Baleen whale call occurrence and soundscape characterization at Chedabucto Bay, Nova Scotia, 2018-2021

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by

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ABSTRACT

Wingfield, J., Li, S., Xu, J., Marotte, E. and Breeze, H. 2022. Baleen whale call occurrence and soundscape characterization at Chedabucto Bay, Nova Scotia, 2018-2021. Can. Tech. Rep. Fish. Aquat. Sci. 3512: v + 58 p.

Chedabucto Bay is the gateway to one of the largest ports in Nova Scotia and is considered an ecologically important area due to its species richness, yet we know very little about the underwater soundscape. To address this knowledge gap, DFO Maritimes began deploying acoustic recorders in the bay in December 2018 to better understand the underwater soundscape and the acoustic presence of baleen whales. Automated detectors were used to identify potential sei, blue, humpback, minke, fin, and North Atlantic right whale calls from December 2018 to May 2020. The percent contributions of wind, vessels, and “other” sources to the total sound energy budget of six frequency bands were calculated for each month from December 2018 to April 2020 and July 2020 to April 2021. We confirmed the presence of fin, blue, sei, and humpback whales. Vessel noise was the dominant contributor of energy in the lowest frequency band in almost every month. Wind was a dominant contributor to the sound energy budget in several frequency bands, particularly during winter months. We continue to monitor this site and have added a second site in the bay.

RÉSUMÉ

Wingfield, J., Li, S., Xu, J., Marotte, E. and Breeze, H. 2022. Baleen whale call occurrence and soundscape characterization at Chedabucto Bay, Nova Scotia, 2018-2021. Can. Tech. Rep. Fish. Aquat. Sci. 3512: v + 58 p.

La baie Chedabucto est la porte d'entrée de l'un des plus grands ports de la Nouvelle-Écosse en plus d'être considérée comme une aire d'importance écologique grâce à sa richesse en espèces. Pourtant, nous en savons très peu sur son environnement sonore sous-marin. Pour combler cette lacune en matière de connaissances, la région des Maritimes du MPO a commencé à déployer des enregistreurs dans la baie en décembre 2018 afin de mieux comprendre le paysage sonore sous-marin et d'évaluer la présence acoustique des baleines à fanons. Des détecteurs automatisés ont été utilisés pour identifier les appels possibles de rorquals boréaux, rorquals bleus, rorquals à bosse, petits rorquals, rorquals communs et baleines noires de l'Atlantique Nord entre décembre 2018 et mai 2020. La contribution en pourcentage des vents, des navires et des « autres » sources à la totalité du bilan d'énergie sonore de six bandes de fréquences a été calculée chaque mois, de décembre 2018 à avril 2020 et de juillet 2020 à avril 2021. Nous avons confirmé la présence de rorquals communs, rorquals bleus, rorquals boréaux et rorquals à bosse. Le bruit des navires était la principale source d'énergie sonore dans la bande de fréquences la plus basse presque chaque mois. Le vent a joué un rôle prépondérant dans le bilan d'énergie sonore dans plusieurs bandes de fréquences, particulièrement pendant les mois d'hiver. Nous continuons de surveiller ce site et avons ajouté un deuxième site dans la baie.

1.0 INTRODUCTION

The Marine Planning and Conservation Program, Maritimes Region, Fisheries and Oceans Canada (DFO), initiated the Coastal Acoustic Monitoring (CAM) Project in December 2018 to better understand the types and levels of underwater noise and the presence of baleen whales at several coastal sites around Nova Scotia. Previous acoustic monitoring efforts, as well as ongoing projects carried out by DFO Science branch in Maritimes Region, have focused on offshore areas and made use of large and complex recording systems that require the use of large vessels to deploy and recover. Similarly, species habitat modelling efforts for baleen whales by DFO Science in the region have largely been restricted to waters > 50 m deep, due to a general lack of search effort and data for coastal waters (Gomez et al. 2020). There has been relatively little scientific attention paid to the occurrence of baleen whales, with a few exceptions (see e.g., Simard et al. 2004; Zwamborn and Whitehead 2017; World Wildlife Fund (WWF)-Canada et al. 2021), and levels of noise in coastal waters off Nova Scotia. This project aimed to fill these information gaps through partnerships with local fishing organizations, tourism operators, and community groups to deploy compact passive acoustic monitoring systems close to the coast.

Six sites were chosen for acoustic monitoring as part of the CAM Project based on the consideration of multiple factors, including anecdotal, historical, or contemporary whale-watch records of baleen whale sightings, the potential for elevated levels of ambient noise generated by anthropogenic activities (particularly shipping), and the potential vulnerability of particular habitats to acoustic disturbance. Monitoring began at our first site, on the southern shore of Chedabucto Bay (Figure 1), in December 2018. Chedabucto Bay has been the focus of many studies over several decades due to the construction of the Canso Causeway in the 1950s, which changed the hydrography of the area (Trites 1979), and the wreck of the SS Arrow in 1970, which led to a massive spill of Bunker C oil (Lee et al. 2020). Chedabucto Bay is a compelling site for acoustic monitoring for a number of reasons. The bay is located between mainland Nova Scotia and Cape Breton and is the pathway to one of the largest ports in Nova Scotia, the Strait Superport (Figure 1). Because of this, the bay is often frequented by commercial vessels. There are also several active fisheries in the bay, including for mackerel (*Scomber scombrus*), shrimp (*Pandalus borealis*), lobster (*Homarus americanus*), and other shellfish (Serdynska and Coffen-Smout 2017; Rozalska and Coffen-Smout 2020). Despite this, we were able to select a deployment location where fishing does not regularly occur, avoiding the potential for disturbing our acoustic mooring but allowing us to effectively record noise from nearby vessels. The deployment site had the added benefit of being easily accessible by our community partner, who was based in Canso. Finally, there have been anecdotal sightings of several marine mammal species in the bay, including fin whales (*Balaenoptera physalus*), minke whales (*Balaenoptera acutorostrata*), Atlantic white-sided dolphins (*Lagenorhynchus acutus*), white-beaked dolphins (*Lagenorhynchus albirostris*), harbour porpoises (*Phocoena phocoena*), and several species of seals (Jacques Whitford Environment Ltd. 2014). A large part of the bay is included within the Canso Ledges Ecologically and Biologically Significant Area due to the rich diversity of invertebrate, fish, and marine mammal species that occur there (Hastings et al. 2014).

The waters off eastern Canada are home to six baleen whale species. In addition to minke and fin whales, blue (*Balaenoptera musculus*), sei (*Balaenoptera borealis*), humpback (*Megaptera novaeangliae*), and North Atlantic right whales (*Eubalaena glacialis*) have been visually sighted and acoustically detected offshore Nova Scotia nearly year-round (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. 2022). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) lists Atlantic blue, North Atlantic right, and Atlantic sei whales as endangered (COSEWIC 2012; COSEWIC 2013; COSEWIC 2019a) and Atlantic fin whales as special concern (COSEWIC 2019b). Despite this, we know very little about the occurrence of these species in coastal waters, where they may be more likely to encounter threats such as increased underwater noise levels from shipping and coastal construction and/or physical disturbance from commercial and recreational vessels. There have been very few sightings of baleen whales within or nearby Chedabucto Bay since 1975, possibly due to the lack of survey effort in this area rather than the absence of whales (Gomez et al. 2020; Johnson et al. 2021; Fisheries and Oceans Canada 2022). In addition to anecdotal sightings of minke and fin whales (Jacques Whitford Environmental Ltd. 2014), there has been one documented summer sighting of a sei whale within the bay and a few sightings of humpback whales near the mouth of the bay (Gomez et al. 2020; Johnson et al. 2021; Fisheries and Oceans Canada 2022).

Passive acoustic monitoring is a cost-effective alternative to visual surveys, and allows for the collection of data year-round in any sea state and during day or night. Prior to the initiation of the CAM Project, the closest acoustic monitoring site to Chedabucto Bay was located approximately 93 km east of the mouth of the bay (referred to as "Stn 2", Delarue et al. 2022). Delarue et al. (2022) detected fin whales from August through April, blue whales from August through May, and humpback whales nearly year-round at this site. They also detected sei, minke, and North Atlantic right whales, but their calls were not adequately detected by the adopted methodology and so their seasonal occurrence was not assessed (Delarue et al. 2022). The estimated detection ranges for the target calls of these species did not extend as far as the mouth of the bay and the bay itself (Delarue et al. 2022).

Each of the six species of baleen whales discussed above 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. 2022). 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 (Baumgartner et al. 2008) to determine the acoustic presence of these species near our recording site.

A soundscape is a recording of all sounds that occur within an area, including from geological, biological, or anthropogenic sources (Southworth 1967; Havlik et al. 2022). A soundscape can therefore be analyzed to determine the type and frequency of occurrence of human activities and weather events taking place in an area and even to assess species richness and general health of an ecosystem (Pijanowski et al. 2011). One way to summarize a marine soundscape is by producing a sound energy budget. In this approach, sound sources are ranked in order of greatest contribution to the overall soundscape (Miller et al. 2008). We chose to characterize the soundscape around our Chedabucto Bay site using a sound energy budget approach similar to that used by Miller et al. (2008) and Nystuen et al. (2010). 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, and we felt that this method would be an informative way to summarize a previously unstudied soundscape. In their investigation of soundscapes off eastern Canada, Delarue et al. (2018) found that vessels and seismic surveys were the main anthropogenic contributors to ambient sound. At their site closest to Chedabucto Bay (Stn 2), Delarue et al. (2018) found that vessel noise contributed the most energy to the overall soundscape in the spring, summer, and early fall. They did not detect any seismic survey noise at this site (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 at our Chedabucto Bay site between

December 2018 to May 2020 and July 2020 to April 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 our Chedabucto Bay site. We also include a comparison of low frequency noise levels and the hourly occurrence of humpback, blue, and sei whale vocalizations as a proof-of-concept for further investigation into the potential impacts of changing sound levels on baleen whale calling behaviour and detectability. To our knowledge, this is the first project to undertake acoustic monitoring within the bay. Major industrial projects have been proposed for this area, including additional marine terminals and a spaceport facility. These projects are likely to impact the soundscape of the bay in the coming years if they move forward. The data we present here could therefore be considered baseline data, and will serve as a valuable reference point should the aforementioned projects move forward. These data are particularly important for the development of management measures for the vulnerable species of baleen whales that occur off eastern Canada. We discuss how our initial analyses will inform our future work and how we can adapt our methods to account for anomalies in our data.

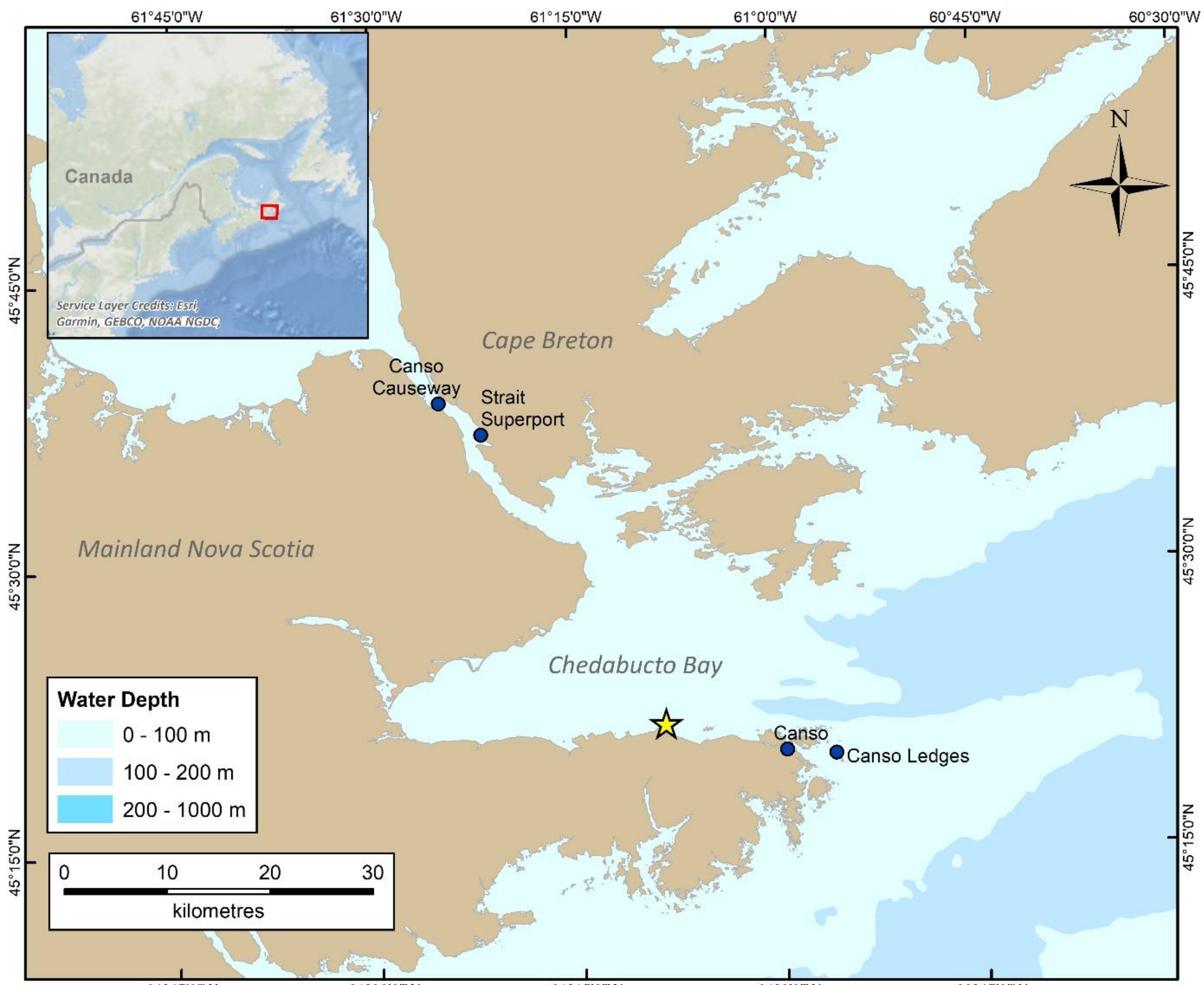

Figure 1. The acoustic mooring deployment site (yellow star) and other points of interest (blue circles) within and surrounding Chedabucto Bay, Nova Scotia, Canada.

2.0 MATERIALS AND METHODS

2.1 Mooring Design and Data Collection

The recording site was located off the southern shore of Chedabucto Bay, Nova Scotia (Figure 1). For each deployment, we mounted a SoundTrap (ST300 STD or ST500 STD model, manufactured by Ocean Instruments) in a modified lobster trap (Figure 2). Table 1 provides a summary of the deployment and recovery details. A Fiobuoy (TD100 or TD200 model, manufactured by Fiomarine) was attached to the cage and programmed to release at a specific date and time. Upon release, the mooring was collected by local fish harvesters and a new mooring was deployed in its place. This schedule allowed for near-continuous year-round recordings. There was a data gap from May 7, 2020 to July 16, 2020 due to operational interruptions caused by the COVID-19 pandemic. The SoundTraps were scheduled to record continuously, with data stored as 12 hour .wav files from December 12, 2018 to June 11, 2019 and as 30 minute .wav files from June 11, 2019 to April 20, 2021. The change in file length was made because shorter files allowed for more efficient processing with limited computer memory. All recordings were made at a 24 kHz sampling rate with the recommended gain setting of “high”, which allowed for a maximum received sound pressure level (SPL) of approximately 172 dB re 1 µPa before clipping. See Appendix B for hydrophone calibration data provided by Ocean Instruments.

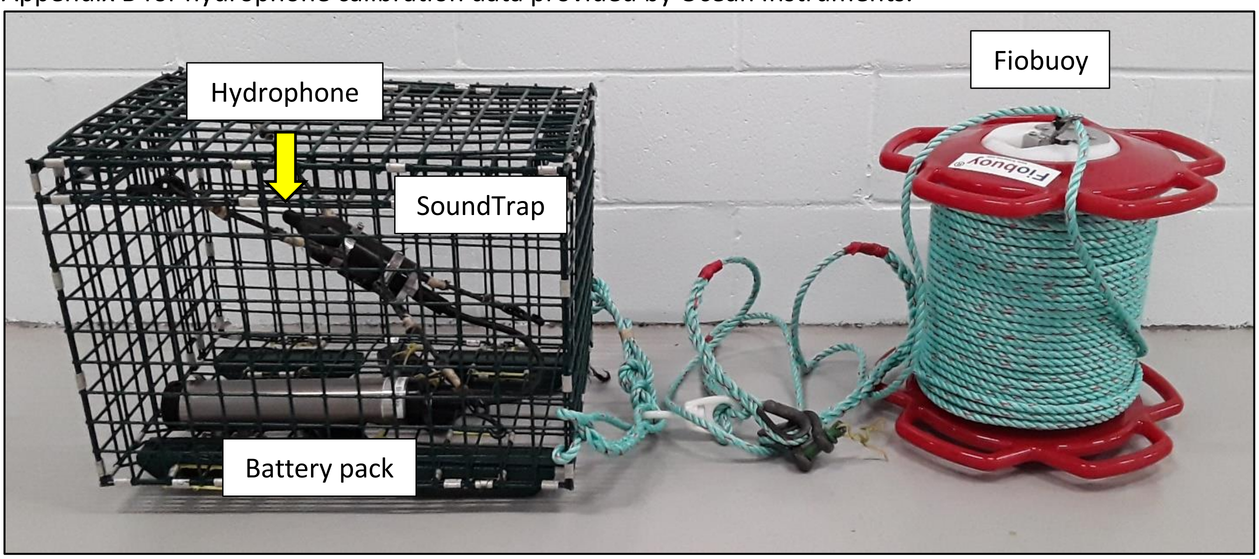

Figure 2. The typical mooring configuration used in each of the coastal deployments. A SoundTrap (ST300 STD, Ocean Instruments) and external battery pack are shown housed in a modified lobster trap, attached to a Fiobuoy (TD100, Fiomarine).

Table 1. Deployment and retrieval dates, SoundTrap model, latitude and longitude, depth, and number of days and hours with recordings (full days only) for each deployment period at Chedabucto Bay.

Deployed	Recovered	SoundTrap model	Latitude	Longitude	Bottom depth (m)	Total number of recording days (hours)
Dec 12 2018	Feb 08 2019	ST300	45 21.69	-61 08.66	46	57 (1368)
Feb 08 2019	Apr 12 2019	ST300	45 21.69	-61 08.65	47	61 (1464)
Apr 12 2019	Jun 11 2019	ST300	45 21.69	-61 02.63	46	59 (1416)
Jun 11 2019	Aug 15 2019	ST300	45 21.69	-61 08.66	46	64 (1536)
Aug 15 2019	Oct 17 2019	ST300	45 21.69	-61 08.67	46	62 (1488)
Oct 17 2019	Dec 19 2019	ST300	45 21.69	-61 08.66	46	60 (1440)
Dec 19 2019	Feb 28 2020	ST300	45 21.69	-61 08.66	46	70 (1680)
Feb 28 2020	May 07 2020	ST300	45 21.69	-61 08.66	46	67 (1608)
Jul 16 2020	Sep 27 2020	ST300	45 21.69	-61 08.67	46	72 (1728)
Sep 27 2020	Dec 01 2020*	ST300	45 21.69	-61 08.67	46	49 (1176)
Dec 01 2020	Apr 26 2021**	ST500	45 21.69	-61 08.66	46	139 (3336)

*recording stopped Nov 16 2020

** recording stopped Apr 20 2021

2.2 Baleen Whale Call Detection and Validation

The purpose of this analysis was to determine the minimum hourly and daily presence of fin, sei, North Atlantic right, humpback, minke, and blue whales within detection range of our mooring. These 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 were producing calls that were not targeted by the detectors. We did not systematically review files with no detections to assess missed call rates, and so we can only comment on minimum presence and not on the absence of these species.

2.2.1 Target Baleen Whale Calls

There are two types of blue whale tonal calls, “A” and “B” calls. “A” calls are of nearly constant frequency at approximately 18 Hz and last approximately 8 seconds while B calls sweep downward in frequency from 18 to 15 Hz and last approximately 11 seconds (Mellinger and Clark 2003). These two call types often occur together, where the B call follows the A call in a continuous transition or after a short silent period (Mellinger and Clark 2003). These calls can be produced as single calls at irregular intervals (Oleson et al. 2007) or in patterned repeated sequences, called songs (Mellinger and Clark 2003; Berchok et al. 2006; McDonald et al. 2006). Tonal calls are thought to be produced by males, and songs are therefore believed to be a breeding display (McDonald et al. 2001; McDonald et al. 2006; Oleson et al. 2007). These calls are ideal candidates for automated detection due to their stereotypic nature and the fact that they are the most commonly recorded vocalizations produced by blue whales in the northwestern Atlantic (Mellinger and Clark 2003).

Fin whale 20 Hz pulses are approximately one second in duration and sweep downward in frequency from approximately 23 to 18 Hz (Watkins et al. 1987). These pulses are often produced in bouts, which can last as long as 32.5 hours (Watkins et al. 1987). Like blue whale tonal calls, these pulses are believed to be produced only by males as a breeding display (Croll et al. 2002). The 20 Hz pulse is highly stereotypic and has been recorded throughout the northwestern Atlantic year-round (Davis et al. 2020), and so despite being sex-biased, this call type is often used to determine minimum fin whale acoustic presence (Davis et al. 2020; Delarue et al. 2022).

Sei whale downsweeps are typically 1.4 seconds in duration and sweep downward in frequency from approximately 82 to 34 Hz (Baumgartner et al. 2008). These calls are most often produced as a single call, but can occur in pairs (doublets) or triplets (Baumgartner et al. 2008). It is not currently known whether this call, believed to be a contact call (Baumgartner et al. 2008), is sex-biased. The low frequency and stereotypic nature of this call makes it a useful candidate for detecting the presence of vocalizing sei whales (Baumgartner et al. 2008; Davis et al. 2020).

Minke whale pulse trains are a series of individual low frequency pulses that can be produced at a constant, increasing, or decreasing inter-pulse interval (Risch et al. 2013). For all three pulse train types, the majority of the energy is distributed between 50 and 300 Hz with median peak frequencies ranging from 58 to 136 Hz (Risch et al. 2013). Individual pulses are typically 0.07 to 0.12 seconds in duration while an entire train is typically 12.4 to 39.8 seconds in duration (Risch et al. 2013). The behavioural function of these calls and whether they are age- and/or sex-biased is currently unknown. Low frequency pulse trains are the best described of all the call types attributed to minke whales in the northwest Atlantic (Risch et al. 2014).

