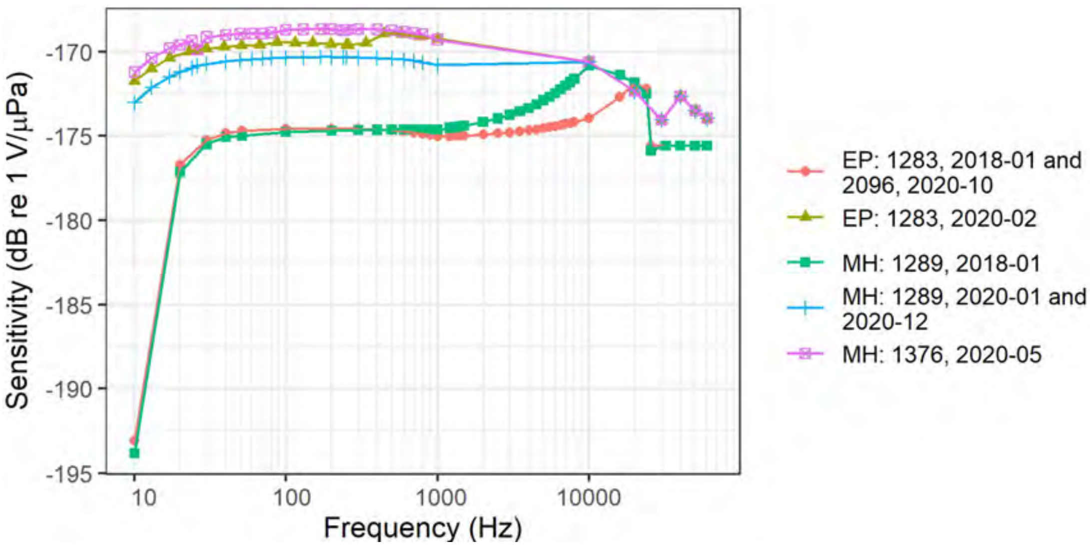


Figure 2. Hydrophone sensitivities used for analysis. The legend indicates the abbreviated site name (EP = East Point, MH = Monarch Head), followed by the icListen serial number, and the deployment name(s).

Acoustic data were processed to compute 1-minute sound pressure level (SPL) in different frequency ranges, including broadband (10–64000 Hz); decade bands (10–100 Hz, 100–1000 Hz, 1–10 kHz, and partial decade band 10–64 kHz); decidecade bands; and for the CORI communication (500–15000 Hz) and echolocation (15–64 kHz) bands for killer whales (Heise et al. 2017). Dolman et al. (2020) and Dofher and Warner (2021) present sound level statistics for these bands except for the two CORI bands; Appendix B in this report contains CORI band sound level statistics for the 2020 data (2018 and 2019 data are in Warner (2020)).

These frequency bands are relevant to different marine mammal species. For example, low-frequency hearing baleen whales such as humpback whales typically have good hearing sensitivity in the 10–100 Hz band, and mid-frequency hearing toothed whales such as killer whales typically have good hearing sensitivity for communication in the 1000–10000 Hz band. The two CORI bands are respectively designed for killer whale communication and foraging (echolocation) sounds. These frequency bands are commonly used to quantify ambient sound levels in other hydroacoustic studies worldwide and have been used historically for other measurements in the Salish Sea (Warner et al. 2019, Warner et al. 2020). Using consistent frequency bands allows for direct comparison with other studies.

The icListen hydrophones were programmed to record continuously, but there were many gaps in the acoustic recordings. There was also a period of time in the East Point recordings, between 26 Feb and 28 Mar 2020, when sound levels appear unrealistically low, so those data were removed from subsequent analysis. This amounted to removing 47% of the provided data in February and 89% of the provided data in March. Figure 3 shows the percent of each month for which we received valid acoustic data, across all three analysis years. Table 2 summarizes the percent of each year for which we received valid acoustic data. Table 3 lists the 2020 data gaps and their explanations.

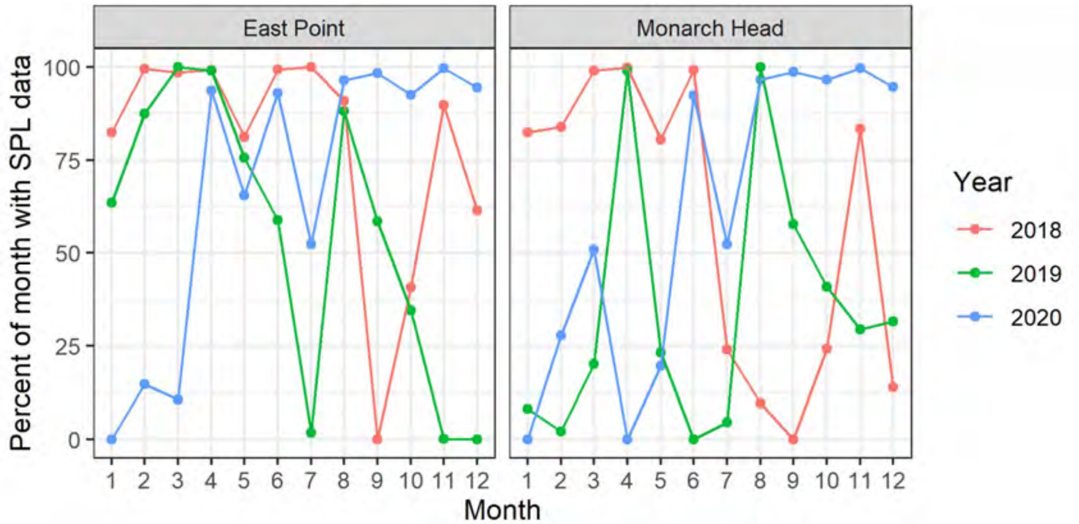


Figure 3. Percent of each month with sound pressure level (SPL) data.

Table 2. Summary of data availability by station and year.

Station	Data availability (% of year)		
	2018	2019	2020
East Point	78.4	55.4	75.9
Monarch Head	58.0	34.9	60.8

Table 3. List of 2020 data gaps or issues identified by JASCO and their explanations provided by SIMRES.

Station	Start	End	Issue	Explanation
East Point	2020 Jan 1	2020 Feb 21	Missing data prior to 21 Feb.	Reason unknown - both wav and FFT files missing.
East Point	2020 Feb 23	2020 Feb 23	Missing data.	Power failure that prevented data from being logged
East Point	2020 Feb 25	2020 Mar 28	Large decrease in sound level starting 25 Feb and ending 8 Mar. Levels in that period are unrealistic.	No maintenance was performed. For this exact period, 24-bit wav files were converted to 16-bit flac. Sound levels would therefore be 48 dB too low.
East Point	2020 Apr 3	2020 Apr 9	Multiple periods of missing data only for few hours at a time.	Power outages 3–7 Apr, maintenance 9 Apr
East Point	2020 May 1	2020 May 12	Missing data 1–12 May	IT issue/missing data - both wav and FFT files.
East Point	2020 May 17	2020 May 17	Missing data for few hours.	Remote maintenance on NUC.
East Point	2020 Jun 20	2020 Jun 24	Sections of missing data.	Issues with logging computer, repairs completed 22 Jun.
East Point	2020 Jul 7	2020 Jul 22	Missing data 8–24 Jul, with small clip of good data 16 Jul.	Old ONC Pepwave router failure, maintenance attempted 16 Jul and equipment replaced 22 Jul.
East Point	2020 Aug 20	2020 Aug 21	Missing data for 1 day.	Reason unknown - both wav and FFT files missing.
East Point	2020 Sep 23	2020 Sep 23	Missing data for few hours.	System maintenance.
East Point	2020 Sep 23	2020 Oct 1	60 Hz tone substantially lower in level during this time than in months before.	New power supply system with UPS installed.
East Point	2020 Oct 1	2020 Oct 4	Missing data for 2 days.	Single hydrophone mooring recovered, 2-element mooring deployed
East Point	2020 Oct 4	2020 Dec 31	Increase in sound level especially at low frequencies, and power supply tone absent.	New hydrophones and better grounding.
East Point	2020 Dec 22	2020 Dec 24	Missing data for about 36 hours.	Storm knocked out power - new UPS allowed 36 h of additional data collection.
Monarch Head	2020 Jan 1	2020 Feb 21	Missing data from 1 Jan to 21 Feb.	Reason unknown - both wav and FFT files missing
Monarch Head	2020 Feb 23	2020 Feb 23	Missing data for few hours.	Power failure at East Point that prevented data from being logged.
Monarch Head	2020 Mar 14	2020 Mar 15	Missing data for 1 day.	Power failure at East Point that prevented data from being logged

Station	Start	End	Issue	Explanation
Monarch Head	2020 Mar 17	2020 May 25	Missing data.	Large boulder crushed underwater cable during storm. New cable and mooring deployed 25 May.
Monarch Head	2020 Jun 17	2020 Jun 23	Sections of missing data.	Lost communications 17 Jun, issues with logging computer at East Point 20-22 Jun, repairs completed 22 Jun.
Monarch Head	2020 Jul 7	2020 Jul 22	Missing data, nearly identical to same outages at East Point.	Old ONC Pepwave router failure, maintenance attempted 16 Jul and equipment replaced 22 Jul.
Monarch Head	2020 Aug 20	2020 Aug 21	Missing data over same period as East Point.	Reason unknown - both wav and FFT files missing.
Monarch Head	2020 Sep 23	2020 Sep 23	Missing data over same period as East Point.	System maintenance at East Point.
Monarch Head	2020 Oct 1	2020 Oct 2	Missing data, but over shorter period than corresponding outage at East Point	System at East point down to replace East point mooring, which prevented logging of Monarch Head data.
Monarch Head	2020 Dec 21	2020 Dec 24	Missing data over same period as East Point.	Storm knocked out power - new UPS allowed 36 h of additional data collection.

2.2. Windspeed Data

The effect of wind on underwater noise recordings is due to wave-entrapped bubble collapse and surface spray. This noise increases with wind speed and generally occurs at frequencies between 300 and 100 kHz (Jensen et al. 1994). Wind speed data for the time period analyzed were obtained from the Environment Canada weather station Saturna Island CS (Climate ID 1017101), or when unavailable, the Eastsound Orcas Island Airport (station 72220804224). Wind speed data were used to filter out time periods when sound levels were affected by wind-driven ambient noise to avoid interfering with the potential effects of implementing the sanctuary zones (above 10 kn).

2.3. AIS Data

Vessels over 300 tons (excluding fishing vessels) and passenger vessels over 150 tons carrying over 12 passengers are required to broadcast AIS information at regular intervals for traffic safety reasons. AIS messages are likely the most reliable and available data source for large vessel traffic in Boundary Pass. Since August 2018, JASCO has continuously acquired AIS data for ships in Boundary Pass at a land-based AIS receiver located near the East Point hydrophone on Saturna Island. These data were supplemented with earlier AIS data collected by SIMRES for the period 1 Jan 2018 to 17 Sep 2019.

