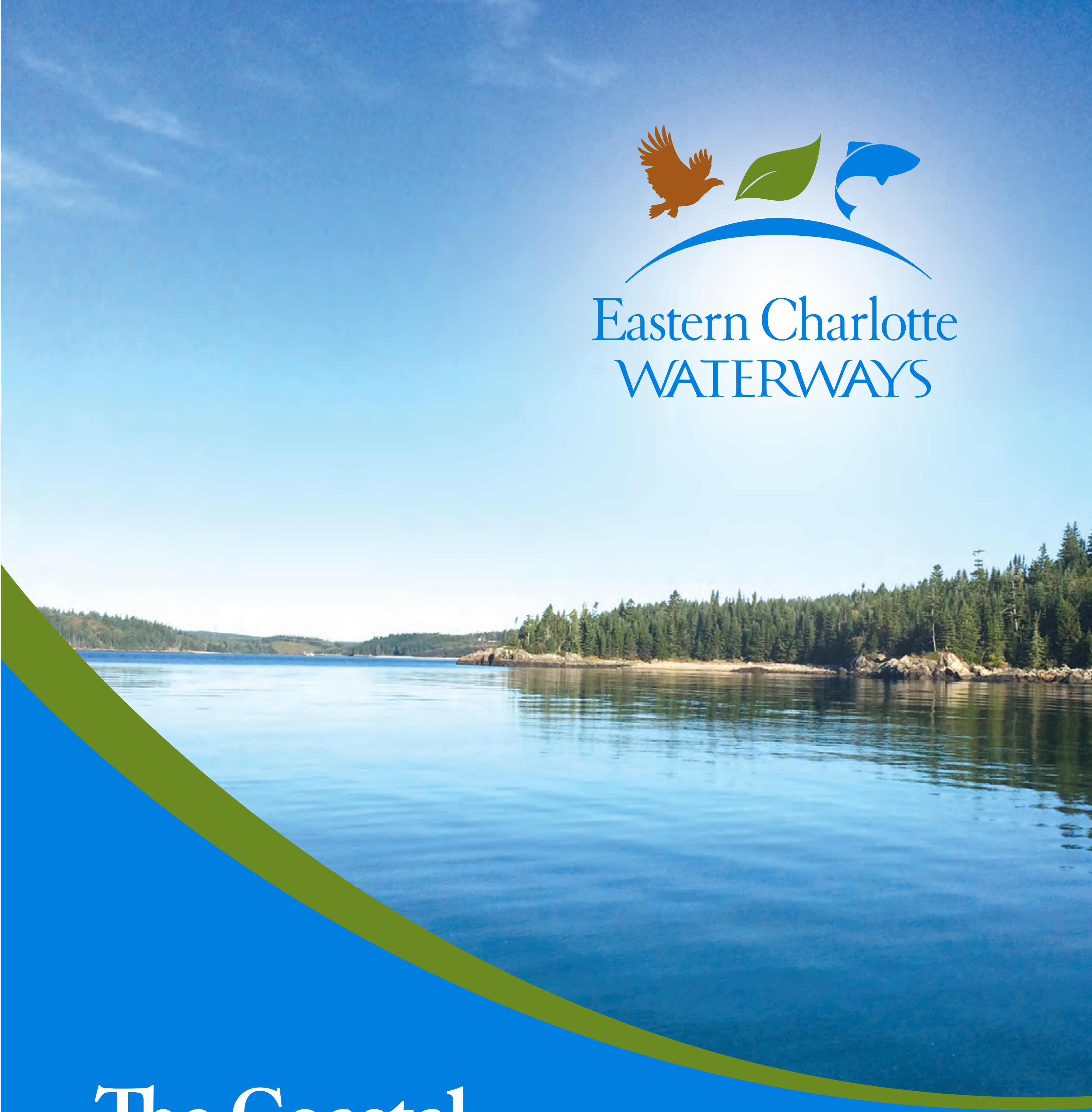

Eastern Charlotte
WATERWAYS

The Coastal Soundscape of the Outer Bay of Fundy


EASTERN
CHARLOTTE
WATER WAY
ASSOC

The Coastal Soundscape of the Outer Bay of Fundy:

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2016

Published by:

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Eastern Charlotte
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This project has been made possible by the generous financial support of:

New Nouveau
Brunswick
Department of Agriculture,
Aquaculture & Fisheries

New Nouveau
Brunswick
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NATIONAL
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Canada

This project was undertaken with the financial support of the Government of Canada.
Ce projet a été réalisé avec l'appui financier du gouvernement du Canada.

Acknowledgments

Eastern Charlotte Waterways acknowledges the generous financial support of **Environment & Climate Change Canada** and their Gulf of Maine Initiative, the **New Brunswick Environmental Trust Fund**, and the **New Brunswick Department of Agriculture, Aquaculture, and Fisheries** and their Total Development Fund. This project would not have been possible without the technical expertise and generous support of University of New Brunswick Professor Emeritus **Dr. John Terhune** who was instrumental in its design and implementation. Thanks also to the leadership of **Aileen Whitehead** at Environment and Climate Change Canada; **Mark Wood** and his staff at Ocean Sonics, who assisted with equipment maintenance and data analysis; **Hilary Moors-Murphy** at Department of Fisheries and Oceans and **Bruce Martin** at Jasco Applied Sciences, who provided assistance with data analysis; and **Chris Taggart** of Dalhousie University and his WHaLE team for their expertise and support.

This project was a complete effort of Eastern Charlotte Waterways and required the expertise of each staff member. Thanks to Karl Whelan, Michelle LeBlanc, Ryan Martin, Dayna Cline, and Danielle St. Louis.

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Executive summary

Since 1992 the global shipping fleet has increased by a factor of four, and with it, the underwater ambient noise level has increased. In an effort to understand the cause and effect of noise pollution on the Outer Bay of Fundy, Eastern Charlotte Waterways completed a comprehensive study of noise levels in the coastal waters of southwestern New Brunswick.

From May until November in 2015 five hydrophones (Ocean Sonics icListen HF) were used to quantify noise levels between Passamaquoddy Bay and Dipper Harbour. Each hydrophone was set to a 20% duty cycle, recording all 1/3 octave band sound levels between 10 and 12,500 Hz for the first 2 minutes of every 10 minute period.

There were 110,000 two minute sound recordings made during the sampling period. For each two minute recording, the mean sound level was calculated for each 1/3 octave band between 10 and 12,500 Hz.

Further analyses were performed on 1/3 octave bands 20 Hz, 63 Hz, 125 Hz, and 1000 Hz. These bands encompass the European Union's Marine Strategy Framework Directive (MSFD) which states that noise levels at 63 Hz and 125 Hz are indicative of noise from industrial shipping activity, the communication range of baleen whales (20 Hz) and frequencies commonly associated with smaller vessels (1000 Hz).

For each location analyses included:

- the temporal variation in daily mean amplitude for select 1/3 octave bands
- mean sound amplitudes as a 24 hour time series for select 1/3 octave bands
- the cumulative density of sound amplitudes for select 1/3 octave bands
- the distribution of noise levels for all 1/3 octave bands between 20 Hz and 12,500 Hz
- a comparison of noise level distributions to the Wenz curves, which are plots of the average ambient noise spectra for different levels of shipping traffic and conditions

Overall, the Outer Bay of Fundy showed large temporal and spatial variation in sound levels. Temporally, sound levels varied on hourly, daily, and monthly scales. Spatially, mean amplitudes showed the regions of Deer Isle/Campobello and Southern Wolves to have the highest levels of noise, while Wolves/Campobello was slightly lower. Deer Isle/Campobello also showed the highest standard deviation in sound levels implying periods of very high and low sound levels. Passamaquoddy Bay showed the lowest sound levels and standard deviation, inferring a more stable and quiet environment when compared to other locations.

This study was a credible first step in the evaluation of marine traffic effects on the Outer Bay of Fundy. However, there is a need for continued monitoring, ideally on a rotating basis in a series of standard sampling sites on a long term yearly basis.

Introduction

Pollution is defined as the introduction of contaminants into the natural environment causing an adverse change. Pollution can take the form of either chemical substances in air, water, and soil; or energy, such as heat, light, or noise (Environmental Protection Agency 2012).

Hearing remains the universal alerting sense in vertebrates. The importance of hearing is increasingly true underwater, where the medium changes the dynamics of light and sound. In the marine environment light is absorbed quickly while sound travels 4.3 times as fast and up to 100 times as far as it does in air. The difference in density of molecules between water and air allows the sound waves to travel more effectively, making sound the preferred method of communication and navigation for many underwater vertebrates (Nieukirk 2013).

Noise pollution can severely limit wildlife's ability to locate prey, mates, other individuals, and predators (Clark et al. 2009; Veirs et al. 2015).This becomes even more difficult for wildlife that communicate over long distances (Weilgart 2007; Williams et al. 2015). Marine mammals can have their calls to one another masked by boat noise, making communication almost impossible (Williams et al. 2013). This can be compounded by the distance between individuals and the specific call frequency being used (Williams et al. 2013). Unfortunately, the lower frequencies used by many baleen whale species strongly overlap with noise emitted by large shipping vessels (Erbe et al. 2014). Therefore marine shipping can have serious implication on important life history characteristics of these animals (Clark et al. 2009). For every increase of 4.5 decibels in the amplitude of noise, the underwater communication range is cut in half.

In deep water, the ambient noise level is increasing by 3-5 dB per decade. A modern day supertanker traveling at 17 knots fills all frequencies beneath 500 Hz with a steady sound of approximately 190 dB re 1µPa at 1 m. Mid-sized tugboats put out between 160-170 dB re 1µPa at 1 m, about the volume of a jet engine measured from one meter away (Jasny 2005). An increase in marine traffic is changing the profile of underwater noise, filling previously empty frequencies with energy, and raising the ambient noise levels (Erbe et al. 2014). It is believed that these dramatic changes in habitat pose a serious threat to the surrounding wildlife (Haviland-Howell et al. 2007). A summary of underwater noise sources is provided in Figure 1.

The Outer Bay of Fundy, located between southern New Brunswick and Nova Scotia, is no exception to the global increases in marine shipping. It is home to the Port of Saint John where large shipping vessels and smaller boats are continually sailing to and from, as well as numerous other ports including Bayside, Back Bay Harbour, Blacks Harbour, Eastport, and Grand Manan. The area is also home to marine mammal species and other marine wildlife that depend on the quality of the habitat. The Outer Bay of Fundy's high levels of marine traffic and rich biodiversity make it suitable for underwater noise monitoring initiatives.

In the summer of 2014, Eastern Charlotte Waterways (ECW) staff began working with Dr. John Terhune, Professor Emeritus at the University of New Brunswick, to develop methodology for the 'Outer Bay of Fundy Fluctuating Industrial Noise Study'. The objective was to undertake the first comprehensive study of noise levels in the open water areas of the Outer Bay of Fundy (OBF). The goal was to measure accurately the temporal and spatial distribution of noise levels at frequencies between 10 and 20,000 Hz in marine environments of less than 200 m in depth between the Bay of Fundy Traffic Separation Scheme shipping lane and Passamaquoddy Bay.

The project was successfully submitted for funding to Environment & Climate Change Canada's Gulf of Maine Initiative and the New Brunswick Environmental Trust Fund. Additional funding was secured from the New Brunswick Department of Agriculture, Aquaculture, and Fisheries' Total Development Fund. The project work began in May, 2015.

Throughout the summer and autumn of 2015, ECW staff deployed hydrophones at five locations in the OBF to evaluate the spatial and temporal distribution of underwater noise. This report includes the study's methodology and analysis of its results.

This study is one of the first to determine baseline noise levels within the Outer Bay of Fundy. The data collected is readily available from ECW, with the hope that environmental managers will use it to assist in the development of mitigation strategies, and researchers will utilize it in a detailed noise analysis to help ensure environmental quality in the Bay of Fundy.

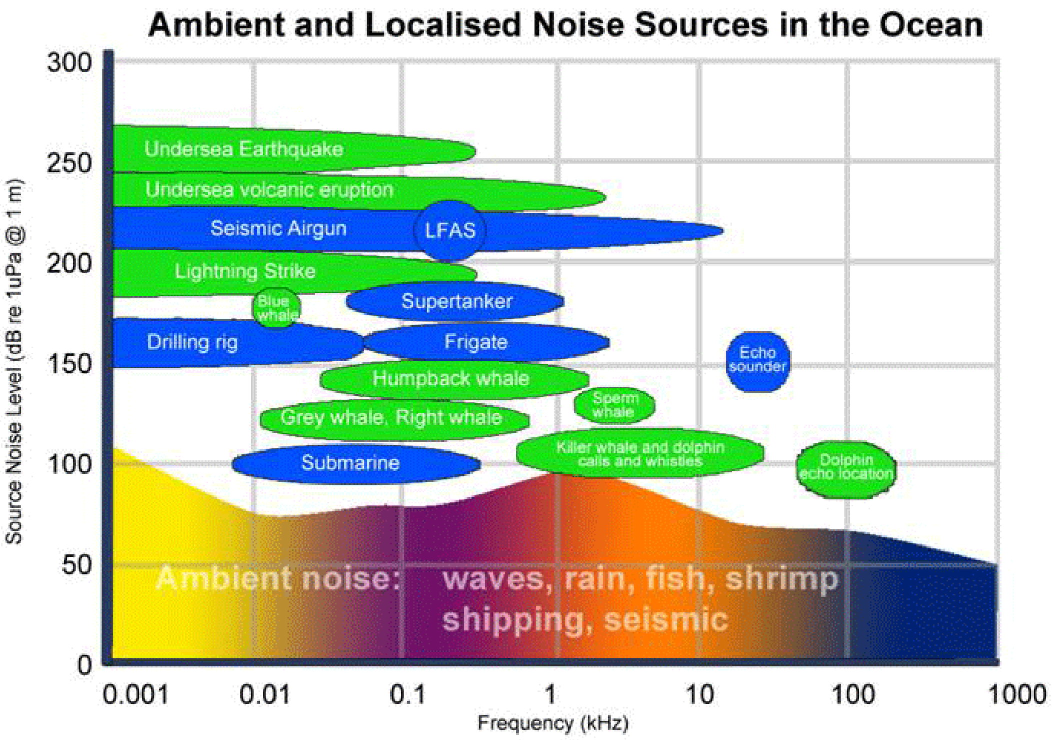


Figure 1: Noise sources in the ocean (Coates 2002)

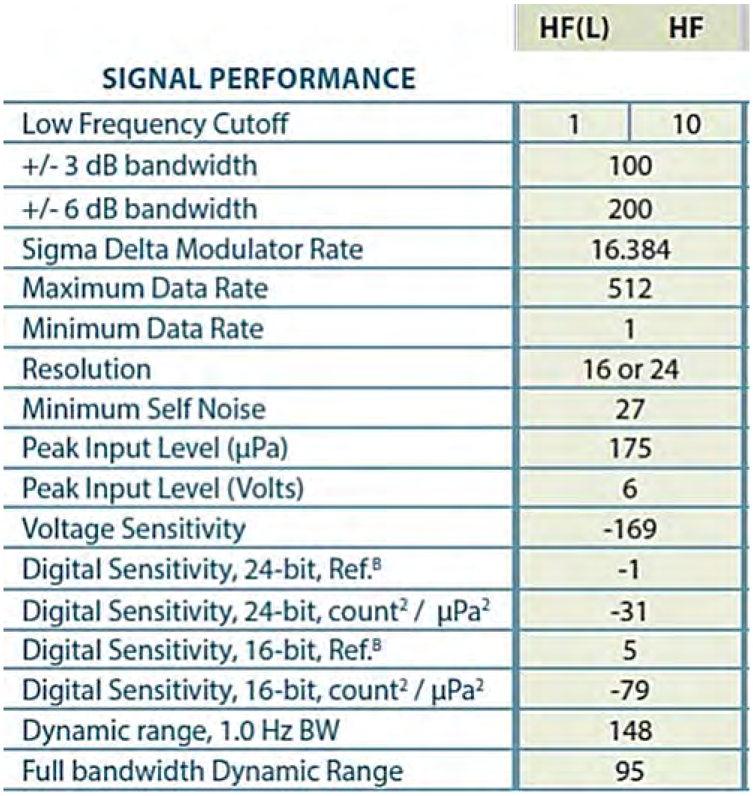
Materials and Methods

Study site

The Outer Bay of Fundy (OBF) lies between southern New Brunswick, Nova Scotia, and eastern Maine. Its tides are semi-diurnal and range between 6-9 m, less than the Inner Bay of Fundy, but still significant. It is home to the port city of Saint John along with numerous smaller ports along the southern edge of New Brunswick and Maine. The OBF is heavily used for fishing, vacation cruises, whale watching tours, and aquaculture. There are also ferries in operation throughout the area. The OBF is utilized by an abundance of wildlife including whales, porpoises, seals, and many species of fish and invertebrates. Throughout the summer months numerous whale species can be found within the area; most notably, the endangered North Atlantic Right whale (Eubalaena glacialis). Along with Right whales, Humpback (Megaptera novaeangilae), Finback (Balaenoptera physalus) and Minke whales (Balaenoptera acutorostrata) are commonly found in the area.

Equipment

The Ocean Sonics icListen HF hydrophone was chosen for the project. The digital hydrophone was deemed to have superior sensitivity for its cost and size. The icListen HF measures 26.7 cm and is encased in titanium. It is able to make sound recordings in .wav file format of sounds in the frequency range of 10 -20,000 Hz in up to 200 m of water, with an internal memory of 128 gigabytes. The signal performance of the hydrophone is found in Figure 2.



SIGNAL PERFORMANCE	HF(L)	HF
Low Frequency Cutoff	1	10
+/- 3 dB bandwidth	100	
+/- 6 dB bandwidth	200	
Sigma Delta Modulator Rate	16.384	
Maximum Data Rate	512	
Minimum Data Rate	1	
Resolution	16 or 24	
Minimum Self Noise	27	
Peak Input Level (µPa)	175	
Peak Input Level (Volts)	6	
Voltage Sensitivity	-169	
Digital Sensitivity, 24-bit, Ref.[B]	-1	
Digital Sensitivity, 24-bit, count^2 / µPa^2	-31	
Digital Sensitivity, 16-bit, Ref.[B]	5	
Digital Sensitivity, 16-bit, count^2 / µPa^2	-79	
Dynamic range, 1.0 Hz BW	148	
Full bandwidth Dynamic Range	95	

Each hydrophone was attached to an Ocean Sonics Gen-2 Glass Fiber Battery Pack. The battery pack housed 72 alkaline D cell batteries. Industrial grade Energizer batteries were purchased from Clear Power Solutions in Saint John, NB and each battery was checked with a volt meter prior to deployment. The hydrophones and battery pack were linked using an armored 5 m category 5 cable with female locking sleeves on both ends. Figure 3 shows the equipment.

A metal, cone-shaped structure (Figure 4) was designed and constructed to house the equipment. This structure kept the hydrophone upright and stable at the proper height above the sea floor. The hydrophone was attached to an inside center bar while the battery pack hung in the hollow open area at the base. This anchor was attached to a rope connecting it to a surface buoy.

Figure 3: Noise monitoring equipment

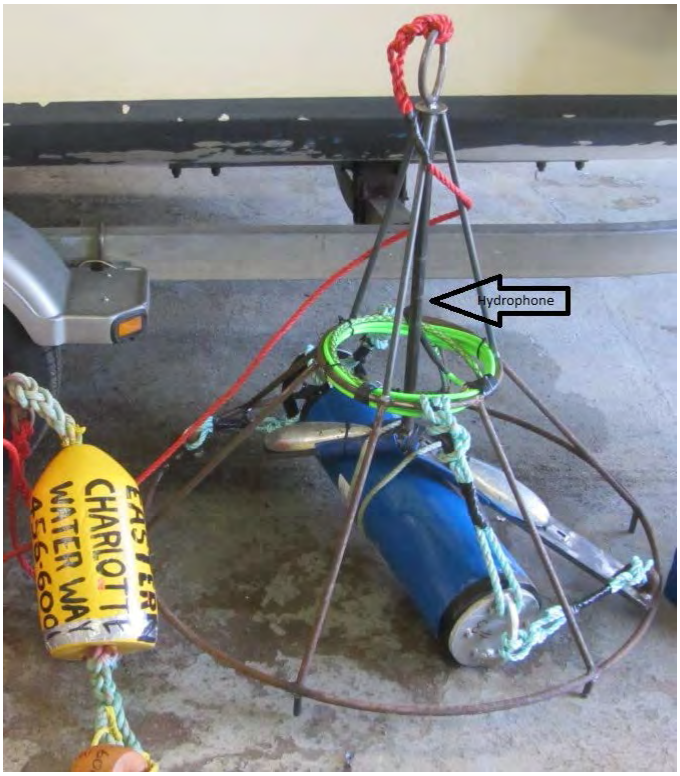


Figure 4: Anchor structure

Deployments

There were five hydrophones deployed at select locations in the Outer Bay Fundy from the end of May until early November, 2015. The internal clocks of the hydrophones were synchronized using an office computer prior to deployment. Each hydrophone was set to a 20% duty cycle for recording waveform data, recording sounds for the first 2 minutes of every 10 minute period, for a total daily recording time of 288 minutes. These recordings were made in .wav file format with a sampling rate of 32,000 samples per second resulting in an active frequency range of 10-16,000 Hz. In addition, the hydrophone measured the power spectrum (FFT) frequency and logged the values in tab-separated values .txt file format. This FFT data started with a sampling rate of 512,000 S/s. This resulted in an analyzing bandwidth of 500 Hz. The sampling rate was lowered to 32,000 S/s to give better resolution in the lower frequency range of 0 to 20,000 Hz. Additionally, initially the FFT sampling was conducted 4 times per second, resulting in an untenable number of observations. This rate was lowered to one observation every 10 seconds. Each of these changes to FFT data collection was made at the beginning of September.

A trial deployment was conducted in the mouth of Beaver Harbour during late May to ensure the hydrophone retrieval methodology was sound. A 4-horsepower gas-powered crab pot hauler designed to haul 250 kg at a rate of 50 m/minute was purchased to assist with hydrophone retrieval. The hydrophones had the power and memory to sustain deployment for a period of six weeks. Depending on logistics and tides, hydrophones would be retrieved after 3-6 weeks in the field, and redeployed in the same location after 2-5 days. In one instance, the Wolves/Campobello hydrophone required a small repair and was out of the water for 10 days. Dates, coordinates, and water depths for hydrophone deployments can be found in Table 1.