Humpback whales produce a wide variety of song and non-song call types of varying durations and frequencies (Payne and McVay 1971; Dunlop et al. 2007; Dunlop et al. 2008; Stimpert et al. 2011). On average, humpback whale vocalizations occur in the frequency range of approximately 30 to 2400 Hz, with peak frequencies ranging from approximately 62 to 1400 Hz (Dunlop et al. 2007; Stimpert et al. 2011). Only male humpbacks sing, and their songs are believed to be a breeding display (Payne and McVay 1971). Both male and female humpbacks produce a variety of nonsong vocalizations thought to relate to foraging and socializing (Dunlop et al. 2007; 2008). The humpback moan detector used in this study was capable of detecting both mid-frequency song and non-song vocalizations.

Right whale upcalls sweep upward in frequency from an average start frequency of 101 Hz to an average end frequency of 195 Hz and last an average of 0.87 seconds (Parks et al. 2007). The upcall, believed to be a contact call, is considered to be the most reliable call for determining right whale presence as it is produced by both sexes and all age classes throughout the northwest Atlantic (Davis et al. 2017; Clark et al. 2010; Parks et al. 2011).

2.2.2 Automated Call Detection and Manual Validation

Acoustic data were downloaded from the recorders and sent to JASCO Applied Sciences for automated baleen whale call detection and classification. The twelve hour .wav files from the December 12, 2019 to June 11, 2019 deployments were subdivided into 30-minute .wav files prior to application of the automated detectors. For all call types except minke whale pulse trains, 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 minke whale pulse trains, the JASCO analysts used a pulse detector, which detected individual pulses that were then assembled into trains that had to match a set of known pulse train characteristics in order to be classified as minke whale pulses. For more detailed information on the detection processes, see Delarue and Gaudet (2020), Kowarski et al. (2020), and Delarue et al. (2022). For the parameters of each of the call type templates used for this report, see Appendix A. Only the data from December 2018 to May 2020 had been analyzed for the presence of baleen whale calls at the time of writing this report, and therefore results from subsequent deployments could not be included.

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. These misclassifications are often referred to as false positives. All files with detections were therefore manually validated by a trained analyst to ensure that the file contained at least one correctly classified call. For the December 12, 2019 to June 11, 2019 dataset, JASCO provided the detection results as a spreadsheet with the number of detections of each call type per 30-minute file. The analyst visually scanned the entirety of each 30-minute file containing at least one detection of any of the target call types, listening to specific sounds when visual confirmation was not possible, using PAMlab lite version 8.3.3 acoustic analysis software (developed by JASCO Applied Sciences). Due to the large number of humpback moan detections, validation was completed on an hourly scale, meaning if a humpback moan detection was validated in the first 30 minute file of the hour, the analyst did not review the second file in that hour, regardless of whether or not it contained a humpback detection. If only the second 30 minute file within an hour contained a humpback moan detection, the analyst reviewed only that file. For the June 11, 2019 to May 07, 2020 dataset, JASCO provided the number of detections per two-minute segment, with accompanying .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 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 PAMlab lite for aural inspection. This new method was adopted as it was much more efficient for the analyst than opening and scanning the entirety of a 30-minute .wav file. Both methods required the analyst to inspect every file containing a detection, and so the final validated results are not expected to differ had the same approach been taken for both datasets.

As mentioned above, humpback whales produce a variety of call types across a wide range of frequencies. Unlike the other species for which a specific call type was targeted, JASCO applied a mid-frequency moan detector capable of detecting song and non-song moans from 100 to 400 Hz and from 100 to 700 Hz to the December 12, 2018 to June 11, 2019 and June 11, 2019 to May 07, 2020 datasets, respectively. While this more generalized detector can detect several call types, there can be many false positive detections caused by the calls of other baleen whale species and noise (Kowarski et al. 2018). We considered all call types together to present overall humpback whale acoustic occurrence, as it was beyond the scope of this study to analyze the call types separately.

While validating the sei whale downsweep detections, the analyst 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. Arch calls sweep upward in frequency from approximately 65 to 70 Hz before dropping to approximately 30 Hz and typically last five to seven seconds (Mellinger and Clark 2003). The downsweeping calls are shorter, lasting approximately one to four seconds, and descend from approximately 90 to 25 Hz (Thompson et al. 1996). Downsweeping calls in particular are highly variable (Mellinger and Clark 2003, Berchok et al. 2006). These call types are produced by both males and females, often in pairs or groups, and are therefore thought to relate to social interaction rather than reproduction (Mellinger and Clark 2003; Berchok et al. 2006; Oleson et al. 2007). The analyst therefore grouped confirmed tonal, arch, and downsweeping calls together to represent overall minimum blue whale presence. This should still be considered as the minimum blue whale acoustic presence as some blue whale arch and dowsnweeping calls are likely to be longer than the duration specified in the sei whale call template, and so it is likely we missed some of these calls.

In addition to blue and sei whales, 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 our final results. There were occasions when the analyst was confident a downsweep was emitted by either a blue, fin, or sei whale, but could not definitively assign a species due to the quality of the call or surrounding noise. These calls were classified as “unknow baleen whale”. This category was presented alongside the results for each of the species. If the analyst could not determine whether a sound was from a baleen whale or other type of animal (e.g., fish), or was anthropogenic/environmental noise, the sound was excluded from further analyses given its source was unknown. Only calls that were definitively assigned to one species or to the unknown baleen whale category were included in further analyses. Calls that were misclassified or missed completely and were discovered while validating the results of a different detector were included as a confirmed presence for the corresponding species.

The validation results were summarized 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. Only complete recording days with data available for the full 24 hours were included in analyses. We defined the seasons as follows: winter- December to February, spring- March to May, summer- June to August, and fall- September to November. The number of hours per day and proportion of days that each species was present per hour were plotted. The number of consecutive hours with at least one call present was determined for each species and the results were plotted as a frequency plot. All analyses and associated figures were completed in R version 4.0.4 (R Core Team 2021) using the packages “lubridate” (Grolemund and Wickham 2011), “ggplot2” (Wickham 2016), “tidyr” (Wickham 2021), “dplyr” (Wickham et al. 2021), “DT” (Xie et al. 2021), “egg” (Auguie 2019), “scales” (Wickham and Seidel 2020), and “stringr” (Wickham 2019).

2.3 Sound Energy Budget Estimation

For the December 12, 2018 to December 19, 2019 data, spectrograms were generated using a short time Fast Fourier Transform (FFT) with a length of 32768, 25 % overlap, and Hanning window applied. This resulted in a time step resolution of 1.024 seconds and frequency resolution of 0.7324 Hz. To reduce the amount of computer memory required and to expedite data processing, the spectrograms for the December 19, 2019 to April 20, 2021 data were generated using a shorter FFT length of 16384, 50 % overlap, and Hanning window applied. This resulted in a time step resolution of 0.3413 seconds and frequency resolution of 1.4648 Hz. Sound pressure levels (SPL, dB re 1 µPa) were calculated for five frequency bands: 30 to 100 Hz, 100 to 500 Hz, 500 Hz to 2 kHz, 2 to 5 kHz, and 5 to 12 kHz by taking the average of the frequencies in each band and applying a one-day moving average across time. This was an exploratory step, meant to inform the sound energy budget analysis. To plot the long-term spectrograms, a one-day moving average was applied. The time resolution of the plotted spectrograms after averaging was 30 minutes.

There are many different approaches for characterizing an underwater soundscape. We chose an approach that would allow us to compare the main contributors of underwater sound across different months. We used an approach similar to Miller et al. (2008) and Nystuen et al. (2010) to estimate the contribution of various sound sources to the total sound energy budget around our recording site for six 1/3 octave bands centered at 100 Hz, 500 Hz, 1 kHz, 2 kHz, 5 kHz, and 10 kHz (Table 2). Note that these six frequency bands were different than the five bands we described above, as the previously described bands were more appropriate for investigating trends in our data and not for the final presentation of the results. We focused on the contributions of two sound sources: vessels and wind. An additional category, called "other", included sound energy attributed to sources other than vessels and wind, such as precipitation or baleen whale calls. The following sections detail the datasets used and the steps taken to estimate the sound energy budgets for each month from December 2018 to May 2020 and July 2020 to April 2021.

Table 2. The lower and upper band limits and center frequency for each of the 26 1/3 octave bands represented in our recordings. The six bands used in the sound energy budget analysis are in bold.

Lower band limit (Hz)	Center frequency (Hz)	Upper band limit (Hz)
28	31.5	35.5
35.5	40	44.7
44.7	50	56.2
56.2	63	70.8
70.8	80	89.1
89.1	**100**	**112**
112	125	141
141	160	178
178	200	224
224	250	282
282	315	355
355	400	447
447	**500**	**562**
562	630	708
708	800	891
891	**1000**	**1122**
1122	1250	1413
1413	1600	1778
1778	**2000**	**2239**
2239	2500	2818
2818	3150	3548
3548	4000	4467
4467	**5000**	**5623**
5623	6300	7079
7079	8000	8913
8913	**10000**	**11220**

2.3.1 Automatic Identification System data

We used Automatic Identification System (AIS) data to determine the proximity of vessels to our mooring, which we then compared to received SPLs in the 1/3 octave bands centered at 100 and 500 Hz to build our vessel noise detector. AIS is an automated system for vessel tracking and identification to avoid collision and to aid in navigation, enforcement, and search and rescue. It is required on all vessels of 300 gross tonnage or more on an international voyage and vessels of 500 gross tonnage or more on a domestic voyage (International Maritime Organization 2015). In addition, most Canadian passenger vessels must be equipped with an AIS transponder and operators of many other vessels opt to install one for safety purposes (Navigation Safety Regulations 2020). The transponders transmit dynamic information, including the vessel's position, speed, course, and heading, every few seconds or few minutes, depending on the vessel's speed and navigation status. Static information, such as the vessel's name and destination, are transmitted less frequently. When the vessel detector was first developed, we did not have access to AIS data for the entire study period, and so two month-long time periods of dynamic AIS data received and stored by the Canadian Coast Guard's terrestrial AIS receiver network were obtained to build the vessel noise detector. To avoid a seasonal bias in vessel traffic, one time period during winter and one during summer were chosen for this analysis; February 8, 2019 to March 12, 2019 and June 11, 2019 to July 13, 2019, respectively. We later had access to the AIS data for the entirety of 2020, and so various dates during that year were used to test and validate the vessel detector. The raw AIS messages were decoded using a Python script package developed at Fisheries and Oceans Canada.[1] We used the date and time (UTC), and the vessel's latitude, longitude (decimal degrees), speed over ground (SOG, knots), and unique Maritime Mobile Service Identity (MMSI) number in our analyses.

2.3.2 Vessel noise detector

Decoded AIS data within a 30 km radius of the mooring location were extracted from the dataset. The period from 60 minutes before the vessel entered this area to the time at which the vessel entered the area was deemed the "start" of the vessel event and the period from 30 minutes before to 30 minutes after the time at which the vessel was closest to the mooring location was deemed the "peak" of the vessel event. During preliminary analysis of the acoustic data, it was observed that the two lower frequency bands, the 1/3 octave bands centered at 100 and 500 Hz, were most sensitive to vessel noise. Figure 3 shows an example of the distance of a vessel from the mooring over time and the mean SPL in the 1/3 octave bands centered at 100 and 500 Hz at the start and peak of the vessel event. In most cases, the dispersion between the SPLs at the peak was greater than at the start of the vessel event. This dispersion could therefore be used as an identifying feature of vessel noise.

The covariance between the SPLs in the 1/3 octave bands centered at 100 and 500 Hz was calculated. A critical covariance value was defined to assess whether or not noise was related to vessel traffic. If the chosen critical value was too small, relatively weak vessel noise would be missed by the detector, and some continuous vessel events may be separated into many temporally shorter events. Conversely, if the chosen critical value was too large, the vessel detector would be sensitive to any change in noise levels, and would therefore lead to false alarms. A critical value of 1.0 was selected by comparing the detector's performance to the AIS data and SPLs. The covariance was computed with a time step of five minutes. The covariance at time t, COV(t), was computed for the period 30 minutes before to 30 minutes after time t. Using this one-hour time window to compute covariance reduced the impact of impulsive signals. A mask value of "1" or "0" was assigned, with a value of "1" meaning the covariance value exceeded 1.0 and therefore vessel noise was detected. Figure 4 shows an example of how the covariance values changed as a vessel approached the mooring. This figure demonstrates that

[1]The Python script package was developed by Lanli Guo, Jinshan Xu, and Shihan Li and a report explaining the package, including the message types it decodes, performance, and potential issues, is in preparation.

covariance between the 100 and 500 Hz 1/3 octave bands increased as a vessel approached the mooring location. The mask values indicated that the detector identified most SPL peaks caused by vessel noise. There were some false alarms, but the increase in noise levels during these false alarm periods was small, and therefore their impact on the final energy budget was negligible. The performance of the vessel noise detector was qualitatively evaluated by visually comparing the distance of vessels from the mooring location (filtered to exclude vessels travelling at speeds of less than one knot), the covariance and mask values, and the SPL in the lowest frequency band (100 Hz 1/3 octave band). Figure 5 illustrates this comparison for June 12 to 19, 2019.

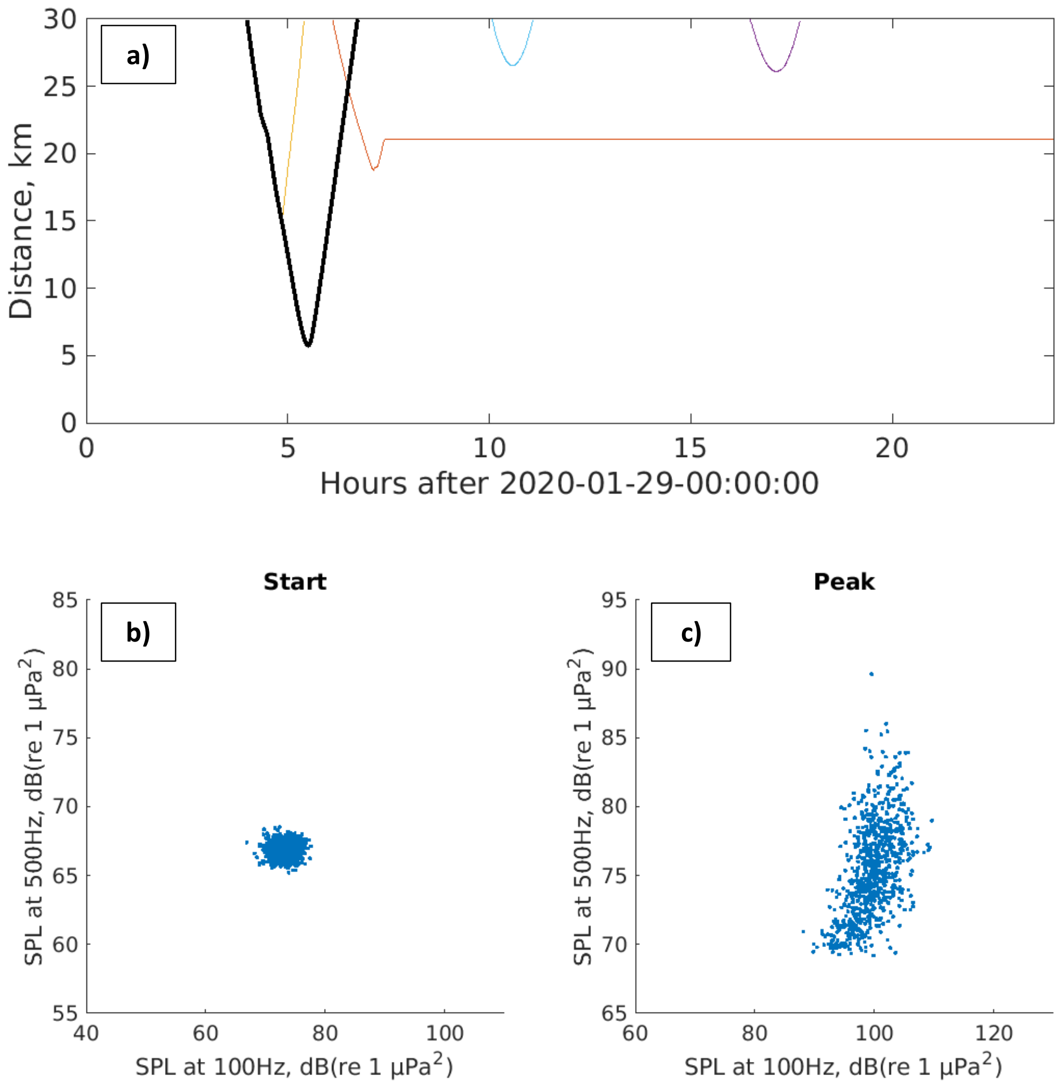

Figure 3. The distance (km) of vessels, each line represents a unique vessel, from the mooring over time (UTC) on January 29th, 2020 (a), and for the vessel represented by the bold black line: plots comparing noise levels in the 1/3 octave frequency bands centered at 100 and 500 Hz at the start (b) and peak (c) of the vessel event. The time periods used to create these plots were from 60 minutes before the start time to the start time (b) and 30 minutes before the peak to 30 minutes after the peak (c).

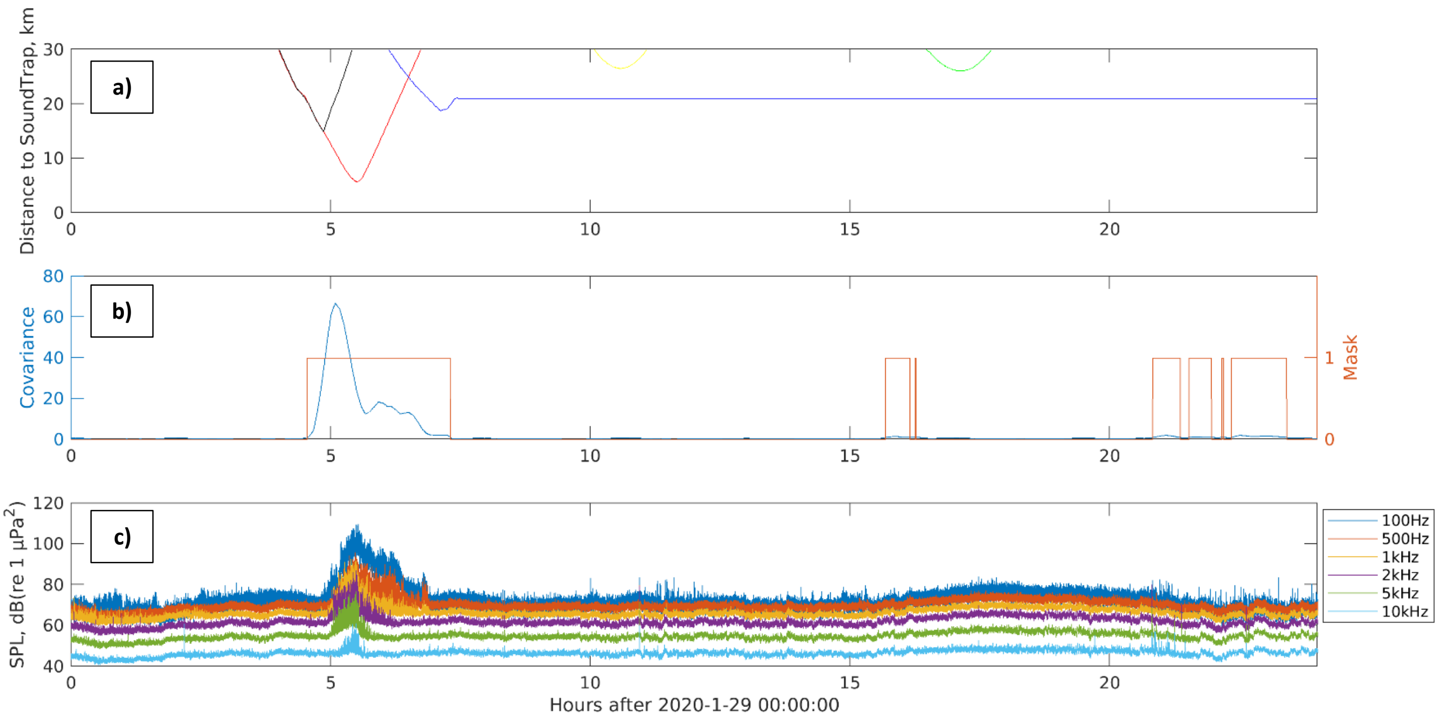

Figure 4. A typical vessel noise detector output. The distance (km) of vessels (note there were 5 vessels present, each a different colour) from the mooring location (a, 30 second resolution), the covariance values between noise levels in the 1/3 octave frequency bands centered at 100 and 500 Hz and resulting mask values (b, 5 minute resolution), and the average SPL in each of the six 1/3 octave bands (c, 0.3413 second resolution) over time (UTC) on January 29, 2019.

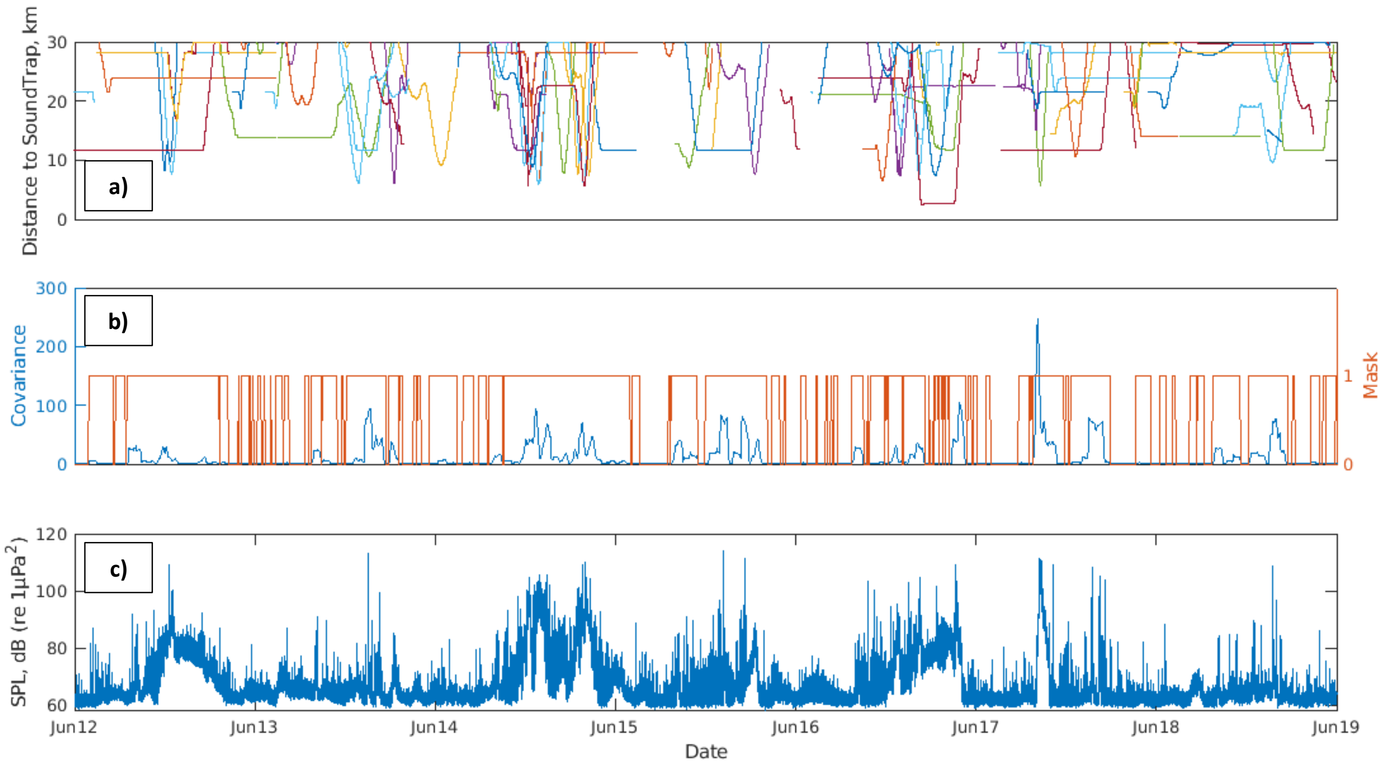

Figure 5. A typical figure used to evaluate the performance of the vessel noise detector. The distance (km) of vessels, travelling at speeds of 1 knot or faster, from the mooring location (a, 30 second resolution), the covariance between noise levels in the 1/3 octave frequency bands centered at 100 and 500 Hz and mask values resulting from the vessel noise detector (b, 5 minute resolution, mask value of 1 indicates the presence of vessel noise), and the SPL in the 1/3 octave band centered at 100 Hz (c, 1.024 second resolution) from June 12 to 19, 2019 (UTC).

