Labrador–Island Transmission Link

Strait of Belle Isle:
Ambient Noise and Marine Mammal Survey

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EXECUTIVE SUMMARY

Nalcor Energy is proposing to develop the *Labrador–Island Transmission Link* (the Project), a High Voltage Direct Current (HVdc) transmission system extending from Central Labrador to the Island of Newfoundland's Avalon Peninsula. In preparation for, and support of, the Project's environmental assessment, this *Ambient Noise and Marine Mammal Survey* was completed to collect and present information on ambient noise and marine mammals in the Strait of Belle Isle (SOBI).

In 2010, acoustic data were recorded at three locations along or near the two identified cable crossing corridors across the SOBI: (1) off Flower's Cove, Newfoundland; (2) near the middle of the SOBI; and (3) near L'Anse Amour, Labrador. Acoustic recorders were deployed and they recorded sounds at the three locations from June to August and from September to December 2010.

Analysis of acoustic data confirmed the presence of several marine mammal species during the recording periods. Humpback whales (*Megaptera novaeangliae*), killer whales (*Orcinus orca*), and dolphins (most likely *Lagenorhynchus albirostris* and *L. acutus*) accounted for the majority of the biological sounds. Humpback whales and dolphins were present in all recordings. The main detection period for the humpback whales and dolphins was before 10 November. Killer whales were present at all three locales but became scarce at the beginning of August, and were not detected during the September to December recording period. The greatest number of detections for these species occurred at the station near the middle of the Strait, followed closely by the Labrador Station. The Newfoundland location recorded considerably less biological acoustic activity. Blue whales (*Balaenoptera musculus*) and a sei whale (*Balaenoptera borealis*) were detected during the June to August recording period. The blue whales were detected at the Newfoundland Station recorder and the sei whale was detected at the Middle Station. Fin whales (*Balaenoptera physalus*) were detected most days of the September to December recording period, and sporadically during the June to August recording period. Additional biological activity was recorded but could not be identified, although many are presumed to be from fish. No pinnipeds were definitively identified in either deployment period.

Analysis of the ambient data indicated that marine noise levels in the SOBI are well within the normal limits of prevailing ocean noise. Below 100 Hz real and pseudo-noise from tidal flow dominate the measured noise. Above 100 Hz local vessel traffic is the dominant noise source when present. Noise measured from the recorder in the middle of the Strait was 5 dB higher during the October to December recording period, likely due to storm activity.

Table of Contents

List of Figures

List of Tables

List of Appendices

1.0 INTRODUCTION

Nalcor Energy is proposing to develop the *Labrador–Island Transmission Link* (the Project), a High Voltage Direct Current (HVdc) transmission system extending from Central Labrador to the Island of Newfoundland's Avalon Peninsula.

The environmental assessment (EA) process for the Project was initiated in January 2009 and is in progress. An Environmental Impact Statement (EIS) is being prepared by Nalcor Energy, which will be submitted for review by governments, Aboriginal and stakeholder groups and the public.

In preparation for and support of the EA of the Project, this *Strait of Belle Isle: Ambient Noise and Marine Mammal Survey* was conducted to measure and document ambient (baseline) sound levels in the marine environment of the Strait of Belle Isle (SOBI), for use in the eventual environmental effects analyses.

The sound data collected as part of this marine survey were also analyzed to detect marine mammal vocalizations in the area during the survey period, as further environmental baseline information for use in the EA.

1.1 Project Overview

The proposed Labrador–Island Transmission Link involves the construction and operation of transmission infrastructure within and between Labrador and the Island of Newfoundland. Nalcor Energy is proposing to establish an HVdc transmission system extending from Central Labrador to the Island's Avalon Peninsula.

The proposed transmission system, as currently planned, will include the following key components:

- an ac-dc converter station in Central Labrador, on the lower Churchill River adjacent to the Lower Churchill Hydroelectric Generation Project;
- an HVdc transmission line extending across Southeastern Labrador to the Strait of Belle Isle. This overhead transmission line will be approximately 400 km in length with a cleared right-of-way averaging approximately 60 m wide, and consist of single galvanized steel lattice towers;
- cable crossings of the Strait of Belle Isle with associated infrastructure, including cables placed under and on the seafloor through various means to provide the required cable protection;
- an HVdc transmission line (similar to that described above) extending from the Strait of Belle Isle across the Island of Newfoundland to the Avalon Peninsula, for a distance of approximately 700 km;
- a dc-ac converter station at Soldiers Pond on the Island of Newfoundland's Avalon Peninsula; and
- electrodes in Labrador and on the Island, with overhead lines connecting them to their respective converter stations.

Project planning and design are currently at a stage of having identified a 2 km wide corridor for the on-land portions of the proposed HVdc transmission line and 500 m wide corridors for the proposed SOBI cable crossings, as well as various alternative corridor segments in particular areas (Figure 1.1). It is these proposed transmission corridors and components that were the subject of Nalcor Energy's environmental baseline study program. Project planning is in progress, and it is anticipated that the Project description will continue to evolve as engineering and design work continue. The EA of the Project will also identify and evaluate alternative means of carrying out the Project that are technically and economically feasible. In conjunction and concurrent with the EA process, Nalcor Energy will be continuing with its technical and environmental analyses of the corridors, to identify and select a specific routing for the Project. The eventual transmission routes and locations will be selected with consideration of technical, environmental, and socioeconomic factors.

1.2 Study Purpose and Objectives

The objective of this study was to determine the ambient underwater noise environment of the Strait of Belle Isle for eventual use in the EIS. Additionally, the acoustic recordings were analyzed for the presence of marine mammal calls to evaluate the acoustic occurrence of cetaceans and pinnipeds in the Strait of Belle Isle during the ice-free period. The Study Area included the Strait of Belle Isle, approximately between Forteau Point/Point Amour and Mistaken Cove/Yankee Point (Figure 1.1).

Figure 1.1 Proposed Strait of Belle Isle Submarine Cable Crossing Corridors

2.0 METHODS

2.1 Location and Study Design

The study area surrounds the proposed SOBI submarine cable crossings. The objectives of the acoustic monitoring were to determine: (1) the ambient noise in the SOBI; and (2) the usage of the SOBI by marine mammals during the ice-free period.

The marine mammals of primary interest are large cetaceans such as blue, fin, humpback, and killer whales. These mammals can be detected at ranges of tens to hundreds of kilometres from the recorders, depending on the noise and sound propagation conditions (Širović *et al.* 2007). Other mammals of interest include pinniped and dolphin species, which are detectable by the recorders at shorter ranges due to their lower source levels and higher frequencies which do not propagate as far. Based on the 20 km width of the SOBI, three recording locations were considered appropriate, with recording stations evenly spaced across the Strait. The sampling rate for the study was intended to be 16 kHz, which provides a usable frequency bandwidth of 10 Hz to 7500 Hz. This frequency range captures all acoustic energy from shipping, construction activities, as well as calls from seals as well as blue, fin, minke, humpback, sei, right, and killer whales. The lower end of dolphin whistles is detectable in this band as well. To better capture the full range of dolphin whistles, a recording sampling rate of 32 kHz is more suitable. The higher sampling rate would capture the upper range of humpback and killer whale calls.

The initial survey period was intended to be late June to September 2010. Toward the end of summer, Nalcor Energy also opted for a second deployment from October to December 2010 to monitor the SOBI in the fall. The sampling rate for the June–September deployment was inadvertently reset to 32 kHz due to a software error. This provided better dolphin, humpback, and killer whale data, at the expense of a shorter recording period (June to mid-August). The second recording period was performed at 16 kHz sampling rate.

The exact deployment locations were chosen in consultation with local fishers, to ensure the recorder locations were as well suited as possible for the study objectives, but also safe from long line and scallop trawling activity. The selected sites have particularly rocky bottoms that fishers often try to avoid.

In this report the three recording stations are referred to as 'Labrador', 'Middle', and 'Newfoundland'. The Labrador recorder was located in the bay between L'Anse Amour and Forteau Point, the Middle recorder was located near the middle of the Strait (about 1 km south of one of the corridors), and the Newfoundland recorder was located near Flower's Cove, along one of the proposed corridors.

2.2 Acoustic Monitoring Equipment

Underwater acoustic monitoring was performed with Autonomous Underwater Recorders for Acoustic Listening Model 2 (AURALs, Multi-Electronique Ltd.) recorders. The AURAL is powered by 64 D-cell industrial alkaline batteries. Data were recorded in 30 min files on a 320 GB IDE hard-disc drive at 16-bits per sample. The recorders were configured for 22 dB of gain (voltage level amplified by 22 dB or a factor of 12.6). The AURALs were set to record continuously at a rate of 32,768 samples per second during the first deployment and 16,384 samples per second during the second deployment, providing useable frequency ranges of 5 to 16,384 Hz and 5 to 8,192 Hz, respectively. Each AURAL was fitted with an HTI-96-MIN precision, low-noise, omnidirectional hydrophone (High Tech Inc.) with -201 dB re 1 V/µPa sensitivity (without preamp).

Each recorder was mounted to a float frame with a xenon flasher/radio beacon (Novatech ST-400B6, Cobham Tracking & Locating Ltd.). The float frame assembly was weighted to the seabed with a 45 kg anchor weight (recycled mooring chain), attached via dual acoustic releases for Deployment 1 (Model 111, InterOcean Systems; Figure 2.1) and a single acoustic release for the Deployment 2.

Figure 2.1 AURAL Recorder (white) on a float frame with dual acoustic releases (yellow) before deployment at the Newfoundland Station.

2.3 Recorder Deployment and Retrieval

Acoustic data were collected over two deployments in 2010. For Deployment 1, three recorders were deployed 19 June 2010, from the *Freda M,* captained by Jarvis Walsh, from Flower's Cove NL. The deployment locations (Table 2.1, Figure 2.2) were chosen in consultation with the vessel operator and crew to ensure they were well suited for the study objectives while avoiding potential interaction with long-line and scallop-trawling activity.

The Deployment 1 recorders were retrieved 30 September 2010 from the *Freda M*. Upon review of the data, it was determined that the recorders had reset unexpectedly during shipment to a sample rate of 32 kHz from the desired rate of 16 kHz. As a result, data collection ended (when the hard-drive reached capacity) between 31 July and 19 August (Table 2.1), rather than in late September. As previously stated, the improved bandwidth did, however, provide better dolphin, humpback, and killer whale data.

Table 2.1 Deployment 1 Locations, June to August 2010. Location, distance to each shore and period of operation for the three recorders deployed 20 June 2010 in the Strait of Belle Isle.

Recorder Station	Latitude (N)	Longitude (W)	Depth (m)	Distance to Nfld (km)	Distance to Labrador (km)	Deployment	Recording End	Retrieval
Newfoundland	51°19.739′	56°45.729′	32	2.2	16.0	20 Jun	31 Jul	30 Sep
Middle	51°21.003′	56°52.950′	116	10.1	10.7	20 Jun	19 Aug	30 Sep
Labrador	51°27.890′	56°53.300′	51	20.0	0.6	20 Jun	18 Aug	30 Sep

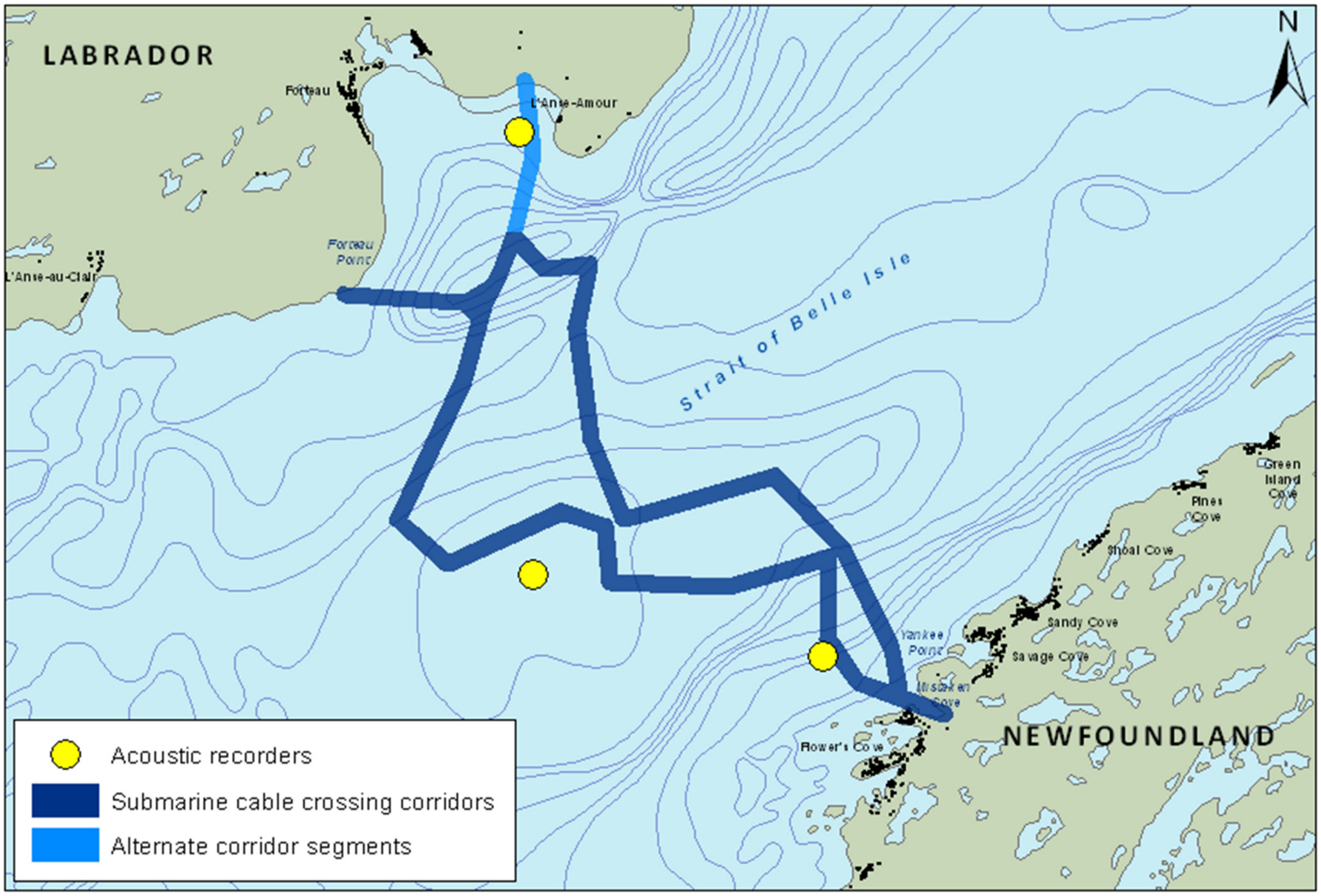


Figure 2.2 Acoustic Recorder Locations for the June to August and September to December 2010 deployment periods in the Strait of Belle Isle. Each station was instrumented in both periods.

For Deployment 2, three recorders were deployed 30 September 2010 at the Deployment 1 locations (Table 2.2, see Figure 2.2). The recorders were configured and tested on location before deployment. Due to equipment availability, the recorders were deployed with a single acoustic release.

Retrieval activities occurred over three days (13 to 15 December 2010) with assistance of the *M/V Labrador Venture* from L'Anse-Amour, captained by Lloyd Normore. Only the Middle recorder was retrieved, as the acoustic releases on the Labrador and Newfoundland recorders did not release. Many attempts over three days to retrieve the Newfoundland and Labrador recorders, using grapple gear and fish-finder sonar, were unsuccessful. A possible transpond ping was received from the Newfoundland recorder and the unit was visible on the fish finder. A return trip is planned for June 2011 to retrieve the Newfoundland and Labrador recorders using a side-scan sonar.

Table 2.2 Deployment 2 Locations, September to December 2010. Location, distance to each shore and period of operation for the three recorders deployed 30 September 2010 in the Strait of Belle Isle.

Recorder Station	Latitude (N)	Longitude (W)	Depth (m)	Distance to Nfld (km)	Distance to Labrador (km)	Deployment	Recording End	Retrieval
Newfoundland	51°19.470′	56°45.920′	32	2.2	16.0	30 Sep	*	*
Middle	51°21.020′	56°53.040′	116	10.1	10.7	30 Sep	11 Dec	13 Dec
Labrador	51°27.510′	56°53.290′	51	20	0.6	30 Sep	*	*

* Retrieval to be re-attempted in June 2011.

2.4 Data Analysis

The acoustic data recorded at the three stations in the SOBI was analyzed by both manual analysis and JASCO's automated detection/classification software suite. A total of 5% of the data from each station was analyzed manually by two trained analysts to identify marine mammal calls and classify them by species and call type. This was achieved through visual examination of spectrograms, combined with auditory (listening) review. All data acquired during both surveys were analyzed with JASCO's automated data processing suite to: (1) compute ambient noise levels; (2) detect marine mammal vocalizations and identify by species; and (3) detect boating and shipping vessel noise.

2.4.1 Manual Analysis

Manual data analysis was conducted on 5% of the data recorded on all recorders (except those not yet retrieved) to establish acoustic occurrence of each species during both survey periods. Acoustic data were recorded continuously during both surveys. For each recorder throughout each survey period, manual analysis was performed on 90 s segments sampled every 30-min (*i.e.*, the first 90 s of each 30-min audio file). In total, for each day (1440 min) of recording, 72 min were manually analyzed, which equates to 5% of the dataset. The annotation of one call per species per sample provided an estimate of the acoustic occurrence of each species within the entire dataset. Additionally, the first and middle samples of each day were fully annotated (*i.e.*, all marine mammal calls were annotated). These fully-annotated samples were used to assess the performance of the detector by comparing the number of manual and automated detections (see Appendix A).

In case of doubt regarding species identification within a sample, the source file of the sample was examined for the presence of more easily identifiable calls. The manual analysis was performed with a custom software tool (*SpectroPlotter*) allowing standardized annotations and consistency of approach between analysts. Calls were identified by species and call type (Table 2.3).

The lead analyst reviewed a subset of annotations from the other analyst to ensure accurate species classification of vocalizations. Emphasis was placed on verifying annotations for which a classification risk was identified (*e.g.*, possible confusion between killer whale and *Lagenorhynchus* sp.) as well as notable or suspicious annotations (*i.e.*, annotations referring to species not commonly in the area). Owing to the large number of "unknown" annotations (see Table 3.1), the review focused on those that were tentatively identified to a species for days with no confirmed manual detections of that species to ensure all detection days were compiled.

The manual annotations were used to determine the acoustic occurrence of each species throughout the operational period of each recorder. A species was considered present on a day if at least one call was detected on at least one sample for that day. This analysis is not intended to yield the relative abundance of species.

2.4.2 Automated Data Analysis

JASCO's automated acoustic analysis software suite was used to: (1) compute ambient sound levels, (2) detect marine mammal calls, and (3) detect anthropogenic and shipping events within the acoustic data, as described in the following sections.

Ambient Noise

Ambient sound levels at each recording station were examined to document baseline underwater sound conditions during each survey period. Ambient noise at each of these stations was analyzed by Hamming-windowed fast Fourier transforms (FFTs) with 1-Hz resolution and 50% window overlap. 120 FFTs performed this way were averaged to yield 1-min average spectra.

Ambient sound levels at each recording station are presented as:

1. Broadband and approximate-decade-band sound pressure levels (SPLs) over time for the frequency bands:
    - 10 Hz to 16 kHz or 10 Hz to 8 kHz (broadband SPL, Deployment 1 and 2, respectively),
    - 10 Hz to 100 Hz,
    - 100 Hz to 1 kHz, and
    - 1 kHz to 10 kHz or 1 kHz to 8 kHz (decade-band SPLs, Deployment 1 and 2, respectively).

2. Spectrograms of the 1-min average spectra computed as described above. These plots show the distribution of sound energy in both time and frequency.

3. Spectral level percentiles: Histograms of each frequency bin for all 1-min data from each recorder were computed. The 5th, 25th, 50th, 75th, and 95th percentiles are plotted. The 95th percentile curve describes the frequency dependent levels exceeded by 5% of the 1-min averages. Equivalently, 95% of the 1-min spectral levels are below the 95th percentile curve. The 95th percentile represents the quietest noise state that can be expected to occur. The 5th percentile typically represents the noise level associated with occasional loud events such as nearby shipping or extreme weather.

The 50th percentile (median of 1-min spectral averages) can be compared to the well-known Wenz ambient noise curves shown in Figure 2.3. The Wenz curves show the variability of ambient spectral levels as a function of frequency based on measurements worldwide over a range of weather, vessel traffic, and geologic conditions. The Wenz curve data are general and are used for approximate comparison only. The limits of prevailing noise from the Wenz curves are overlaid as dashed lines on the percentile spectral levels for comparison.

Table 2.3 Marine Mammal Call Types Annotated During Manual Analysis.

Species	Call Type	Description
Humpback Whale	Moans	LF FM calls, may have harmonic structure (Thompson *et al.* 1986, Dunlop *et al.* 2007).
	Cries	HF FM calls, usually without harmonics, may have multiple inflexion points (Thompson *et al.* 1986, Dunlop *et al.* 2007).
	Grunts/Snorts/ Wops	Grunting sounds, peak frequency usually below 500 Hz, often upsweeping at the end (Thompson *et al.* 1986, Dunlop *et al.* 2007).
	Growl/Purr/ Trill	LF purring sounds with marked harmonic structure (Thompson *et al.* 1986, Dunlop *et al.* 2007).
	Overlap	Overlapping calls produced concurrently by several humpbacks.
	Other	Humpback calls that do not match the above categories.
Minke Whale	Downsweep	Short downsweeping calls between 200 and 50 Hz (Edds-Walton 2000).
	Pulse Train	Series of pulses between 200 and 400 Hz, usually 40–60 s in duration (Mellinger *et al.* 2000).
	Other	Minke whale calls that do not match the above categories.
Fin Whale	Narrowband Downsweep	Pulse down-sweeping from 25 to 18 Hz, about 1 s long (Watkins 1981).
	Broadband Downsweep	Pulse down-sweeping from 50 Hz or higher to 18 Hz (Watkins 1981).
	Other	Fin whale calls that do not match the above categories.
Blue Whale	Infrasonic Downsweep	Downsweeping call between 18 and 15 Hz, 5–15 s in duration (Berchok *et al.* 2006).
	Infrasonic Monotonic	Flat call between 18 and 15 Hz, 5–20 s in duration (Berchok *et al.* 2006).
	Audible Downsweep	Downsweeping call between 90 and 30 Hz, about 2 s in duration (Berchok *et al.* 2006).
	Other	Blue whale calls that do not match the above categories.
Sei Whale	Downsweep	Downsweeping moan from 100 to 30 Hz, about 1.5 s in duration (Baumgartner *et al.* 2008).
	Other	Sei whale calls that do not match the above categories.
Killer Whale	Pulsed Calls	Characterized by harmonic structure. Fundamental frequency usually around 800–1000 Hz. Stereotyped calls often repeated within a sound file (Ford 1989).
	Clicks/Buzzing	Broadband clicking sounds, presumably for echolocation (Barrett-Lennard *et al.* 1996).
	Whistles	FM calls usually without harmonics (Ford 1989).
	Overlap	Overlapping calls produced concurrently by several animals.
	Other	Killer whale calls that do not match the above categories.
Lagenorhynchus sp.	Whistles	FM calls, usually between 5 and 16 kHz, 0.05 to 1 s in duration (Rasmussen and Miller 2002).
	Clicks	Broadband clicking sounds, presumably for echolocation.
	Overlap	Overlapping calls produced concurrently by several animals.
	Other	Dolphin calls that do not match the above categories.
Harbour Seal	Roars	Roaring sounds with highest energy around 1.2 kHz, 7 to 10 s in duration (Van Parijs *et al.* 2002).
	Other	Harbour seal calls that do not match the above categories.
Harp Seal	Grunts/Other	Calls assigned to harp seals based on context.
Unknown	Grunts	Grunt-like calls, generally produced by unidentified seals.
	Undescribed	Biological sounds matching no call type listed above. Includes calls unclassifiable from context.

