Baleen whale call occurrence and soundscape characterization at Ingonish, Nova Scotia, 2019-2021

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by

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Abstract

Wingfield, J., Li, S., Xu, J., Marotte, E. and Breeze, H. 2024. Baleen whale call occurrence and soundscape characterization at Ingonish, Nova Scotia, 2019-2021. Can. Tech. Rep. Fish. Aquat. Sci. 3587: v + 46p.

The areas surrounding Ingonish, Nova Scotia, support several fisheries and there have been sightings of endangered marine animals there. Despite this, this area has previously been under-surveyed, both visually and acoustically. To better understand year-round baleen whale occurrence and the composition of the soundscape in the area, acoustic data were collected off Ingonish from November 2019 to November 2021 as part of the Coastal Acoustic Monitoring (CAM) Project, initiated by DFO Maritimes Region. Automated detectors were used to identify potential sei, minke, North Atlantic right, humpback, blue and fin whale calls. Sound energy budgets, the percent contributions of wind, vessels, and "other" sources to the total soundscape, were calculated for six frequency bands. We detected fin, blue, North Atlantic right, sei, and humpback whale calls. Fin whales were the most frequently detected species. Humpback whale calls occurred almost exclusively during late October to February. Vessel noise dominated the 1/3 octave band centered at 100 Hz throughout the study period. Wind was often the dominant contributor of sound in several frequency bands throughout the winter months. During the summer months, the contribution of energy from vessel noise increased. Monitoring off Ingonish ceased in November 2023, but the CAM Project is ongoing as we continue to monitor four sites within Chedabucto Bay and one at the mouth of Halifax Harbour.

Résumé

Wingfield, J., Li, S., Xu, J., Marotte, E. and Breeze, H. 2024. Baleen whale call occurrence and soundscape characterization at Ingonish, Nova Scotia, 2019-2021. Can. Tech. Rep. Fish. Aquat. Sci. 3587: v + 46p.

Plusieurs pêches sont pratiquées dans les environs d'Ingonish, en Nouvelle-Écosse, et des animaux marins en voie de disparition y ont été observés. Pourtant, cette région n'a pas fait l'objet de suffisamment de relevés par le passé, tant visuels qu'acoustiques. Dans le cadre du projet de surveillance acoustique côtière de la région des Maritimes de Pêche et Océans Canada, on a recueilli des données acoustiques au large d'Ingonish entre novembre 2019 et novembre 2021 afin de mieux caractériser la présence de baleines à fanons et la composition du paysage sonore dans la région tout au long de l'année. Des détecteurs automatisés ont été employés pour enregistrer les vocalisations potentielles de rorquals boréaux, de petits rorquals, de baleines noires de l'Atlantique Nord, de rorquals à bosse, de rorquals bleus et de rorquals communs. Les budgets énergétiques des ondes sonores de six bandes de fréquences ont été calculés, ce qui correspond à la contribution en pourcentage du vent, des navires et des « autres » sources à l'ensemble du paysage sonore. Ont été détectées des vocalisations de rorquals communs, de rorquals bleus, de baleines noires de l'Atlantique Nord, de rorquals boréaux et de rorquals à bosse. L'espèce la plus fréquemment détectée était le rorqual commun. Les vocalisations de rorquals à bosse ont été enregistrées presque exclusivement entre la fin octobre et février. Le bruit associé aux navires a dominé la bande de tiers d'octave centrée sur 100 Hz au cours de la période d'étude. Le vent a souvent été le facteur dominant en matière de son dans plusieurs bandes de fréquences tout au long des mois d'hiver. Au cours des mois d'été, la contribution de l'énergie provenant du bruit des navires a augmenté. Les activités de surveillance au large d'Ingonish ont pris fin en novembre 2023, mais le projet de surveillance acoustique côtière se poursuit. En effet, quatre sites dans la baie de Chedabucto et un site à l'ouverture du port d'Halifax sont encore sous surveillance.

1.0 Introduction

Underwater noise has been shown to impact many marine species, from invertebrates to whales (Bartol 2017; Walsh et al. 2017; Erbe et al. 2019; Duarte et al. 2021) and has therefore been the focus of studies throughout the world's oceans. In 2008, the European Union's Marine Strategy Framework Directive became the first legislative document to identify noise as a pollutant (European Commission 2008; Merchant et al. 2022). In Canada, there are multiple federal laws, guidelines, and initiatives that can be used to help manage anthropogenic noise, although many of them were written before noise was widely known to negatively impact the marine environment (see Table 1 in Breeze et al. 2022). Fisheries and Oceans Canada's (DFO) Marine Environmental Quality (MEQ) initiative seeks to identify priority stressors in the marine environment, to assess the management of those stressors, and to address any gaps in management. Underwater noise was identified at the national level as a stressor by MEQ staff within the Marine Planning and Conservation (MPC) division. There are several large ports and planned developments within and near coastal Nova Scotian waters, all of which have the potential to produce underwater noise that may impact the marine environment. DFO Maritimes Region's Science Branch has been conducting passive acoustic monitoring to characterize whale occurrence, and more recently the soundscape, at sites throughout the northwest Atlantic since 2012, but until 2018, there was no similar work being done in coastal environments. Due to this lack of coastal monitoring, little was known about the presence of marine mammals and the composition of the soundscapes in these coastal environments. To address these gaps, MPC-MEQ Maritimes Region staff initiated the Coastal Acoustic Monitoring (CAM) Project in 2018. The CAM Project has two main objectives: to better understand the sources and levels of underwater noise and to characterize the acoustic presence of baleen whales at coastal sites across Nova Scotia. The project began in June 2018 with the testing of various acoustic mooring configurations near Lunenburg. The first official deployment took place off the southern shore of Chedabucto Bay in December 2018 (Wingfield et al. 2022a). Since its inception, the CAM Project has grown to include 9 deployment sites, 5 of which were active as of April 2024, across the eastern coast of Nova Scotia.

General deployment areas were identified based on a variety of criteria including local knowledge, anecdotal, historical, or contemporary records of marine mammal and/or turtle sightings (particularly endangered species), proximity to ecologically and biologically significant areas and marine protected areas (MPAs) or proposed MPAs, and the potential for elevated noise levels due to nearby anthropogenic activities (particularly vessel traffic). By leveraging the expert local knowledge of fishing organizations, tourism operators, and community groups, we were able to select specific deployment sites at suitable depths where the mooring would not be at risk of entanglement in fishing gear, as many sites are located in active fishing areas. These local groups also conducted the deployments and retrievals of the gear. We began monitoring off Ingonish (Figure 1) in June 2019. We chose this site because there are many whale-watch operators nearby who have recorded sightings of marine mammals and because it is as an Ecologically and Biologically Significant Area (EBSA) (Hastings et al. 2014). There have been many sightings of marine species near Ingonish and in the broader Sydney Bight area, including four species listed as endangered under the Species at Risk Act (SARA), which are the leatherback turtle (*Dermochelys coriacea*) (Atlantic Leatherback Turtle Recovery Team 2006), North Atlantic right whale (*Eubalaena glacialis*) (DFO 2014), blue whale (*Balaenoptera musculus*) (Beauchamp et al. 2009), and beluga whale (*Delphinapterus leucas*) (James 2000; Schaefer et al. 2004; DFO 2012; Hamelin et al. 2017; Gomez et al. 2020; Johnson et al. 2021; World Wildlife Fund (WWF)-Canada et al.

2021). Fin whales (*Balaenoptera physalus*), which are listed as Special Concern (DFO 2017a), have also been sighted in the area (Schaefer et al. 2004; Gomez et al. 2020). There have also been sightings of minke (*Balaenoptera acutorostrata*), long-finned pilot (*Globicephala melas*), and humpback (*Megaptera novaeangliae*) whales, Atlantic white-sided dolphins (*Lagenorhynchus acutus*), harbour porpoises (*Phocoena phocoena*), and seals (Schaefer et al. 2004; Gomez et al. 2020). While this site is not near a major shipping lane, there is still the potential for vessel noise as there are several whale-watch operators and many fisheries within the Sydney Bight area including lobster (*Homarus americanus*), snow crab (*Chionoecetes opilio*), rock crab (*Cancer irroratus*), groundfish, and herring (*Clupea harengus*) (Schaefer et al. 2004; McCullough et al. 2005; DFO 2020). The deployment location was also easily accessible by the local fish harvester who conducted the deployments and retrievals.

Six species of baleen whales inhabit the waters off Atlantic Canada and have been sighted and acoustically detected off Nova Scotia (Risch et al. 2014; Kowarski et al. 2018; Davis et al. 2020; Gomez et al. 2020; WWF-Canada et al. 2021; Delarue et al. 2022; Wingfield et al. 2022b). Each of these six species produces well documented and distinct call types that have been widely used to determine their spatial occurrence throughout the northwest Atlantic (Risch et al. 2013; Kowarski et al. 2018; Davis et al. 2020; Delarue et al. 2022; Wingfield et al. 2022b). We targeted the 20 Hz pulse produced by fin whales (Watkins 1981; Watkins et al. 1987), tonal notes produced by blue whales (Mellinger and Clark 2003; Berchok et al. 2006), song and non-song moans produced by humpback whales (Dunlop et al. 2008; Kowarski et al. 2018), pulse trains produced by minke whales (Risch et al. 2013), upcalls produced by North Atlantic Right whales (Parks and Tyack 2005; Parks et al. 2011), and broadband downsweeps produced by sei whales (*Balaenoptera borealis*) (Baumgartner et al. 2008) to determine the acoustic presence of these species near our recording site.

The second component of this project was to characterize the soundscape near the deployment site. A soundscape is defined as all sounds that occur within an area, including from geological, biological, or anthropogenic sources, considered as a whole (Southworth 1967; Havlik et al. 2022). It is therefore possible to determine the type and frequency of occurrence of human activities and weather events taking place in an area and to assess the health of an ecosystem and species richness within by analyzing the soundscape (Pijanowski et al. 2011). We chose to characterize the soundscape around our Ingonish site using a sound energy budget approach similar to that used by Miller et al. (2008) and Nystuen et al. (2010). In this approach, the percentage of energy contributed to the overall soundscape by different sources is estimated. This allowed us to compare the changes in contributions of vessels, wind, and all remaining sources (grouped as "other") to the overall soundscape across different months and between years. The same approach was taken for a previous report summarizing the results from the original CAM project site within Chedabucto Bay (Wingfield et al. 2022a).

Prior to the initiation of the CAM Project, the closest passive acoustic monitoring to have occurred near Ingonish was approximately 43 km northeast of our deployment location (referred to as "Stn 1" in Delarue et al. 2022) (Figure 1), where blue, fin, and humpback whales were detected year-round, and minke and North Atlantic right whales were detected at least once. Sei whales were not detected at this site, although that may have been due to inadequate methodology rather than true absence (Delarue et al. 2022). Delarue et al. (2018) found that vessel noise contributed the most energy to the overall soundscape at Stn 1 throughout the first year of the study, except during some periods in winter and spring when environmental noise from storms was a contributor. Vessel noise remained a significant contributor in the second year of the study, but an increase in flow-induced mooring noise resulted in a larger difference between the total and vessel-only sound energy levels (Delarue et al. 2018). There was a regular ferry service between Sydney and Port-aux-Basques, Newfoundland, that may have contributed to the sound energy levels despite being approximately 25 km from the recording Stn 1 (Delarue et al. 2018). Noise from seismic surveys was detected during the summer in the final year of the study (Delarue et al. 2018).

While data collection is ongoing, here we present the methodology and results of our baleen whale call detection and sound energy budget analyses for data collected off Ingonish between June 2019 and November 2021. Our main objectives for this work were to summarize the minimum occurrence of baleen whales and to determine the dominant contributors to the overall soundscape around the Ingonish site. Given the lack of both visual and acoustic monitoring efforts in the area prior to this study, the data we present here could be considered baseline data and serve as a reference point should anthropogenic activities in the area increase and/or baleen whale occurrence patterns shift. We also include a comparison of low frequency noise levels and the daily occurrence of fin, blue, and humpback whale vocalizations to investigate the potential impacts of vessel presence on baleen whale calling behaviour and detectability. We discuss how the results from this site compare to those from the original CAM site within Chedabucto Bay (Wingfield et al. 2022a) to obtain a better understanding of baleen whale presence and the soundscape across Nova Scotia. These data are particularly important for the development of management measures for the vulnerable and endangered species that are known to inhabit the area.

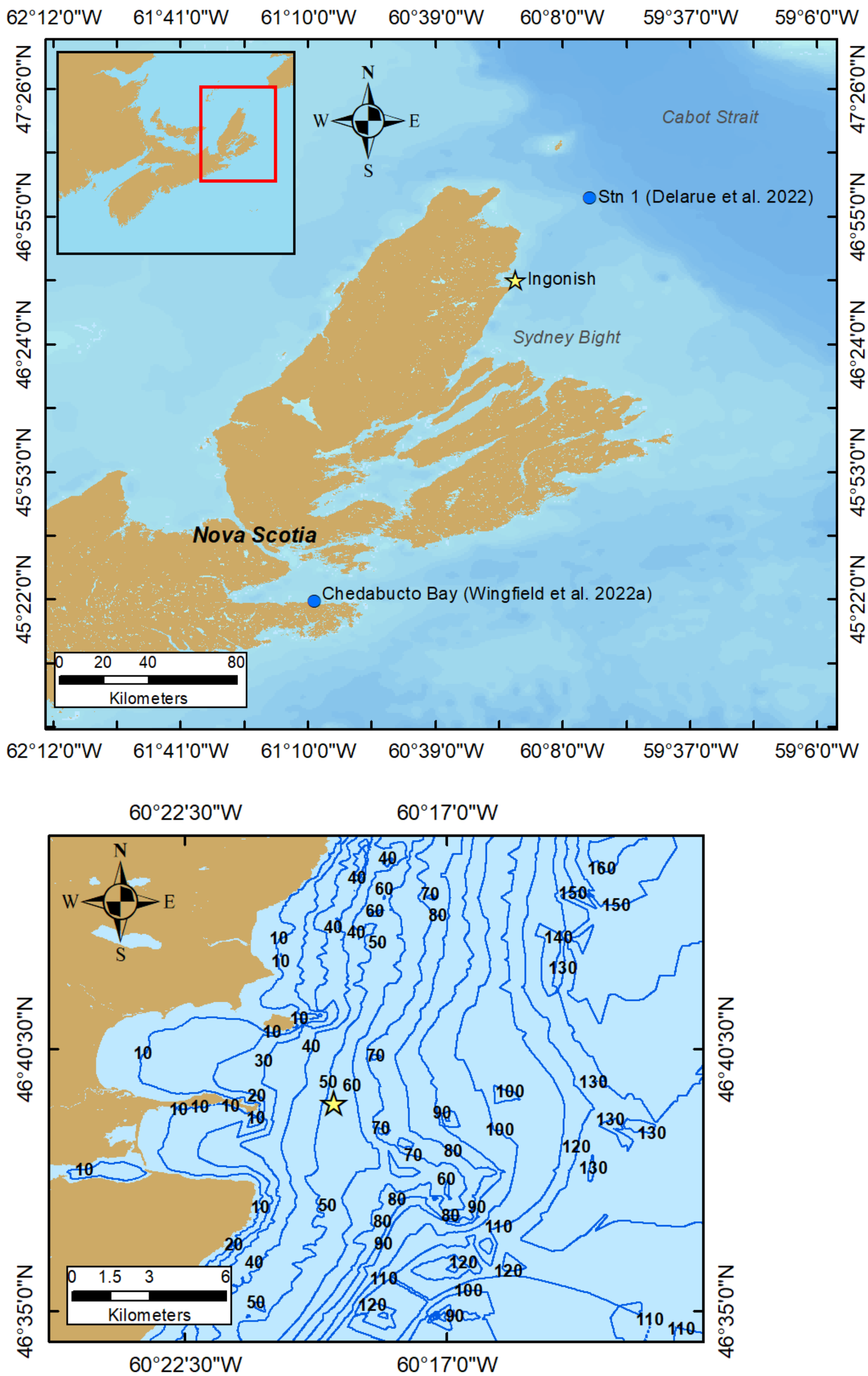

Figure 1. Top panel: The acoustic mooring deployment site (yellow star) off Ingonish, Nova Scotia, Canada, and other sites of interest (blue circles). Bottom panel: A close-up view of the deployment site (yellow star) with 10 m depth contour lines (m).