Since large vessels typically transit in the international shipping lanes and outside of the ISZ, most vessels that would enter the sanctuary zones are expected to be small. However, large vessels can be much louder than small vessels, and can mask small-vessel noise even if they are farther away. We wanted to exclude periods when sounds from large vessels dominated the sound field. To do this, we used the AIS data to limit our analysis to times when large vessels would not be expected to heavily influence sound levels at the hydrophones.

AIS data were first spatially filtered to exclude vessel position reports when the direct source-receiver path was blocked by land. Figure 1 shows a map of the spatial filter applied to the AIS data. The remaining AIS data were then split into “large” or “small” vessel categories based on the vessel class broadcast in the ship’s AIS messages. Small vessels were those classified as “Pleasure Craft” or “Sailing” vessels; large vessels were any AIS-broadcasting vessels aside from those classes.

Next, filtering was applied to remove times when large vessels were within 6 km of the hydrophones, except during time periods when a small vessel was six times closer to the hydrophone than the nearest large vessel. This exception was applied to retain periods when small vessels were expected to dominate the sound levels at the hydrophones.

2.4. Acoustic Detections of Large Vessels

An automated detector was used to determine time periods when large vessels that did not broadcast AIS messages were present. This detector was applied to determine times when large vessels, not identified by AIS, were present and possibly affecting noise statistics inside the ISZ. The detector compares sound levels in established frequency ranges to threshold values. If the criteria is met, a ‘shippingFlag’ value of either 1 (vessel is present) or 2 (vessel is nearby) is set. The highest sound level within the minutes flagged as having a vessel present is assigned as the closest point of approach (CPA). The criteria values are outlined in Table 4; criteria names are shown in italics in the description below. The criteria are:

- The background SPL within the frequency range is calculated as a long-term average over the *background window duration*.
- Each minute’s SPL (within the frequency range) must be greater than the background value by the *Shipping to background noise threshold*.
- Each minute’s SPL (within the frequency range) must exceed the total broadband SPL by *Shipping to RMS Threshold.*
- Each minute’s SPL must be greater than the *min broadband SPL.*
- The average number of tonals detected over a *Min shipping duration* minute window must be greater than *Minimum # of shipping tonals.*
- The duration of the shipping detection must be greater than *Minimum shipping duration* and less than *Maximum shipping duration.*

If all of the criteria are met, the ‘shippingFlag’ is set to 1, indicating that a vessel is present in that minute of data. We then assume that the anthropogenic shoulder before and after the shipping detection flag ‘1’ values have energy from the vessel that did not meet the criteria and should not be considered as ‘ambient’. This window is given a value of 2 for the shipping detection flag. This system of 1 and 2 attempts to distinguish between vessels that are nearer and farther from the hydrophone, i.e., for large vessels the sequence is typically a series of flags of 2 (approach), then 1 (over/nearest), then 2 (departure). This distinction, however, is not used for this study. Only vessel presence (either a ‘1’ or ‘2’ state) is used here.

Table 4. Parameters of the vessel detector.

Parameter	Vessel detector
fmin flag (Hz)	40
fmax flag (Hz)	315
Minimum broadband SPL (dB)	105
Minimum # of shipping tonals	3
Background window duration (minutes)	720
Minimum shipping duration (minutes)	5
Maximum shipping duration (minutes)	360
Typical shipping passing duration (minutes)	30
Shipping to background noise threshold (dB)	3
Shipping to RMS threshold (dB)	12
Anthropogenic shoulder (minutes)	15

2.5. Water Currents

At the East Point and Monarch Head locations, current speeds were obtained from the WebTide Tidal Prediction Model (v0.7.1) (Foreman et al. 2000, Institute of Ocean Sciences 2015) with 1 minute resolution (interpolated from 15 minute base resolution). The WebTide current model predicts currents at specified geographic coordinates but does not provide depth-dependent currents, so the modelled currents may not be representative of the currents at the seabed where the hydrophones were deployed. There did not appear to be a correlation between modelled current speed and sound level at either hydrophone. Flow noise is clearly seen on the signals measured by these hydrophones, and the lack of correlation likely represents a mismatch between WebTide model predictions and true currents at these sites. That could be explained by back-eddies that are known to be present near shore and especially around the protruding land features of East Point and Monarch Head. This lack of a correlation between measured noise and predicted current speed was also found previously (Warner et al. 2019). We therefore do not have confidence in the WebTide predictions at these near-shore sites, and we decided not to filter results based on the modelled currents being above a threshold. This unfortunately leads to inclusion of time periods that are dominated by water flow noise in all years. A possible approach to deal with this issue could be to develop a flow noise detector, but that has not been implemented here. The optimal solution would be to install current meters near the hydrophone sites if these data are to be used for future noise studies.

2.6. Cumulative Distribution Functions

Cumulative Distribution Functions (CDF) of ambient noise levels were used to investigate the effect of the implementation of ISZ, intended to reduce vessel traffic, on ambient sound levels inside the ISZ. In this report, sound level is shown on the x-axis and exceedance probability is shown on the y-axis. The CDFs represent the cumulative probability of sound levels exceeding a given sound level. CDFs of this type are also used in the Fisheries and Oceans Canada (DFO) Canadian Science Advisory Secretariat noise mitigation working paper (see DFO 2017). Comparing two CDF curves representing different conditions can show how sound level statistics (percentiles) change. For example, if the curve for “condition 1” is shifted to the right relative to the curve for “condition 2”, sound levels for condition 1 are generally higher than those of condition 2.

To investigate the effect of the interim sanctuary zones, exceedance CDFs were created for the three different years and seven frequency bands to see if the curves were shifted to the left (quieter) when the ISZ was implemented (2019 and 2020 compared to 2018). However, changes in covariate parameters unrelated to ISZ implementation can have large effects on ambient noise levels relative to those from vessels avoiding the interim sanctuary zones. These larger effects can mask potential trends, so an effective way to address them is to exclude times when they are in effect from the ISZ analysis. We therefore limited the ISZ analysis to the following time periods and conditions:

- Measurements between June and October of all years, since the ISZ’s were not in place in other months,
- Measurements between 7 am and 7 pm because it was less likely that small vessels are within the sanctuary zones at night,
- Periods when wind speed was less than a threshold to minimize the effect of wind-driven ambient noise effects,
- Periods when AIS-broadcasting vessels were at least six times farther from the hydrophone than the closest Sailing or Pleasure Craft vessel, or when AIS-broadcasting vessels (except Sailing or Pleasure Craft vessels) were at least 6 km from the hydrophone, and
- Periods when the large-vessel detector was not triggered.

2.7. Limitations on Interpreting Results

There are several factors and assumptions that must be considered before interpreting the numeric results in this study. The following list summarizes the limitations:

1. Gaps in the acoustic data were not necessarily consistent between Stations and time periods resulting in uneven sampling of time periods between years;
2. Calibrations were performed on hydrophone data but for some deployments, outdated hydrophone sensitivities were used for analysis, consequently, some of the sound levels are ~6 dB too high in the 10 Hz to 5 or 10 kHz band (the upper frequency depending on the hydrophone) and 2–3 dB too high in the 25–64 kHz band;
3. Non-acoustic system noise changed throughout the deployments and between deployments. The changes in levels were larger than the expected change in noise due to implementing the ISZs;
4. The acoustic large-vessel detector results could not be validated because we did not have an independent data source of large and small vessel presence; and
5. Accurate current speeds were unavailable at the hydrophone locations so we could not filter out time periods contaminated by flow noise.

3. RESULTS

3.1. Influence of Wind

Figure 4 shows the wind speed distributions in Boundary Pass for times with acoustic data during the study period. Wind speeds were generally considerably higher during winter than summer. Previous analysis of SIMRES data from East Point and Monarch Head showed that sound levels were correlated with wind speeds above ~10 kn (Warner 2020). We therefore filtered out sound levels during time periods with wind speeds greater than or equal to 10 kn for subsequent analysis that compared sound levels between years (Section 3.3). Figure 5 shows the proportions of each month where SPL data are available after wind filtering.

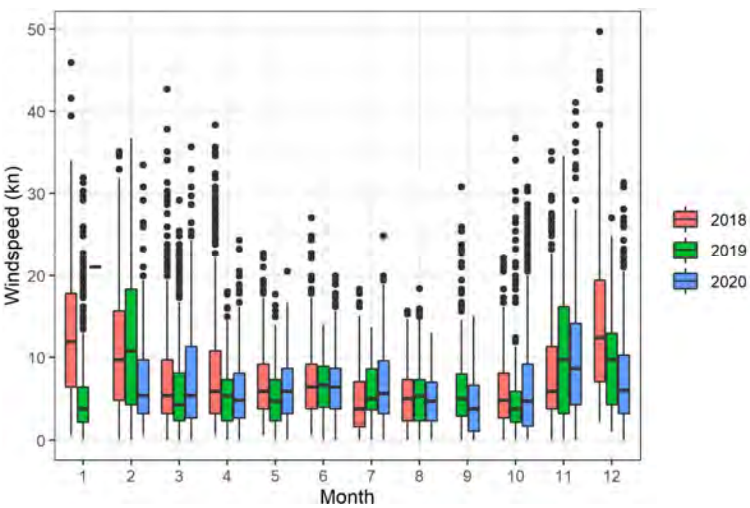


Figure 4. Hourly wind speed distribution in Boundary Pass during the study period. The box-and-whisker thresholds used for this plot are described in the Glossary (page xiv).

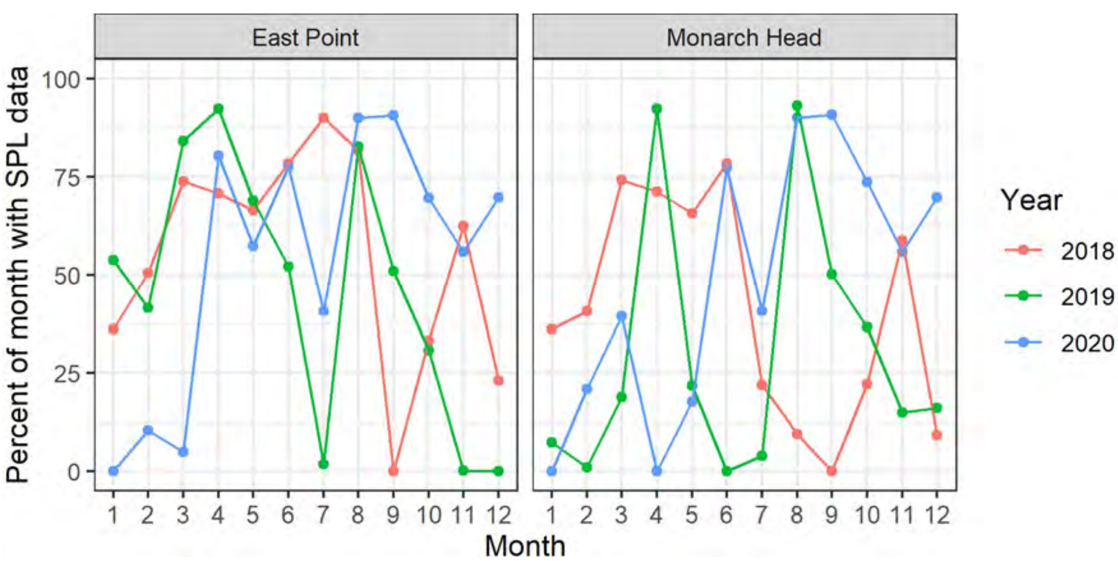


Figure 5. Percent of each month with sound pressure level (SPL) data after filtering out times with wind speed greater than 10 kn.