2.3.3 Estimating vessel noise

All sound energy during periods when the mask value was 1 was attributed to vessels. The new baseline SPL was calculated by taking the average of the SPL immediately before and the SPL immediately after the period when the mask value was "1". The difference between this average and the original overall SPL was calculated for each masking event to determine the sound energy levels contributed by vessels. Figure 6 illustrates this process for January 29, 2020.

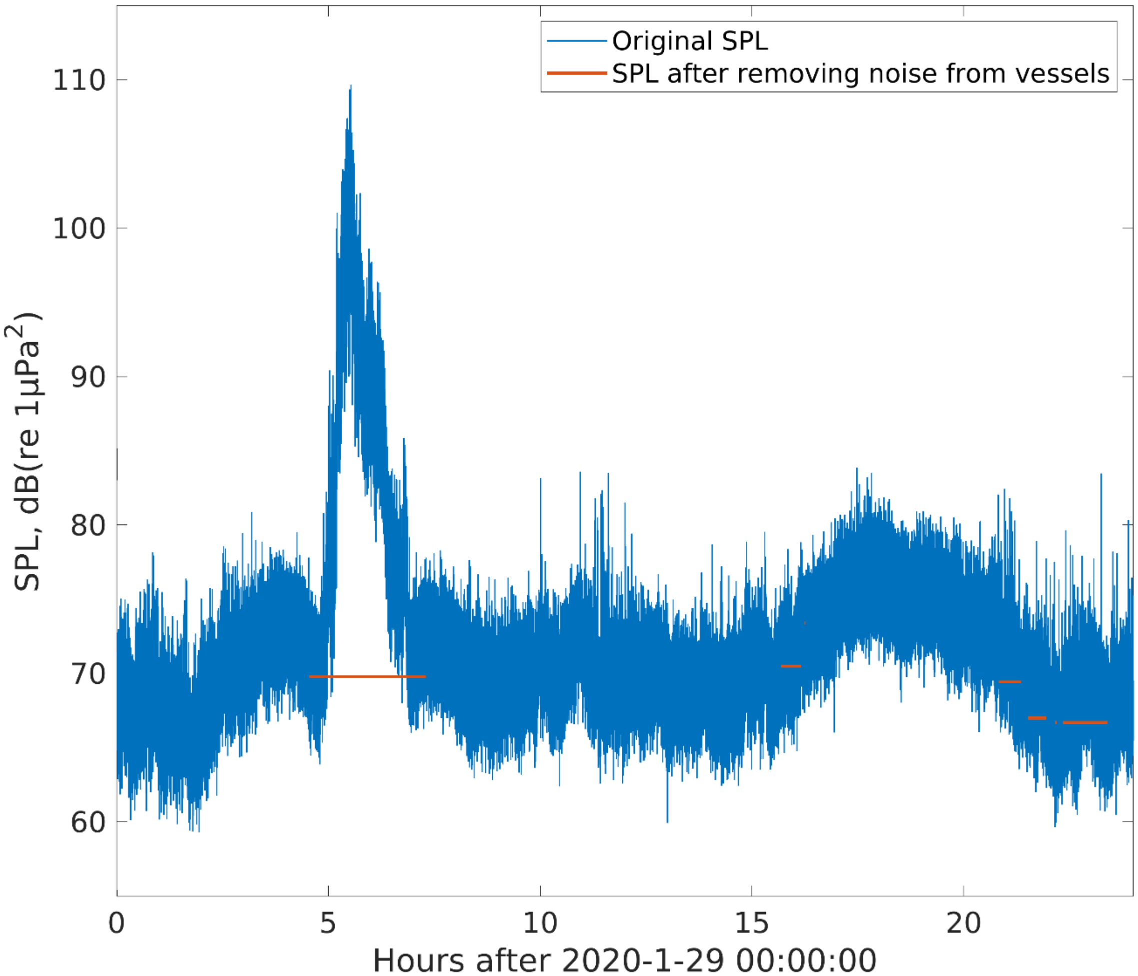

Figure 6. The original sound pressure level (SPL, blue line) and newly calculated average SPL after removing noise during a vessel event identified by the vessel noise detector (orange line) for the 100 Hz 1/3 octave band on January 29, 2020 (UTC).

2.3.4 Estimating sound energy contributed by wind

Wind velocity data were extracted for the grid location closest to the mooring location (45.3587, -61.1539) from Environment Canada's High Resolution Deterministic Prediction System (HRDPS) dataset (*https://weather.gc.ca/grib/grib2_HRDPS_HR_e.html*). The HRDPS is a set of nested limited-area model (LAM) forecast grids from the non-hydrostatic version of the Global Environment Multiscale (GEM) model with a 2.5 km horizontal grid spacing for the inner domain over one main Pan-Canadian region. The data had a temporal resolution of one hour and spatial resolution of 2.5 km.

The hourly wind speed data were interpolated to a 30-minute resolution in order to match the temporal resolution of the spectrograms. The average SPLs of each wind speed (0.05 m/s resolution) were calculated over each frequency band. Callaghan et al. (2008) found that the minimum wind speed needed to produce white caps was ~3.7 m/s. Whitecaps are an indicator of breaking waves, which are the main mechanism for increasing wind-induced ambient sound (Farmer and Vagle 1988; Medwin and

Beaky 1989). Therefore, when the average wind speed was greater than 3.7 m/s, we assumed that increases in SPL after vessel noise was removed were caused by wind. It is possible that some of the sound energy during these periods was actually from precipitation and/or a biological source, but considering the prolonged length and pressure levels of wind-induced sound, other sources of ambient sound were unlikely to have a significant influence on the sound budget results.

The top panel of Figure 7 shows the original SPL, the SPL after removing vessel noise, and the SPL after removing sound contributed by vessels and wind in the 1/3 octave band centered at 500 Hz for February 4 to 11, 2020. The bottom panel shows the wind speed for the corresponding time period. For time periods during which the wind speed was 3.7 m/s or higher, the new baseline SPL (wind and vessel noise removed) was estimated by taking the average of the SPLs immediately before and after the period during which wind speeds were greater than 3.7 m/s. The sound energy contributed by wind was therefore estimated by calculating the difference in SPL between this baseline and sound levels after only vessel noise was removed, and then determining the energy associated with the difference.

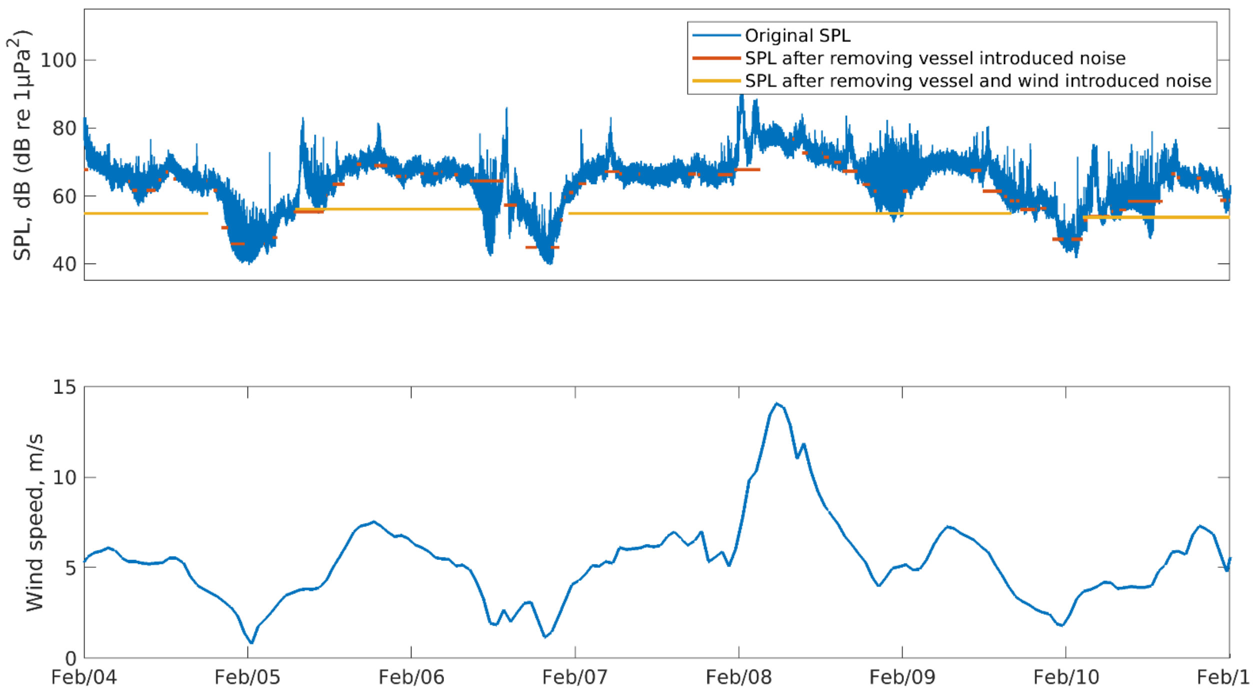

Figure 7. The original sound pressure level (SPL, blue line), the calculated average SPL after sound energy during vessel events was removed (orange line), and the calculated average SPL after sound energy during vessel events and during periods when the wind speed was greater than 3.7 m/s was removed (top panel) in the 500 Hz 1/3 octave band and the wind speed (m/s) (bottom panel) from February 4 to 11, 2020 (UTC).

2.3.5 Estimating the sound energy budgets

After the sound energy from vessels and wind were isolated as described above, the remaining sound energy was attributed to all other sources, grouped as “other”, and the percent energy contributions of vessels, wind, and “other” sources in each of the six 1/3 octave bands were calculated for each month.

2.4 Hourly Call Occurrence and Low Frequency SPL

This analysis was meant to be a preliminary investigation into how best to compare sound levels to baleen whale call presence. We were most interested in comparing call occurrence to sound in the lower frequency bands, 30 to 100 Hz and 100 to 500 Hz, as this is where the majority of the energy from vessel noise occurs. We therefore focused this analysis on the occurrence of sei whale downsweeps, blue whale arch and downsweeping calls, and humpback whale moans, as these calls occur within the frequency range of the chosen bands. Note that these bands are different than those used to present the results of the sound energy budget analysis. This was intentional, as we wanted to include frequencies below 89 Hz, which is the lower limit of the lowest frequency band used in the sound budget analysis. We believed that this comparison would be more meaningful if calls occurred during three or more consecutive hours, and so we randomly chose six days, two days per species, that met this condition. The days chosen were March 15 and 16, 2019 for blue whales, December 21, 2018 and May 5, 2019 for humpback whales, and April 24, 2019 and October 8, 2019 for sei whales. Sound levels in each of the two frequency bands were calculated by applying a 30-minute moving average at a time step of approximately one second. These sound levels and the hourly occurrence of each call type were plotted together for each 24-hour period.

3.0 RESULTS

3.1 Data Collection

We successfully collected data near-continuously from December 2018 to April 2021. To consider only full recording days, all deployment and recovery days were removed from our dataset prior to analysis. On October 30, 2019, a fish harvester accidentally brought our mooring to the surface. The mooring was re-deployed the following day by our community partner. We therefore removed October 30 and 31, 2019 from our dataset. March 10, 2019 and March 8, 2020 were removed from the dataset as the spring time change resulted in the loss of one hour. A gap in data collection occurred from May 07, 2020 to July 16, 2020 due to interruptions caused by the COVID-19 pandemic (Table 1). During the September 27, 2020 to December 01, 2020 deployment, the SoundTrap stopped recording on November 16, 2020. The cause for this is unknown, as the SoundTrap, external battery pack, and batteries were in good condition. During the December 01, 2020 to April 26, 2021 deployment, the SoundTrap stopped recording on April 20, 2021 due to depleted battery levels. We therefore also removed November 16, 2020 and April 20, 2021 from the dataset prior to analysis. A total of 500 full days (12000 hours) were analyzed for the presence of baleen whale calls and a total of 760 full days (18240 hours) were included in the sound energy budget analyses.

3.2 Baleen Whale Call Occurrence

3.2.1 Detector performance

A complete evaluation of detector performance was beyond the scope of this report, as we had not yet systematically reviewed files with no detections to assess missed call rates. For detectors with similar or the same parameters, Delarue et al. (2018) found that while missed call rates for the blue whale tonal, humpback moan, and fin whale 20 Hz pulse detectors were typically low, there were certain time periods at certain sites where many calls were missed. This was usually due to a low signal to noise ratio (SNR), individual calls within a long series of calls being missed, or a combination of these two scenarios. Given our Chedabucto Bay site is coastal and near a major shipping lane, it is likely that some calls were missed by the detectors due to low SNR.

Although we do not know how many calls we may have missed, we can be certain that we did not include any false positive detections in our analyses since an analyst manually reviewed every file with a detection. Many false positives were identified during the validation process. All right whale detections were false positives, triggered by humpback whale vocalizations and noise. Most sei whale detections were false positives, triggered by seal, humpback, and blue whale vocalizations, and noise. Minke whale pulse train detections occurred during only two hours, and all were false positives. The humpback moan detector was often triggered by noise year-round and by grey seal vocalizations during winter months. The fin whale detector was often triggered by low frequency noise. Delarue et al. (2022) found similar high false positive rates for the same sei whale downsweep detector and for a right whale upcall detector that was similar but not identical to the one we used. The false positive rates were so high that they deemed the detection methods for these species to be inadequate (Delarue et al. 2022). It should therefore be noted that the low number of validated sei whale calls and complete absence of validated right whale calls may be a reflection of the methods used. This is yet another reason for why it is important to interpret our results as the minimum call occurrence for each species.

The majority of blue whale vocalizations confirmed through the validation process were of arch and downsweeping calls. There were only nine hours during which tonal calls were confirmed, and there was always at least one arch or downsweeping call present during those hours. The blue whale tonal detector was often triggered by low frequency noise. Given this detector's poor performance and the lack of a detector specifically targeting arch or downsweeping calls, it is possible that we did not adequately detect blue whale vocalizations with the adopted methodology. However, we can still interpret these results as the minimum blue whale call occurrence, as the sei whale downsweep detector identified many arch and downsweeping calls.

3.2.2 Baleen whale minimum occurrence

We confirmed the presence of fin, sei, humpback, and blue whales through manual validation of the automated detections. As mentioned above, there were no confirmed right whale upcalls or minke whale pulse trains. Humpback whale calls occurred during 4.5% and nearly 25% of all recording hours and days, respectively (Table 3). Fin whale 20 Hz pulses occurred during 4.6% and nearly 20% of all recording hour and days, respectively (Table 3). Blue whale calls were much less common, occurring during only 0.8% and 7.4% of all recording hours and days, respectively. Unknown baleen whale downsweeps occurred during a similar percentage of recording hour and days as blue whale calls, 0.7% and 9.2%, respectively (Table 3). Sei whales downsweeps occurred during the lowest percentage of hours (0.1%) and days (1.0%) (Table 3).

Fin whale 20 Hz pulses occurred in March and April of both years, in May 2019, and during August through February 2019 (Figure 10). The pulses occurred during almost every day in August and October 2019, often during several hours each day (Figure 10). Sei whale downsweeps were rare, occurring during only two days in April, one day in June, and two days in October 2019 (Figure 10). Humpback whale vocalizations occurred most often during December through January in both years and during mid-April through mid-June 2019 and in April 2020 (Figure 10). Blue whale vocalizations occurred from January to May in both years and during one day in June 2019 (Figure 10). In both years, blue whale vocalizations occurred most often in March (Figure 10). The seasonal occurrence of unknown baleen whale downsweeps was most similar to that of blue whales; unknown downsweeps occurred from late January in both years through June in 2019 and through April in 2020 (Figure 10).

There were no obvious diel patterns in fin whale call occurrence during fall, winter, and spring (Figure 11). There appeared to be slightly higher call occurrence during the nighttime hours in summer (Figure

11). Fin whale pulses were confirmed during only five days in winter, and so the higher proportions at 05:00, 06:00, and 10:00 were due to there being three of those five days with calls confirmed in each hour. There were no diel patterns in the presence of sei whale downsweeps during the five days they occurred (Figure 11). The peak at 08:00 in summer is because there was only one hour during the summer with a confirmed sei whale detection (Figure 11). Humpback whale call occurrence was highest during nighttime hours in spring, and to a lesser degree in winter (Figure 11). There were no diel patterns in humpback whale call occurrence during summer and fall. Blue whale call occurrence appeared to be highest in the late afternoon to early evening (~15:00-19:00) in spring (Figure 11). The high proportion at 08:00 in the summer was due to there being only one confirmed hour with a blue whale vocalization throughout the entire season. There were no discernible diel patterns in unknown baleen whale call occurrence in any season. The high proportion at 11:00 during the summer was due to there being only one confirmed hour with an unknown baleen whale downsweep throughout the entire season.

Vocalizations from all four species and the unknown baleen whale downsweeps often occurred during only one consecutive hour (Figure 12). Calls occurred during two or more consecutive hours less often, with the frequency generally declining as the number of consecutive hours increased (Figure 12). Humpback and fin whale vocalizations occurred during the highest number of consecutive hours, with a maximum of 21 for humpback whales and 16 for fin whales (Figure 12).

Table 3. The percentage (%) of recording days during which at least one call occurred for each species and for the unknown baleen whale category.

Species	**Number of Days Confirmed**	**% of Days Confirmed**	**Number of Hours Confirmed**	**% of Hours Confirmed**
Fin whale	88	17.6	550	4.6
Sei whale	5	1.0	19	0.1
Humpback whale	116	23.2	547	4.5
Blue whale	37	7.4	96	0.8
Unknown baleen whale	46	9.2	87	0.7

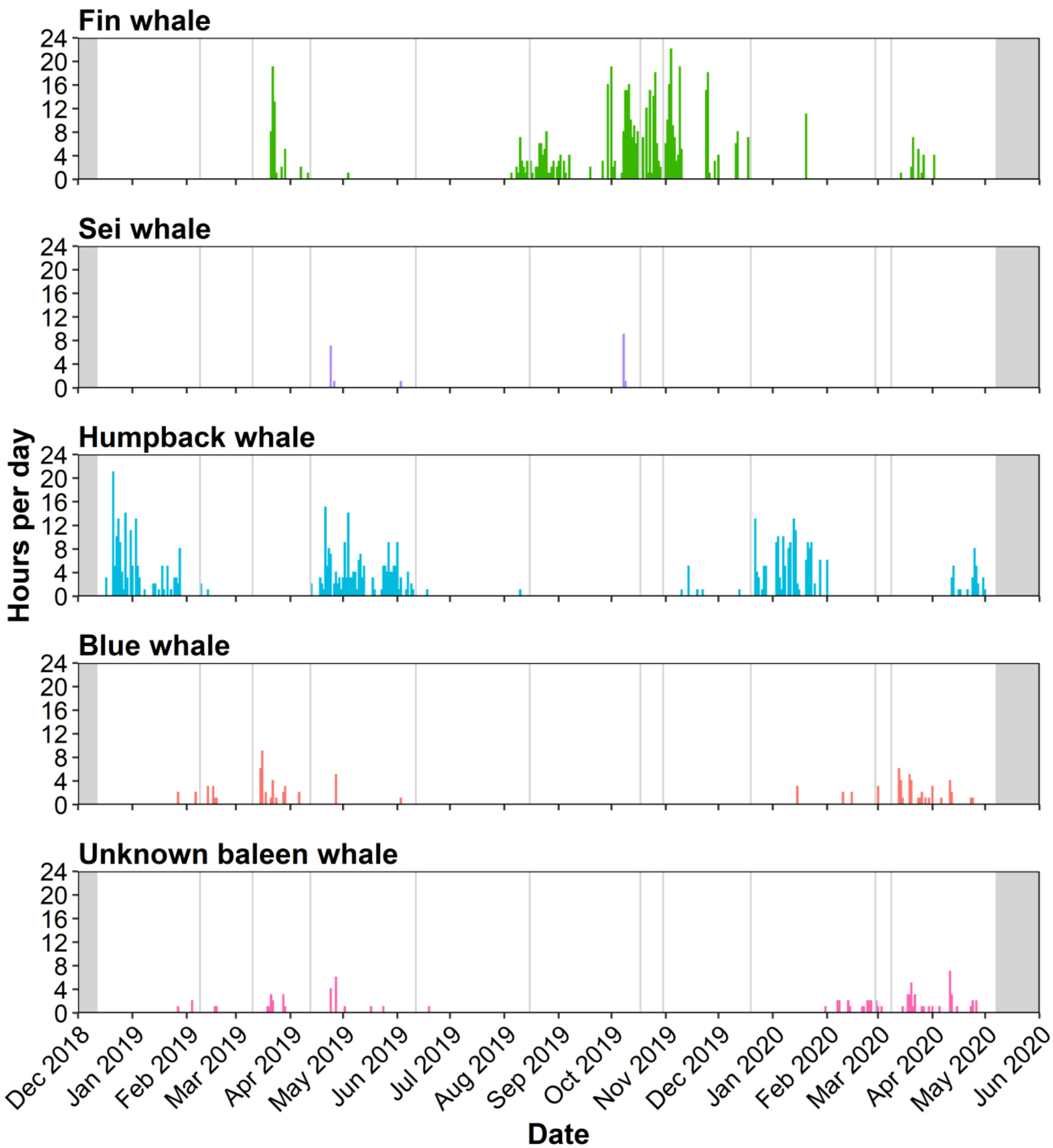

Figure 10. The number of hours per day during which at least one call of each species occurred from December 2018 to May 2020. The grey shading indicates days during which the recorder was not deployed or deployed for less than twenty-four hours (see section 3.1).