Locations

To effectively quantify noise levels from Passamaquoddy Bay to the Bay of Fundy Traffic Separation Scheme hydrophones were placed in various locations between Dipper Harbour and Passamaquoddy Bay (see Figure 5). Locations were initially chosen based on anticipated ship activity levels. There were no issues with the following hydrophone locations as initially chosen:

- The Passamaquoddy Bay hydrophone was placed approximately ¾ of the way between the southern tip of Saint Andrews and Deer Island.
- The Wolves/Campobello hydrophone was placed equidistance from the Wolves archipelago and the northern tip of Campobello Island. It was on the western side of the Grand Manan ferry route, in close proximity.
- The Southern Wolves hydrophone was placed just south of the Wolves archipelago.

Adjustments were made to these two locations after they were chosen:

- The Deer Isle/Campobello hydrophone was initially located in Head Harbour Passage, equidistance from Indian Island off the southeast of Deer Island and Wilson's Beach at the northwest point of Campobello Island. A small adjustment was made, moving the location towards Wilson's Beach. A steep underwater ledge runs through Head Harbour Passage, as well as a strong current. By moving the location slightly to the east, the deployment was in significantly less water, making it easier to retrieve the hydrophone.
- The Dipper Harbour hydrophone was located south of Dipper Harbour, approximately 34 km west of the Saint John Harbour. The initial location was 22 km east of that, at the edge of the Bay of Fundy Traffic Separation Scheme. This location had to be significantly adjusted because of the strength of the currents near to the traffic separation scheme.

Sound analyses

The two main aspects of sound are its amplitude and frequency. The amplitude of sound is measured in decibels (dB) and is the pressure created from a sound wave relative to a reference value; the reference value in water is 1 micro pascal (μPa). The frequency of sound describes the number of cycles per second (CPS). One cycle is considered the rise and fall of the wave and its return to first position. CPS is measured in hertz (Hz). Lower frequency sounds have fewer Hz than higher frequencies. The human threshold of audible frequencies is estimated to be 20-20,000 Hz. Other species can have larger and different ranges.

Each time a hydrophone was retrieved its data was downloaded to two external hard drives to ensure a backup copy existed. Waveform data was analyzed using Noiselab Pro (version 4.04) software, which calculated the mean sound level for each 1/3 octave band from 10 to 12,500 Hz for each two minute recording. Each file was then calibrated to account for noise levels caused by the hydrophone itself. These values were provided by Dr. Terhune.

Analyses were performed on the 1/3 octave bands 20 Hz, 63 Hz, 125 Hz, and 1000 Hz. Recently, the European Union's Marine Strategy Framework Directive (Vandergraff et al. 2012; Tasker et al. 2010) has stated that noise levels at 1/3 octave bands 63 and 125 Hz are indicative of anthropogenic caused noise from industrial shipping activity and should be included in all assessments of underwater noise. The communication range of baleen whales (20 Hz) and frequencies commonly associated with smaller vessels (1000 Hz) were also considered.

Analyses were chosen to determine the spatial and temporal distribution of noise in the Outer Bay of Fundy. The cumulative distribution of select 1/3 octave bands was established, and full spectrum analyses of all frequencies was conducted for each location. All analyses were completed using statistical program R.

Table 1: Hydrophone locations, deployment and retrieval dates, sound logging start and stop times, and ocean depth deployed at during low tide

Location	Lat	Long	Deployed	Logging start	Retrieved	Logging stop	Depth at low tide
Dipper Harbour	45.04895	-66.44554	19-Jun-15	13:00	29-Jul-15	11:00	36 m
			30-Jul-15	15:00	13-Sep-15	12:00	
			18-Sep-15	17:00	02-Nov-15	16:30	
Southern Wolves	44.90559	-66.73756	27-May-15	12:00	23-Jun-15	13:00	94 m
			25-Jun-15	12:00	30-Jul-15	11:00	
			05-Aug-15	17:00	16-Sep-15	14:30	
			18-Sep-15	12:00	28-Oct-15	14:30	
Wolves/Campobello	44.95206	-66.80949	27-May-15	12:00	25-Jun-15	9:00	83 m
			06-Jul-15	13:00	30-Jul-15	11:00	
			05-Aug-15	17:00	16-Sep-15	14:30	
			18-Sep-15	12:00	28-Oct-15	15:00	
Deer Isle/Campobello	44.93322	-66.9542	26-May-15	9:00	26-Jun-15	9:00	45 m
			01-Jul-15	13:00	29-Jul-15	16:00	
			04-Aug-15	10:00	11-Sep-15	11:30	
			15-Sep-15	15:00	27-Oct-15	11:45	
Passamaquoddy Bay	45.0175	-67.01833	26-May-15	9:00	23-Jun-15	10:30	25 m
			25-Jun-15	12:00	29-Jul-15	15:30	
			31-Jul-15	15:00	14-Sep-15	14:00	
			17-Sep-15	20:00	27-Oct-15	11:15	

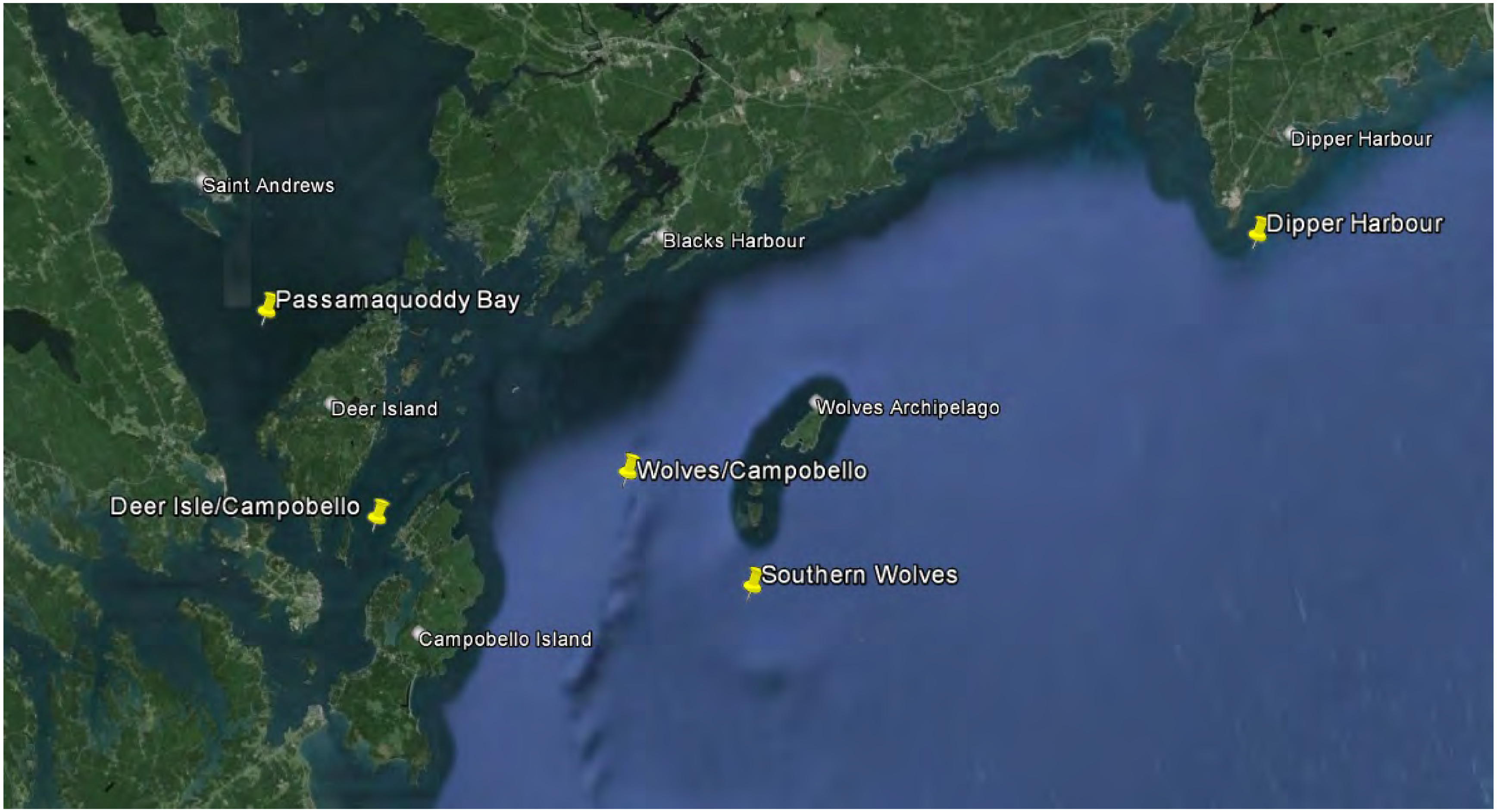


Figure 5: Hydrophone locations within the Outer Bay of Fundy

Results

Overview

All sound levels are referred to in decibels relative to one micro pascal (dB re 1 µPa). All sound frequencies are referred to in hertz (Hz). Results for each location are expressed in five graphs that describe the varying noise levels throughout the summer. For each location these graphs are labeled A-E.

- Graph A displays the temporal variation in daily mean amplitude for select 1/3 octave bands 20, 63, 125, 1000 Hz.
- Graph B displays mean values for each hour in a 24 hour time series, calculated using data from the entire sampling period.
- Graph C is the cumulative density of sound amplitudes for select 1/3 octave bands 20, 63, 125, 1000 Hz over the entire sampling period; or the amount of sampling time that a given band exceeded a certain amplitude.
- Graph D is the distribution of noise levels and the amount of time [5%, 25%, 50% (median), 75% and 95%] those levels were exceeded over the entire sampling period for all 1/3 octave bands between 20 Hz and 12,500 Hz.
- Graph E is a comparison of Graph D to the Wenz curves (Wenz 1962). Wenz curves are plots of the average ambient noise spectra for different levels of shipping traffic and meteorological conditions.

The Wenz curves are a tool used to describe the sources of ambient noise levels at varying amplitudes and frequencies using spectrum values. We converted 5%, 25%, 50%, 75% and 95% quantiles to spectrum values [amp-10log (Frequency*0.23)] and plotted values onto the Wenz curves to determine the likely noise sources.

Note that the sound levels are expressed differently in the Wenz curves than the other graphs. For graphs A-D at each location, the levels are expressed in terms of 1/3 octave bands, which is representative of mammalian ability to detect signals in noise. For Graph E, the Wenz ambient level graphs, the sound levels are expressed at the spectrum level (1 Hz wide bands), describing the sound levels in an absolute or physical sense.

A few recordings had unusually high or low amplitudes. These were likely caused by strumming of the rope going to the surface, gravel being swept by the current, or animals crawling on the hydrophone. The percentile analysis did not include the maximum and minimum 5% to exclude these extreme and likely erroneous observations.

Tidal streams

Prior to spatial and temporal analysis, all results were analyzed for the effect of tidal streams. Tides in the Outer Bay of Fundy are semi-diurnal and notoriously extreme. When the tide is coming in or going out (non-slack tide), the rope connecting the hydrophone anchor to the surface buoy is pulled tight. This can create vibrations known as 'strum'. Strum noise can dramatically increase amplitudes at certain frequencies. To ensure strum noise did not impact the spatial and temporal analyses of the data, a one-way analysis of variance (ANOVA) for tides (either slack tide or non-slack tide) was conducted for each 1/3 octave band. Slack tide times were established as one hour before and after high or low tide values as given by Environment Canada's tides.gc.ca resource. Inevitably, with such a large data set (up to 20,000 values), the power to detect statistically relevant differences was very large resulting in many bands only slightly increasing in sound levels (<1dB) during non-slack tide times, but still calculated to be statistically significant. Therefore, any statistically significant values were further investigated to determine if the difference in sound levels was high enough (>2.5 dB re 1 µPa) to be considered as influenced by tidal streams. Bands that did not differ by >2.5 dB re 1 µPa were considered to be un-altered and all values from the sampling period were used. Bands that did prove to be influenced by tidal streams were only analyzed using sound levels during slack tide. The results of this ANOVA assessment can be found in Table 2.

Table 2: Bands with >2.5 dB re 1 µPa difference between slack tide and non-slack tide

Location	**Bands with >2.5 dB re 1 µPa difference between slack tide and non-slack tide**
Dipper Harbour	20-50 Hz
Southern Wolves	20-40 Hz
Wolves/Campobello	20-40 Hz
Deer Isle/Campobello	20-63 Hz & 6300-12500 Hz
Passamaquoddy Bay	N/A

Passamaquoddy Bay

Table 6A: Daily mean±SD and the month with the highest means for 1/3 octave bands 20, 63, 125 and 1000 Hz for the Passamaquoddy Bay location

Frequency	Daily mean±SD (dB re 1 µPa)	Highest monthly sound level (mean±SD, dB re 1 µPa)
20 Hz	70±2.8	June (71±7.1)
63 Hz	72±2.5	August (74±4.5)
125 Hz	77±2.3	June (78±9.2)
1000 Hz	78±4.8	October (83±7.9)

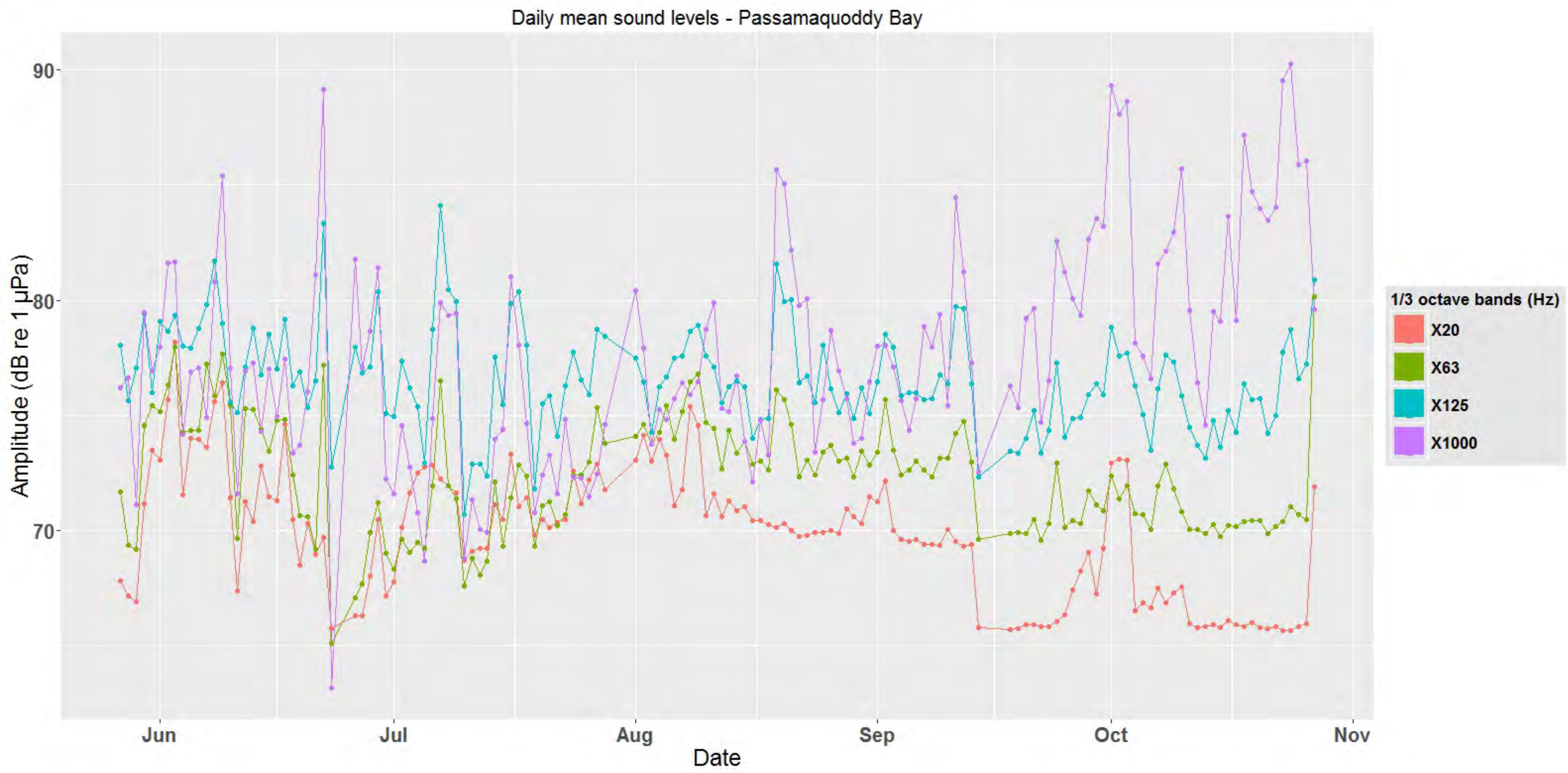


Figure 6A: Daily mean sound levels for 1/3 octave bands 20, 63, 125, 1000 Hz throughout the entire sampling period for Passamaquoddy Bay

Noise levels, for all four bands, began to rise between 7:00 and 9:00 and maintained higher levels throughout the day before dropping again at 19:00 (Figure 6B). Distinct peaks were exhibited at 12:00 (125 and 63 Hz) and 14:00 (20 and 1000 Hz).

Table 6B: Hourly mean±SD for 1/3 octave bands 20, 63, 125 and 1000 Hz for the Passamaquoddy Bay location

Frequency	**Hourly mean±SD (dB re 1 µPa)**
20 Hz	70±0.8
63 Hz	72±1.6
125 Hz	77±3.5
1000 Hz	78±3.9

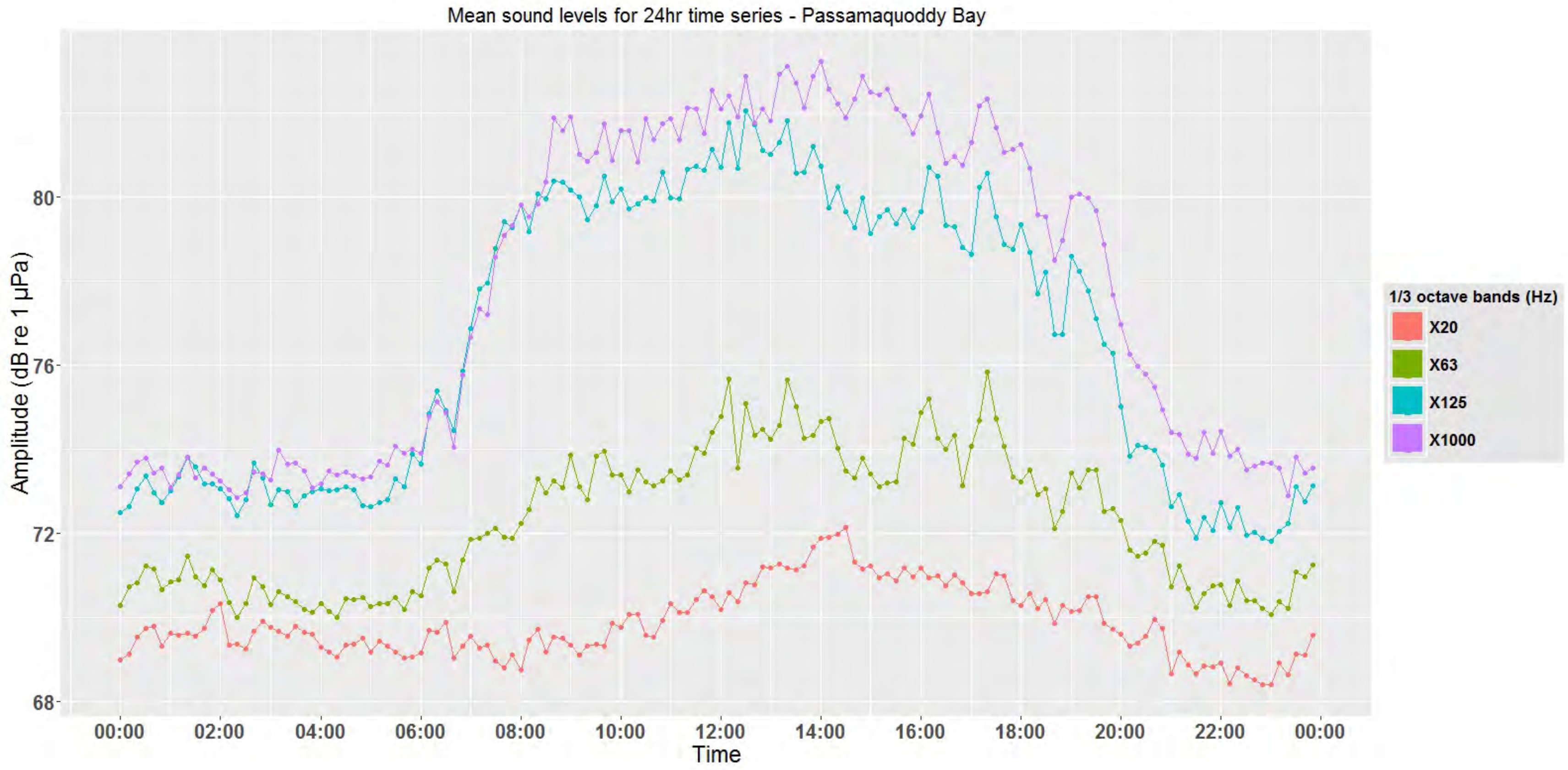
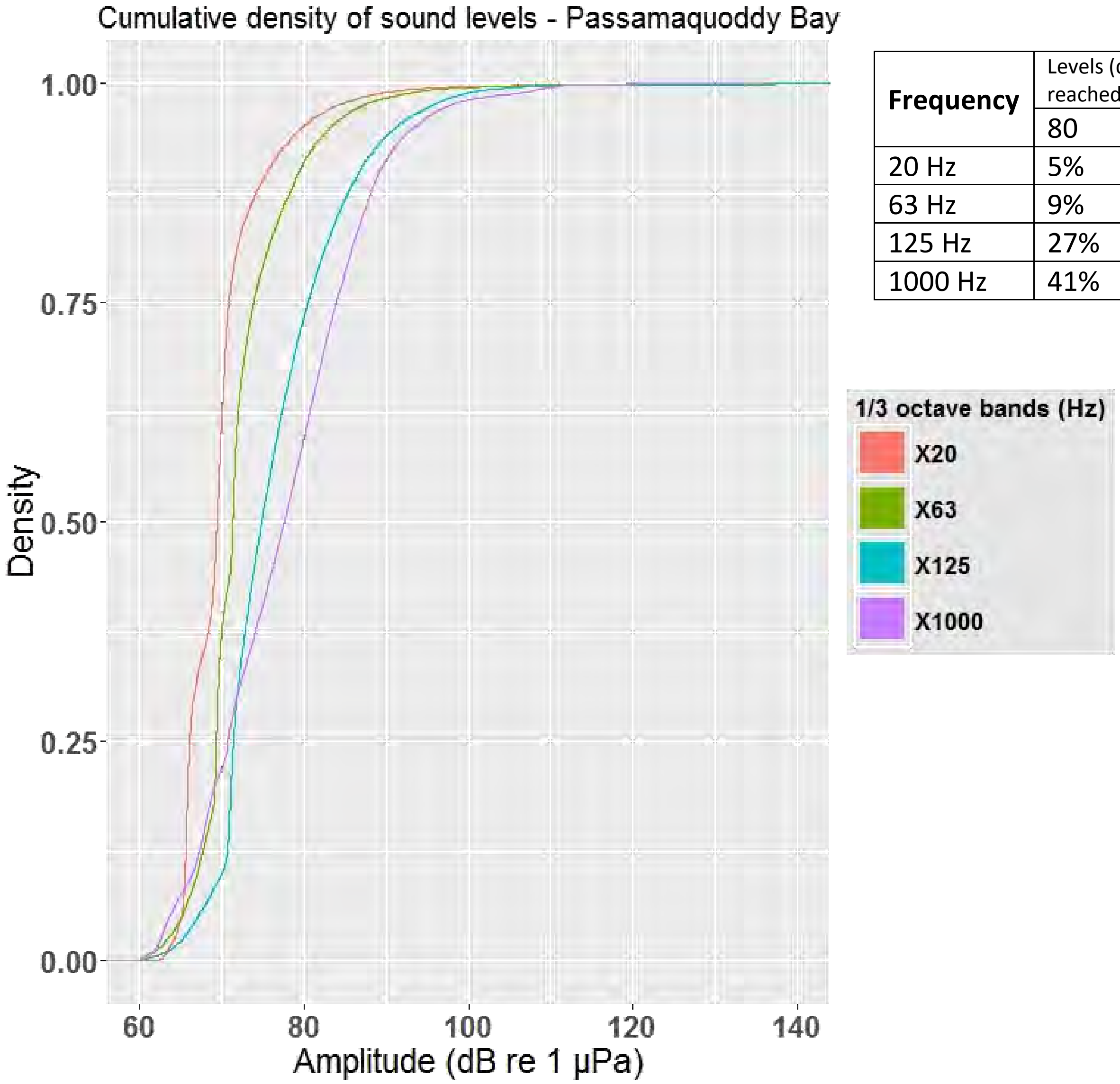


Figure 6B: Mean sound levels at each time of recording over a 24hr period for 1/3 octave bands 20, 63, 125, 1000 Hz for Passamaquoddy Bay. Means were calculated for every time of recording throughout a day from levels throughout the entire sampling period



Frequency	Levels (dB re 1upa) reached for % of time	
	80	100
20 Hz	5%	0%
63 Hz	9%	0%
125 Hz	27%	0%
1000 Hz	41%	0%

Table 6C: Percent of time that sound levels were reached for 1/3 octave bands 20, 63, 125, 1000 Hz for Passamaquoddy Bay.