Notes: Abbreviations: FM, frequency-modulated; HF, high-frequency; and LF, low-frequency.

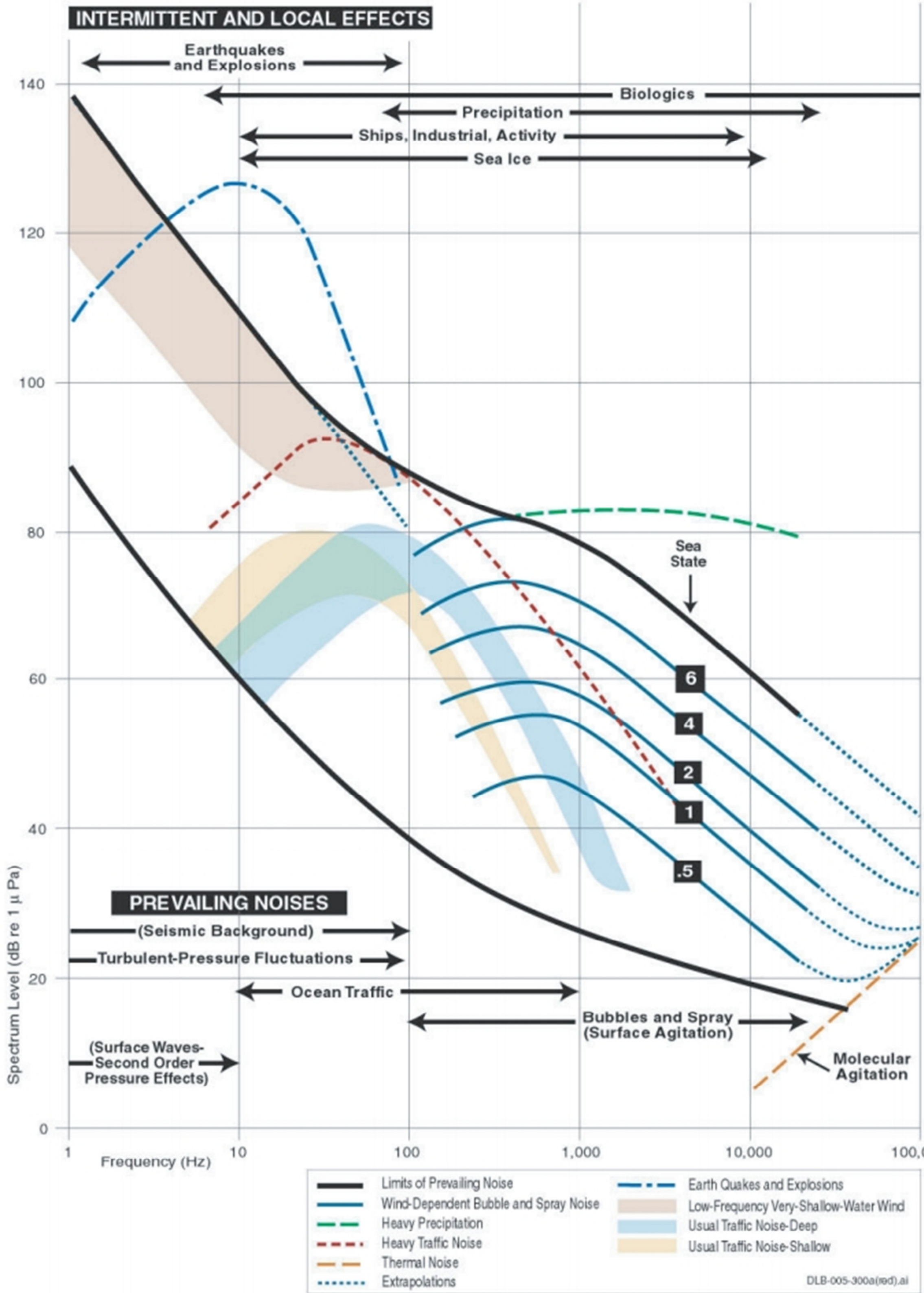


Figure 2.3 Wenz Curves of Ambient Noise in the Ocean. Pressure spectral density levels of marine ambient noise from weather, wind, geologic activity, and commercial shipping (Ocean Studies Board 2003 adapted from Wenz 1962). Thick lines indicate limits of prevailing noise.

Marine Life Call Detection

The automated detection of marine life calls consists of three stages: (1) short time Fourier analysis; (2) contour following with parameter extraction; and (3) contour sorting. The detection and sorting algorithms are designed for high probability of detection of vocalizations. The call sorter provides a means of computing call counts from large datasets where only a portion of the data can be analyzed manually in a reasonable timeframe. Evaluation of the sorter's performance as a classifier requires comparison against known correct classifications. Comparisons of the sorter outputs to the manual analysis results were used to generate precision and recall values (see Appendix A) for the detector/classifier, which in turn allowed us to obtain accurate estimates of call counts.

Short-Time Fourier Transform (Spectrogram) Analysis

The automated detection of acoustic events, such as marine life sounds, was performed via spectrogram in the time/frequency domain. The data are converted to a time/frequency representation using a short-time Fourier transform (STFT; Oppenheim and Schafer 1975). To detect transient calls by marine mammals, a short-time span is analyzed at each time step to investigate changes in frequency content as a function of time. The choice of STFT parameters affects the overall performance of the detector/sorter. The parameters available and their effects are described in Table 2.4. The effects of different STFT parameters on two types of signals are shown in Figure 2.4. The actual signal processing implementation uses a fast Fourier transform (FFT; Oppenheim and Schafer 1975).

Table 2.4 STFT Analysis Parameters.

Parameter	Definition	Effect of Increasing	Effect of Decreasing
Sample Rate (determined by data collection system)	Number of data samples acquired per second. Highest frequency that can be analyzed is one half the sample rate (the Nyquist frequency).	More demanding signal processing.	Less acoustic information since there is less frequency range represented. Faster to process.
Analysis Window Length	Total number of data points in the FFT. Set to a power of 2 for efficient FFT implementations.	Increases the frequency resolution, but decreases the time resolution. Frequency resolution is equal to 1/window length, *e.g.*, a 2-s long FFT has a resolution of 0.5 Hz. Longer is better for signals where the frequency changes slowly in time.	Better if the signal frequencies change rapidly in time.
Zero-Padding	If the number of actual data samples in the FFT is less than the FFT length, then remaining points are set to zero.	Increasing the zero padding allows the analysis to keep a high frequency resolution, but with better time resolution. This technique provides a better resolution, but does not improve the ability to discriminate two closely spaced tonal frequencies which would otherwise require more data and a longer FFT.	Some signals have constant frequencies for short durations, which are best represented by long FFTs with less actual data in the FFT.
Analysis Window Advance	The number of data points that the data flow advances with each FFT, *e.g.*, with a 2048-point FFT, we can advance by 25% or 512 data points.	Provides lower time resolution, speeds up the analysis, and makes each output more sharply defined. A 'window' function in time is normally applied before an FFT to reduce frequency sidelobes. As a result there should always be some overlap to ensure all data is represented.	Provides more output points when a signal is present, thereby improving detection and contour following. This increases processing time due to data redundancy.

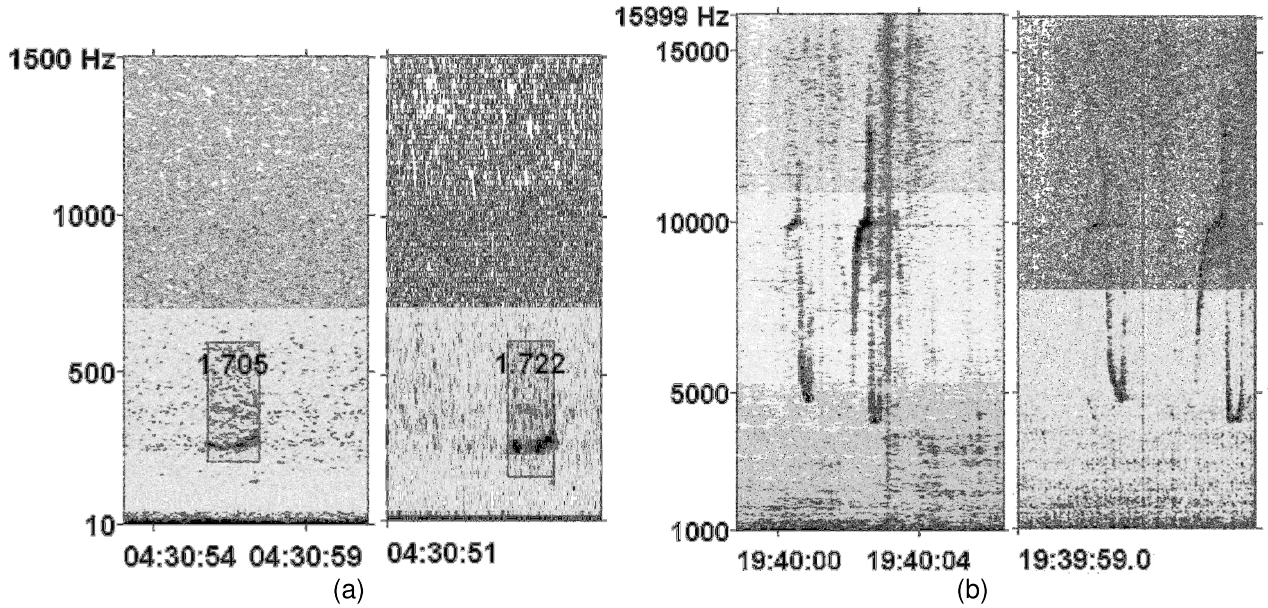


Figure 2.4 Effects of Different STFT Settings. (a) Humpback moan recorded at a sample rate of 32 kHz. Left panel of (a) was analyzed with a 0.25 s analysis window, and an advance of 0.0625 s. Right panel of (a) was analyzed with a 0.0625 s analysis window and 0.016 s advance. (b) A dolphin whistle processed with the same settings. The short settings are better suited to the rapidly changing dolphin whistle, while the longer settings are better suited to the slowly changing humpback moan.

The data were analyzed in a processing block of specific duration. As an example for discussion, assume a block size of 128 s. Assuming the sample rate is 16,384 Hz, and using an analysis FFT window size of 2048 pts (1/8 second) with window advance of 1024 pts, the processing block has 2047 time window steps (16 window step advances per second times 128 s per block). Detection of time-frequency cells with energy peaks must occur before the contour-following and sorting. For all time steps in the processing block, the data in each frequency bin are sorted and normalized by the median amplitude for that frequency bin. The normalized values are then compared to an empirically chosen detection threshold. The bins above the threshold are set to one and the bins below the threshold are set to zero. This is referred to as the contour data space, which is a binary 0/1 matrix. Typically the detection thresholds for the normalized data are four times the median value. This approach has been found to provide better performance for tonal and whistle events than a split-window mean normalization scheme or a simple energy threshold.

Contour Following and Parameter Extraction

This study implemented a simple yet robust contour-following algorithm that is a variation of the flood-fill algorithm (Nosal 2008). The contour data space is passed to a contour-follower algorithm that joins cells with detected energy. For each 'test' cell that is a '1' in the contour space, the joining algorithm searches adjacent points that are also '1'. The merged cells create a contour of the vocalization. Figure 2.5 shows the contour 'mask' which are the adjacent cells that may be added to a contour. The contour joining algorithm moves from oldest data to newest and from lowest frequency to highest. Each detected time-frequency bin can be added to only one contour. This algorithm does not distinguish between different calls.

As shown in Figure 2.5, the starting cell for joining to the contour is the center white cell which must be a '1' to initiate contour following. All green and blue cells are checked and those equal to 1 are added to the contour. The algorithm advances from left to right in time; therefore gray cells left of the test cell need not be checked. However, checking the far left cells may join broken contours. Note that a contour can be broken—a '1' in the green cells is added to the contour even if all blue cells are '0'.

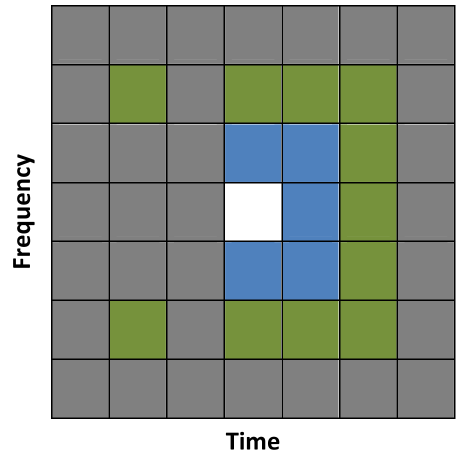


Figure 2.5 Contour-Follower Mask

Once a contour is complete, the following features are extracted:

- Start time,
- Duration,
- Minimum frequency, and
- Maximum frequency.

This algorithm is sensitive to noise generated by small pleasure craft or fishing vessels near a recorder, which can generate many contours that may be mistaken for marine life calls. Therefore, a boating detector is implemented in the contour follower to reduce false-positive detections. Boating is considered detected when at least five frequencies have detected contours for 5 s. Files with at least two detections of boating are omitted from further processing.

Contour Sorting

A 'contour-sorter' algorithm compares the extracted parameters against a defined set of call types. The best match, in terms of duration and bandwidth, is selected as the output type. The algorithm supports three types of contours:

- Regular Contours—output as a complete object from the contour follower, *e.g.*, simple downsweep calls and whistles.

- Multi-Component Contours—generally occupy several frequency bands at once, such as harmonics of a killer whale call, a humpback song, or sub-harmonics below 16 kHz produced by dolphin or beluga feeding buzzes.

- Multi-Time Component Contours—groups of related contours that are broken in time, *e.g.*, seal trills and groups of beluga, dolphin, or beaked whale whistles.

Call types are defined by the following parameters:

- Minimum frequency—often lower than the published lower frequency bound for the species and call type.

- Maximum frequency—either the maximum frequency expected for the call type, or the maximum frequency in the data, whichever is lower.

- Minimum duration—at least one STFT time slice.
- Maximum duration.
- Minimum bandwidth.
- Maximum bandwidth—not often used.
- MultiComponent (Boolean): for call types where contours should be grouped in frequency with some time overlap before applying the frequency, duration, and bandwidth constraints. Each contour that is added to the multi-component contour has the following constraints applied:
    - minComponentDuration—minimum duration for a contour to be added to the multi-component contour.
    - minComponentBW—minimum bandwidth for a contour to be added to the multi-component contour.
    - Minimum and maximum frequencies as per the global definition.
- MultiTimeComponent (Boolean): for call types where contours should be grouped in time before applying the frequency, duration, and bandwidth constraints. Each contour that is added to the multi-time-component contour has the following constraints applied:
    - minTimeComponentDuration—minimum duration for a contour to be added to the multi-time-component contour.
    - minTimeComponentBW—minimum bandwidth for a contour to be added to the multi-time-component contour.
    - Minimum and maximum frequencies as per the global definition.

Figure 2.6 shows a block diagram of the contour sorter algorithm. The algorithm consists of two loops. The outer loop iterates through the contour list. For each contour that has not yet been sorted, the contour's features are compared to each defined call type in the inner loop. If the call type is a multi-component or multi-time-component type, the contour list is searched for unsorted calls that meet the call association criteria. The total contour duration, minimum and maximum frequencies, and call bandwidth are compared to the call type definition. If the contour falls within the call type's bounds, then the bandwidth (BW_i) and duration (T_i) indices are computed:

$$BW_i = \frac{BW_{contour}}{BW_{call}} \quad T_i = \frac{T_{contour}}{T_{call}}$$

If either of these indices exceeds an empirically chosen threshold of 1.5 times the current best index, then the current best-match call type is updated. The 1.5 threshold for updating the best-match call type means that the algorithm prefers call types that are defined earlier. Therefore, if for a particular recording killer whales are more likely to occur than singing humpbacks, the killer whale call should be defined before that for humpbacks.

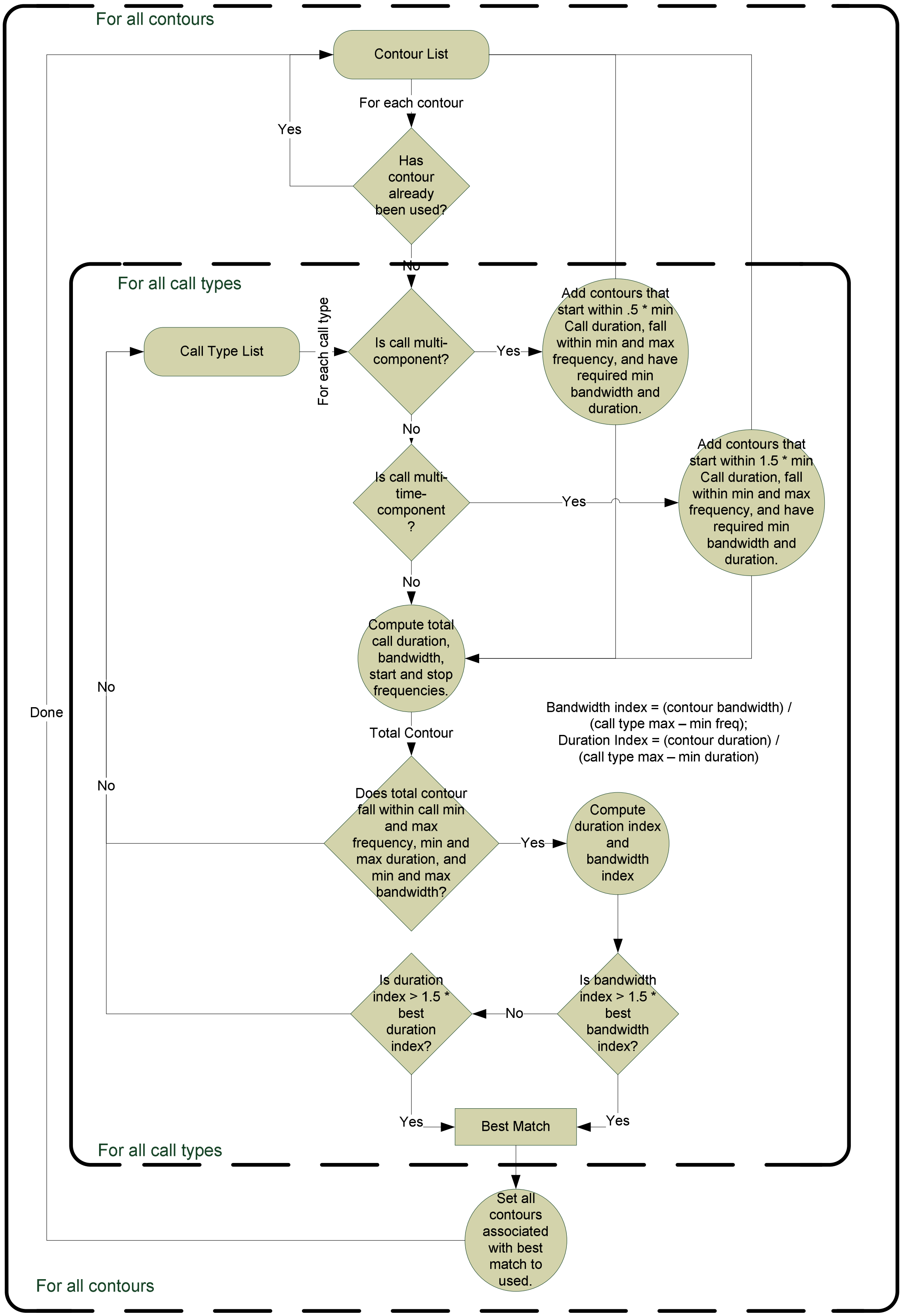


Figure 2.6 Contour Sorter Algorithm Block Diagram

Figure 2.7 is an example of all three types of contours applied to dolphin calls. Referring to Figure 2.7, the far left event in green is a feeding-buzz sub-harmonic detection that was assembled from discrete contours for each harmonic using the multi-component contour type. At middle right is a single whistle contour type, and at the far right is a group of whistles that was associated together using the multi-time-component call type definition. The purple box to the right shows an impulse that extends below the minimum defined frequency for dolphin calls. The purple box in the time series window at the middle of the display is a detection below 1000 Hz which is not visible in the spectrogram. The parameters for the STFT were a 2048-point analysis window with a 512-point advance.

The SOBI data analysis required two marine mammal data runs. The first data run searched for low-frequency calls from large mammals. The second data run searched for dolphin whistles. Table 2.5 and Table 2.6 show the parameters used for each detection run. These parameters are based on published duration and minimum and maximum frequency values for the most common calls of the species expected in the study area. These bands should therefore capture most vocalizations for these species.

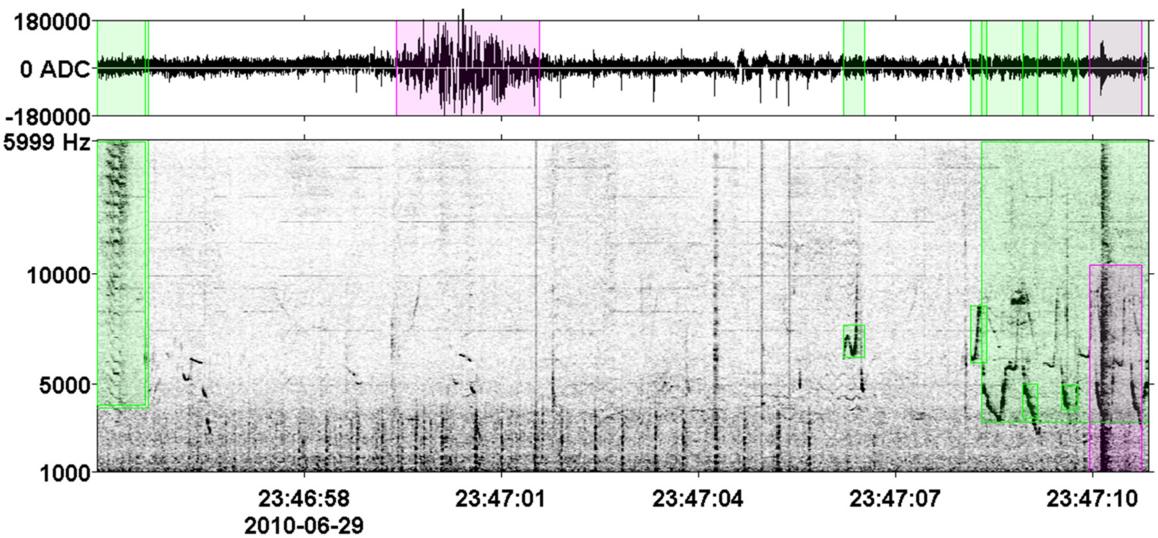


Figure 2.7 (Top) Time Series and (Bottom) Spectrogram of Examples of Three Types of Contours from the Sorter Output using SOBI-specific parameters.

Table 2.5 Automated Detection Parameters for Low-Frequency Marine Life Vocalizations (using 0.25-s FFTs with 0.25 s Real Data, 0.0625-s advance, and a detection threshold of 4) based on published values of call duration and minimum and maximum frequency.