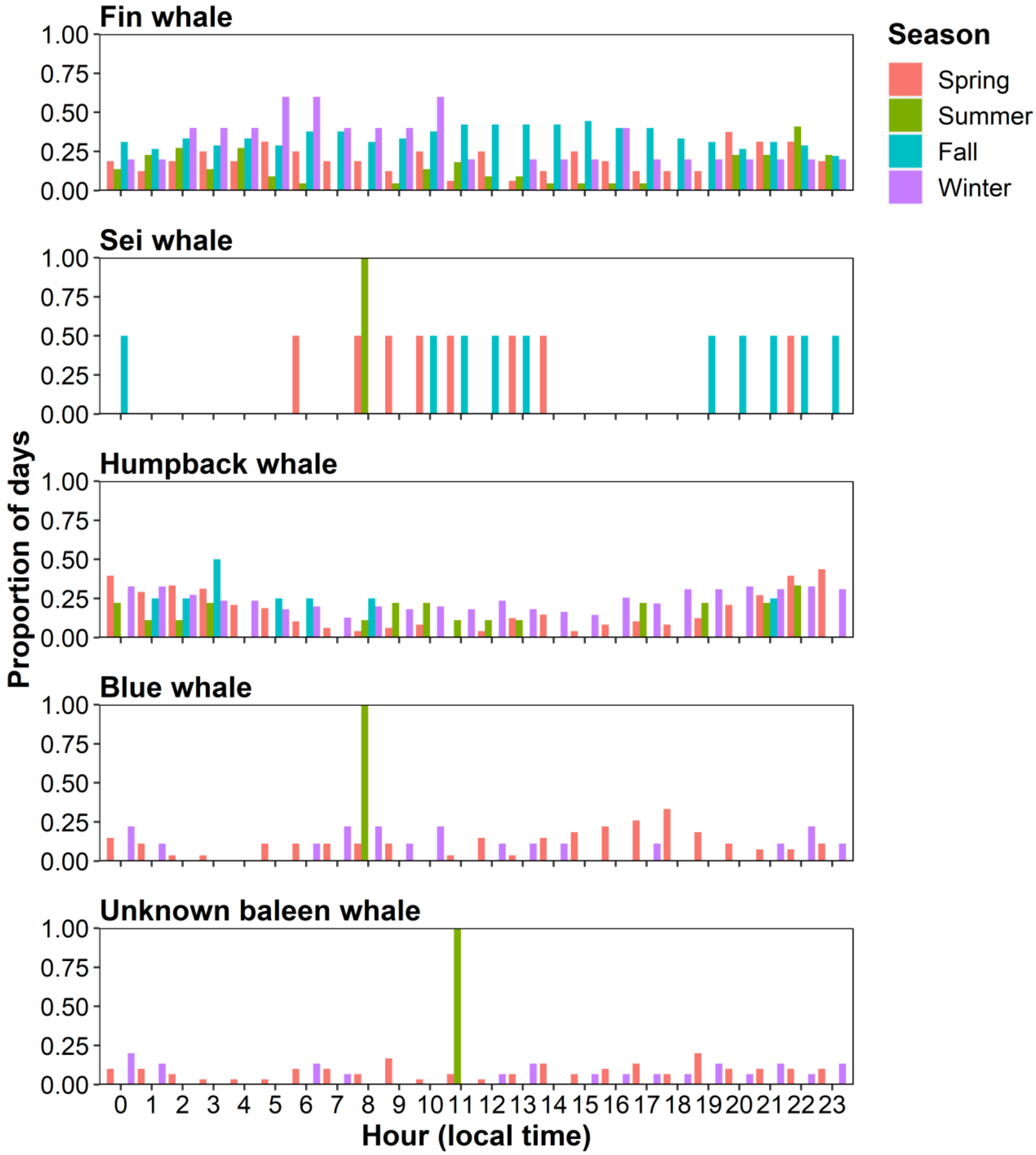

Figure 11. The proportion of days during which at least one call occurred in each hour. Only days during which the species of interest was present were considered. The seasons were divided as spring: March to May, summer: June to August, fall: September to November, and winter: December to February.

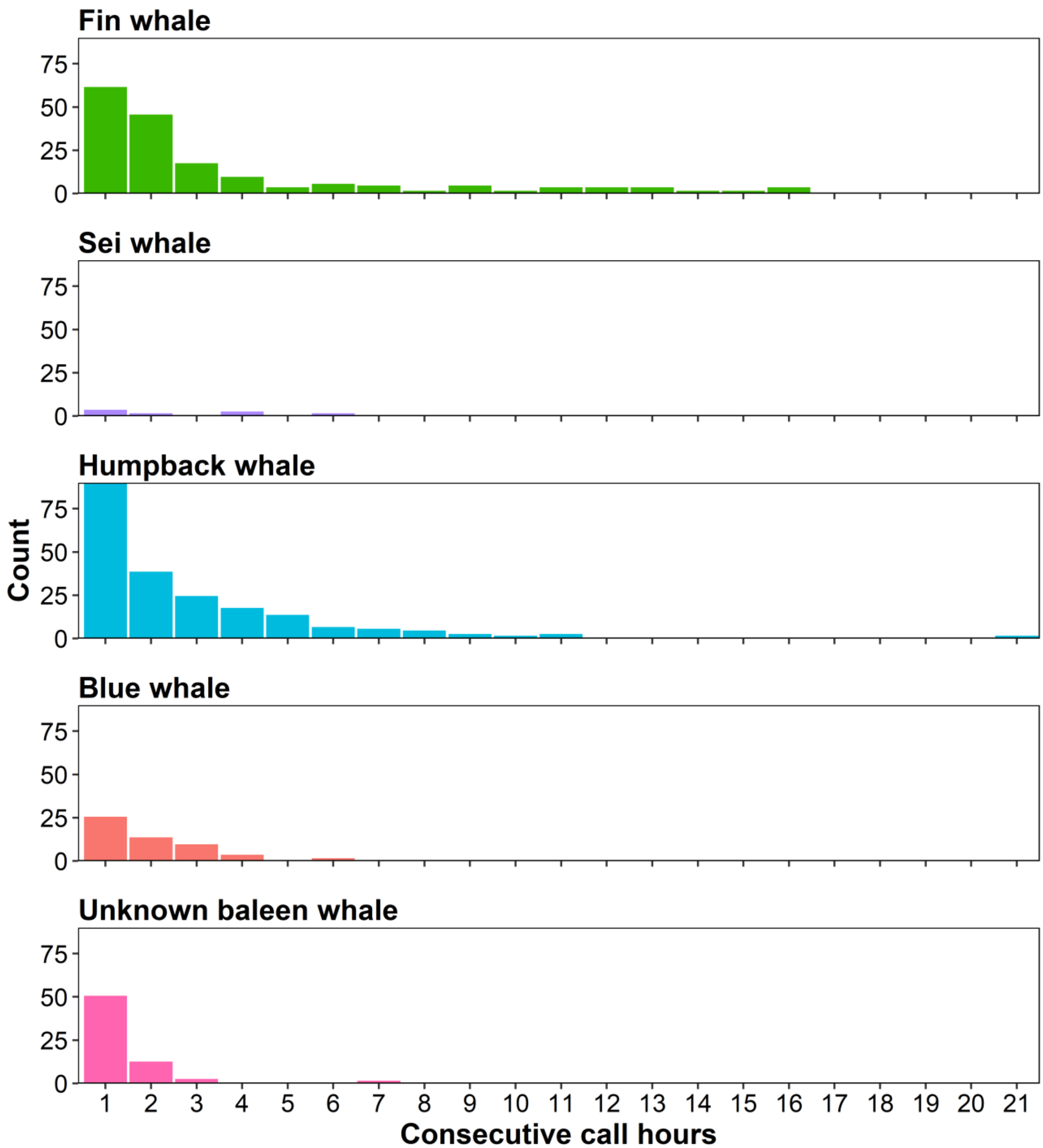

Figure 12. The frequency of occurrence of periods of consecutive hours during which at least one call was present for each species.

3.3 Sound Energy Budget Estimation

Throughout the study period, sound levels were typically highest in the 30 to 100 Hz and 100 to 500 Hz frequency bands (Figure 13). While there were large variations in sound levels on a daily scale, overall sound levels remained relatively consistent from December 2018 to April 2021 (Figure 13). There were noticeable peaks in sound levels in the lowest frequency band (30 to 100 Hz) in January, June, and

October 2019 and February 2020. Sound levels in the two lowest frequency bands were elevated in October and November 2020 (Figure 13). Sound levels in these two frequency bands were noticeably lower during the subsequent deployment. Figures C1 to C26 in Appendix C show the monthly spectrograms for January 2019 to April 2021. There were high levels of low frequency sound for periods of 3-10 days throughout August to November 2020 (Figures C18 to C21). The analysis of AIS data revealed the cause to be the prolonged presence of one vessel close to our mooring location.

Wind speeds were typically highest during the winter months (Figure 14). Wind speeds were high throughout December 2018 and 2019, but comparatively low during December 2020. The large peak in wind speed in early September 2019 was due to post-tropical storm Dorian (Figure 14). The average SPLs in all five frequency bands began to increase as wind speeds surpassed 3.7 m/s, with the lowest band (30-100 Hz) showing a more gradual increase than the other bands until ~6-8 m/s (Figure 15). At wind speeds greater than 8 m/s, SPLs in the five frequency bands increased at a similar rate. The SPLs generally stopped increasing in all frequency bands when wind speeds were greater than ~20 m/s in the December 2018 to December 2019 dataset and greater than ~12 m/s in the January 2020 to April 2021 dataset (Figure 15).

Overall, wind and vessels were the two most dominant sources of sound in the soundscape for the six frequencies examined (Figure 16). Vessel noise was the largest contributor to the sound energy budget in the lowest frequency band from December 2018 to February 2019, while wind sound was the largest contributor in all other bands (Figures 14). In March and April 2019, vessel noise became more prevalent in the lowest frequency bands, and by May vessel noise contributed the majority of the energy in the soundscape in all frequency bands (Figure 16). This trend continued until August 2019, when the contributions of wind noise to the energy budgets of the higher frequencies began to increase (Figure 16). Vessel noise once again dominated the soundscape in October 2019, followed by an increase in wind sound and sound from “other” sources in November 2019 (Figure 16). From December 2019 to April 2020, vessel noise remained the largest contributor of energy in the lowest frequency band, while sound from wind began to increase in all other bands (Figure 16). Vessel noise was the dominant contributor of energy in July 2020 in all frequency bands, comprising almost the entire noise budget in the lowest frequency band (Figure 16).

As mentioned above, August to November 2020 was an anomalous period in our dataset, with several multi-day periods of elevated noise levels in the lower frequency bands caused by the prolonged presence of a single vessel. Due to the irregular movement of this vessel, it was not properly accounted for in the vessel noise detector and the noise was therefore erroneously attributed to the wind and “other” categories during these months. The sound energy budgets during these months therefore misrepresent the contributions of each source. Had the noise from the vessel been attributed correctly, we would expect the sound energy budgets to be similar to those during the same period in 2019, when vessel noise was the dominant contributor of sound energy in the lower frequency bands.

From December 2020 through March 2021, there were no further multi-day periods with increased sound caused by irregular vessel movement, and the majority of the sound in the lowest frequency band was again attributed to vessels. The contribution of wind sound to the total energy budget remained high in most other bands (Figure 16). Finally, in April 2021, vessel noise contributed less to the energy budget in the lowest frequency band than in previous months as sound from “other” sources increased (Figure 16).

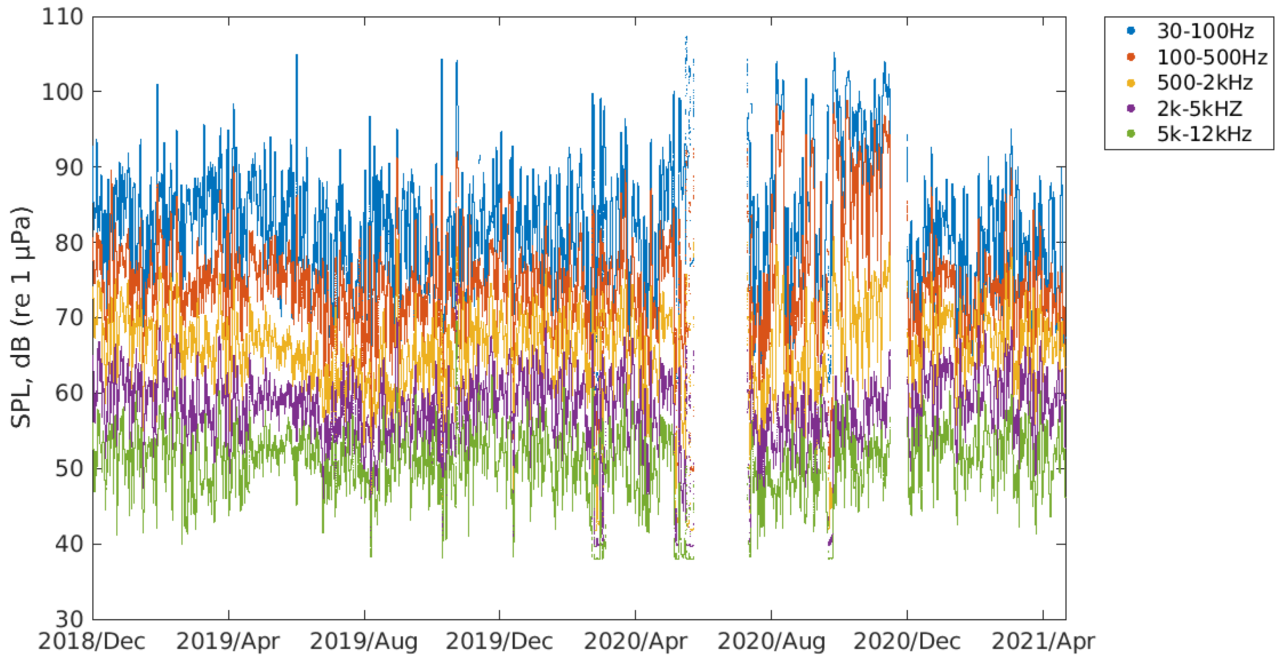

Figure 13. The sound pressure level (SPL) in each of the five frequency bands, calculated using a one day moving average. The date is in UTC.

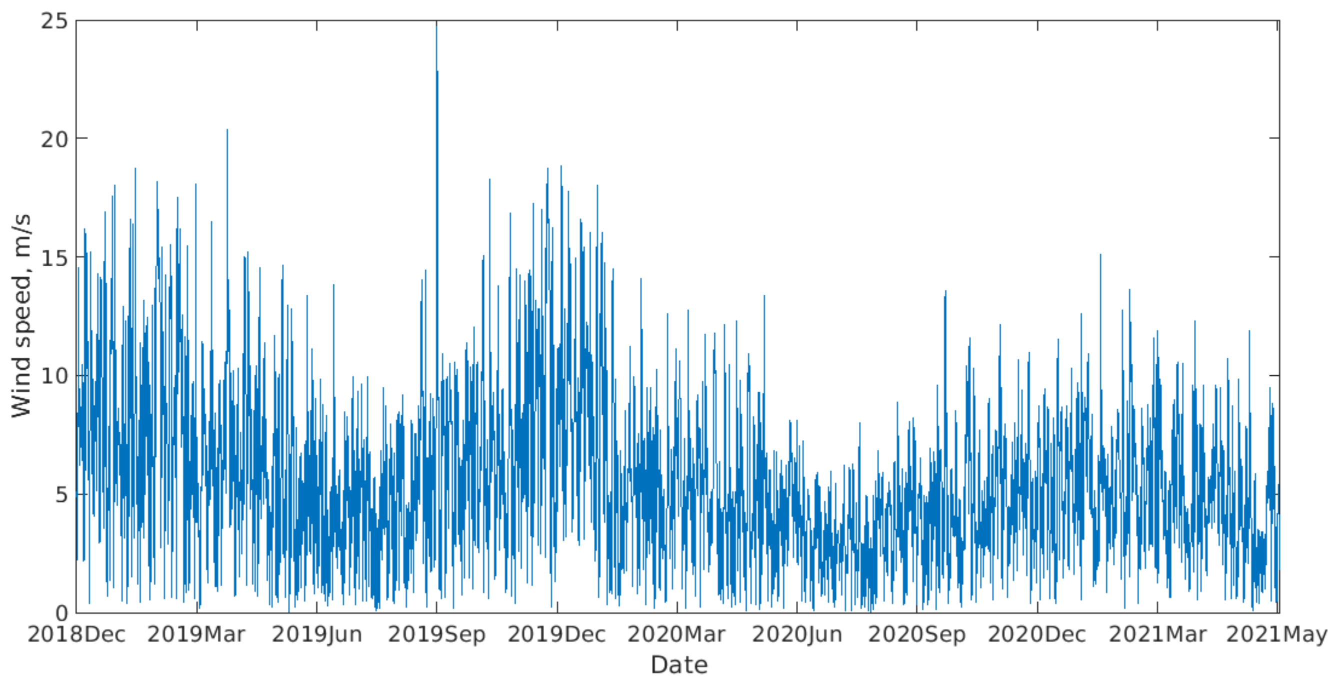

Figure 14. Six-hour averages of wind speeds from December 2018 to April 2021 extracted for the grid location closest to the mooring site (45.3587, -61.1539).

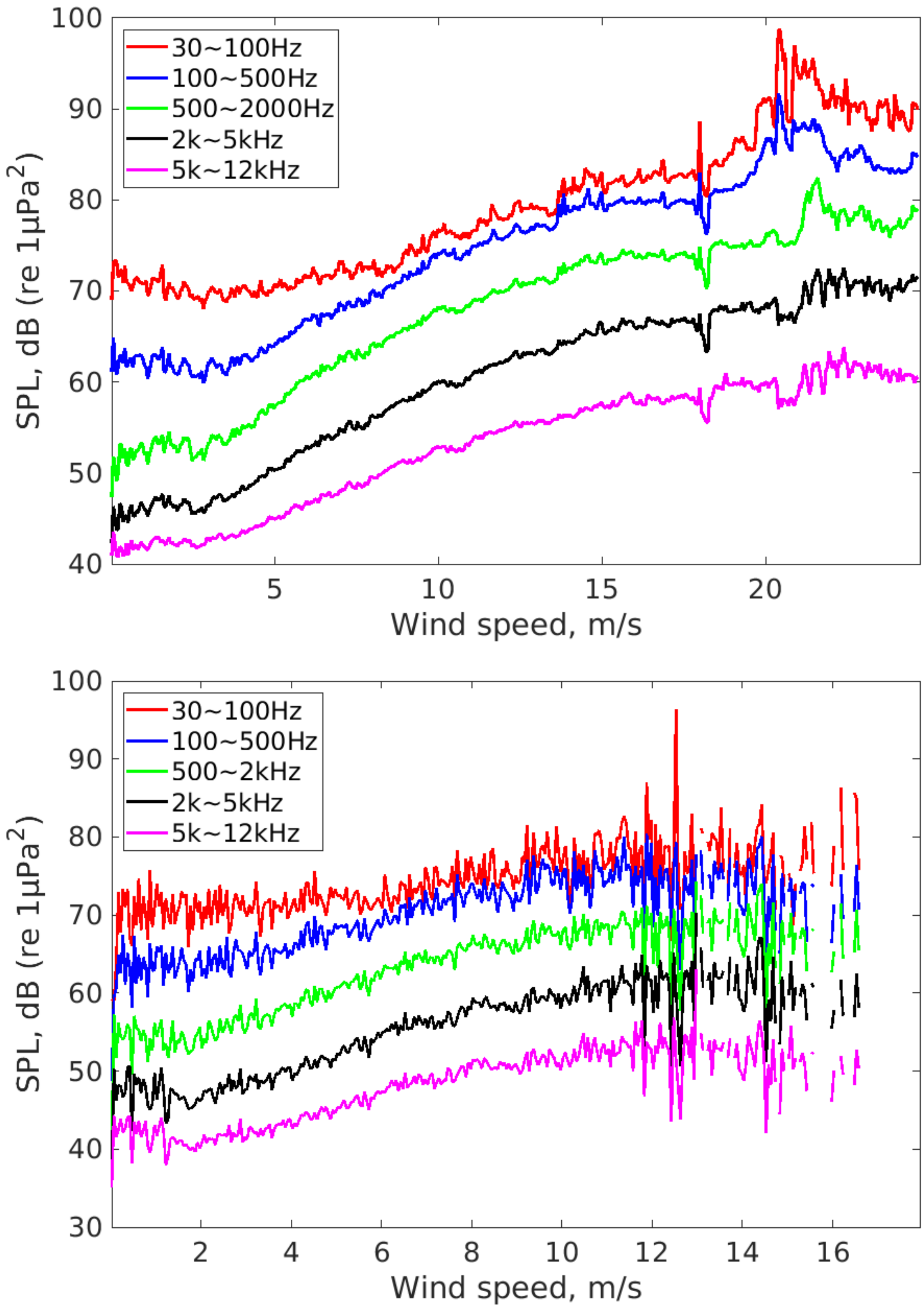

Figure 15. The relationship between the sound pressure level (SPL) in each of the five frequency bands and the wind speed (0.05 m/s resolution) from December 2018 to December 2019 (top panel) and January 2020 to April 2021 (bottom panel).