2.0 Methods

2.1 Mooring Design and Data Collection

Passive acoustic moorings were deployed approximately every two to four months from June 2019 to November 2021 off Ingonish, Nova Scotia (Figure 1, Table 1). We used a TR Porpoise (manufactured by Turbulent Research Inc. Canada) for the first two deployments and SoundTraps (ST300 STD, ST500 STD, or ST600 STD model, manufactured by Ocean Instruments New Zealand) for all subsequent deployments (Table 1). We mounted the recorder in a lobster trap (dimensions: 38 x 61 x 38 cm) that was modified to ensure no animals could be trapped (Figure 2). We then attached the cage to a Fiobuoy (time/date model, manufactured by Fiomarine Australia) (Figure 2). We programmed the Fiobuoy to release at a predetermined date and time. Upon release, a local fish harvester retrieved the mooring and deployed a new mooring in its place. The mooring was carefully designed to eliminate flow noise and mooring self-noise. We set all recorders to record continuously, resulting in 29-minute .wav files from the TR Porpoise deployments and 30-minute .wav files from the SoundTrap deployments. All recordings were made at a sampling rate of 24 kHz. We set the gain to 30 dB for the TR Porpoise recordings and the recommended gain setting of “high” was used for the SoundTrap recordings. See Appendix A for the hydrophone calibration data for the SoundTraps. Calibration data for the Porpoises could not be collected as one was lost during a subsequent deployment and the other was not functioning at the time of testing.

Table 1. The deployment and recovery dates, the in-water recording period, recorder type, latitude and longitude (decimal degrees), bottom depth (metres), and the total number of complete 24 hour recording days (hours in brackets) for each deployment throughout the two year study period. TR: Turbulent Research, ST: SoundTrap.

Deployed	**Recovered**	**In-water recording period**	**Recorder**	**Latitude (DD)**	**Longitude (DD)**	**Bottom depth (m)**	**Total number of recording days (hours)**
Jun 17 2019	Aug 07 2019	NA[1]	TR Porpoise	46.659	-60.322	56.1	NA
Aug 08 2019	Nov 12 2019	NA[2]	TR Porpoise	46.659	-60.323	54.9	NA
Nov 15 2019	Apr 23 2020	Nov 15 2019 to Mar 13 2020	TR Porpoise 29	46.659	-60.323	54.9	118 (2832)
Aug 13 2020	Oct 20 2020	Aug 13 2020 to Oct 20 2020	TR Porpoise 40	46.659	-60.323	55.0	67 (1608)
Oct 20 2020	Apr 21 2021	Oct 21 2020 to Feb 27 2021	ST500 5470	46.659	-60.322	55.8	128 (3072)
Apr 21 2021	Jul 01 2021	Apr 21 2021 to Jul 01 2021	ST300 5955	46.659	-60.323	57.2	70 (1680)
Jul 07 2021	Sep 01 2021	Jul 07 2021 to Sep 01 2021	ST600 6085	46.659	-60.322	57.8	55 (1320)
Sep 01 2021	Nov 10 2021	Sep 01 2021 to Nov 10 2021	ST300 5955	46.660	-60.322	55.0	69 (1656)
						Total	**507 (12,168)**

[1]A technical defect with the Porpoise prevented data from writing to the memory cards and thus no data exist for this deployment.
[2] The data from this deployment exist but the date and time stamps were lost due to a corruption issue.

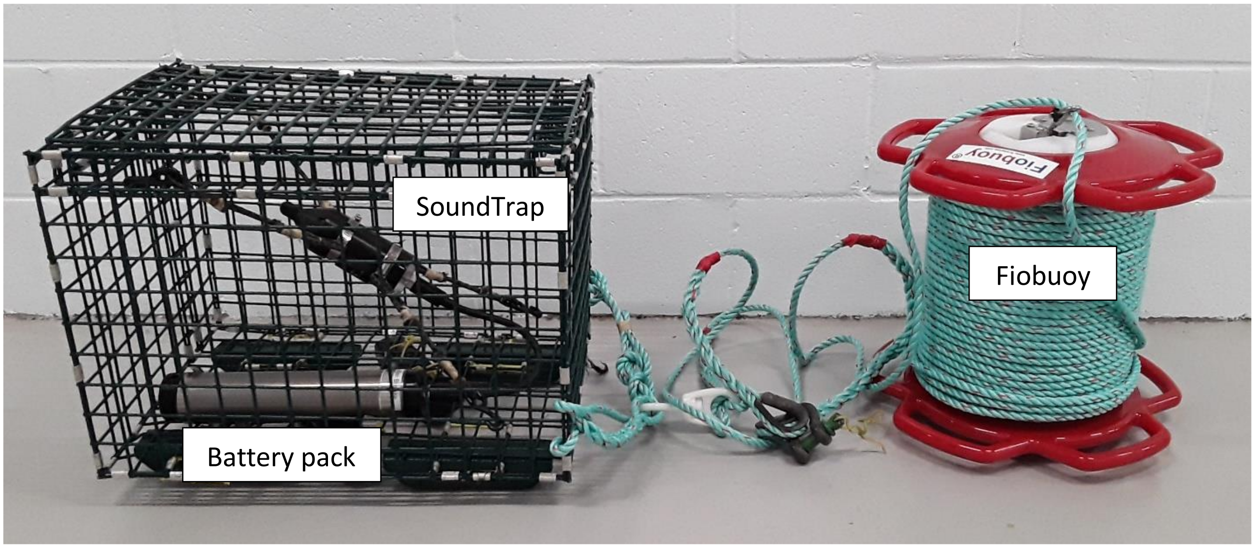

Figure 2. The typical mooring configuration used in each of the CAM Project deployments. A SoundTrap (ST300 STD, Ocean Instruments) and external battery park are shown housed in a modified lobster trap which is attached to a Fiobuoy acoustic release (TD100, Fiomarine).

2.2 Baleen Whale Call Detection and Validation

2.2.1 Call types and automated detection

The .wav files were sent to JASCO Applied Sciences for automated detection and classification of blue whale "A" and "B" calls (hereafter referred to as tonal calls), fin whale 20 Hz pulses, sei whale downsweeps, minke whale pulse trains, humpback whale mid-frequency song and non-song vocalizations, and North Atlantic right whale upcalls. These are the same call types that were targeted by the detectors used in Wingfield et al. (2022a), and so a detailed description of the calls can be found in section 2.2.1 of that report and the references therein. To detect minke whale pulse trains, JASCO analysts applied a pulse detector that combined individually detected pulses into pulse trains which were then compared to known pulse train parameters. For all other call types, JASCO analysts applied contour-based detectors which identified continuous contours of elevated energy and matched them to templates representing the target call types. The contours were assigned to a call type if their parameters were within the range of values specified in the template of the corresponding call. For a detailed description of the detection process, see Kowarski et al. (2020) and Delarue et al. (2022). For the parameters of each of the call type templates used, see Appendix B.

2.2.2 Manual validation of the detections

A call from another species, anthropogenic noise, or some other sound may have been misclassified as the target call type if the characteristics of the sound matched those of the target call type template. Therefore, each automated detection was visually and/or aurally validated by an analyst so that only true calls were included in the analyses. JASCO provided .wav and .png files of every two-minute segment that contained at least one detection of any of the target call types. The analyst visually inspected each two-minute .png image file to validate the detections. If the detection could not be confirmed or dismissed through visual inspection alone, the analyst opened the corresponding .wav file in JASCO's PAMlab lite (version 8.3.3) software for aural inspection.

The humpback moan detector was capable of detecting several humpback whale call types. It was beyond the scope of this study to consider the call types separately, and so we considered all validated humpback vocalizations together as overall minimum humpback whale acoustic presence. While validating the sei whale downsweep detections, the analysts discovered that many of the detections were actually of blue whale arch and downsweeping calls. In the northwestern Atlantic, blue whales produce these two call types in addition to tonal calls. Arch and downsweeping calls were not targeted with a specific detector as they are less stereotyped than tonal calls and thus more difficult to detect using automated methods. The analysts therefore grouped confirmed tonal, arch, and downsweeping calls together to represent overall minimum blue whale acoustic presence. The arch and downsweeping calls types are described in section 2.2.2 of Wingfield et al. (2022a) and the references cited therein.

Fin whales also produce low frequency downsweeps. Given their variable nature (Delarue 2008) and the fact that these calls were rare and almost always accompanied by 20 Hz pulses, we did not include their occurrence in the final results. There were occasions when the analyst was confident a downsweep was emitted by either a blue or sei whale, but could not definitively assign a species due to low call quality or noise interference. These calls were classified as “unknown baleen downsweeps”. This category was presented alongside the results for each of the species. Only calls that were definitively assigned to one species or to the unknown baleen downsweep category were included in further analyses. Calls that were misclassified or missed completely by the detectors but were discovered while validating the results of a different detector were included as a confirmed presence for the corresponding species.

The results can only be considered as the minimum occurrence of these species as whales may have been present but were not vocalizing, their calls may have been masked by noise, the detectors may have missed calls, or whales may have been producing calls that were not targeted by the detectors. A systematic review of files with no automated detections was beyond the scope of this study and so missed call rates and overall detector accuracy could not be assessed at this time. We summarized the validated results as minimum hourly and daily presence of each species, with presence defined as an hour or day containing at least one file with at least one validated call. Deployment and recovery days and days where the recording was interrupted for any reason were not included in further analyses. All analyses and associated figures were completed in R version 4.2.2 (R Core Team 2022) using the packages “xlsx” (Dragulescu and Arendt 2020), “lubridate” (Grolemund and Wickham 2011), “ggplot2” (Wickham 2016), “tidyr” (Wickham 2021), “dplyr” (Wickham et al. 2021), “DT” (Xie et al. 2021), “egg” (Auguie 2019), and “stringr” (Wickham 2019).

2.3 Sound Energy Budget Estimation

The raw .wav files were processed into spectrograms using a short time Fast Fourier Transform (FFT) with a length of 16384, 50% overlap, and a Hanning window applied. The resulting spectrograms had a time resolution of 0.3413 seconds and a frequency resolution of 1.4648 Hz.

We chose a sound energy budget approach, similar to that of Miller et al. (2008) and Nystuen et al. (2010), to summarize the contributions of vessels, wind, and all other sources to the overall soundscape near the recording site for six 1/3 octave bands centered at 100 Hz, 500 Hz, 1 kHz, 2 kHz, 5 kHz, and 10 kHz. The steps taken to calculate the sound energy budgets for each month are described in detail in section 2.3 of Wingfield et al. (2022a). All steps taken were the same for this report, but using the relevant spatial and temporal parameters for our study period at Ingonish. We extracted wind speed data from Environment Canada’s High Resolution Deterministic Prediction System (HRDPS) dataset

(Environment and Climate Change Canada (ECCC) 2022) for the in-water grid point closest to our mooring location (46.659, -60.323). The data had a temporal resolution of one hour and spatial resolution of 2.5 km. We obtained Automatic Identification System (AIS) data within a 30 km radius of the deployment site from the Canadian Coast Guard (CCG) for the entire study period. We chose a 30 km radius as it was deemed large enough to capture a sufficient number of vessel passes to design and evaluate the vessel noise detector. We conducted qualitative visual checks of several periods to ensure the vessel noise detector was performing well (Figure 3). When selecting which periods to review, we avoided periods with several nearby vessels and periods with very few or no nearby vessels as these situations made it difficult to tell if the detector was working reliably. A quantitative evaluation of the detector could not be performed as there were many factors affecting vessel detectability, including the vessel source level, currents, differing sound speed profiles, etc.

Figure 3. A typical figure used to evaluate the performance of the vessel noise detector. The time period shown for all panels is from January 6 to 14, 2020 (UTC). Top panel: The distance (km) of vessels, travelling at speeds of 1 knot or faster, from the mooring location (30 second resolution); Middle panel: The covariance between noise levels in the 1/3 octave bands centered at 100 and 500 Hz (blue line) and mask values (orange line) resulting from the vessel noise detector (5 minute resolution, mask value of 1 indicates the presence of vessel noise); Bottom panel: The sound pressure level (SPL) in the 1/3 octave band centered at 100 Hz (0.3413 second resolution).

2.4 Sound Level and Baleen Whale Call Presence Comparison

To investigate whether vessel presence and associated noise levels may have affected baleen whale calling behaviour and/or the detectability of calls, we plotted the number of hours per day with at least one confirmed call for fin, blue, and humpback whales against the median and maximum daily averaged sound pressure levels (SPLs) for the 1/3 octave bands centered at 63 and 125 Hz. The monitoring of continuous noise levels in these frequency bands was recommended in Descriptor 11 of the European Union's Marine Strategy Framework Directive as a means to attain "Good Environmental Status", defined as "when the introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment" (European Commission 2008; European Commission 2017). There were too few detections of minke, North Atlantic right, and sei whales to make a meaningful comparison and so we did not create plots for these species.

3.0 Results

3.1 Data Collection

Acoustic data were successfully collected during 507 complete days (12,168 hours) from November 2019 to November 2021 (Table 1). A connectivity issue with the TR Porpoise mainboard prevented data from writing to the memory cards during the first deployment from June to August 2019. Another corruption issue resulted in the loss of time and date information for the data collected during the second deployment from August to November 2019, and therefore these data were excluded from the analyses. The TR Porpoise stopped recording earlier than expected during the November 2019 to April 2020 deployment and data collection was subsequently paused in April 2020 due to the COVID-19 pandemic, resulting in a data gap from March 13 to August 13, 2020 (Table 1). A small leak in the SoundTrap ST500 during the October 2020 to April 2021 deployment caused the recorder to stop approximately two months early, resulting in a data gap from February 27 to April 21, 2021 (Table 1). Finally, a storm prevented the timely deployment of the mooring in July 2021, resulting in a gap in data collection from July 1 to 7, 2021.

3.2 Baleen Whale Call Occurrence

3.2.1 Detector performance

There were 50,182 2-minute segments identified by the detectors as containing at least one potential baleen whale call and each was reviewed by a trained analyst. The minke whale pulse train detector was very rarely triggered, and all detections were determined to be noise. There were no minke whale calls found while validating calls from the other species, therefore minke whales are absent from the results. The "unknown baleen downsweeps" most resembled blue and sei whale downsweeps and it is likely that they belonged to one of those two species. There were many false positive detections across all detectors, often triggered by noise or the incorrect species. Delarue et al. (2022) used only manually validated detections of sei and North Atlantic right whale calls as the proportion of files with detections that were true positives (precision) for these detectors was less than the threshold of 0.75 across all sites. It should therefore be noted that the low number of validated sei and North Atlantic right whale calls in this study may be a reflection of the methods used. During the winter months from December through February, the humpback whale detector was often falsely triggered by grey seal vocalizations. It is important to consider the results presented here as the minimum call occurrence for each species.

A complete evaluation of the performance of each detector, including missed call rates, would have required the review of several additional files and was therefore beyond the scope of this report. For detectors with similar or the same parameters, Delarue et al. (2018) found that detectors targeting stereotyped calls or those that are unique in spectral content, like the fin whale 20 Hz pulse, performed better than detectors targeting calls with greater overlap in spectral content, such as humpback moans and blue whale tonal calls. Delarue et al. (2022) found that average precision scores for the fin whale 20 Hz, blue whale tonal, and humpback moan detectors were 0.75 or greater, while average recall scores ranged from 0.40 to 0.60, meaning many calls were missed during some periods (Delarue et al 2022). Calls can be missed for a variety of reasons, including low signal to noise ratio (SNR), presence of confounding signals, and a high degree of variability within call types. While it cannot be determined at this time how many calls might have been missed in this study, reviewing every detection meant that all false positives were removed from the analysis and only true calls were considered further.

3.2.2 Baleen whale minimum call occurrence

The calls of fin, blue, humpback, sei, and North Atlantic right whales were confirmed to be present through manual validation of the automated detections. Fin whale pulses were the most frequently occurring vocalization in the acoustic data; they were present during the greatest number of deployment days (175) and hours (1,008) (Table 2). Blue whale calls and unknown downsweeps occurred on just under one third of all deployment days (165) while humpback whale calls occurred on just over one quarter of all deployment days (131) (Table 2). Although humpback whale calls occurred during fewer days than blue whale calls and unknown downsweeps, they occurred during the second-highest number of hours (701). Sei and North Atlantic right whale calls were confirmed to be present during only 10 and 5 days and during 15 and 14 hours, respectively (Table 2).

Table 2. The number and percent (%) of days and number and percent of hours that each species and unknown downsweeps were confirmed to be present throughout the study period. Percentages were calculated using the totals of 507 days and 12,168 hours.

Species	Days detected	% days	Hours detected	% hours
Fin	175	34.52	1008	8.28
Blue	165	32.54	493	4.05
Humpback	131	25.84	701	5.76
Sei	10	1.97	15	0.12
North Atlantic right	5	0.99	14	0.12
Unknown downsweeps	165	32.54	466	3.83

Fin whale calls occurred in almost every month, often during consecutive days, throughout the study period (Figure 4). Fin whale pulses were not detected from mid-February to mid-March, 2020, and present during only one day, May 31, from late April to July, 2021 (Figure 4). On the days calls were present, they occurred during a median of three hours (Table 3). There was one day in November 2019 during which fin whale pulses were present in all 24 hours.