3.2. Removal of Periods with Large Vessels

Times when large AIS-broadcasting vessels were expected to influence sound levels at the East Point and Monarch Head hydrophones were excluded according to the filtering described in Section 2.3. Figure 6 shows the remaining data for each month after applying the AIS filtering in addition to the wind filtering described in the previous section.

Times when large non-AIS-broadcasting vessels were detected acoustically (Section 2.4) were filtered out of subsequent analysis. Figure 7 shows the remaining data for each month after applying the acoustic detector filtering in addition to the AIS and wind filtering. Table 5 summarizes the percent of data remaining after filtering at each Station and for each year, and the percent of data removed by all filtering.

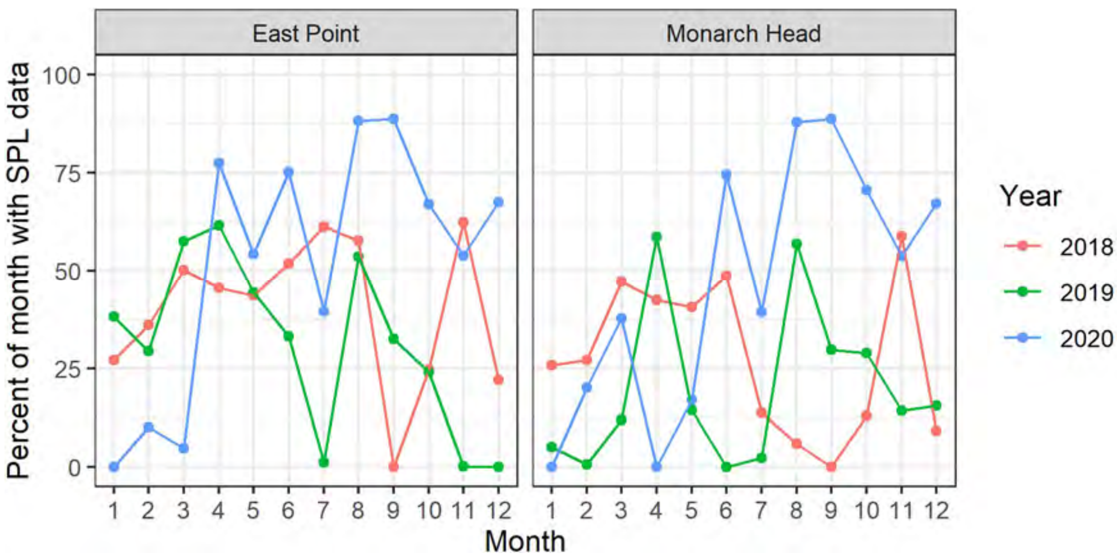


Figure 6. Percent of each month with sound pressure level (SPL) data after applying the AIS filtering criteria, in addition to the wind filtering.

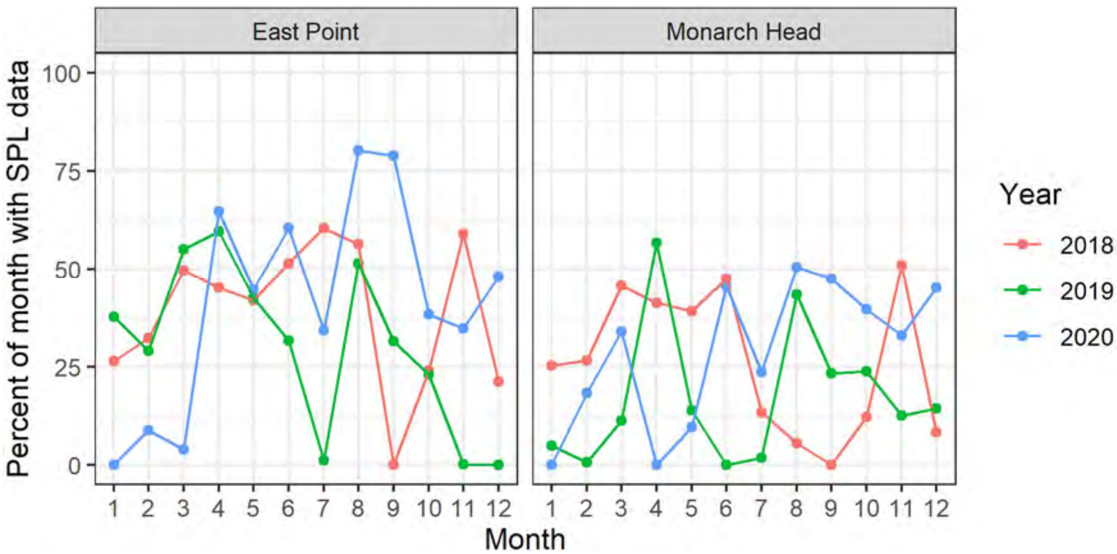


Figure 7. Percent of each month with sound pressure level (SPL) data after filtering out time periods with acoustic detections of large vessels, in addition to the AIS and wind filtering.

Table 5. Summary of data availability by station and year, after applying wind and vessel filtering, and the proportion of data removed by this filtering. Table 2 lists the data availability before filtering.

Station	Data availability (% of year)			Percent of data removed by wind and large vessel filtering (%)		
	2018	2019	2020	2018	2019	2020
East Point	39.1	30.3	41.5	50.1	45.3	45.3
Monarch Head	26.3	17.4	29.0	54.7	50.1	52.3

3.3. Cumulative Distribution Functions and Long Term Trends

Figures 8–14 show CDFs for sound levels in different frequency bands after applying the windspeed filtering (Section 3.1), large-vessel filtering (Section 3.2), and temporal filtering (between June and October from 7 am to 7 pm each day). Curves shifted more to the right indicate louder conditions. For example, Figure 8 for Monarch Head shows that broadband levels (for almost all percentiles) were highest in 2020 and lowest in 2018. The apparent convergence of the curves at the ~100% and ~0% exceedance probability represent the extreme measurements for the year and are not relevant to this analysis. The curves for East Point during 2019 and 2020 for exceedance probability below 70% (lower sound level) agree, indicating that the quieter periods for these years had similar levels. The 2018 curve at these exceedance probabilities is shifted left, which indicates the quieter times in 2018 were quieter than in the other years. Median levels (when the exceedance probability equals 50%) represent a type of average where half the time levels are higher, and half the time levels are lower. At East Point, median levels were highest in 2019 and lowest in 2018. At Monarch Head, median levels were highest in 2020 and lowest in 2018.

It can be useful to investigate a few key exceedance probabilities from these CDF curves. Table 6 summarizes the sound level statistics for the 95, 50, and 5% exceedance probabilites (L_{95}, L_{50}, L_5, respectively), as well as the mean level (L_{eq}; not shown on CDF curves). These statistics were chosen as they represent relatively quiet times (L_{95}), loud times (L_5), intermediate times (L_{50}), and the long-term average level (L_{eq}) and are common statistics for analysis. Table 7 lists the differences in these sound level statistics between years.

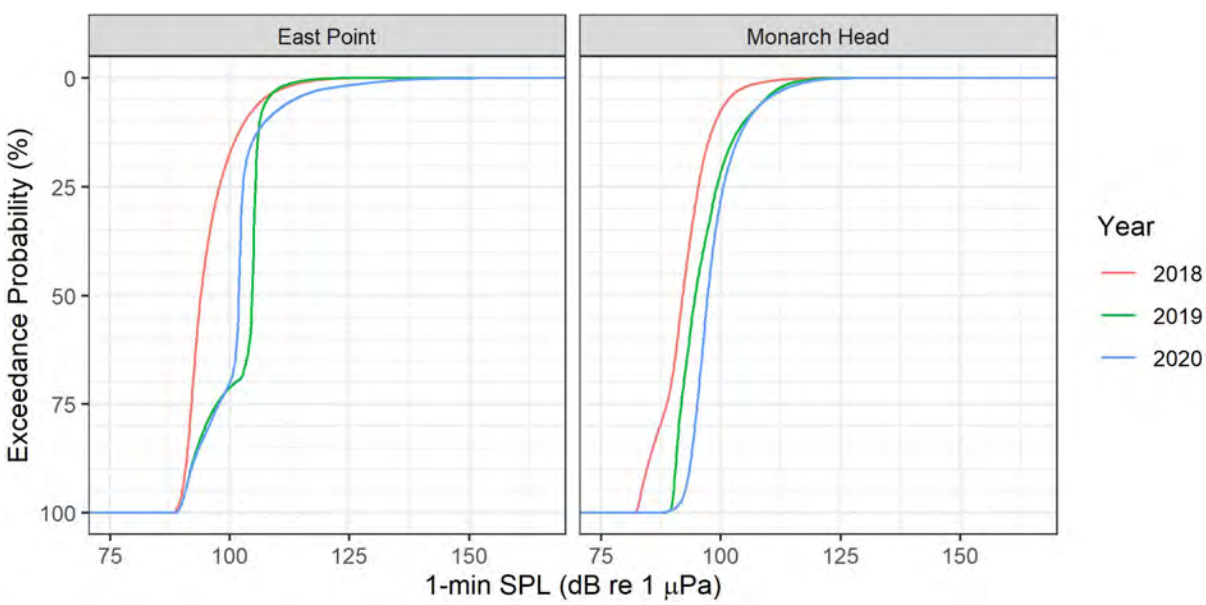


Figure 8. Broadband (10–64000 Hz) sound level cumulative distribution functions (CDF) after windspeed, large vessel, and temporal filtering.

