Harbour porpoise (*Phocoena phocoena*) presence in relation to underwater noise levels at four industrial areas in the Bay of Fundy, Canada

by

Amanda Babin, B.Sc.

B.Sc., Mount Allison University, 2009

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of

Masters of Science

in the Graduate Academic Unit of Biology

Supervisors: John (Jack) Terhune, Ph.D., Biology
Jeffrey Houlahan, Ph.D., Biology

Examining Board: Heather Hunt, Ph.D., Biology, Chair
Lilly Both, Ph.D., Psychology

This thesis is accepted by the
Dean of Graduate Studies

THE UNIVERSITY OF NEW BRUNSWICK

May, 2013

ABSTRACT

Underwater noise pollution has the potential to displace marine mammals from important habitat. Four industrial sites in the Bay of Fundy, Canada, were investigated for underwater noise levels and harbour porpoise presence from October 2011 to December 2012. The highest broadband (0.1-16 kHz) noise level recorded was 162 dB_{lin} re 1µPa. Noise levels exceeded 120 dB_{lin} re 1µPa ~50% of the time. Noise levels adjusted to estimate levels perceived by porpoise exceeded 120 dB_{ht} (*Phocoena phocoena*) re 1µPa ~3% of the time. Year-round sampling confirmed that some harbour porpoise remain in the Bay of Fundy throughout the winter. Percent porpoise presence did not differ between the quietest and loudest 5-30% of dB_{lin} and dB_{ht} (*Pp*) noise samples. A LNG tanker case study suggested porpoise were temporarily displaced during docking, but not during offloading or disembarking. Porpoise were not displaced by the moderate noise levels encountered at the four study sites.

ACKNOWLEDGEMENTS

I sincerely thank my supervisor, Jack Terhune, for the opportunity to complete my master's degree in my field of passion, marine bioacoustics. I also appreciate my supervisory committee, especially Jeff Houlahan and Connie Stewart, for always being available to provide advice with patience.

The provision of equipment and support for field work were provided by the St. Andrews Biological Station, Department of Fisheries and Oceans, and the Biology Department of the University of New Brunswick. The hydrophones were provided by the Maas Family Foundation. The technician, Don Scott, is thanked for designing and building the recording devices, and providing ongoing maintenance.

Everyone who helped coordinate field work deserves a special thank you – Fraser Forsythe with Canaport LNG, Alec Ketchum with the Saint John Port Authority, and Jason Green and Jody Hanley with Cooke Aquaculture. I also acknowledge my peers who helped during field work sessions – Kristen LeGault, Gretchen Lescord, and Alexandra Morris.

Kraig Babin was invaluable by condensing many hours of data manipulation into minutes with scripting. Thank you to my family and friends for their support.

Table of Contents

List of Tables

List of Figures

List of Symbols, Nomenclature or Abbreviations

AEP – Auditory Evoked Potential; an electro-physical method of measuring hearing thresholds.

ADD/AHD – Acoustic Deterrent Device/Acoustic Harassment Device; ADD also called pinger, AHD also called seal scarer. Devices intended to alert (ADD) or cause a minimal amount of pain (AHD) by emitting sounds at frequencies which seals and porpoise are sensitive to, with the purpose of decreasing their presence around various net types.

ARD – Automatic Recording Device; systems used to record underwater noise through a hydrophone.

dB – decibel; a logarithmic measure of amplitude. Commonly reported as Sound Pressure Level (SPL, dB re 1 µPa). Continuous noise reported as root-mean-square (rms), impulse noise reported as peak (pk) or peak-to-peak (pk-pk). Background noise commonly reported as Spectrum Level (dB re $1\mu Pa^2/Hz$, dB re $1\mu Pa/\sqrt{Hz}$).

This study reports SPL_{rms} as dB_{lin} re 1 µPa where lin stands for linear, and dB_{ht} (*Phocoena phocoena*) re 1 µPa where ht stands for hearing threshold.

DPM/DP10M – Detection Positive Minutes/Detection Positive 10 Minutes; a POD measure of the number of minutes or 10 minutes in which porpoise were detected.

GT – Gross Tonnage; a measure of a ship's overall internal capacity.

(k)Hz – (kilo)Hertz; a measure of frequency.

NBHF – Narrow Band High Frequency; a description of harbour porpoise echolocation characteristics.

POD – Porpoise Detector; a device constructed with two bandpass filters to detect the NBHF characteristics of a harbour porpoise.

TTS/PTS – Temporary Threshold Shift/ Permanent Threshold Shift; an upward shift in the hearing threshold (decreased sensitivity) which may be temporary if hair cells are fatigued, or permanent if hair cells are damaged.

Harbour porpoise (*Phocoena phocoena*) presence in relation to underwater noise levels at four industrial areas in the Bay of Fundy, Canada

1. Introduction

Underwater noise is considered to be a major factor affecting the habitat of marine mammals. Marine mammals evolved the use of acoustics for many major life functions, including communication with conspecifics, navigating their environment, and hunting for prey (NRC 2005, Verfuβ *et al.* 2005). Anthropogenic noise sources such as shipping have increased low-frequency ambient noise in oceans worldwide. This noise pollution may decrease communication ranges, or cause marine mammals to leave potentially important habitats. This study investigates whether underwater noise affects harbour porpoise (*Phocoena phocoena*) presence in industrial areas of the Bay of Fundy, Canada.

The dominant underwater noise source for low frequencies between 20 and 300 Hz is shipping. Ship noise mainly comes from the collapsing of bubbles made by propeller cavitation, which typically creates sound around 50 Hz but has components up to 100 kHz (Richardson *et al.* 1995). Between 1965 and 2003, the global number of commercial vessels doubled and worldwide gross tonnage (GT) quadrupled, which increased ambient ocean noise in the 30-50 Hz range by 10-12 dB (McDonald *et al.* 2006). Currently, there are approximately 100,000 merchant ships worldwide with the capacity of over 100 GT (McKenna *et al.* 2012).

Between 2004 and 2007, the octave band level of ambient noise in the 50-350 Hz range was recorded in the mouth of the Bay of Fundy near Grand Manan. The Bay of Fundy levels were found to be high, exceeding 105 dB re 1 μPa, 96% of the time. However, the ambient octave band level varied by 30 dB within 24 hr (Parks *et al.* 2009).

Band levels can be reported as one octave wide (bandwidth is 70.7% of center frequency), so that the top frequency in the band is twice that of the bottom frequency (ie. center frequency of 1000 Hz would cover the 707-1414 Hz band). It is common to report noise levels in 1/3 octave bands (bandwidth is 23.2% of center frequency; ie. center frequency of 1000 Hz would cover the 891-1122 Hz band), such as in this study, to estimate the critical bandwidth of the mammalian ear (Southall *et al.* 2003). The mammalian auditory system integrates noise in frequency components approximately 1/3 octave wide, and so this critical bandwidth is appropriate when analyzing communication signals and the effect of anthropogenic noise (Southall *et al.* 2003). Ambient and anthropogenic noise levels further inward from the mouth of the Bay of Fundy are currently unreported, and are addressed in this study.

The effects of increased noise on marine mammals have gained attention over the past three decades (Richardson *et al.* 1995, Yuen *et al.* 2005). A wide variety of responses have been found, depending upon the noise source characteristics (e.g., frequencies, amplitude, duration), the environment through which sound is propagating (e.g., shallow vs. deep, bottom substrate types), the hearing abilities of the receiver, as well as the context in which the noise is received (Southall *et al.* 2007). For example, humpback whales (*Megaptera novaeangliae*) and fin whales (*Balaenoptera physalus*) seem less likely to react to passing tankers when actively feeding than when resting (Richardson *et al.* 1995). Therefore, responses are not stereotyped among species or individuals, and thus are very difficult to predict.

A common method of quantifying effects of noise on marine mammals is to estimate the zones of influence (Richardson *et al.* 1995). These include a zone of audibility, which is defined as the range at which a marine mammal species is expected to be able to hear a noise source, a zone of masking whereby the noise source impedes the detection of signals, a zone of responsiveness, the area in which a noise source is expected to affect a marine mammal behaviourally or physiologically, and a zone of injury, where a marine mammal could be expected to suffer discomfort, hearing loss, or tissue damage.

The zone of audibility depends on the sound propagation characteristics of the environment, the background noise level, and the hearing abilities of the animal. Background noise levels are determined by a complex interaction of natural and anthropogenic sources and the environment. For instance, low-frequency ambient noise increases rapidly with increasing wind speeds in shallow depths (Madsen *et al.* 2006). Audibility is nearly impossible to detect in the wild since there is usually no outward behavioural display to low sound levels. In a captive setting, hearing abilities can be assessed in two ways: behaviourally, by training animals to indicate when they are able to hear a signal, or electro-physically, by placing electrodes near the brain and recording neurological signals through a method called Auditory Evoked Potential (AEP; Richardson *et al.* 1995).

In many behavioural tests, animals are presented with a signal of a certain frequency and amplitude, and if detected the next signal will be 4 dB lower. This continues until the animal cannot detect the signal, in which case the next amplitude is increased by 4 dB (the staircase method). If the signal is again detectable, this is called a reversal. The average signal level at a certain number of reversals indicates the 50% detection threshold, the inverse of which is called sensitivity (Kastelein *et al.* 2002).