Band	Frequency (Hz)	Duration (s)	Min. Bandwidth (Hz)	Species/Call Type
1	12–120	0.7–20	12	Blue whale (Berchok *et al.* 2006)
2	8–50	0.5–2	15	Fin whale (Watkins 1981)
3	30–180	0.4–2	50	Sei whale (Baumgartner *et al.* 2008)
4	100–10000	0.5–5.0	500	Humpback complex calls (multi-component) (Thompson *et al.* 1986, Dunlop *et al.* 2007)
5	300–7000	0.5–5.0	1000	Killer whale (multi-component) (Ford 1989)
6	100–1000	0.5–5.0	20	Humpback moan (Thompson *et al.* 1986, Dunlop *et al.* 2007)

Table 2.6 Automated Detection Parameters for Dolphin Whistles (using 0.064-s FFTs with 0.064 s real data, 0.016-s advance, and a detection threshold of 3) based on published values of call duration and minimum and maximum frequency. Dolphin species likely encountered are *Lagenorhynchus albirostris* and *L. acutus*.

Band	Frequency (Hz)	Duration (s)	Min. Bandwidth (Hz)	Species/Call Type
1	3000–16000	0.3–10	1000	Dolphin whistles (Rasmussen and Miller 2002)

Vessel Noise Detection

The vessel detector locates narrow tonal peaks characteristic of vessel motors, pumps, and gearing (Arveson and Vendittis 2000). A spectrogram of typical vessel noise is shown in Figure 2.11. The vessel detector generates spectra using a 2-s FFT with a Hamming window and 50% overlap. Sixty of these FFTs were averaged to create 1-min average spectra. The spectra between 1 Hz and 1000 Hz were normalized in frequency, using a split-window normalizer, and searched for narrowband peaks. A positive detection is indicated when a peak occurs in three out of four adjacent 1-min intervals. The detection confidence increases with the number of peaks detected. This technique is appropriate for large shipping vessel traffic only. It is inappropriate for fishing vessels and pleasure craft, which produce sound that varies in frequency due to speed changes and effects of bouncing on the waves.

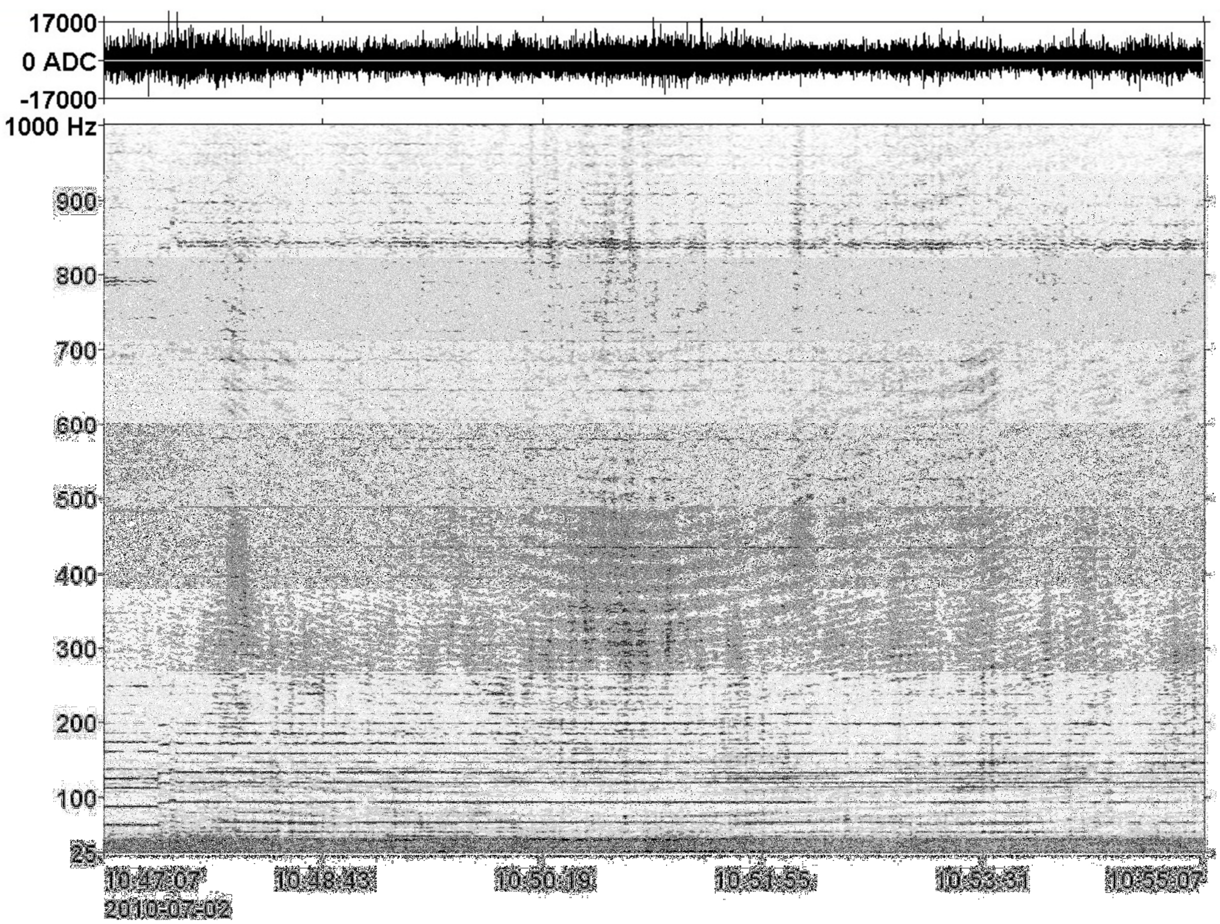


Figure 2.11 Spectrogram of Tonal Vessel Noise at the Middle Station, 2 July 2010 (2-s FFT, 2-s time window, 1.5 s overlap, Hamming window). Upward curved pattern is due to the Lloyd mirror effect. Changes in frequency of the tonals indicate changes in vessel engine speed or gearing.

2.4.3 Combining Automated and Manual Marine Mammal Detections

The performance of the automated detector was assessed individually for each species for all fully-manually-annotated samples. Detector performance was assessed by calculating the precision (*P*) and recall (*R*) metrics, which characterize the relationship between the given automated detector and the dataset. The precision can be seen as a measure of exactness (*i.e.*, how many detected calls were identified correctly), and the recall, of completeness (*i.e.*, how many calls within the data were actually detected). Table 2.7 summarizes the detector performance for each species. There were insufficiently many manual detections of blue and sei whale calls to calculate *P* and *R*.

Table 2.7 Performance of Automated Vocalization Detectors for Each Species. Insufficiently many blue and sei whale calls were detected manually to calculate *P* and *R.*

Species	Recall (%)	Precision (%)
Humpback whale	27	57
Fin whale	34	90
Killer whale	45	67
Dolphins	19	60

Species-specific call counts were plotted to depict the relative abundance of species among stations for each survey period. The number of vocalizations was estimated from the number of automated detections in the frequency bands listed in Table 2.5 and Table 2.6. Because the automated detections may include noise events (*i.e.*, false positives) and may not include all calls within the data (*i.e.*, false negatives), total call counts were estimated with the use of the *P* and *R* values. Provided that the data samples used to calculate *P* and *R* are a good representation of the entire dataset and that at least 100 calls were annotated for a given species, these values can be used to extrapolate the actual number of vocalizations within the data as the number of true detections plus the number of missed detections (see Appendix A for details).

Call count estimates were compiled based on manual classifications. If no call was manually detected for a species in a given file sample, then the automated vocalization count, if any, was zeroed for that file and species. For Deployment 1 (June to August), detection numbers were summed over 2-week periods, corrected and mapped. For Deployment 2 (October to December), the corrected detection numbers at the Middle Station were plotted as a continuous time series.

2.5 Study Team

Recorder deployments and retrievals were performed by Jeff MacDonnell, Eric Lumsden, and Julien Delarue. The manual analysis team consisted of Julien Delarue (lead analyst) and Frederic Paquet. Frederic Paquet analyzed data from the Newfoundland and Middle Stations for Deployment 1 and from the Middle Station during Deployment 2. Julien Delarue analyzed the data recorded at the Labrador Station during Deployment 1. Julien Delarue also aided Frederic Paquet in identifying unknown calls throughout the manual analysis.

Julien Delarue is JASCO's lead marine biologist, with over seven years experience in acoustic identification of marine mammals in the Arctic, St. Lawrence River, and Gulf of Maine. Frederic Paquet is a marine mammal observer and tour guide, and has over 1000 h experience in marine mammal acoustic identification.

Data processing and ambient noise result extraction were performed by Bruce Martin and Jeff MacDonnell for Deployments 1 and 2.

3.0 RESULTS AND DISCUSSION

The ambient noise and marine mammal survey results are presented separately for each deployment period: Deployment 1, from June to August 2010; and Deployment 2, from September to December 2010. During Deployment 1, marine mammal detections included sounds of blue, fin, sei, humpback, and killer whales along with dolphin whistles (likely from white-beaked and/or white-sided dolphins). Humpback whales, killer whales, and dolphins were the most commonly detected species and were recorded throughout the study periods. Blue, fin, and sei whales were detected sporadically, likely indicating relatively low occurrence in the SOBI.

Ambient noise levels in the SOBI were 5 to 13 dB lower at the Labrador Station than at the other two stations for frequencies below 250 Hz. The sound levels at all stations were strongly affected by vessel traffic and tidal flow pseudo-noise. A lunar cycle can be observed in the tidal noise effect. Average ambient noise at the Middle Station was 5 dB higher during Deployment 2 than during Deployment 1, likely due to increased wind speeds observed during the fall.

3.1 Deployment 1: Recording Period June to August 2010

3.1.1 Detections of Marine Mammal Vocalizations, Biological Sounds, and Vessel Noise

A total of 2,890 sound events were annotated manually in the data from the first deployment, of which 1,910 were identified as marine mammal calls (Table 3.1). Humpback whale calls comprised the bulk of the identified sounds, followed by dolphin and killer whale calls. The Middle Station had the most annotated sounds, followed closely by Labrador. There was considerably less biological acoustic activity at the Newfoundland Station than at the other two stations, even when accounting for the shorter recording period at Newfoundland. Unknown sounds were primarily unidentified biological sounds (*e.g.*, fish or distant marine mammals) but may have included some non-biological sounds.

Table 3.1 Marine Mammal Calls Identified by Manual Analysis for each station and species. No other species were detected.

Species	Labrador	Middle	Newfoundland	Total
Blue whale	0	0	9	**9**
Fin whale	2	9	0	**11**
Sei whale	0	1	0	**1**
Humpback whale	521	427	56	**1004**
Killer whale	46	297	23	**366**
Dolphin	221	232	66	**519**
Unknown	365	448	167	**980**
Total	**1155**	**1414**	**321**	**2890**
Recording Days	**59**	**60**	**41**	

Blue Whale (*Balaenoptera musculus*)

Blue whale calls (Figure 3.1) were detected only on four days in July, at the Newfoundland Station. The short-term nature of these detections suggests that the detected animals were transiting through the Strait rather than foraging in the area. On 30 July several concurrent calls were recorded that differed in received sound level, suggesting that more than one blue whale was present near the Newfoundland recorder (Figure 3.2).

Blue whales have been sighted in the past on the Gulf of St. Lawrence side of the SOBI (Sears *et al.* 1991, Kingsley and Reeves 1998) but recent sightings are rare, primarily due to limited effort (Richard Sears, personal communication).

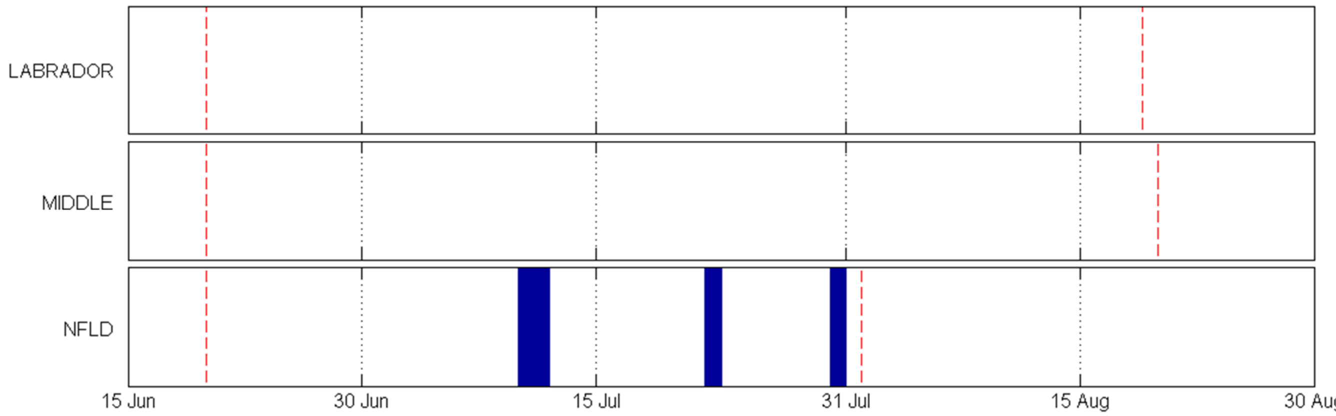


Figure 3.1 Occurrence of Manually Detected Blue Whale Calls in the SOBI between 20 June and 19 August 2010. No calls were detected at the Labrador and Middle Stations. Red dashed lines indicate recording start and end.

Figure 3.2 Spectrogram of Blue Whale Calls recorded 30 July 2010 at the Newfoundland Station (Hamming window, 4096-point FFT, 1024-point overlap).

Killer Whale (*Orcinus orca*)

Killer whale calls were detected at all three stations. The number of detection days ranged from four at the Newfoundland Station to 22 at the Middle Station (Figure 3.3). Killer whales were present consistently from late June to early July at the Middle Station, while detections were less regular after that. Estimated call counts were always highest at the Middle Station. Killer whales were not detected until 17 July at the Newfoundland Station. Following this date and until the end of its operational period, this station recorded the second highest call counts, except during the third period 21 July to 4 August (Figure 3.4), call counts at the Middle Station were usually an order of magnitude higher than at the other stations. The call counts at the Middle Station were relatively constant until 4 August and then abruptly decreased, possibly indicating a lower abundance of killer whales in the study area (Figure 3.4).

On several occasions, unique calls were detected at both the Labrador and Middle Stations, suggesting that the same animals may be the source of the detections occurring on the same day at these two stations. The detection of unique stereotyped pulsed calls (Ford 1989; Figure 3.5) on different days suggests that at least some pods or whales belonging to the same community occupied the area recurrently.

It is unclear whether the distinction between mammal- and fish-eating killer whales observed in the north eastern Pacific holds for north Atlantic killer whales. Several observed attacks of killer whales on minke whales in the Gulf of St. Lawrence (Wenzel and Sears 1988) suggest that at least some individuals and pods prey on marine mammals. More recently, killer whales were observed killing a minke whale in two separate occurrences off the coast of Newfoundland in summer 2010, in Trinity Bay and south of St. John's (CBC News 2010). The predictable aggregation of humpback whales in summer does not explain killer whale presence in the SOBI in summer. Indeed, although 15.6 and 17.8% of humpback whales sighted in the Gulf of St. Lawrence or off Newfoundland-Labrador, respectively, bear killer whale teeth marks attesting to a previous attack, few individuals acquire new scars after their first sighting on the feeding grounds (Mehta *et al.* 2007). This suggests the scars are acquired during travel from low-latitude breeding grounds to high-latitude feeding grounds when the animals are young (Mehta *et al.* 2007). The decrease in killer whale detections after 4 August while humpback whale call counts remained high (see following section) may indicate that the detected killer whales target other prey or there are other factors associated with the presence of killer whales in the SOBI.

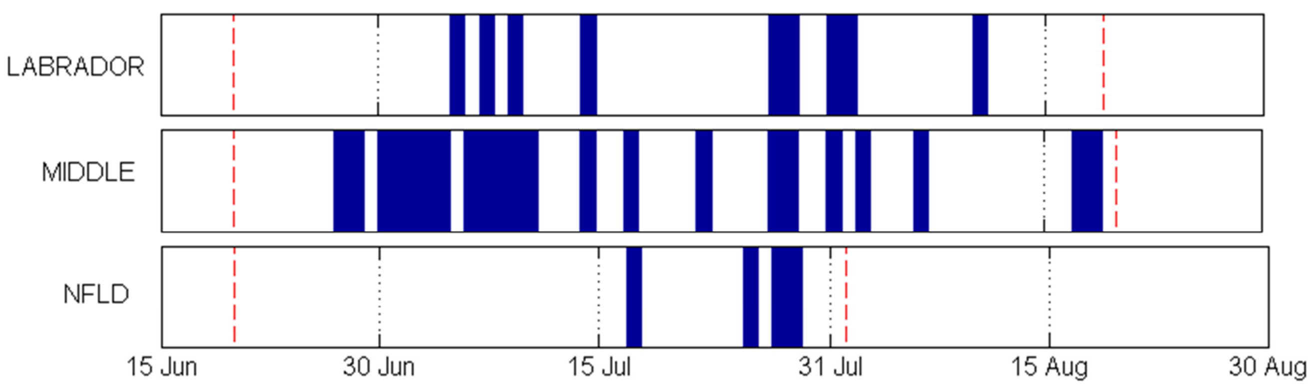


Figure 3.3 Occurrence of Manually Detected Killer Whale Calls in the SOBI between 20 June and 19 August 2010. Red dashed lines indicate recording start and end.

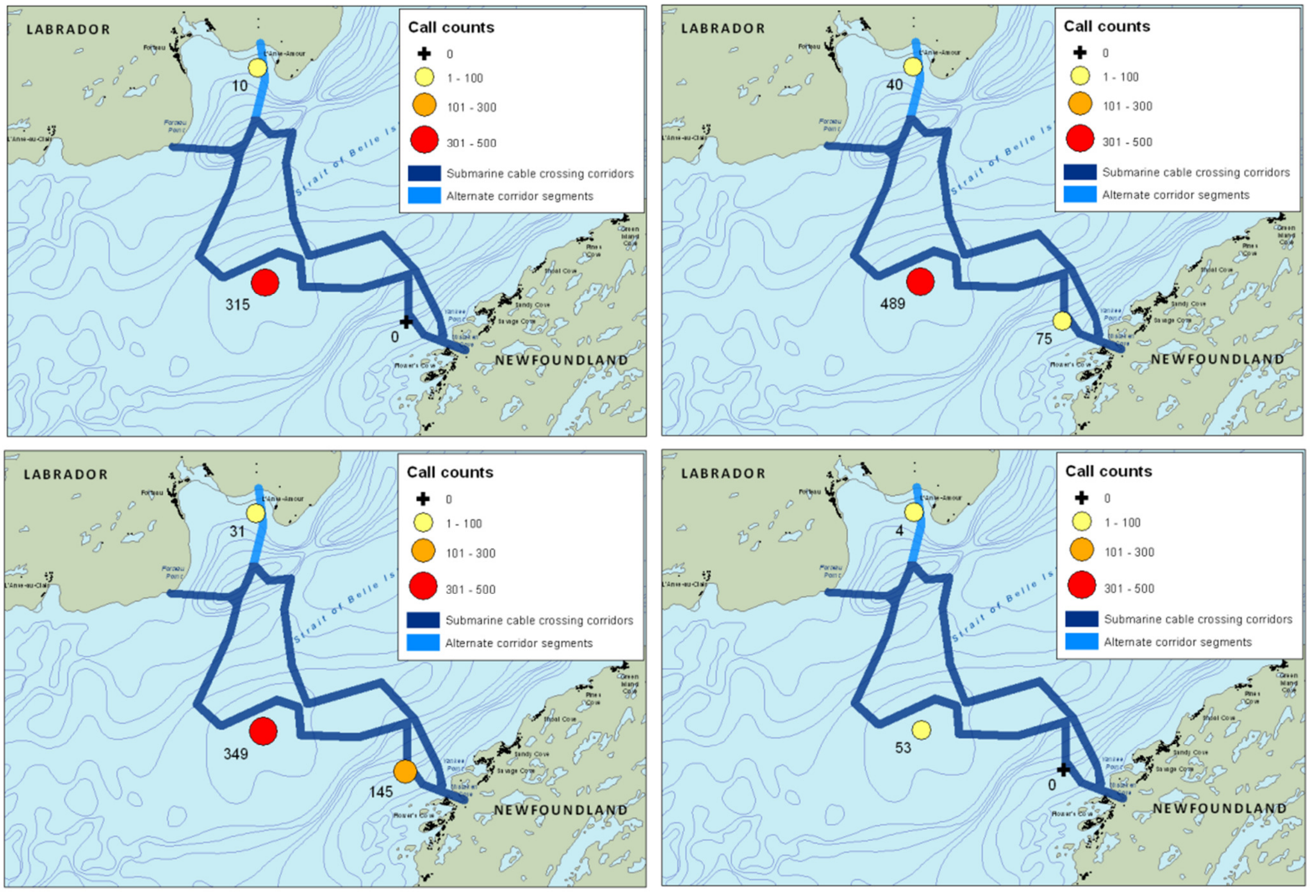


Figure 3.4 Killer Whale Call Counts. Each tile shows the sum of the call counts over two weeks: (Top left) 20 June to 5 July; (top right) 6 to 20 July; (bottom left) 21 July to 4 August; and (bottom right) 5 to 19 August 2010. The Newfoundland recorder stopped working 31 July.

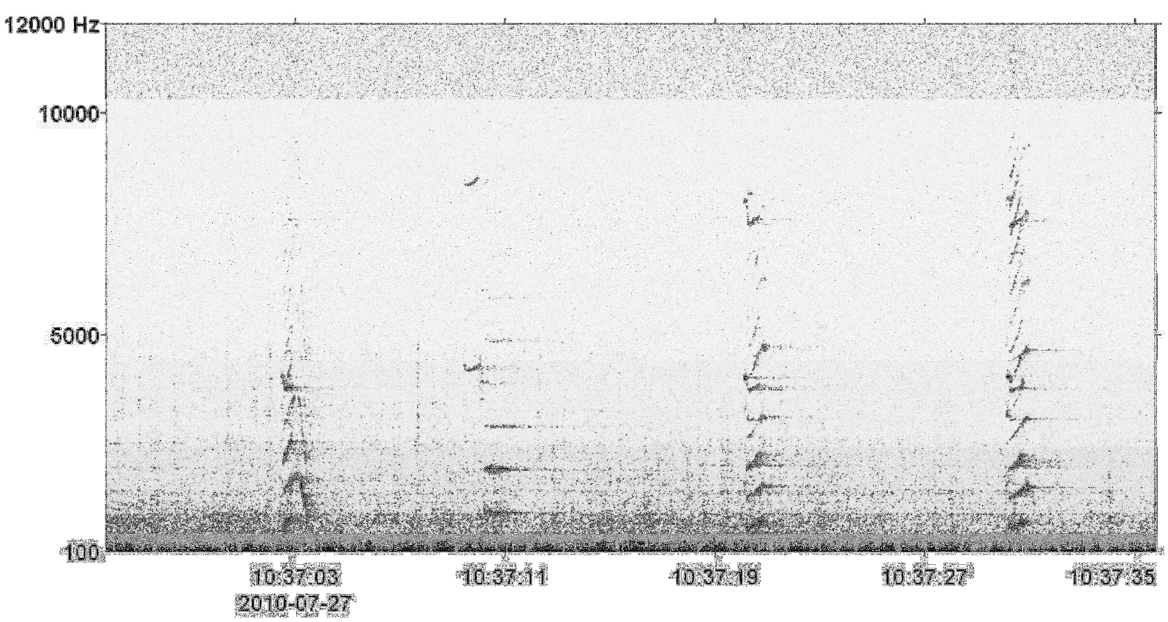


Figure 3.5 Spectrogram of Killer Whale Calls recorded 27 July 2010 at the Middle Station (Hamming window, 2048-point FFT, 512-point overlap).