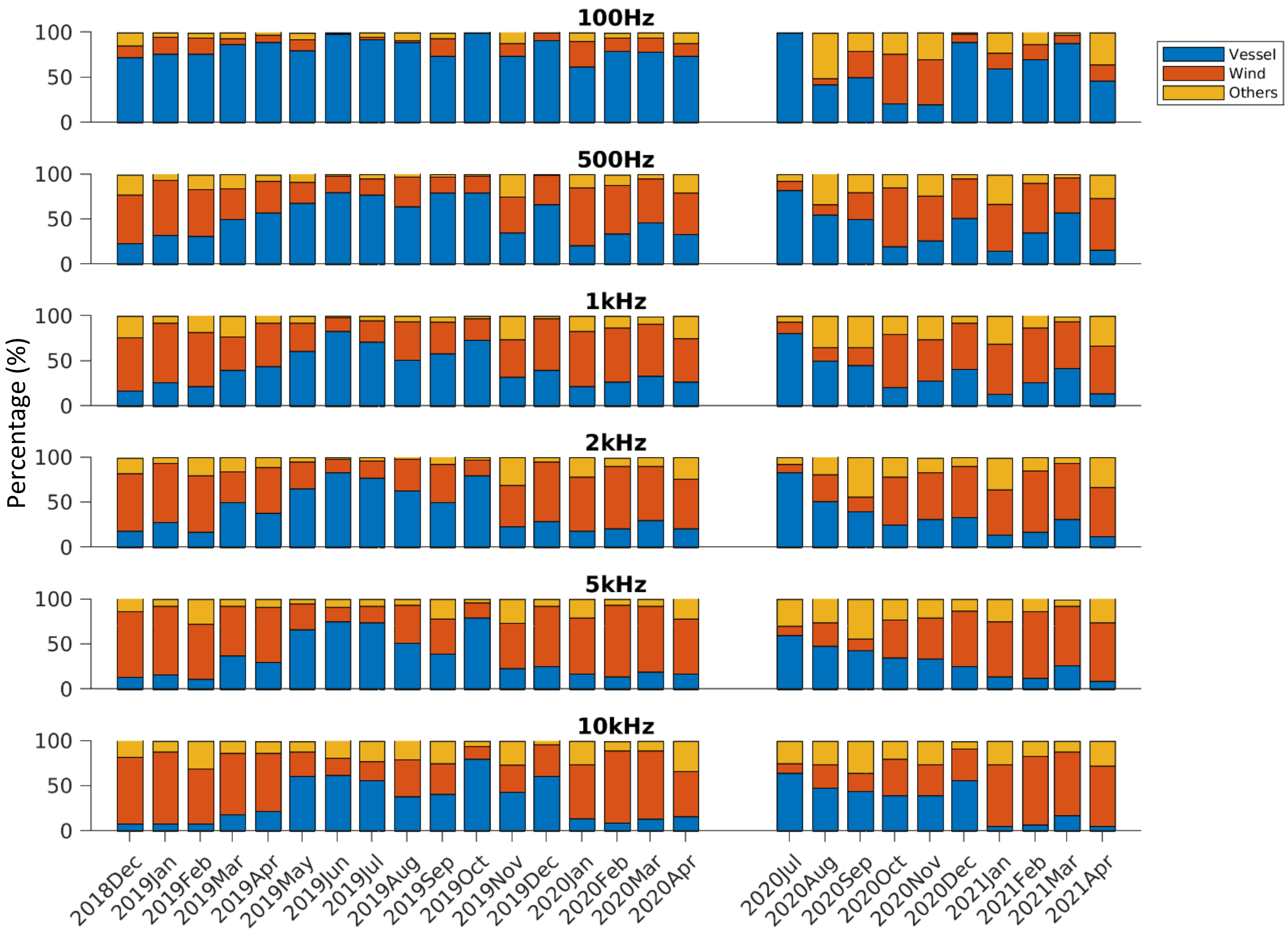

Figure 16. The percent (%) contribution of each source to the total sound energy budget for each of the 6 frequency bands from December 2018 to April 2021. There were no data for May and June 2020 due to an interruption in data collection.

3.4 Hourly Call Occurrence and Low Frequency SPL

On December 21, 2018, humpback whale calls first occurred after a period of loud vessel noise ended at approximately 07:00 and were detected in every subsequent hour during which noise levels remained low (Figure 15). During the period of elevated noise from 04:00 to 07:00, there appeared to be very faint humpback whale calls that were missed by the detector, likely due to a low SNR. On May 5, 2019, humpback whale calls occurred during several consecutive hours until 06:00, when loud vessel noise began to dominate the soundscape (Figure 16). Noise levels remained high and there were no further calls detected or visible in the spectrograms for the remainder of the day (Figure 16). On March 15, 2019, blue whale tonal and downsweeping calls occurred during a period of loud vessel noise from 17:00 to 23:00 (Figure 17). Blue whale calls were absent during a period of similar noise levels earlier in the day. There were several loud downsweeping and arch calls present during the hour of 20:00, and it is therefore possible that these calls caused the increase in SPL in the 30 to 100 Hz frequency band during that hour. On March 16, 2019, blue whale downsweeping and arch calls were detected throughout periods of elevated noise levels caused by wind and vessels (Figure 18). On April 24, 2019, sei whale downsweeps were present during periods when noise levels were low and absent during periods of loud vessel noise (Figure 19). There were no downsweeps visible in the spectrogram during these periods of elevated noise, suggesting calls were truly absent rather than missed by the detector. On October 8, 2019, sei whale downsweeps were present during hours with low ambient noise and also during hours with loud vessel noise (Figure 20).

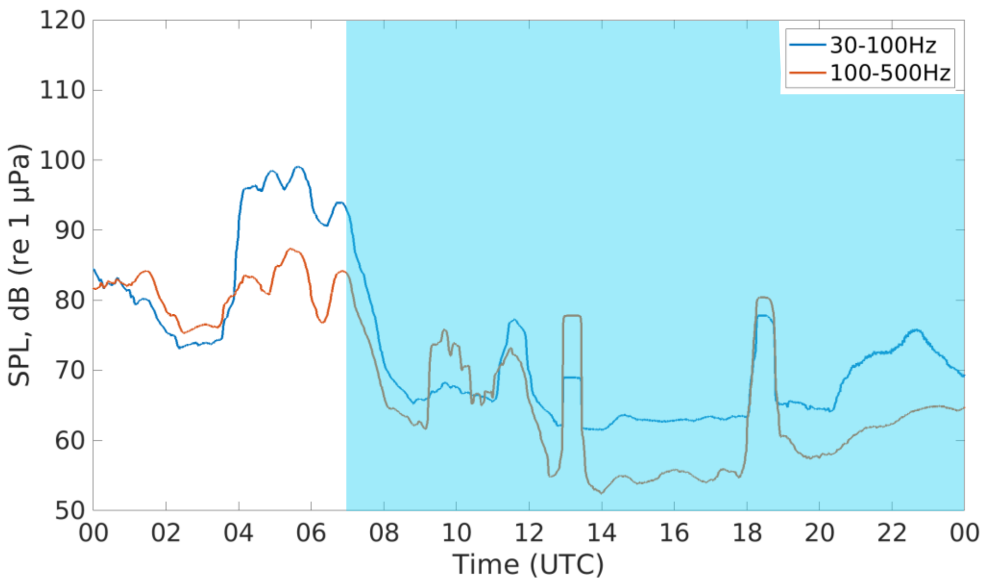

Figure 15. The hourly presence of humpback whale calls (blue polygon) and sound pressure level (SPL) in the 30 to 100 Hz and 100 to 500 Hz frequency bands during December 21, 2018.

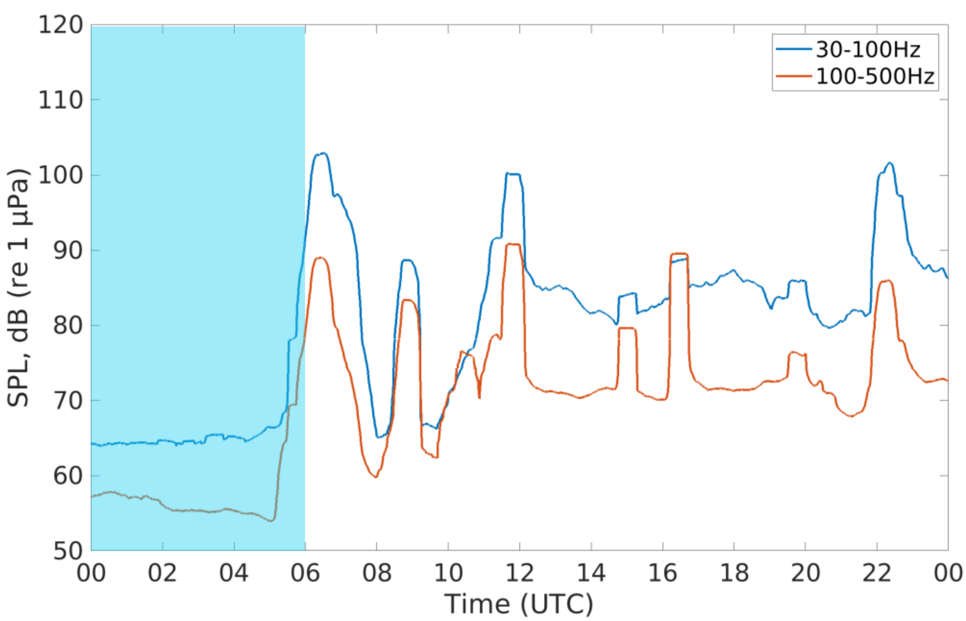

Figure 16. The hourly presence of humpback whale calls (blue polygon) and sound pressure level (SPL) in the 30 to 100 Hz and 100 to 500 Hz frequency bands during May 5, 2019.

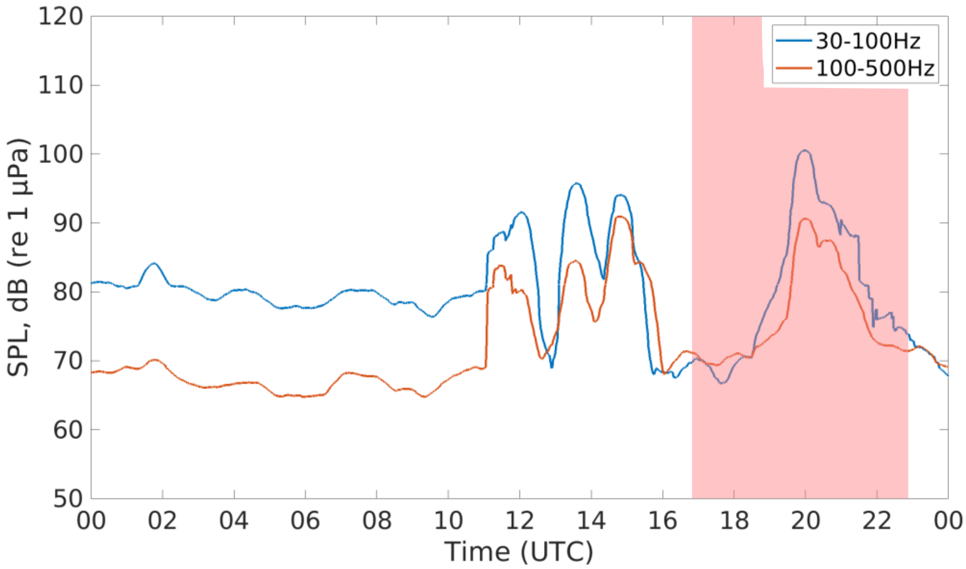

Figure 17. The hourly presence of blue whale calls (coral polygon) and sound pressure level (SPL) in the 30 to 100 Hz and 100 to 500 Hz frequency bands during March 15, 2019.

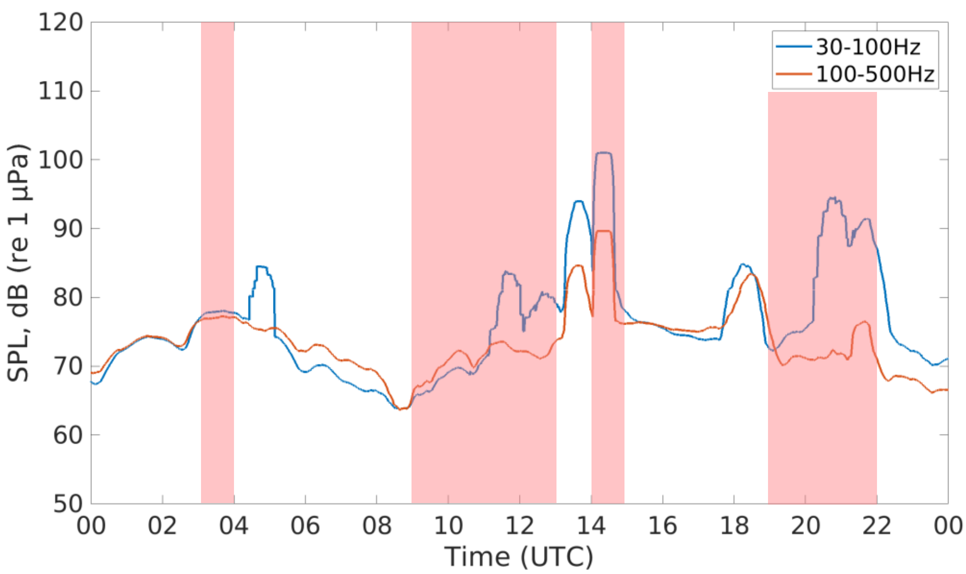

Figure 18. The hourly presence of blue whale calls (coral polygons) and sound pressure level (SPL) in the 30 to 100 Hz and 100 to 500 Hz frequency bands during March 16, 2019.

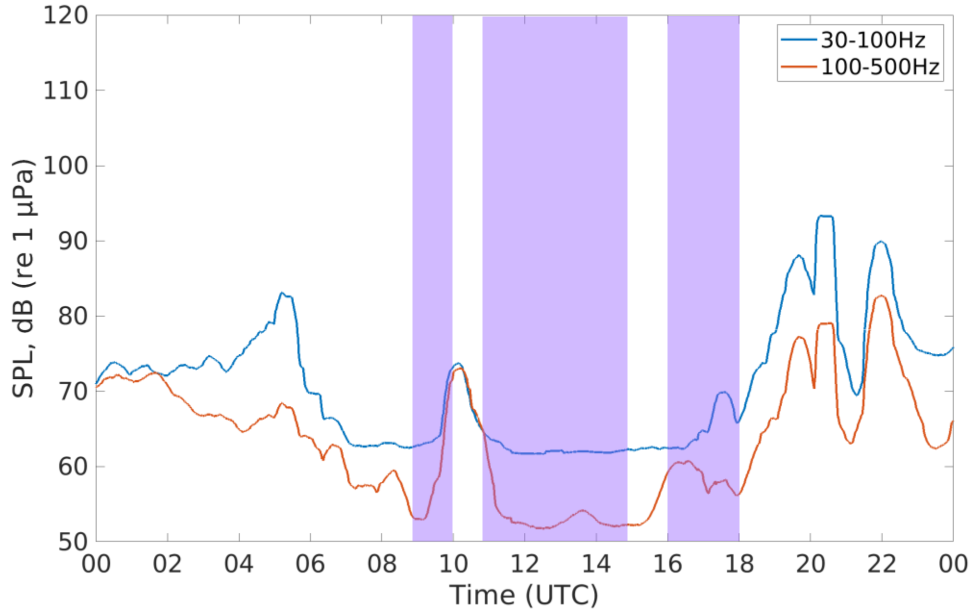

Figure 19. The hourly presence of sei whale calls (purple polygons) and sound pressure level (SPL) in the 30 to 100 Hz and 100 to 500 Hz frequency bands during April 24, 2019.

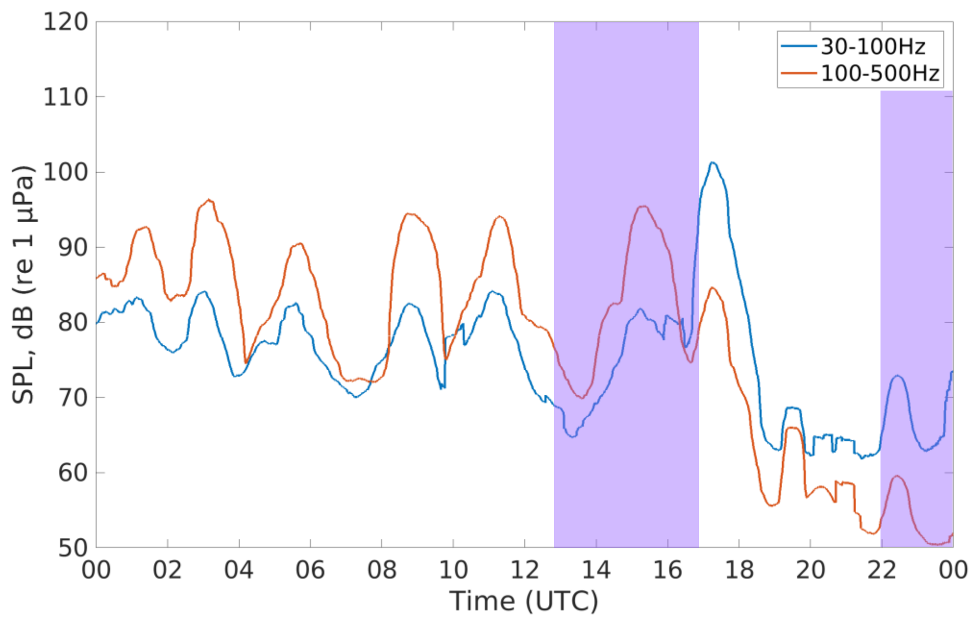

Figure 20. The hourly presence of sei whale calls (purple polygons) and sound pressure level (SPL) in the 30 to 100 Hz and 100 to 500 Hz frequency bands during October 8, 2019.

4.0 DISCUSSION

We have demonstrated that it is possible to use data from relatively low-cost underwater acoustic recorders to not only investigate baleen whale minimum occurrence, but also to characterize the soundscape at our Chedabucto Bay deployment site. It is important to compare the presence of baleen whales to trends in noise energy levels to better understand how underwater noise may impact the detection and/or calling behaviour of these species throughout the year. This work sheds light on the previously unstudied underwater soundscape of this busy coastal location.

4.1 Baleen Whale Call Occurrence

It is important to consider that the results in this report represent the minimum occurrence of each species and that we have likely 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 different call type than the one targeted by the detector. As Davis et al. (2020) stated, targeting seasonal and sex-biased call types will lead to an underestimation of overall whale presence. 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. 2022). Modelling the detection range of various call types for our 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 adopted methodology for detecting sei, North Atlantic right, and minke whales was likely inadequate, which may explain their rare occurrence or complete absence during the study period (Delarue et al. 2022). While we likely missed calls, we can be certain the calls we included in our results were accurately classified since a trained analyst manually reviewed every detection.

The majority of baleen whale calls that we detected occurred in fall and winter months. These findings contradict the traditional narrative that baleen whales spend the winter months in lower latitude breeding areas, but are consistent with the findings of Davis et al. (2020), Kowarski et al. (2018), Delarue et al. (2022), and Wingfield et al. (2022), who detected these species throughout the year at offshore sites in the northwest Atlantic. It is also consistent with the findings of P. Lane and Associates (1992), who reported fin whale sightings near Canso and in Chedabucto Bay during winter and spring and with those of Gomez et al. (2020), who reported sightings of these species year-round in the northwest Atlantic. We confirmed very few calls in June 2019 and no calls in July 2019. Noise levels were not noticeably higher during these months, and so it is more likely that baleen whales were outside of the detection range or were producing non-target vocalizations.

Fin whale pulses occurred primarily in March of both years and from August 2019 to January 2020. Occurrence was particularly high throughout October and into early November 2019. This was consistent with anecdotal sightings of this species in the area during the spring and winter (P. Lane and Associates 1992). Davis et al. (2020) also observed high occurrence of fin whale calls during these two months at sites on or near the Scotian Shelf edge. Delarue et al. (2022) frequently detected fin whales from late summer to spring at Stn 2, the site closest to Chedabucto Bay. The lack of calls from April to August in our dataset may have been due to fin whales producing downsweeps, their summertime call type, which were not the target of the detector. It is therefore likely that we underestimated fin whale presence during the summer. There did not appear to be any obvious diel trends in fin whale call occurrence, with the exception of slightly higher call occurrence during nighttime hours in summer. Only males have been observed producing these pulses, and they are therefore thought to function as a breeding display (Croll et al. 2002). Croll et al. (2002) hypothesized that these pulses are used to attract females from far distances to aggregations of patchily distributed prey. The nighttime peak in pulse occurrence may therefore relate to a change in behaviour, from foraging during the day when prey are aggregated at depth to mate attraction in the evening when prey are scattered. Fin whale song is characterized by long, repeated, patterned sequences of pulses. It is therefore not surprising that pulses occurred during many consecutive hours on several occasions.

Sei whale downsweeps were rare, 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). However, there have been temporary influxes of sei whales into coastal waters off New England in response to prey distribution (Schilling et al. 1992). On-shelf acoustic detections in the Gulf of Maine and southern New England demonstrate greater use of these areas than previously described (Davis et al. 2020). Davis et al. (2020) detected sei whales frequently during summer months on the Scotian Shelf. Macklin (2022) found that possible sei whale detections occurred year-round at a site ~107km east of our site ("Stn 2" in Delarue et al. 2022). These potential detections peaked in August (Macklin 2022). Definite detections were rarer at this site, peaking in May and June (Macklin 2022). Definite detections were much more common at sites farther offshore (Macklin 2022). It is possible that the lack of sei whale calls in our data is the result of poor detector performance and not a reflection of their occurrence. 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 occurrence of this species. There were too few confirmed calls to assess seasonal and diel patterns in occurrence.

Humpback whale calls occurred primarily during the winter and spring, consistent with the findings of Vu et al. (2012) and Stanistreet et al. (2013) on Stellwagen Bank, and Kowarski et al. (2018) around the Gully Marine Protected Area (MPA). Kowarski et al. (2018) observed similar peaks in call occurrence in December and January, and hypothesized that this was due to whales visiting productive foraging grounds prior to migrating further south. The increase in the number of calls that we observed in April and May following the near-complete absence of calls in February and March may have been due to an increase in the number of whales, as individuals that migrated south return to the area. Kowarski et al. (2018) hypothesized this could be the reason for a similar seasonal calling pattern observed near the Gully. Alternatively, humpback whales may have remained in the area and were either not vocalizing or producing non-target vocalizations throughout February and March. Kowarski et al. (2019) found that almost the entire vocal repertoire of humpback whales detected off eastern Cape Breton during April and May 2016 consisted of songs. It is therefore possible that the increase in humpback whale call occurrence at our site from mid-April through May represents the onset of song production. Categorizing the call types was beyond the scope of this study, but we may be able to assume that the calls we recorded during December, January, and April through June were predominately song or song fragments, given the findings of Kowarski et al. (2018; 2019). We observed an increase in call occurrence during nighttime hours in spring. An increase in singing during nighttime hours has been observed across the world in both breeding and foraging areas, which suggests this behaviour is not related to season or location (Kowarski et al. 2019). It is more likely that this pattern represents a change in mating strategy as the focus shifts from physical visual displays during daylight hours to acoustic displays at night when visibility is reduced (Au et al. 2000). Of the species we detected, humpback whales had the longest consecutive call streak (21 hours). There were several occasions when calls occurred during three or more consecutive hours. Humpbacks often sing for several hours (Garland et al. 2013), and so it is likely that the calls that occurred during several consecutive hours were part of song sequences. Our results could be expanded upon in the future by investigating the occurrence of humpback whale song and non-song vocalizations.