AEP tests often use the staircase method as well; however, the animal does not behaviourally indicate whether the signal was detected. Instead, neural activity in the auditory pathway is recorded through small voltages detected by electrodes. An electrode is placed about 5 cm behind the blowhole, with a reference electrode in front of the dorsal fin (Yuen *et al.* 2005).

A graph of the 50% detection threshold amplitudes over a range of frequencies is called an audiogram. Audiograms obtained from AEP methods nearly always show higher hearing thresholds than audiograms obtained from behavioural techniques (Richardson *et al.* 1995).

In the case of baleen whales (Mysticetes), the difficulty in obtaining information in the wild and the impracticality of keeping them captive means that hearing abilities are almost completely unknown. Researchers and policy makers have therefore had to rely on educated guesses from vocalization frequencies and ear anatomy characteristics (Southall *et al.* 2007). Conversely, smaller toothed whales (Odontocetes) are easier to physically manipulate and researchers have been able to test their hearing abilities in captive settings (e.g., Kastelein *et al.* 2002). For example, the harbour porpoise audiogram (Figure 1) shows that they can hear well (within 10 dB of maximum sensitivity) between 16 and 140 kHz, with slightly reduced sensitivity at 64 kHz. Maximum sensitivity (33 dB_{rms} re 1 μPa) is found between 100 and 140 kHz, which is the range in which they echolocate (Kastelein *et al.* 2002). Harbour porpoise have more sensitive hearing over a broader frequency range than most other odontocetes tested (Kastelein *et al.* 2012).

However, these behavioural audiograms are often done on one test subject who is assumed to represent the hearing abilities of their entire species. Few species have been investigated (~20 of 87 species; Southall *et al.* 2007).

The zone of masking can overlap the zone of audibility, depending on the frequency and amplitude of the noise source in relation to the hearing abilities of the receiver. The difference between the sound level of a barely audible tone, and the background noise level (often expressed as spectrum level; dB re 1μPa^2/Hz) is termed the critical ratio (Richardson et al 1995). By increasing background noise levels above hearing thresholds, the detection range of signals is decreased. For example, in the Stellwagen Bank National Marine Sanctuary, right whale (*Eubalaena glacialis*) communication ranges were decreased by 84% when exposed to two commercial ships within 13 hr. The average number of ships in the area is six per day (Rolland *et al.* 2012).

When background noise impedes the vocalizations of cetaceans from reaching conspecifics, individuals may modify their vocalizations by increasing duration, shifting center frequencies, increasing amplitude (the Lombard effect), or ceasing vocalizations until background noise decreases (Richardson *et al.* 1995). For example, bottlenose

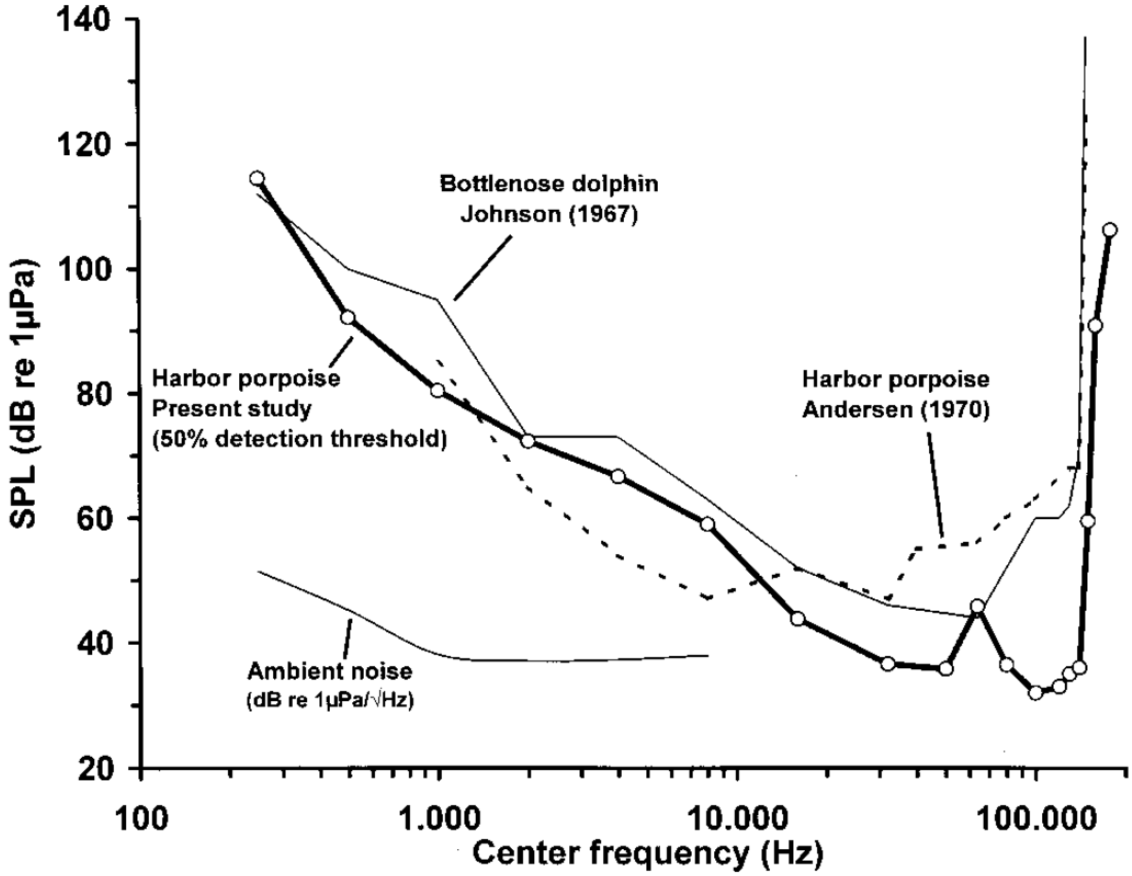

Figure 1. Harbour porpoise audiogram (Sound Pressure Level, average 50% detection thresholds in dB_{rms} re 1µPa) for narrow-band frequency modulated (±1%) signals with center frequencies between 0.25 and 180 kHz. Harbour porpoise (Andersen 1970) and bottlenose dolphin (Johnson 1967) audiograms also shown. Spectral level of ambient noise in porpoise tank shown up to 8 kHz. Adapted from Kastelein *et al.* (2002).

dolphins (*Tursiops truncatus*) and belugas (*Delphinapterus leucas*) have been observed increasing the source levels of their echolocation signals when background noise is high (Richardson *et al.* 1995). Also, Blainville's beaked whales (*Mesoplodon densirestris*) ceased echolocation when exposed to mid-frequency sonar which was thought to resemble orca (*Orcinus orca*) calls (Tyack *et al.* 2011).

The zone of responsiveness is the area in which an animal responds to a noise in its environment by changing their behaviour. Changes may include avoiding the noise source by swimming away at a faster rate than normal, or having a physiological response, such as heart rate or respiration rate increase. Many lab and field studies have been done in this area since it is relatively simple to measure such parameters. In general, no studies have demonstrated significant behavioural reactions at received levels below ~100 dB_{rms} re 1 µPa for odontocetes (Tougaard and Henriksen 2009). Most marine animals tend to avoid an area when noise levels exceed 120 dB re 1µPa (Richardson *et al.* 1995), and wild harbour porpoise exposed to 140 dB re 1 µPa typically show sustained avoidance behaviour (Southall *et al.* 2007). In this study, noise levels above 120 dB re 1µPa were considered 'high' as a criterion for testing when this level is exceeded; however, levels above 180 dB re 1µPa are known to exist and would appropriately be called high. Therefore, noise levels between 120 and 180 dB re 1µPa are in actuality, moderate.

Physiological responses, if maintained, can have population consequences. An opportunistic study in the outer Bay of Fundy provides evidence that a local population of right whales (*Megaptera novaeangliae*) may be chronically stressed. Following the events of September 11th 2001, when an attack prompted the closing of ports, the number of large vessels in the area was reduced to one or two down from four or five. This reduction lead to a 6 dB decrease in underwater noise, mostly from frequencies below 150 Hz. When compared to pre-September 11th levels in 2001 and in the four years subsequent, right whale stress levels (as measured from faecal glucocorticoids) significantly decreased (Rolland *et al.* 2012). If it was indeed the reduced shipping noise which allowed lower stress levels, then perhaps right whales in this area are chronically stressed due to the nearby shipping lane. Such long-term physiological stress may impede this population from recovering from whaling.

The zone of injury is typically measured in terms of a hearing threshold shift (TS), which can either be temporary if the hair cells are merely fatigued (TTS), or permanent if they are physically damaged (PTS; Southall *et al.* 2007). TTS is defined as a decrease in hearing sensitivity of equal to or greater than 6 dB (Southall *et al.* 2007). However, statistically significant differences in hearing thresholds have been found at lower values (Kastelein *et al.* 2012). TTS has been measured in two mid-frequency odontocete species (bottlenose dolphin and beluga), and one high-frequency odontocete species (harbour porpoise; Southall *et al.* 2007). There is no information on PTS for any cetacean (baleen or toothed whale). Data from humans and terrestrial mammals may be used in the absence of marine mammal data to estimate TTS and PTS levels since there are enough similarities in morphology and cochlear function of the mammalian ear (Southall *et al.* 2007). Extrapolating from these data, TTS is expected to occur in high-frequency cetaceans like the harbour porpoise when underwater sound levels of a single pulse reach 224 dB_{pk} re 1 µPa, and PTS at 230 dB_{pk} re 1 µPa (Southall *et al.* 2007). Policy makers have set the injury threshold for cetaceans at 180 dB_{rms} re 1 µPa (NRC 2005).