Humpback Whale (*Megaptera novaeangliae*)

Humpback whales were the most commonly detected species and were present almost continuously throughout the first recording period. The number of detection days ranged from 21 at the Newfoundland Station to 45 at both the Labrador and Middle Stations. The maximum recording duration was 60 days at the Middle Station. Humpbacks were first detected on 22 June at the Newfoundland Station and 23 June at the Labrador and Middle Stations. Detections lasted until the end of recording at all three stations (Figure 3.6).

In addition to humpbacks being detected on half of the days at the Newfoundland Station (which is partially explained by the Newfoundland Station recording period being 19 days shorter than the other two stations), there were usually few detections per day, few calls per detection event, with detection events shorter and fainter in comparison to the other two stations. This indicates that the detected calls may often have been produced by distant whales and that humpback whales used this side of the SOBI less heavily during the recording period. This is confirmed by the observation that estimated call counts at the Newfoundland Station were always the lowest, and one to two orders of magnitude lower than the highest call counts (Figure 3.7). In three out of the four periods, the highest call counts were recorded at the Labrador Station, which is in agreement with the observations of typically larger aggregations on the Labrador side of the SOBI, where they prey on bait fish (Patricia Nash, personal communication). Despite a decrease in call counts in the third period, the occurrence of vocalizing humpback whales appears to have been relatively stable throughout the recording period July to August.

On a few occasions, humpbacks ceased vocalizing when killer whales were calling, but this would only have affected their detection probability for a few consecutive files. Figure 3.8 shows an example of humpback whale calls.

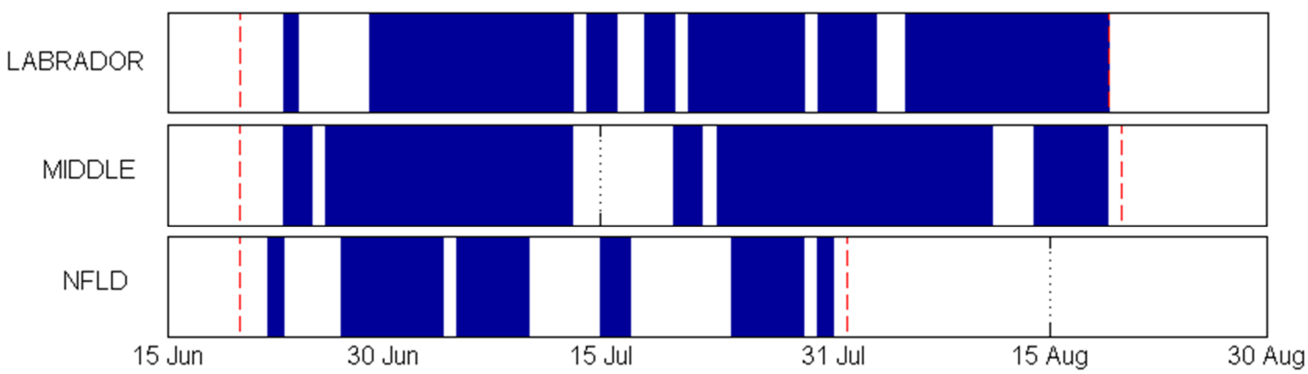


Figure 3.6 Occurrence of Manually Detected Humpback Whale Calls in the SOBI between 20 June and 19 August 2010. Red dashed lines indicate recording start and end.

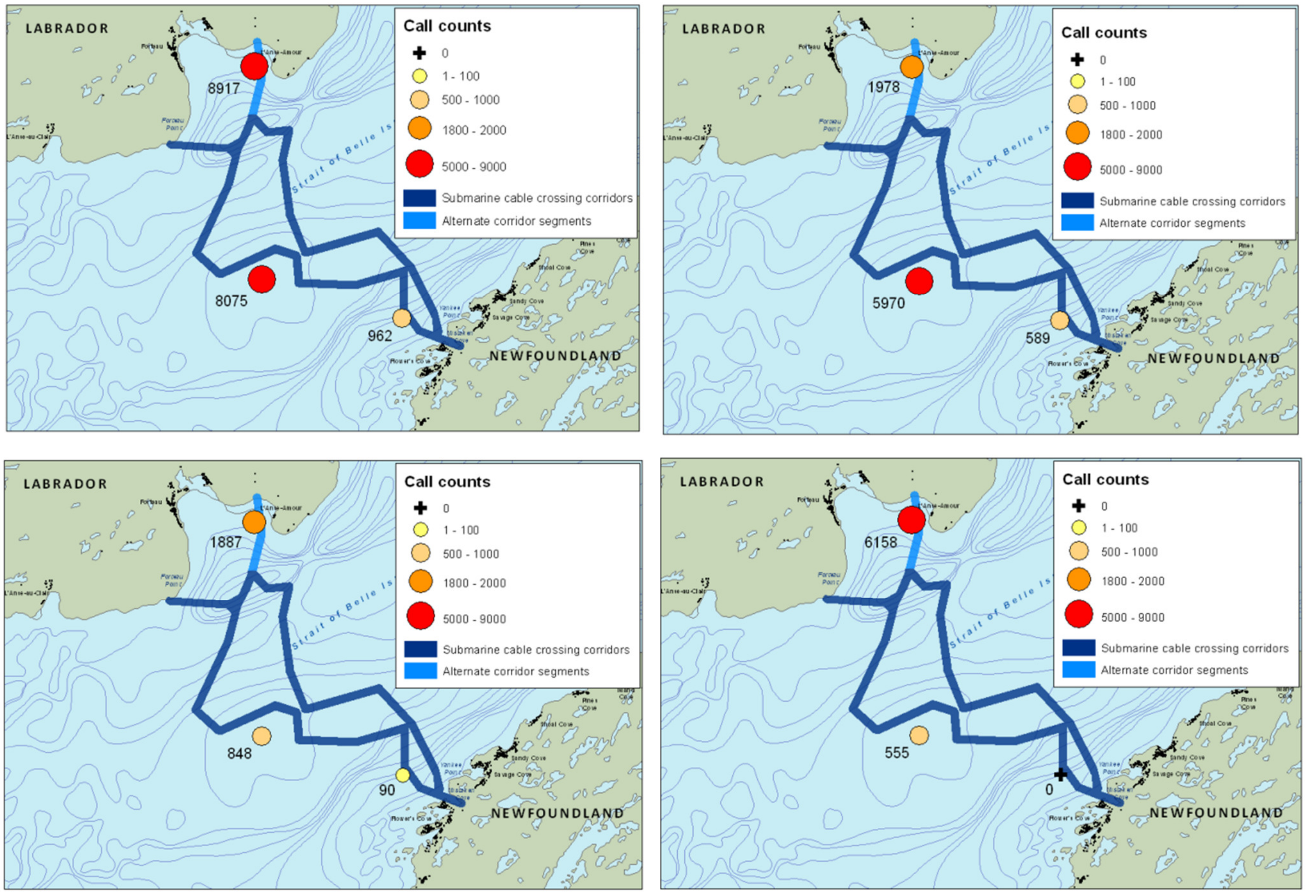


Figure 3.7 Humpback Whale Call Counts. Each tile shows the sum of the call counts over two weeks: (Top left) 20 June to 5 July; (top right) 6 to 20 July; (bottom left) 21 July to 4 August; and (bottom right) 5 to 19 August 2010. The Newfoundland recorder stopped working 31 July.

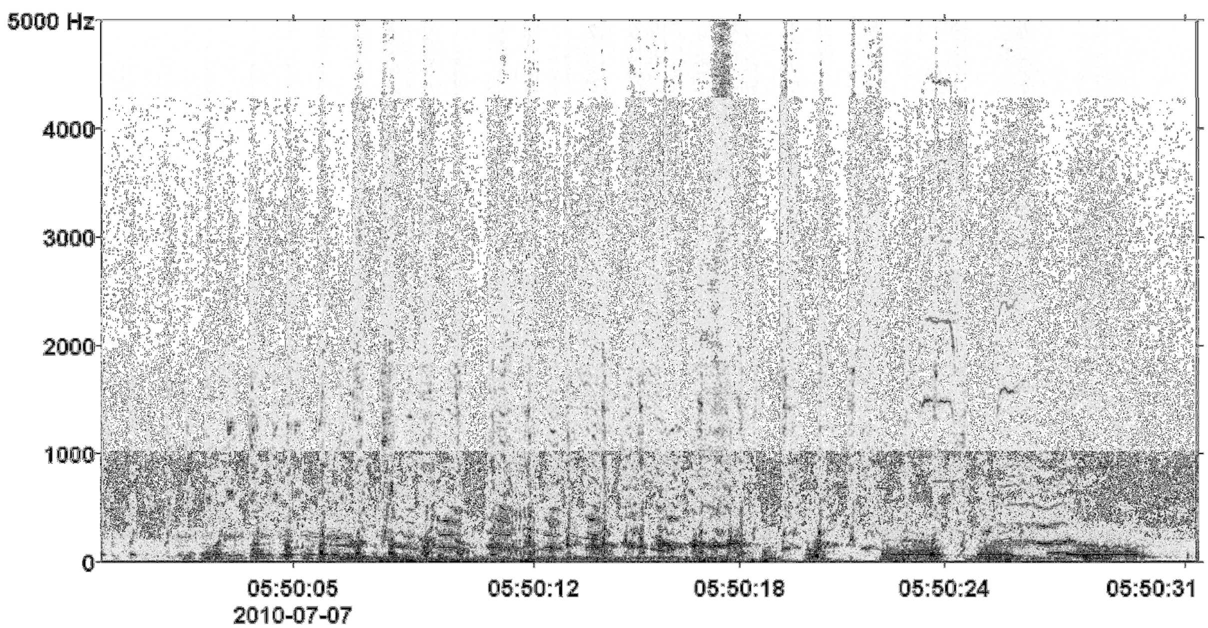


Figure 3.8 Spectrogram of Humpback Whale Calls recorded 7 July 2010 at the Middle Station (Hamming window, 2048-point FFT, 512-point overlap).

Dolphin (*Lagenorhynchus albirostris, L. acutus*)

Dolphin whistles were detected at all three stations. The first detections occurred 27 and 28 June at the Newfoundland and Middle Stations, respectively, and 15 July at the Labrador Station. Whistles were recorded sporadically until the end of the operational period of each recorder. The number of detection days ranged from nine at the Newfoundland Station to 18 at the Middle Station (Figure 3.9).

Estimated call counts were essentially null until 20 July at the Labrador Station. The highest call counts were recorded at the Newfoundland or the Middle Station during the first three periods, before increasing dramatically and shifting towards the Labrador Station in the last period. Call counts decreased and were relatively uniform at all stations during the second and third period (Figure 3.10).

The patterns of dolphin acoustic occurrence at all stations seem to oppose that of killer whales: dolphin call counts were highest at the Newfoundland Station early in the recording period when no killer whales were detected there; they decreased during the middle of the recording period when killer whales were most consistently detected at the Middle Station; finally dolphin whistle detections increased dramatically at the Labrador Station in the last detection period when killer whale call counts decreased abruptly throughout the SOBI (Figure 3.4, Figure 3.10). It is unclear if this reflects an adaptation (vocal or distributional) to predation by killer whales on dolphins or normal patterns habitat of use.

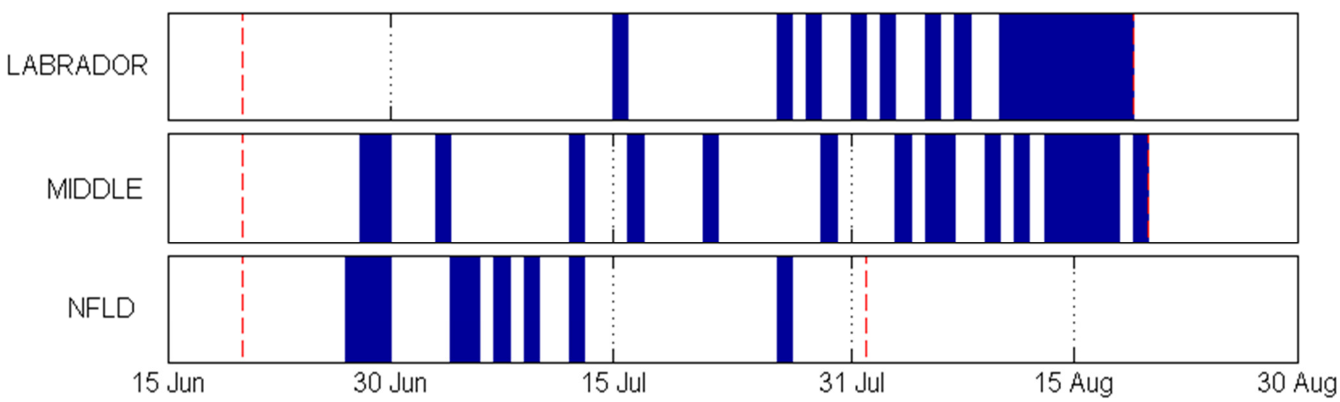


Figure 3.9 Occurrence of Manually Detected Dolphin Whistles in the SOBI between 20 June and 19 August 2010. Red dashed lines indicate recording start and end.

Most detected whistles were likely produced by white-beaked dolphins. This is the most commonly sighted dolphin species in this area (Kingsley and Reeves 1998). However, white-sided dolphins are also present in this area (Kingsley and Reeves 1998) and the temporal pattern of detections also matches the timing of their observation in the adjacent Gulf of St. Lawrence (MICS, unpublished data) where they typically appear from late July onwards. The lack of published call descriptions for both species and the similarity of their calls similarity makes distinguishing them challenging. A representative example of dolphin calls is shown in Figure 3.11.

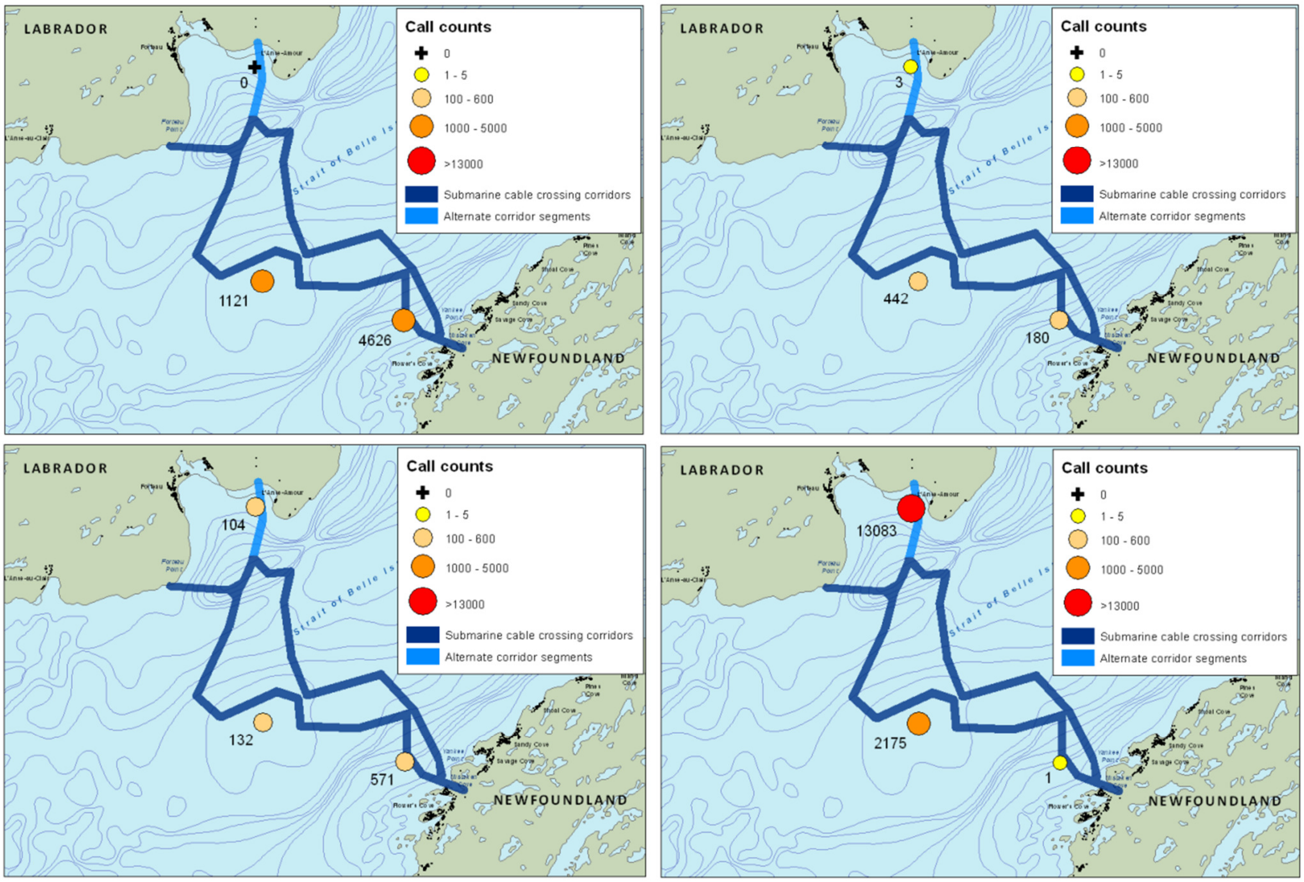


Figure 3.10 Dolphin Whistle Call Counts. Each tile shows the sum of the call counts for a two week period: (Top left) 20 June to 5 July; (top right) 6 to 20 July; (bottom left) 21 July to 4 August; and (bottom right) 5 to 19 August 2010. The Newfoundland recorder stopped working 31 July.

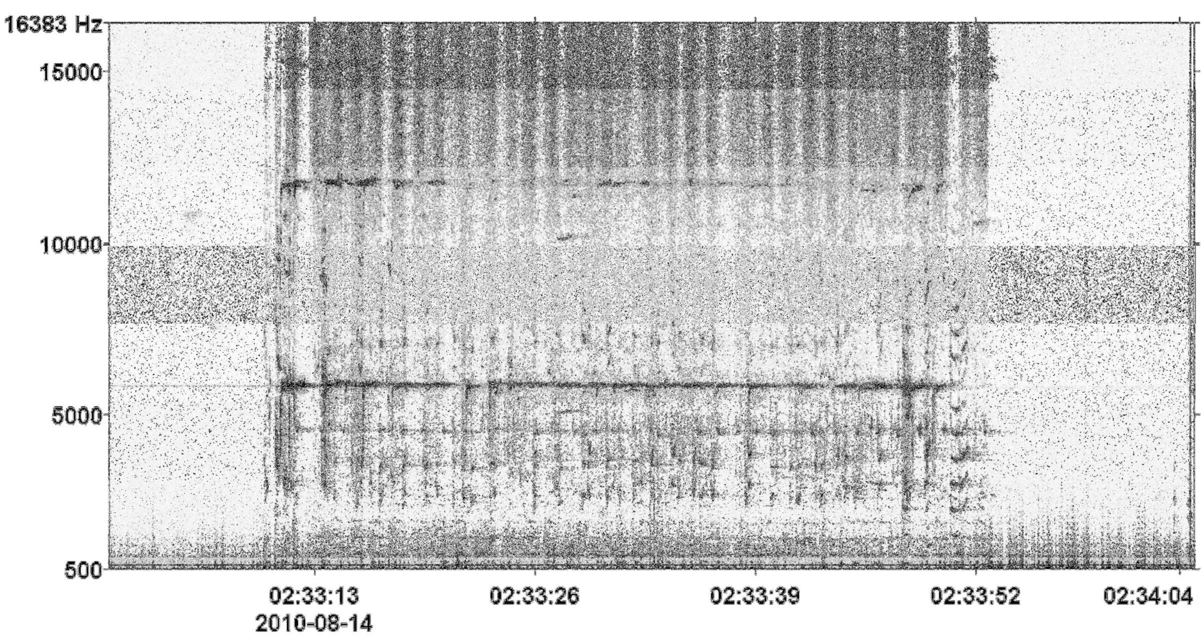


Figure 3.11 Spectrogram of Dolphin Whistles (likely white-beaked dolphins) recorded 14 August 2010 at the Middle Station (Hamming window, 2048-point FFT, 512-point overlap).

Fin Whale (*Balaenoptera physalus*)

Fin whale calls were detected manually once at the Labrador Station and six times at the Middle Station. Detections occurred from 1 July to 16 August 2010 (Figure 3.12). In summer they occur in or near the SOBI (Patricia Nash, personal communication) and aggregate in several areas of the Gulf of St. Lawrence (COSEWIC 2005). A sample fin whale call is shown in Figure 3.13.

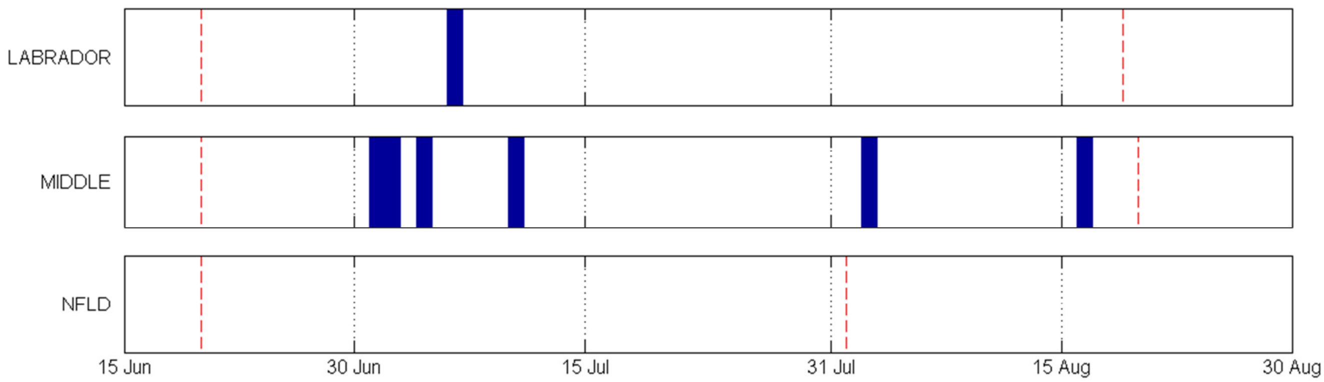


Figure 3.12 Occurrence of Manually Detected Fin Whale Calls in the SOBI between 20 June and 19 August 2010. There were no detections at the Newfoundland Station. Red dashed lines indicate recording start and end.