Blue whale calls were present from January through April in both years, and during one day in June 2019. Blue whales have been sighted (McDonald et al. 2006; Sears and Perrin 2018; Moors-Murphy et al. 2019) and their calls have been detected (Marotte and Moors-Murphy 2015; Delarue et al. 2018; Moors-Murphy et al. 2019; Davis et al. 2020; Wingfield et al. 2022) year-round in the northwest Atlantic. Although we used a tonal call detector, the vast majority of blue whale calls that we validated were arch and dowsnweeping calls detected by the sei whale downsweep detector. While these call types are more common during the summer months, they have also been detected throughout the winter and early spring on the Scotian Shelf (Moors-Murphy et al. 2019; Wingfield et al. 2022). Downsweeping calls are believed to be associated with social interaction (Oleson et al. 2007; McDonald et al. 2001), and so perhaps we detected whales communicating with one another on their way to or from productive foraging areas. Tonal calls are most often detected during the fall and winter months on the Scotian Shelf (Davis et al. 2020; Delarue et al. 2022; Wingfield et al. 2022), and so it is possible that we underestimated blue whale occurrence during these months given the tonal detector's poor performance. The tonal detector was often triggered by vessel noise, which has the potential to mask tonal calls. This is difficult to avoid, particularly in coastal areas with heavy vessel traffic. The sei whale downsweep detector likely missed some blue whale arch and downsweeping calls as these calls can be longer than the maximum duration specified in the sei whale downsweep detection parameters. It would be worth investigating whether the sei whale downsweep detector could be modified to create a reliable blue whale downsweep detector, as downsweeps may be more reliably detected than tonal calls in noisy coastal environments. We observed an increase in blue whale call occurrence in the late afternoon and early evening hours in spring. Lewis et al. (2018) observed an increase in downsweeping call occurrence at dusk, and hypothesized that blue whales fed on aggregated krill at depth during the day, and were then free to call at dusk as their prey began to scatter.

Seasonal patterns in the occurrence of "unknown baleen whale" downsweeps were very similar to the occurrence of blue whale arch and downsweeping calls, which suggests that the unknown downsweeps may have been blue whale calls. It is common practice to label a call as unknown if the analyst cannot confidently identify the species in order to avoid misrepresenting call occurrence. However, we felt there was still value in presenting these calls to show a more complete picture of general baleen whale presence.

We did not detect any valid North Atlantic right whale upcalls or minke whale pulses throughout the study period. The absence of right whale upcalls was consistent with the absence of visual sightings in the bay from 1951 to the present (Fisheries and Oceans 2014; Johnson et al. 2021). Many right whales now forage in the Gulf of St. Lawrence, following a shift in distribution from the Gulf of Maine and Bay of Fundy that took place in 2015 (Simard et al. 2019). It is possible that right whales were within or near Chedabucto Bay during our study period but they were not calling, or their calls were masked by noise. However, given the lack of right whale sightings in the bay, it is more likely that the area is not frequented by this species. Unlike right whales, minke whales have previously been sighted in the bay (Gromack et al. 2010). Risch et al. (2019) found the high number of false positive minke whale pulse detections in their dataset from the North Sea consisted mainly of vessel and seismic noise. All of our minke whale detections were false positives, and although we did not analyze these in detail, the cause seemed to be predominately vessel noise. In addition to falsely triggering the detector, vessel noise may have masked minke whale pulses. Delarue et al. (2022) stated that the current methods for detecting right and minke whale calls may be inadequate. These detectors are plagued by false positives, and so it is possible that the lack of calls we observed was due to poor detector performance. These detectors may need to be adjusted to better capture the occurrence of these species.

4.2 Sound Energy Budget Estimation

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 work, which cites vessels as the dominant contributor to sound energy below 200 Hz throughout the world's oceans (Wenz 1962; Hildebrand 2009; Southall et al. 2017). In our previous work (Breeze et al. 2021), we discovered that the crane ship Thialf (MMSI 353979000) caused elevated noise levels at our Chebucto Head site in April 2020 as its dynamic positioning system was constantly engaged in order to hold station. At the time, Thialf was supporting the final phase of decommissioning of the Sable Offshore Energy Project. As part of this work, the Thialf was expected to make four to six trips, each lasting a week to ten days, to Chedabucto Bay from May through fall 2020. Further investigation into the AIS data revealed that an unknown vessel, MMSI 353979008, remained near our mooring for six to eight days from August 8 to 14, September 3 to 10, September 28 to October 4, October 19 to 24 and November 10 to 16, 2020. During each of these periods, we observed elevated noise levels in the lower frequency bands. Interestingly, the MMSI number for the Thialf did not appear in our AIS dataset for Chedabucto Bay. Given that the MMSI number of the unknown vessel is only one digit different from that of the Thialf and that its presence in the bay matches what was planned for the Thialf, we suspect that the unknown vessel was actually the Thialf. The vessel's AIS operator may have incorrectly entered the MMSI number, which has been known to happen (Harati-Mokhtari et al. 2007). The vessel detector was not well equipped to handle irregular vessel movements, and so sound energy from the Thialf was erroneously attributed to wind and "other" sources from August to November 2020. It is likely that had the sound energy been accurately categorized, vessel noise would have been the dominant contributor to the energy in the lowest frequency band as it was in all other months except April 2021.

In April 2021, the vessel we suspect is the Thialf was not present and overall vessel density did not appear to be vastly different from prior months. Wind speeds were similar to adjacent months, and so it is not clear why vessels were not the dominant contributor to the sound energy budget of the 1/3 octave band centered at 100 Hz. Precipitation data for weather stations near our mooring were not readily available for this time frame, and so we were unable to investigate whether the increase in energy from "other" sources in the lowest frequency band was due to rainfall. However, rainfall is unlikely to be the cause as its typical frequency range is from 300 Hz to 10 kHz and peaks around 500 to 1000 Hz (Wenz 1962; Hildebrand 2009). April 2021 did not appear to be noisier than February or March 2021 when comparing spectrograms. Perhaps the vessels present in this month were quieter than in other months, meaning less sound energy from vessels rather than an increase in sound energy from "other" sources.

Wind was the dominant contributor to the sound energy budget for most winter months (December 2018-February 2019, January 2020-March 2021, December 2020-March 2021) in all but the lowest frequency bands. 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. During May, June and July 2019, and July 2020,[2] we found that vessel noise was the dominant contributor to the sound energy budgets of all six frequency bands. We compared vessel density plots throughout 2020 and found the summer months seemed to have higher vessel density than winter months, which would explain the increase in energy contributed by vessels during this time. Wind speeds were also generally lower during the spring and summer months (Figure 14).

It is difficult for us to comment on the contributions of "other" sources to the noise energy budgets as we did not investigate the specific sources of these sounds. This category may have included fish sounds, noise from construction on land, noise from vessels other than engine noise (eg. generators, on-deck operations), and/or rainfall. This category may have also included unexpected and overlooked sound sources, such as commercial airplanes. Erbe et al. (2018) recorded the passage of commercial airplanes at shallow water sites off Indonesia and Australia at levels expected to be audible to several species of marine fauna, including manatees and dolphins. We recorded a passing airplane at our Eastern Shore Islands site, which is a similar depth to our Chedabucto Bay site. 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. It would be 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 April 2021.

4.3 Hourly Call Occurrence and Low Frequency SPL

While we cannot infer a relationship between sound levels and calling behaviour with such a small sample size, we have demonstrated that there are interesting trends worth considering further in future work. Humpback whale vocalizations were present less often during periods with loud vessel noise. It is possible that humpback whales stopped calling or left the area during these periods, but it is also possible that their calls were masked by noise and therefore missed by the detector (Dunlop 2016). Blue and sei whale downsweeps occurred during both relatively quiet periods and during periods of loud vessel noise. Perhaps the lower frequency calls of blue and sei whales were less likely to be masked by noise than humpback calls. Or, sound levels may have impacted the calling behaviour of these species. Di Iorio and Clark (2010) found that blue whales in the Saint Lawrence Estuary increased call production in response to noise from seismic sparker operations. Melcón et al. (2012) found that blue whales in the Southern California Bight were less likely to produce calls when mid-frequency active sonar was present, but more likely to produce calls when vessel noise was present. We plan to investigate the relationship

[2] No data were collected in May and June 2020.

between baleen whale call occurrence, vessel noise, and ambient sound levels using a more robust quantitative approach in future work.

4.4 Conclusions and Future Directions

We have shown that Chedabucto Bay and its approaches are frequented by four of the six baleen whale species found in Atlantic Canadian waters and that it is possible to characterize the soundscape of a coastal area with a single low-cost hydrophone. The sound energy budget approach allowed us to investigate the dominant contributors to the soundscape in Chedabucto Bay. Baseline information about soundscapes is useful in determining changing contributions of different sound sources over time. We included the spectrograms for each month which summarize the sound levels, but a more quantitative comparison of actual noise levels would be useful for future analyses.

We used standard 1/3 octave bands to summarize the contributions of different sound sources to the total energy budget. It may be useful to reanalyze our data in light of the recommendations within the European Marine Strategy Framework Directive to examine the 1/3 octave bands centered on the frequencies of 63 and 125 Hz (Van der Graaf et al. 2012; Garrett et al. 2016). However, we found that frequencies of 100 Hz and 500 Hz adequately summarized noise from vessels, with the exception of August to November 2020. The consistent noise of the crane vessel Thialf's dynamic positioning system impacted the accuracy of our sound energy budget estimations during this time. We plan to investigate other methods to better account for the increased ambient noise caused by non-typical vessel presence in future work.

We continue to monitor at this site and plan to expand upon these results with more years of data and with data from our new site on the north side of the bay. We would also like to investigate methods to isolate additional contributors to the sound energy budget, such as precipitation.

5.0 ACKNOWLEDGEMENTS

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7.0 APPENDIX A

Table A1. The parameters of each of the baleen whale detector templates used in the analysis of the December 12, 2018 to June 11, 2019 acoustic data from Chedabucto Bay.

	Template parameters		
Detector name (target call)	**Frequency (Hz)**	**Duration (sec)**	**Bandwidth (B; Hz)**
BlueWhale: InfrasoundMoan (blue whale tonal)	15-22	8.00-30.00	1<B<5
SW:HIdownsweeps (blue whale downsweeps) (sei whale downsweep)	20-150	0.50-1.70	19<B<120
GlFinWhale:GlMoan (fin whale 20 Hz pulse)	10-40	0.40-3.00	>6
MFMoanLow (humpback whale moan)	100-400	0.50-5.00	>50
GlRightWhale:GlMoan (North Atlantic right whale upcall)	65-260	0.60-1.20	70<B<195

Table A2. The parameters of each of the baleen whale call detector templates used in the analysis of the June 11, 2019 to May 07, 2020 acoustic data from Chedabucto Bay.

	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 downsweeps) (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_Up2 (North Atlantic right whale upcall)	65-260	0.50-1.20	B>25

Table A3. The parameters of the minke whale pulse detector template used in the analysis of the entire acoustic dataset from Chedabucto Bay (December 12, 2018 to May 07, 2020).

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

8.0 APPENDIX B

Table B1. The calibration data for each SoundTrap ST300 used throughout the study.

Serial Number	Source Frequency	Source Level	End-to-End Calibration
671379496	250 Hz	120 dB re. 1 µPa	-176.1 dB re V/µPa
671137831	250 Hz	120 dB re. 1 µPa	-176.6 dB re V/µPa
671137830	250 Hz	120 dB re. 1 µPa	-176.4 dB re V/µPa
5240	250 Hz	120 dB re. 1 µPa	-176.6 dB re V/µPa

Table B2. 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	5512	250 Hz	-37.6 dB re. 1 µPa	-1.8 dB re V/µPa
			End-to-End Calibration	**-179.3 dB re V/µPa**

9.0 APPENDIX C

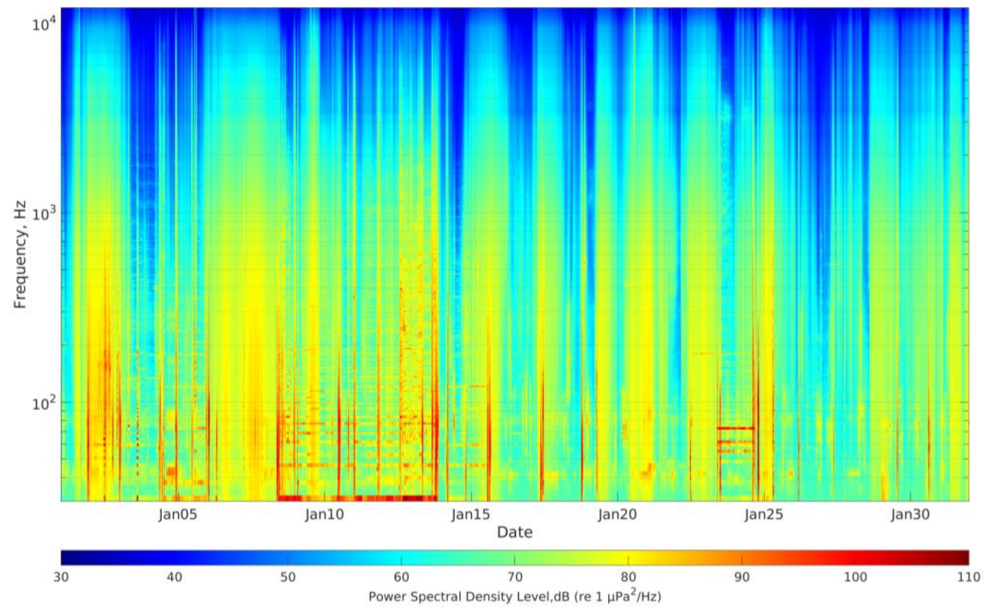

Figure C1. The spectrogram for the month of January 2019 (UTC).

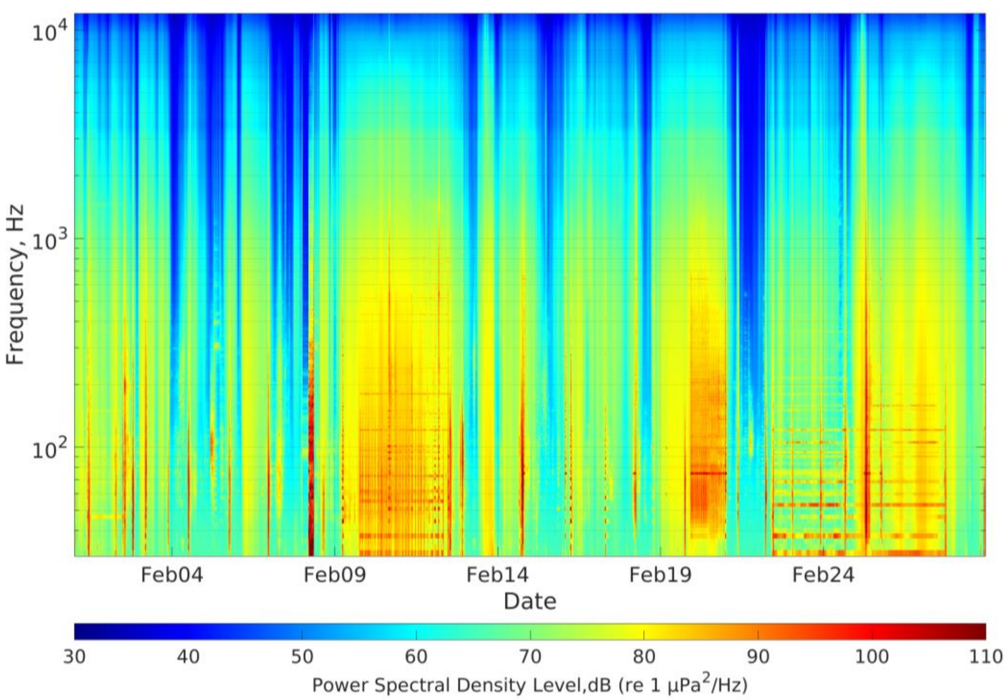

Figure C2. The spectrogram for the month of February 2019 (UTC).

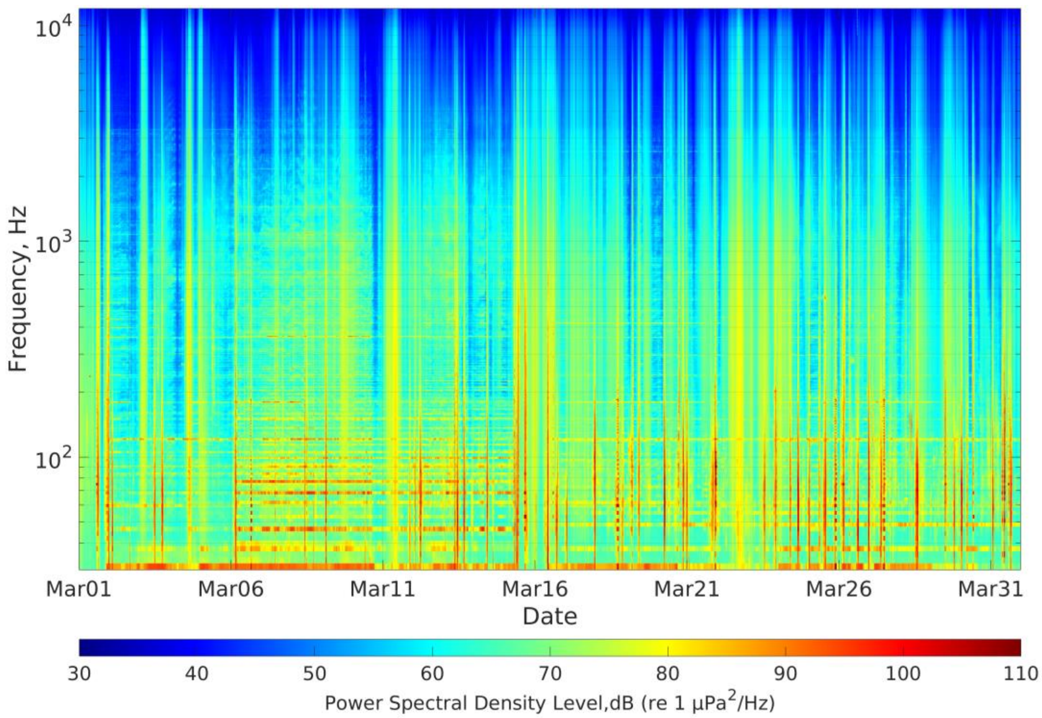

Figure C3. The spectrogram for the month of March 2019 (UTC).

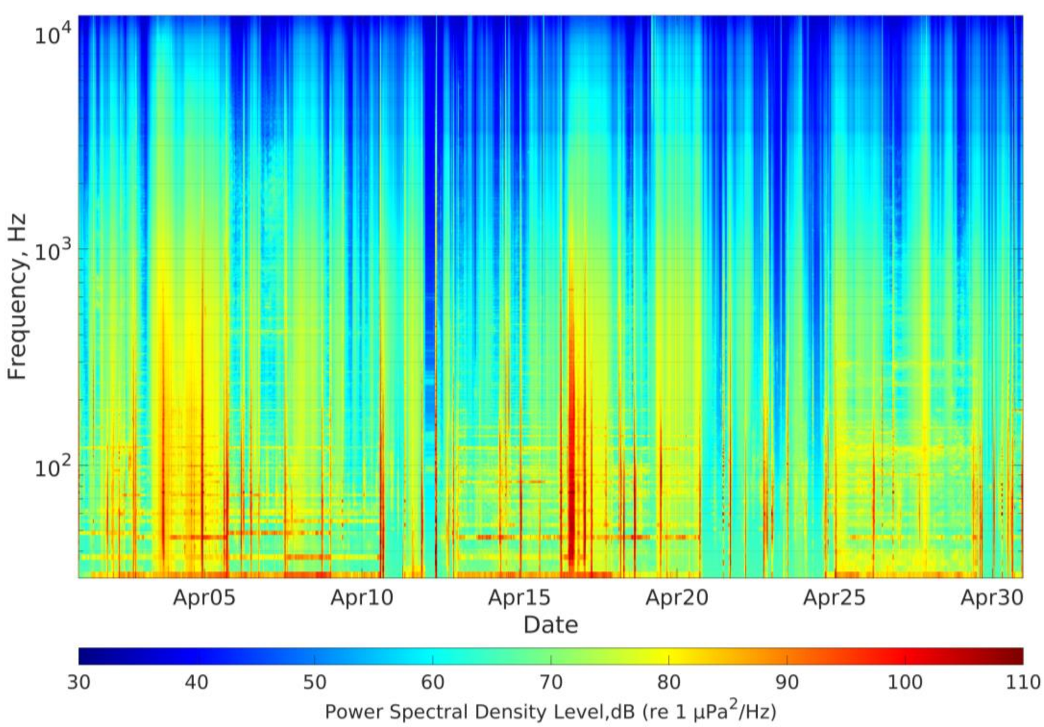

Figure C4. The spectrogram for the month of April 2019 (UTC).

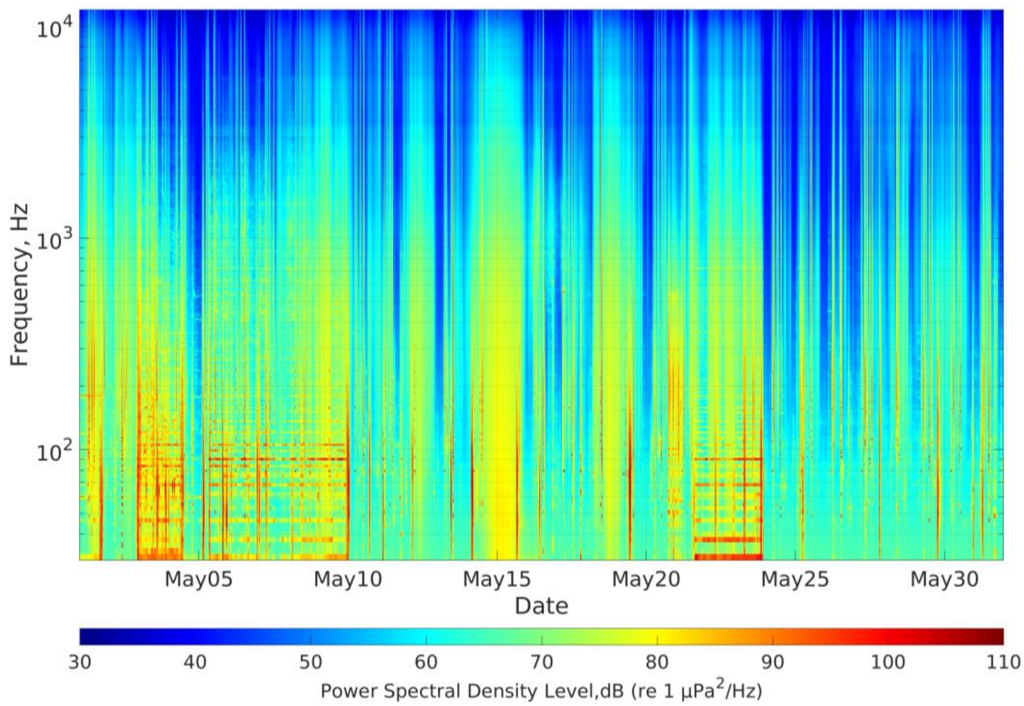

Figure C5. The spectrogram for the month of May 2019 (UTC).