Other sources of anthropogenic noise in the ocean besides shipping include seismic exploration, coastal and offshore construction (e.g., pile driving for wind farms, dredging), acoustic deterrent/ harassment devices (ADD or AHD), and aquaculture operations. Seismic exploration utilizes airgun arrays that create noise levels between

225 and 255 dB_{pk} re 1 μPa (Richardson *et al.* 1995) in the low frequencies. These have been found to increase average background noise levels by 13 dB in the 10-585 Hz range, and by 15 dB in the 15-28 Hz range. These levels affect low-frequency specialists such as fin whales (*Balaenoptera physalus*) by causing their calls to shift down in center and peak frequencies (Castellote *et al.* 2012).

While there are currently no seismic exploration activities in the industrial areas of the Bay of Fundy within this study, there are construction efforts, pingers/ seal scarers, and aquaculture operations. Coastal and offshore construction often requires pile driving and dredging. Dredging can create noise levels of 160 dB_{rms} re 1 μPa at 100 Hz (Richardson *et al.* 1995). Pile driving is an impulsive sound with high intensity (e.g., 230 dB re 1μPa at 1 m; Nedwell *et al.* 2005 in Tougaard *et al.* 2009). It can take over 100 min to drive large (1.8 m diameter) piles into the seabed (Bailey *et al.* 2010). The effects of pile driving on harbour porpoise presence, as measured by echolocation activity, has been investigated with respect to construction of offshore wind farms in the North Sea (Carstensen *et al.* 2006, Tougaard *et al.* 2009, Thompson *et al.* 2010, Brandt *et al.* 2011). The zone of responsiveness has been observed to be approximately 20 km for harbour porpoise exposed to pile driving in shallow waters (Baily *et al.* 2010, Dahne *et al.* 2013). It is likely that porpoise are relatively silent while moving out of the area since echolocation activity from porpoise near the construction activity decreased before their maximum swimming speed (approximately 4.3 m/s) would allow them to leave the area (Brandt *et al.* 2011). Regardless, it is clear that porpoise are physically leaving the construction areas since echolocation activity increases around a distance of 22 km (Brandt *et al.* 2011).

Construction plans can employ mitigation techniques in an effort to decrease noise pollution. These include avoiding pile driving when Marine Mammal Observers detect an animal in the area, warning animals in the area with a seal scarer, using a ramp-up period of lower intensity noise as another warning system, and/or surrounding the area with a curtain of bubbles to decrease noise levels. Following the precautionary approach, construction should be planned when marine mammals have migrated out of the area. To determine if porpoise move out of the study areas in the winter months, porpoise detectors were deployed year-round.

A seal scarer, or Acoustic Harassment Device (AHD), is intended to induce a strong reaction by causing minimal amounts of pain. These devices can reach 189 dB_{pk} re 1 µPa at 14 kHz, and can deter porpoise from a construction site by 1-3.5 km (Brandt *et al.* 2011). However, harbour porpoise may habituate to these devices. Habituation has been observed in the Bay of Fundy by harbour porpoise exposed to a pinger, or an acoustic deterrent device (ADD). At the beginning of exposure, porpoise were displaced by over 200 m; however, this displacement decreased to 100 m within 4 d (Cox *et al.* 2001).

Ramp-up periods have been shown to reduce source levels by 10 dB when hammer strokes are started with low energy and separated by 5, 3, 2, then 1 min, with a slow increase in energy over the next 20 min (Bailey *et al.* 2010). Bubble curtains can be used to reduce sound by reflecting and absorbing sound energy. In one study, sound levels were reduced by 14 $dB_{pk\text{-}pk}$ re 1 µPa, which was enough to stop harbour porpoise from reacting behaviourally outside of the bubble curtain (Lucke *et al.* 2011).

A harbour porpoise experienced a temporary threshold shift when exposed to 124 dB_{rms} re 1µPa at 4 kHz (Kastelein *et al.* 2012), which is lower than any other cetacean species tested so far (Lucke *et al.* 2009).

Harbour porpoise reside in subarctic and temperate coastal waters which receive heavy shipping traffic. They are often reported as being shy and avoiding boats (American Cetacean Society 2004). The local porpoise population is reported to enter the Bay of Fundy in the early summer between May to July (Neave and Wright 1968). In small groups of 1-2 they follow upwellings and eddies formed by strong tidal currents which concentrate prey species such as herring (*Clupea harengus*; Diederichs *et al.* 2008). However, there have been sightings of large groups (50-100) of porpoise feeding together (American Cetacean Society 2004). Harbour porpoise are income feeders, meaning their small size requires them to follow their prey to allow nearly constant feeding (Johnston *et al.* 2005). They may consume 10% of their body weight per day (American Cetacean Society 2004). Therefore, the distribution and abundance of herring has been found to be the most important factor affecting the distribution of porpoise within the Bay of Fundy (Gaskin *et al.* 1985).

During the cooler months, it is thought that porpoise migrate south to the Gulf of Maine (Neave and Wright 1968, Read and Westgate 1997). However, there have been recent observations of harbour porpoise seen year round (Tollit *et al.* 2011). In an effort to better understand local harbour porpoise presence, the current study deployed porpoise detectors year-round.

The estimated 89,700 harbour porpoise which make up the Bay of Fundy/ Gulf of Maine population (Palka 2000) may be affected by the presence of approximately 100 aquaculture facilities in the Bay of Fundy (Haarr *et al.* 2009), and over 600 commercial ships entering the Port of Saint John in New Brunswick each year (Canadian Coast Guard Marine Communications and Traffic Services 2011[1]). Harbour porpoise have been found to be temporarily displaced by shipping and aquaculture activities, such as cleaning the nets with high pressure hoses (Haarr *et al.* 2009, Kastelein *et al.* 2010).

Harbour porpoise echolocation signals can be detected by automatic detectors due to the narrow frequency band in which click trains are produced. Porpoise use a narrow-band, high-frequency (NBHF) signal, centered at 130 kHz (Dudzinski *et al.* 2011). Therefore, a bandpass filter at 130 kHz with a reference filter at 92 kHz may be used to detect the presence of a harbour porpoise click train. This is the basic function of a porpoise detector (POD; Chelonia Ltd., UK). This study uses PODs to examine the relationship between underwater noise levels and harbour porpoise presence in four industrial areas within the Bay of Fundy.

The main three objectives of this study were to 1) report underwater noise levels in industrial areas of the Bay of Fundy, 2) determine if harbour porpoise are present in the Bay of Fundy year-round, and 3) to determine if the underwater noise levels at these industrial areas affect harbour porpoise presence.

2. Methods

From October 2011 to December 2012, underwater noise, primarily from shipping and aquaculture activities, and harbour porpoise echolocation activity was recorded at four industrial sites along the New Brunswick coast of the Bay of Fundy.

[1]Paul Toner, Officer in Charge, MCTS, Fisheries and Oceans Canada, Saint John CCG Base, 506-636-4269

2.1 *Study Sites*

Two aquaculture facilities, the Saint John Port, and a Liquefied Natural Gas (LNG) terminal were used to investigate whether underwater noise from industrial sites in the Bay of Fundy was affecting the presence of harbour porpoise. The locations of the four study sites in relation to Grand Manan Island and Nova Scotia may be seen in Figure 2.

Figure 2. Location of four industrial study sites along the New Brunswick coast of the Bay of Fundy. CC-Charlie's Cove, SC-Seeley's Cove, SJH-Saint John Harbour, LNG-Liquefied Natural Gas terminal. CC and SC were 17.5 km apart, SC and SJH were 50 km apart, and SJH and LNG were 8.7 km apart.

The Saint John Harbour (SJH) site is located at the Saint John Port (45° 12.604'N, 65° 58.680'W), and was accessed with permission of the Saint John Port Authority. This is the main destination for ships in the Bay of Fundy Traffic Separation Scheme (shipping lane). Between 2007 and 2011, this port received 70 cruise ships and approximately 28 million metric tonnes of cargo per year, on average. Ninety-five percent of the cargo is liquid bulk (petroleum, chemicals, etc.), making the Saint John Port the largest petroleum port in Canada. There is also vessel traffic from smaller fishing and recreational vessels, as well as construction activities associated with coastal development. The recording equipment was located at terminal 11 on the southwest entrance of the port within a channel approximately 390 m wide (Figure 3). The area is dredged annually to a depth of 12 m at low tide, reaching 20 m at high tide. Ships with scrap metal cargo dock less than 100 meters northwest into the channel from the recording equipment, with the stern-end facing the devices. Cruise ships (180 to 290 m long) dock across the channel, with the stern-end approximately 700 m (linear) from the recording equipment.

The devices were deployed from a rotating metal L-shaped structure which was welded to a metal rail running along the concrete wall of the wharf. This allowed the equipment to be easily tied on from shore, then to be extended approximately 1.5 m from the concrete wall and locked in place. This distance from the wharf avoided excess self noise caused by the hydrophone hitting the wall.