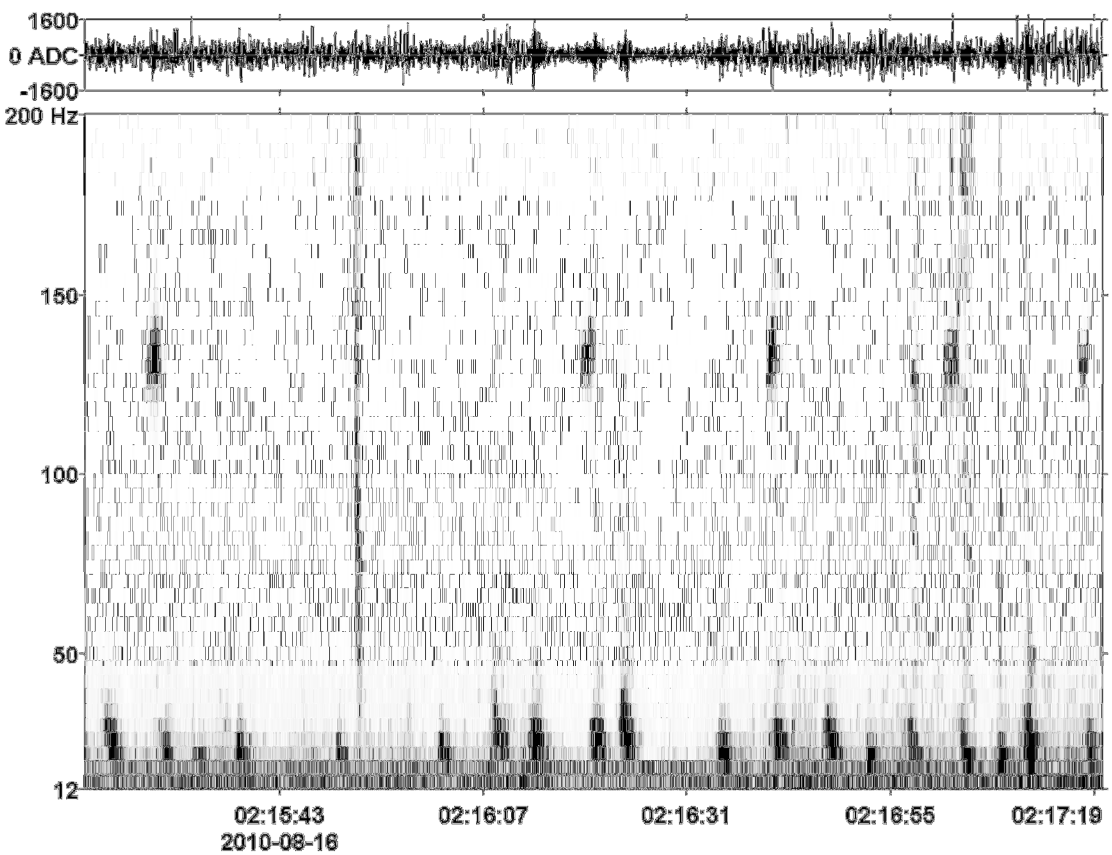


Figure 3.13 Spectrogram of Fin Whale Calls recorded 16 August 2010 at the Middle Station (Hamming window, 8192-point FFT, 512-point overlap). Both the 30–15 Hz downsweeps and 130–140 Hz upsweeps are typical of fin whales.

Sei Whale (*Balaenoptera borealis*)

Calls from one sei whale were detected at the Middle Station on 4 July. The three calls detected (Figure 3.14) were stereotyped downsweeps matching those recorded from sei whales off Massachusetts (Baumgartner *et al.* 2008). Sei whales are not known to occur in the Gulf of St. Lawrence (COSEWIC 2003). Olsen *et al.* (2009) have tracked sei whales in the Labrador Sea via satellite telemetry in spring, and sei whales have been sighted off West Greenland in summer (Heide-Jørgensen *et al.* 2007) so this isolated detection may come from an individual otherwise summering between Labrador and Greenland.

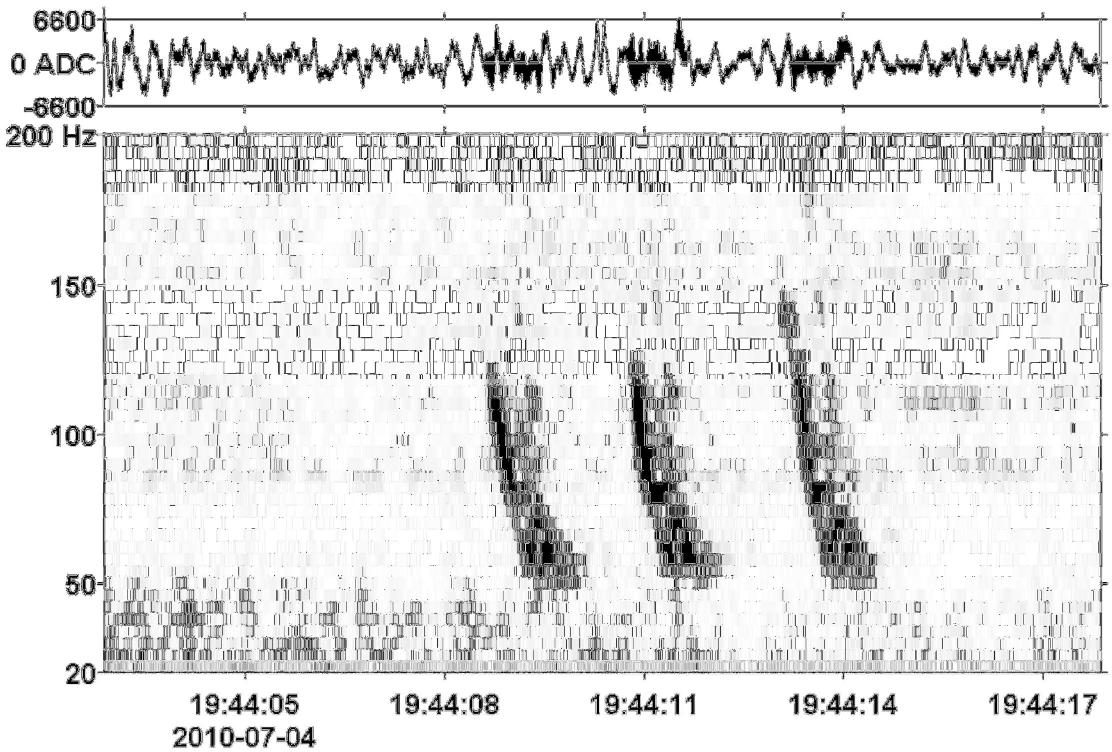


Figure 3.14 Spectrogram of Sei Whale Calls recorded on 4 July 2010 at the Middle Station (Hamming Window, 4096-Point FFT, 1024-Point Overlap).

Unidentified Biological Detections

Many calls of presumed biological origin were encountered whose source could not be identified. Some of these calls were likely produced by pinnipeds. Harp seals are a possible source since individuals are known to remain in the Gulf of St. Lawrence in June and early July (MICS, unpublished data), thus exiting through the SOBI while the recorders were operational. Hooded seals would likely have transited through the area before the recording period. Indeed, all hooded seals equipped with satellite tags that transited through the SOBI out of the Gulf of St. Lawrence did so in early May (Bajzak *et al.* 2009). Grey and harbour seals are rare in the SOBI (Robillard *et al.* 2005) and are unlikely the source of unknown calls.

Fish were also likely responsible for some low-frequency grunting sounds detected throughout the recording period. Gadoids (*e.g.*, cod, haddock) produce various sounds, usually associated with spawning, but also occurring outside of the spawning season (Hawkins and Rasmussen 1978).

Vessel Noise

Vessel noise detections for the SOBI recorders during Deployment 1 are shown in Figure 3.15. Marine life detections were suppressed for any files that had more than two 5-s vessel detections. The Labrador recorder was located near L'Anse-Amour, resulting in many vessel noise detections.

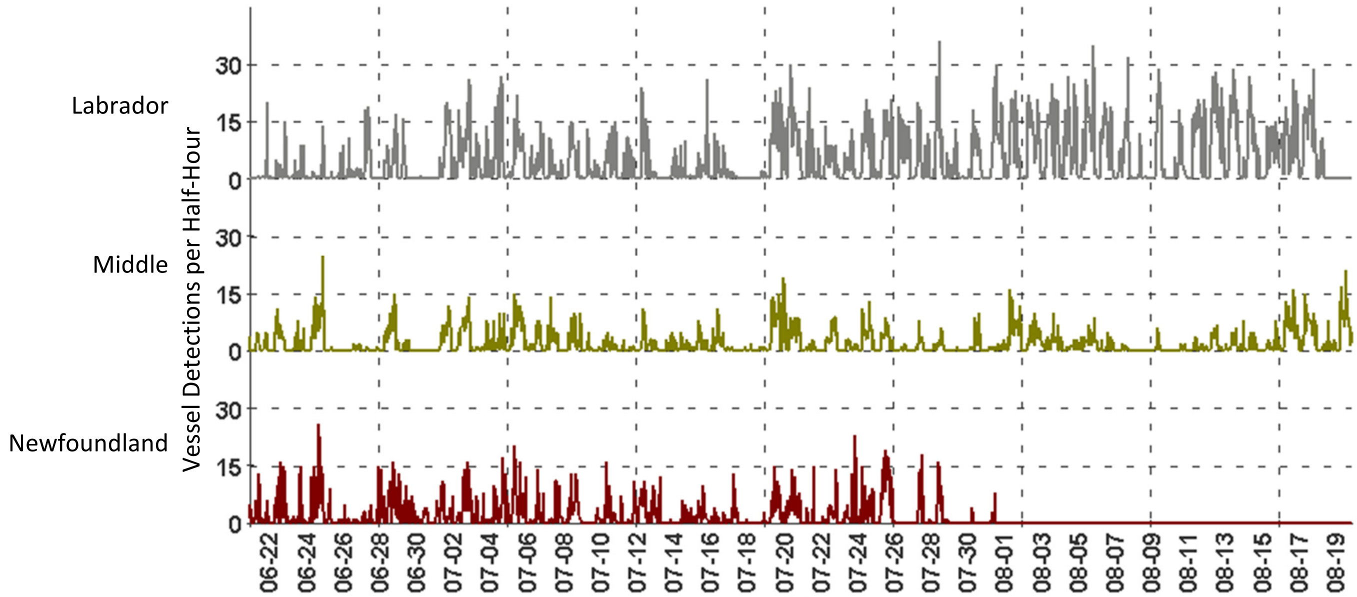


Figure 3.15 Vessel Noise Detections Per 30-min Recording, June to August 2010, in the Strait of Belle Isle.

3.1.2 Ambient Noise

Ambient sound levels for Deployment 1 (June to August 2010) are shown in Figure 3.16. Higher resolution versions of these plots are provided in Appendix B. As expected, all plots show that the lowest frequencies dominate the ambient noise levels. The percentile spectral level plots show that the bounds for the noise are within the Wenz curve limits of prevailing noise (see Figure 2.3). The band-level plots and spectrograms show regular events below 70 Hz that occur approximately twice per day. These events are attributed to real and pseudo-noise from tidal water flow around the hydrophones. The spectrograms and percentile spectral level plots show the flow noise peaks between 20 and 40 Hz, which is attributed to pseudo-noise from the mooring.

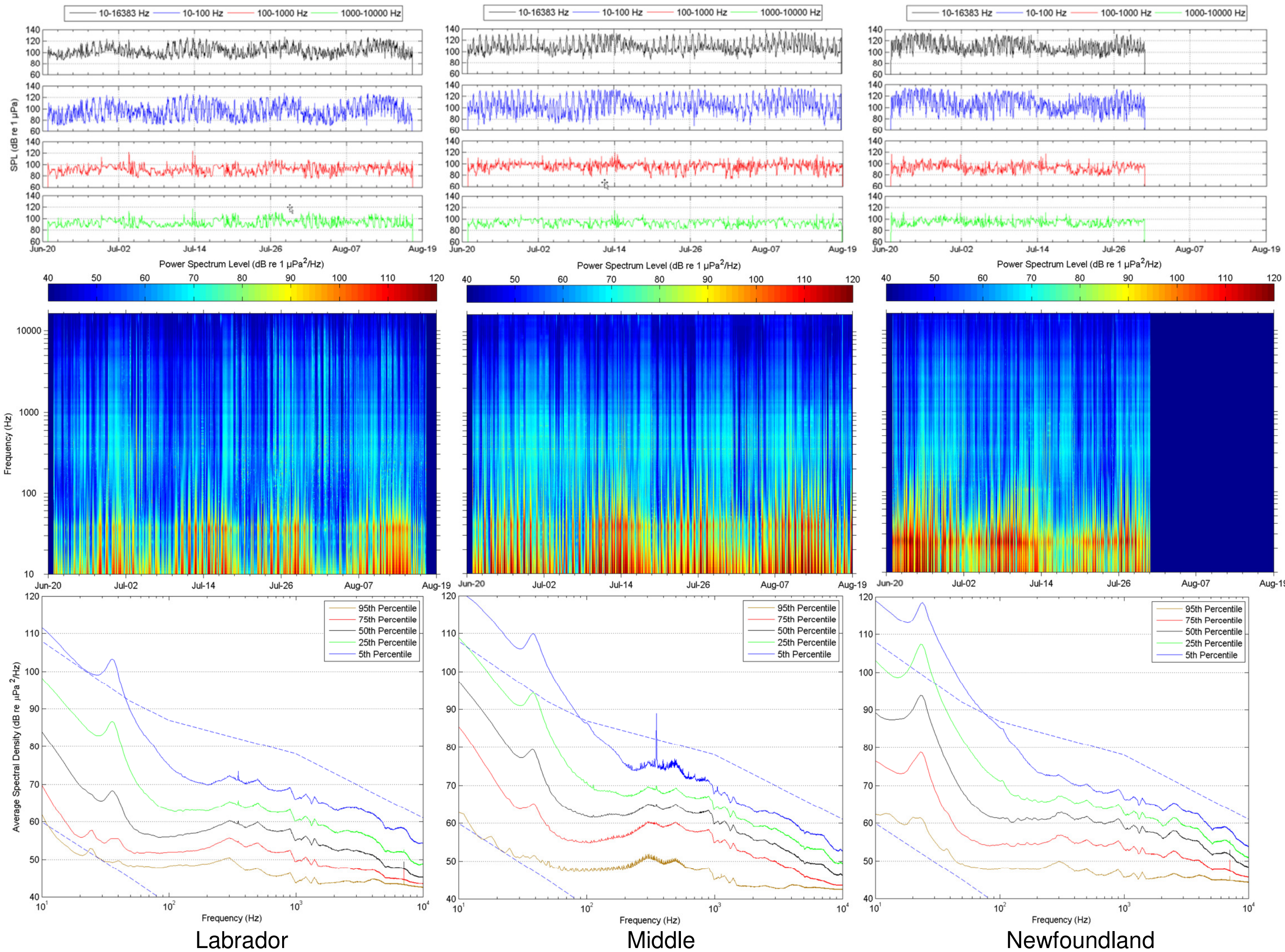


Figure 3.16 (Top) Decade-Band Sound Pressure Levels (SPL), (Middle) Spectrograms, and (Bottom) Percentile 1-min Average Spectral Densities of Underwater Noise at the Labrador, Middle, and Newfoundland Stations, June to August 2010.

Tidal Cycle and Ambient Noise Levels

The 10 to 100 Hz band SPLs (top of Figure 3.16) show that tidal noise has an amplitude modulation with a 14-day period. This is attributed to the lunar cycle of the tides. The lunar distance over the summer is shown in Figure 3.17, time aligned with the 10 to 100 Hz band SPLs for each station.

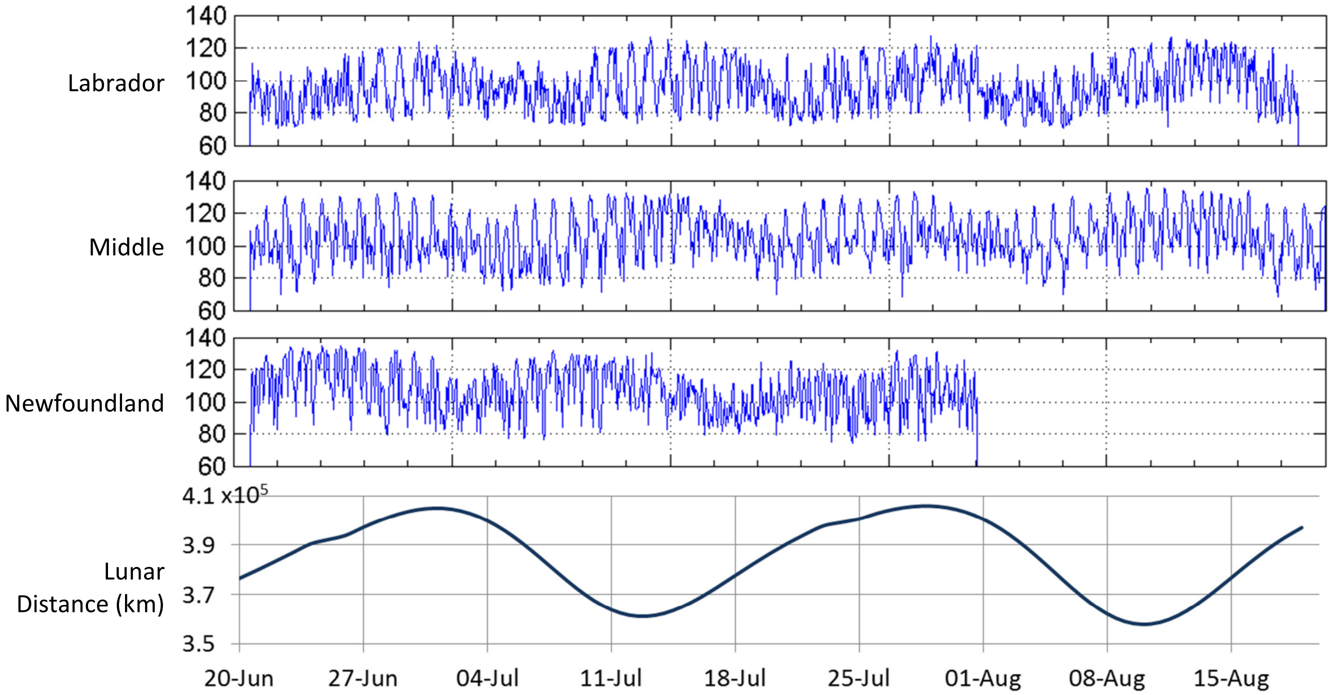


Figure 3.17 Sound Pressure Level (dB re 1 µPa) in the 10 to 100 Hz Band at each station compared to lunar distance during Deployment 1, June to August 2010. The tidal dependence of noise levels is generally minimal during neap tide at the quarter moon.

Marine Mammal Calls and Ambient Noise Levels

The spectrograms have a speckled pattern in the cyan colour range between 100 and 1000 Hz which is due to strong biologic activity having a discernible effect on noise levels (Figure 3.16). For instance, the events around 100 Hz in late July at the Labrador Station are due to humpback whale calls. Similarly the events between 500 and 1000 Hz at the Newfoundland Station in mid-July may be due to killer whale calls (Figure 3.16).

Vessel Noise and Ambient Noise Levels

Throughout the first recording period there are frequent vertical cyan spikes in the spectrograms (middle of Figure 3.16) that are attributed to rain and local vessel traffic. Rain is a broadband noise source with a bandwidth of 2000 to 10,000 Hz or higher.

Vessel traffic in the SOBI is mostly by small- to medium-sized fishing vessels and work boats. These vessels typically have diesel engines with revolutions per minute between 1200 and 3000, or fundamental frequencies of 200 to 500 Hz. These frequencies are then modulated upwards by the multi-bladed propellers and exhausts at or below the waterline. The propellers normally cavitate at all speeds on these vessels which results in a broadband noise effect. Figure 3.18 compares the vessel detections with SPLs in the 100 to 1000 Hz and 1000 to 10,000 Hz bands. Vessel noise is a dominant noise source above 100 Hz, especially above 1000 Hz.

The 5th percentile 1-min average spectral density level for the Middle Station shows a strong spike at 364 Hz. This is attributed to a local vessel making regular passes near the recorder, as shown in Figure 3.19.

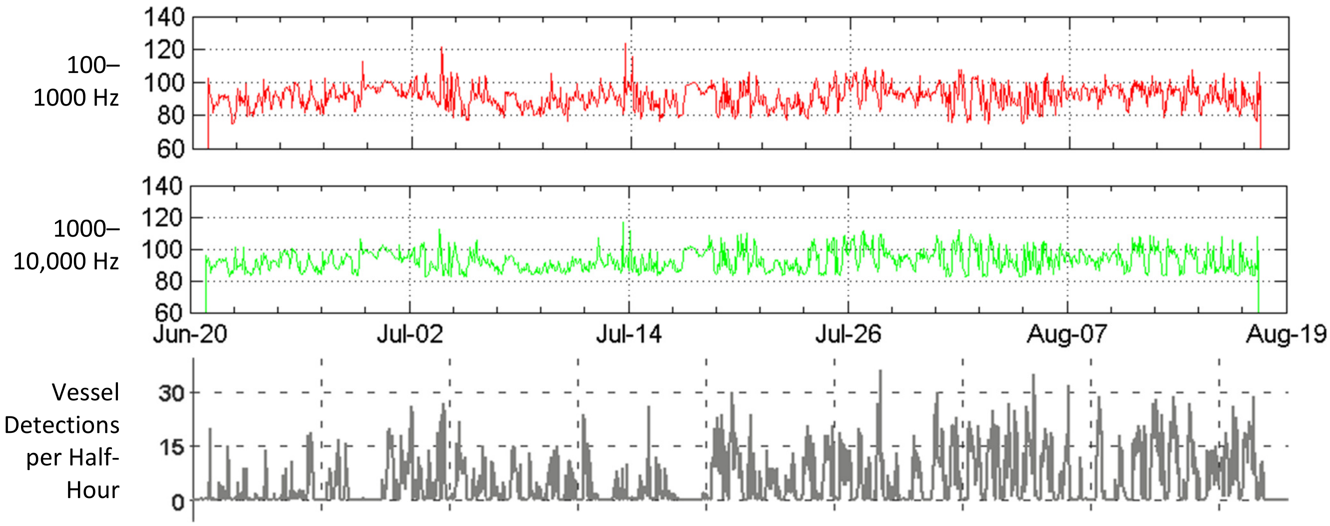


Figure 3.18 Sound Pressure Levels (dB re 1 µPa) in the 100 to 1000 Hz and 1000 to 10,000 Hz Bands Compared to Number of Vessel Noise Detections Per 30-min Recording at the Labrador Station, June to August 2010.

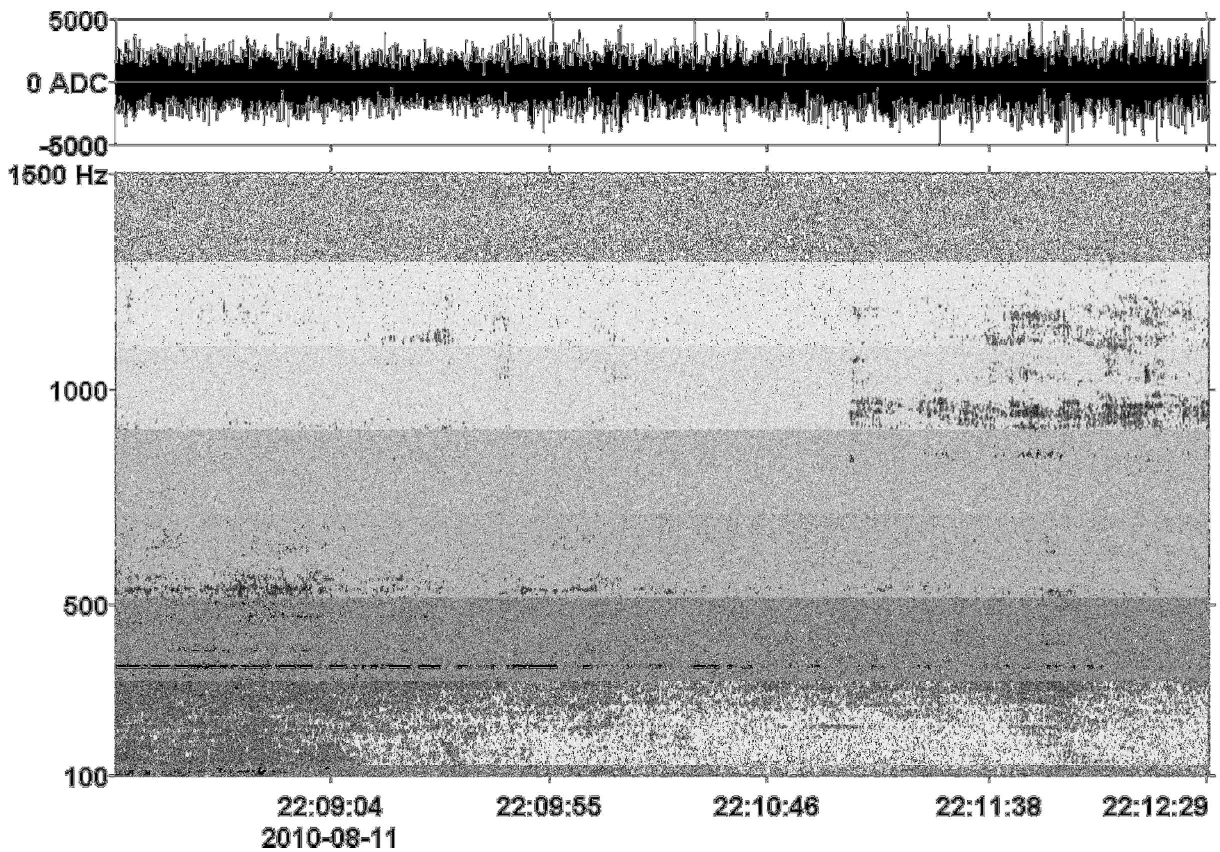


Figure 3.19 (Top) Time-Series and (Bottom) Spectrogram of 364-Hz Tonal and Broadband Noise from Local Vessel Traffic at the Middle Station, 11 August 2010. 4096-point FFT, 1024 point advance.