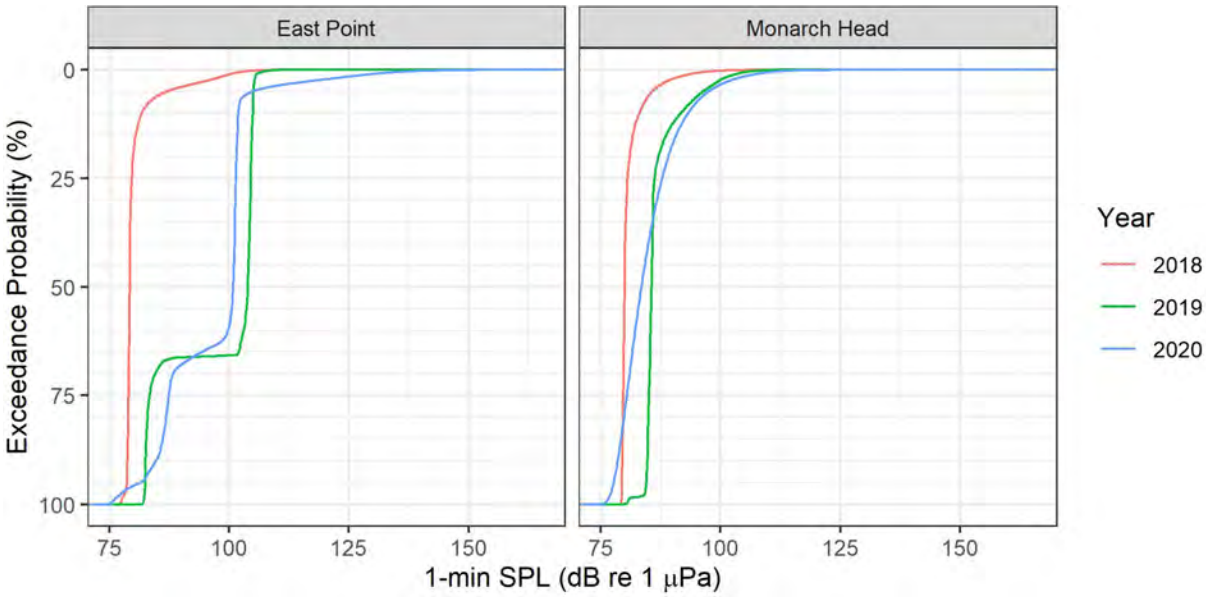


Figure 9. 10–100 Hz sound level cumulative distribution functions (CDF) after applying windspeed, large vessel, and temporal filtering.

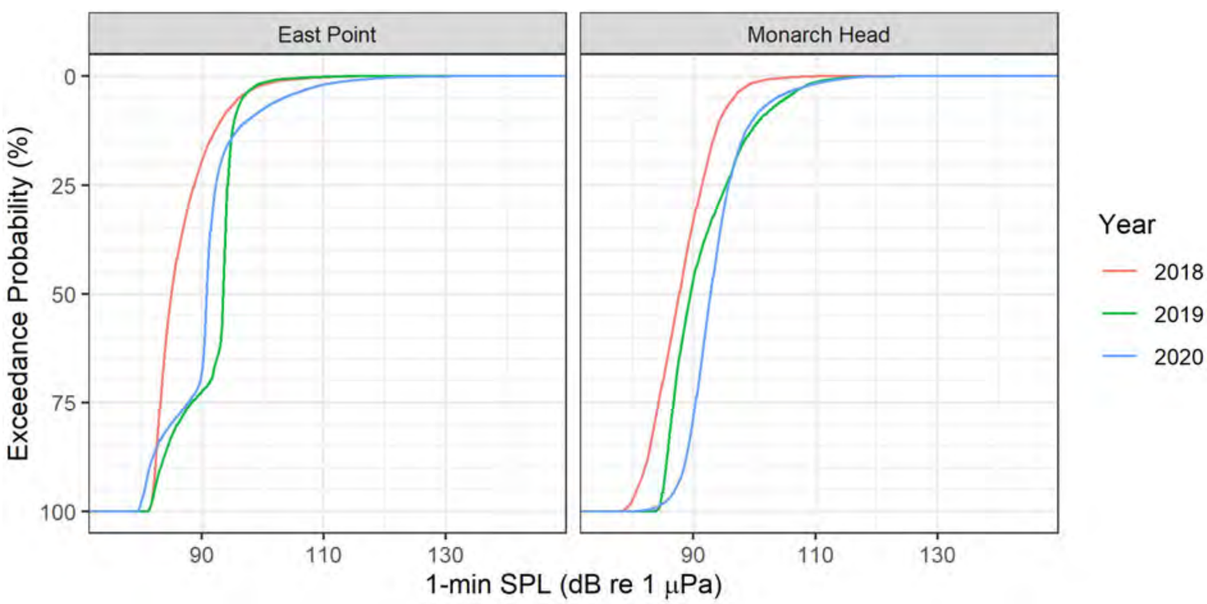


Figure 10. 100–1000 Hz sound level cumulative distribution functions (CDF) after applying windspeed, large vessel, and temporal filtering.

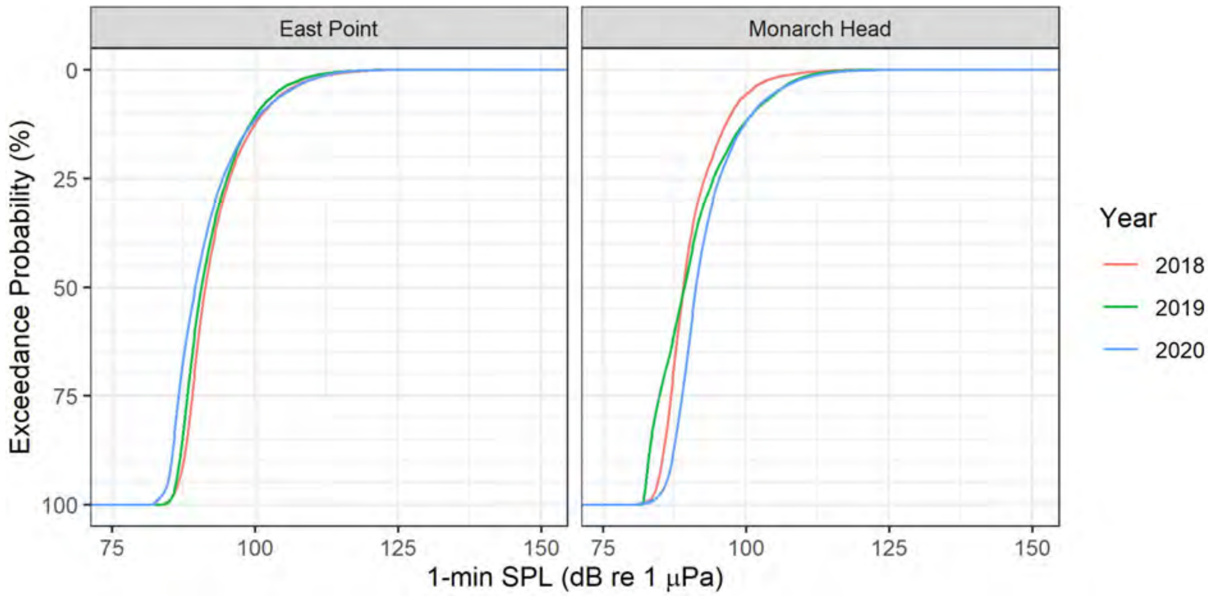


Figure 11. 1–10 kHz sound level cumulative distribution functions after applying windspeed, large vessel, and temporal filtering.

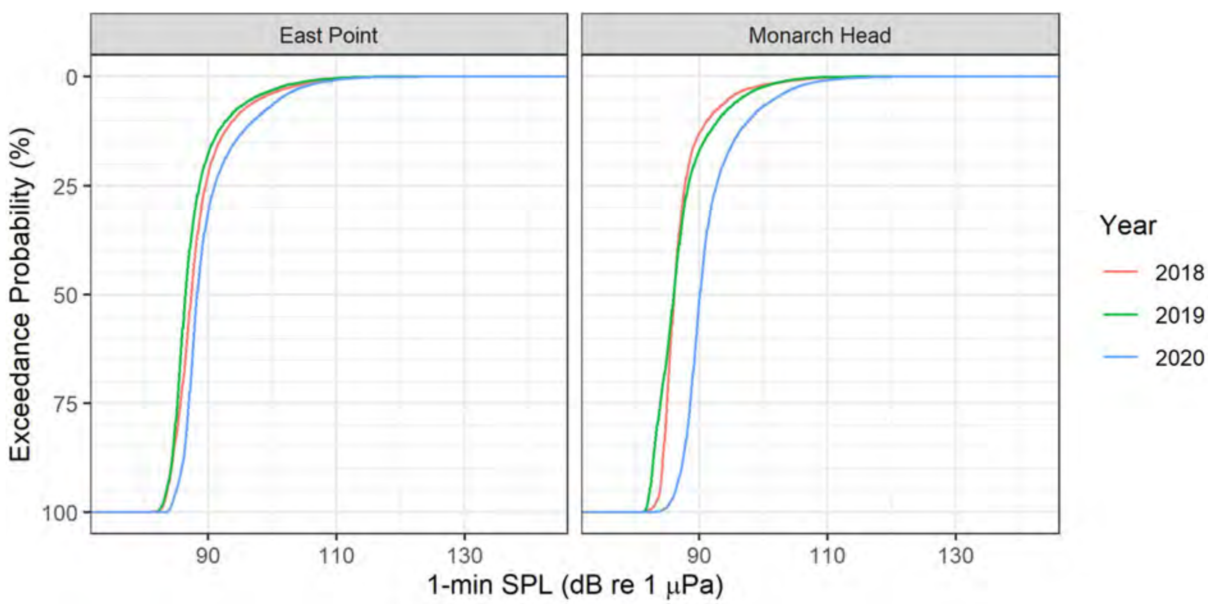


Figure 12. 10–64 kHz sound level cumulative distribution functions after applying windspeed, large vessel, and temporal filtering.