Figure 6C: Cumulative density of sound levels for 1/3 octave bands 20, 63, 125, 1000 Hz for Passamaquoddy Bay. Values are calculated from levels throughout the entire sampling period.

The full distribution of sound levels is plotted by taking points at 5%, 25%, 50%, 75% and 95% from the cumulative density and applying it to all bands between 20-12500 Hz. For the most part, the 200 Hz band showed the highest levels except for the median and at 25% where 400 Hz was slightly higher (Figure 6D). A steep rise in sound levels up to 200 Hz is very pronounced and followed by a much more shallow decline in higher frequencies (Figure 6D).

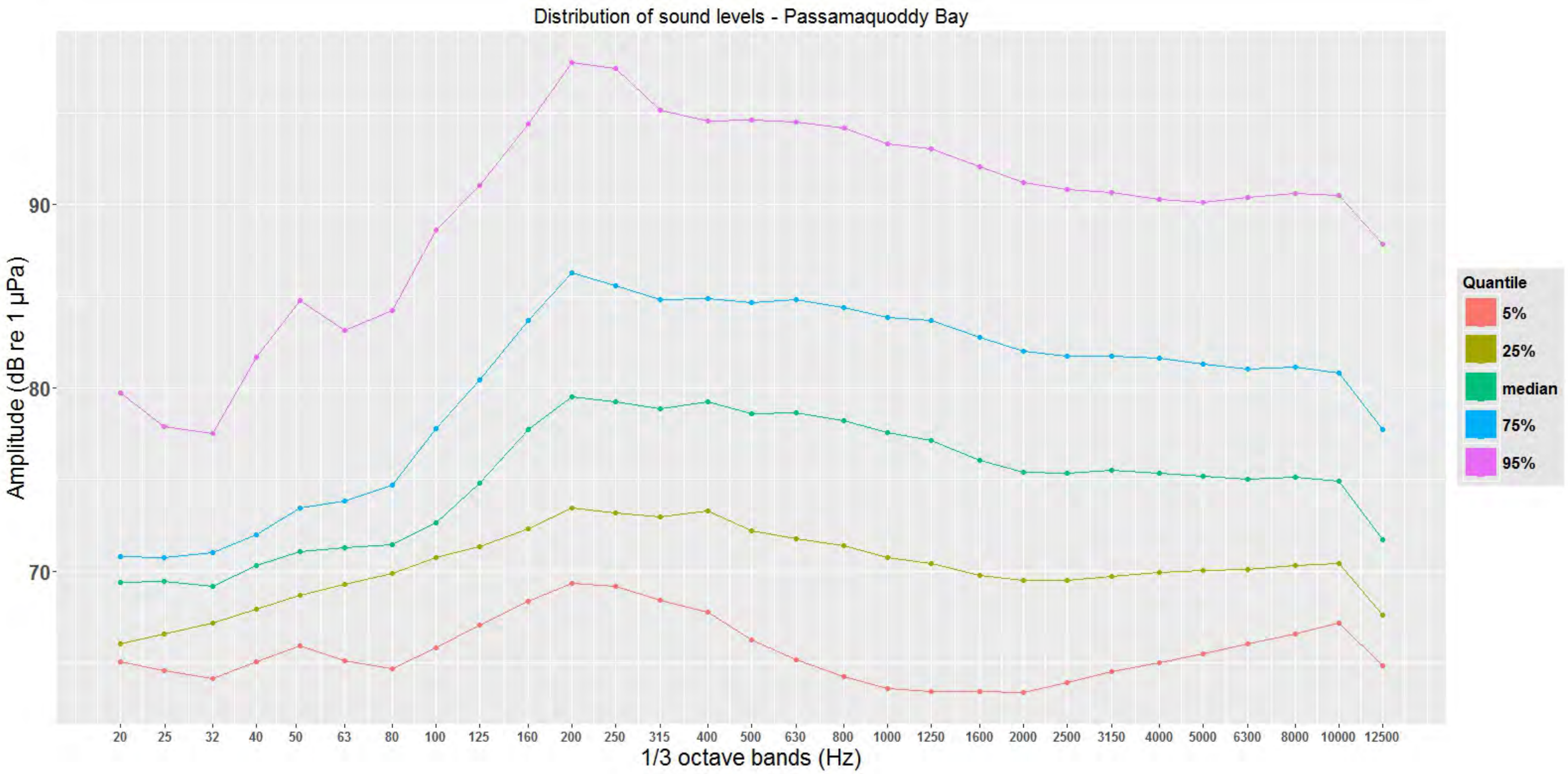


Figure 6D: Distribution of sound levels for 1/3 octave bands 20-12,500 Hz for Passamaquoddy Bay. Quantiles displayed as levels that were reached 5%, 25%, 50% (median), 75% and 95% of the time. All values were calculated from levels throughout the entire sampling period.

Comparisons to the Wenz curves showed that the ambient level (5%) and 25% quantile mostly fell below the usual traffic noise levels (Figure 6E). Median and 75% quantiles fell within usual traffic noise for the lower frequencies around 25 Hz and 200 Hz. The 95% quantile mostly showed values within usual traffic noise, with the exception of a peak around 200 Hz with values expected of high traffic noise (Figure 6E). It seems that frequencies below 1000 Hz are closely associated with marine traffic noise while the decreasing slope at higher frequencies resembles patterns for wind dependent bubbles and spray (Figure 6E).

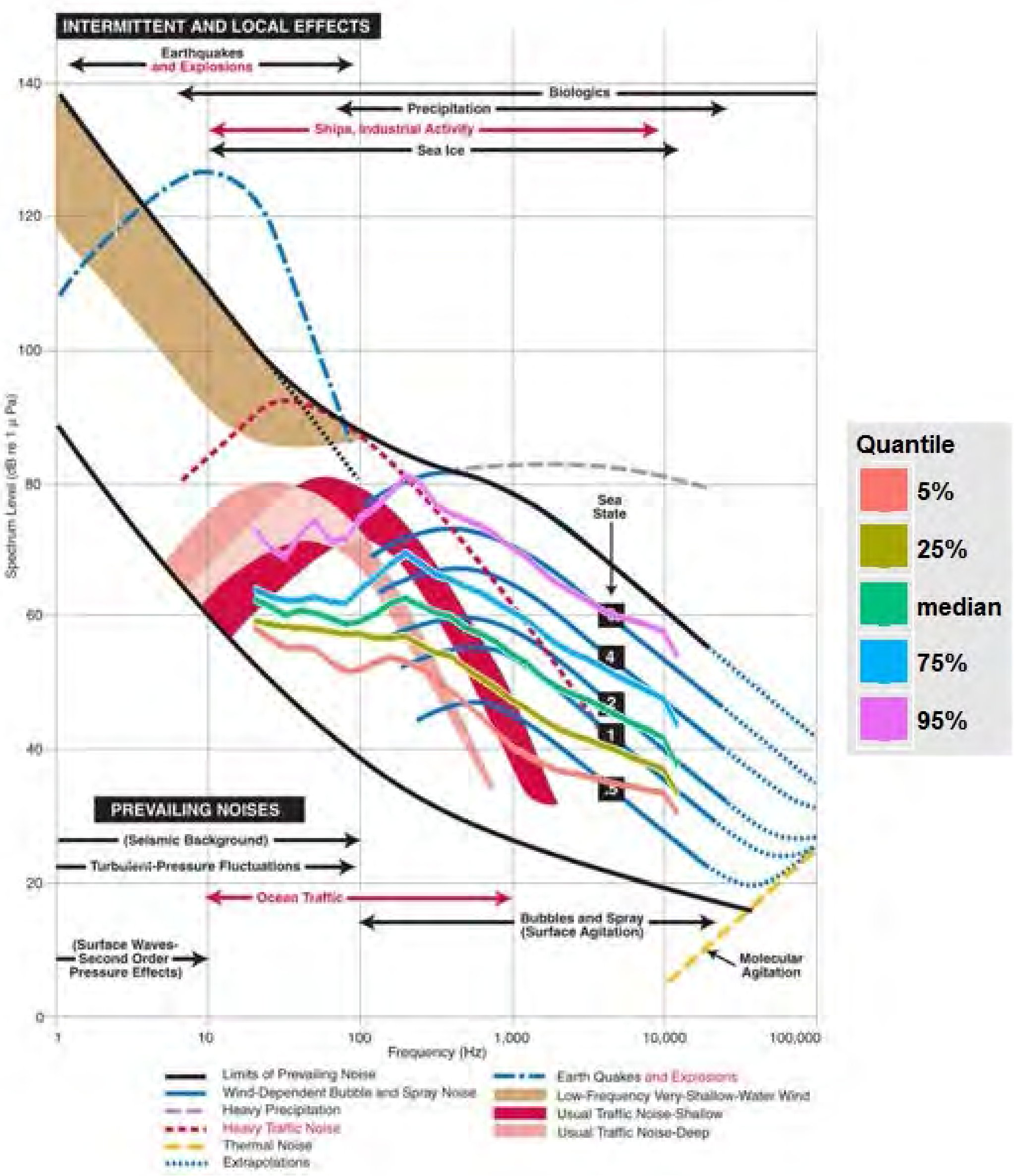


Figure 6E: Full spectrum analysis in reference to Wenz curves for likely sources of noise per amplitude and frequency for Passamaquoddy Bay

Dipper Harbour

Table 7A: Daily mean±SD and the month with the highest means for 1/3 octave bands 20, 63, 125 and 1000 Hz for the Dipper Harbour location

Frequency	Daily mean±SD (dB re 1 μPa)	Highest monthly sound level (mean±SD, dB re 1 μPa)
20 Hz	79±5.9	June (84.0±11.34)
63 Hz	81±3.9	June (85.09±5.62)
125 Hz	84±3.5	June (89.65±6.23)
1000 Hz	83±5.6	October (88.79±7.35)

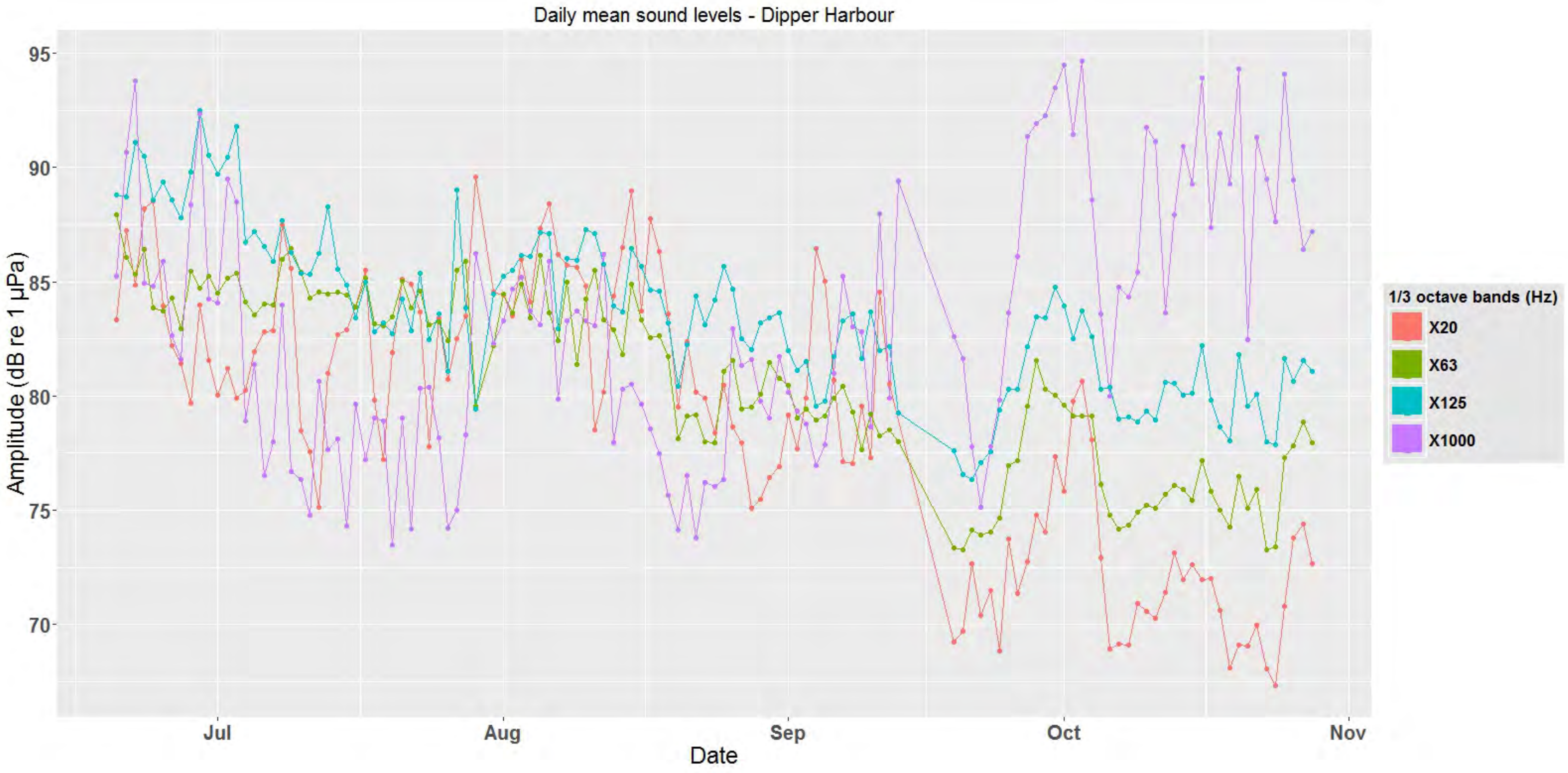


Figure 7A: Daily mean sound levels for 1/3 octave bands 20, 63, 125, 1000 Hz throughout the entire sampling period for Dipper Harbour

Table 7B: Hourly mean±SD for 1/3 octave bands 20, 63, 125 and 1000 Hz for the Dipper Harbour location.

Frequency	Hourly mean±SD (dB re 1 µPa)
20 Hz	79±1.3
63 Hz	81±0.4
125 Hz	84±1.3
1000 Hz	83±1.0

Noise levels for bands 20, 63 and 125 Hz showed multiple peaks throughout the 24hr period and tended to synchronize with one another; peaks from all 3 bands occurred within an hour of each other (Figure 7B). The 1000 Hz band had much less pronounced peaks and instead showed a gradual rise up to 13:00 followed by a slow decline. The four peaks in the 125 Hz band corresponds to the sailing times of the ferry between Saint John, N.B and Digby, N.S.

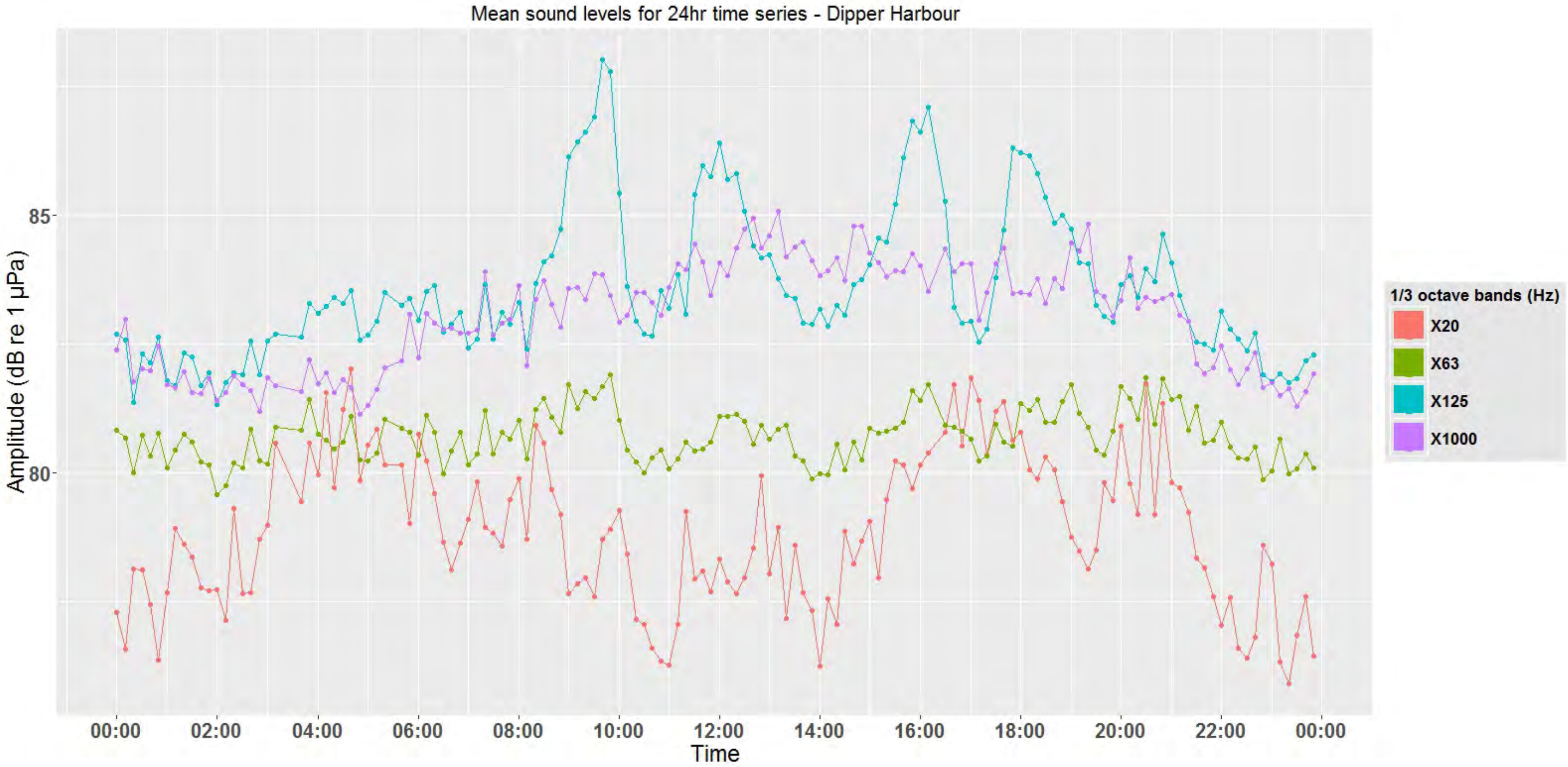


Figure 7B: Mean sound levels at each time of recording over a 24hr period for 1/3 octave bands 20, 63, 125, 1000 Hz for Dipper Harbour. Means were calculated for every time of recording throughout a day from levels throughout the entire sampling period.