Like fin whales, blue whale calls occurred in almost all months during the study period (Figure 5). There were several consecutive days with calls in March, October, and November 2020 and from late April through September 2021 (Figure 5). There were some differences in call occurrence across years; although present throughout January 2020, blue whale calls occurred during only two days in January 2021 (Figure 5). Blue whale calls occurred on more days during mid-August to October 2021 than during the same period in 2020 (Figure 5). On the days calls were present, they occurred during a median of two hours (Table 3). Blue whales were detected during a maximum of 18 hours during one day in October 2020. The majority of blue whale vocalizations confirmed through the validation process were of arch and downsweeping calls. The blue whale tonal detector was often triggered by low frequency noise, mostly from vessels. Given this detector's poor performance and the lack of a detector specifically targeting arch or downsweeping calls, it is possible that blue whale vocalizations were not adequately detected with the adopted methodology. However, the results can still be interpreted as a minimum estimate of blue whale call occurrence, as the sei whale downsweep detector identified many arch and downsweeping calls.

A much higher degree of seasonality was observed in humpback whale call occurrence compared to fin and blue whale call occurrence. Almost all humpback whale calls occurred from late October to late January in all years (Figure 6). During this time, humpback whale calls occurred during several consecutive days. On the days calls were present, they occurred during a median of four hours (Table 3). Humpback whale calls occurred during a maximum of 20 hours on two days in December 2019.

Sei whale calls occurred during ten days throughout the study period (Figure 7). There were too few detections to infer any seasonal patterns in occurrence. On the days calls were present, they occurred during a median of one hour per day (Table 3). Sei whale calls occurred during a maximum of three hours per day in October 2020.

North Atlantic right whale calls occurred during two days in November 2019, and during one day each in December 2019, October 2020, and October 2021 (Figure 8). Their calls occurred during one hour on November 21, 2019, December 27, 2019, and October 27, 2020, for three hours on November 20, 2019, and the maximum of eight hours on October 21, 2021 (Table 3).

Unknown downsweeps occurred in all months for which there were data, except August 2020 and January 2021 (Figure 9). There were only four days with at least one downsweep from January to mid-March 2020. Notably, unknown downsweeps occurred during almost every day from late April to August 2021 (Figure 9). There were more days with downsweeps during mid-August to mid-October in 2021 compared to the same period in 2020. On the days calls were present, unknown downsweeps occurred during a median of two hours per day (Table 3). The maximum of 10 hours per day occurred in June 2021.

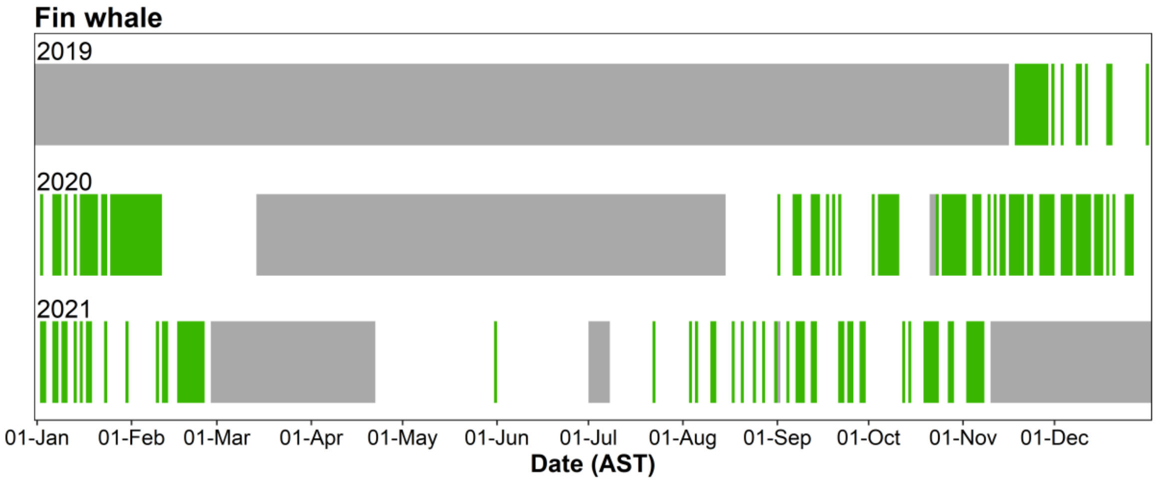

Figure 4. The days during which at least one fin whale call occurred from November 2019 to November 2021. The grey shaded areas represent periods during which a recorder was either not deployed, was deployed but had stopped recording prematurely, or was deployed for less than 24 hours. AST: Atlantic Standard Time.

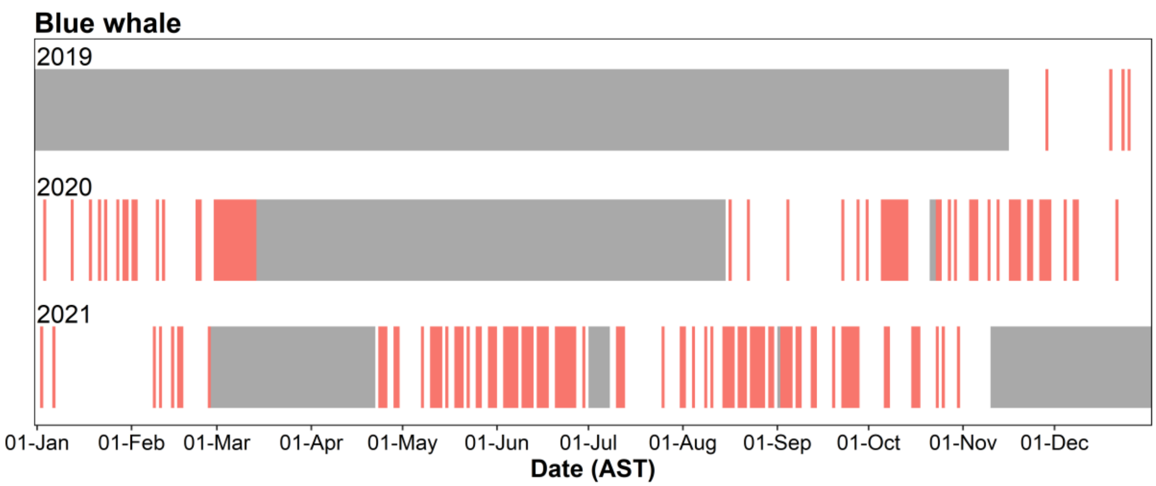

Figure 5. The days during which at least one blue whale call occurred from November 2019 to November 2021. The grey shaded areas represent periods during which a recorder was either not deployed, was deployed but had stopped recording prematurely, or was deployed for less than 24 hours. AST: Atlantic Standard Time.

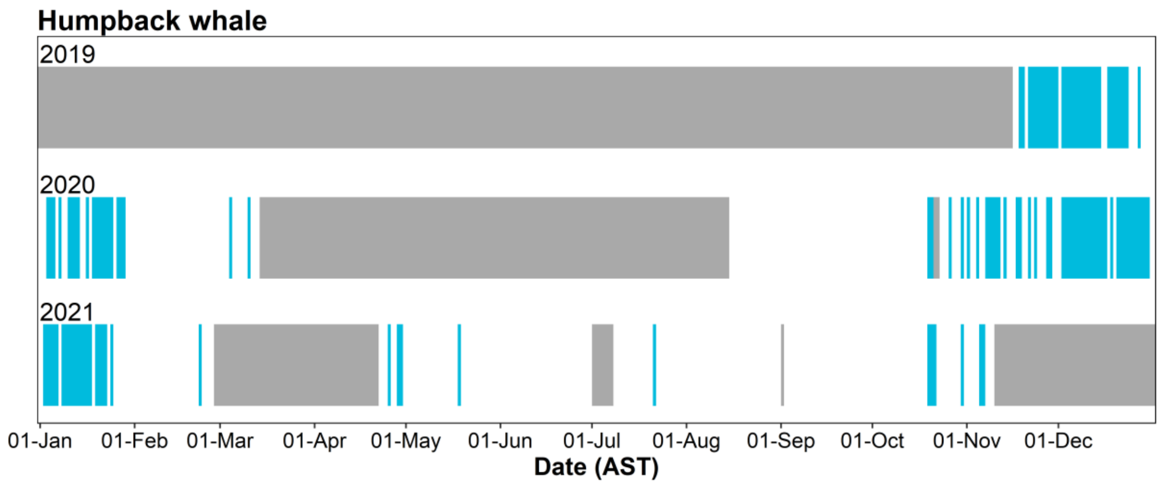

Figure 6. The days during which at least one humpback whale call occurred from November 2019 to November 2021. The grey shaded areas represent periods during which a recorder was either not deployed, was deployed but had stopped recording prematurely, or was deployed for less than 24 hours. AST: Atlantic Standard Time.

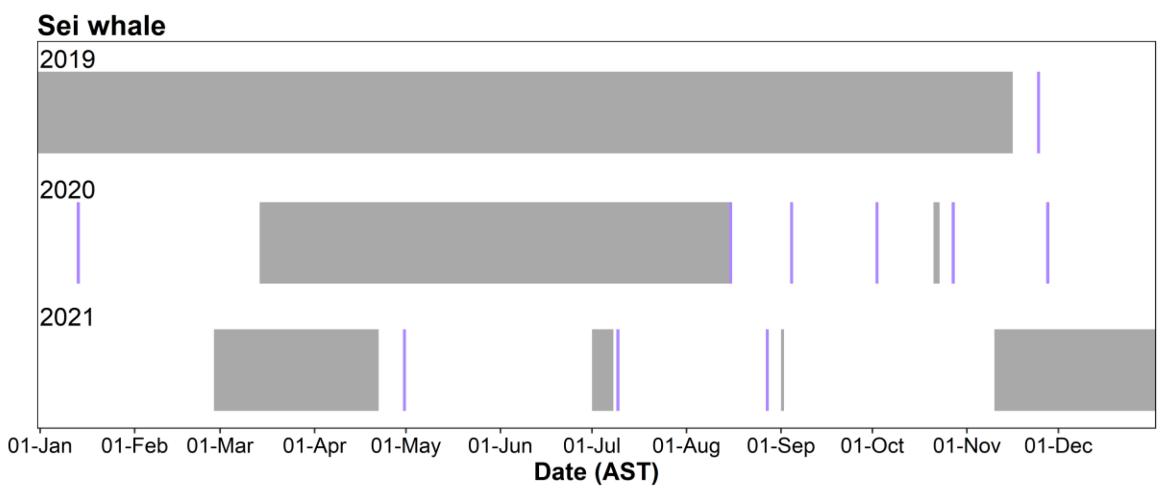

Figure 7. The days during which at least one sei whale call occurred from November 2019 to November 2021. The grey shaded areas represent periods during which a recorder was either not deployed, was deployed but had stopped recording prematurely, or was deployed for less than 24 hours. AST: Atlantic Standard Time.

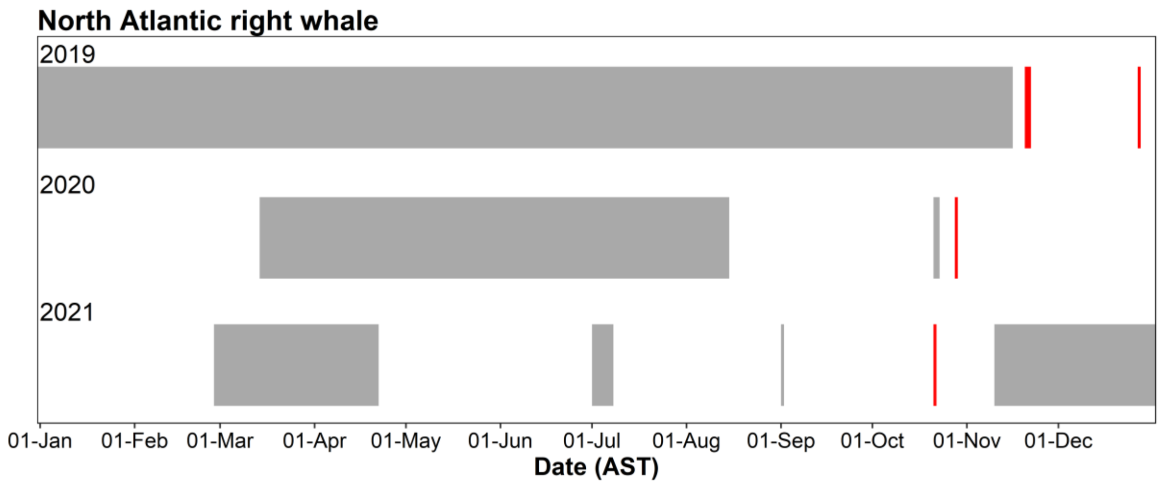

Figure 8. The days during which at least one North Atlantic right whale call occurred from November 2019 to November 2021. The grey shaded areas represent periods during which a recorder was either not deployed, was deployed but had stopped recording prematurely, or was deployed for less than 24 hours. AST: Atlantic Standard Time.

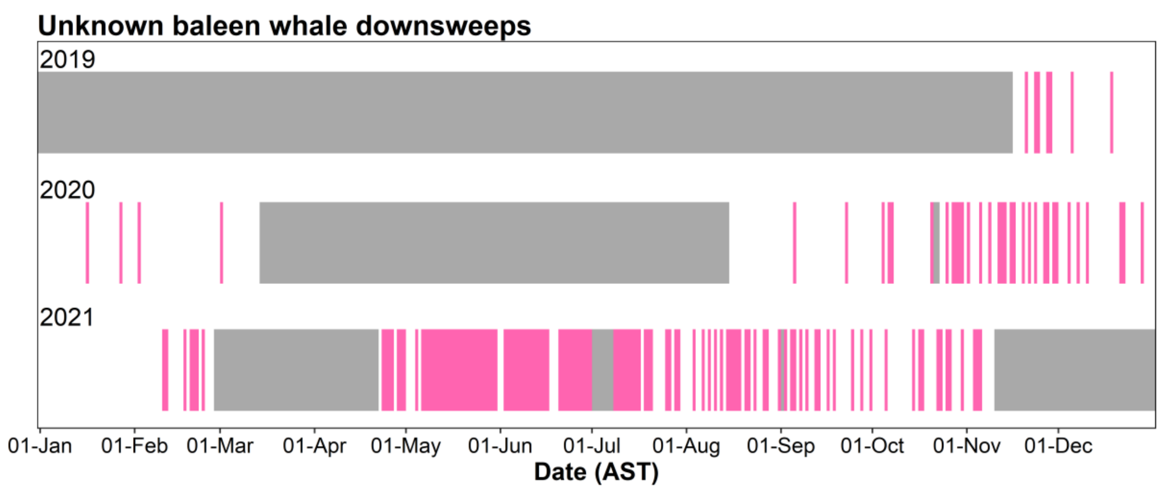

Figure 9. The days during which at least one unknown baleen whale downsweep occurred from November 2019 to November 2021. The grey shaded areas represent periods during which a recorder was either not deployed, was deployed but had stopped recording prematurely, or was deployed for less than 24 hours. AST: Atlantic Standard Time.

Table 3. The median hours per day that each species and unknown downsweeps were confirmed to be present and the associated 25, 75, and 100% quartiles. Days during which the species of interest was absent were omitted from the calculations.

Species	**25%**	**50% (Median)**	**75%**	**100%**
Fin	2	3	8	24
Blue	1	2	3	18
Humpback	2	4	8	20
Sei	1	1	2	3
North Atlantic right	1	1	3	8
Unknown downsweeps	1	2	4	10

3.3 Sound Energy Budget Estimation

The highest SPLs occurred in the lowest frequency bands throughout the study period (Figure 10). The SPLs varied on a daily scale in all frequency bands, but overall levels remained relatively consistent in the highest frequency band (10 kHz) (Figure 10). In all other bands, and particularly in the 100, 500, and 1000 Hz frequency bands, sound levels slightly increased from November 2019 to January 2020, decreased from January to March 2020, steadily increased again from August 2020 to February 2021, then decreased from April to August 2021 before remaining relatively consistent from August to November 2021 (Figure 10). Figures C1 to C20 in Appendix C show the monthly spectrograms for November 2019 to November 2021.