Canaport LNG provided access to the Liquefied Natural Gas terminal (LNG 45° 12.604'N, 65° 58.680'W). This site is 8.7 km (linear) southeast from the Saint John Harbour site, but is still well within the Saint John Harbour limits. This site is approximately 25 km from the exit of the Traffic Separation Scheme. The terminal was

Figure 3. Location of recording equipment within the Saint John Harbour (SJH) site. Scrap metal ships and cruise ships dock approximately 100 m and 700 m away from the equipment, respectively.

built in 2009, and receives LNG tankers (up to 300 m long) about once a month. These tankers take 3 hr to dock, with the help of 2-3 tugs, then take 12-20 hr to offload, and another 3 hr to disembark. Also, a large monobuoy is located approximately 1 km offshore, where crude oil tankers (up to 380 m) unload while constantly being pulled away from the structure by a tug to avoid collision. Lobster fishermen were also active in the area during their season from November 8th 2011 to January 14th 2012, March 31st 2012 to June 29th 2012, and November 13th 2012 to the end of data collection (December 12th 2012). The equipment was submerged in the water, suspended from the jetty (approximately 150 m from shore) between the two outermost dolphin moorings on the west side, providing open exposure to the Bay of Fundy (Figure 4). The distance

Figure 4. Location of recording equipment at the Liquefied Natural Gas (LNG) terminal study site. Crude oil tankers offload at the Monobuoy approximately 1 km away.

from this jetty to the seafloor is approximately 38 m. The LNG tankers dock with their stern-end approximately 50 m away from the devices.

Cooke Aquaculture provided access to two of their aquaculture operations – Charlie's Cove (CC 45° 01.781'N, 66° 52.009'W) and Seeley's Cove (SC 45° 04.908'N, 66° 38.646'W). The two sites are separated by approximately 18.5 km (linear), with Charlie's Cove being further down the coast toward the mouth of the Bay of Fundy. Charlie's Cove is approximately 54 km from the edge of the Traffic Separation Scheme, with the Wolves Islands obstructing the path at 45° 57'N, 66° 42'W. The more inward site, Seeley's Cove, is approximately 50 km from the Saint John Harbour site, and approximately 39 km from the edge of the Traffic Separation Scheme. These aquaculture facilities grow out Atlantic salmon (*Salmo salar*). The areas are subject to regular vessel traffic, including small (6.5 m long) skiffs which are used to deploy SCUBA divers to retrieve mortalities twice a week in the summer, and once a week in the winter. Feeding barges (14 m long) are used to spray food pellets over the cages twice a day in the summer, and once a day in the winter. These barges are also used to clean the nets with high pressure hoses, approximately twice a year. Larger barges (15 m long) are used for sea lice treatments as required, and for harvesting once a year. There were also scallop and lobster fishermen working in the surrounding waters. The scallop season runs all year long, and the lobster season was the same as detailed for the LNG site. The recording equipment was deployed off the flotation ring of an aquaculture cage (100 m circumference), typically on the second cage in the first row from the landward direction of approach, and on the far side facing the third cage (Figures 5 and 6). These locations were chosen to reduce wave action relative to the offshore side of the cage site. Too much wave action would lift the PODs abruptly, causing them to become horizontal. This would be an issue as PODs automatically turn on when vertical, and were programmed to turn off when the angle was greater than 55° from vertical.

At the Charlie's Cove site, the cage of deployment was 300 m from a small island to the south, and 2.8 km from the mainland of Back Bay. This cage is in water 36.5 m deep, and has groups of islands sheltering it from the full exposure of the Bay of Fundy. In contrast, the Seeley's Cove site is fully exposed to the Bay of Fundy, with only a 500 m piece of land jutting out to protect the cages. The cage of deployment was approximately 270 m east of this land mass, in water 27 m deep.

2.2 *Underwater noise recordings*

Automatic Recording Devices (ARDs) connected to hydrophones were programmed to record 3 min of underwater noise every 30 min for approximately one week per deployment. Three ARDs were constructed in house, and two commercial

Figure 5. Location of recording equipment at the Charlie's Cove (CC) aquaculture site.

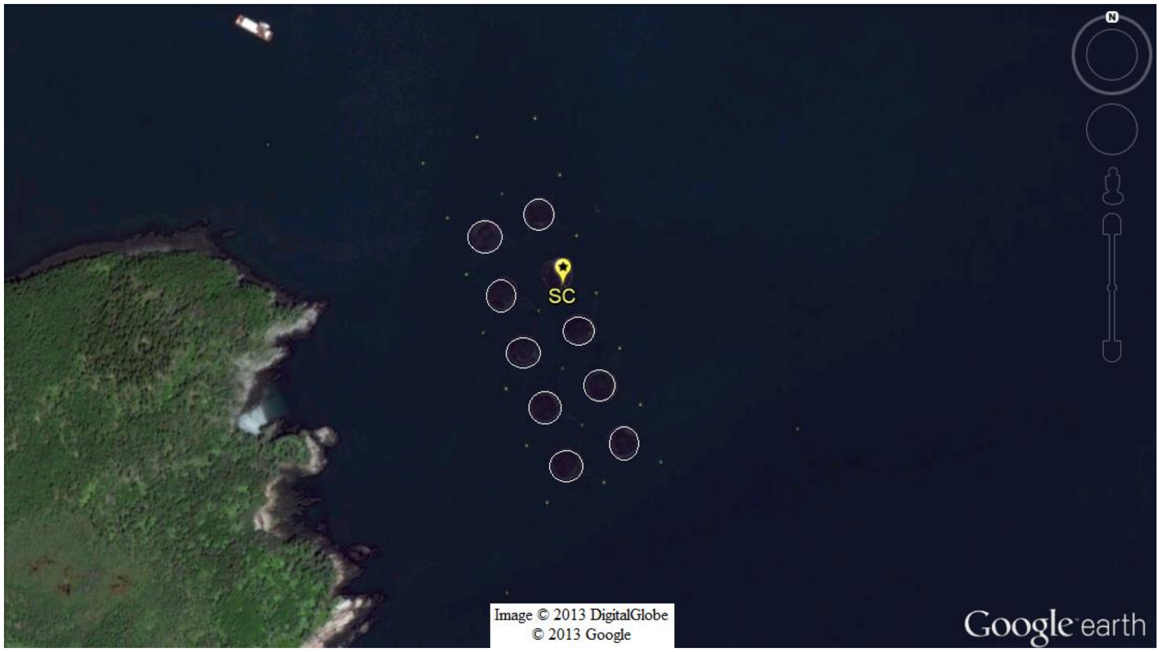

Figure 6. Location of recording equipment at the Seeley's Cove (SC) aquaculture site.

ARDs were purchased from Wildlife Acoustics Inc. in January 2012. The original number of ARD systems dictated that three of the four study sites were sampled each month.

The constructed ARDs, labeled by the colour of their Pelican case (Black, Orange, and Grey), consisted of a Dell Inspiron notebook, a timer, an adjustable impedance matching device, and two 12-volt batteries. The waterproof Pelican cases were outfitted with external hydrophone connecters. When one of the five hydrophones was plugged in, the timer would count to 30 min, then turn on the system for a 3 min recording. Recordings were made using the program Ishmael (v 2.0). A bandwidth from 0.025 to 16 kHz was recorded and saved as a .wav file. The commercial ARDs (Wildlife Acoustics Inc, Massachusetts, Song Meter SM2+ firmware version 3.1.9) had built-in hydrophones, one with an 8 m cable and the other 30 m. These systems were also programmed to take 3 min noise recordings (between 0.025 and 16 kHz) every 30 min, stored as .wav files. Most recordings had a 44.1 kHz sampling rate (see Table 1 for exceptions), which is appropriate when monitoring odontocetes (Au and Hastings 2008).

The five hydrophones (Vemco Ltd., Nova Scotia, model VLHT) were labeled by their colour-coding, as well as their cable length (Long_Green, Long_Red, Short_Red/Yellow, Short_Red/White, Short_Red/Green/White). Capacitance increases with longer cable lengths. The Long hydrophone cables were 56 m, and the Short hydrophone cables were 12 m, except for the Short_Red/Green/White cable which was 20 m. Since hydrophone sensitivities varied (see Appendix A), they were rotated for use with each ARD, and were rotated among sites, to aid the comparison of noise levels.

Noise recordings were uploaded to the NoiseLAB program (v 3.0) for visual and auditory inspection. Noise levels for all 1/3 octave bands between 0.25 and 16 kHz were extracted using NoiseLAB Batch Processor (v 3.1). One-third octave band levels were used as an approximation of the critical bandwidth of the mammalian ear, so that they may be directly compared with hearing thresholds for pure tones (Richardson *et al.* 1995, Tougaard and Henriksen 2009). Calibration values (see Appendix A) and hydrophone-specific frequency responses were applied to the 1/3 octave band noise levels to obtain linear amplitude measures (dB_{lin} re 1µPa). Frequencies below 100 Hz were not used in the analyses to avoid the uncertainty in the calibration values around 60 Hz which are likely confounded by an indoor electronic hum.