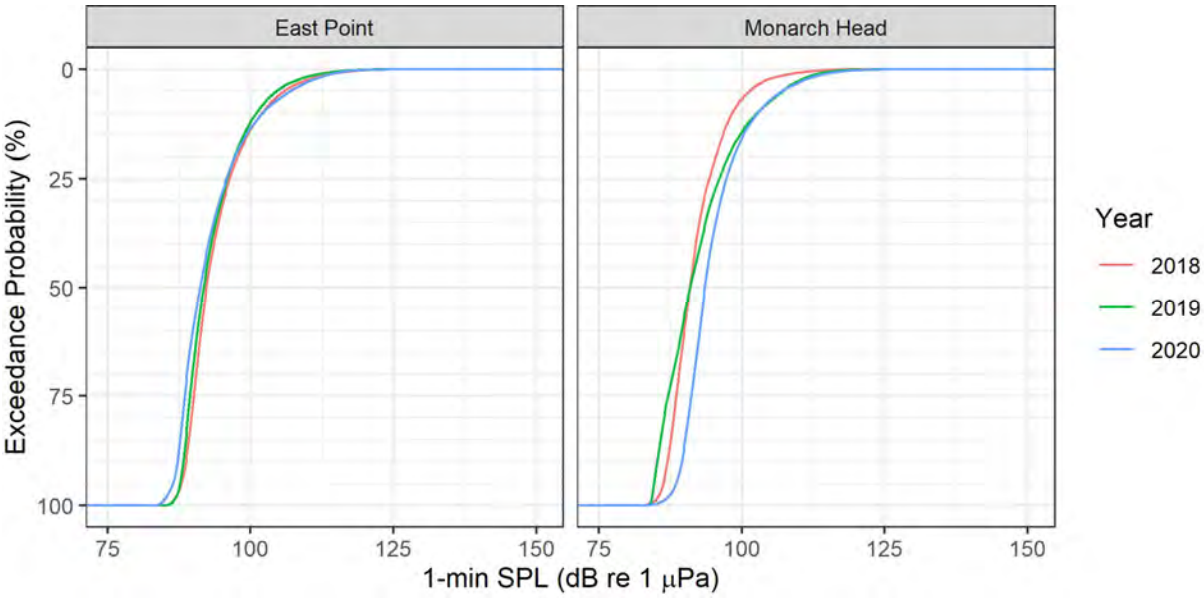


Figure 13. 500–15000 Hz sound level cumulative distribution functions after applying windspeed, large vessel, and temporal filtering.

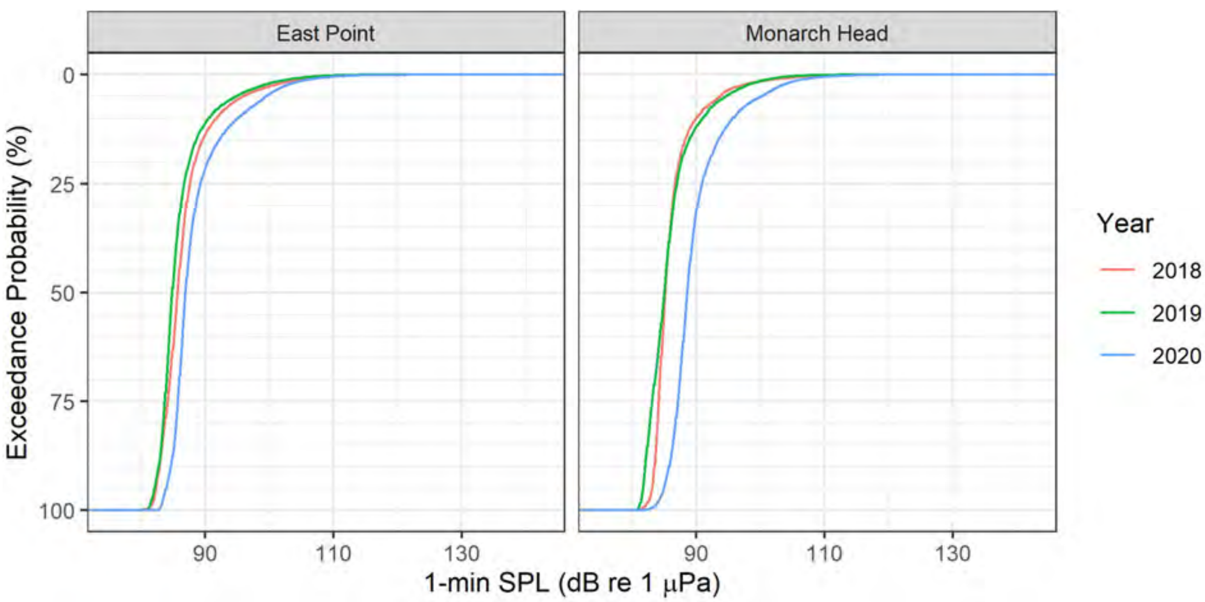


Figure 14. 15–64 kHz sound level cumulative distribution functions after applying windspeed, large vessel, and temporal filtering.

Table 6. Ambient noise statistics during after applying windspeed, large vessel, and temporal filtering. Sound pressure levels (SPL) are listed with units dB re 1 µPa.

Station	Frequency range	2018 SPL				2019 SPL				2020 SPL			
		L_{95}	L_{50}	L_{5}	L_{eq}	L_{95}	L_{50}	L_{5}	L_{eq}	L_{95}	L_{50}	L_{5}	L_{eq}
East Point	Broadband 10–64000 Hz	90.1	94.0	106.8	103.1	90.8	104.7	107.8	105.1	90.7	101.9	113.3	126.9
	1st decade 10–100 Hz	78.7	79.3	87.0	88.8	82.5	103.9	105.1	102.6	80.47	100.9	104.8	126.8
	2nd decade 100–1000 Hz	82.1	85.1	96.1	93.4	82.3	93.6	96.7	94.3	80.6	90.9	103.4	108.9
	3rd decade 1–10 kHz	86.6	91.3	105.3	101.3	86.2	90.7	103.9	99.6	84.7	89.6	105.7	105.3
	4th decade 10–64 kHz	83.6	87.4	98.2	95.9	83.5	86.5	97.0	93.9	85.0	88.3	101.2	103.7
	CORI communication 500–15000 Hz	87.9	92.3	105.9	102.0	87.7	91.8	104.6	100.4	86.5	91.2	107.0	105.9
	CORI echolocation 15–64 kHz	82.3	85.7	95.9	94.2	82.1	84.9	94.8	91.9	83.9	86.9	99.5	103.4
Monarch Head	Broadband 10–64000 Hz	83.4	92.0	101.5	97.9	90.1	94.6	109.1	103.7	92.5	97.3	109.4	105.6
	1st decade 10–100 Hz	79.5	80.0	85.6	85.4	84.5	85.6	96.3	91.4	77.7	83.5	97.4	98.1
	2nd decade 100–1000 Hz	80.7	87.7	96.5	91.9	85.0	89.6	105.2	100.5	87.0	92.9	103.6	100.5
	3rd decade 1–10 kHz	84.5	89.0	100.5	96.7	82.5	89.2	105.4	99.6	86.0	91.2	105.2	100.8
	4th decade 10–64 kHz	83.8	86.1	94.6	92.8	82.3	86.0	96.4	92.1	86.2	90.1	101.8	97.9
	CORI communication 500–15000 Hz	86.3	91.0	101.3	97.5	84.7	91.0	107.2	101.4	88.5	93.6	107.0	102.7
	CORI echolocation 15–64 kHz	83.1	85.2	93.6	91.9	81.7	85.0	94.5	90.5	84.9	88.6	100.1	96.1

Table 7. Comparison of ambient noise statistics after applying windspeed, large vessel, and temporal filtering. A negative value denotes that 2019 or 2020 was quieter than 2018.

Station	Frequency range	SPL difference (dB) between 2019 and 2018				SPL difference (dB) between 2020 and 2018			
		L_{95}	L_{50}	L_5	L_{eq}	L_{95}	L_{50}	L_5	L_{eq}
East Point	Broadband 10–64000 Hz	0.7	10.7	1.0	2.0	0.6	7.9	6.5	23.8
	1st decade 10–100 Hz	3.8	24.6	18.1	13.8	1.77	21.6	17.8	38.0
	2nd decade 100–1000 Hz	0.2	8.5	0.6	0.9	−1.5	5.8	7.3	15.5
	3rd decade 1–10 kHz	−0.4	−0.6	−1.4	−1.7	−1.9	−1.7	0.4	4.0
	4th decade 10–64 kHz	−0.1	−0.9	−1.2	−2.0	1.4	0.9	3.0	7.8
	CORI communication 500–15000 Hz	−0.2	−0.5	−1.3	−1.6	−1.4	−1.1	1.1	3.9
	CORI echolocation 15–64 kHz	−0.2	−0.8	−1.1	−2.3	1.6	1.2	3.6	9.2
Monarch Head	Broadband 10–64000 Hz	6.7	2.6	7.6	5.8	9.1	5.3	7.9	7.7
	1st decade 10–100 Hz	5.0	5.6	10.7	6.0	−1.8	3.5	11.8	12.7
	2nd decade 100–1000 Hz	4.3	1.9	8.7	8.6	6.3	5.2	7.1	8.6
	3rd decade 1–10 kHz	−2.0	0.2	4.9	2.9	1.5	2.2	4.7	4.1
	4th decade 10–64 kHz	−1.5	−0.1	1.8	−0.7	2.4	4.0	7.2	5.1
	CORI communication 500–15000 Hz	−1.6	0.0	5.9	3.9	2.2	2.6	5.7	5.2
	CORI echolocation 15–64 kHz	−1.4	−0.2	0.9	−1.4	1.8	3.4	6.5	4.2

Many of the differences in the CDF plots and Table 7 are due to changes in system noise of the hydrophones (system noise artefacts and the corresponding large changes in levels can be seen in Dofher and Warner (2021)) and are likely unrelated to the real ambient noise levels or the influence of interim sanctuary zone vessel restrictions. A vessel noise modelling study predicted a negligible decrease (0.2 dB broadband) in mean sound levels near East Point due to the implementation of an ISZ (Matthews and Grooms 2020). To compare the magnitude of the expected change in level to the long-term variability in sound levels, we plotted the L_{95}, L_{50}, and L_5 exceedance levels at both sites over the full study period (i.e., unfiltered data; Figures 15–17).