Wind speeds were highest throughout November and December 2019 with several days exceeding 10m/s and a few days with speeds exceeding 15 m/s (Figure 11). The maximum wind speed of 23.1 m/s occurred on December 16, 2019. Wind speeds were typically lowest during the summer months (June and July) (Figure 11). The average SPLs in each of the six frequency bands increased at similar rates as the wind speed increased from 0 to approximately 10 m/s (Figure 12). At speeds of 10 m/s and higher, the average SPLs in the 100 Hz, 500 Hz, and 2 kHz bands continued to increase at a similar rate, with some fluctuations occurring from approximately 12 to 16 m/s (Figure 12). The rate of increase of the average SPL in the 5 kHz frequency band slowed as wind speed increased beyond 10 m/s (Figure 12). Average SPLs in the highest frequency band (10 kHz) began to stabilize as wind speeds exceeded 10 m/s but then decreased as wind speeds reached 17.5 m/s and higher (Figure 12).

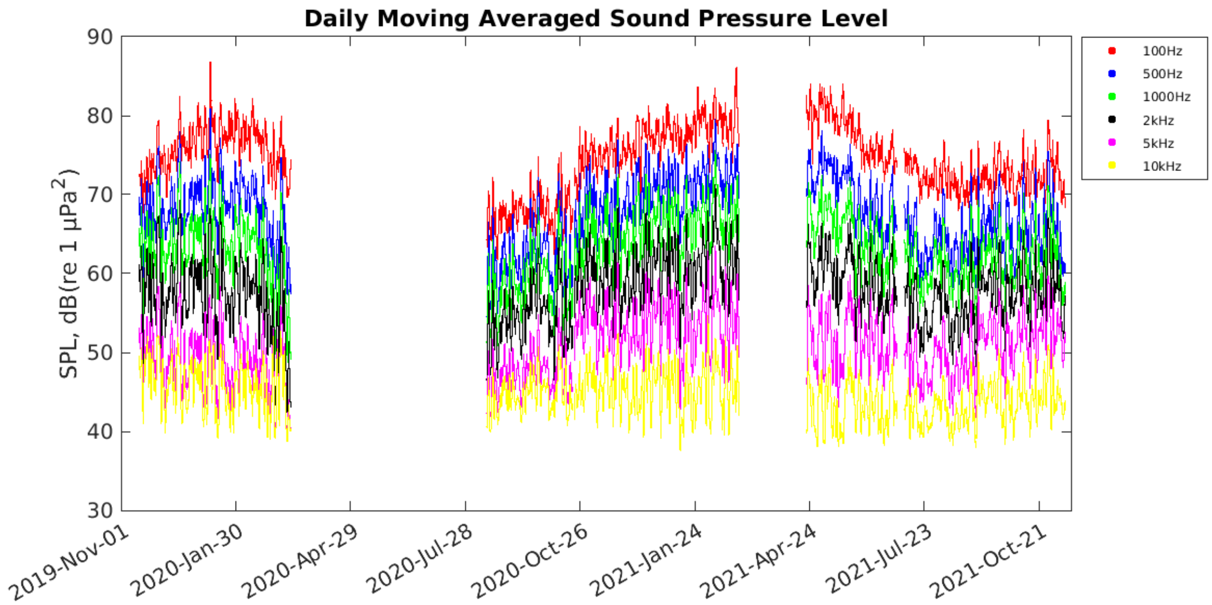

Figure 10. The sound pressure level (SPL) (daily moving average) in each of the six 1/3 octave bands throughout the study period. Missing data were due to gaps in data collection. The date is in UTC.

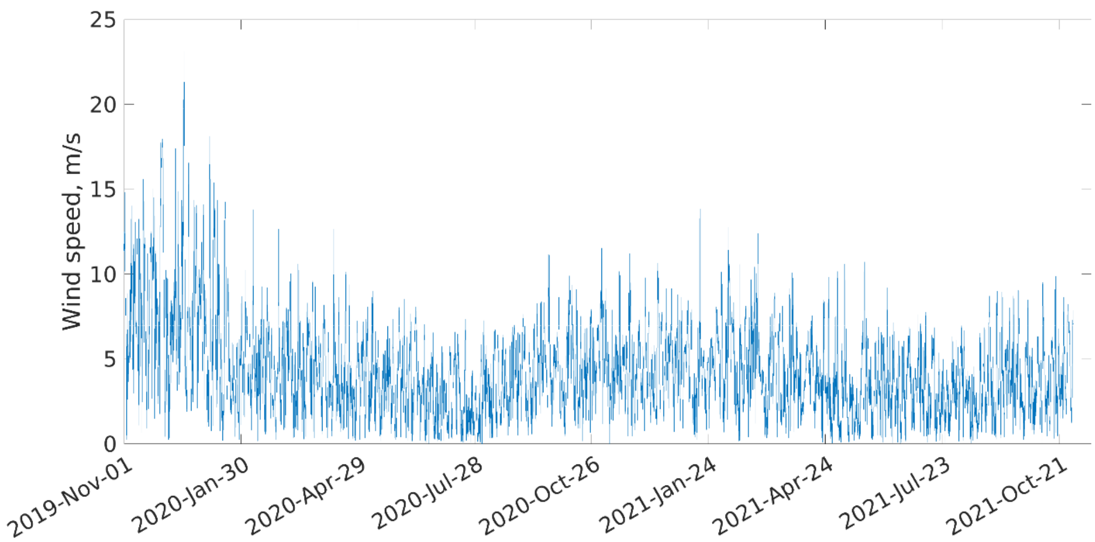

Figure 11. Hourly wind speeds extracted from the HRDPS dataset (ECCC 2022) for the in-water grid point nearest to the mooring location (46.659, -60.323) from November 2019 to November 2021. The date is in UTC.

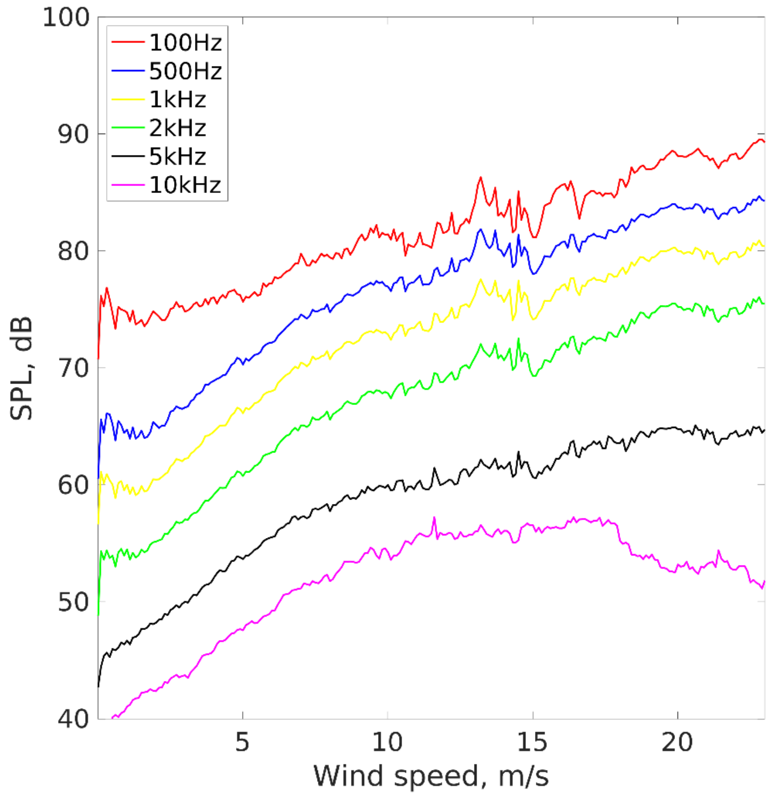

Figure 12. The relationship between the sound pressure level (SPL) in each of the six frequency bands and the wind speed (0.1 m/s resolution) from November 2019 to November 2021.

The vessel noise detector was deemed suitably reliable following the qualitative visual inspection of the classification results for several week-long periods. Vessel noise dominated the lowest frequency band, the 1/3 octave band centered at 100 Hz, throughout the study period (Figure 13). In January 2020, vessel noise also dominated the soundscape in the 500 Hz, 1 kHz, and 2 kHz frequency bands (Figure 13). In the same month, sound from wind dominated the soundscape in the two highest frequency bands (5 kHz and 10 kHz) (Figure 13). In all other months from November 2019 to March 2020, wind was typically the dominant source of sound near the study site, with sound from "other" sources contributing more to the 500 Hz, 1 kHz, 2 kHz, and 5 kHz frequency bands in November 2019 than in other months (Figure 13). From August 2020 to February 2021, the contributions of vessels, wind, and "other" sources to the soundscape were more or less consistent across the 500 Hz, 1 kHz, 2 kHz, 5 kHz, and 10 kHz frequency bands, with wind being the dominant contributor (Figure 13). In April 2021, vessels were the dominant contributor of noise to the soundscape in all frequency bands (Figure 13). From May 2021 to August 2021, the three sources contributed very similar amounts of energy to the overall soundscape in all but the lowest frequency band (Figure 13). In September and October 2021, wind became a more dominant contributor to the overall soundscape in all but the lowest frequency band (Figure 13). Finally, "other" sources dominated the soundscape in all but the two lowest frequency bands in November 2021, but this may be a reflection of the small sample size (ten days) rather than an actual trend.

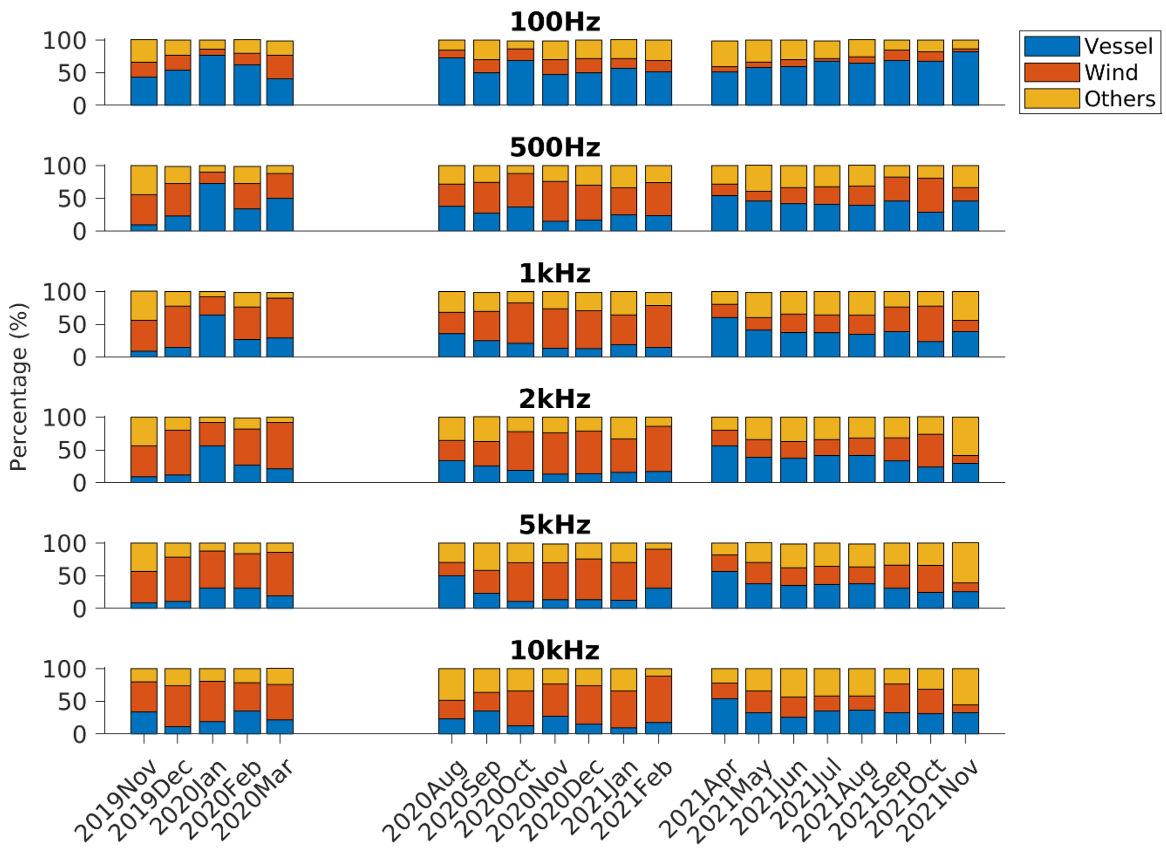

Figure 13. The percent (%) contribution of each source to the total sound energy budget for each of the 6 frequency bands from November 2019 to November 2021. There were no data from April 2020 through July 2020 and in March 2021 due to interruptions in data collection and recorder malfunctions.

3.4 Sound Level and Baleen Whale Call Presence Comparison

The maximum daily averaged SPLs in the 1/3 octave bands centered at 63 Hz and 125 Hz were mostly consistent within the 95 to 115 dB re 1 µPa range, with values being greater for the 63 Hz band compared to the 125 Hz band (Figure 14). There was a noticeable decline in the maximum daily averaged SPLs in late February through early March 2020 (Figure 14). Median daily averaged SPLs in both bands increased from approximately 75 to 85 dB re 1 µPa between November 2019 and February 2020, then decreased to 75 dB re 1 µPa throughout February 2020 (Figure 14). Median daily averaged SPL values in both frequency bands increased steadily from approximately 70 to 80 dB re 1 µPa from August 2020 to February 2021, decreased to approximately 70 (63 Hz) and 65 (125 Hz) dB re 1 µPa, and remained at those levels throughout the rest of the study period (Figure 14).

Humpback, blue, and fin whale calls occurred on days with both low and high maximum and median daily averaged SPLs (Figure 14). Fin whale calls often occurred during more than eight hours per day in November 2019, between late January and early February 2020, and from October 2020 through February 2021 and from September to November 2021 (Figure 14). Fin whale calls were noticeably absent from mid-February to mid-March 2020, which coincided with a decrease in median and maximum daily averaged SPLs in the 63 and 125 Hz frequency bands, and from late April to July 2021 (with the exception of one day), which coincided with a decrease in median daily averaged SPLs in the 63 and 125 Hz frequency bands (Figure 14). Blue whale calls occurred during fewer hours per day than humpback whale calls, with most days having fewer than four hours with calls (Figure 14). The number of hours per day with blue whale calls exceeded four during at least one day in January, February, March, October, and November 2020, and in June, August, and September 2021 (Figure 14). There did not appear to be a correlation between the number of hours during which blue whale calls were present per day and the daily averaged median and maximum SPLs in the 1/3 octave bands centered at 63 and 125 Hz throughout the study period (Figure 14). On days calls were present, humpback whale calls often occurred during more than four hours per day (Figure 14). There did not appear to be a correlation between the number of hours during which humpback whale calls were present per day and the daily averaged median and maximum SPLs in the 1/3 octave bands centered at 63 and 125 Hz (Figure 14).