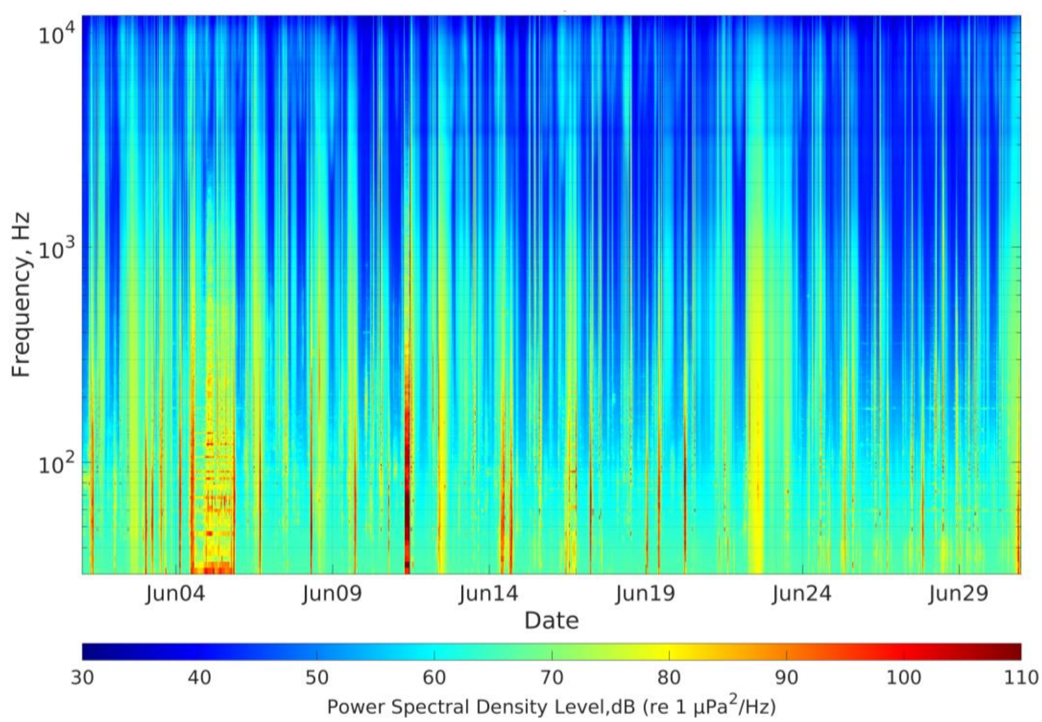

Figure C6. The spectrogram for the month of June 2019 (UTC).

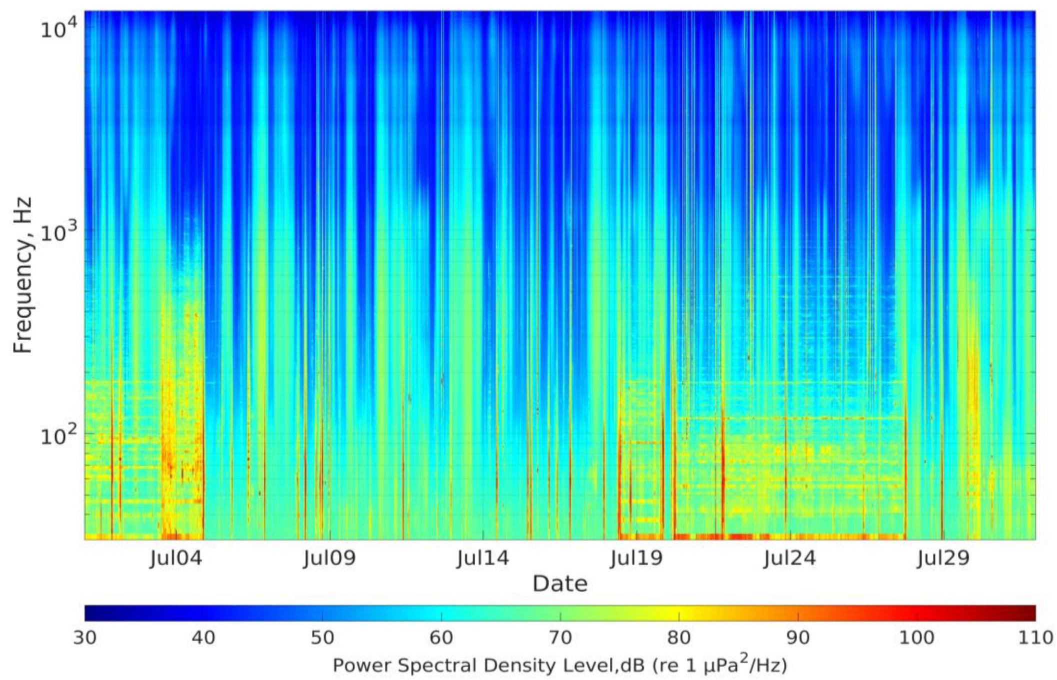

Figure C7. The spectrogram for the month of July 2019 (UTC).

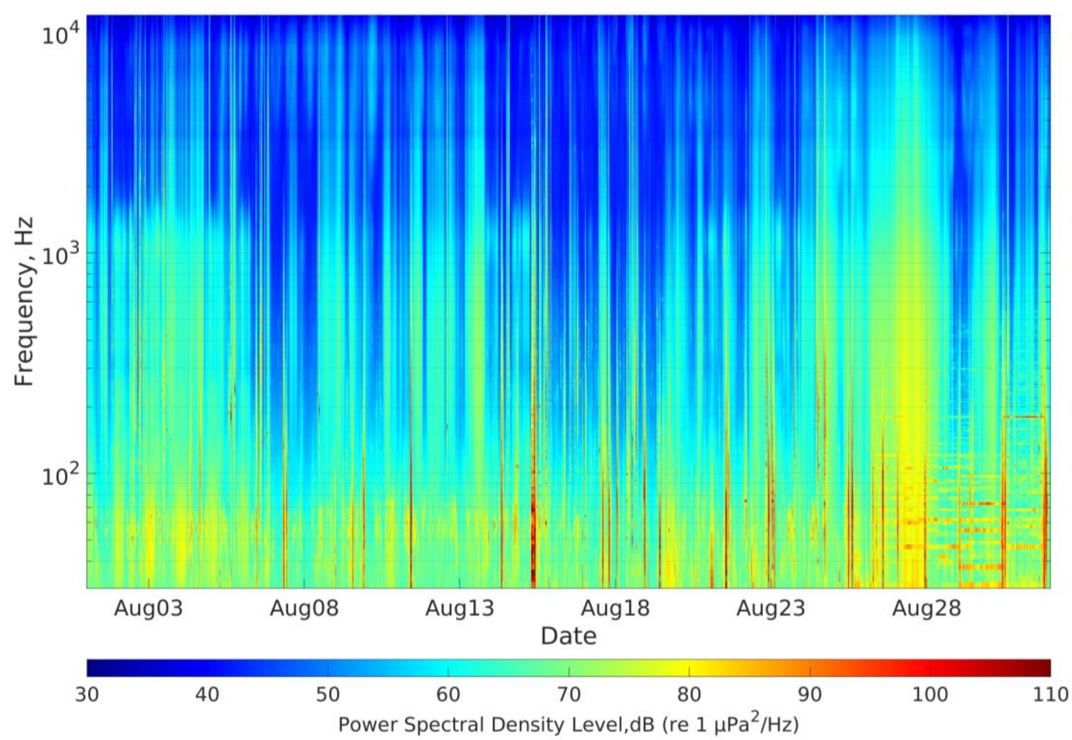

Figure C8. The spectrogram for the month of August 2019 (UTC).

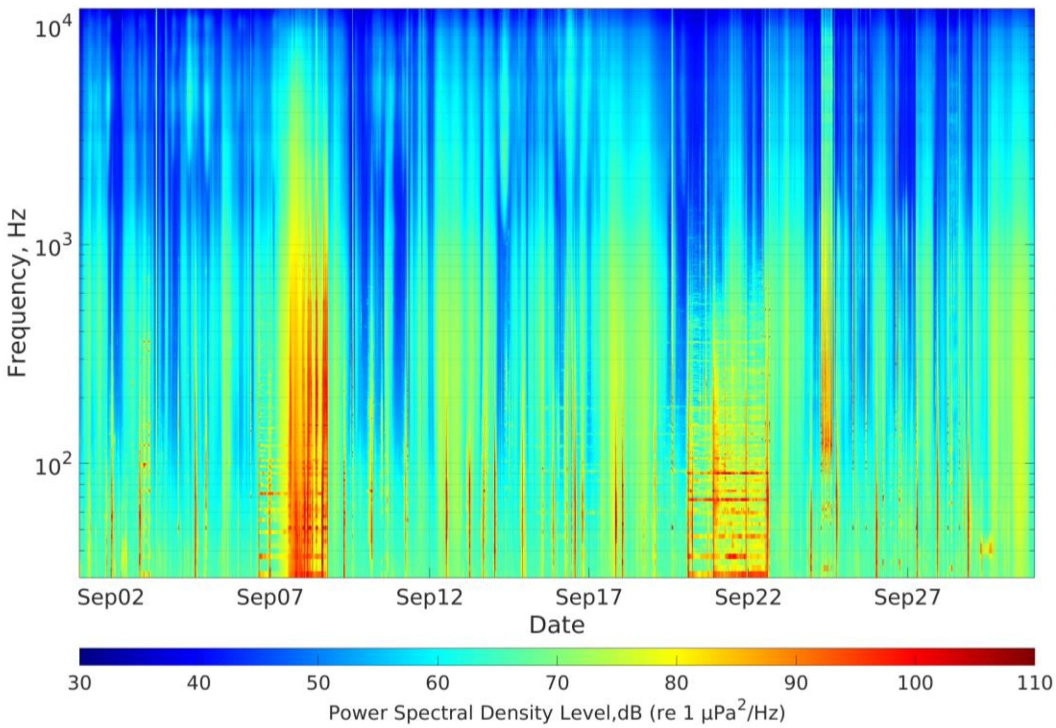

Figure C9. The spectrogram for the month of September 2019 (UTC).

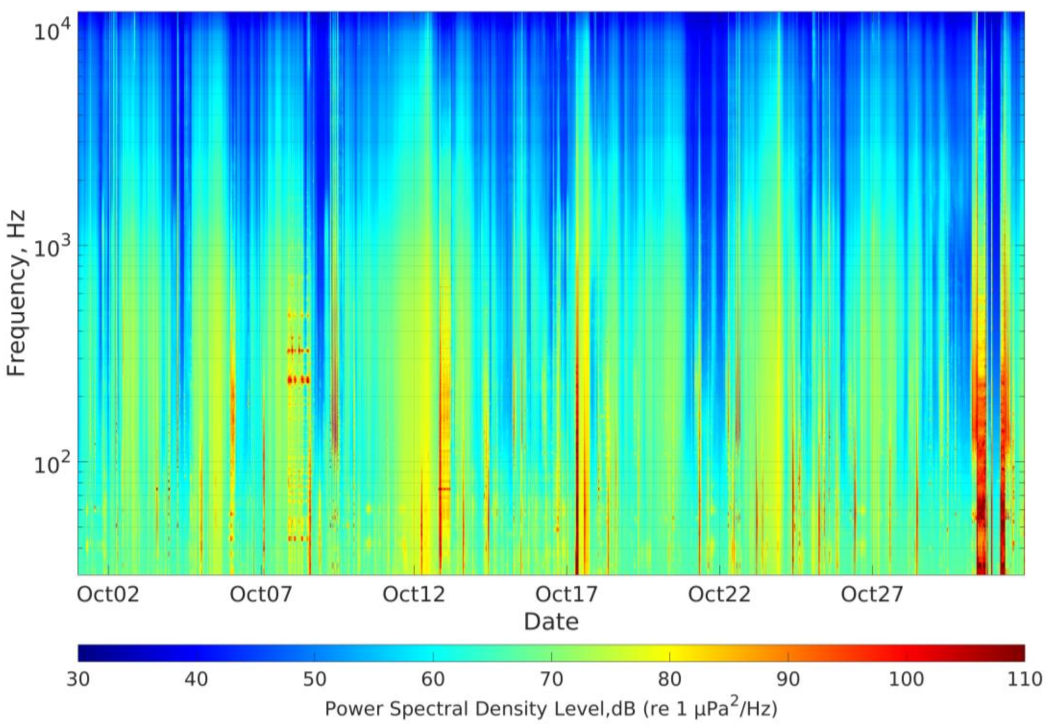

Figure C10. The spectrogram for the month of October 2019 (UTC).

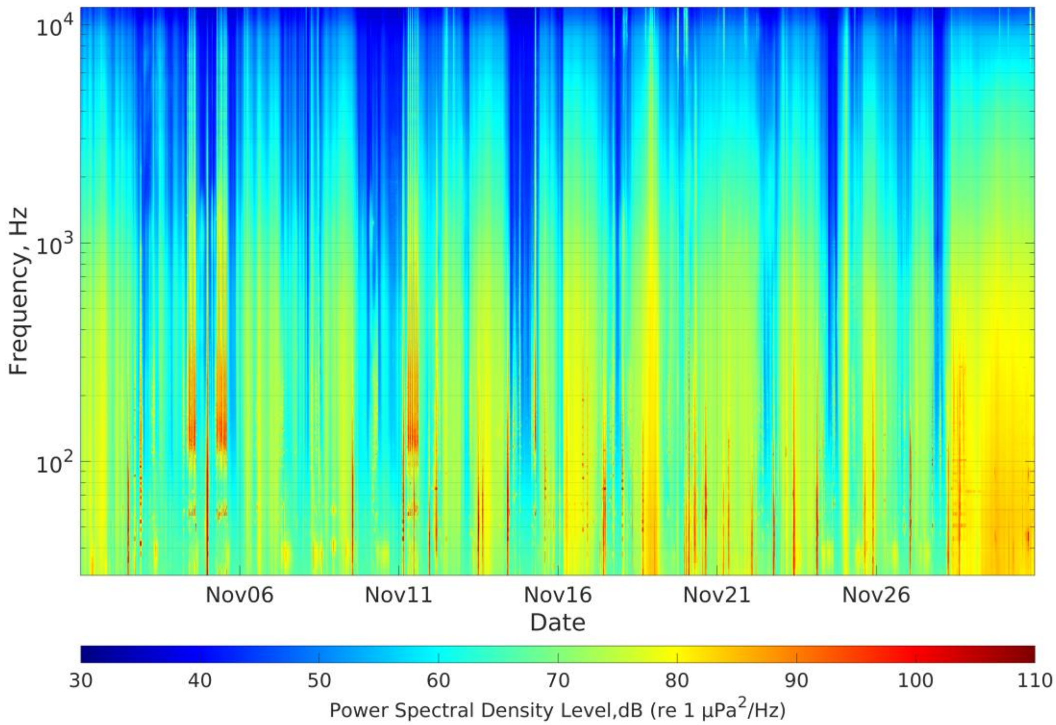

Figure C11. The spectrogram for the month of November 2019 (UTC).

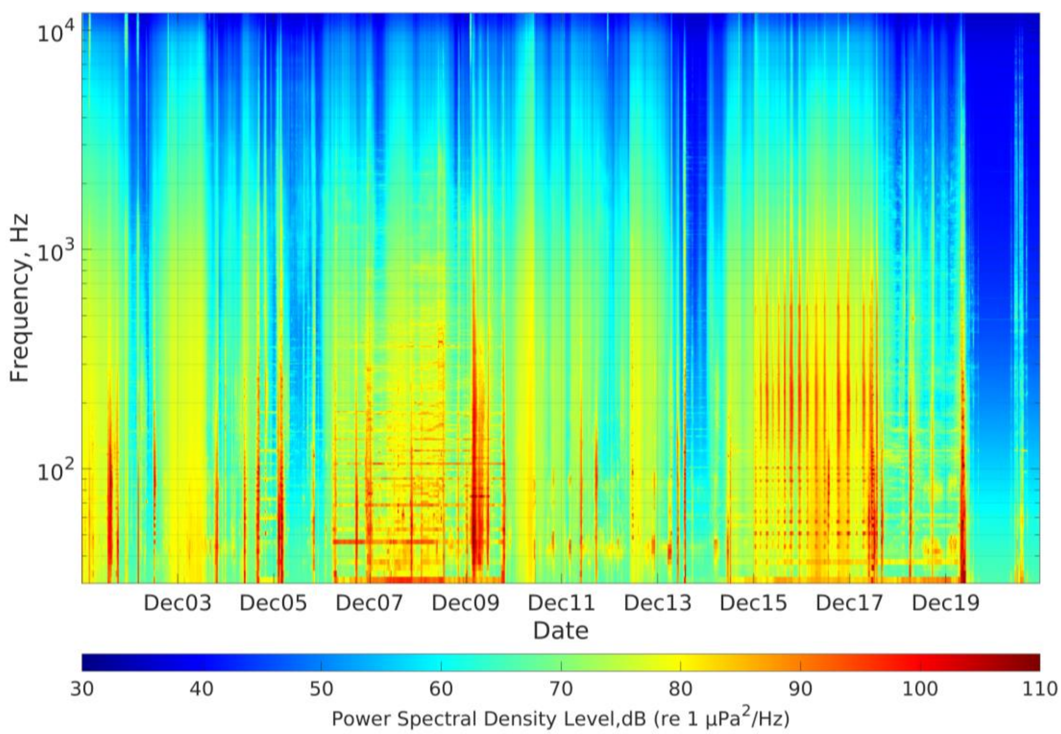

Figure C12. The spectrogram for the month of December 2019 (UTC).

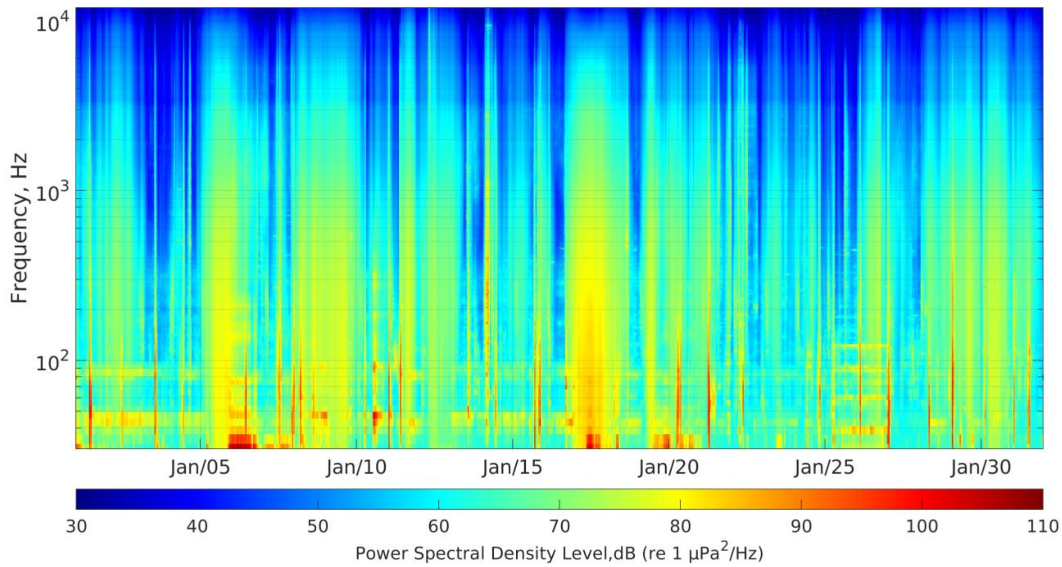

Figure C13. The spectrogram for the month of January 2020 (UTC).

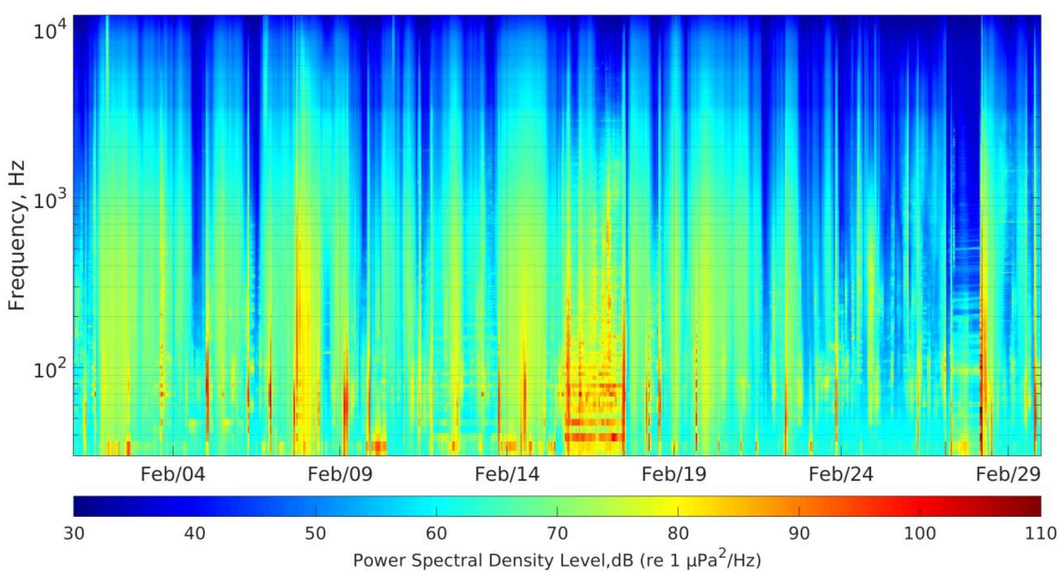

Figure C14. The spectrogram for the month of February 2020 (UTC).

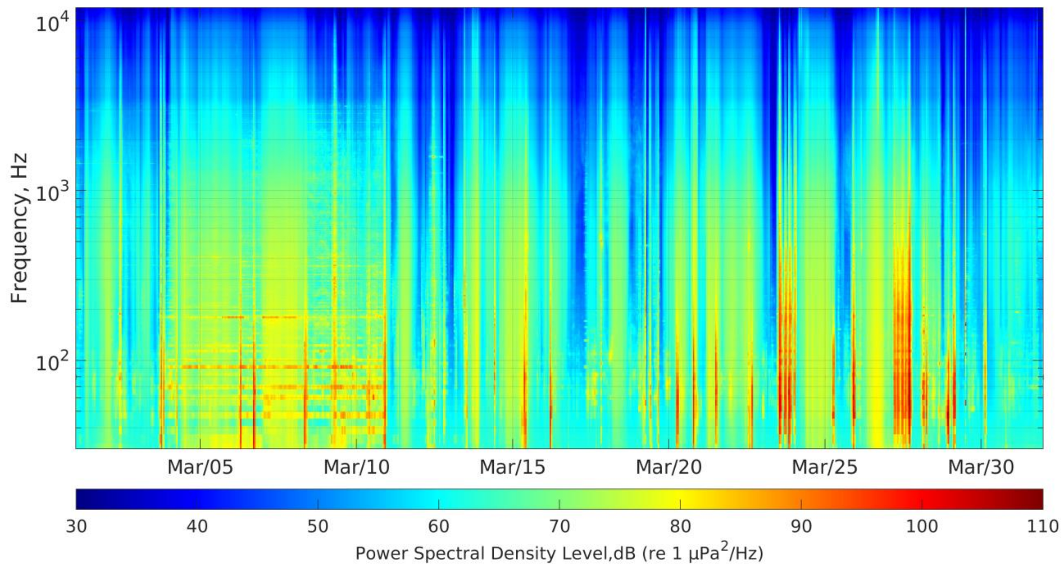

Figure C15. The spectrogram for the month of March 2020 (UTC).