Ambient sound levels were defined as the level which is exceeded by 95% of the sound levels within a trial (Clark et al. 2009). Therefore, the maximum value of the lowest fifth percentile and all values below this threshold were considered ambient within each trial.

Linear amplitudes were adjusted to estimate the noise levels perceived by harbour porpoise for biological relevance. Audiograms measured from harbour porpoise show a U-shaped curve with highest sensitivities (defined as 10 dB within maximum sensitivity of 33 dB re 1µPa) between 16 and 140 kHz, but with slightly decreased sensitivity at 64 kHz (Figure 1). Porpoise hearing abilities have not been tested below 250 Hz. In order to estimate hearing thresholds at lower frequencies, Terhune (2013) derived a frequency weighting function by fitting the hearing thresholds from the measured audiograms and extrapolating down to 0.025 kHz (upper limit = 20 kHz). This method produced the following equation:

$$dB = 46.4 - 35.6 \log (kHz) \qquad \text{eq. 1}$$

This allowed frequency-specific decibel losses (see Appendix B) to be subtracted from the linear amplitudes, resulting in perceived amplitudes denoted dB_{ht} (*Phocoena phocoena*) where ht stands for hearing threshold (Nedwell *et al.* 2007). Broadband levels were calculated using 1/3 octave band values for both dB_{lin} and dB_{ht} (*Pp*). The dB_{ht} (*Pp*) metric is analogous to the human dB(A) weighting function (Terhune 2013).

2.3 *Porpoise detection*

Porpoise Detectors (PODs; Chelonia, UK) are a passive acoustic monitoring tool which records the occurrence and timing of harbour porpoise echolocation click trains. We used two T-PODs (nos. 435 and 731), and two C-PODs (nos. 1628 and 1629). These PODs were deployed along with the ARD-hydrophone pairs for approximately 1 week per month, and were constantly detecting porpoise when deployed.

T-POD 435 (v 4) was 0.7 m long and 0.09 m in diameter, with a screwing lid at one end and a horizontally omnidirectional hydrophone enclosed in vinyl (same impedance as seawater) on the other end. Within this housing were two bundles of six 1.5-volt D-cell alkaline batteries powering 128 MB of digital memory, an amplifier, and analogue electronic filters. These filters are programmed to detect the stereotyped narrowband high frequency (NBHF) echolocation click trains of harbour porpoise by comparing the energy reaching the target filter at 130 kHz to the reference filter at 92 kHz. This POD had the following settings: Click bandwidth 4, Noise adaptation ++, Sensitivity 10, Scan limit on N of clicks logged 240, Transducer code 3, Digital version N 10, Analogue version N 7, Switch type 2, Sensitivity 4, Check 206, V divisor 194, G min 33, G max 219.

T-POD 731 (v 5) was 0.85 m long and 0.09 m in diameter, and was divided into two parts which screwed together in the middle. One side housed fifteen 1.5-volt D-cell alkaline batteries which powered the same hardware as detailed above for T-POD 435. The analogue narrowband-pass filters were also in use, with the following settings: Click bandwidth 4, Noise adaptation ++, Sensitivity 16, Scan limit on N of clicks logged 240, Transducer code 5, Digital version N 10, Analogue version N 11, Switch type 2, Sensitivity 4, Check 253, V divisor 1, G min 81, G max 179.

C-PODs 1628 and 1629 were 0.66 m long and 0.09 m in diameter. Each houses twelve 1.5-volt D-cell alkaline batteries, and has the same hydrophone installation as the T-PODs. Data are stored on a 4 GB SD card for easy extraction, including beginning times of click trains, center frequency, intensity, envelope, and bandwidth.

Porpoise detection data were downloaded onto a Dell Latitude D610 PC and analyzed with the accompanying software, T-POD-v8.exe or CPOD.exe. These software programs employed a detection algorithm to classify click trains into groups based on their likelihood of being harbour porpoise. These groups are NBHF, Other cet, Sonar, and unclassified, whereby NBHF stands for narrowband high frequency echolocation (includes harbour porpoise), and Other cet identifies other cetacean (whale) species. The detection algorithms differ between T-PODs and C-PODs. Cet All (includes Cet Hi and Cet Lo) were used in the analyses of T-POD data, and Cet Hi, Cet Med, and Cet Lo were used in the analyses of C-POD data. Data were exported as the number of click trains per min and per 10 min, as well as the binomial equivalent (0 click trains per min equals 0/absent, >0 equals 1/present) denoted Detection Positive (10) Minutes. False positive rates were not measured, but are assumed to be very low based on previous studies (Kyhn et al. 2012), and also because of the narrow bandpass filters. False positive detections should not influence the results due to large sample sizes.

2.4 *Sampling Design*

Each month between October 2011 and December 2012, ARD-hydrophone noise recording equipment and PODs were deployed at three of the four study sites. The LNG and SJH sites had attachment locations well above the water-level, and so required equipment with long cables. Therefore, T-POD 731 and C-POD 1629 were fixed to 50 m ropes, and alternated between these two sites. The noise recording equipment alternated between the WA30m system and any of the constructed ARDs with the Long hydrophones. At SC and CC, the equipment was attached directly to the flotation ring of the aquaculture cages. These sites were sampled alternately by T-POD 435 and C-POD

1628 which were fixed to approximately 8 m ropes, and by the WA8m system and any of the constructed ARDs with the Short hydrophones. The equipment was deployed in the following configuration (Figure 7).

The main anchor (6.8-9.1 kg) line stabilized the equipment in water currents, and a second anchor (3.6 kg) line was used to deploy the POD and hydrophone (Figure 7a). The second line was connected to the main anchor line with a sliding, stainless steel clip. The second line was a rope (varying in length from 8 m to 50 m) to which the POD was fixed. The hydrophone cable was connected to this line approximately 2 m above the POD via a stainless steel triangular spacer (Figure 7b). This spacer prevented the hydrophone from rubbing against the anchor lines which would have created excess self noise.

At all sites, the equipment were deployed for approximately one week, then removed for data extraction and cleaning. The resulting collection schedule is given in Table 1.

2.5 *Statistical Analyses*

All statistical analyses were performed using the R programming language (v 2.15.2; R Development Core Team 2005). The significance level was set at 5%, unless otherwise stated.

2.5.1 *Underwater noise analyses*

Descriptive statistics are provided for the noise levels recorded at the four industrial sites of the Bay of Fundy examined herein. Boxplots and kernel-density plots for each trial may be found in Appendix C. Average noise levels for each month were used as

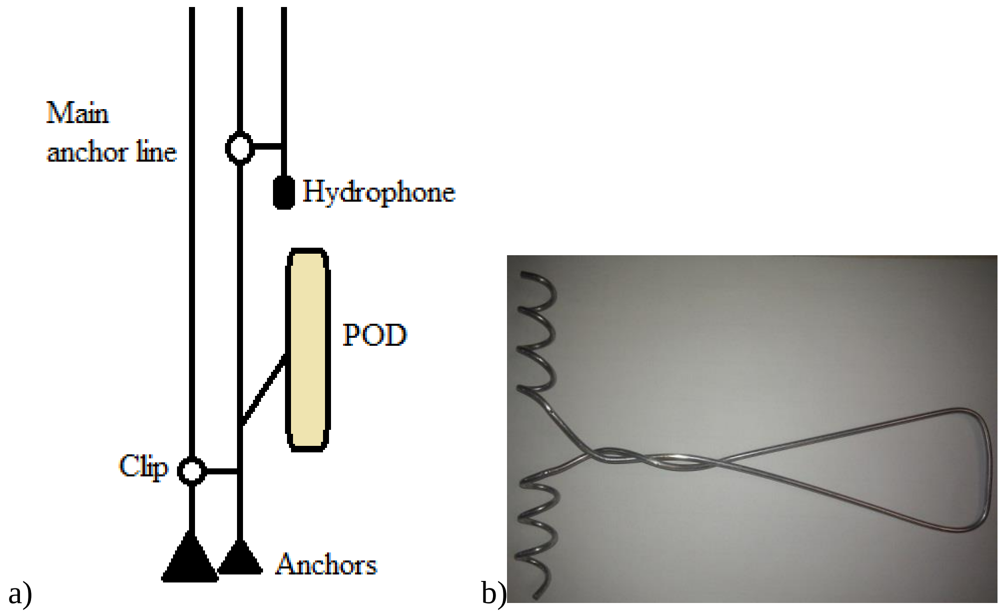

Figure 7 a) underwater configuration of noise recording and porpoise detecting equipment, b) stainless steel spacer attaching hydrophone cable (right side) to the secondary anchor line.

replicates in a one-way analysis of variance (ANOVA) to determine differences among sites. Tukey's Honestly Significant Difference (HSD) was used to perform post-hoc testing. Similarly, trial-specific ambient levels were used as replicates in a one-way ANOVA to compare among sites. Furthermore, the percent of ambient samples within the day and night (determined by sunrise and sunset on each day) were arcsine-squareroot transformed and used as replicates in a two-way ANOVA (Site, Day/Night). The same analysis was performed on percent of high noise (>120 dB_{lin} re 1μPa) samples within the day and night. When time of day was non-significant within the two-way ANOVAs, data were pooled between day and night and a one-way ANOVA was performed.