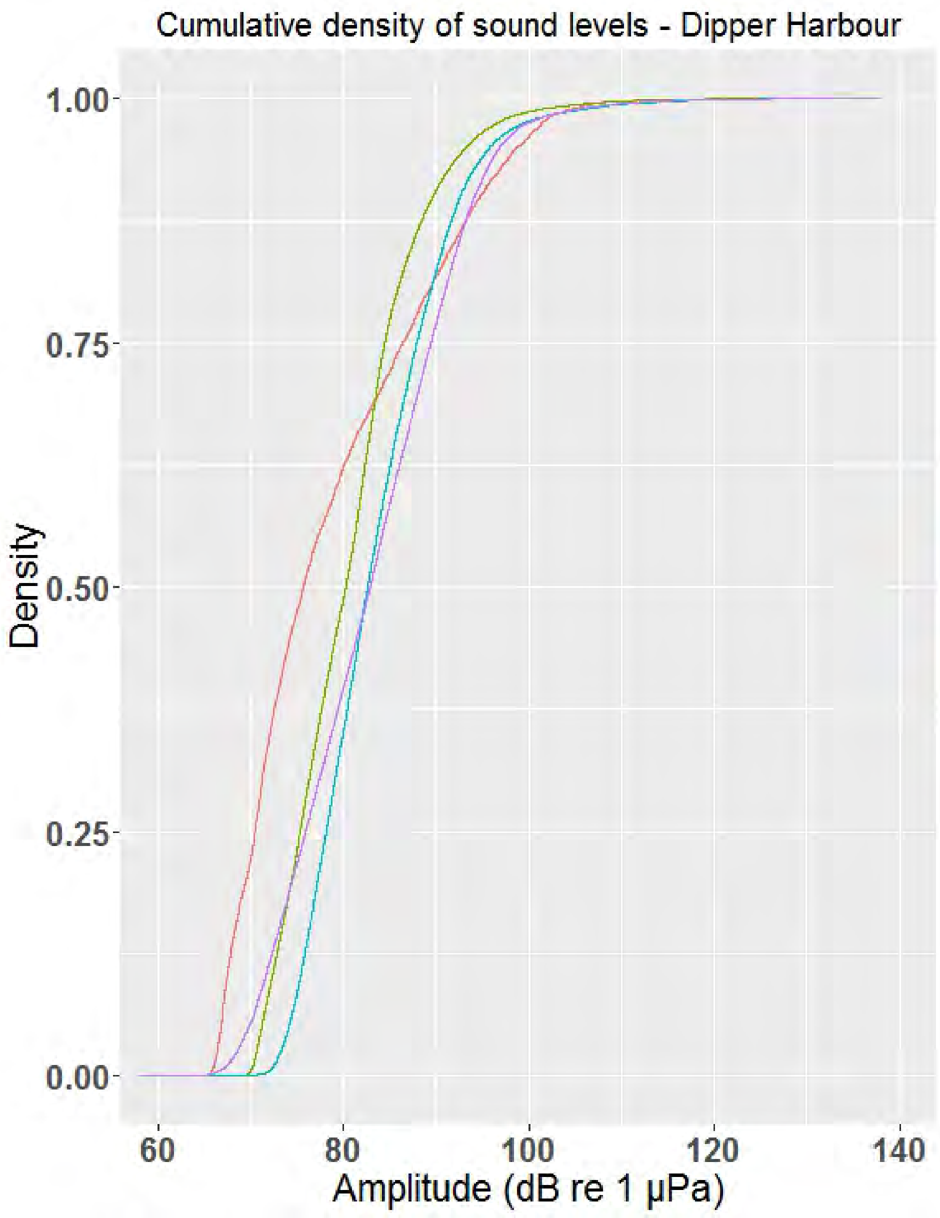


Figure 7C: Cumulative density of sound levels for 1/3 octave bands 20, 63, 125, 1000Hz for Dipper Harbour. Values are calculated from levels throughout the entire sampling period.

Frequency	Levels (dB re 1upa) reached for % of time	
	80	100
20 Hz	38%	0%
63 Hz	52%	0%
125 Hz	66%	0%
1000 Hz	61%	0%

Table 7C: Percent of time that sound levels were reached for 1/3 octave bands 20, 63, 125, 1000Hz for Dipper Harbour

The full distribution of sound levels showed the 200Hz band to be the highest at all percentile values, except the 95th, where the 20Hz band was as high (Figure 7D). Across all frequencies, the upper spectrum levels showed that 5% of the time sound levels were commonly above 95 dB re 1 µPa (Figure 7D).

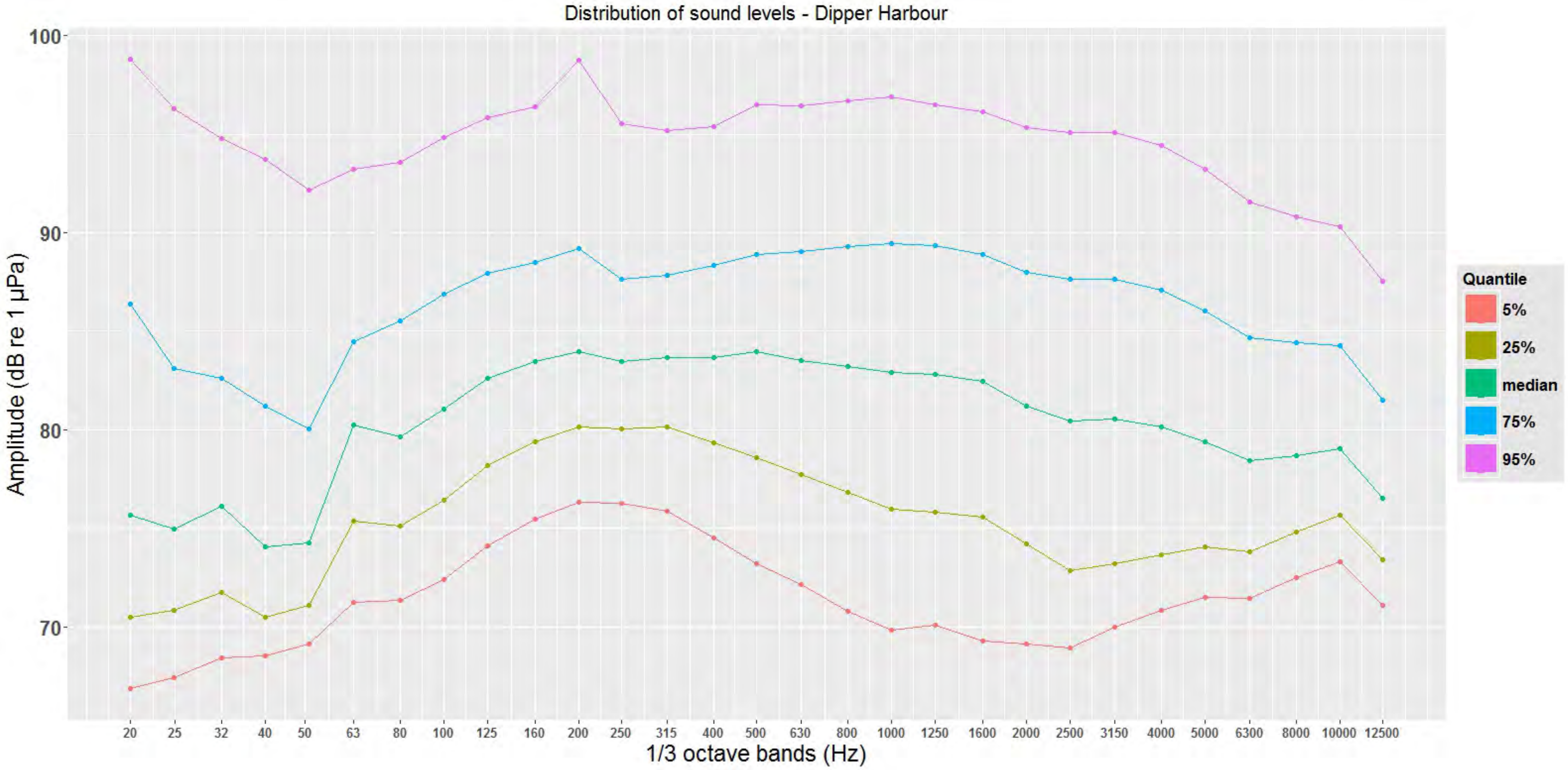


Figure 7D: Distribution of sound levels for 1/3 octave bands 20-12,500Hz for Dipper Harbour. Quantiles displayed as levels that were reached 5%, 25%, 50% (media), 75% and 95% of the time. All values were calculated from levels throughout the entire sampling period.

Ambient noise levels and the 25% quantile tended to be below the spectrum for usual traffic noise (Figure 7E). The median values and 75% quantiles were within the spectrum ranges in usual traffic noise (Figure 7E). The 95% quantile was mostly between the upper levels of usual traffic noise and high traffic noise. Most frequencies below 1000 Hz fell within varying degrees of traffic noise, whereas frequencies above 1000 Hz followed patterns of wind dependent bubbles and spray (Figure 7E).

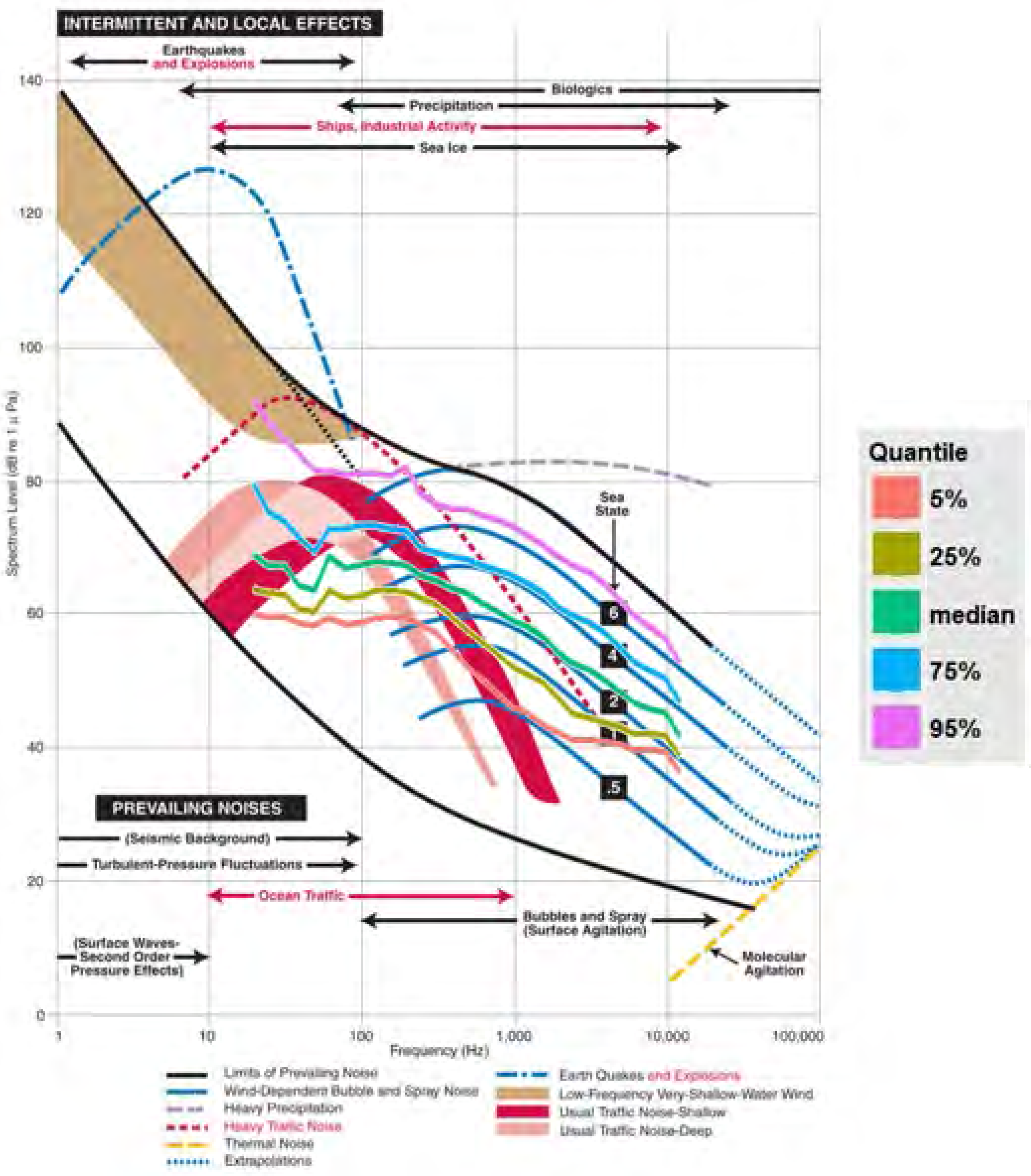


Figure 7E: Full spectrum analysis in reference to Wenz curves for likely sources of noise per amplitude and frequency for Dipper Harbour.

Deer Isle/Campobello

Table 8A: Daily mean±SD and the month with the highest means for 1/3 octave bands 20, 63, 125 and 1000 Hz for the Deer Isle/Campobello location

Frequency	Daily mean±SD (dB re 1 µPa)	Highest monthly sound level (mean±SD, dB re 1 µPa)
20 Hz	88±6.9	June (98±17.7)
63 Hz	83±6.5	June (94±13.7)
125 Hz	83±6.5	June (93±10.6)
1000 Hz	84±4.1	June (88±8.5)

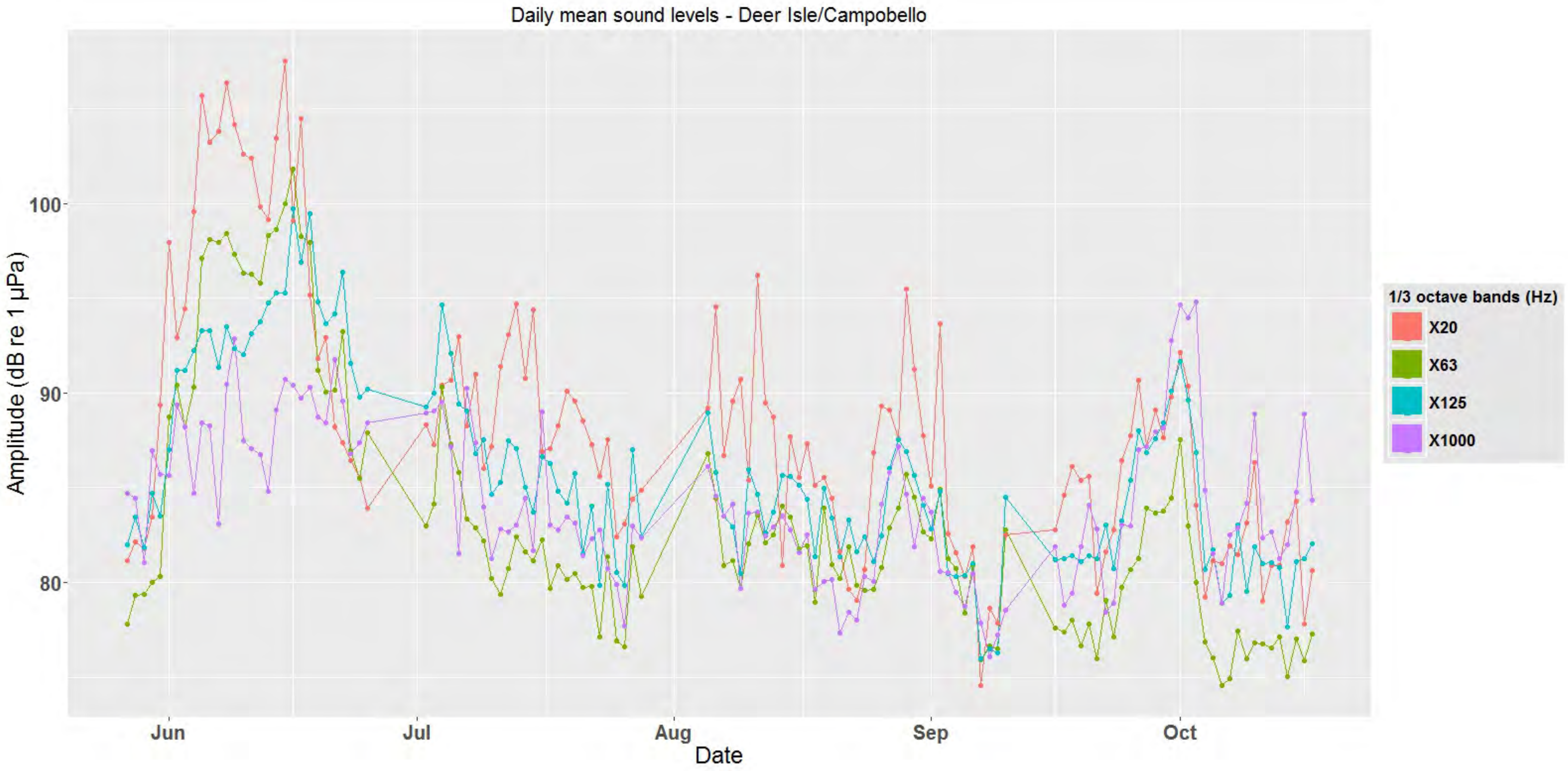


Figure 8A: Daily mean sound levels for 1/3 octave bands 20, 63, 125, 1000Hz throughout the entire sampling period for Deer Isle/Campobello

At 20Hz, sound levels stayed relatively consistent over a 24hr period and remained above 85 (dB re 1 µPa) with a few exceptions (Figure 8B). In the other 3 bands, sound levels showed a gradual rise before peaking at 15:00 and then followed by a more dramatic decline (Figure 8B). Both 125 and 1000Hz peaked above 90 (dB re 1 µPa), while the 63Hz band peaked just below 87.5 (dB re 1 µPa).

Table 8B: Hourly mean±SD for 1/3 octave bands 20, 63, 125 and 1000 Hz for the Deer Isle/Campobello location

Frequency	**Hourly mean±SD (dB re 1 µPa)**
20 Hz	88±1.0
63 Hz	83±1.4
125 Hz	86±2.3
1000 Hz	84±4.4

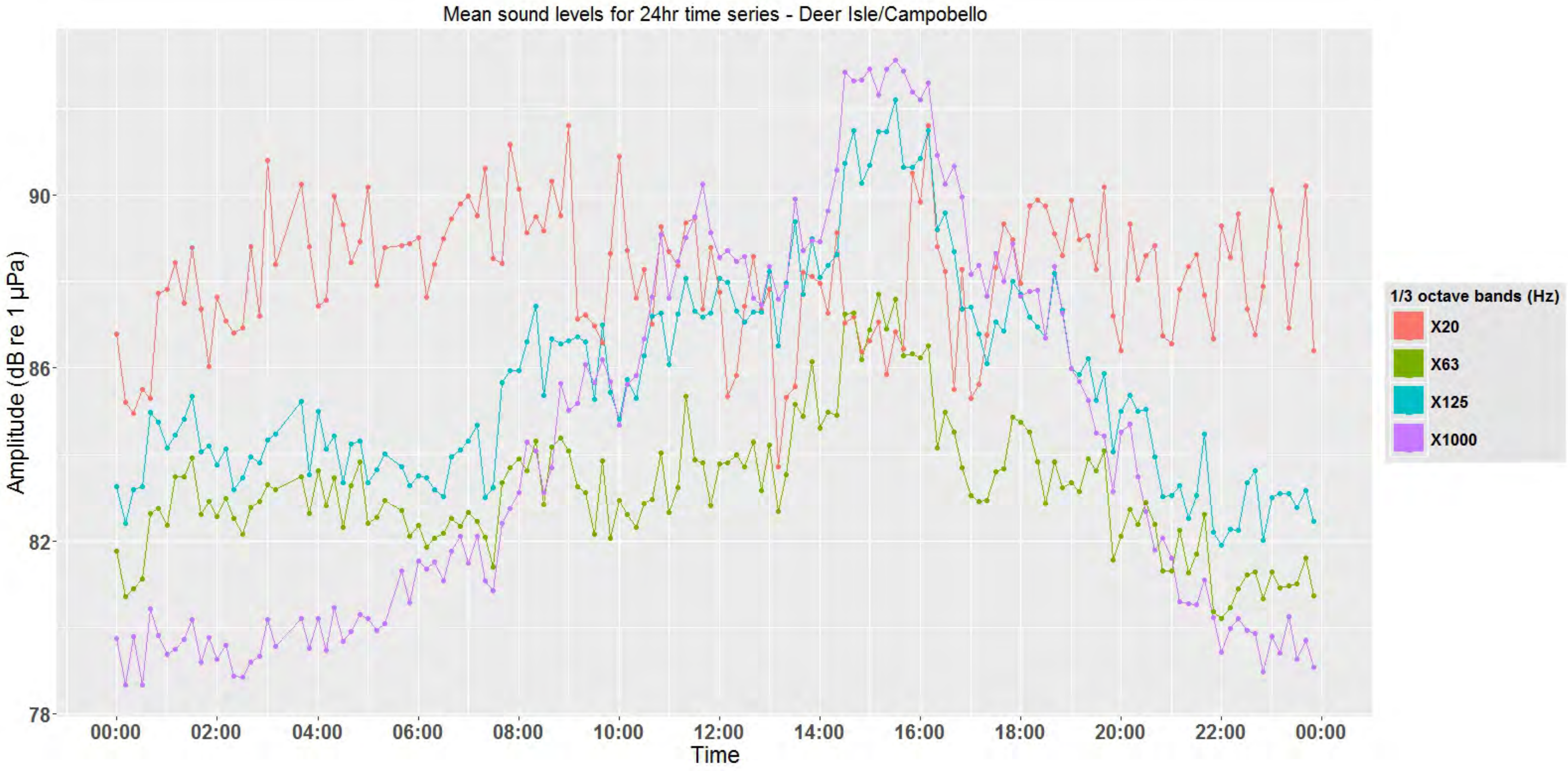


Figure 8B: Mean sound levels at each time of recording over a 24hr period for 1/3 octave bands 20, 63, 125, 1000Hz for Deer Isle/Campobello. Means were calculated for every time of recording throughout a day from levels throughout the entire sampling period.