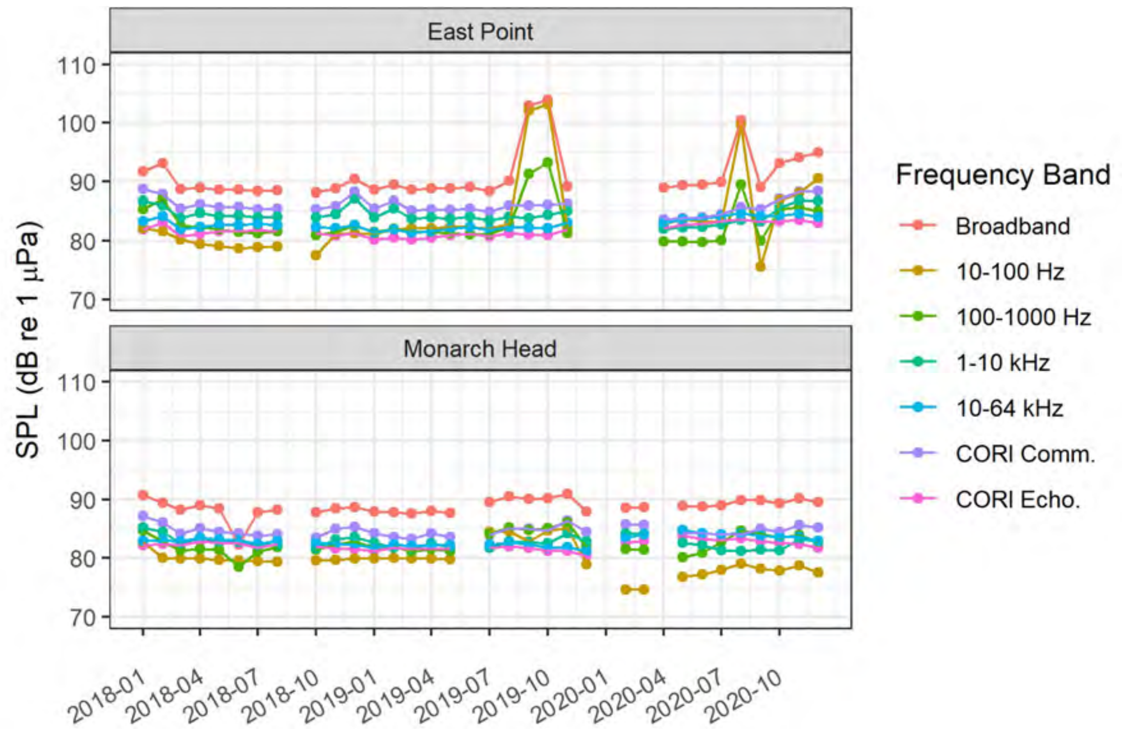


Figure 15. L_{95} sound pressure level (SPL) for each month.

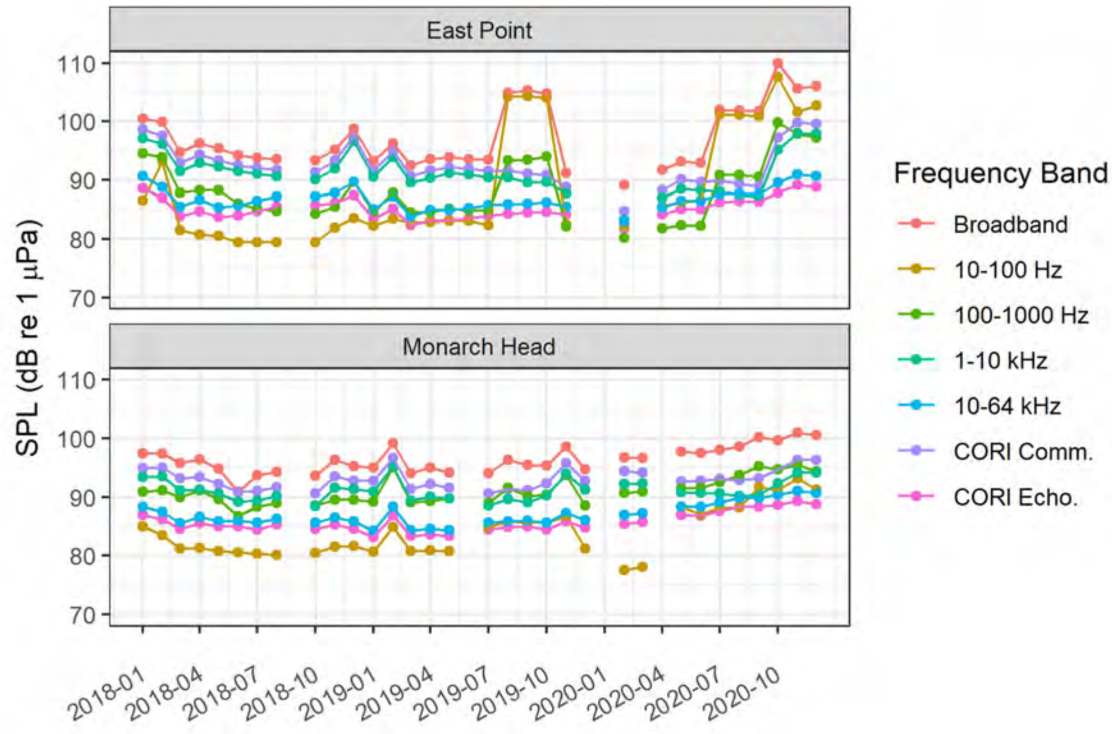


Figure 16. L_{50} (median) sound pressure level (SPL) for each month.

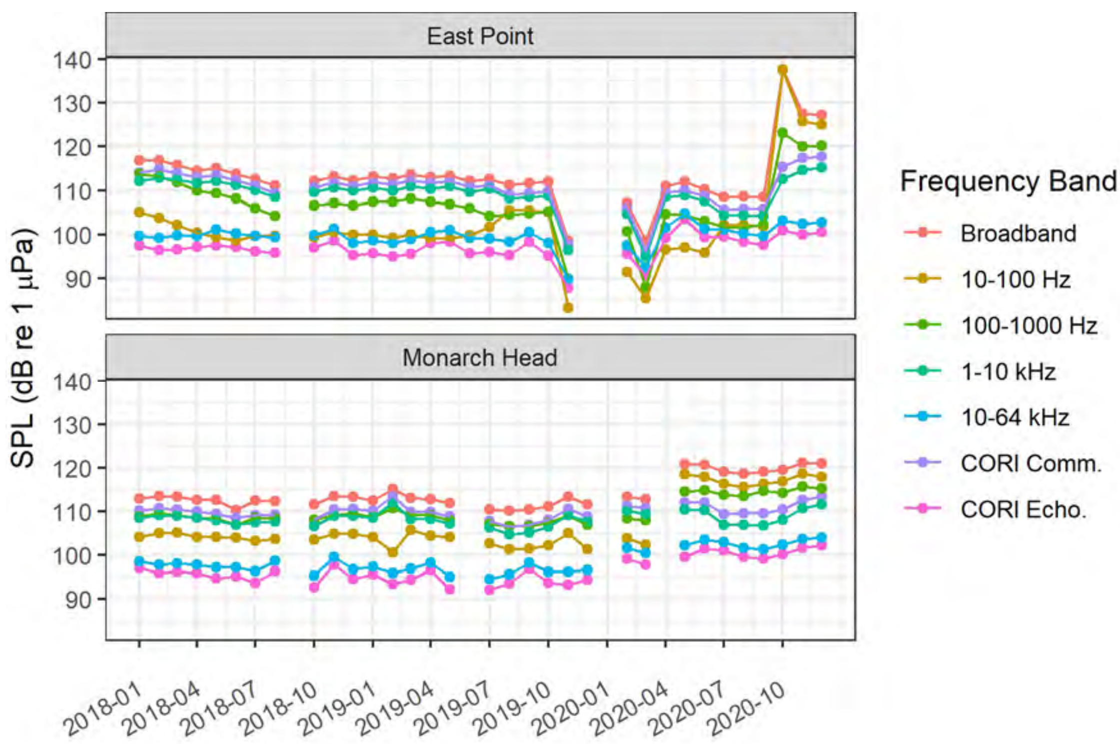


Figure 17. L_5 sound pressure level (SPL) for each month.

At East Point, the L_{95} (Figure 15) and L_{50} (Figure 16) plots show the effect of higher levels from the 60 Hz tone associated with the hydrophone's power supply during Aug-Oct 2019 and Jul-Sep 2020. The lower L_{95} levels in Sep 2020 were due to the power supply noise decreasing for a portion of that month. The decrease in November 2019 levels may not be generally representative of conditions at East Point because there was less than one day of acoustic recording acquired that month and the sound levels during that brief time happened to be similar to the lower trend of previous measurements (this is why the L_5 data, shown in Figure 17, were so much lower). The lower levels in February and March 2020 (which are sometimes not visible below the lower y-axis limit of the plots; see Dofher and Warner, 2021 for tabulated numbers) are likely due to a calibration issue for data recorded during periods within these months (explained earlier in Table 3). The higher levels during Oct-Dec 2020 did not appear to be related to power supply noise but were influenced by much higher low-frequency energy. The spectra for these months had a fundamentally different shape at frequencies below ~10 kHz. This change is due to new hydrophones and better electrical grounding (Table 3), which suggests that sound levels prior to Oct 2020 at frequencies less than 10 kHz were too low by ~10 dB. For frequencies less than 10 kHz, the L_5 levels (Figure 17) gradually decreased throughout 2018 but then remained relatively stable in 2019. The cause of this trend is unclear but could be related to the electrical grounding issue that was addressed in Oct 2020.

At Monarch Head, the low-frequency noise floor was higher during Jul-Dec 2019 (Figure 15). The power spectral density (PSD) plots during this time (Dolman et al. 2020) show a modulation in the low-frequency noise floor with frequency. This effect is due to a pulse per second GPS chip inducing clicks in the acoustic recordings (Warner et al. 2019). That noise does not appear to be present in the 2020 recordings. The distribution of sound levels in 2020 appears wider than those in previous years but it is not clear why. The L_5 levels in 2020 (Figure 17) were higher than those in previous years, and the broadband levels were dominated by low-frequency sounds (10–100 Hz) whereas they were dominated by higher-frequency sounds in previous years. There is a trend in summer months (Jul-Sep) in 2019 and 2020 where the L_5 is lower, but not in 2018. This may be due to the ECHO Program's Slowdown trials in Boundary Pass over this same time period.

The changes in sound level due to system noise and calibration issues shown and described above are much larger than the expected change in mean sound level that is likely from implementing the ISZ. Many of the sound level statistics increased in 2019 and 2020 when the ISZ was implemented relative to 2018 when there was no ISZ in place (Table 7). This is opposite of what is expected, and the unusual result is attributed to the limited ability to characterize such small changes in the presence of the confounding influences discussed above. The results therefore must be considered inconclusive regarding being able to document a real mean noise level change with confidence.

4. CONCLUSION

Without controlling for other factors that influence ambient noise, it is difficult to quantify small changes in noise level due to implementing a sanctuary zone. For example, windspeed and non-acoustic system noise were found to influence ambient sound levels at both the East Point and Monarch Head hydrophones. Windspeed was explicitly controlled for by filtering out data when speeds were above 10 kn. It is worth noting that the Monarch Head hydrophone is in the lee of Saturna Island for Westerlies and Northerlies, whereas the East Point Hydrophone is in the lee for Northerlies. Thus, wind direction may also influence sound levels. An analysis of the effect of wind speed and direction may reveal different thresholds that could be applied to filter out the effect of wind at each station, potentially increasing the accuracy of the comparison.

Large vessels were not expected to transit within the sanctuary zones, and changes in large-vessel traffic could affect sound level statistics at both stations. AIS-based filtering of large vessel presence and an acoustic detector to detect larger ships were applied to limit this effect. It is difficult to quantify the performance of the detector used here without an independent means of determining small and large vessel presence, so its effectiveness cannot be confirmed. One option would be to use video data to ground-truth the approach (Warner et al. 2019). Some video studies are already underway by SIMRES and others, and it may be possible to incorporate their findings in a later update.