Variation among Stations

Figure 3.20 compares the third-octave band SPLs for the 50th percentile among recording stations. Sound levels at the Labrador Station were at least 4 dB lower than the maximum of the Newfoundland and Middle Stations in all frequency bands. The Middle Station is highest in the mid-frequencies of 100 to 1000 Hz.

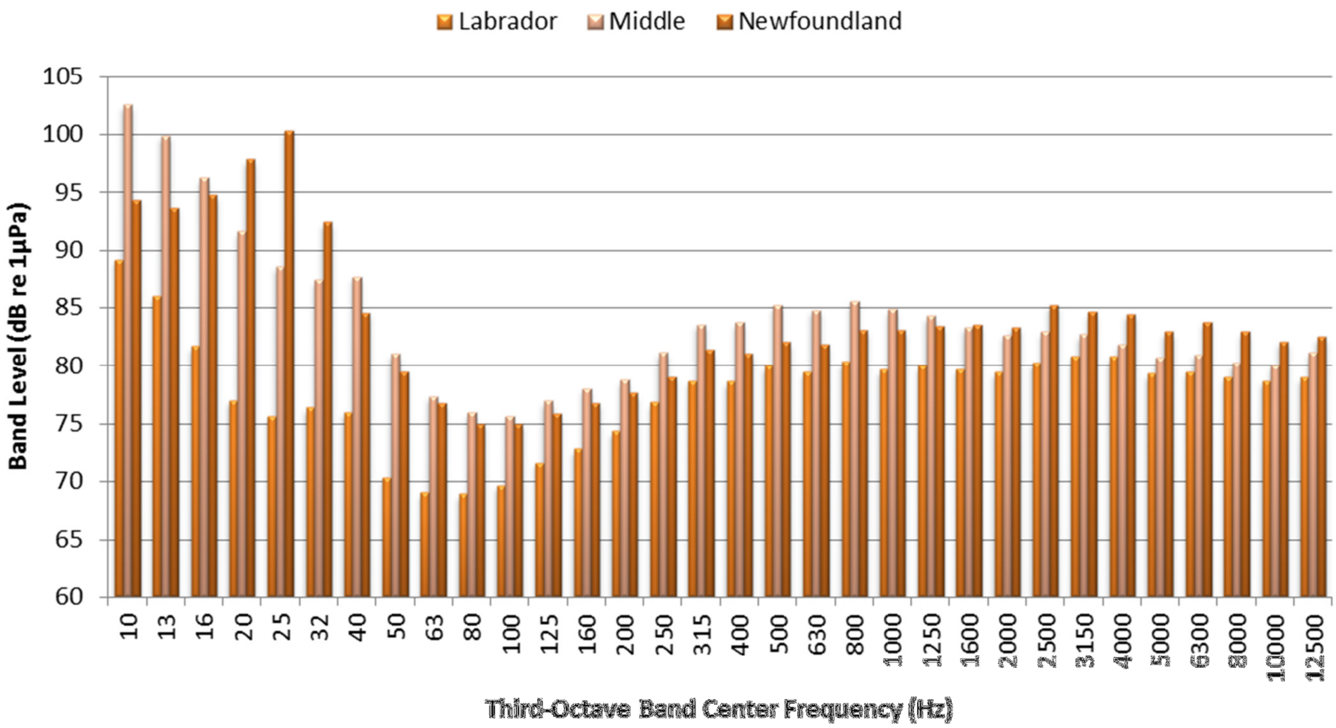


Figure 3.20 Third-Octave Band Sound Pressure Levels for the median of the received sound at each station, June to August 2010.

3.2 Deployment 2: Recording Period September to December 2010

The data analyzed for Deployment 2 consisted only of the Middle Station recordings since the recorders at the Labrador and Newfoundland Stations are not yet retrieved. The only detected marine mammals were fin whales, humpback whales, and dolphins. All three species were recorded quite consistently from early October until early- to mid-November. The large increase in occurrence of fin whale calls compared to Deployment 1 may be due to a larger number of individuals in the area, but most likely to more vocally active individuals due the onset of singing in that species. Humpback whales also appeared to transition to singing behaviour at the end of the Deployment 2 recording period.

Ambient sound levels at the Middle Station during Deployment 2 were 3 to 5 dB higher than during Deployment 1 for frequencies above 80 Hz. Below 80 Hz, sound levels at the Middle Station were 7 dB higher during Deployment 1 than during Deployment 2.

3.2.1 Detections of Marine Mammal Vocalizations

Blue Whale (*Balaenoptera musculus*)

No blue whale calls were detected at the Middle Station during Deployment 2.

Killer Whale (*Orcinus orca*)

No killer whale calls were detected at the Middle Station during Deployment 2.

Humpback Whale (*Megaptera novaeangliae*)

Humpback whales were detected from 30 September until 8 December 2010, with a virtually continuous detection period between 10 October and 8 November (Figure 3.21). Call counts per file peaked between 28 to 30 October, with up to 1000 calls per file (Figure 3.22). These high calling rates, compared to those during Deployment 1, are likely attributable to increased calling rates associated with the onset of singing in this species. Patterned sequences, which may be maturing songs, were detected. These sequences were characterized by numerous and complex calls, yielding high call count estimates. The decrease in detections around mid-November presumably coincides with the departure of humpback whales to Caribbean breeding grounds where they aggregate in winter (Katona and Beard 1990).

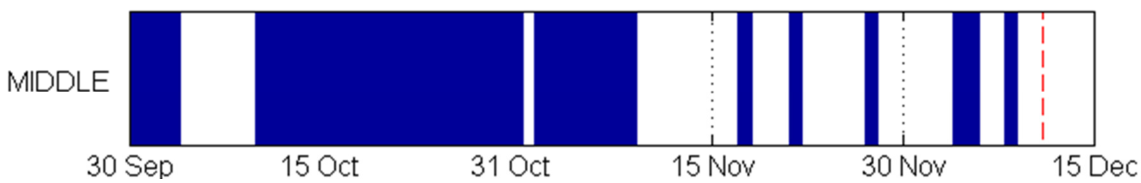


Figure 3.21 Occurrence of Manually Detected Humpback Calls at the Middle Station, September to December 2010. Red dashed lines indicate recording start and end.

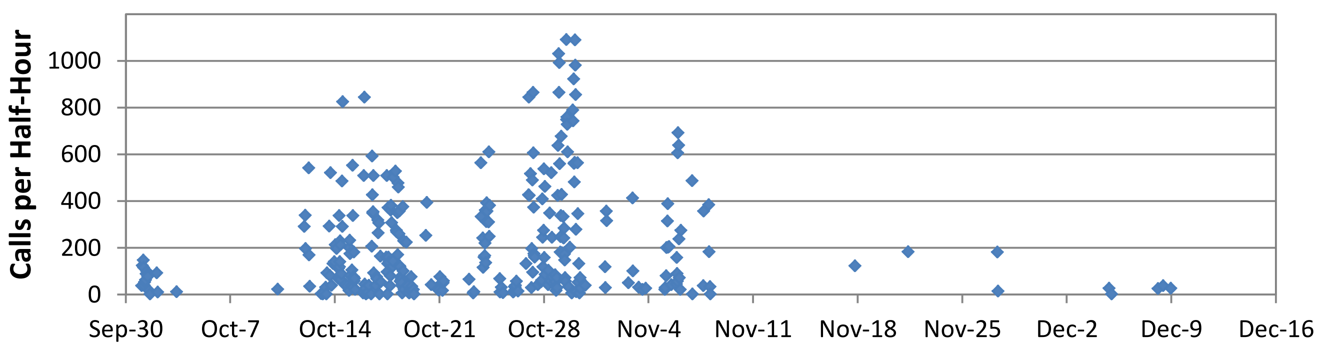


Figure 3.22 Humpback Automated Call Counts per 30-min Recording at the Middle Station from September to December 2010 in the Strait of Belle Isle.

Dolphin (*Lagenorhynchus albirostris, L. acutus*)

The dolphin whistle detections followed a similar temporal trend to humpback whale calls. Whistles were detected from 30 September to 4 December with almost daily detections between 11 October and 14 November (Figure 3.23). Call counts were typically low with the exception of a few peaks in mid- and late October (Figure 3.24). Some whistles detected by manual analysts were too faint to pass the threshold imposed by the detector and thus do not appear in Figure 3.24 (*e.g.*, on 4 December).

Figure 3.23 Occurrence of Manually Detected Dolphin Whistles, September to December 2010. Red dashed lines indicate recording start and end.

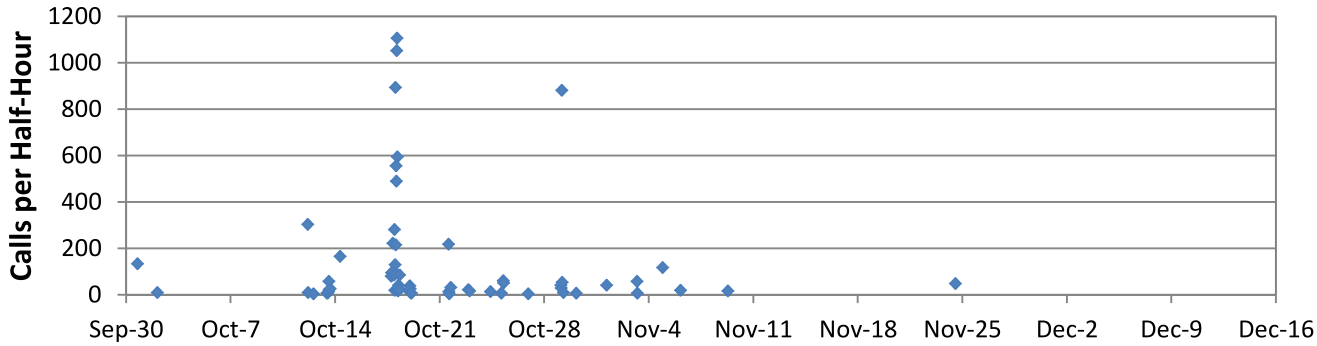


Figure 3.24 Dolphin Whistle Automated Call Counts per 30-min Recording at the Middle Station from September to December 2010 in the Strait of Belle Isle.

Fin Whale (*Balaenoptera physalus*)

Fin whale calls were detected from 30 September to 8 November and on 27 November (Figure 3.25). Call counts per file are shown in Figure 3.26.

All the detections consisted of songs, *i.e.*, stereotyped sequences of identical pulses separated by a constant interval (Watkins 1981). With the exception of the isolated 27 November detection, all songs were characterized by the 12-s pulse interval reported for the Gulf of St. Lawrence fin whales (Delarue *et al.* 2009). The songs detected 27 November were characterized by a 13.5-s pulse interval, consistent with that described for fin whale songs in the Davis Strait in winter (Simon *et al.* 2010).

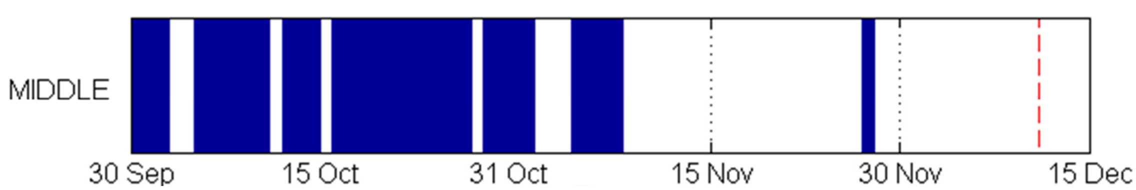


Figure 3.25 Occurrence of Manually Detected Fin Whale Calls, September to December 2010. Red dashed lines indicate recording start and end.

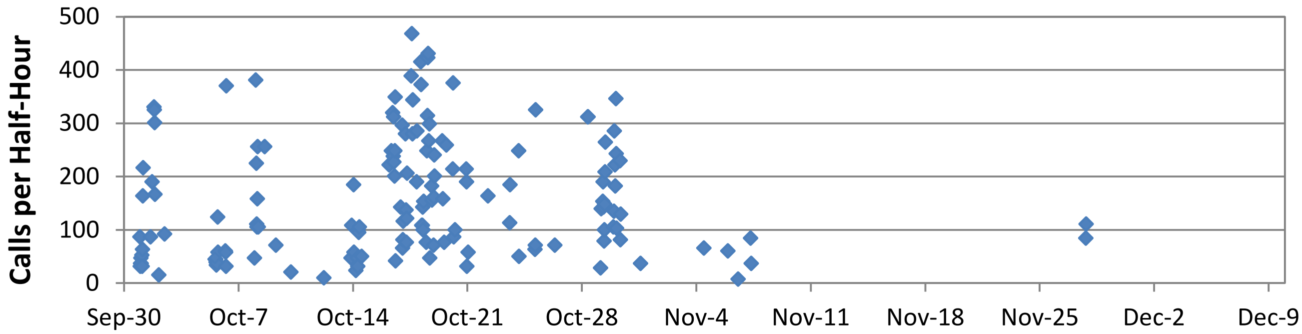
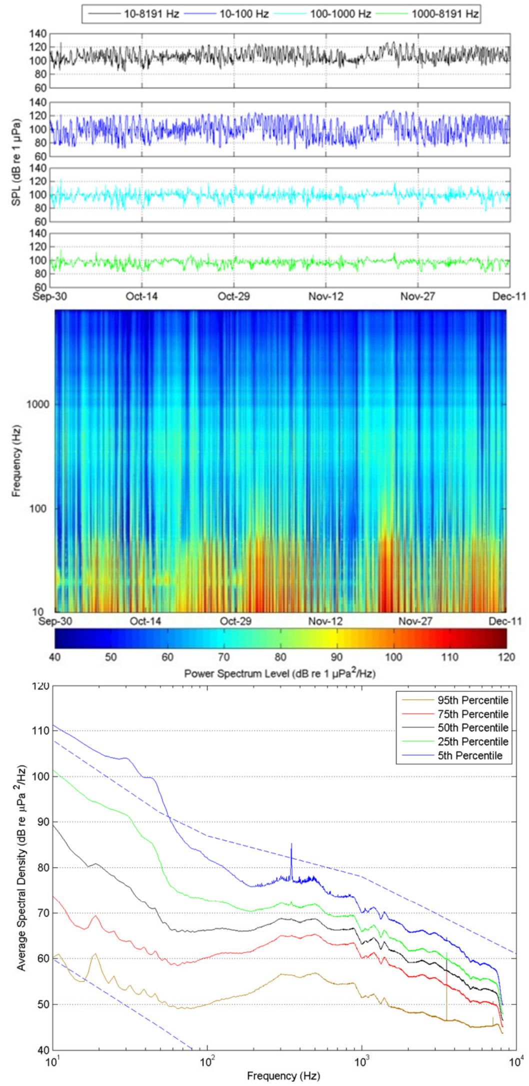


Figure 3.26 Fin Whale Automated Call Counts per 30-min Recording at the Middle Station from September to December 2010 in the Strait of Belle Isle.

3.2.2 **Ambient Noise**

Ambient sound levels during Deployment 2 at the Middle Station are shown in Figure 3.27. The plots show similar structure to those of Deployment 1. The real and pseudo-noise from tidal water flow around the hydrophone caused regular peaks below 70 Hz and has an amplitude modulation from the lunar cycle. The same 364 Hz source detected in the 5th percentile spectrum at the Middle Station during Deployment 1 was also detected in the 5th percentile spectrum of Deployment 2.



Middle

Figure 3.27 (Top) Decade-Band Sound Pressure Levels (SPL), (Middle) Spectrograms, and (Bottom) Percentile 1-min Average Spectral Densities of Underwater Noise at the Middle Station, September to December 2010.

Seasonal Variation

The 50th percentile spectrum indicates that the average sound levels for Deployment 2, September to December 2010, are approximately 5 dB above those of Deployment 1, June to August 2010. This is attributed to increased storm activity in the fall and winter. The median third-octave band levels for the Middle Station during Deployments 1 and 2 are shown in Figure 3.28. This clearly shows the higher sound levels for frequencies above 63 Hz for Deployment 2 compared to Deployment 1.

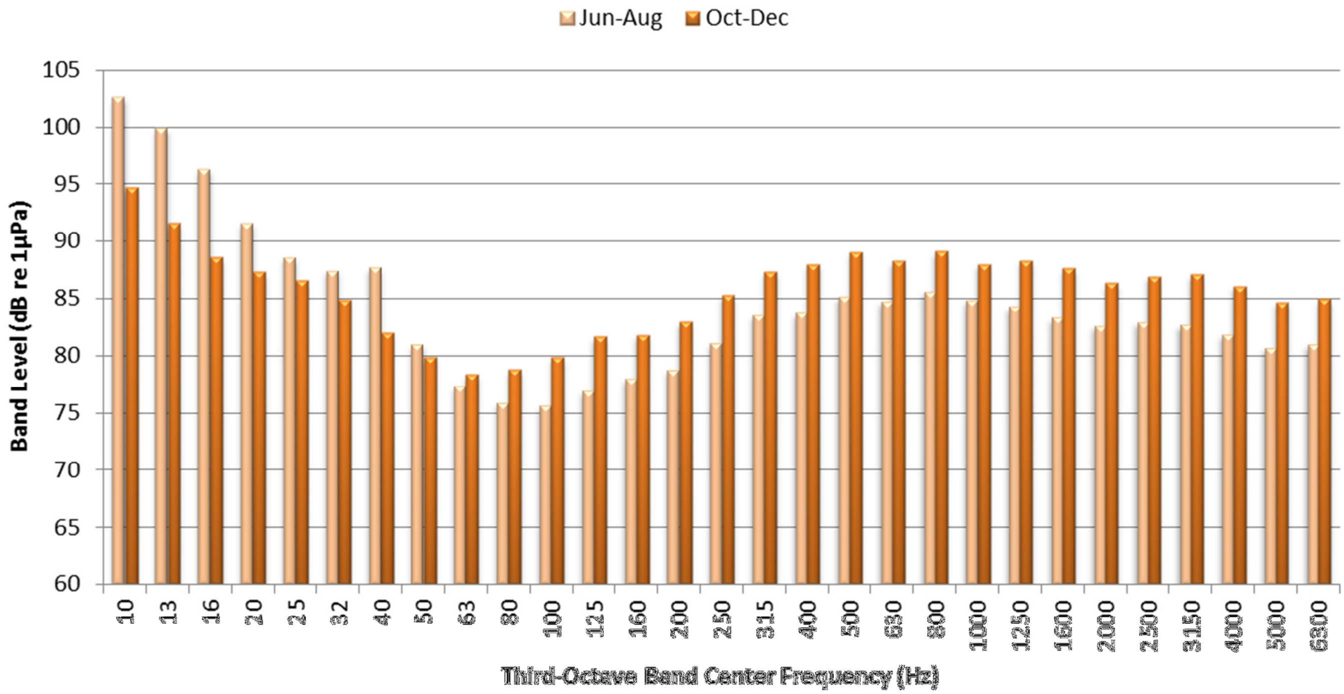


Figure 3.28 Median (50th percentile) Third-Octave Band Sound Pressure Levels at the Middle Station during the June to August (Deployment 1) and September to December (Deployment 2) 2010 recording periods.

4.0 SUMMARY

Nalcor Energy is proposing to develop an HVdc transmission system extending from Central Labrador to the Island of Newfoundland's Avalon Peninsula. The EA of the Project is ongoing, with an EIS currently being completed by Nalcor Energy.

In preparation for and support of the Project's EA, this *Ambient Noise and Marine Mammal Survey* was completed with the objective to collect and present information on underwater ambient sound levels and marine mammal acoustic presence in the Strait of Belle Isle.

Acoustic data were recorded in summer and fall 2010 at three locations along or near the two identified cable corridors across the Strait of Belle Isle. Acoustic recorders were deployed and recorded data for two recording periods: initially data was recorded from the three locations from June to August, and then re-deployed to record data from September to December.

Analysis of acoustic data confirmed the presence of several marine mammal species during the survey periods. Humpback whales, killer whales, and dolphins (*Lagenorhynchus* sp.) accounted for most of the acoustic detections. The main detection period for humpback whale calls and dolphin whistles was before 10 November. Killer whale calls were detected at all three stations but were rare after the beginning of August, and were not detected during the September to December recording period. The greatest number of detections for these species was observed from the recorder near the middle of the Strait, followed closely by the Labrador Station. The Newfoundland Station recorded considerably less biological acoustic activity. Blue whale calls and a sei whale call were detected sporadically during the June to August recording period, with the blue whale calls detected at the Newfoundland Station and the sei whale call detected at the Middle Station. Fin whale calls were detected sporadically during the June to August recording period and almost daily until 8 November during the September to December recording period, which coincides with the onset of singing and may not necessarily mean an increased number of fin whales in the area. Additional biological activity was detected but could not be uniquely identified, and there were no confirmed pinniped recordings.

Ambient noise levels in the SOBI are well within the Wenz curve limits of prevailing noise. Below 100 Hz real and pseudo-noise from tidal water flow dominate the measured noise. Above 100 Hz local vessel traffic is the dominant noise source when present. Noise measured from the recorder in the Middle of the Strait was 5 dB higher during the September to December recording period than during the June to August period.

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Appendix A

Automated Detector Performances and Call Count Estimation

APPENDIX A AUTOMATED DETECTOR PERFORMANCES AND CALL COUNT ESTIMATION

A.1 Dataset

The performance of the automated vocalization detectors was tested using the fully-manually-annotated 90-s samples. Because manual analysis was performed on data samples from all three recorders throughout Deployment 1, the test dataset of fully-manually-annotated samples represents well the noise conditions in the study area throughout the survey period. Table A.1 shows the number of vocalizations in the fully-annotated samples for each species. Fewer than 100 vocalizations were annotated manually for both blue and sei whales, so the performance metrics (Precision and Recall, see below) could not be calculated.

Table A.1 Number of fully-manually-annotated samples and associated vocalizations used to calculate the automated detector performance metrics for fin, humpback, and killer whales and dolphins.