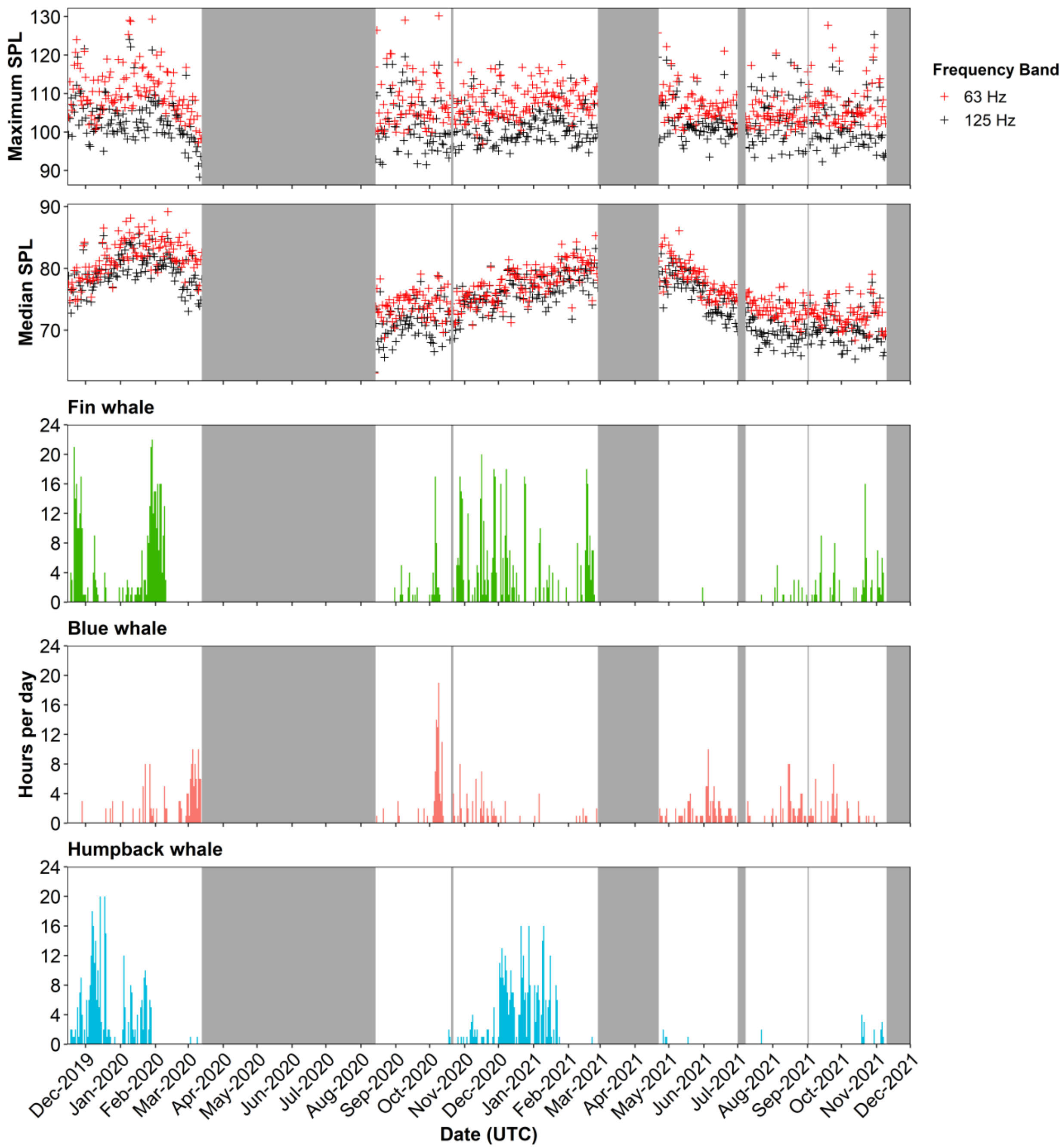

Figure 14. The maximum and median daily averaged SPL values (dB re 1 µPa) for the 1/3 octave bands centered at 63 Hz and 125 Hz and the number of hours per day during which at least one fin, blue, or humpback whale call occurred from November 2019 to November 2021. The grey shaded areas represent periods during which a recorder was either not deployed, was deployed but had stopped recording prematurely, or was deployed for less than 24 hours. UTC: Coordinated Universal Time.

4.0 Discussion

We have demonstrated through the use of relatively low-cost passive acoustic monitoring that blue, fin, humpback, sei, and North Atlantic right whales occur near the coast of Ingonish, that vessel noise dominates the lower frequencies throughout the year, and that wind-generated sound often dominates the soundscape in several frequency bands throughout the winter months. These results increase our understanding of baleen whale occurrence in an otherwise sparsely surveyed area and provide insight into the sources and intensity of sound to which these whales and other marine animals may be exposed.

4.1 Baleen Whale Call Occurrence

It is important to consider that the results in this report represent a minimum estimate of the occurrence of baleen whales, as we may have underestimated actual presence due to a number of reasons. Whales may have been in the area but not vocalizing, calls may have been masked by noise, the detector may have missed the target call, or the species was present but producing a call type not targeted by the detector. Targeting sex-biased call types, like the fin whale 20 Hz pulse and blue whale tonal calls, will lead to an underestimation of overall whale presence (Davis et al. 2020). The detection range of humpback and blue whale calls has been found to vary seasonally in the northwest Atlantic, with ranges typically being wider in summer compared to winter (Kowarski et al. 2018; Wingfield et al. 2022b). Modelling the detection range of various call types for this site was beyond the scope of this report, but if we assume seasonal patterns are similar to sites further offshore, it is possible that there was a seasonal bias in the detectability of calls. We did not systematically review files with no detections to investigate missed call rates, but a previous study found that these detectors can miss a number of calls (Delarue et al. 2018). The methods used for detecting sei, North Atlantic right, and minke whales were likely inadequate, which may explain their rare occurrence or complete absence during the study period (Delarue et al. 2022). These inadequacies are discussed further later in this section. While we likely missed calls, we can be certain that only true calls were included in our results as each file with a detection was reviewed by an expert analyst.

Fin whales were the most frequently detected species, occurring during over one third of all deployment days. The 20 Hz pulse is often repeated in long sequences, or songs, and so it was to be expected that this call type would occur across several hours and days. Patterns in occurrence were similar across each of the three years in our study period, which suggests there were no major annual changes in fin whale vocal behaviour. Consistent with patterns in occurrence throughout much of the Scotian Shelf, fin whale pulses occurred predominately from August through February, and less so in late spring through early summer (Davis et al. 2020; Delarue et al. 2022). The scarcity of calls during the late spring-early summer period is likely due to a decrease in singing behaviour and therefore the proportion of 20 Hz pulses in the vocal repertoire decreases (Watkins 1981; Stafford et al. 2007; Roy et al. 2018; Delarue et al. 2022). It is also possible that fin whales left the area during this time, and therefore there were fewer vocalizing whales rather than a reduction in individual vocalization rates. Sound levels were no higher than they were during periods when fin whales were frequently detected, and so it is unlikely that the decrease in detections from March to August is due to masking. Patterns in call occurrence at our Chedabucto Bay site were similar (Wingfield et al. 2022a). Although despite there being several days with calls in January and February 2020 at Ingonish, calls were almost completely absent from these months in our Chedabucto Bay dataset.

Blue whales were detected throughout the study period, with no obvious seasonal pattern in call occurrence. There may have been more obvious seasonal patterns in the occurrence of tonal versus downsweeping calls, as was observed within and near the Gully MPA (Wingfield et al. 2022b), but we were only interested in general blue whale call occurrence and thus separating the call types was beyond the scope of this report. These results are consistent with the year-round occurrence of blue whale calls observed by Delarue et al. (2022) at Stn 1, the site closest to Ingonish, and by Davis et al. (2020), Delarue et al. (2022), and Wingfield et al. (2022b) on the broader Scotian Shelf. There seemed to be a higher proportion of days with calls from May through August at our site than at the site closest to ours (Stn 1) in Delarue et al. (2022) and more broadly on the Scotian Shelf in Davis et al. (2020). This is likely due to the fact that we included downsweeping calls in our results, which are a non-song call and are more likely to be produced during summer months than the tonal calls, which are believed to be a mating display produced only by males (Berchok et al. 2006; Wingfield et al. 2022b). In Chedabucto Bay, blue whales were detected exclusively from January through June, while at Ingonish they were detected in all months for which there were data. Blue whale detections were more common at Ingonish and occurred during more hours per day on average than in Chedabucto Bay (Wingfield et al. 2022a). The Gulf of St. Lawrence has been identified as an important foraging area for blue whales and many studies have found the Cabot Strait to be an important migration corridor for blue whales moving in and out of the Gulf (Sears et al. 1990; Lesage et al. 2018; Moors-Murphy et al. 2019; Gomez et al. 2020). Given the Ingonish site is much closer to both of these areas than Chedabucto Bay, there are likely to be more individuals moving through the general area and thus more calls detected at Ingonish. The majority of our blue whale detections were downsweeping calls, often detected by the sei whale downsweep detector, rather than the specifically targeted tonal calls. The sei whale downsweep detector was not developed to target blue whale downsweeps and so it is possible that several blue whale downsweeps were missed, thus it is important to consider these results as the minimum blue whale occurrence. Efforts are underway within DFO's Science branch to build and refine a blue whale arch and downsweeping call detector, which will improve the detectability of this species (A. Babin and G. Macklin, personal communication, December 2023).

Humpback whale vocalizations exhibited the strongest seasonality of all of the species. They occurred primarily during the fall and winter months from late October to late January. This period corresponds to the onset and continuation of singing at a site off Cape Breton (Kowarski et al. 2022). These results are consistent with those of Vu et al. (2012) and Stanistreet et al. (2013) on Stellwagen Bank, with Kowarski et al. (2018) and Davis et al. (2020) around the Gully MPA on the eastern edge of the Scotian Shelf, and with the winter peak in occurrence at the site closest to the Ingonish site, Stn 1, in Delarue et al. (2022). There was a peak in the number of days and hours with calls in December and January, consistent with the results of Kowarski et al. (2018) and our Chedabucto Bay study (Wingfield et al. 2022a). Kowarski et al. (2018) found that the majority of calls during this time were song calls. Humpback whale song is often repeated for several hours, and therefore one would expect there to be a higher number of detections during months when males are singing. Delarue et al. (2022) observed an increase in springtime calling from April to mid-June at Stn 1 as did we at our Chedabucto Bay site (Wingfield et al. 2022a). We had data from the Ingonish site during this period for only one year, 2021. During this time, there were only a few days with calls. The near-absence of calls in the spring and summer months may be due to a migration to other areas, like breeding grounds in the West Indies (Whitehead and Moore 1982). It is also possible that humpback whales remained in the area but changed their vocal behaviour to call more sporadically, making them more difficult to detect. Seasonal patterns in call occurrence were similar across each of the three years within our study period.

There were only ten days with sei whale calls throughout the study period, and therefore we were unable to assess seasonal or annual trends in call occurrence. The ten days were spread across all four seasons and each of the three years in our study period. Delarue et al. (2022) did not detect any sei whale downsweeps at Stn 1 and these calls were rare at our Chedabucto Bay site (Wingfield et al. 2022a). The scarcity of sei whale calls is perhaps due to the fact that this species occurs predominately in offshore areas and is uncommon in coastal on-shelf waters (Horwood 2009; Prieto et al. 2012). Sei whales have been detected year-round at sites farther offshore, closer to the edge of the Scotian Shelf (Davis et al. 2020; Macklin 2022). The lack of sei whale calls may have also been the result of poor detector performance. Delarue et al. (2018; 2022) noted the poor performance of this detector and subsequently chose to present only calls that had been manually validated in their final results. The detector was systematically triggered by blue and fin whale downsweeps and by seismic airgun pulses (Delarue et al. 2018). In our study, the sei whale detector was often triggered by grey seal vocalizations, humpback moans, blue whale arch and downsweeping calls, and noise. The sei whale detector may need to be modified to better capture the acoustic occurrence of this species. Sei whale sightings within the Gulf of St. Lawrence are rare and it is likely not a key habitat for this species, unlike for blue whales (COSEWIC 2019). This species would therefore be less likely to travel through the Cabot Strait making them generally less common near the Ingonish site and surrounding area.

Like sei whale downsweeps, North Atlantic right whale upcalls were rare in our Ingonish dataset. They occurred during only five days and fourteen hours in October, November, and December. As with the sei whale downsweep detector, the North Atlantic right whale upcall detector may not have adequately detected upcalls and therefore the low number of upcalls may be a reflection of poor detector performance rather than lack of whales (Delarue et al. 2022). There were no upcall detections at the Chedabucto Bay site (Wingfield et al. 2022a). This may be because the Ingonish site was closer to the southern Gulf of St. Lawrence, where many North Atlantic right whales spend the summer foraging following a shift in distribution from the Gulf of Maine and Bay of Fundy in 2015 (Simard et al. 2019). The nearby Cabot Strait was identified as the main migratory corridor for North Atlantic right whales moving in and out of the Gulf of St. Lawrence (Durette-Morin et al. 2022). It is possible we detected North Atlantic right whales on a delayed migration south from a summer and fall of foraging in the Gulf of St. Lawrence. Work is underway to explore the effectiveness of other automated detectors to improve upcall detectability.

Like blue whale calls, unknown downsweeps were heard on many more days and hours and throughout more months of the year in our Ingonish dataset compared to our Chedabucto Bay dataset (Wingfield et al. 2022a). Also like blue whale calls, the unknown downsweeps were spread throughout the months and years during the study period, and were noticeably absent in January 2021. It is therefore possible that most of these unknown downsweeps were in fact emitted by blue whales. It is common practice for an analyst to label a call as unknown if the quality of the call is poor or if it is partially masked by noise to avoid misrepresenting the presence of a certain species. We still felt these results were worth presenting given the analyst was confident these sounds were in fact emitted by a baleen whale, most likely a blue or sei whale. The frequency range and duration of these unknown downsweeps most closely matched the characteristics of the downsweeps of these two species.

All minke whale pulse train detections were false positives and we did not come across any true pulse trains while validating the results of the other detectors. Delarue et al. (2022) had not implemented an automated detector, but did confirm the presence of minke whale pulse trains through manual validation at Stn 1, their site closest to our Ingonish site. This and the fact that minke whales have been sighted in the area demonstrates that this species is expected to occur there. It is possible that minke whale pulse trains in our dataset were masked by noise or that whales were producing non-target vocalizations or not vocalizing at all. It is also possible that the current methods for detecting this particular call type are inadequate and in need of improvement.

4.2 Sound Energy Budget Estimation

Sound pressure levels across each of the five frequency bands were mostly consistent throughout the study period, with some exceptions. It is possible that inter-deployment fluctuations in the SPL values were the result of varying hydrophone sensitivities, given we used recorders from different manufacturers. Vessel noise contributed the most energy to the lowest frequency band, the 1/3 octave centered at 100 Hz, in almost every month during the study period. This result is consistent with both historical and contemporary works, which cite vessels as the dominant contributor to sound energy below 200 Hz throughout the world's oceans (Wenz 1962; Hildebrand 2009; Southall et al. 2017). Although Ingonish is not a major port, there are recreational, whale watch, and fishing vessels in the area. Vessel noise often contributed more energy to the overall soundscape during spring and summer months compared to fall and winter months. This is likely because recreational and whale watch vessels operate during the spring and summer months when the weather and sea conditions are more suitable. There are also likely to be more fishing vessels in the area during this time, as the crab fishery begins in April (M. Oravecz, personal communication, October 2023), the groundfish fishing season runs from April to September (DFO 2017b), and the lobster fishing season runs from mid-May to mid-July (DFO 2022). It is not clear why vessel noise was a greater contributor to the soundscape in January 2020 than in adjacent months and in January 2021. Wind speeds were not noticeably lower in January 2020, and so it is likely that there was more energy contributed by vessels rather than a reduction in energy contributed by wind. We did not process AIS data beyond the few days used to validate the vessel noise detector, and so vessel traffic patterns should be investigated further.

Wind generated sound is the dominant source of ambient noise from 400 Hz to 50 kHz in most locations throughout the world's oceans (Knudsen et al. 1948; Hildebrand et al. 2021). Nystuen et al. (2010) found that wind was the dominant sound source 93 % of the time from April through September in the Bering Sea. Hildebrand et al. (2021) found that wind speed and noise levels were highly correlated at frequencies of approximately 500 Hz to 10 kHz. Wind speeds were typically higher in the fall and winter months near Ingonish, which is consistent with our findings that wind generally contributes more energy to the overall soundscape during these months. We observed an unusual result where the SPLs in the 10 kHz frequency band decreased at wind speeds of 17.5 m/s and higher. It is more typical for SPLs to reach a plateau with increasing wind speed but unusual to observe a decline. It is possible that this was due to sea ice buffering the higher frequency component of the wind during winter periods or due to the direction of the wind.

The "other" category may have included fish or cetacean vocalizations, buoy noise, noise from vessels other than engine noise (eg. generators, on-deck operations), and/or rainfall. Sounds in this category contributed more energy to the soundscape during November 2019 and November 2021 than in other months. November 2019 was a particularly wet month in Ingonish, with 254 mm of total rainfall (ECCC 2023). It is therefore possible that rain may have contributed more energy to the soundscape relative to vessels or wind during that month. We had data for only the first ten days in November 2021, and it is possible that this small sample size affected the accuracy of our results. Baleen whale call occurrence did not appear to be correlated with the contributions of "other" sound sources to the overall energy budget, and therefore it seems unlikely that whale calls were an important contributor in this category. The contribution of energy by "other" sources was typically slightly greater in spring and summer months compared to winter months at Ingonish. This may be related to the type of falling precipitation. Falling snow in winter months is likely to create less noise than falling rain in spring and summer months. It is worth investigating the sources of sound in the "other" category further, particularly for months during which these sources contribute a large amount of energy to the soundscape, like in November 2019.

Overall, Ingonish was a quieter site than our site within Chedabucto Bay (results from this site are described in Wingfield et al. 2022a). As expected, vessel noise was less dominant in the soundscape near Ingonish compared to Chedabucto Bay. There are no major ports in Ingonish and therefore no major commercial shipping channels nearby like there are through Chedabucto Bay. Wind was a more dominant contributor to the soundscape in winter months compared to other months at both the Chedabucto Bay and Ingonish sites. Finally, the contribution of energy from "other" sources to the overall soundscape was variable across the months for both sites.