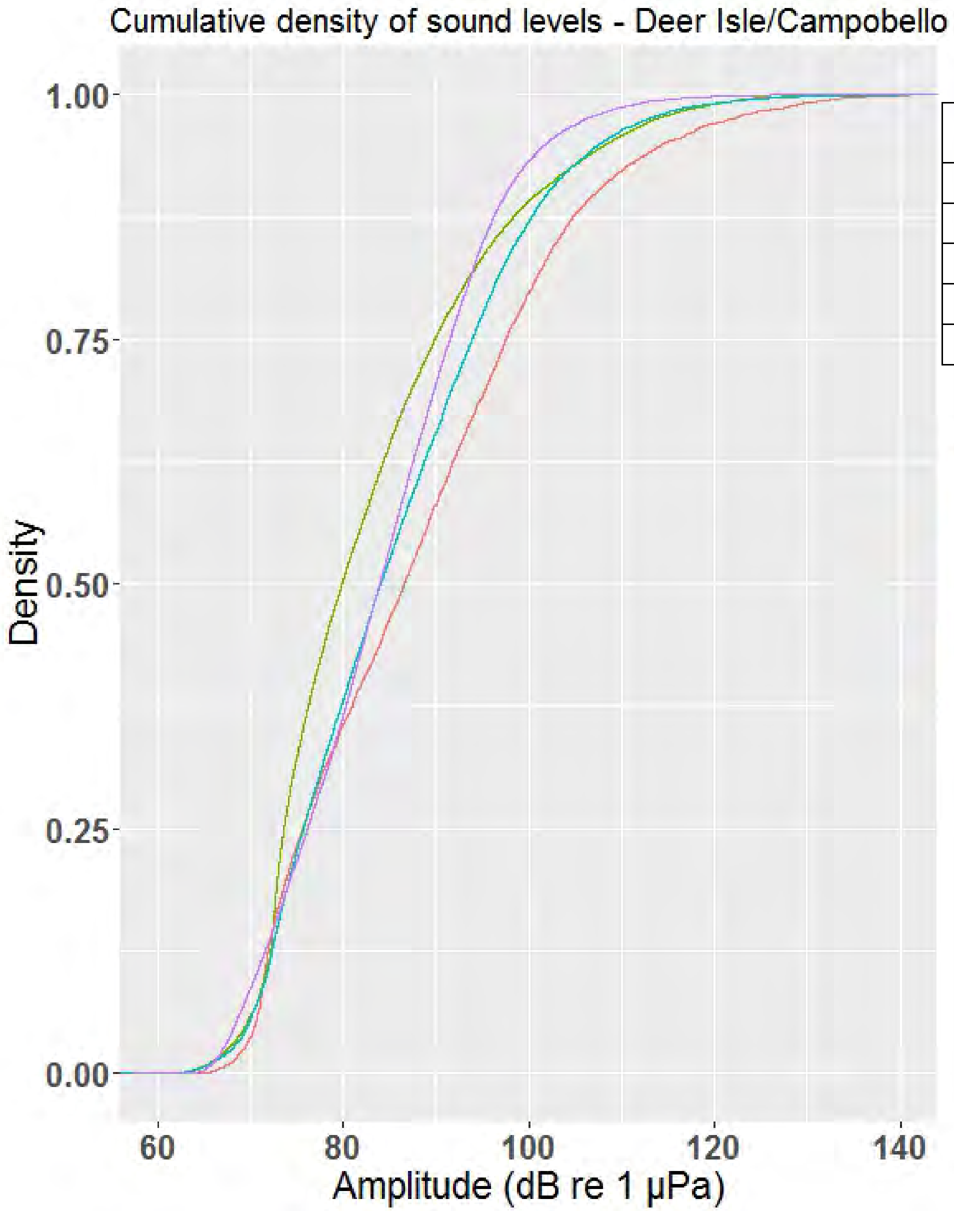


Figure 8C. Cumulative density of sound levels for 1/3 octave bands 20, 63, 125, 1000Hz for Deer Isle/Campobello. Values are calculated from levels throughout the entire sampling period.

Frequency	Levels (dB re 1upa) reached for % of time	
	80	100
20 Hz	65%	21%
63 Hz	51%	11%
125 Hz	62%	13%
1000 Hz	65%	7%

Table 8C: Percent of time that sound levels were reached for 1/3 octave bands 20, 63, 125, 1000Hz for Deer Isle/Campobello

The distribution of sounds levels showed that the 20Hz band was consistently the loudest at all percentiles except for the 25% and 5% quantile (Figure 8D). Unlike other areas, there was a pronounced peak at the 160Hz frequency instead of at 200Hz. The lower percentile (5% and 25%) sound levels stayed relatively consistent across all bands whereas the top 95th percentile showed larger amounts of variation in sound levels ranging from 114.48 to 92.74 dB re 1 µPa (Figure 8D).

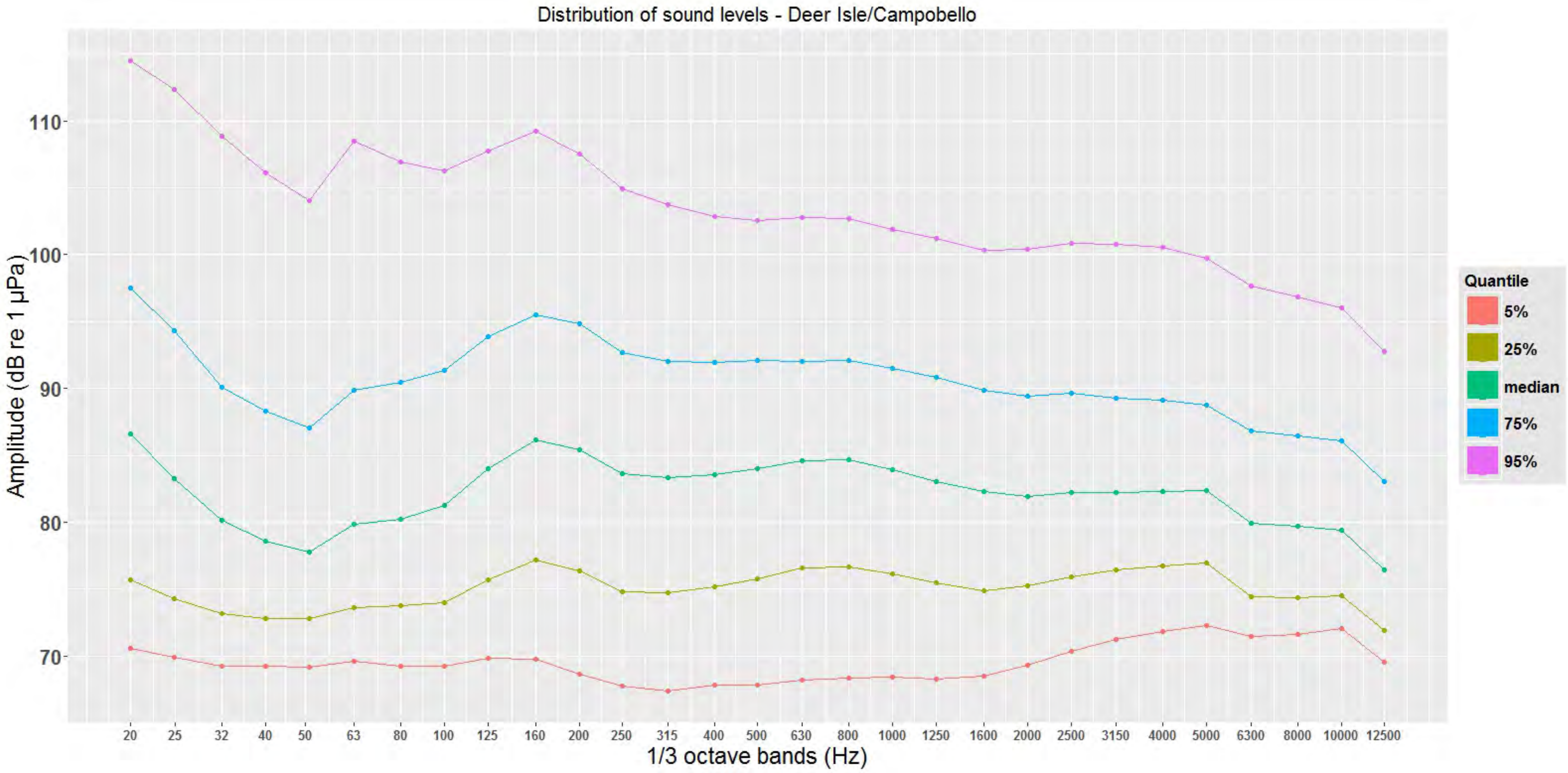


Figure 8D: Distribution of sound levels for 1/3 octave bands 20-12,500Hz for Deer Isle/Campobello. Quantiles displayed as levels that were reached 5%, 25%, 50% (median), 75% and 95% of the time. All values were calculated from levels throughout the entire sampling period.

For median and 75% quantiles, spectrum values fell within or above usual traffic noise, (Figure 8E). The 95% quantile actually exceeded higher traffic noise values. The 25% and 5% quantile mostly fell below usual traffic noise values (Figure 8E). Once again, noise at frequencies greater than 1000Hz seemed to be associated with wind dependent bubbles and spray (Figure 8E).

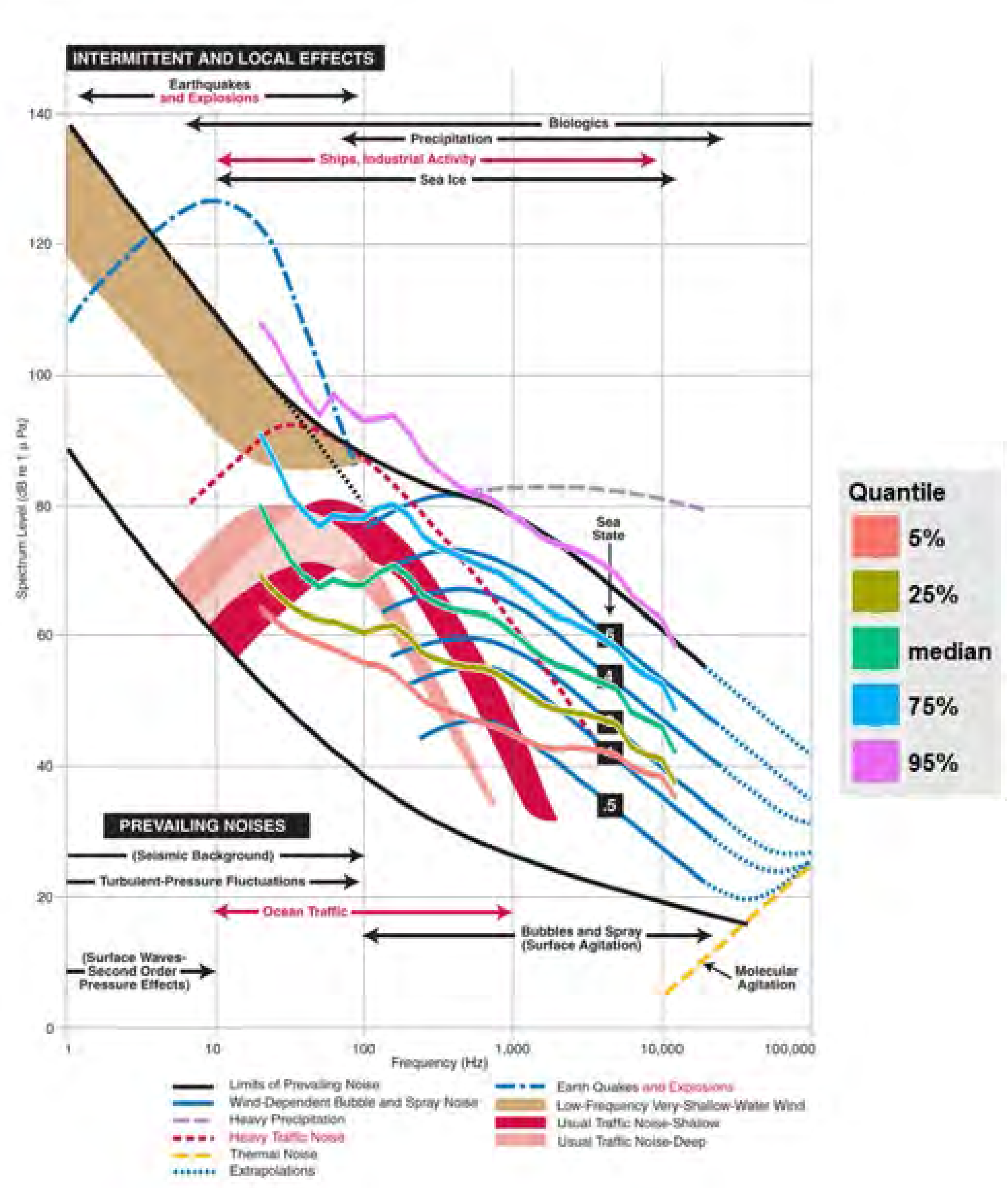


Figure 8E: Full spectrum analysis in reference to Wenz curves values for likely sources of noise per amplitude and frequency for Deer Isle/Campobello

Southern Wolves

Table 9A: Daily mean±SD and the month with the highest means for 1/3 octave bands 20, 63, 125 and 1000 Hz for the Southern Wolves location

Frequency	**Daily mean±SD (dB re 1 μPa)**	**Highest monthly sound level (mean±SD, dB re 1 μPa)**
20 Hz	80±4.2	June (81±9.6)
63 Hz	83±2.7	June (86±8.8)
125 Hz	89±3.8	June (95±8.5)
1000 Hz	84±5.0	October (88±8.4)

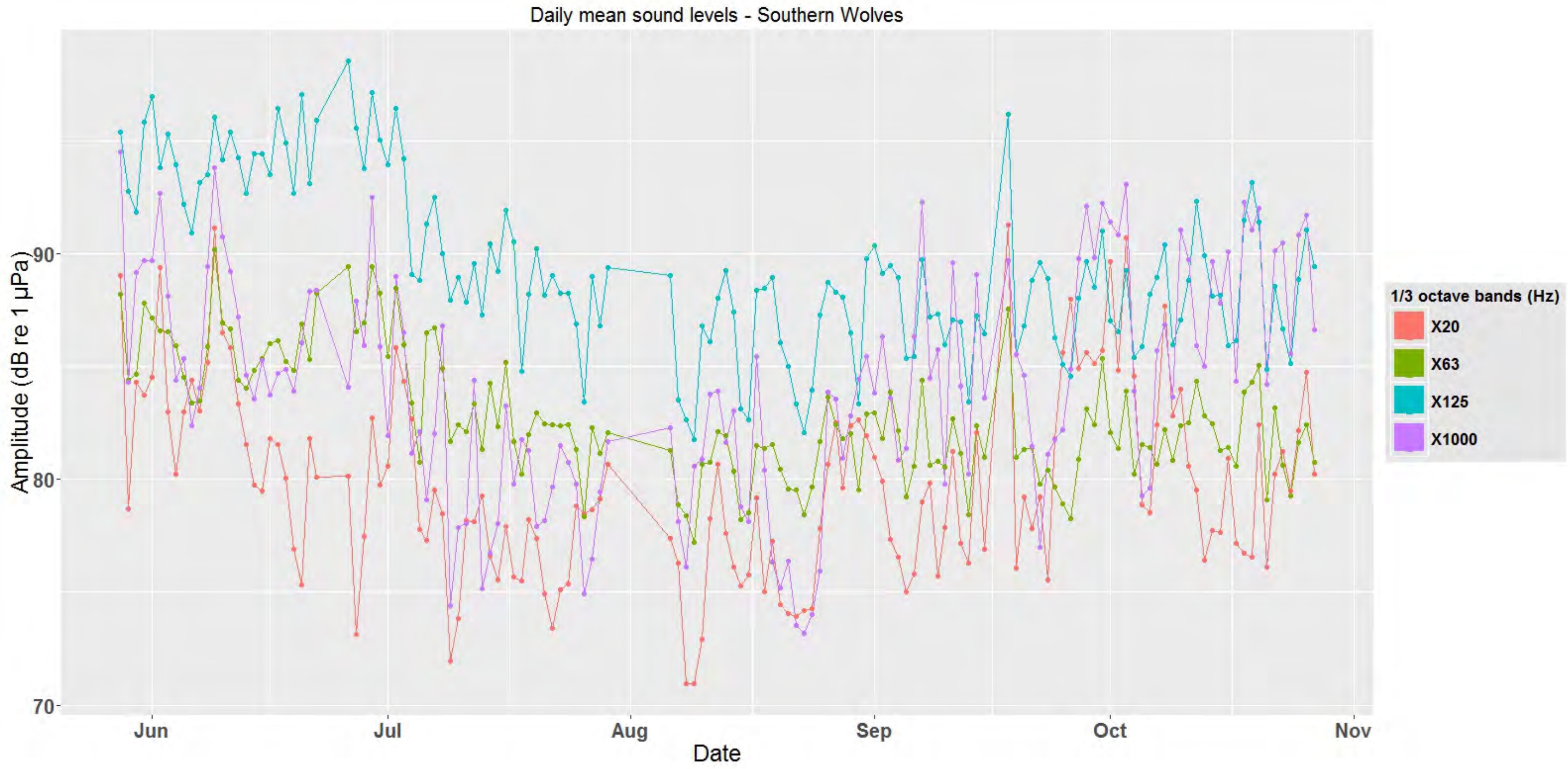


Figure 9A: Daily mean sound levels for 1/3 octave bands 20, 63, 125, 1000 Hz throughout the entire sampling period for Southern Wolves

Table 9B: Hourly mean±SD for 1/3 octave bands 20, 63, 125 and 1000 Hz for the Southern Wolves location

Frequency	Hourly mean±SD (dB re 1 μPa)
20 Hz	80±1.5
63 Hz	83±5.2
125 Hz	89±4.0
1000 Hz	84±2.9

Distinct peaks in sound levels occur around 8:00, 10:00, 12:00, 14:00, 16:00, 18:00, 20:00 and 22:00 for all four bands (Figure 9B). These peaks correspond to the sailing times of the Grand Manan Island ferries. For the 125Hz band, peaks in sound were always above 90 and even exceeded 95 dB re 1 μPa at 14:00 and 16:00 (Figure 9B). The 63Hz band also exceeded 90 dB re 1 μPa at each peak. The 20Hz band had much lower levels and fluctuated less (Figure 9B).

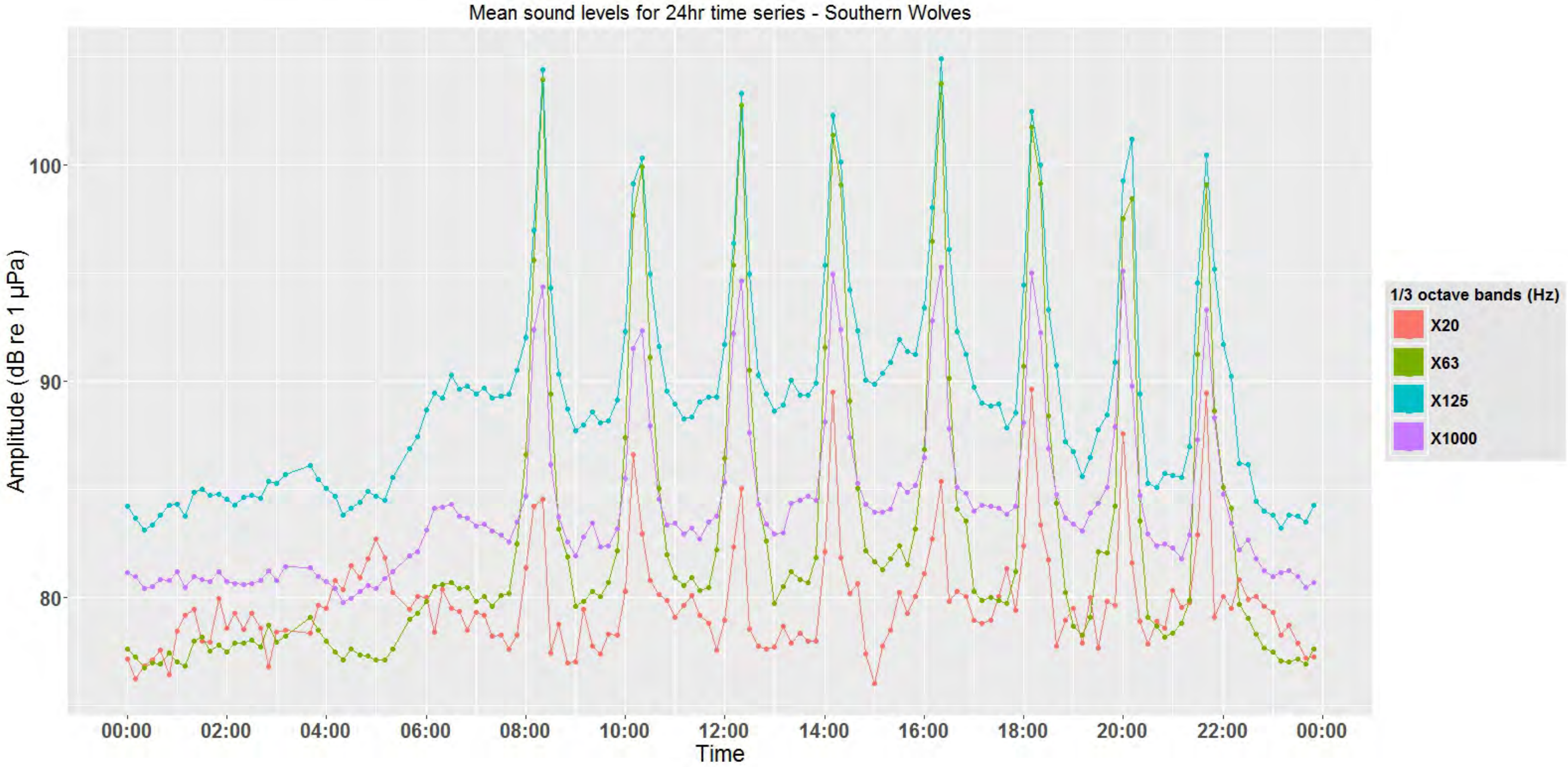


Figure 9B: Mean sound levels at each time of recording over a 24hr period for 1/3 octave bands 20, 63, 125, 1000Hz for Southern Wolves. Means were calculated for every time of recording throughout a day from levels throughout the entire sampling period.