System noise on some of the hydrophone data analyzed for this report was described for SIMRES's 2016 and 2017 datasets (Warner et al. 2019), and at least some of the same system noise effects were observed in the 2018–2020 data sets. Most of the trends in the long-term sound level statistics are system-noise related, and these effects are often dependent on the specific equipment used but also vary with time when equipment is consistent. This is a common problem with hydrophone systems. It is less a problem for marine mammal detections, which is the primary purpose of SIMRES's hydrophones, but it substantially affects noise measurements. We recommend that SIMRES attempt to minimize system noise effects, such as due to power supply noise, in their future hydrophone deployments if further acoustic sound level analysis is to be undertaken.

This study focussed on the effects of daytime (7 am to 7 pm) sound levels with the assumption that vessel traffic within the sanctuary zone would be largely composed of smaller recreational or fishing vessels that are typically less active at night. It might be possible to use an acoustic small-vessel detector to assess the frequency with which small vessels were present at any hour of the day, but it would not determine if the vessel was in the sanctuary. We caution against comparing sound levels with and without small vessel detections because an acoustic detector will only work during louder periods. Any differences in sound levels may only be representative of the detector performance and may not accurately reflect the influence of small vessels on sound levels.

The high-frequency calibration information for some hydrophones also appears to be specific to a 64 kHz sample rate, or half of the sample rate used for the 2018–2019 recordings at both sites and the October to December 2020 recordings at East Point. The roll-off at ~25 kHz (Figure 2) is likely not real, and the consequence of the assumed decrease with frequency can be seen with elevated levels in the PSD plots (Dolman et al. 2020, Dofher and Warner 2021). This likely caused the high-frequency band levels (10–64 kHz and the CORI echolocation band from 15–64 kHz) to be 2–3 dB higher in level and weighted towards higher frequencies than they otherwise would be. The inconsistency of the high-frequency calibration applied in data processing makes it difficult to directly compare levels between all years. Errors in the low-frequency sensitivity used for some deployments further complicates this issue. Additional details of the calibration and equipment operation settings would be required to reprocess the data so that it could be compared across years more easily.

Another complicating factor that was not accounted for was the uneven sampling of time periods between years. The uneven sampling was mostly related to gaps in the acoustic recordings and less so by filtering out high wind speed and large vessel presence. For example, there were no data for Monarch Head in June 2019, but there were a large fraction of data available for June in 2018 and 2020. If there were seasonal patterns in vessel traffic, then the uneven sampling could have affected the sound levels. For example, differences in small vessel traffic and its underwater noise may have been partially caused by the COVID-19 pandemic in 2020.

After applying filtering for wind speed, large vessel presence, and temporal filtering, measured sound levels were generally found to be higher in years with the sanctuaries (2019 and 2020) than without. Although there were some frequency bands and statistics for which sound levels decreased in the years with the sanctuaries in place than without, the decreases were small compared to the increases. These results are opposite of what was expected, and attributed to the variability in measurements which precluded an accurate measurement of the real differences. For quick reference, Table 8 lists the measured differences from 2019 to 2018, and Table 9 lists the differences from 2020 to 2018.

Many of these differences are attributed to changes in system noise. Furthermore, calibration errors affected some of the deployments, making it difficult to compare levels between deployments. These effects make it impossible to quantify small noise reductions that are expected from implementing the interim sanctuary zones; therefore, this study is inconclusive in terms of assessing the effectiveness of the Saturna Island ISZ on underwater noise levels. Accurately measuring the effect of the sanctuaries would require carefully calibrated and consistent acoustic monitoring equipment before and during sanctuary implementation, while simultaneously recording small vessel presence using a non-acoustic method (e.g., using a camera, radar, or lidar). The direct measurement of tidal currents near the hydrophones would also be necessary to allow filtering of data to reduce non-acoustic effects.

Table 8. Comparison of 2019 and 2018 ambient noise statistics after applying windspeed, AIS, large-vessel, and temporal filtering. A negative value denotes that 2019 was quieter than 2018. Data are replicated from Table 7.

Frequency range	SPL difference (dB) between 2019 and 2018 East Point				SPL difference (dB) between 2019 and 2018 Monarch Head			
	L_{95}	L_{50}	L_{5}	L_{eq}	L_{95}	L_{50}	L_{5}	L_{eq}
Broadband 10–64000 Hz	0.7	10.7	1.0	2.0	6.7	2.6	7.6	5.8
1st decade 10–100 Hz	3.8	24.6	18.1	13.8	5.0	5.6	10.7	6.0
2nd decade 100–1000 Hz	0.2	8.5	0.6	0.9	4.3	1.9	8.7	8.6
3rd decade 1–10 kHz	−0.4	−0.6	−1.4	−1.7	−2.0	0.2	4.9	2.9
4th decade 10–64 kHz	−0.1	−0.9	−1.2	−2.0	−1.5	−0.1	1.8	−0.7
CORI communication 500–15000 Hz	−0.2	−0.5	−1.3	−1.6	−1.6	0.0	5.9	3.9
CORI echolocation 15–64 kHz	−0.2	−0.8	−1.1	−2.3	−1.4	−0.2	0.9	−1.4

Table 9. Comparison of 2020 and 2018 ambient noise statistics after applying windspeed, AIS, large-vessel, and temporal filtering. A negative value denotes that 2020 was quieter than 2018. Data are replicated from Table 7.

Frequency range	SPL difference (dB) between 2020 and 2018 East Point				SPL difference (dB) between 2020 and 2018 Monarch Head			
	L_{95}	L_{50}	L_{5}	L_{eq}	L_{95}	L_{50}	L_{5}	L_{eq}
Broadband 10–64000 Hz	0.6	7.9	6.5	23.8	9.1	5.3	7.9	7.7
1st decade 10–100 Hz	1.77	21.6	17.8	38.0	−1.8	3.5	11.8	12.7
2nd decade 100–1000 Hz	−1.5	5.8	7.3	15.5	6.3	5.2	7.1	8.6
3rd decade 1–10 kHz	−1.9	−1.7	0.4	4.0	1.5	2.2	4.7	4.1
4th decade 10–64 kHz	1.4	0.9	3.0	7.8	2.4	4.0	7.2	5.1
CORI communication 500–15000 Hz	−1.4	−1.1	1.1	3.9	2.2	2.6	5.7	5.2
CORI echolocation 15–64 kHz	1.6	1.2	3.6	9.2	1.8	3.4	6.5	4.2

LITERATURE CITED

[ANSI] American National Standards Institute. S1.1-1994 (R2004). *American National Standard: Acoustical Terminology*. NY, USA. https://webstore.ansi.org/Standards/ASA/ANSIS11994R2004.

[ANSI] American National Standards Institute and [ASA] Acoustical Society of America. S1.13-2005 (R2010). *American National Standard: Measurement of Sound Pressure Levels in Air*. NY, USA. https://webstore.ansi.org/Standards/ASA/ANSIASAS1132005R2010.

[DFO] Fisheries and Oceans Canada. 2011. *The Marine Environment and Fisheries of Georges Bank, Nova Scotia: Consideration of the Potential Interactions Associated with Offshore Petroleum Activities*. Canadian Technical Report of Fisheries and Aquatic Sciences 2945, Dartmouth, NS, Canada. 492 p. https://waves-vagues.dfo-mpo.gc.ca/Library/344232.pdf.

[DFO] Fisheries and Oceans Canada. 2017. *Evaluation of the Scientific Evidence to Inform the Probability of Effectiveness of Mitigation Measures in Reducing Shipping-Related Noise Levels Received by Southern Resident Killer Whales*. Canadian Science Advisory Secretariat Science Advisory Report 2017/041. 21 p. https://waves-vagues.dfo-mpo.gc.ca/Library/40646713.pdf.

[ISO] International Organization for Standardization. 2006. *ISO 80000-3:2006 Quantities and units – Part 3: Space and time*. https://www.iso.org/standard/31888.html.

[ISO] International Organization for Standardization. 2017. *ISO 18405:2017. Underwater acoustics – Terminology*. Geneva. https://www.iso.org/standard/62406.html.

Dofher, T.S. and G.A. Warner. 2021. *SIMRES East Point and Monarch Head Hydroacoustic Measurements: Ambient Sound from February to December 2020*. Document Number 02369, Version 1.0. Technical report by JASCO Applied Sciences for Transport Canada.

Dolman, J.N., C.C. Wilson, and G.A. Warner. 2020. *SIMRES East Point and Monarch Head Hydroacoustic Measurements: Ambient Sound from January 2018 to December 2019*. Document Number 02262, Version 1.0. Technical report by JASCO Applied Sciences for Transport Canada.

Foreman, M.G.G., W.R. Crawford, J.Y. Cherniawsky, R.F. Henry, and M.R. Tarbottom. 2000. A high-resolution assimilating tidal model for the northeast Pacific Ocean. *Journal of Geophysical Research* 105(C12): 28629-28651. https://doi.org/10.1029/1999JC000122.

Heise, K., L.G. Barrett-Lennard, R. Chapman, T. Dakin, C. Erbe, D.E. Hannay, N.D. Merchant, J. Pilkington, S. Thornton, et al. 2017. *Proposed Metrics for the Management of Underwater Noise for Southern Resident Killer Whales*. Coastal Ocean Report Series. Volume 2017/2. Report for the Coastal Ocean Research Institute. © Ocean Wise 2017, Vancouver, BC, Canada. 31 p. http://wildwhales.org/wp-content/uploads/2017/09/Read-the-Report.pdf.

Institute of Ocean Sciences. 2015. WebTide Northeast Pacific Data (v0.7). Bedford Institute of Oceanography. http://www.bio.gc.ca/science/research-recherche/ocean/webtide/nepacific-nepacifique-en.php (Accessed 16 Jan 2019).

Jensen, F.B., W.A. Kuperman, M.B. Porter, and H. Schmidt. 1994. *Computational Ocean Acoustics*. 1st edition. Modern Acoustics and Signal Processing. AIP Press, New York. 612 p.

Matthews, M.-N.R. and C.H. Grooms. 2020. *Assessment of Vessel Noise within Southern Resident Killer Whale Interim Sanctuary Zones*. Document Number 01979, Version 1.0. Technical report by JASCO Applied Sciences for Transportation Development Centre of Transport Canada.

Warner, G.A., J.D. Wood, S. Frey, L. McWhinnie, A.O. MacGillivray, Z. Li, and D.J. Tollit. 2019. *Salish Sea Ambient Noise Evaluation 2016–2017: Enhancing Cetacean Habitat and Observation Program*. Document Number

01756, Version 2.0. Technical report by JASCO Applied Sciences, SMRU Consulting, Coastal and Ocean Resource Analysis Laboratory for Vancouver Fraser Port Authority.