4.3 Sound Levels and Baleen Whale Call Presence Comparison

The monitoring of SPLs in the 1/3 octave bands centered at 63 and 125 Hz was recommended under Descriptor 11 of the European Union's Marine Strategy Framework Directive due to the levels being considered a proxy for sound generated by commercial vessels. We observed an increase in the median daily averaged SPLs in these two frequency bands in January 2020, which was reflected in the increased contribution of vessels to the total sound energy budget for that month. It looks likely that the median daily averaged SPL in these two frequency bands would have peaked in March and April 2021 had there been data for these months, which is around the time of the start of several fishing seasons in the area. The increase in median daily averaged SPL in these frequency bands from August 2020 to February 2021 may be due to sound from wind, as wind speeds were slightly elevated during this period. However, these frequencies are below the typical frequencies we would expect sound from even the highest winds to occur (Wenz 1962). In the spring and summer months, the majority of the noise energy is likely contributed by vessels given their increased relative contribution to the sound energy budget during these months.

We detected blue, fin, and humpback whale calls during several hours on days with both high and low maximum and median daily averaged SPLs in each of the two frequency bands, which suggests that noise from vessels was likely not loud enough to alter whale calling behaviour and/or mask calls, at least on a daily scale, throughout the study period. There has been some concern over whether these frequency bands cover a suitable range for indicating the presence of overall noise levels from vessels (Merchant et al. 2022). Vessel noise may peak at higher frequencies (Picciulin et al. 2016; Mustonen et al. 2019), and so for future reports we could expand this analysis to include higher frequency bands, such as the 1/3 octave band centred on 200 Hz as suggested by Picciulin et al. (2016).

4.4 Conclusions and Next Steps

We verified acoustic detections of five of the six species of baleen whales found in Atlantic Canadian waters in the dataset from the Ingonish site. Two of these species, blue and North Atlantic right whales, are listed as endangered (Beauchamp et al. 2009; DFO 2014), and one, fin whale, is listed as special concern (DFO 2017a). These results increase our understanding of the occurrence of these listed species and of sei and humpback whales in a previously under-surveyed area.

Baseline information about soundscapes is useful in determining changing contributions of different sound sources over time. We used six standard 1/3 octave bands to summarize the contributions of different sound sources to the total energy budget so that our results would be comparable to those in our Chedabucto Bay report (Wingfield et al. 2022a). In the future, it may be useful to also include the 1/3 octave bands centred at 63 Hz and 125 Hz as recommended in Descriptor 11 of the European Union's Marine Strategy Framework Directive (Van der Graaf et al. 2012; Garrett et al. 2016; European Commission 2017), as we've done for the SPL and baleen whale call comparison analysis.

While there were some temporal similarities in baleen whale call presence and in the composition of the soundscape between our Chedabucto Bay and Ingonish sites, there were marked differences that demonstrate the importance of collecting acoustic data at a variety of sites across Nova Scotia. Notable differences were the occurrence of North Atlantic right whale upcalls in our Ingonish dataset and the absence of these calls in our Chedabucto Bay dataset, and the fact that vessel noise was much more dominant in the soundscape in Chedabucto Bay compared to Ingonish.

We continue to monitor off Ingonish and will therefore have a longer time series to compare annual differences in the results in future reports. We would also like to investigate methods to isolate additional contributors to the sound energy budget, such as precipitation. We are currently undergoing an adjustment to our baleen whale call analysis procedure to streamline the detection and validation process. This will involve the use of a different set of automated detectors, including one currently under development for blue whale arch and downsweeping calls.

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7.0 Appendix A

Table A1. The calibration data for the SoundTrap ST300 and ST600 at high gain.

Serial Number	Source Frequency	Source Level	End-to-End Calibration
5955	250 Hz	120 dB re. 1 µPa	-176.4 dB re V/µPa
6085	250 Hz	120 dB re. 1 µPa	-177 dB re V/ µPa

Table A2. The calibration data for the SoundTrap ST500 recorder and hydrophone (separate components) and resulting end-to end calibration value.

Component	Serial Number	Source Frequency	Source Level	Sensitivity
Hydrophone	1224	250 Hz	120 dB re. 1 µPa	-177.5 dB re V/µPa
Recorder	5470	250 Hz	-39.4 dB re. 1 V	-1.8 dB re V/µPa
			End-to-End Calibration	**-179.3 dB re V/µPa**

8.0 Appendix B

Table B1. The parameters of each of the baleen whale detector templates used in the automated detection of calls in the acoustic data from November 15, 2019 to October 20, 2020 at Ingonish.

	Template parameters		
Detector name (target call)	**Frequency (Hz)**	**Duration (sec)**	**Bandwidth (B; Hz)**
Atl_BlueWhale_IM (blue whale tonal)	14-22	8.00-30.00	1<B<5
SW (blue whale downsweep) (sei whale downsweep)	20-150	0.50-1.70	19<B<120
Atl_FinWhale_21 (fin whale 20 Hz pulse)	10-40	0.40-3.00	>6
MFMoanLow (humpback whale moan)	100-700	0.50-5.00	>50
N_RightWhale_Up1 (North Atlantic right whale upcall)	65-260	0.60-1.20	70<B<195
N_RightWhale_Up2 (North Atlantic right whale upcall)	65-260	0.50-1.20	B>25

Table B2. The parameters of each of the baleen whale detector templates used in the automated detection of calls in the acoustic data from October 21, 2020 to November 10, 2021 at Ingonish.

	Template parameters		
Detector name (target call)	**Frequency (Hz)**	**Duration (sec)**	**Bandwidth (B; Hz)**
Atl_BlueWhale_IM2 (blue whale tonal)	15-22	8.00-30.00	1<B<5
SW (blue whale downsweep) (sei whale downsweep)	20-150	0.50-1.70	19<B<120
Atl_FinWhale_21.2 (fin whale 20 Hz pulse)	8-40	0.30-3.00	>6
MFMoanLow (humpback whale moan)	100-700	0.50-5.00	>50

N_RightWhale_Up1 (North Atlantic right whale upcall)	65-260	0.60-1.20	70<B<195

Table B3. The parameters of the minke whale pulse detector template used in the analysis of the entire acoustic dataset from Ingonish (November 15, 2019 to November 10, 2021).

Detector name (target call)	**Pulse frequency range (Hz)**	**Pulse duration (s)**	**Pulse gap (s)**	**Pulse train duration (s)**	**Train length (# of pulses)**
minkeWhalePulses (minke whale pulse train)	50-500	0.025-0.30	0.25-2.00	10-100	20-40

9.0 Appendix C

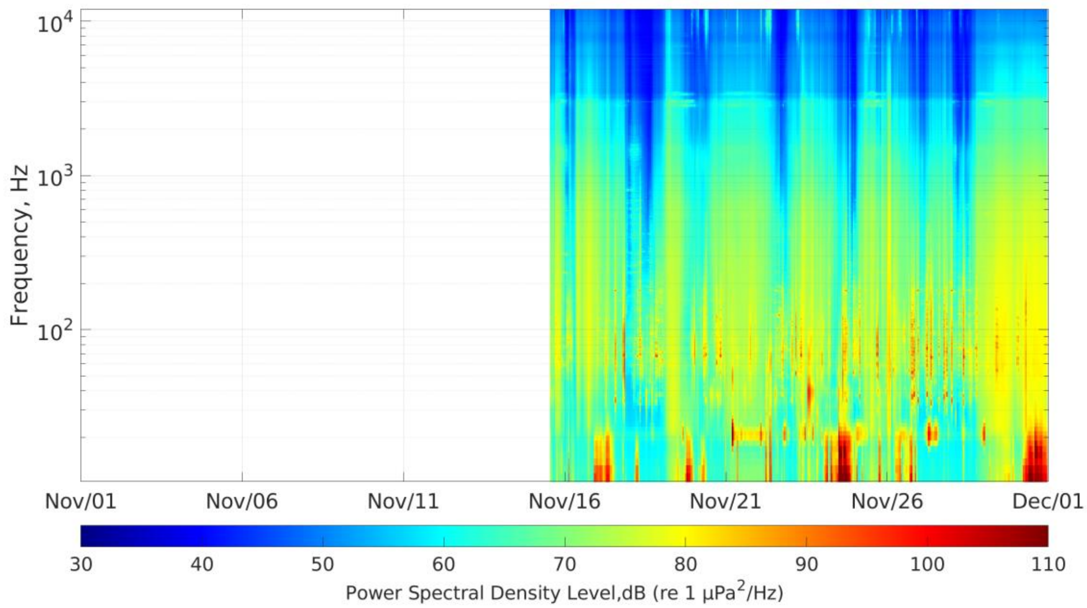

Figure C1. Hourly averaged spectrogram for the month of November 2019 (UTC).

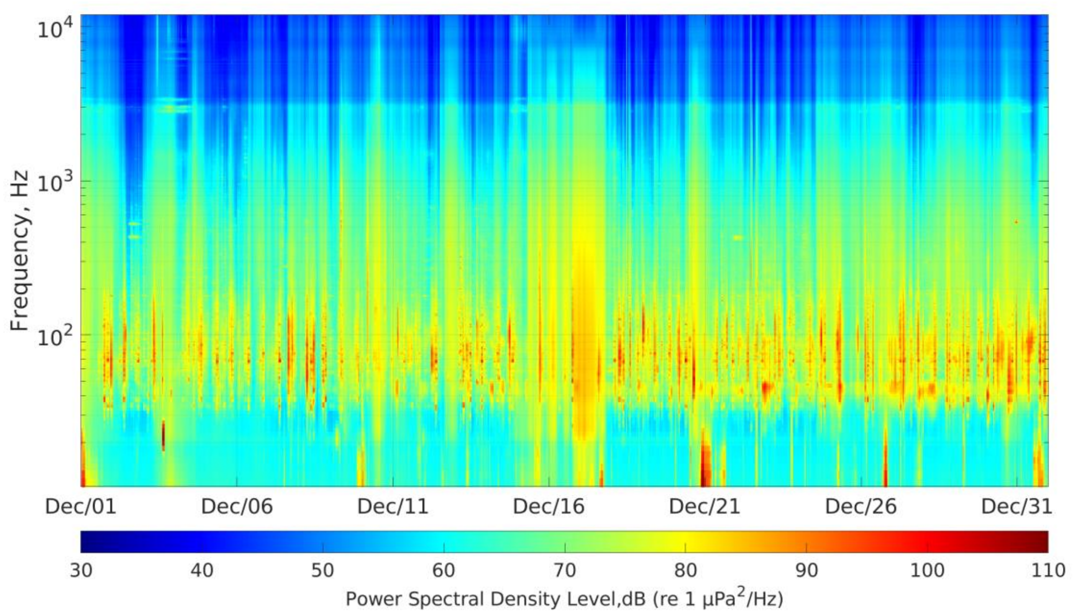

Figure C2. Hourly averaged spectrogram for the month of December 2019 (UTC).

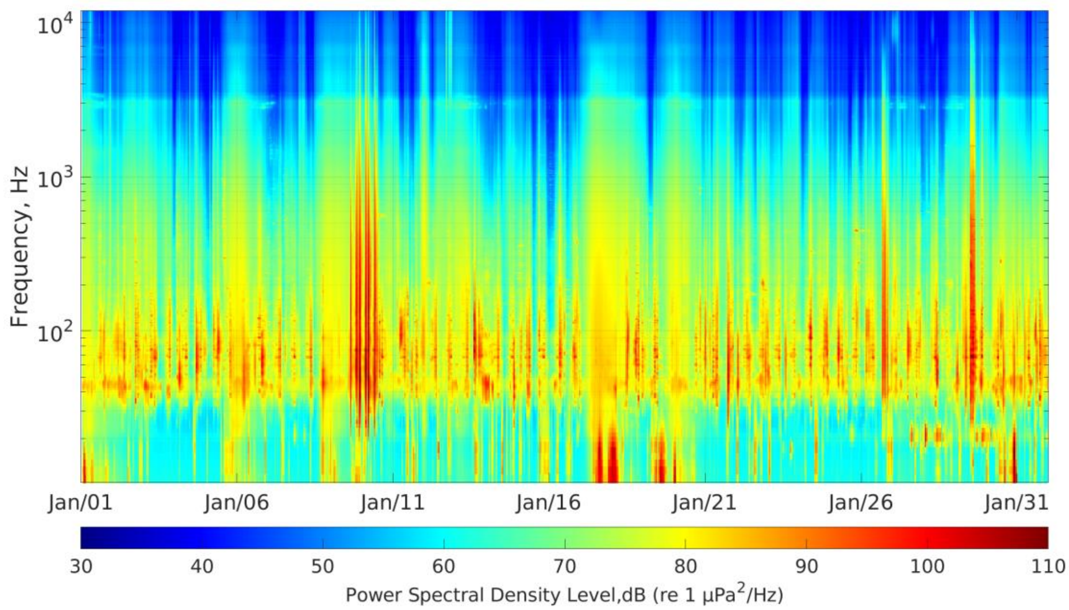

Figure C3. Hourly averaged spectrogram for the month of January 2020 (UTC).

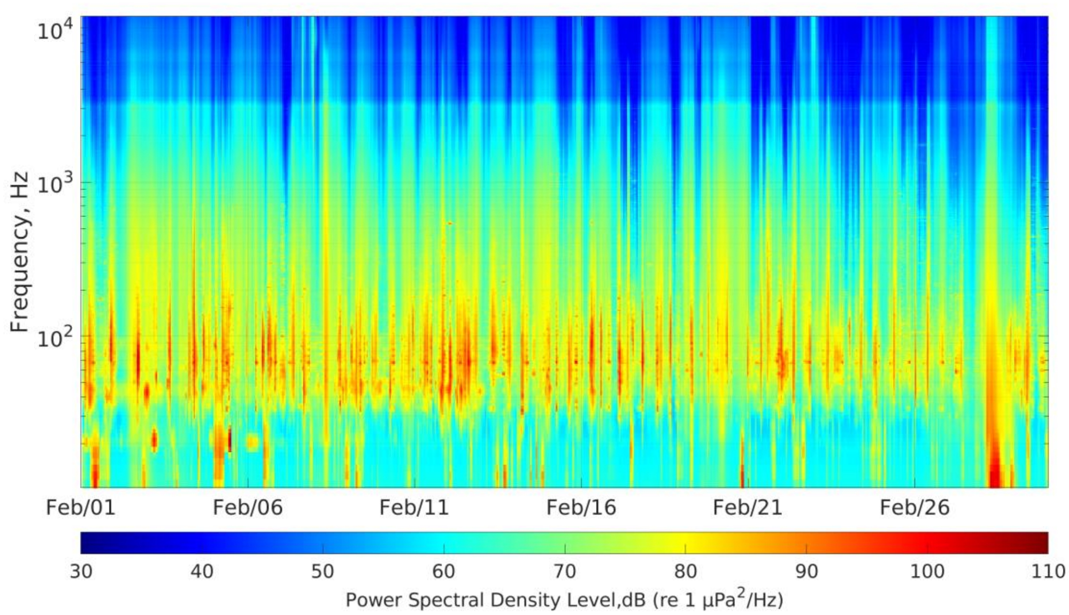

Figure C4. Hourly averaged spectrogram for the month of February 2020 (UTC).

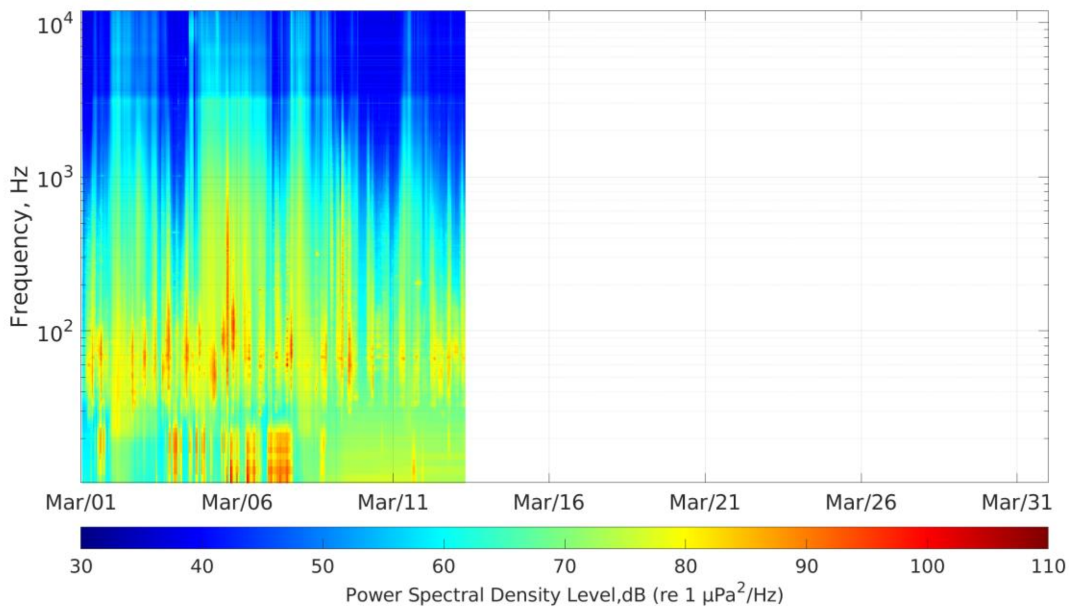

Figure C5. Hourly averaged spectrogram for the month of March 2020 (UTC).