Table 1. Schedule of underwater noise and porpoise presence data collection at the Saint John Harbour (SJH), Liquefied Natural Gas (LNG), Seeley's Cove (SC), and Charlie's Cove (CC) field sites.

Porpoise detections	Noise recordings	POD	ARD	Hydrophone
LNG				
Oct 14-24 2011	Oct 14-19 2011	C-POD 1629	Grey	Long Red
Nov 18-25 2011	Nov 18-19 2011	T-POD 731	Black	Long Red
Feb 16-Mar 1 2012	Feb 16-20 2012*	T-POD 731	Orange	Long Red
Mar 21-28 2012	Mar 21-23 2012	C-POD 1629	Orange	Long Red
Apr 17-25 2012	Apr 17-26 2012	T-POD 731	WA30m	Built-in
-	Jun 13-28 2012	C-POD 1629	WA30m	Built-in
Jul 23-31 2012	Jul 23-31 2012	T-POD 731	WA30m	Built-in
Aug 9-15 2012	Aug 9-10 2012	C-POD 1629	Black	Long Green
Oct 17-24 2012	Oct 17 2012	T-POD 731	Orange	Long Green
-	Nov 14-21 2012	C-POD 1629	WA30m	Built in
Dec 10-13 2012	Dec 10-12 2012	T-POD 731	Black	Long Green
SJH				
Dec 12-20 2011	Dec 12-16 2011	C-POD 1629	Orange	Long Green
-	Jan 25-29 2012*	T-POD 731	Black	Long Green
Feb 17-24 2012	Feb 17-21 2012	C-POD 1629	Grey	Long Green
-	Apr 17-18 2012	C-POD 1629	Black	Long Red
May 9-16 2012	May 9-16 2012	C-POD 1629	WA30m	Built in
Jun 13-28 2012	Jun 13 2012	T-POD 731	Orange	Long Green
Aug 10-14 2012	Aug 10-11 2012	T-POD 731	WA30m	Built in
Sep 21-22 2012	Sep 21-28 2012	T-POD 731	WA30m	Built in
-	Oct 17-25 2012	C-POD 1629	WA30m	Built in
Dec 17-20 2012	Dec 17-21 2012	C-POD 1629	WA30m	Built in
SC				
Oct 22-28 2011	Oct 19-22 2011	T-POD 435	Black	Short Red/White
Dec 14-20 2011	Dec 14-16 2012	C-POD 1628	Black	Short Red/Yellow
Jan 27-30 2012	Jan 23-29 2012	T-POD 435	Orange	Short Red/Green/White
-	Feb 15-22 2012	C-POD 1628	WA8m	Built in
Jul 25-30 2012	Jul 25-Aug 3 2012	T-POD 435	WA8m	Built in
Aug 10-17 2012	Aug 10-25 2012	T-POD 435	WA8m	Built in
Sep 21-26 2012	Sep 21-23 2012	C-POD 1628	Orange	Short Red/Green/White
Nov 16-20 2012	Nov 16-22 2012	T-POD 435	WA8m	Built in
-	Dec 4-5 2012	C-POD 1628	WA8m	Built in
CC				
Oct 19-28 2011	Oct 23-24 2012	C-POD 1628	Orange	Short Red/Yellow
Nov 14-25 2011	Nov 16-17 2012*	T-POD 435	Grey	Short Red/White
Jan 25-30 2012	-	C-POD 1628	WA8m	Built in
-	May 7-20 2012	T-POD 435	WA8m	Built in
Jun 14-27 2012	Jun 14-27 2012	C-POD 1628	WA8m	Built in
Jul 25-Aug 2 2012	Jul 25-31 2012	C-POD 1628	Black	Short Red/Yellow
-	Sep 21-26 2012	T-POD 435	WA8m	Built in
-	Oct 16-23 2012	T-POD 435	WA8m	Built in
Nov 16-21 2012	Nov 24-28 2012	C-POD 1628	Black	Short Red/Green/White

*sampling rate = 22.05 kHz, therefore only recorded up to the 8 kHz 1/3 octave band

For the Liquefied Natural Gas (LNG) terminal, hourly wind speed was provided. Regressions of noise levels (matched to the closest hr) and ambient noise levels versus wind speed were performed.

2.5.2 *Porpoise presence and echolocation activity analyses*

Average number of click trains per min (echolocation activity) within the day and night for each month was used as replicates for a two-way ANOVA (Site, Day/Night). Similarly, percent presence of porpoise within the day and night for each month were arcsine-squareroot transformed and used as replicates for a two-way ANOVA (Site, Day/Night). Again, when time of day was non-significant within the two-way ANOVAs, data were pooled between day and night and a one-way ANOVA was performed.

The number of consecutive minutes of porpoise presence was defined as residence time. These were descriptively compared with the time of day in which they occurred.

Regressions of percent presence within each hr versus wind speed and water temperature data provided by the LNG terminal were performed.

2.5.3. *Effects of underwater noise on harbour porpoise presence and echolocation activity analyses*

The relationship between dB_{lin} and dB_{ht} (*Pp*) noise levels was illustrated. Linear levels (dB_{lin}) are reported for comparison with the existing literature, and adjusted levels (dB_{ht} (*Pp*)) are useful when considering noise from the perceptive ability of the harbour porpoise auditory system. Descriptive statistics of dB_{ht} (*Pp*) noise levels are given.

The percent of high noise samples (>120 dB_{ht} (*Pp*) re 1µPa) within the day and night were arcsine-squareroot transformed and used as replicates in a two-way ANOVA (Site, Day/Night). However, this analysis did not pass assumptions, so a non-parametric 2-way ANOVA (Friedman's test) was run, followed by Kruskal-Wallis and Wilcox Signed Rank tests.

To determine if underwater noise levels had an effect on porpoise presence, two analyses were performed. The first was descriptive, plotting average echolocation activity in the day and night within each 10 dB_{lin} and 10 dB_{ht} (*Pp*) noise bin. The second analyses compared percent presence during the day and night within extreme noise levels (using both dB_{lin} and dB_{ht} (*Pp*)). The most extreme comparison was between the bottom (quietest) and top (loudest) 5% of noise samples within each trial, increasing by 5% increments to the least extreme comparison between the bottom and top 30% of noise samples. Percent presence within the day and night for each trial were determined within the quietest and loudest noise samples. These values were used as replicates in non-parametric 2-way ANOVAs (Friedman's test, *muStat* package v 1.7.0) for each comparison (5%, 10%, 15%, 20%, 25%, and 30%). Non-parametric tests were used because assumptions did not pass some of the time, and so all tests were done non-parametrically for consistency. Results were comparable between parametric and non-parametric tests.

The number of minutes between each noise recording and the occurrence of a Detection Positive Minute was investigated backward and forward in time. Longer time-to-last and time-to-next intervals associated with louder noise levels, and shorter intervals associated with quieter noise levels, would indicate that high noise levels are displacing porpoise from the area. Time-to-last and time-to-next presence was considered within the day and night, and within 10 dB_{lin} and 10 dB_{ht} (*Pp*) noise bins to determine if increasing interval lengths with increasing noise levels were observed. Trends were observed descriptively.

Finally, a case study examining porpoise presence during an LNG tanker presence is provided. Linear and dB_{ht} (*Pp*) noise levels and percent porpoise presence are illustrated in the following time periods: Before, Docking, Offloading, Disembarking, After. Higher noise levels are expected to occur when the tanker is present. If porpoise presence decreases with increased noise levels, then tanker disturbance would be concluded to displace porpoise short-term.

3. Results

3.1 *Underwater Noise Analyses*

Underwater noise was recorded in 3 min segments every 30 min at four industrial sites in the Bay of Fundy. Each site-month recording session was considered a trial, with 38 trials total (LNG-11, SJH-10, SC-9, CC-8). When possible, each trial was analyzed separately to avoid possible erroneous comparisons between noise recording equipment and site-specific physical characteristics (Madsen *et al.* 2006, Appendix A). Each 1/3 octave band between 100 Hz and 16 kHz was used in the analyses. Due to calibration limitations, 100 Hz was the lowest 1/3 octave band used. This was considered acceptable because noise levels in the 1/3 octave bands between 25 and 80 Hz never exceeded those in the 100 Hz band.

A main objective of the current study was to describe the underwater sound levels within industrial areas of the Bay of Fundy. A summary table of measures describing the underwater sound dataset may be found in Table 2.

As can be seen from the descriptive statistics, these industrial areas have variable sound levels both within and between trials. However, it is clear that the Liquefied Natural Gas (LNG) terminal was often the loudest site (8.6 dB louder than the SJH site, on average), and the Charlie's Cove aquaculture site was often the quietest (5.7 dB quieter than the SC site, on average). Average noise levels did not significantly differ between the LNG and Saint John Harbour sites, or between the Seeley's Cove and Charlie's Cove aquaculture sites. Average noise levels at the LNG terminal (Mean (SD): 128 (13.3) dB re 1µPa) were significantly louder (at a 10% significance level) than those at Seeley's Cove (117 (7.8) dB re 1µPa, 1-way ANOVA with Tukey's HSD: p=0.058), and were significantly louder than those at Charlie's Cove (110 (4.7) dB re 1µPa, 1-way ANOVA with Tukey's HSD: p=0.001). Average noise levels at the Saint John Harbour (124 (7.6) dB re 1µPa) were also significantly louder than those at Charlie's Cove (1-way ANOVA with Tukey's HSD: p=0.02; Table 3).