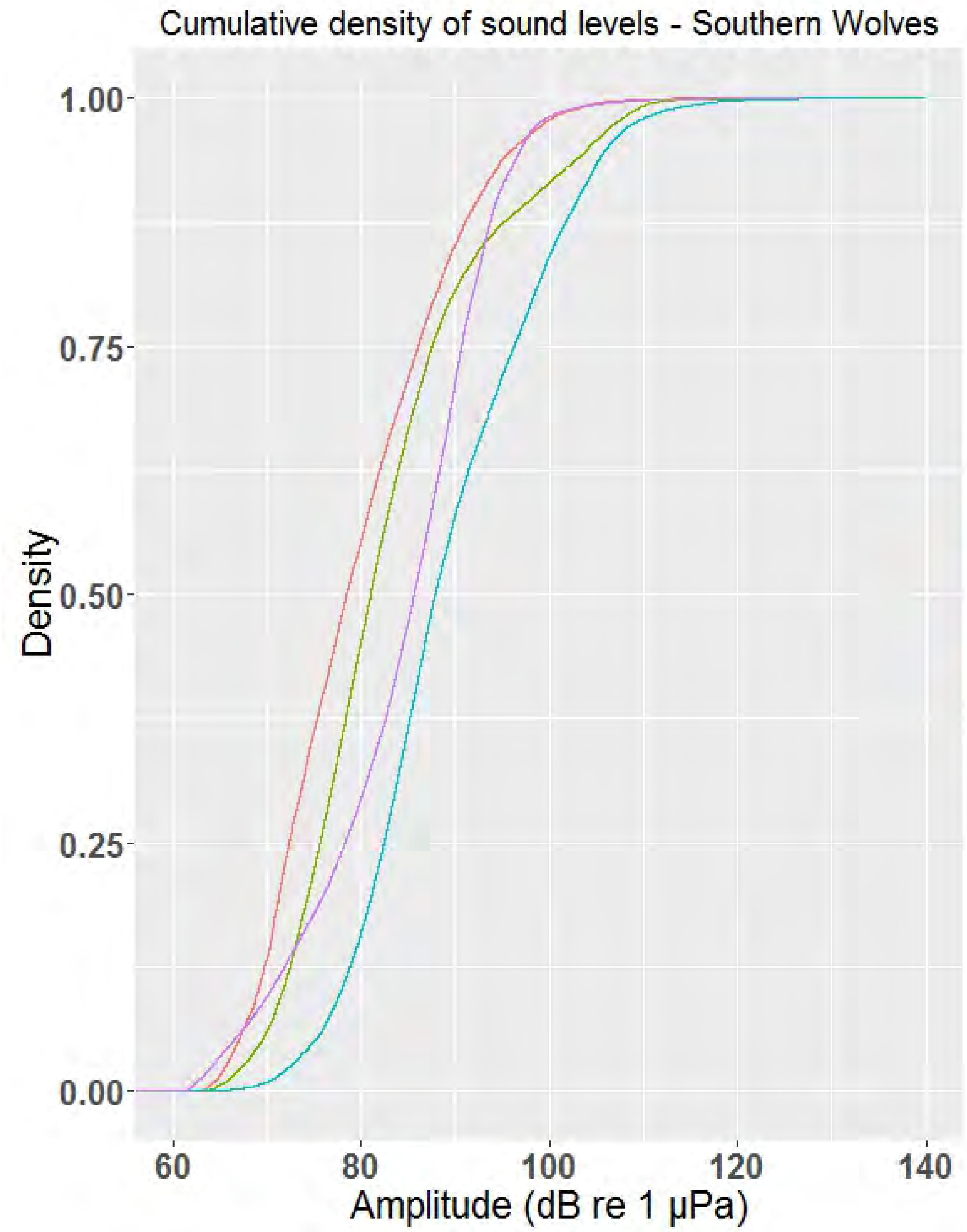


Figure 9C: Cumulative density of sound levels for 1/3 octave bands 20, 63, 125, 1000 Hz for Southern Wolves. Values are calculated from levels throughout the entire sampling period.

Frequency	Levels (dB re 1upa) reached for % of time	
	80	100
20 Hz	45%	0%
63 Hz	55%	8%
125 Hz	85%	17%
1000 Hz	71%	0%

Table 9C: Percent of time that sound levels were reached for 1/3 octave bands 20, 63, 125, 1000Hz for Southern Wolves

The full distribution of sound levels showed peaks for bands 160-250Hz for the median and all quantiles except the top 95% quantile (Figure 9D). The 95% quantile showed that 80Hz reached the highest threshold of sound levels for 5% of the time (Figure 9D). All frequencies reached 90 dB re 1 µPa for 5% of the time except at 32, 10000 and 12500Hz (Figure 9D).

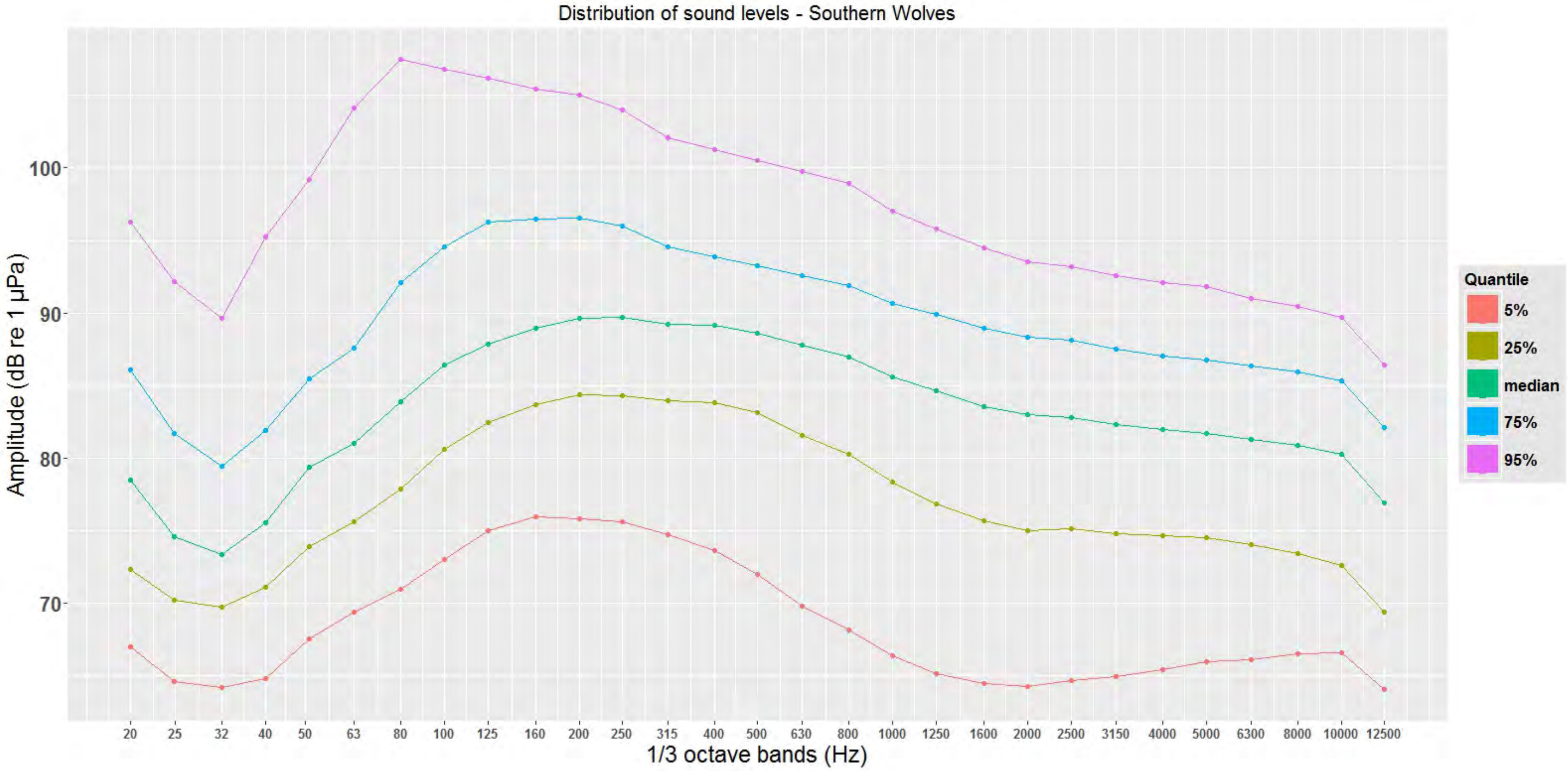


Figure 9D: Distribution of sound levels for 1/3 octave bands 20-12,500Hz for Southern Wolves. Quantiles displayed as levels that were reached 5%, 25%, 50% (median), 75% and 95% of the time. All values were calculated from levels throughout the entire sampling period.

Ambient and 25% quantile noise levels were mostly below usual traffic noise except around 200Hz and 100Hz, where they were within (Figure 9E). Median and 75% quantile values remained within usual traffic noise, while the 95% quantiles remained above, and even exceeded high traffic noise around 80Hz (Figure 9E). After 1000Hz levels seemed mostly influenced by wind dependent bubbles and spray.

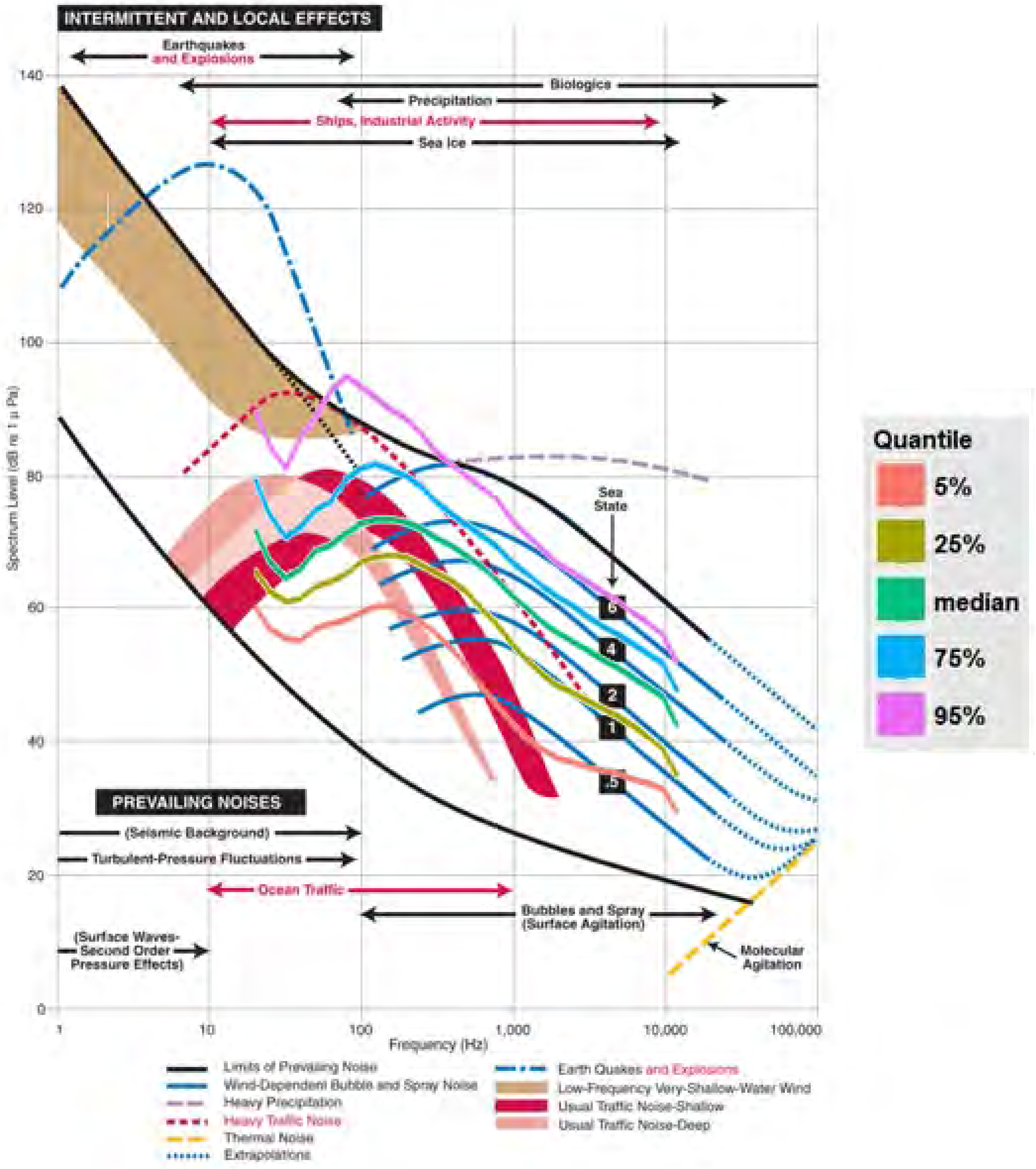


Figure 9E: Full spectrum analysis in reference to Wenz curves values for likely sources of noise per amplitude and frequency for Southern Wolves.

Wolves/Campobello

Table 10A: Daily mean±SD and the month with the highest means for 1/3 octave bands 20, 63, 125 and 1000 Hz for the Wolves/Campobello location

Frequency	Daily mean±SD (dB re 1 µPa)	Highest monthly sound level (mean±SD, dB re 1 µPa)
20 Hz	84±4.2	July (88±9.6)
63 Hz	83±2.0	June (85±8.9)
125 Hz	86±3.0	June (91±8.4)
1000 Hz	83±5.0	October (87±7.4)

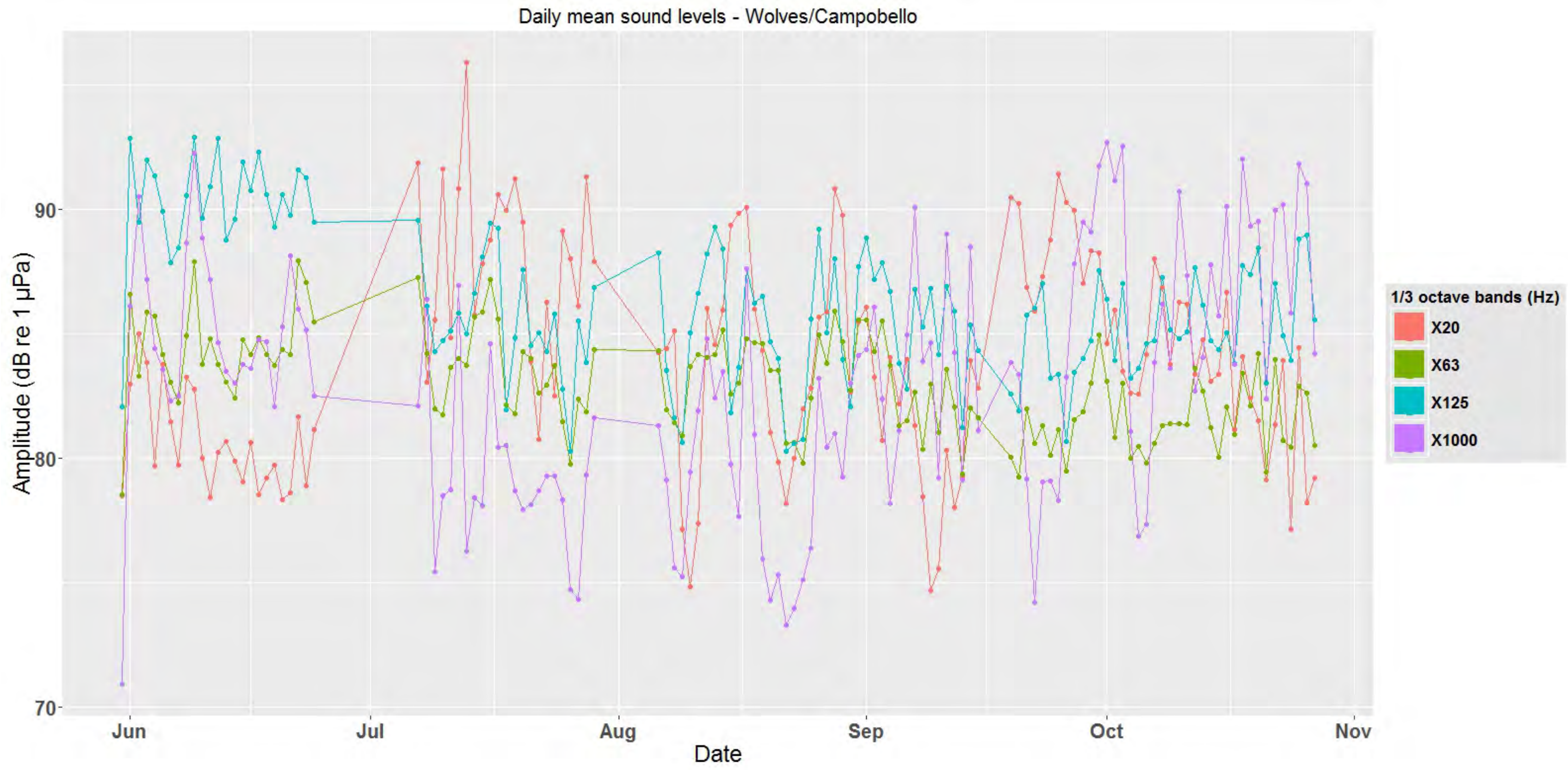


Figure 10A: Daily mean sound levels for 1/3 octave bands 20, 63, 125, 1000 Hz throughout the entire sampling period for Wolves/Campobello

The hourly average levels show eight very distinct peaks around 8:30, 10:00, 12:30, 14:00, 16:30, 18:00, 20:30 and 21:30 for 63, 125, and 1000 Hz bands (Figure 10B). These peaks correspond with the sailing times of the Grand Manan Island ferries. For each of the 63 and 125Hz bands these peaks exceeded 90 (dB re 1 µPa), while the 1000 Hz band reached 87.5 dB re 1 µPa. The 20 Hz frequency remained around 87.5 dB re 1 µPa throughout the entire 24 hour period (Figure 10B).

Table 10B: Hourly mean±SD for 1/3 octave bands 20, 63, 125 and 1000 Hz for the Wolves/Campobello location

Frequency	**Hourly mean±SD (dB re 1 µPa)**
20 Hz	84±1.2
63 Hz	83±6.2
125 Hz	86±4.7
1000 Hz	83±3.8

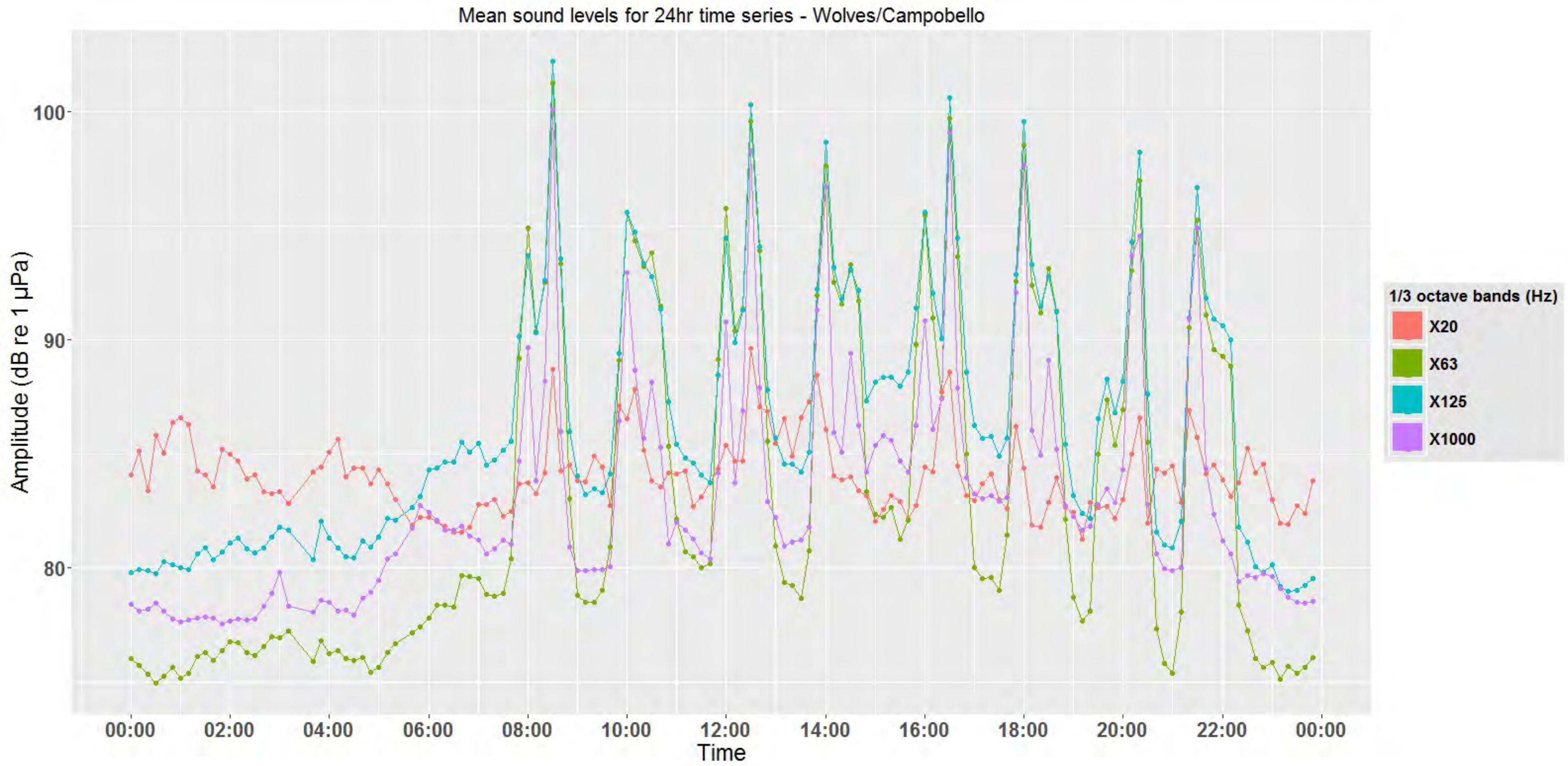


Figure 10B: Mean sound levels at each time of recording over a 24hr period for 1/3 octave bands 20, 63, 125, 1000Hz for Wolves/Campobello. Means were calculated for every time of recording throughout a day from levels throughout the entire sampling period.