Warner, G.A. 2020. *SIMRES Ambient Noise: Effects due to the Saturna Island 2019 Interim Sanctuary Zone*. Document Number 02265, Version 2.0. Technical report by JASCO Applied Sciences for Transport Canada.

Warner, G.A., J.D. Wood, A.O. MacGillivray, Z. Li, H. Frouin-Mouy, D.J. Tollit, R. Joy, C.C. Wilson, and T.M. Yack. 2020. Chapter 1. Hydroacoustic Monitoring. *In ECHO Program 2019 Voluntary Vessel Slowdown Hydroacoustic Studies: Final Report*. 01994, Version 1.0. Technical report by JASCO Applied Sciences and SMRU Consulting for Vancouver Fraser Port Authority.

APPENDIX A. HIGH-FREQUENCY HYDROPHONE SENSITIVITY

Figure A-1 shows high-frequency hydrophone sensitivity for the East Point hydrophone (SN 1283) that was obtained by JASCO from SIMRES after processing raw data from 2018 and 2019, and Figure A-2 shows high-frequency hydrophone sensitivity for the East Point hydrophone (SN 2096) that was obtained by JASCO from SIMRES after processing raw data from 2020. These figures show that the sensitivities used in data analysis (Figure 2) were inaccurate. In addition to the hydrophone, a 20 pole Butterworth low-pass filter was applied by the icListen where the −3 dB cut-off frequency was 40% of the sample rate.

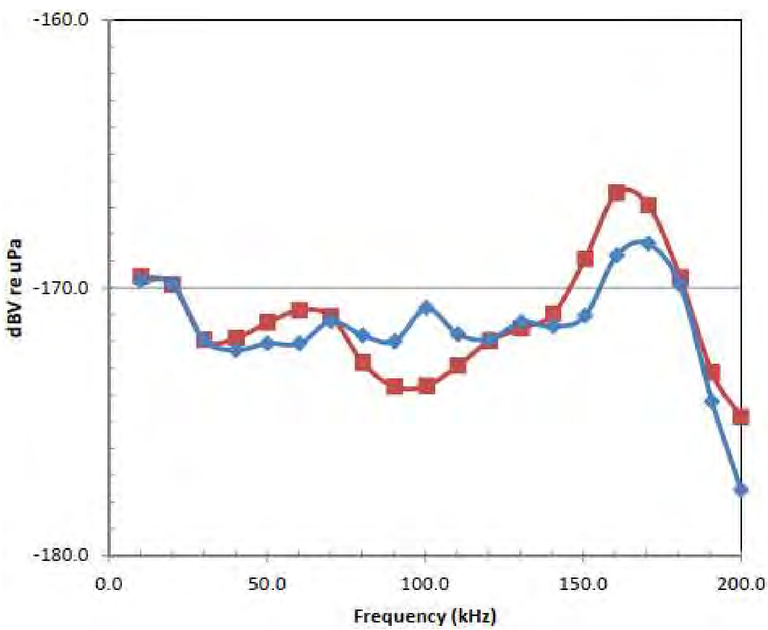


Figure A-1. Hydrophone (SN 1283) sensitivity for high frequencies.

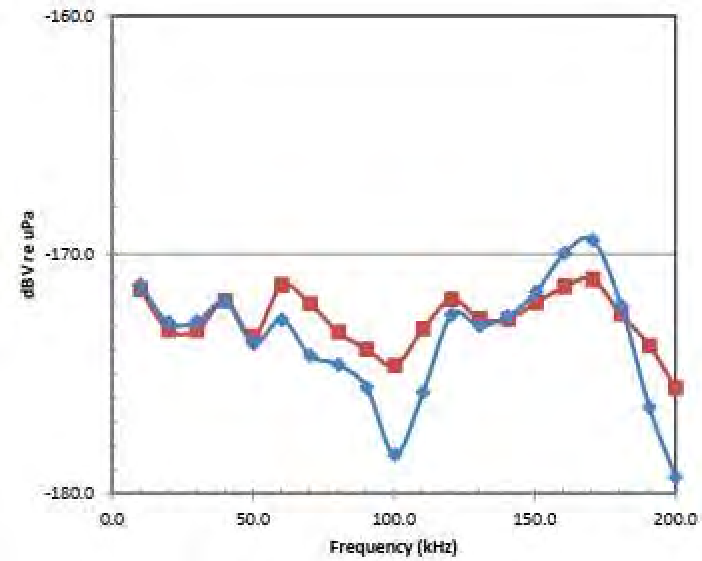


Figure A-2. Hydrophone (SN 2096) sensitivity for high frequencies.

APPENDIX B. TABULATED CORI BAND SOUND LEVEL STATISTICS

Acoustic data were processed to compute 1 min sound pressure level (SPL) in the CORI communication and echolocation bands for each calendar month at both sites (Table B-1). Corresponding broadband and decade band statistics are listed in Dofher and Warner (2021). Corresponding levels for 2018 and 2019 can be found in Warner (2020).

Table B-1. Tabulated CORI band sound level statistics for East Point and Monarch Head (units: dB re 1 µPa).

Period	Statistic	East Point		Monarch Head	
		CORI communication 500–15000 Hz	CORI echolocation 15–64 kHz	CORI communication 500–15000 Hz	CORI echolocation 15–64 kHz
Jan 2020	Min	N/A*	N/A*	N/A*	N/A*
	L_{95}				
	L_{75}				
	L_{50}				
	L_{25}				
	L_5				
	Max				
	Mean				
Feb 2020	Min	35.1	35.7	83.4	81.9
	L_{95}	36.8	36.3	85.8	82.6
	L_{75}	41.1	38.1	90.1	83.9
	L_{50}	84.7	81.8	94.4	85.4
	L_{25}	93.6	86.8	100.5	89.3
	L_5	105.9	95.5	111.3	99.1
	Max	128.6	118.4	124.8	119.2
	Mean	101.5	91.0	104.5	93.5
Mar 2020	Min	35.1	35.6	83.2	82.0
	L_{95}	36.7	36.4	85.7	83.0
	L_{75}	39.9	37.4	89.8	84.2
	L_{50}	44.3	39.2	94.2	85.8
	L_{25}	52.1	44.5	100.5	90.0
	L_5	96.2	90.6	110.8	97.8
	Max	130.0	121.9	127.1	118.6
	Mean	94.0	84.9	104.1	92.9
Apr 2020	Min	82.8	81.1	N/A*	N/A*
	L_{95}	83.7	82.1		
	L_{75}	85.3	83.0		
	L_{50}	88.3	84.2		
	L_{25}	94.7	87.5		
	L_5	109.5	99.2		
	Max	127.4	120.8		
	Mean	103.3	93.7		

Period	Statistic	East Point		Monarch Head	
		CORI communication 500–15000 Hz	CORI echolocation 15–64 kHz	CORI communication 500–15000 Hz	CORI echolocation 15–64 kHz
May 2020	Min	55.1	41.8	82.0	82.3
	L_{95}	83.9	82.7	84.4	83.8
	L_{75}	85.6	83.7	88.4	85.2
	L_{50}	90.1	85.1	92.7	86.9
	L_{25}	97.1	89.4	100.2	90.1
	L_{5}	110.0	103.5	112.0	99.6
	Max	127.0	125.2	126.0	120.4
	Mean	103.2	98.9	105.5	94.8
Jun 2020	Min	83.1	81.9	80.6	81.7
	L_{95}	84.0	82.9	84.2	83.3
	L_{75}	85.8	83.7	88.0	84.9
	L_{50}	89.7	85.1	92.8	86.8
	L_{25}	95.7	88.8	99.6	91.0
	L_{5}	108.7	99.3	112.0	101.5
	Max	124.8	119.7	130.0	127.3
	Mean	102.5	94.2	105.5	96.3
Jul 2020	Min	83.2	82.0	81.0	81.6
	L_{95}	84.5	83.3	84.0	83.1
	L_{75}	87.1	84.8	88.3	85.2
	L_{50}	89.9	86.2	93.1	87.6
	L_{25}	95.1	89.2	99.3	91.5
	L_{5}	105.7	99.5	109.4	101.1
	Max	125.2	121.3	126.3	120.3
	Mean	100.6	94.0	103.6	95.2
Aug 2020	Min	84.9	82.5	80.6	81.6
	L_{95}	85.7	83.6	84.0	83.4
	L_{75}	87.2	84.9	88.6	85.8
	L_{50}	89.4	86.4	92.9	88.4
	L_{25}	93.6	88.6	98.7	91.5
	L_{5}	105.8	98.3	109.5	99.6
	Max	123.7	127.4	129.1	124.1
	Mean	99.8	94.1	103.4	95.5
Sep 2020	Min	83.5	81.6	80.7	81.3
	L_{95}	85.4	83.2	85.0	82.9
	L_{75}	87.0	84.7	89.9	86.1
	L_{50}	88.9	86.3	93.2	88.4
	L_{25}	93.5	88.5	99.6	91.2
	L_{5}	105.8	97.6	109.6	99.1
	Max	123.7	119.3	132.4	121.5
	Mean	99.6	92.5	103.8	94.0
Oct 2020	Min	83.4	81.9	80.6	81.0
	L_{95}	87.1	83.3	84.5	82.6
	L_{75}	92.2	85.5	90.2	85.2

Period	Statistic	East Point		Monarch Head	
		CORI communication 500–15000 Hz	CORI echolocation 15–64 kHz	CORI communication 500–15000 Hz	CORI echolocation 15–64 kHz
	L_{50}	97.2	87.9	94.7	88.7
	L_{25}	104.1	92.6	101.6	92.5
	L_5	115.4	101.0	110.4	100.2
	Max	151.0	142.7	132.8	119.3
	Mean	111.1	105.1	104.7	94.9
Nov 2020	Min	83.7	81.9	80.3	80.9
	L_{95}	88.3	83.5	85.6	82.4
	L_{75}	94.7	86.5	92.1	86.4
	L_{50}	99.8	89.2	96.3	89.3
	L_{25}	105.3	93.0	102.0	93.9
	L_5	117.4	100.0	112.7	101.7
	Max	137.2	117.8	131.2	116.5
	Mean	111.3	94.4	106.2	95.4
Dec 2020	Min	83.0	81.5	38.9	38.4
	L_{95}	88.4	83.0	85.2	81.8
	L_{75}	94.3	85.8	91.9	85.5
	L_{50}	99.6	88.8	96.3	88.8
	L_{25}	105.8	93.7	102.5	95.0
	L_5	117.7	100.5	113.4	102.2
	Max	141.6	119.9	133.4	120.1
	Mean	112.2	94.9	107.1	96.0

* No acoustic data were available for this month.