The February 2012 trial at the LNG terminal reached the highest sound level recorded (162 dB re 1µPa) with the highest mean (145 dB re 1µPa). During this trial, the LNG tanker Shagra visited the terminal. An underwater sound profile of the tanker's visit, and concurrent harbour porpoise echolocation activity, may be seen under the section 3.3 *Effects of Underwater Noise on Harbour Porpoise Presence and Echolocation Activity Analyses*.

Table 2. Descriptive statistics of broadband (0.1-16 kHz) underwater sound levels (dB re 1µPa) from 1/3 octave bands recorded between October 2011 and December 2012 at the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) aquaculture sites. N denotes the number of samples.

Trial	N	Range	Mean	SD
LNG				
Oct_2011	285	107-141	128	7.1
Nov_2011	43	121-146	134	8.2
Feb_2012	169	112-162	145	10.1
Mar_2012	84	101-149	141	7.5
Apr_2012	273	114-160	136	8.6
Jun_2012	445	114-157	135	8.5
Jul_2012	328	104-158	134	10.4
Aug_2012	73	103-133	110	5.7
Oct_2012	23	91-114	103	6.7
Nov_2012	331	107-153	129	11.1
Dec_2012	97	107-135	115	7.0
SJH				
Dec_2011	184	103-148	116	9.2
Jan_2012	69	98-130	115	7.3
Feb_2012	112	116-156	122	7.0
Apr_2012	59	91-156	139	11.2
May_2012	215	105-155	131	11.2
Jun_2012	12	103-150	120	12.8
Aug_2012	33	114-137	127	5.2
Sep_2012	327	99-147	117	10.0
Oct_2012	355	99-155	128	11.5
Dec_2012	186	102-153	125	9.6
SC				
Oct_2011	157	85-135	112	9.8
Dec_2011	83	85-127	101	11.6
Jan_2012	274	106-144	127	7.8
Feb_2012	330	102-142	118	10.1
Jul_2012	423	102-157	115	10.7
Aug_2012	714	92-157	118	11.5
Sep_2012	79	109-149	123	10.6
Nov_2012	134	103-145	116	7.6
Dec_2012	27	112-136	125	5.0
CC				
Oct_2011	44	99-118	104	5.8
Nov_2011	26	103-122	109	4.3
May_2012	584	96-142	117	11.7
Jun_2012	566	96-152	108	10.9
Jul_2012	285	93-146	105	9.8
Sep_2012	221	98-143	112	9.7
Oct_2012	316	100-157	115	11.7
Nov_2012	179	98-148	113	8.0

Table 3. ANOVA table comparing average noise levels (dB re 1µPa) among four industrial sites: the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) aquaculture sites.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-statistic	p-value
Site	3	1686	562.1	6.556	0.00128
Residuals	34	2915	85.7		

Two of the highest average noise levels from the Seeley's Cove aquaculture site were recorded during September and December 2012. During these months, sea lice treatments were being performed. Also, an acoustic harassment device (AHD) was detected during the May 2012 trial at Charlie's Cove, which coincided with the highest average noise level observed at this site. During the 2 d period when the AHD was detected, noise levels averaged 136 dB_{lin} re 1µPa (124 dB_{ht} (*Pp*) re 1µPa). The remainder of the May 2012 trial had an average noise level of 114 dB_{lin} re 1µPa (91 dB_{ht} (*Pp*) re 1µPa).

It is important to quantify ambient sound levels in an area as an estimate of background noise levels. Trial-specific ambient noise levels were compared between sites, with ambient levels being significantly higher at the LNG terminal (114 (10.3) dB re 1µPa) than the Seeley's Cove (103 (9.5) dB re 1µPa, 1-way ANOVA with Tukey's HSD: $p=0.03$) and Charlie's Cove (99 (2.3) dB re 1µPa, 1-way ANOVA with Tukey's HSD: $p=0.003$; Table 4) aquaculture sites. Ambient levels at Saint John Harbour averaged 108 (6.3) dB re 1µPa.

Table 4. ANOVA table comparing trial-specific ambient noise levels (dB re 1µPa) among four industrial sites: the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) aquaculture sites.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-statistic	p-value
Site	3	1104	368.1	5.715	0.0028
Residuals	34	2190	64.4		

Sound levels may be largely attributed to anthropogenic sources when daytime levels are higher than nighttime since the majority of vessel-based work occurs during the day. This trend was investigated by labeling each sample 'Day' or 'Night' according to the timing of the sunrise and sunset on the day of recording (Table 5). There was a significant interaction between Site and Day/Night (2-way ANOVA: $F_{3,68} = 0.0094$, $p=0.02$); therefore, the two factors were combined. Overall, the average percentage (arcsine-squareroot transformed) of ambient samples during the night at all sites (5.7-9.5%) was higher than those found during the day at the aquaculture sites (SC 1.3%, CC 0.6%, 1-way ANOVA with Tukey HSD: $p<0.007$). Percentages of ambient samples during the night were not significantly different from those during the day at the LNG (Day 2.9%, Night 6.1%, on average) or Saint John Harbour (Day 2.6%, Night 5.7%, on average) sites. Of the Charlie's Cove night samples, 9.5% were ambient on average, which was significantly higher than all other site-day/night averages (1-way ANOVA with Tukey HSD: $p<0.005$; Table 6).

Marine mammals are generally considered to avoid an area once underwater sound levels reach 120 dB re 1µPa (Richardson *et al.* 1995). In the current study, levels

Table 5. Trial-specific ambient levels (dB re 1μPa) and the number of ambient samples in the Day and Night recorded between October 2011 and December 2012 at the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) aquaculture sites.

Trial	Ambient	# ambient/total Day	# ambient/total Night
LNG			
Oct_2011	113	9/134	5/151
Nov_2011	122	0/12	2/31
Feb_2012	119	0/65	8/104
Mar_2012	128	4/55	0/29
Apr_2012	121	7/168	6/105
Jun_2012	120	6/296	16/149
Jul_2012	114	6/203	10/125
Aug_2012	104	3/48	0/25
Oct_2012	91	0/15	1/8
Nov_2012	111	3/132	14/199
Dec_2012	107	0/35	4/62
SJH			
Dec_2011	103	0/56	9/128
Jan_2012	102	0/31	3/38
Feb_2012	116	0/42	5/70
Apr_2012	119	1/33	2/26
May_2012	111	7/140	3/75
Jun_2012	103	1/12	-
Aug_2012	114	1/19	0/14
Sep_2012	102	2/159	14/168
Oct_2012	105	5/176	12/179
Dec_2012	109	9/70	9/116
SC			
Oct_2011	88	0/60	7/97
Dec_2011	87	0/27	4/56
Jan_2012	113	1/108	12/166
Feb_2012	104	8/141	8/189
Jul_2012	103	3/253	11/170
Aug_2012	104	16/417	13/297
Sep_2012	111	0/38	4/41
Nov_2012	104	0/39	6/95
Dec_2012	112	0/10	1/17
CC			
Oct_2011	99	0/15	2/29
Nov_2011	103	0/13	1/13
May_2012	99	13/364	16/220
Jun_2012	98	0/366	28/200
Jul_2012	95	0/177	15/108
Sep_2012	100	0/106	11/115
Oct_2012	101	0/152	15/164
Nov_2012	100	1/70	8/109

Table 6. ANOVA table comparing the percent of ambient noise samples (dB re 1μPa) recorded during the day and night, and among four industrial sites: the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) aquaculture sites.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-statistic	p-value
Site + Day/Night	7	0.5415	0.07736	8.141	3.61×10^{-7}
Residuals	68	0.6461	0.0095		

exceeded this arbitrary value in approximately 50% of the samples for all trials combined. The LNG terminal had high noise levels (>120 dB re 1μPa) 82% of the time on average, ranging from no high noise samples within the October 2012 trial, to all samples being above 120 dB re 1μPa in the November 2011 trial (Table 7). The Saint John Harbour site had less variability and exceeded the arbitrary level much less often (59%) than the LNG terminal, but still had a high proportion of high noise levels in some months (Appendix C). Therefore, the average percent of high noise levels did not differ between the LNG terminal and the Saint John Harbour site. The aquaculture sites exceeded 120 dB re 1uPa much less often. Seeley's Cove had high noise levels 38% of the time on average, with a maximum of 85% in December 2012 (Appendix C). Charlie's Cove only had high noise levels 19% of the time on average, with a maximum of 36% in May 2012 (Appendix C). The percentage of high noise samples did not differ between day and night when a 2-way ANOVA (Site, Day/Night) was performed, therefore day/night percentages were pooled. Both the LNG terminal and Saint John Harbour site had significantly higher occurrences of high noise levels than the Charlie's Cove aquaculture site (1-way ANOVA with Tukey HSD: $p<0.01$; Table 8). It has been observed that harbour porpoise in the wild have sustained avoidance reactions when underwater noise levels exceed 140 dB re 1µPa (Southall *et al.* 2007). In this study, this level was exceeded 11% of the time, on average (LNG 28%, SJH 10 %, SC 3%, CC 2%).