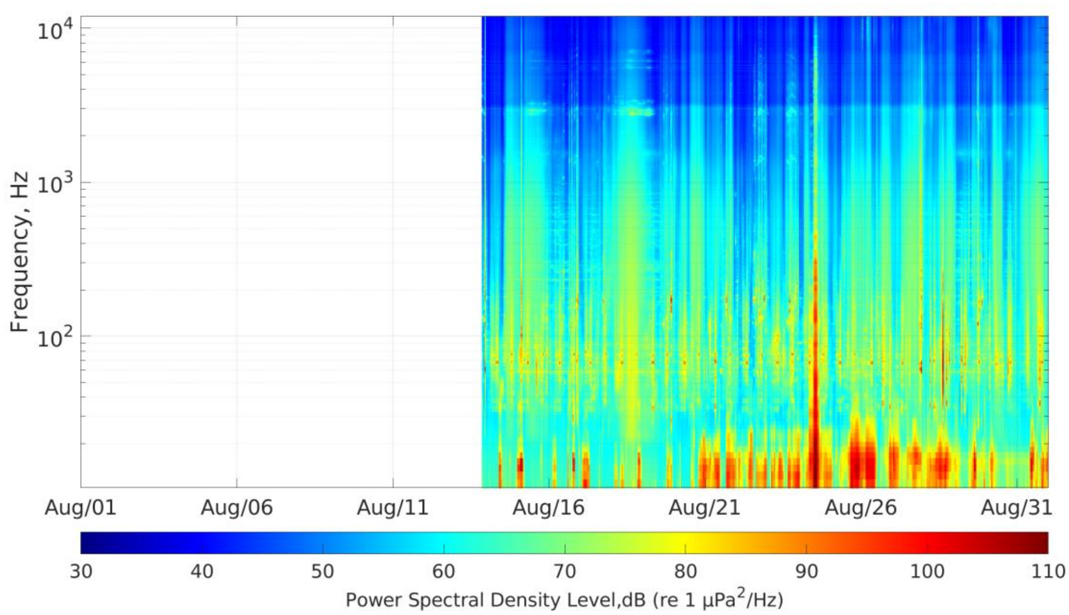

Figure C6. Hourly averaged spectrogram for the month of August 2020 (UTC).

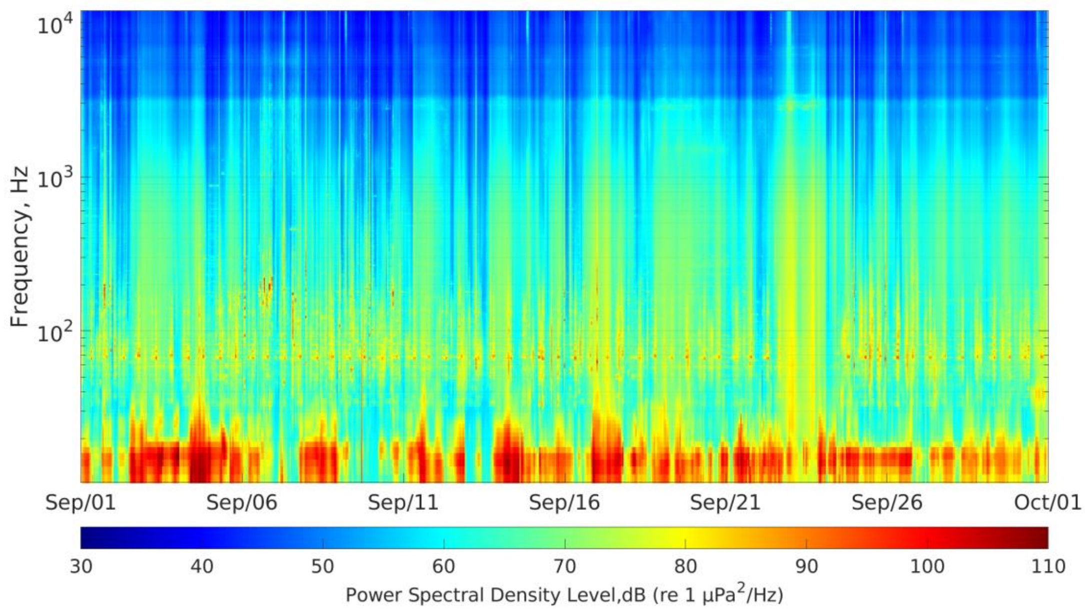

Figure C7. Hourly averaged spectrogram for the month of September 2020 (UTC).

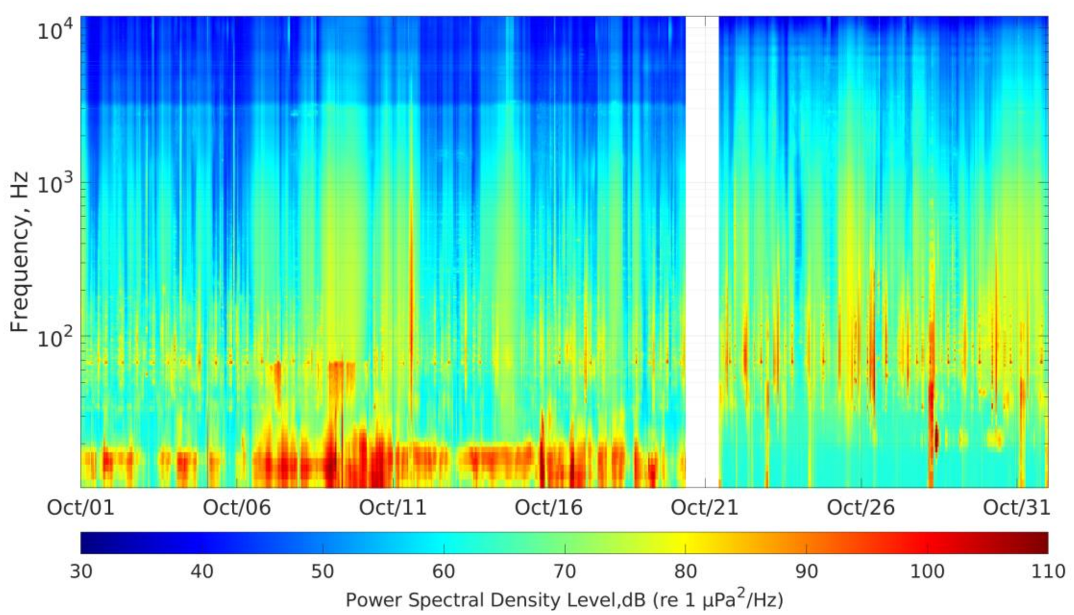

Figure C8. Hourly averaged spectrogram for the month of October 2020 (UTC).

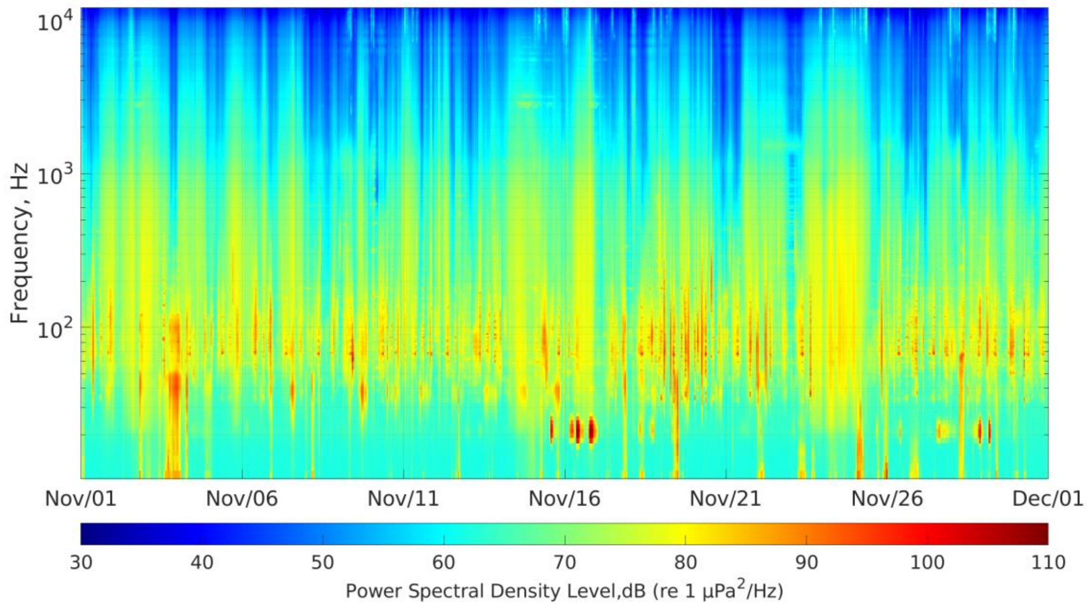

Figure C9. Hourly averaged spectrogram for the month of November 2020 (UTC).

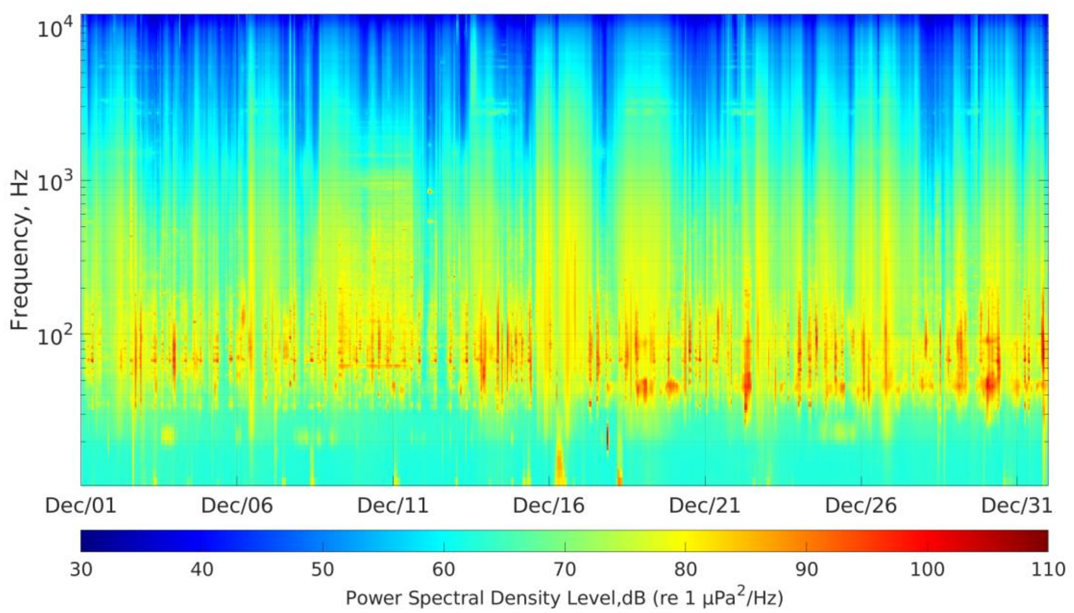

Figure C10. Hourly averaged spectrogram for the month of December 2020 (UTC).

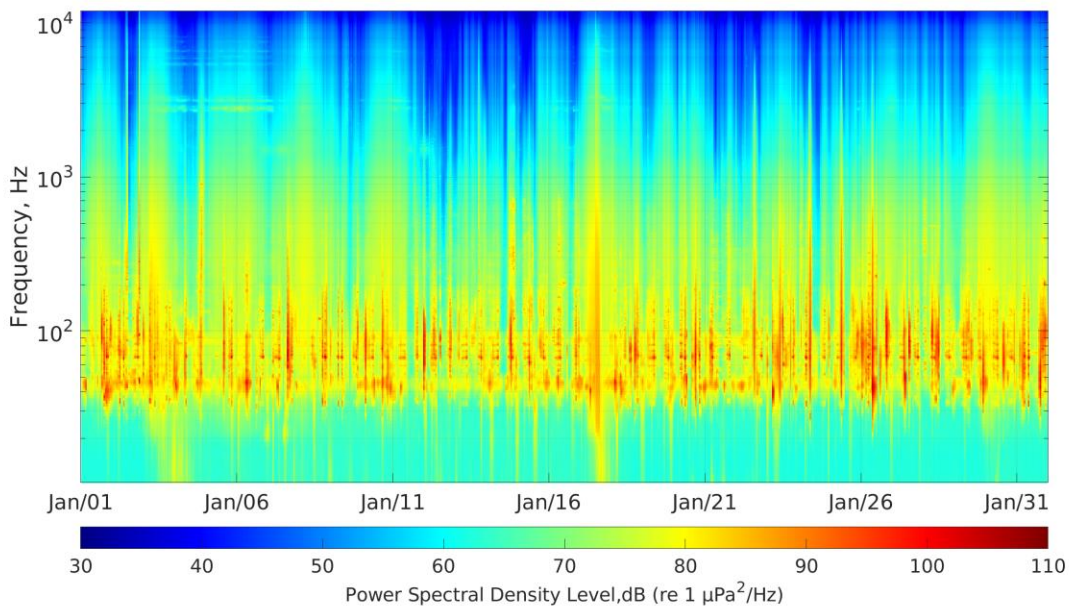

Figure C11. Hourly averaged spectrogram for the month of January 2021 (UTC).

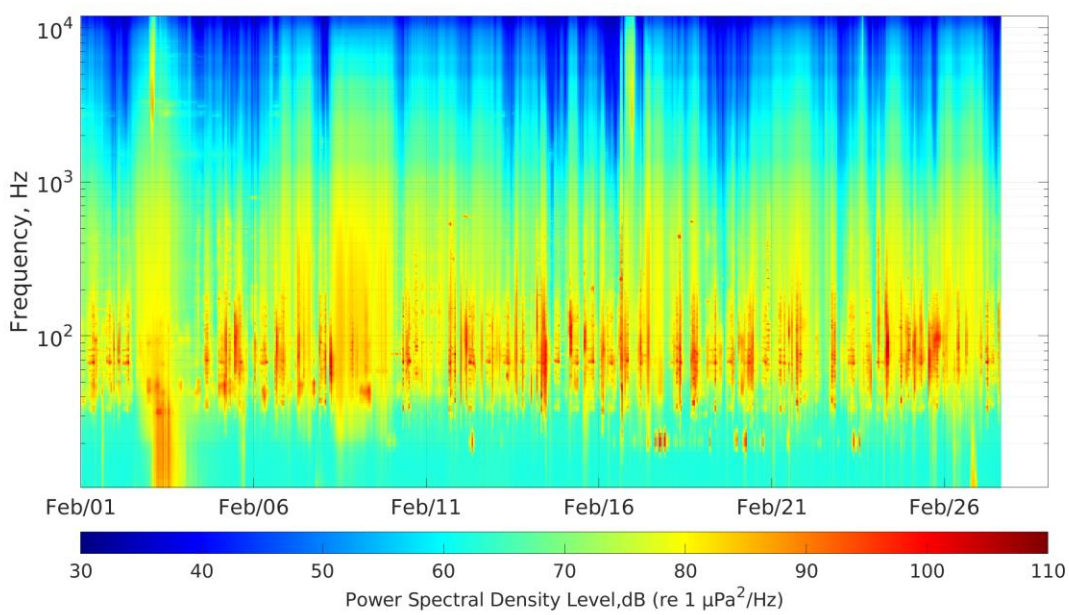

Figure C12. Hourly averaged spectrogram for the month of February 2021 (UTC).