Species	Samples	Vocalizations
Fin whale	23	159
Humpback whale	33	250
Killer whale	16	291
Dolphins	11	329

A.2 Definitions: *TP*, *TN*, *FN*, and *FP*

The decisions made by classifiers/detectors can be represented by a structure known as a confusion matrix. This confusion matrix consists of four categories: true positives (*TP*), false positives (*FP*), true negatives (*TN*) and false negatives (*FN*). Table A.2 depicts the confusion matrix, where 'P' is the signal event we want to detect/classify and 'N' is a non-event that we don't want to detect/classify (*i.e.*, noise). The definition of 'P' varies depending on the detector or classifier.

Table A.2 Confusion matrix.

		True Result	
		P	N
Classification Result	P	*TP*	*FP*
	N	*FN*	*TN*

A true positive (*TP*) corresponds to a signal of interest being correctly classified as such. A false negative (*FN*) is a signal of interest being classified as noise (*i.e.*, missed). A false positive (*FP*) is a noise classified as a signal of interest (a.k.a. a false alarm). A true negative (*TN*) is a noise correctly classified as such.

TP, *FP*, and *FN* were calculated for each detector by comparing manual annotations of detections with detections from the automated detector analysis of the entire dataset, where assuming the manual annotations were assumed to be correct. *TP* and *FN* were calculated on all annotated calls (vocalization recordings). If an annotation is well detected then it is a *TP*, otherwise it's a *FN*. As recordings are not fully annotated (only 1 annotation per species and per sample) FPs are calculated on recordings that don't have any annotations of the target species (noise recordings). If the number of false alarms in the tested recording is greater than zero then the total number of *FP* is increased by one. Noise recordings were randomly selected such that the number of noise recordings equals the number of vocalization recordings. FPs are re-calculated 100 times by re-shuffling the noise recordings. The final *FP* is the average of all the *FP* values obtained.

A.3 Performance Metrics: Precision and Recall

To assess the performance of the detectors, the precision and recall metrics were calculated from *TP*, *FP*, and *FN*:

$$precision = \frac{TP}{TP + FP} \quad recall = \frac{TP}{TP + FN} \tag{1}$$

The precision can be seen as a measure of exactness, and the recall is a measure of completeness. For instance, a precision score for humpback whale of 0.9 means that 90% of the detections classified as humpback were in fact humpback calls, but says nothing about whether all the humpback vocalizations from the dataset were identified. A recall score for humpback of 0.8 means that 80% of all the humpback vocalizations in the dataset were correctly classified, but says nothing about how many of those classifications were wrong. Thus, a perfect detector/classifier would have precision and recall scores of 1. Note that the precision or recall alone cannot describe the performance of a detector/classifier on a given dataset, both metrics are required.

The precision-recall (*P-R*) metric presents advantages over the True-Positive Rate (TPR) and False-Positive Rate (FPR) generally used in Receiver Operating Characteristic (ROC) curves. Firstly, this metric is more adapted to skewed datasets. Secondly, it has been demonstrated that an algorithm dominates in ROC space if and only if it dominates in *P-R* space (Davis and Goadrich 2006). Finally, a significant advantage of using *P-R* values over ROC values comes in defining a *TN* count in continuous data. A subjective criterion is necessary to define a length of time that counts as one *TN* value over a continuous recording that contains no targeted vocalizations, whereas *TN* need not be calculated for the *P-R* metric. Therefore, using *P-R* values is better suited to the analysis of the summer data.

A.4 Call Count Estimation

A realistic estimation of call counts can be achieved with the use of the precision (*P*) and recall (*R*) values obtained. These values characterize the relationship between the detector/classifier and the dataset. Therefore, these values are specific and are dependent to both the classifier and the dataset and changing either will result in new *P* and *R* values. Provided that the subset of data used to characterize *P* and *R* are a good representation of the entire dataset, these values can be used to extrapolate the total number of vocalizations for a given species as follows. The total number of detections (N_{det}) found by the classifier is the sum of the true and false positives.

$$N_{\text{det}} = TP + FP \tag{2}$$

and from the definition of *P* (Equation 1), *TP* can be defined as:

$$TP = P \cdot (TP + FP) = P \cdot N_{\det} \tag{3}$$

The total number of vocalizations in the data (N_{voc}) is the sum of those correctly identified (*TP*) and those that were missed (*FN*):

$$N_{voc} = TP + FN \tag{4}$$

Therefore *R* (Equation 1) becomes:

$$R = \frac{TP}{TP + FN} = \frac{TP}{N_{voc}} \tag{5}$$

Combining Equations 3 and 5 yields the total number of vocalizations in terms of the number of detections, *P*, and *R*:

$$N_{voc} = \frac{TP}{R} = \frac{P \cdot N_{\det}}{R} \tag{6}$$

Appendix B

Ambient Noise Results

APPENDIX B AMBIENT NOISE RESULTS

B.1

B.1.1

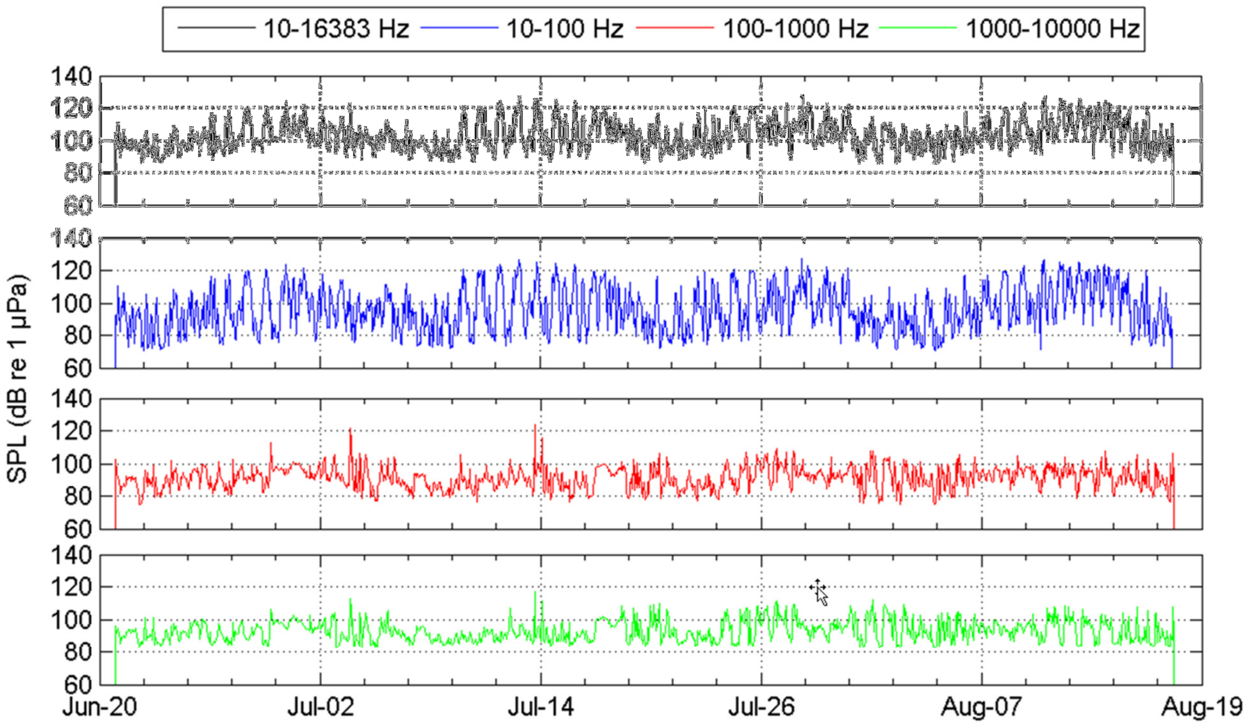

Figure B.1 Decade-Band Sound Pressure Levels (SPL) of Underwater Noise at the Labrador Station, June to August 2010.

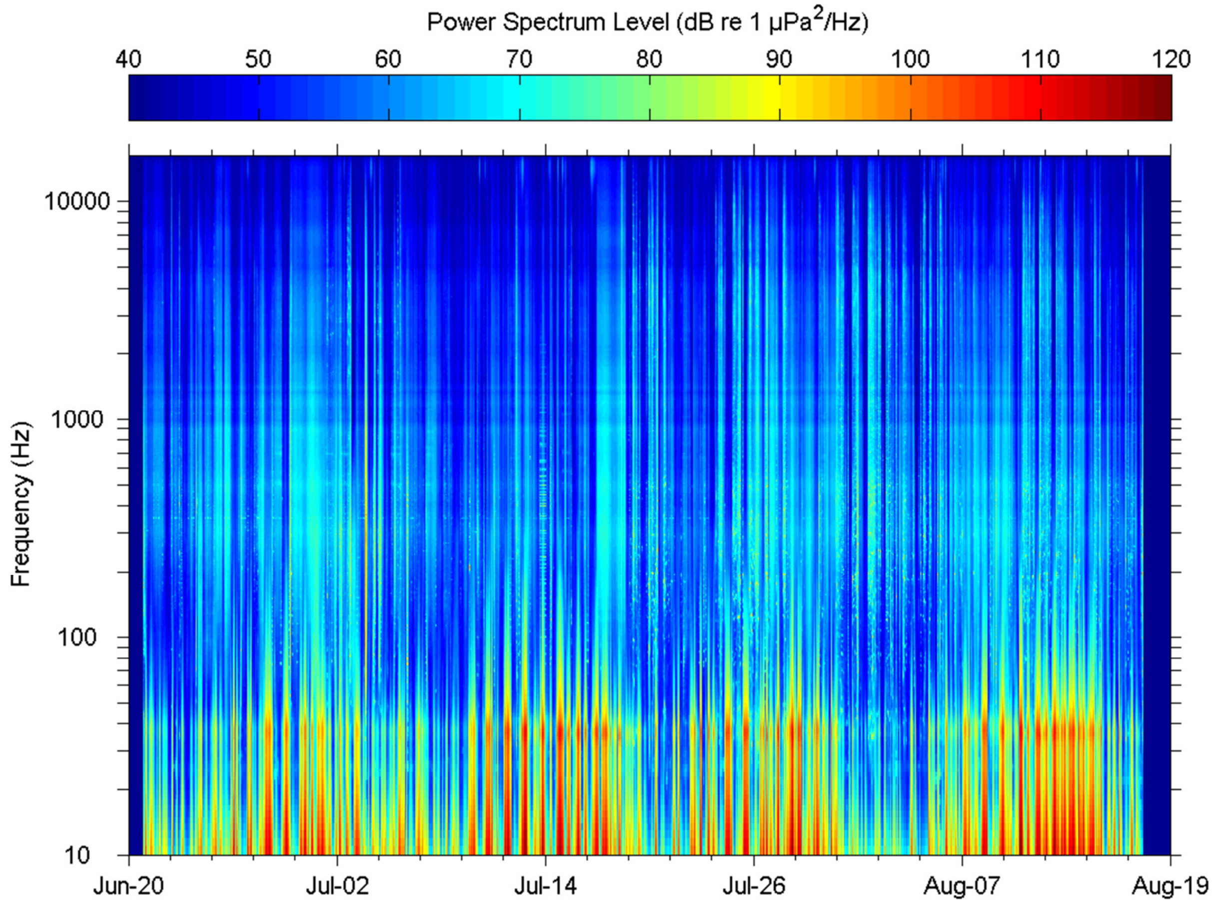

Figure B. 2 Spectrogram of Underwater Noise at the Labrador Station, June to August 2010.

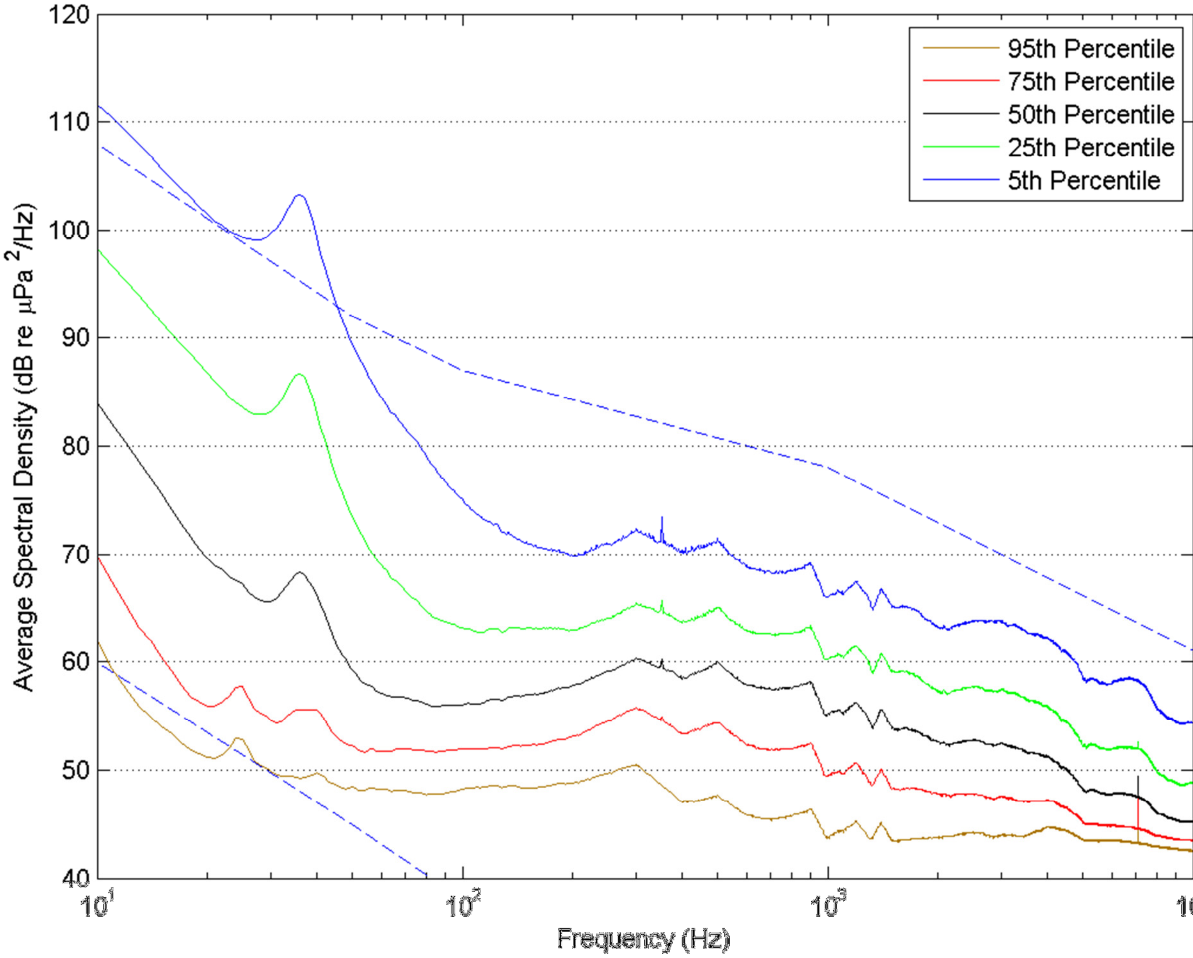

Figure B.3 Percentile 1-min Average Spectral Density Levels of Underwater Noise at the Labrador Station, June to August 2010. Dashed lines are the Wenz curve limits of prevailing noise (see Figure 2.3).

B.1.2

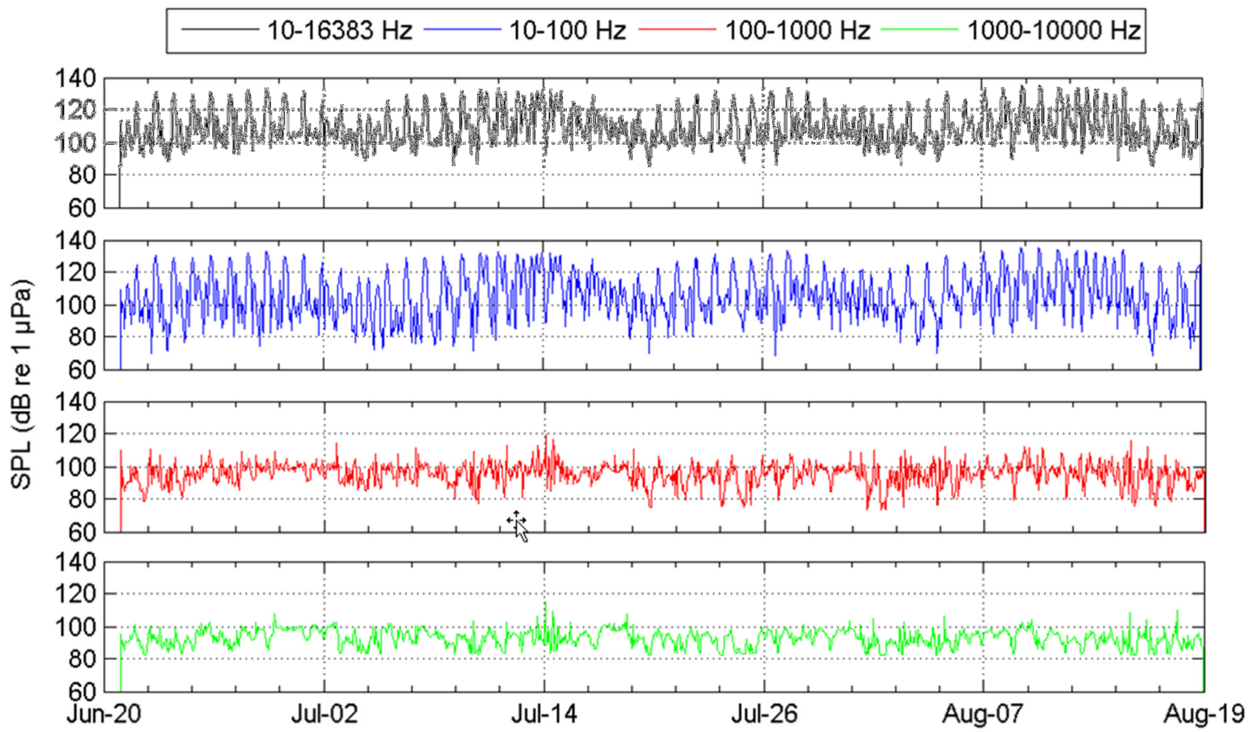

Figure B.4 Decade-Band Sound Pressure Levels (SPL) of Underwater Noise at the Middle Station, June to August 2010.

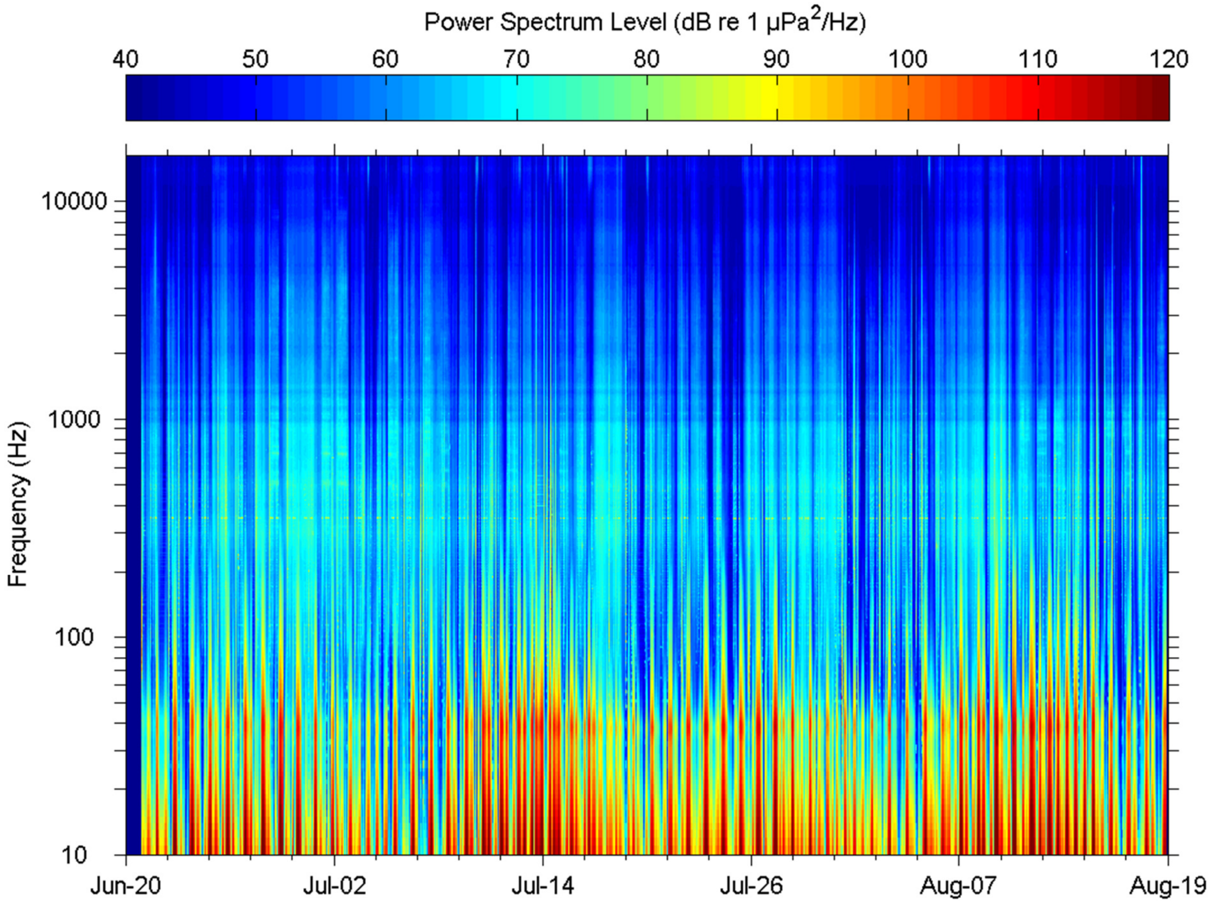

Figure B.5 Spectrogram of Underwater Noise at the Middle Station, June to August 2010.