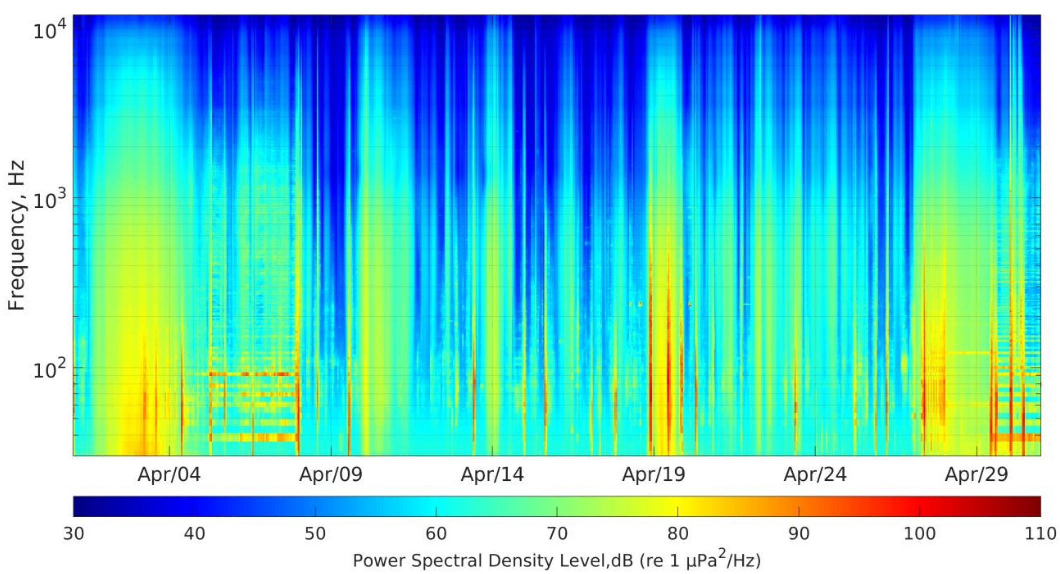

Figure C16. The spectrogram for the month of April 2020 (UTC).

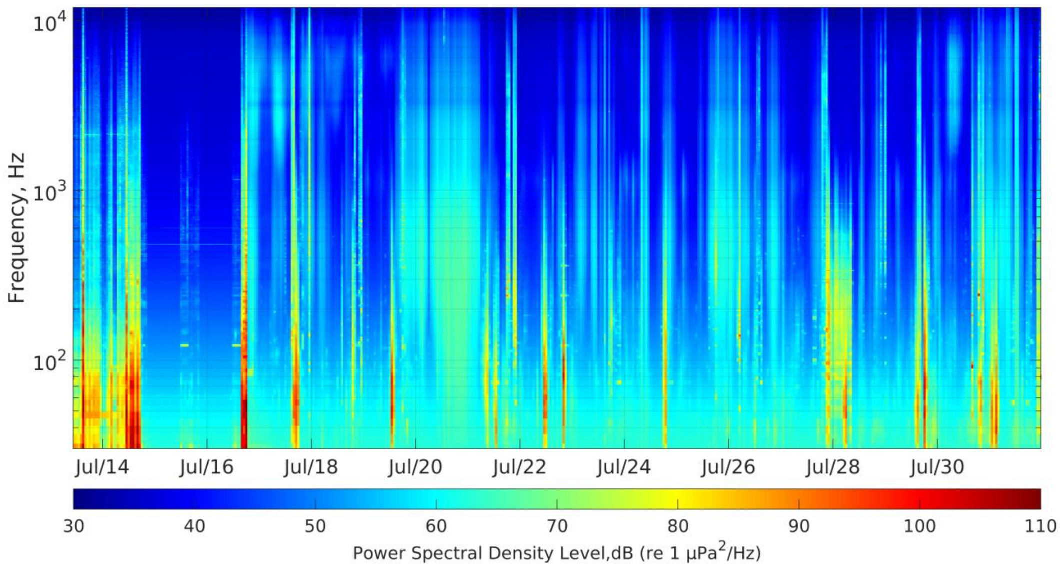

Figure C17. The spectrogram for the month of July 2020 (UTC).

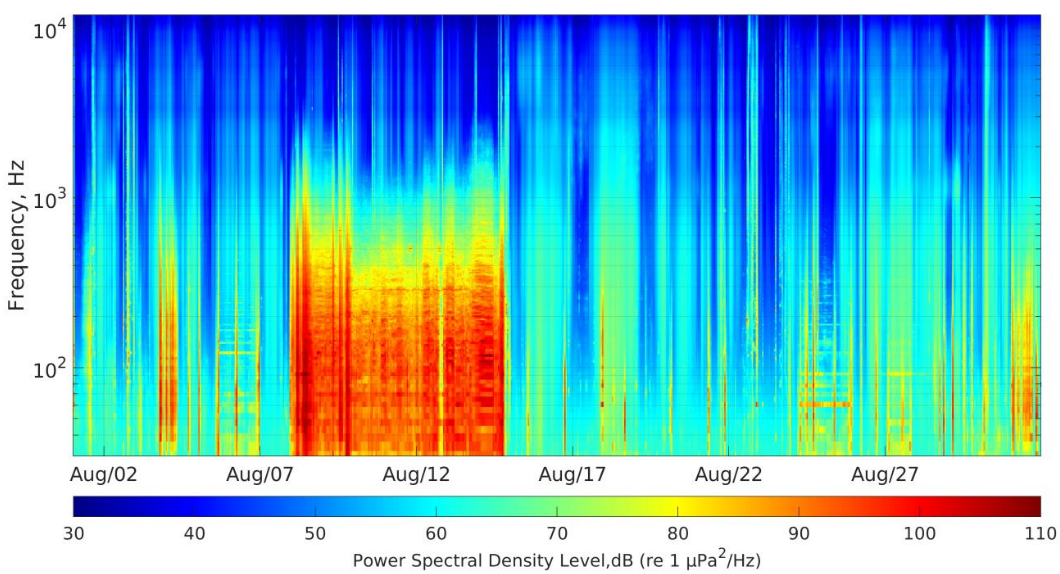

Figure C18. The spectrogram for the month of August 2020 (UTC).

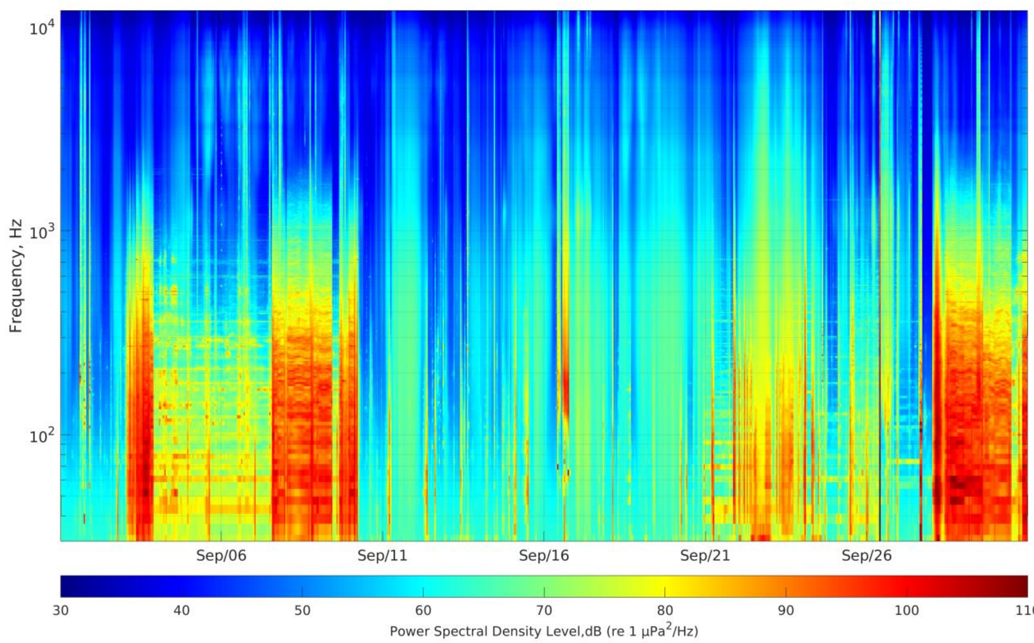

Figure C19. The spectrogram for the month of September 2020 (UTC).

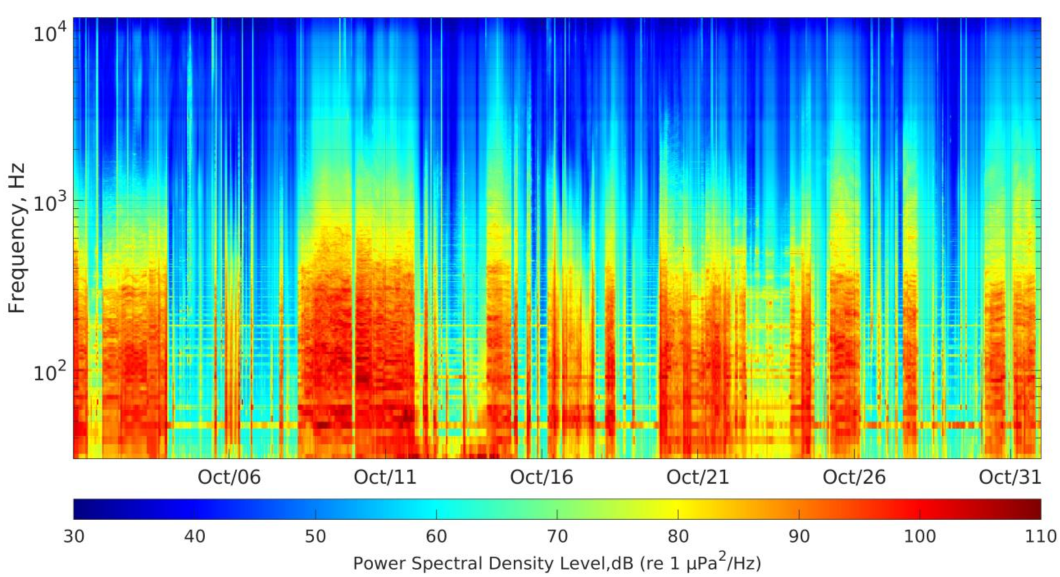

Figure C20. The spectrogram for the month of October 2020 (UTC).

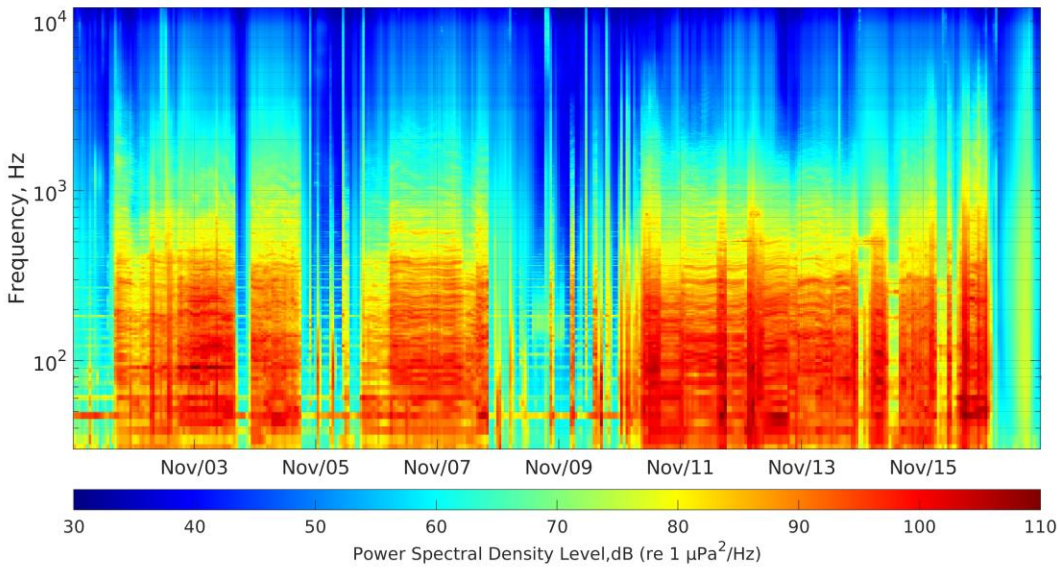

Figure C21. The spectrogram for the month of November 2020 (UTC).

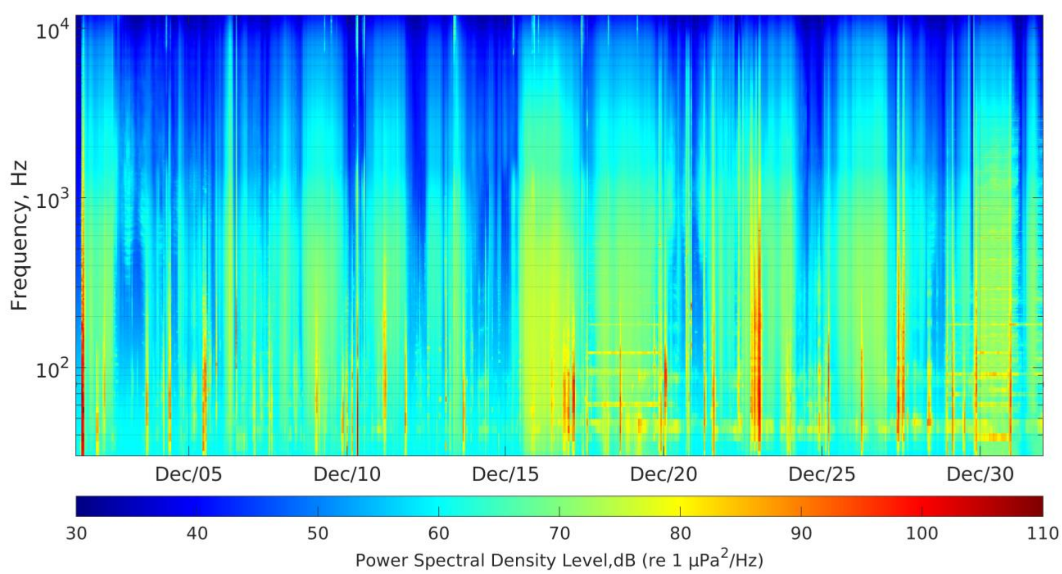

Figure C22. The spectrogram for the month of December 2020 (UTC).

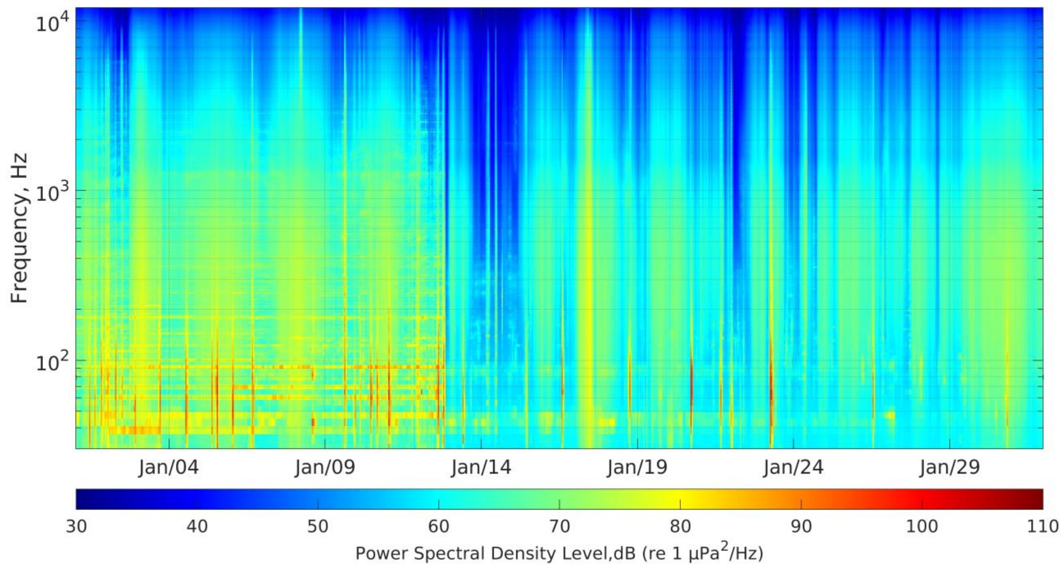

Figure C23. The spectrogram for the month of January 2021 (UTC).

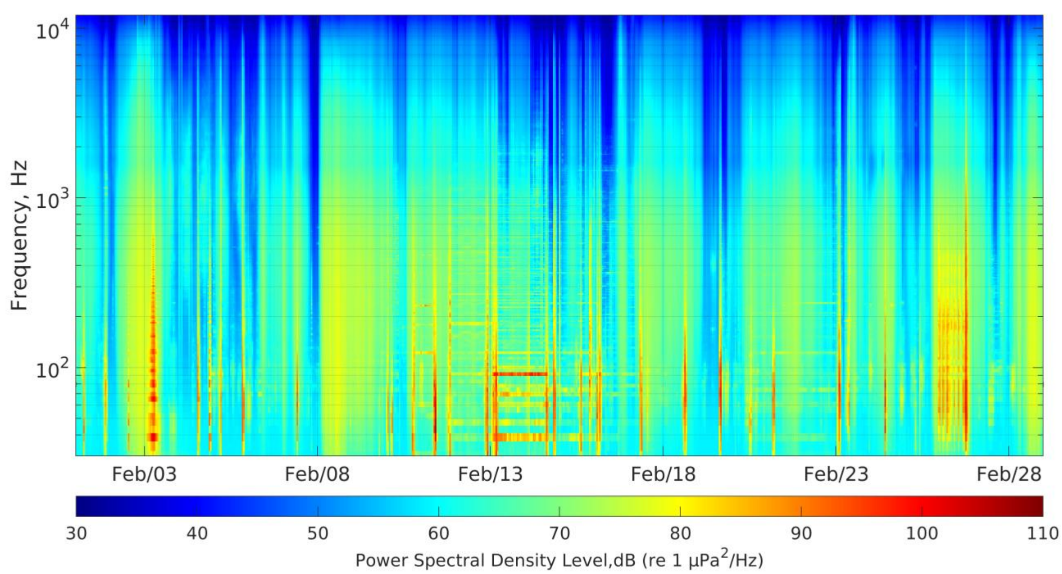

Figure C24. The spectrogram for the month of February 2021 (UTC).

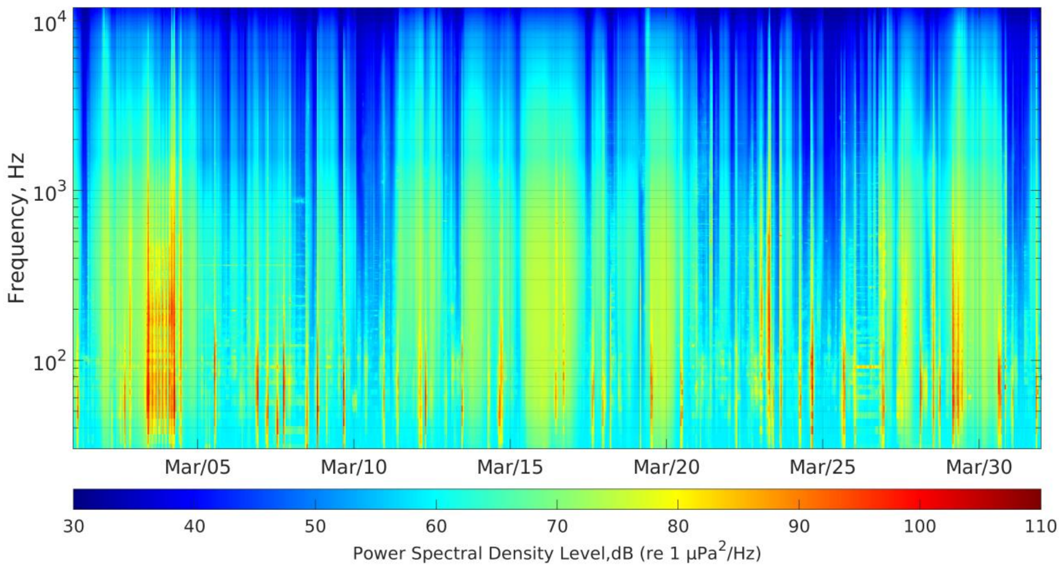

Figure C25. The spectrogram for the month of March 2021 (UTC).

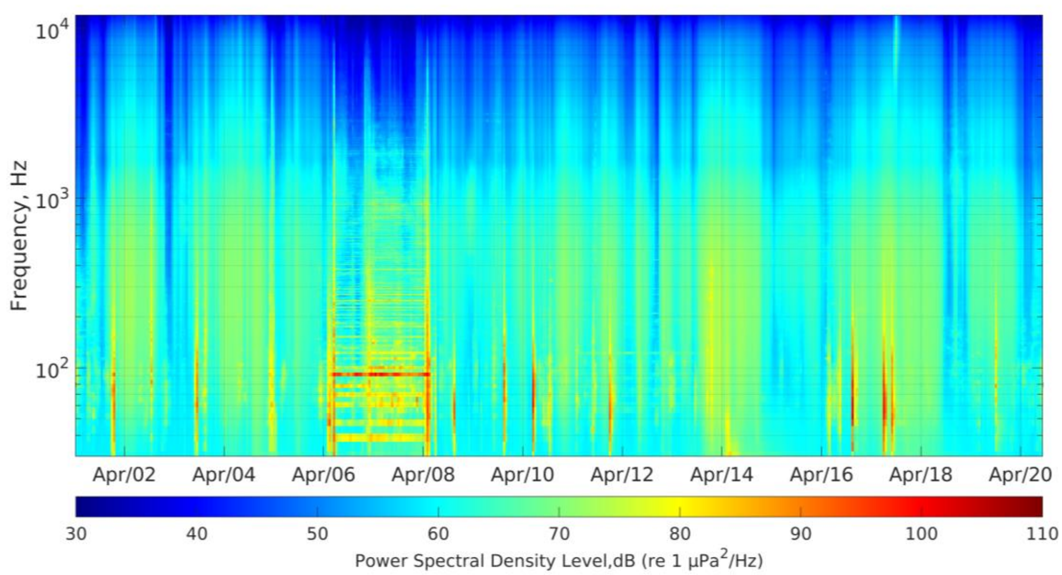

Figure C26. The spectrogram for the month of April 2021 (UTC).