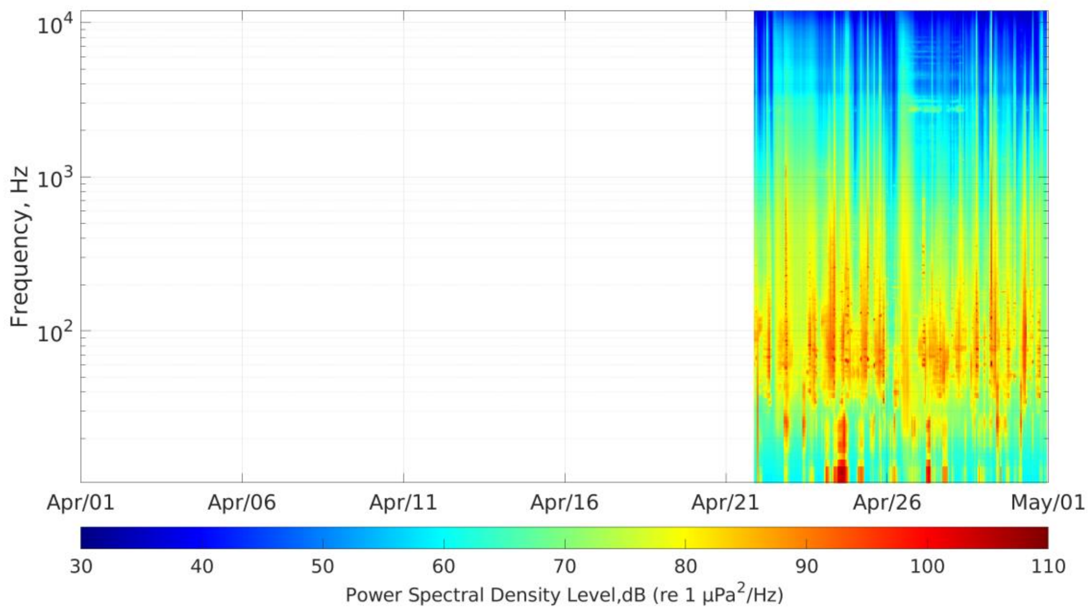

Figure C13. Hourly averaged spectrogram for the month of April 2021 (UTC).

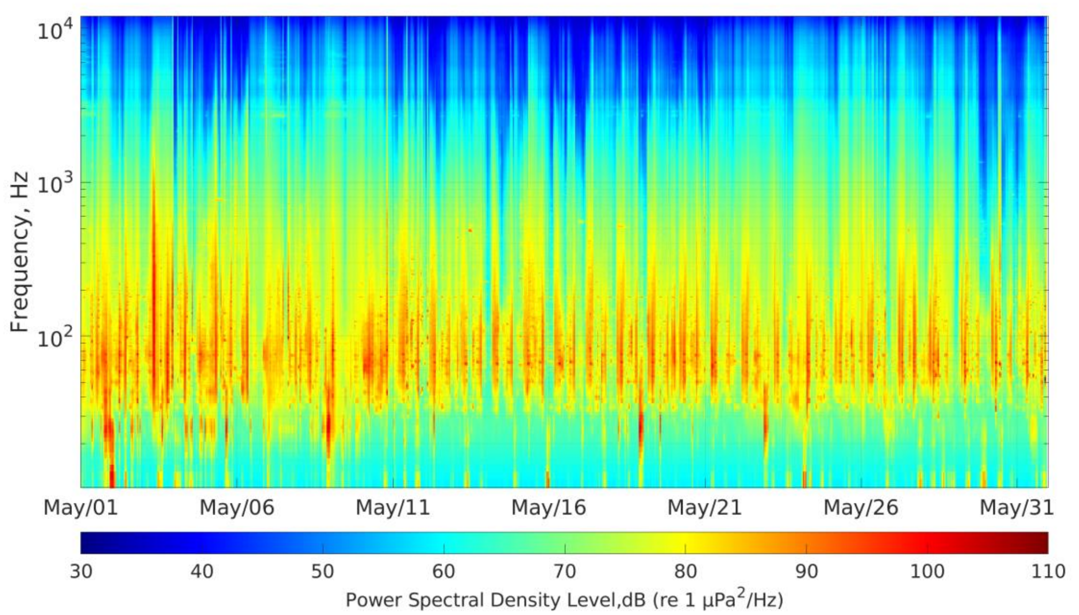

Figure C14. Hourly averaged spectrogram for the month of May 2021 (UTC).

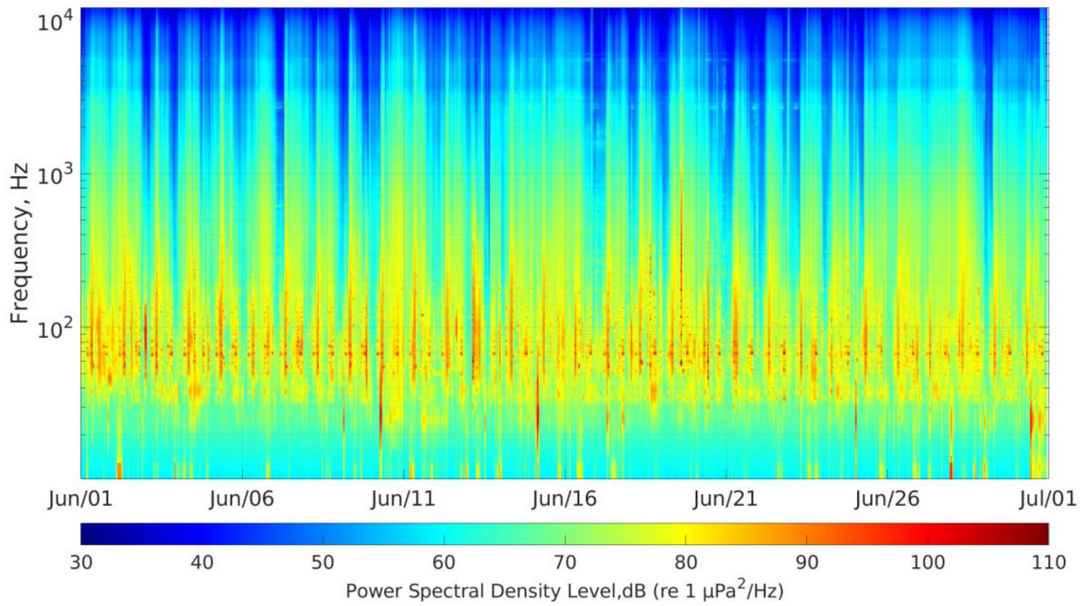

Figure C15. Hourly averaged spectrogram for the month of June 2021 (UTC).

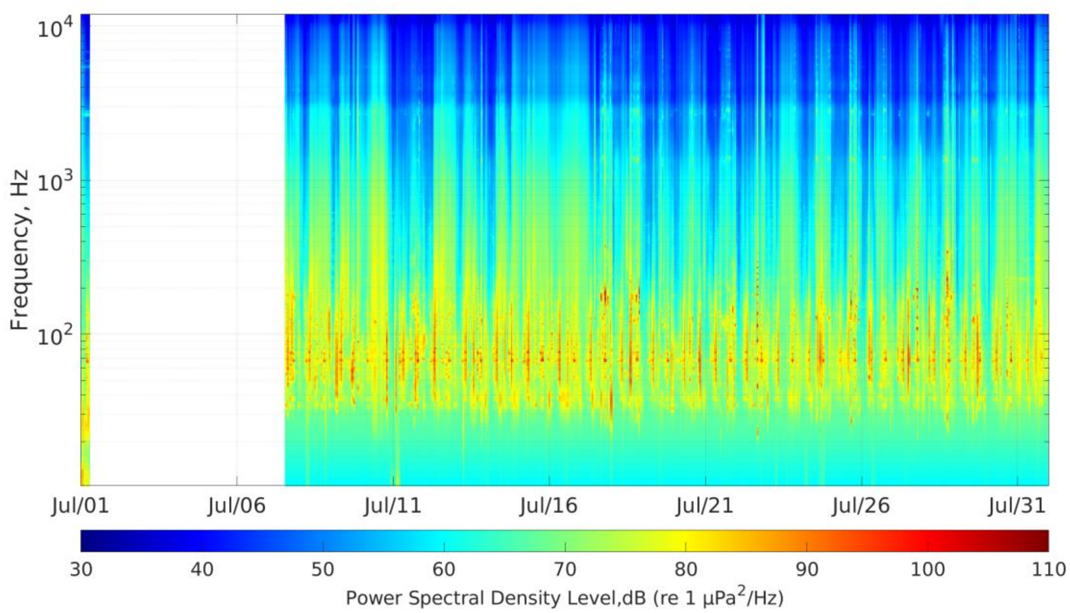

Figure C16. Hourly averaged spectrogram for the month of July 2021 (UTC).

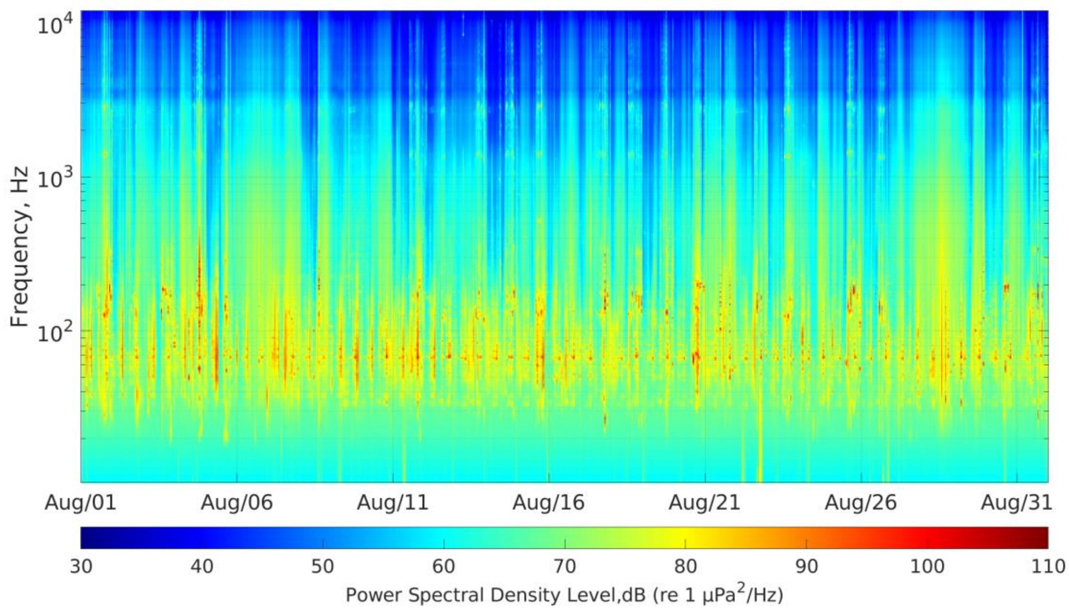

Figure C17. Hourly averaged spectrogram for the month of August 2021 (UTC).

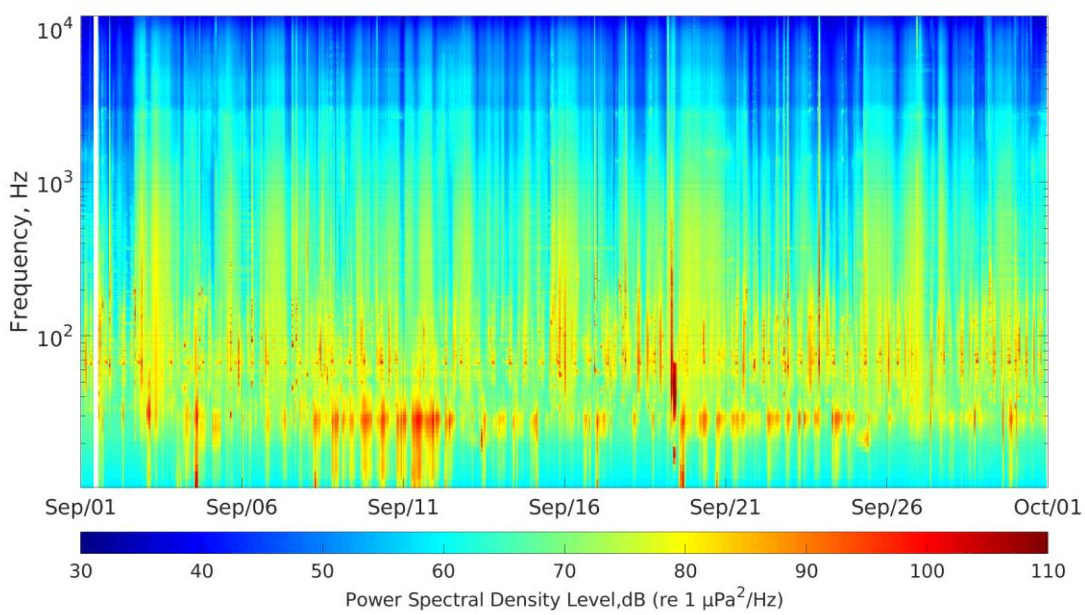

Figure C18. Hourly averaged spectrogram for the month of September 2021 (UTC).

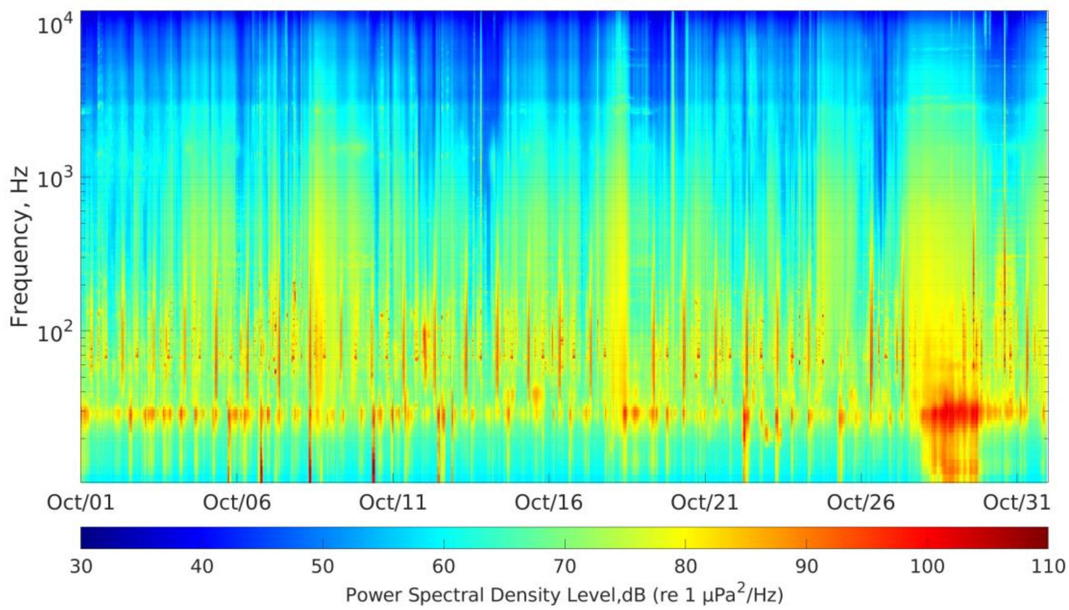

Figure C19. Hourly averaged spectrogram for the month of October 2021 (UTC).

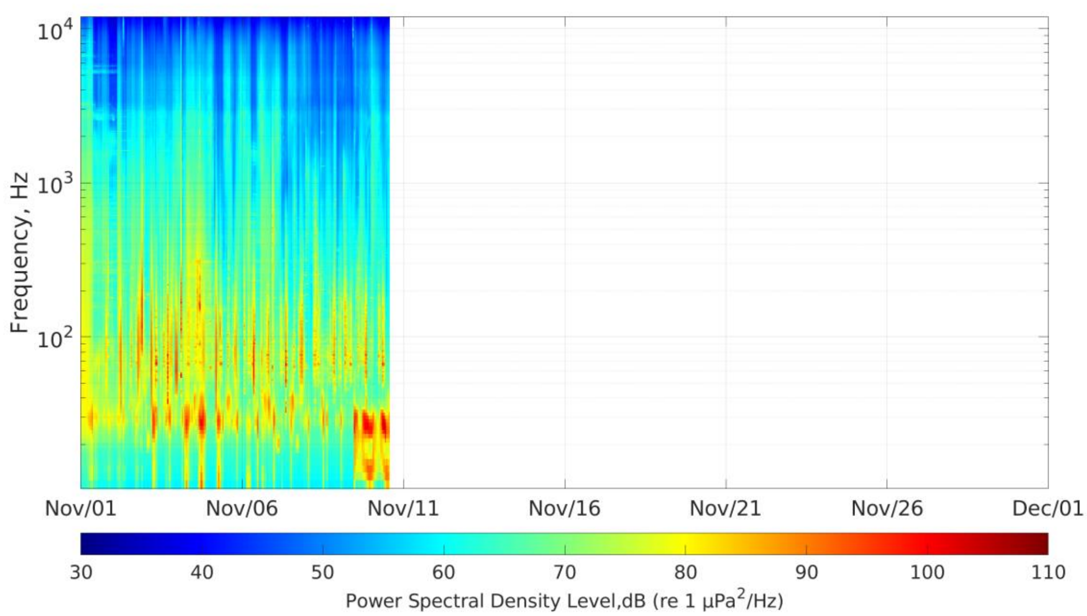

Figure C20. Hourly averaged spectrogram for the month of November 2021 (UTC).