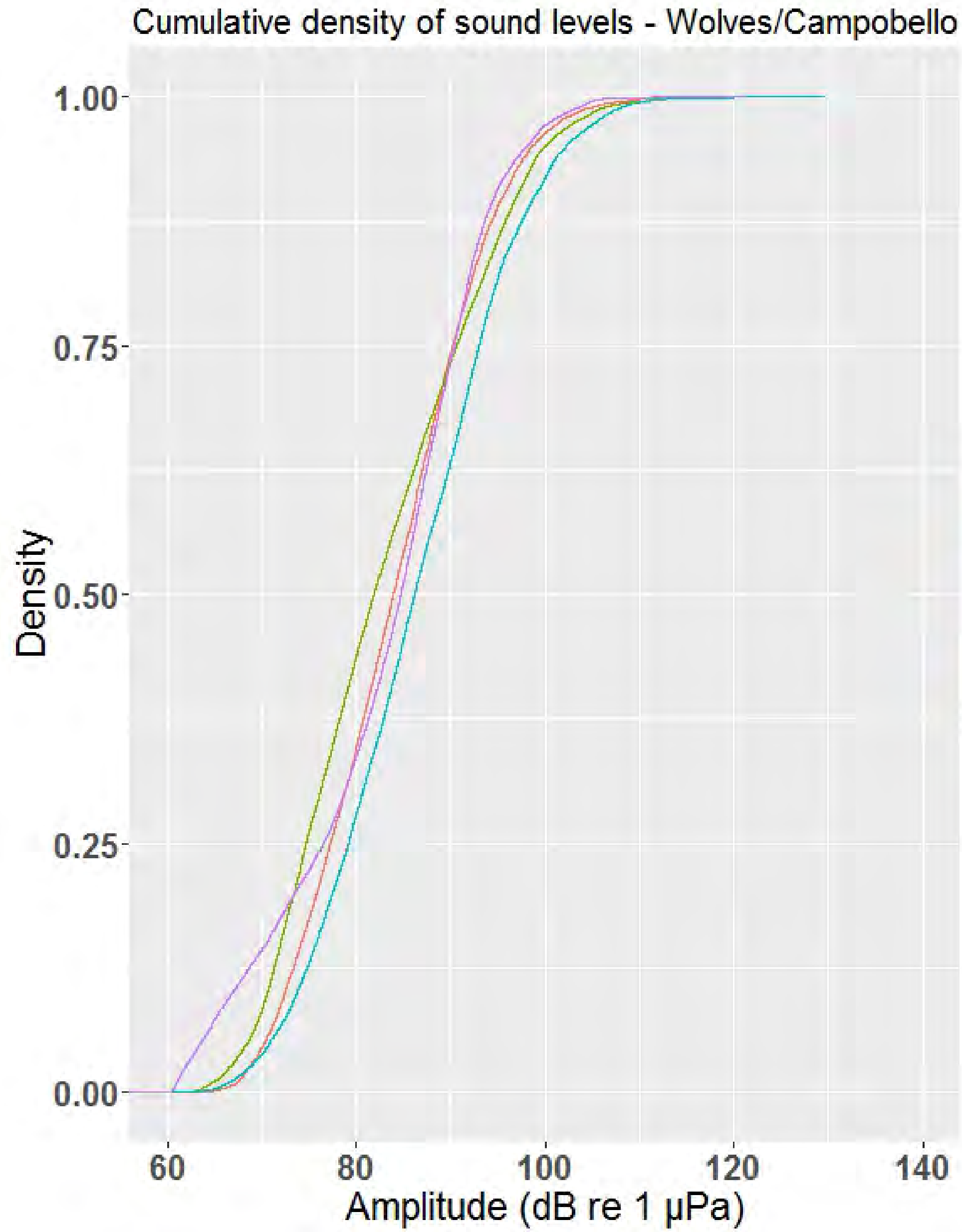


Figure 10C: Cumulative density of sound levels for 1/3 octave bands 20, 63, 125, 1000Hz for Wolves/Campobello. Values are calculated from levels throughout the entire sampling period.

Frequency	Levels (dB re 1upa) reached for % of time	
	80	100
20 Hz	66%	0%
63 Hz	58%	5%
125 Hz	73%	9%
1000 Hz	67%	0%

Table 10C: Percent of time that sound levels were reached for 1/3 octave bands 20, 63, 125, 1000Hz for Wolves/ Campobello

The distribution of sound levels across all frequencies showed three main peaks in sound levels occurring at 20, 80, and 200 Hz bands (Figure 10D). For the median and lower percentiles the 80 Hz band does not peak, therefore its lower threshold of sound levels tended to be lower than other frequencies (Figure 10D). The 200 Hz band is only slightly above the 80 Hz band in respect to the 75% and 95% values. Frequencies below 2000 Hz consistently remained above 95 dB re 1 µPa for 5% of the time (Figure 10D).

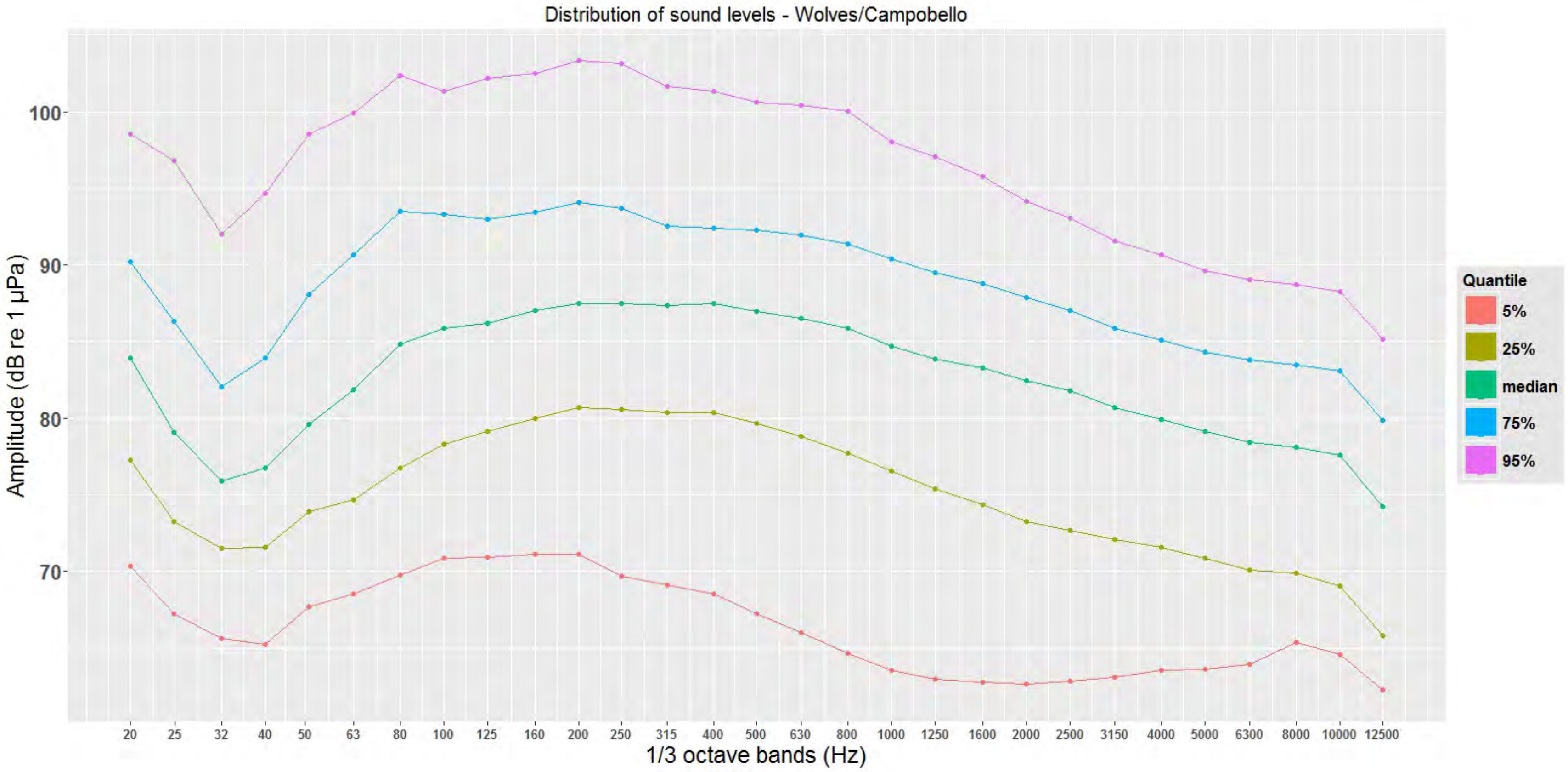


Figure 10D: Distribution of sound levels for 1/3 octave bands 20-12,500Hz for Wolves/Campobello. Quantiles displayed as levels that were reached 5%, 25%, 50% (median), 75% and 95% of the time. All values were calculated from levels throughout the entire sampling period.

Wolves/Campobello showed ambient noise levels below usual traffic noise except at very low frequencies surrounding 25 Hz (Figure 10E). The 25% quantile values mostly fell below usual traffic noise except for frequencies below 40 Hz and above 125 Hz. Median and 75% quantile values fell mostly within usual traffic noise (Figure 10E). The 95% quantile fell mostly in between usual and high traffic noise, but did exceed high traffic noise at 80 Hz and above. For frequencies above 1000 Hz most noise is associated with wind dependent bubbles and spray (Figure 10E).

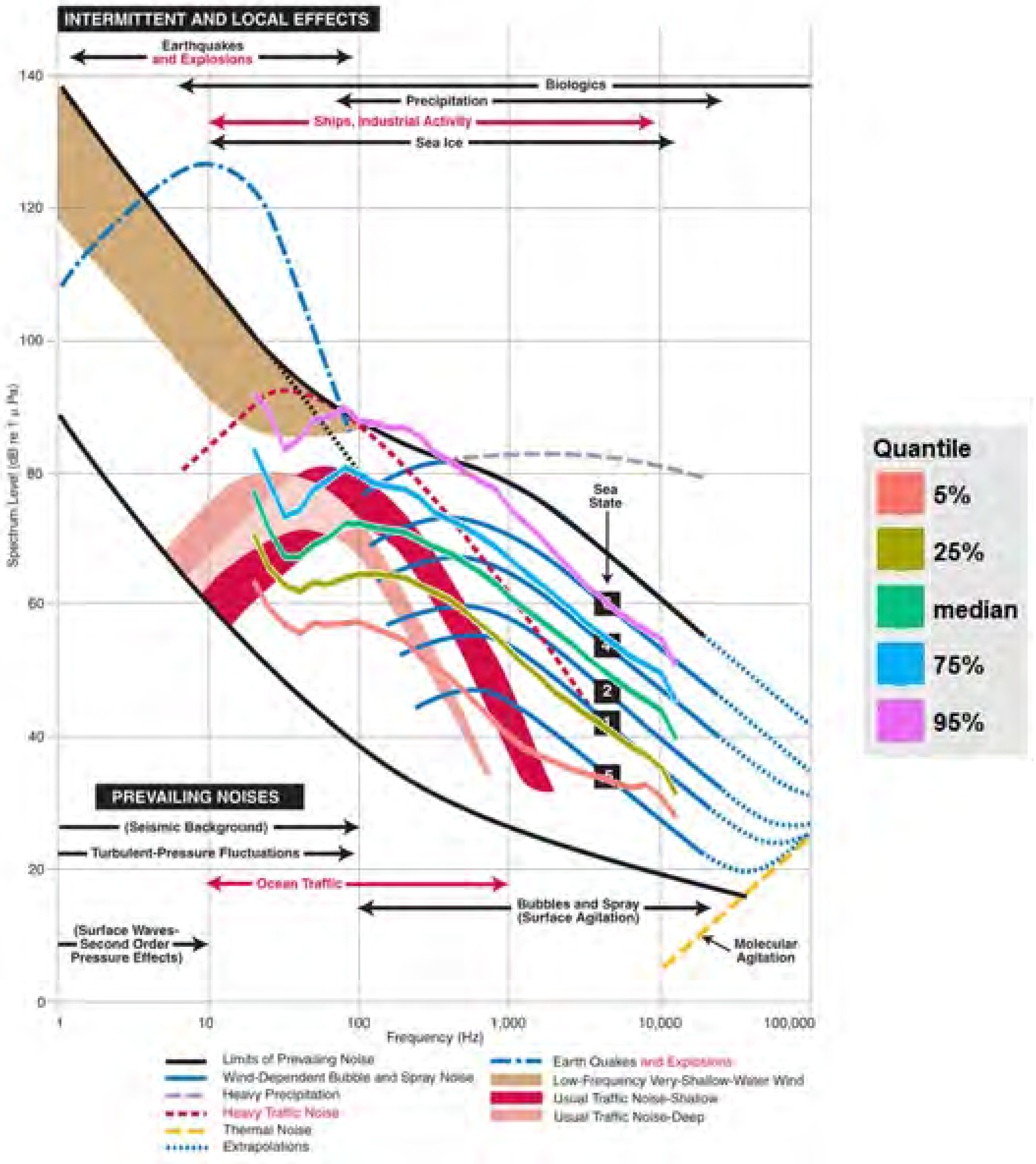


Figure 10E: Full spectrum analysis in reference to Wenz curve values for likely sources of noise per amplitude and frequency for Wolves/Campobello

Location comparisons

Sound levels in all four of the select 1/3 octave bands showed a large amount of variation from one location to another (Figure 11). The 125 Hz band was the loudest frequency in Dipper Harbour, Southern Wolves, and Wolves/Campobello. The 63 Hz band was normally within the lowest two bands in amplitude at a given location (Figure 11). The 20 Hz and 1000 Hz bands showed the most variation in amplitude. Overall, mean sound levels never exceeded 90 dB re 1 μPa (Figure 11).

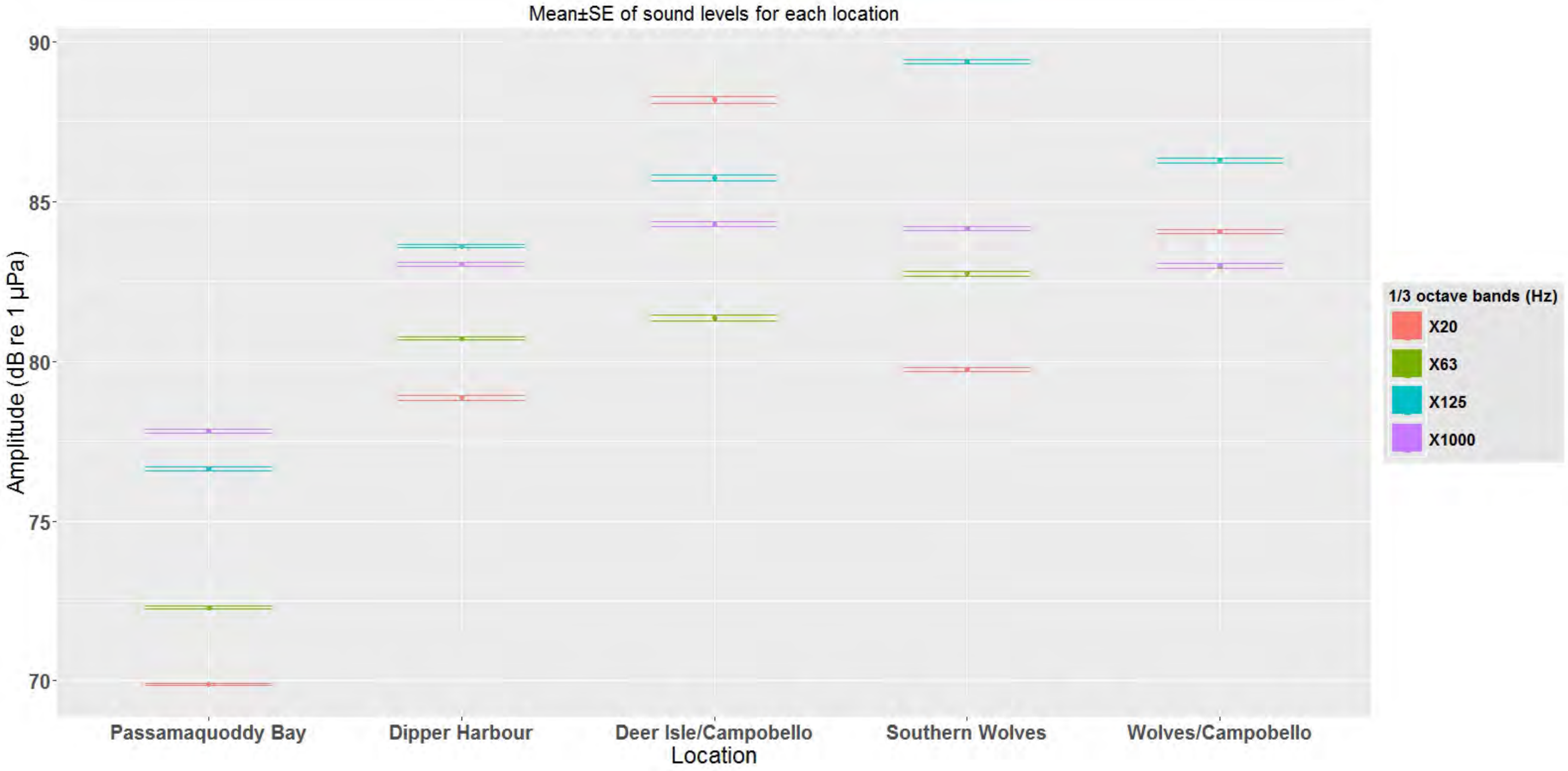


*Figure 11: Mean±SE of sound levels for 1/3 octave bands 20, 63, 125 and 1000 Hz for each location (*the X63 value for Wolves/Campobello overlaps with X1000)*

Sound levels, averaged across all 1/3 octave bands, were highest at Deer Isle/Campobello with a mean±SD of 84±11 dB re 1 µPa (Figure 12). Sound levels were lowest in Passamaquoddy Bay at 76±8.7 dB re 1 µPa. The mean±SD of sound levels for Southern Wolves, Wolves/Campobello, and Dipper Harbour were 84±9.9, 82±10.2 and 82±7.9 dB re 1 µPa, respectively (Figure 12). Note: these are averaged values and are not equivalent to the broadband sound levels that would be reported if analyzing bandwidth was set to 20 or 12,500 Hz.

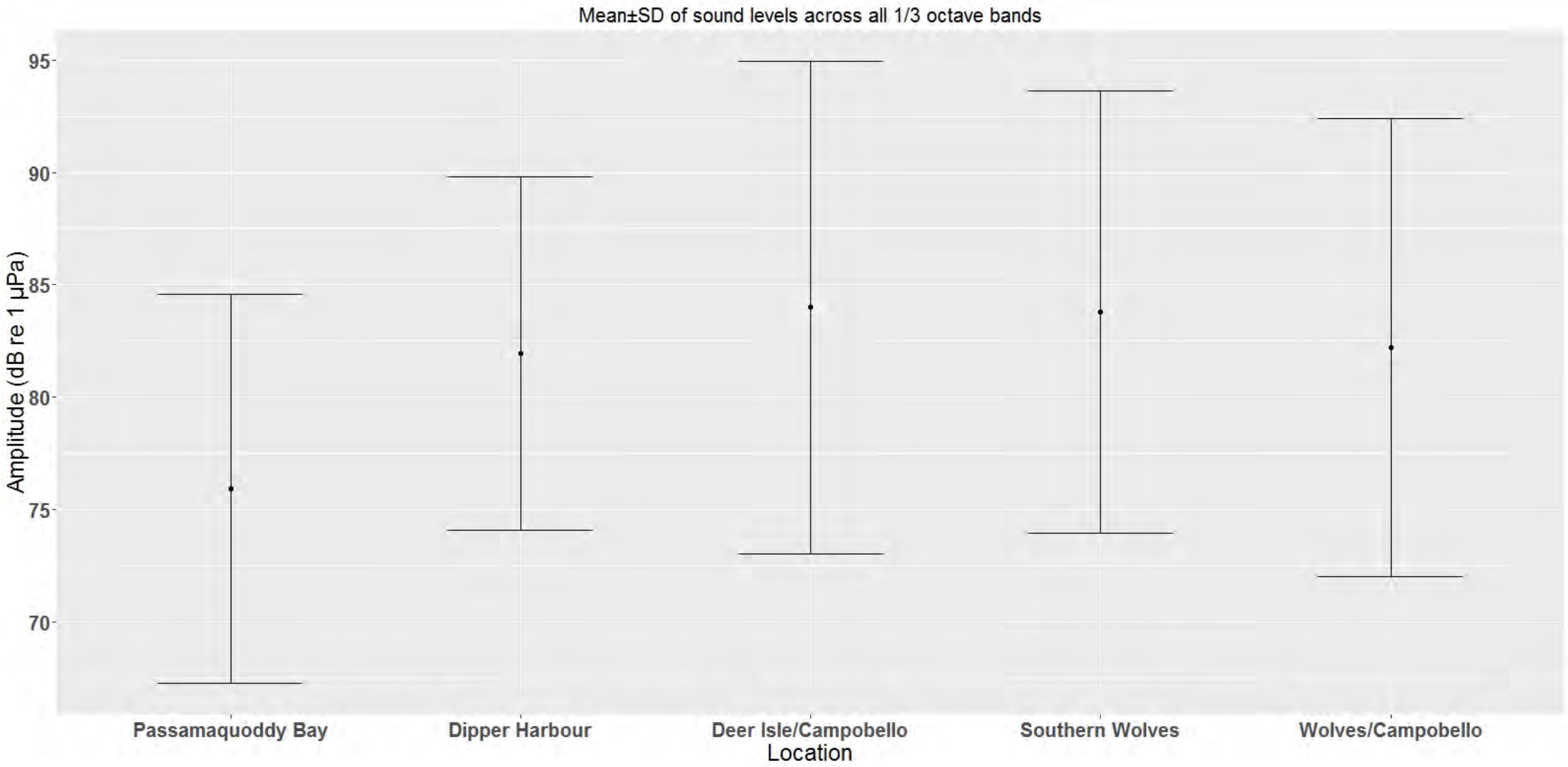


Figure 12: Mean±SD of sound levels including values from 1/3 octave bands 20-12,500Hz for each location. Means were calculated from all values across all frequencies between 20-12,500Hz.

The 20 Hz band exceeded a monthly mean of 95 dB re 1 µPa at Deer Isle/Campobello for the month of June; all other means remained below 90 dB re 1 µPa (Figure 13). Passamaquoddy Bay showed the lowest monthly levels of all locations while Deer Isle/Campobello and Wolves/Campobello were normally the two highest (Figure 13).