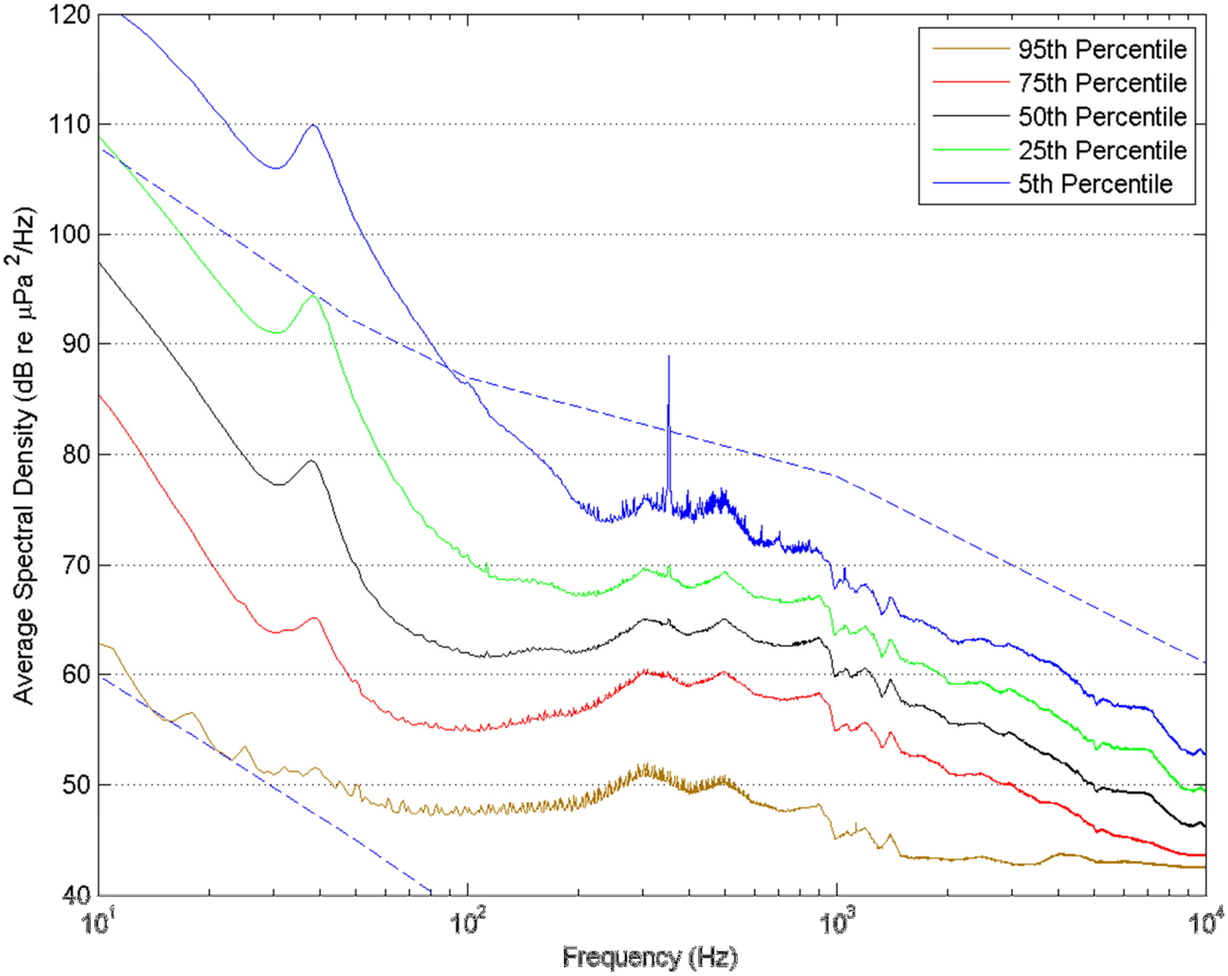

Figure B.6 Percentile 1-min Average Spectral Density Levels of Underwater Noise at the Middle Station, June to August 2010. Dashed lines are the Wenz curve limits of prevailing noise (see Figure 2.3).

B.1.3

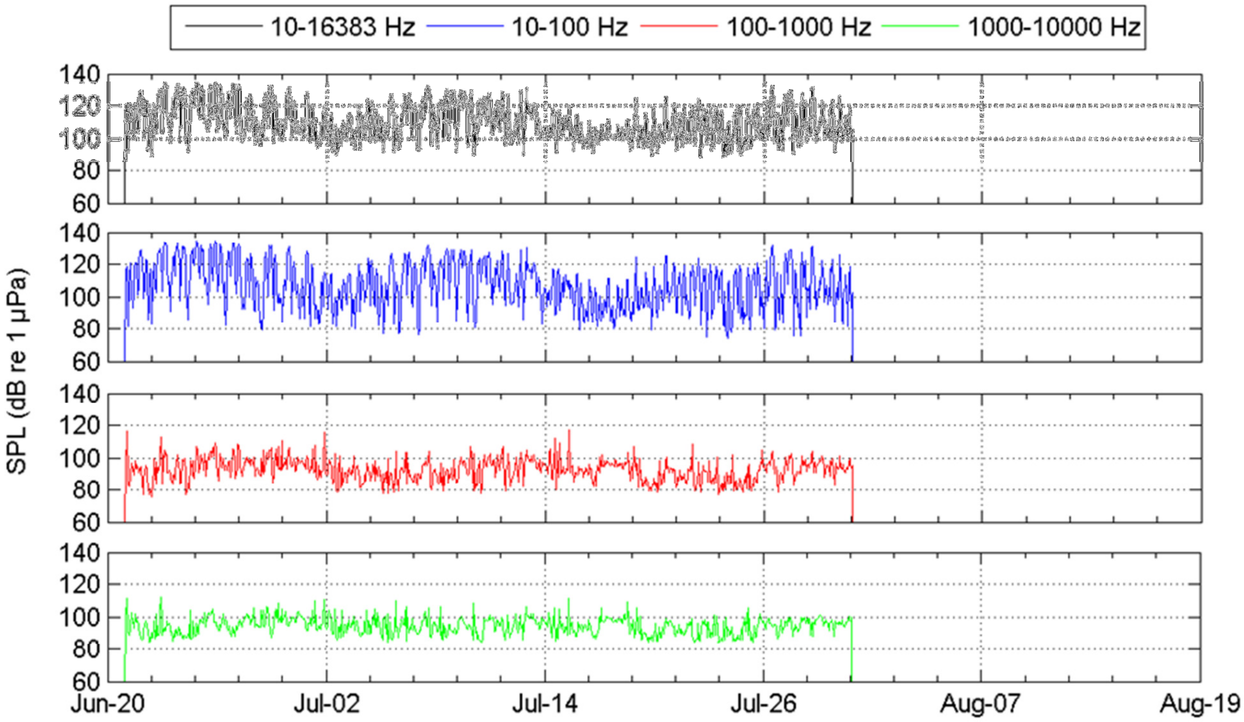

Figure B.7 Decade-Band Sound Pressure Levels (SPL) of Underwater Noise at the Newfoundland Station, June to August 2010.

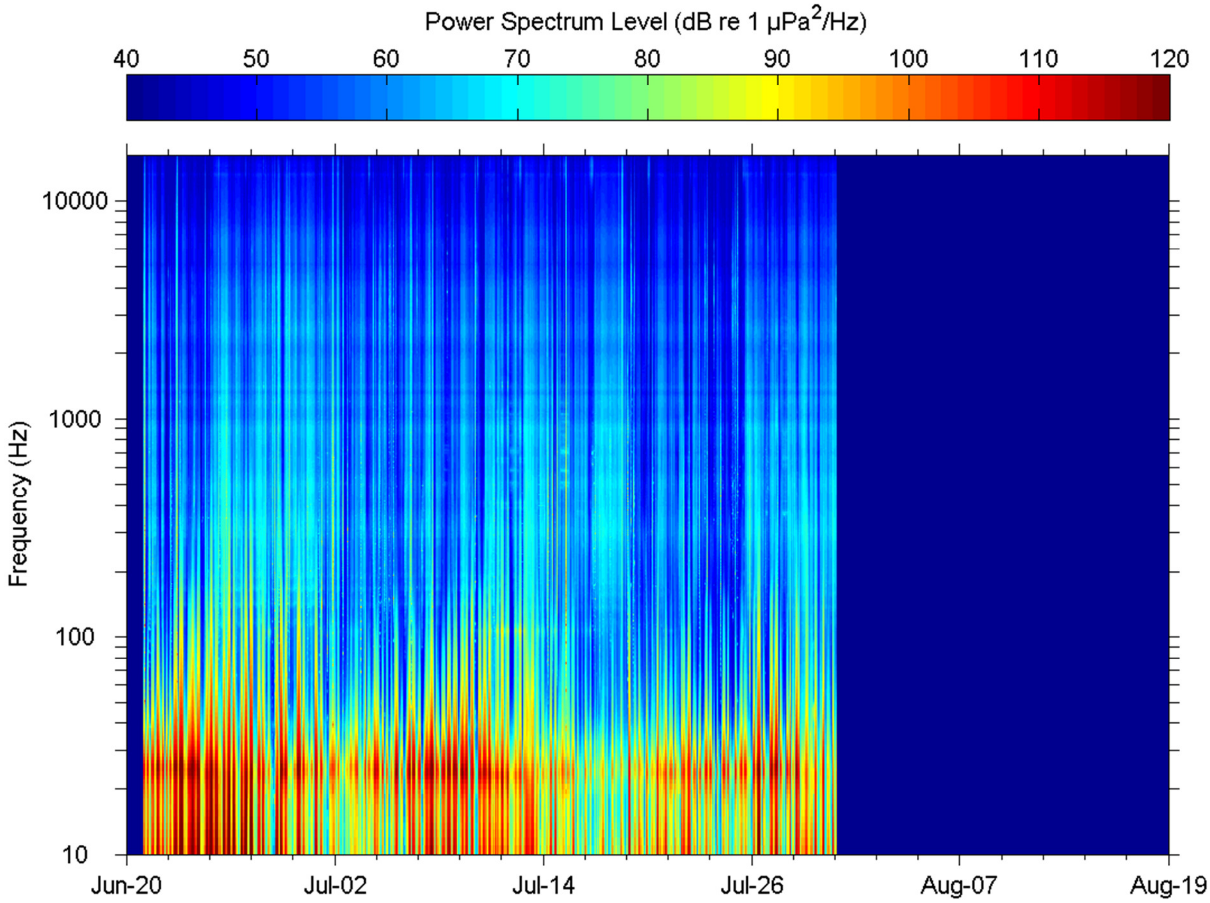

Figure B.8 Spectrogram of Underwater Noise at the Newfoundland Station, June to August 2010.

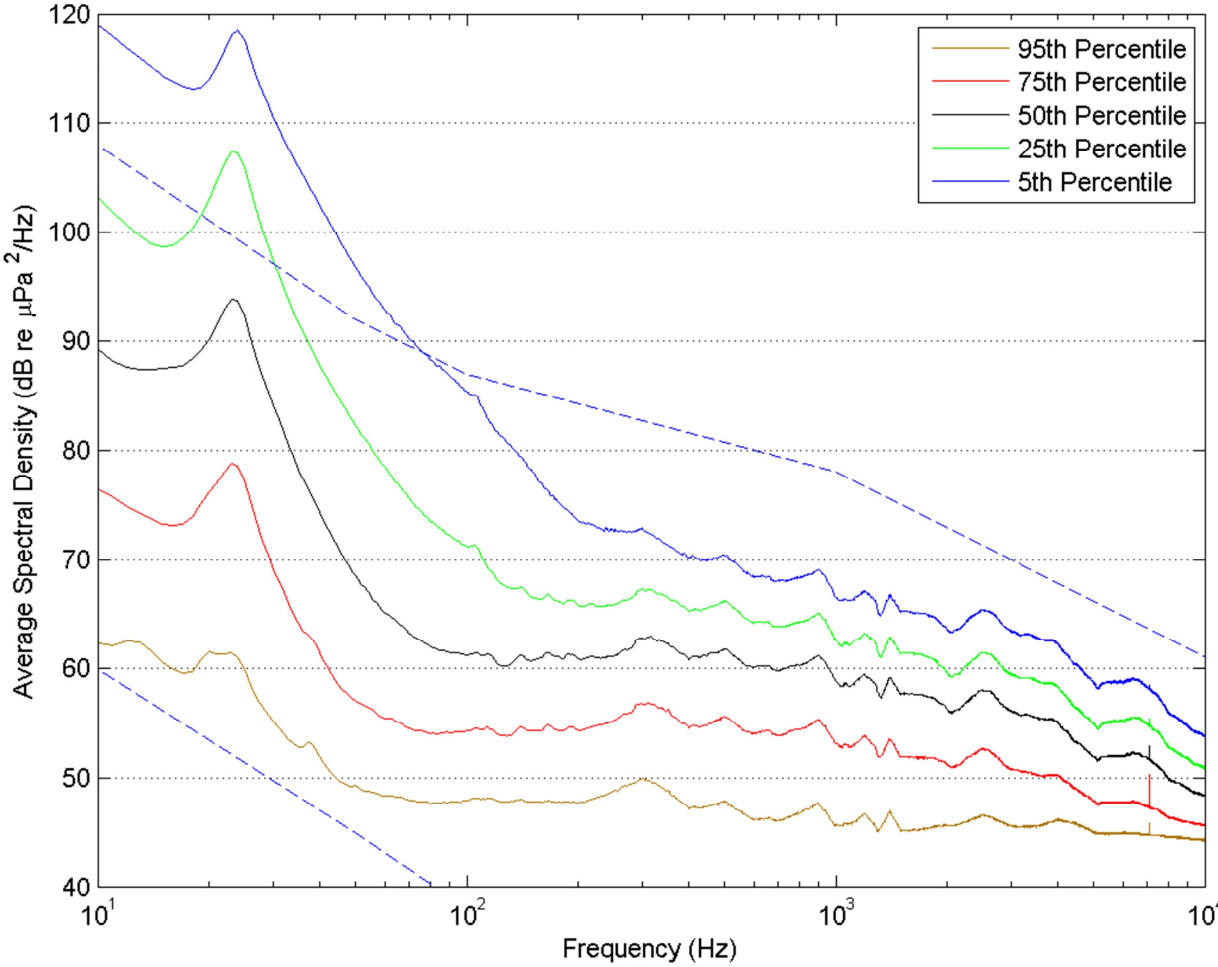

Figure B.9 Percentile 1-min Average Spectral Density Levels of Underwater Noise at the Newfoundland Station, June to August 2010. Dashed lines are the Wenz curve limits of prevailing noise (see Figure 2.3).

B.2

B.2.1

The Labrador recorder has yet to be retrieved.

B.2.2

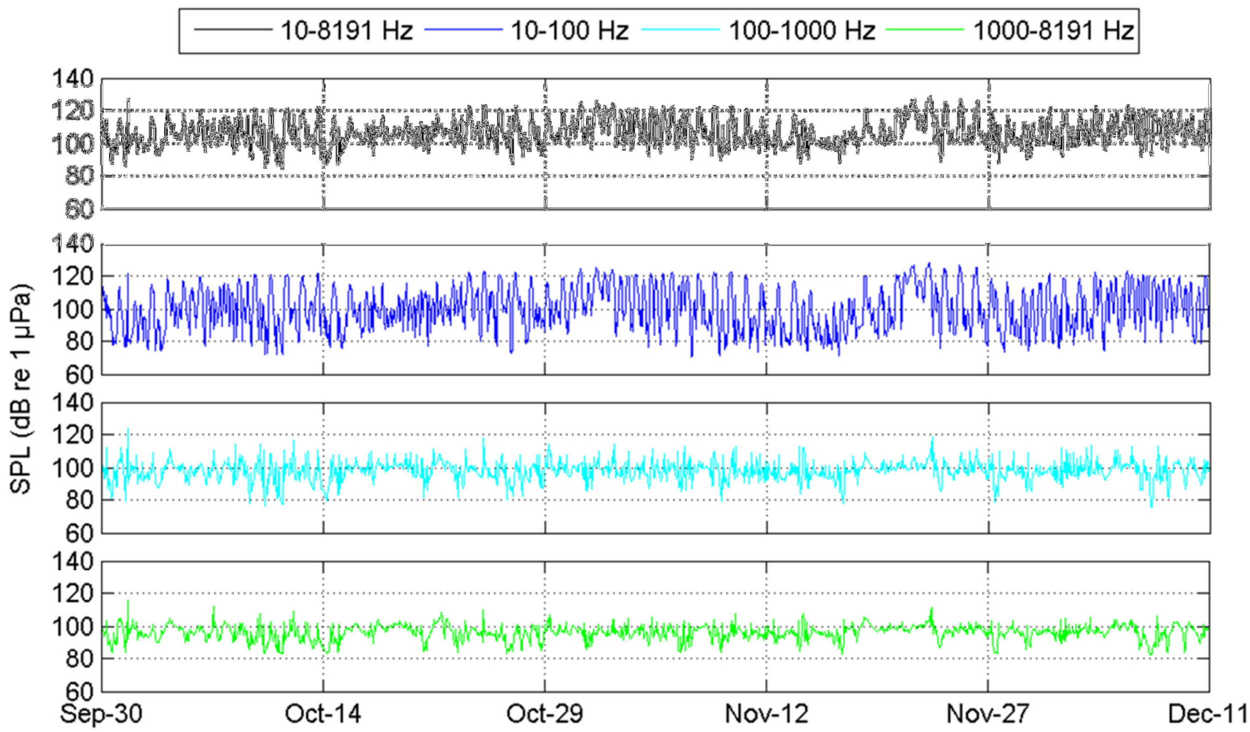

Figure B.10 Decade-Band Sound Pressure Levels (SPL) of Underwater Noise at the Middle Station, September to December 2010.

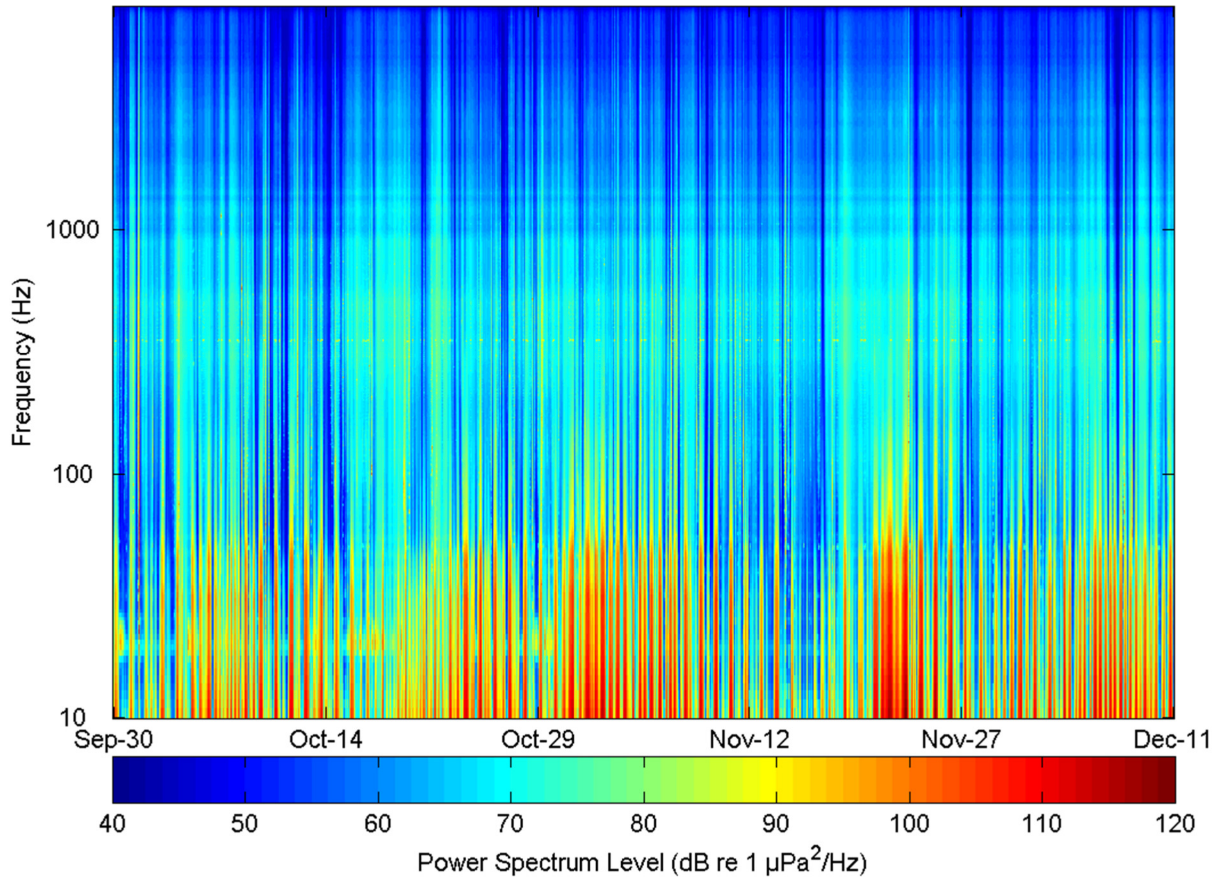

Figure B.11 Spectrogram Plot for the Middle Station, September to December 2010.

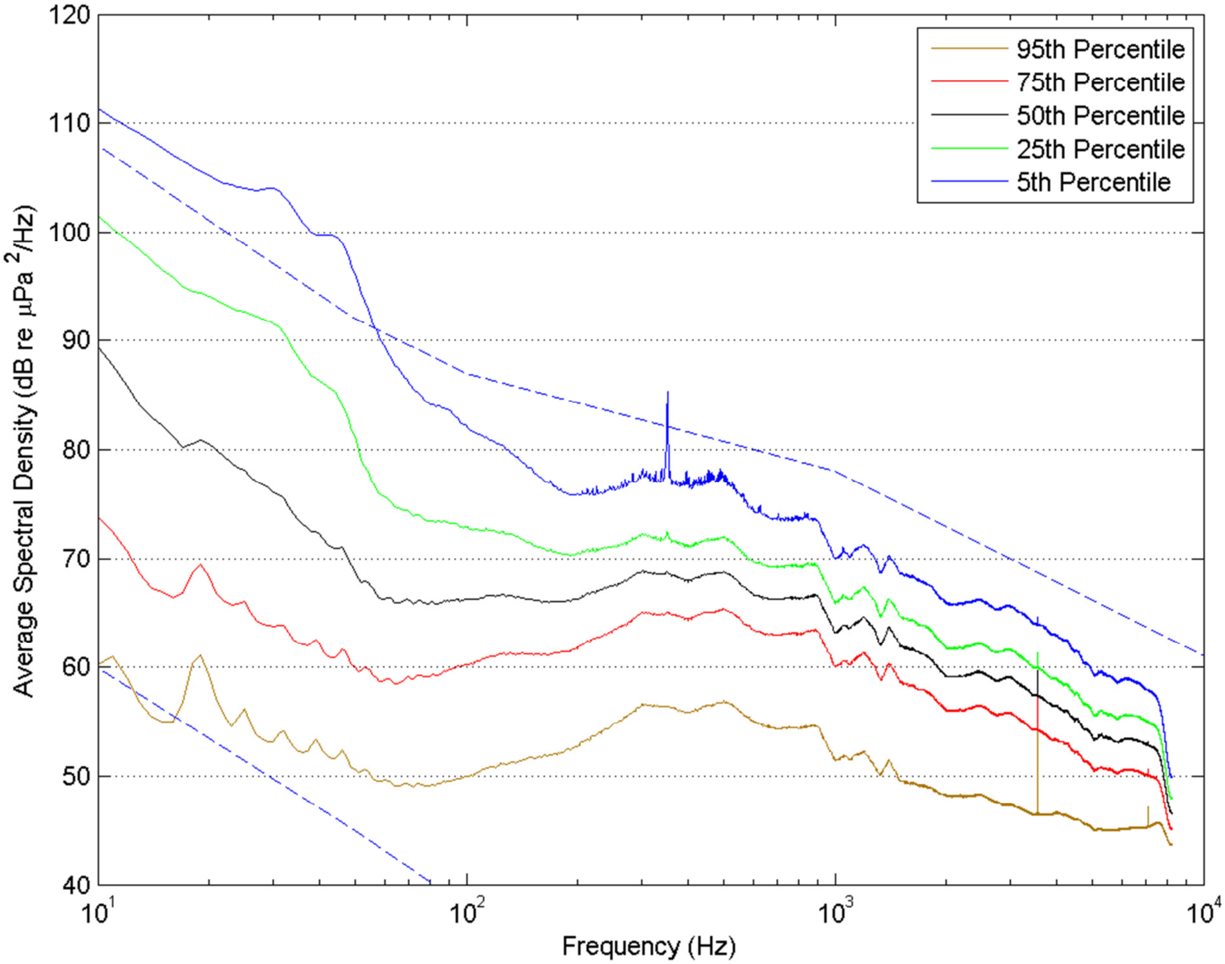

Figure B.12 Percentile 1-min Average Spectral Density Levels of Underwater Noise at the Middle Station, September to December 2010. The large spike near 360 Hz in the 5th percentile is likely due to a strong source on a vessel regularly passing the Middle Station. Dashed lines are the Wenz curve limits of prevailing noise (see Figure 2.3)

B.2.3

The Newfoundland recorder has yet to be retrieved.