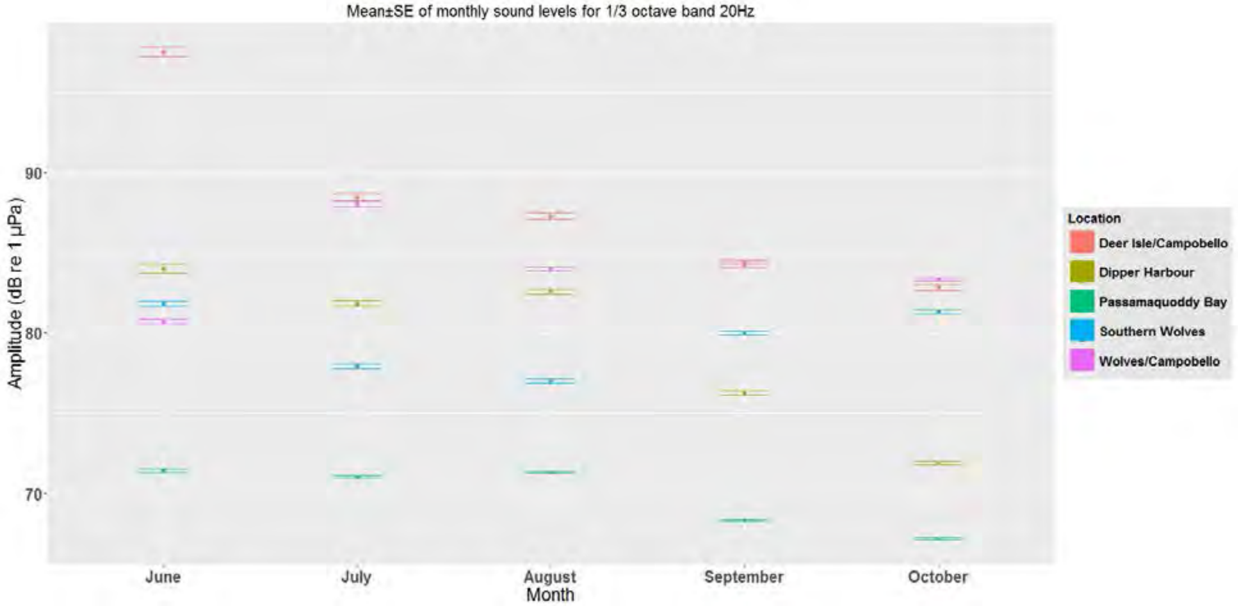


Figure 13: Monthly Mean±SE sound levels at each location for 1/3 octave band 20Hz. May is excluded since too few of days were sampled.

During the entire sampling period mean sound levels for the 63 Hz band never exceeded 90 dB re 1 µPa (Figure 14). Location sound levels were highest during June except for Passamaquoddy Bay where the highest levels were during August (Figure 14).

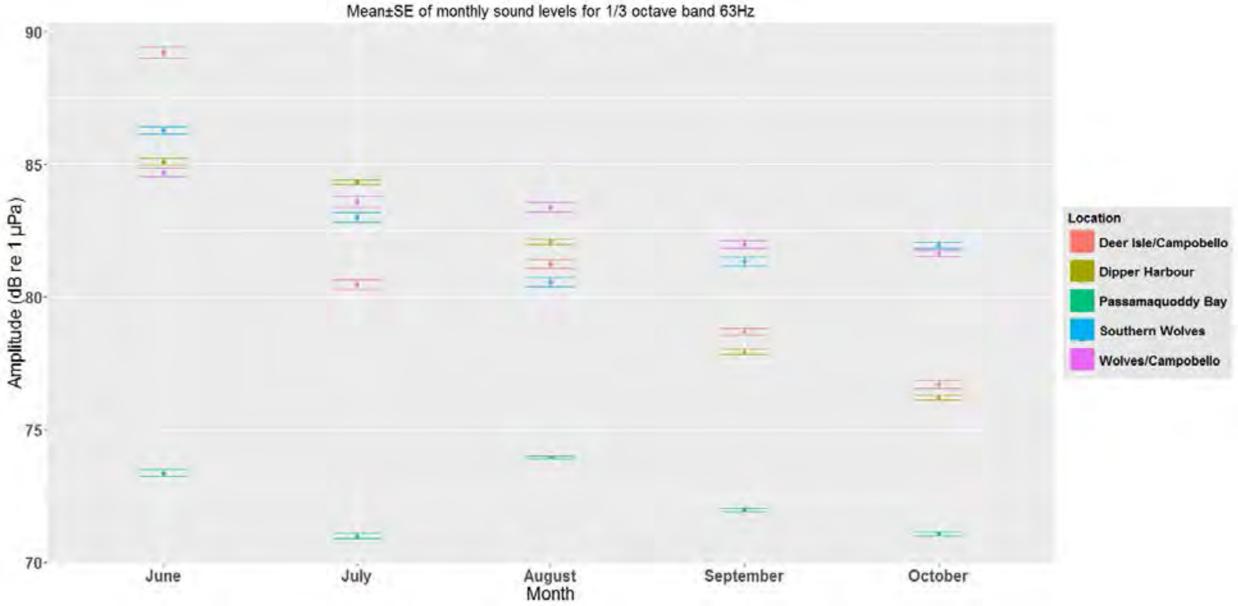


Figure 14: Monthly Mean±SE sound levels at each location for 1/3 octave bands 63Hz. May is excluded since too few of days were sampled.

Southern Wolves showed the highest mean sound levels for the 125 Hz band over the entire sampling period (Figure 15). During the month of June these monthly levels exceeded 90 dB re 1 µPa for Deer Isle/Campobello, Wolves/Campobello, and Southern Wolves. For each location the highest sound levels were during June (Figure 15).

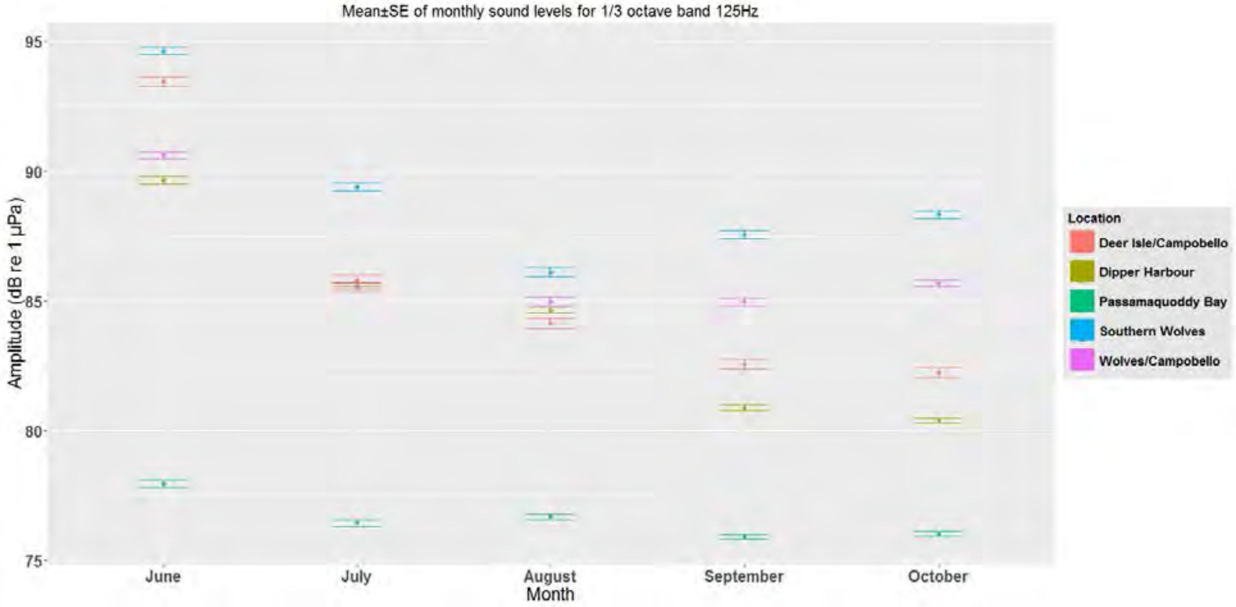


Figure 15: Monthly Mean±SE sound levels at each location for 1/3 octave bands 125Hz. May is excluded.

For 1/3 octave band at 1000Hz, the highest monthly levels were in June and October (Figure 16). Passamaquoddy Bay showed the lowest values of all locations while Deer Isle/Campobello showed the highest levels for June, July and August. Over the entire sampling period, mean monthly levels never exceeded 90 dB re 1 µPa (Figure 16).

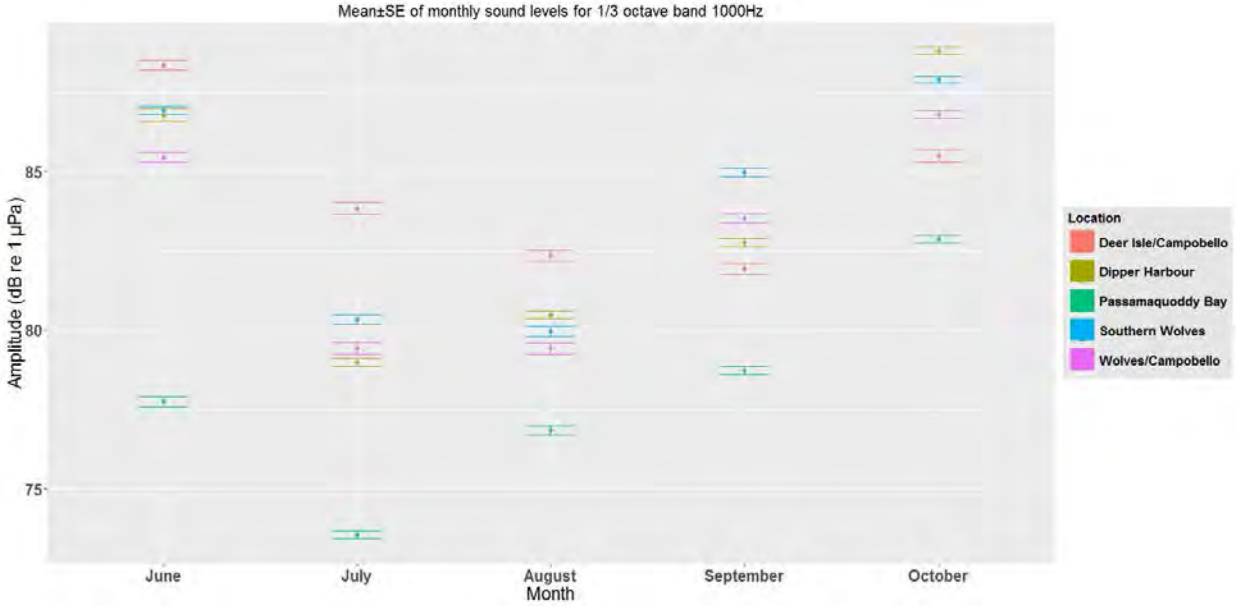


Figure 16: Monthly Mean±SE sound levels at each location for 1/3 octave bands 1000 Hz. May is excluded since too few of days were sampled.

Discussion

We found a large amount of temporal and spatial variation of noise levels in the Outer Bay of Fundy. Temporally we found that noise levels varied considerably on an hourly, daily, and monthly scale. These temporal trends closely aligned with marine traffic schedules and fishing seasons, during which increased traffic is to be expected. Spatially, sound levels were mostly controlled by proximity to areas with high levels of marine traffic. Physical geographic attributes such as islands also showed to have a controlling effect on sound levels when present. The main two sources of noise were ‘usual marine traffic’ and ‘wind-dependent bubbles and spray’. Overall, average noise levels within the sampled areas appear to be at a reasonable threshold however, levels showed a large amount of variation and were prone to periods of extreme highs and lows.

We found that at most sites, sound levels were significantly affected by tidal streams at some frequencies. This was mostly segregated to lower frequencies ranging from 20-63 Hz, but in one location (Deer Isle/Campobello) higher frequencies between 6300-12500 Hz were also affected. Sound levels for these frequencies increased by >2.5 dB re 1 µPa during times when the tide was either coming in or going out. Accounting for this variation is extremely important in determining anthropogenic sources of noise pollution and should always be taken into account to distinguish between naturally occurring and human induced sound. This becomes especially important when determining the effects of marine traffic on mammals, such as fin whales which use low frequencies (20-80 Hz) to communicate (Clark 2009).

Overall noise levels

According to the Marine Strategy Framework Directive (MSFD), underwater noise levels should not exceed an average yearly value of 100 dB re 1 µPa for 1/3 octave bands 63 Hz and 125 Hz (Tasker et al. 2010). For all locations, the noise level of both 63 Hz and 125 Hz bands did not exceed these guidelines for the six month sampling period. Even though these values do not include an entire year of sampling, comparisons to the MSFD guidelines remain effective.

Spatial variation

The mean amplitude, including values from all frequencies between 20-12500 Hz (Figure 12), showed Deer Isle/Campobello and Southern Wolves to have the highest levels of noise, while Wolves/Campobello was slightly lower (1 dB re 1 µPa). Deer Isle/Campobello also showed the highest standard deviation in sound levels implying periods of very high and low sound levels. Southern Wolves and Wolves/Campobello showed very similar mean±SD readings, unsurprisingly as these two locations were in approximately equal proximity to the Grand Manan ferry. Passamaquoddy Bay showed the lowest sound levels and second lowest standard deviation, inferring a more stable and quiet environment when compared to other locations.

Mean noise levels for select 1/3 octave bands (20, 63, 125 and 1000 Hz) over the entire sampling period were lowest in Passamaquoddy Bay. Of interest within Passamaquoddy Bay, the 20 Hz frequency was the lowest in amplitude of the four select 1/3 octave bands. In most other areas the 20 Hz band was the highest. This is likely because Passamaquoddy Bay is less utilized by larger ships which emit lower frequencies and also because the surrounding islands block sound from the Deer Island and Grand Manan ferry routes.

The surrounding islands seem like a plausible explanation for the lower sound levels in Passamaquoddy Bay, as islands essentially shield the area from sound waves (McDonald et al. 2008). In contrast, the Dipper Harbour location had much less marine traffic in close proximity (Figure 17) but still exhibited higher levels of noise, likely because it was in open ocean with no obstacles to mitigate sound waves from the Port of Saint John and the Grand Manan ferries. This suggests that Passamaquoddy Bay is an area able to provide acoustic refugia to marine mammals and other wildlife.

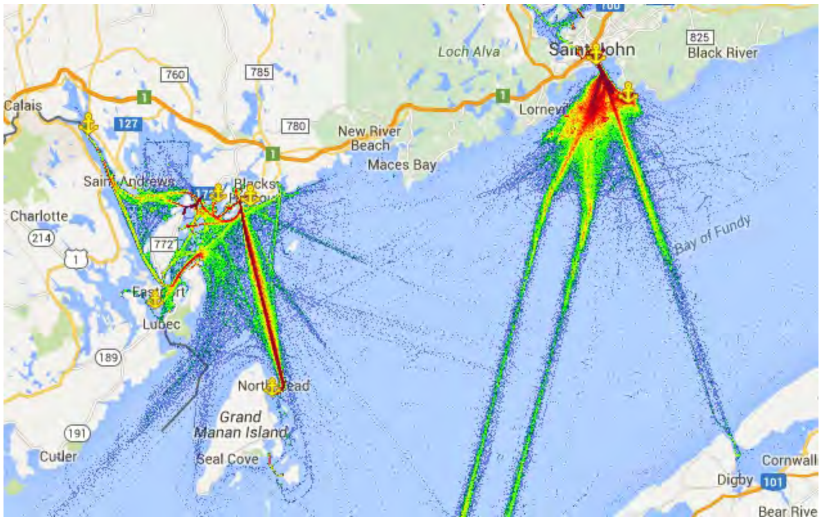


Figure 17. Ship density maps from 2014. Map acquired from www.marinetraffic.com

Across analyses for all locations, Deer Isle/Campobello had the highest amplitudes of sound for the longest periods of time. Cumulative densities showed that the 20Hz band exceeded 100 dB re 1 µPa approximately 20% of the time (Figure 8C) and all bands below 5000Hz exceeded 100 dB re 1 µPa for at least 5% of the time (Figure 8D).

These higher levels are likely a result of heavy marine traffic in Head Harbour Passage and the physical characteristics of the passage. Its location between two islands, with a deep ledge, refracts sound waves. Tidal streams in this location also had the greatest affect, again, likely associated with the channel’s geography. Normally, two ferries have a route within this area but they were not in service during 2014. Levels will likely be higher when the ferries are in use. The Deer Isle/Campobello location requires further monitoring to ensure that the area does not become more polluted.

Comparisons between locations showed large variation between the bands’ order of amplitude; no one band was consistently the highest or lowest across locations (Figure 11). This is likely because each location is frequented by different types and sizes of vessels. Marine vessels emit noise levels at varying frequencies depending on the size, shape, speed and propeller depth (Erbe et al. 2012; Veirs et al. 2015). Therefore, the areas where higher frequencies (1000 Hz) were the loudest (Passamaquoddy Bay) are likely frequented more often by smaller vessels. Each of the four select 1/3 octave bands showed dissimilar trends in amplitudes for Southern Wolves and Wolves/Campobello. This was surprising as both locations are very close to the same two ferries travelling between Grand Manan and Blacks Harbour. Perhaps, this may have been caused by the geography of the location and sound waves reflecting off the surrounding islands and the ocean floor in different ways.

Temporal variation

Unsurprisingly, mean sound levels were lowest between 23:00 and 3:00 for all areas sampled. This overnight period traditionally has less boat activity. Ferries are not operating, and fishing vessels and recreational boating is occurring in daylight. Daily sound levels normally began to rise around 7:00 and remained high until decreasing between 19:00 and 22:00.

In Figure B for both Southern Wolves and Wolves/Campobello distinct peaks can be seen throughout the day. These daily peaks are extremely visible in all bands. These patterns are because of the Grand Manan ferry crossing directly through the sampled area. Each peak is the moment when the ferries are closest to the hydrophones. Wolves/Campobello shows a main larger peak that is always before or after a smaller peak; this second smaller peak is likely the second Grand Manan ferry a short distance away from the hydrophone.

For the Dipper Harbour location similar trends apply as previously stated, except, Dipper Harbour was picking up noise levels from the Digby Ferry. The Digby Ferry was further away from Dipper Harbour than Southern Wolves and Wolves/Campobello was to the Grand Manan Ferry. The Digby Ferry also ran on a less frequent schedule. The increased distance and less frequent schedule explains the fewer peaks with lower amplitudes for Dipper Harbour when compared to Southern Wolves and Wolves/Campobello. Monthly means for the 125 Hz band also showed to be highest at these three locations and is likely a result of the ferries.

For sites not strongly influenced by ferry noise (Passamaquoddy Bay and Deer Isle/Campobello), the majority of frequencies were loudest during the month of June, except for the 1000Hz band at Passamaquoddy Bay. This is likely caused by increased boat traffic during the lobster fishing season that runs from May until the end of June. These trends are highly visible in the daily mean values of amplitude for Deer Isle/Campobello. In Figure 8A there is an abrupt rise in daily mean values of amplitude near the beginning of June and these values remain relatively high throughout June followed by an abrupt fall at the beginning of July.

Sources of noise levels

The Wenz curves were used to determine the likely sources of noise within each location. The Wenz curves are a model based on mean sound levels of various types of marine traffic, sea states, weather, and seismic disturbances. By comparing the quantiles for each band (All Figures D) we were able to determine likely sources of noise for each location.

Overall, 5% (ambient noise levels) and 25% quantiles tended to be within or below the usual traffic noise levels expected. This was especially true for frequencies around 25 Hz and around 125 or 200 Hz, depending on location. At every location a decrease in slope can be seen through the higher frequencies beginning at 1000 Hz which closely resembles patterns expected for wind-dependent bubbles and spray.

Median values at each location, for the majority of frequencies, tended to fall within the usual traffic noise levels, except in Passamaquoddy Bay where they fell below. This was not surprising as Passamaquoddy Bay tends to have less traffic and ferry noise than other locations. This indicates that 50% of the time the other areas are experiencing noise levels at or above those that would be caused by usual shipping traffic.

The 75% quantile values usually exhibited patterns similar to usual traffic noise or slightly above, except in Passamaquoddy Bay where it fell below. The 95% values were normally at or above heavy traffic noise. This infers that at least 5% of the time sound levels experienced were that of heavy traffic noise in most locations, except Passamaquoddy Bay.

Overall, most upper quantile noise levels within the Outer Bay of Fundy seem to be associated with usual traffic noise or wind dependent bubbles and spray. Ambient levels showed to be below usual traffic noise indicating that marine traffic is not raising the ambient levels of noise within the Outer Bay of Fundy. However, the data used for Wenz curves comparisons was over the entire sampling period including times when little marine traffic was occurring (23:00-3:00). Therefore, these curves would likely be higher in amplitude if only data was used from times when shipping activity was regularly occurring.

Conclusion and recommendations

Noise levels in the sampled areas are below 100 dB re 1 µPa for longer time periods. However, noise levels commonly exceeded that recommended threshold in acute short term peaks at multiple locations; particularly Deer Isle/Campobello. Although the MSFD states that levels above 100 dB re 1 µPa for bands 63 and 125 Hz are only indicative of a polluted environment if experienced over longer periods (Tasker et al 2010), acute shorter term rises in noise levels can still cause problems for marine wildlife (Weilgart 2007). The data from the Outer Bay of Fundy shows hourly and daily averages that commonly exceeded 100 dB re 1 µPa. Therefore mitigation strategies for underwater noise must be considered to ensure levels do not increase above the recommended threshold for extended periods.

As shipping traffic and marine activities increase, responsible environmental management requires scientific research to assess the effect of increasing noise levels on wildlife that inhabit the impacted marine environments. This study was a credible first step in the evaluation of the effects of marine traffic on the Outer Bay of Fundy. Additional research is needed to determine the habitat range of marine mammals in the Outer Bay of Fundy. By quantifying habitat ranges we can apply noise data to those areas and identify impacts and mitigation strategies.

There is also a need for continued sound monitoring, ideally using the five hydrophones from this study on a rotating basis in a series of standard sampling sites on a long term yearly basis. The data from this study are only indicative of sound levels for their respective area, and should only be taken as such. We suggest hydrophones be placed in close proximity to the Port of Saint John as this is the busiest port and likely experiences the highest sound levels within the Bay of Fundy. By gathering long term data at a multitude of locations, forecasting for future noise and its impact on marine life within the Bay of Fundy can be completed using credible sound modelling. By doing so, actions can be taken beforehand to ensure this local environmental pressure is effectively managed, as part of a multi-stressor approach to environmental management in the Bay of Fundy.

Researchers will continue to work with the data collected for this study. Efforts are underway to quantify the amount of distance whale calls can travel before becoming inaudible because of ocean noise. Whale calls will be identified within the recorded audio files and their amplitude measured at select call frequencies. The amplitudes for each call will then be compared to local rises in the ambient noise levels at each call's location. For every increase of 4.5 dB in ambient noise level whale communication distance is cut in half. By taking the increase in sound levels above ambient levels throughout the sampling period we can determine at what times, what locations, and by how much, whale communication is being masked by marine traffic noise. While the project to collect baseline noise data in the Outer Bay of Fundy has been a success, there is much work left to be done.

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