The Liquefied Natural Gas terminal provided hourly wind speed data. It is known that underwater noise levels depend partly on wind speed, and ambient levels are directed related to wind speed (Richardson *et al.* 1995). However, when hourly wind speeds were correlated with sound levels (matched to the closest hr), only six of the eleven months had significant relationships ($8.4x10^{-5} \leq p \leq 0.04$), and r^2 values did not exceed 0.04. The only exception was found during October 2012, which had an r^2 of 0.68 (n=23, $p=1.1x10^{-4}$); however, this month also had the lowest sample size. It should be noted that the data were often temporally correlated.

The sample sizes were too low to investigate the relationships between ambient levels and wind speed for each trial separately, and so all months were pooled for this analysis. The relationships between ambient levels and the maximum and average wind speeds were non-significant according to a regression; however, some trends were observed (Figure 8). At the LNG site, August and October 2012 were the quietest months, which correspond with the lowest maximum wind speeds. The maximum wind speed in November 2011 was also very low, but the levels for this month were comparable with the other months. This could be because the minimum wind speed during November 2011 was higher than in any other month.

Table 7. Number of high noise samples (> 120 dB re 1μPa) in the Day and Night recorded between October 2011 and December 2012 at the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) aquaculture sites.

Trial	# high noise/total Day	# high noise/total Night
LNG		
Oct_2011	119/134	128/151
Nov_2011	12/12	31/31
Feb_2012	65/65	94/104
Mar_2012	53/55	29/29
Apr_2012	162/168	101/105
Jun_2012	292/296	124/149
Jul_2012	180/203	108/125
Aug_2012	5/48	0/25
Oct_2012	0/15	0/8
Nov_2012	102/132	139/199
Dec_2012	4/35	12/62
SJH		
Dec_2011	12/56	47/128
Jan_2012	10/31	5/38
Feb_2012	20/42	34/70
Apr_2012	32/33	24/26
May_2012	115/140	62/75
Jun_2012	6/12	-
Aug_2012	17/19	13/14
Sep_2012	73/159	46/168
Oct_2012	139/176	135/179
Dec_2012	53/70	66/116
SC		
Oct_2011	13/60	20/97
Dec_2011	8/27	0/56
Jan_2012	90/108	129/166
Feb_2012	70/141	53/189
Jul_2012	125/253	8/170
Aug_2012	223/417	32/297
Sep_2012	32/38	6/41
Nov_2012	15/39	16/95
Dec_2012	8/10	15/17
CC		
Oct_2011	0/15	0/29
Nov_2011	0/13	2/13
May_2012	155/364	54/220
Jun_2012	54/366	2/200
Jul_2012	16/177	0/108
Sep_2012	20/106	30/115
Oct_2012	51/152	17/164
Nov_2012	14/70	1/109

Table 8. ANOVA table comparing the percent of high noise samples (>120 dB re 1μPa) among four industrial sites: the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) aquaculture sites.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-statistic	p-value
Site	3	2.300	0.7666	5.795	0.0026
Residuals	34	4.498	0.1323		

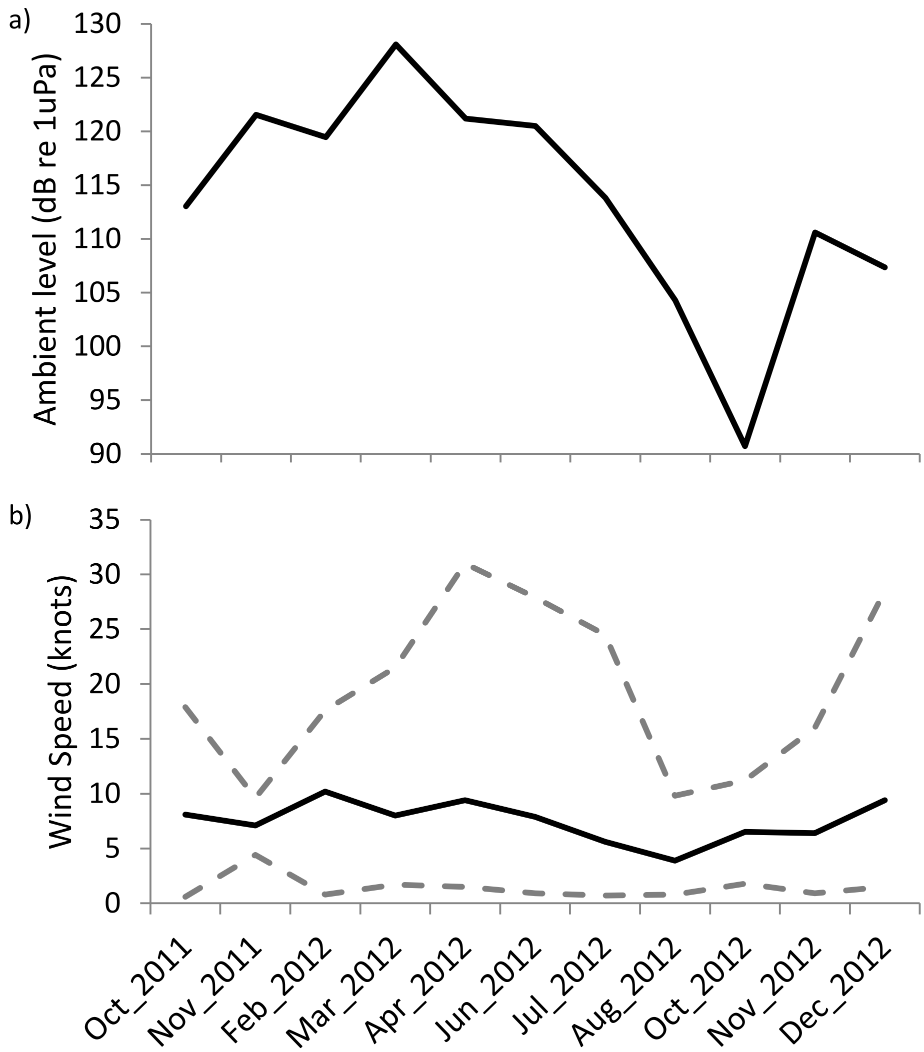

Figure 8 a) Ambient noise levels (dB re 1µPa) and b) wind speeds (knots; black-average, grey-minimum and maximum) between October 2011 and December 2012 at the Liquefied Natural Gas (LNG) terminal.

3.2 *Porpoise Presence and Echolocation Activity Analyses*

Harbour porpoise echolocation click trains were detected minute-by-minute with PODs. PODs were sampling concurrently with noise recording equipment. Data were expressed as echolocation activity (number of click trains per min or ten min) and as presence/absence (0 = no click trains, 1 = greater than zero click trains). Trials were analyzed separately when possible, which included the hourly proportion of DP10M and residence time analyses. In total, there were 289,069 min of porpoise detection effort (28,855 ten min samples), with an overall average presence of 9.3% (as calculated from Detection Positive Minutes). C-PODs reached the maximum click trains per min count (4096) 4.7% of the time. There were many observational confirmations of porpoise presence (i.e. February 2012 deployment at LNG, November 2012 deployment at Seeley's Cove). The monthly distribution of these porpoise detection samples can be seen in Table 9.

The relationship between time of day and porpoise activity was often the inverse of the underwater noise relationship, with higher presence in the nighttime than daytime (Table 10). Echolocation activity did not significantly differ between day (average 3.7 clicks per min) and night (average 6.5 clicks per min; 2-way ANOVA: $F_{1,50}$=2.997, p=0.09), or between sites ($F_{3,50}$ = 5.132, p=0.004). There was no interaction between the two factors. Since there were no day/night differences among echolocation activity, time of day was pooled. After this pooling, there were no differences in echolocation activity among sites (1-way ANOVA: $F_{3,25}$=2.43, p=0.09).

Percent presence was significantly higher in the night (average 11.3%) than day (average 6.8%; 2-way ANOVA: $F_{1,50}$=0.384, p=0.03; Table 11). Percent presence was

Table 9. Number of minutes of porpoise detection effort (samples) from the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) sites between October 2011 and December 2012. Parentheses show the number of minutes of effort in 10 min blocks.

	LNG	SJH	SC	CC
October 2011	14,453 (1,443)		9,331 (933)	13,049 (1,303)
November 2011	9,911 (990)			15,712 (1,570)
December 2011		11,380 (1,138)	8,590 (857)	
January 2012			3,768 (375)	7,094 (708)*
February 2012	20,069 (2,005)	10,021 (1,001)		
March 2012	10,101 (1,008)			
April 2012	11,281 (1,124)			
May 2012		10,231 (1,022)		
June 2012		21,571 (2,152)		18,511 (1,849)
July 2012	11,671 (1,165)		7,292 (727)	
August 2012	8,701 (868)	5,782 (577)	9,346 (932)	11,342 (1,133)
September 2012		1,428 (141)	7,188 (717)	
October 2012	10,199 (1,018)			
November 2012			5,087 (507)	7,209 (719)
December 2012	4,385 (437)	4,366 (436)		
Total	100,771 (10,058)	64,779 (6,467)	50,602 (5,048)	72,917 (7,282)

*Trial was missing 122 samples; these were replaced with zeros when analyses required continuity.

significantly higher at the LNG terminal (16.4%) than at the Saint John Harbour (4.5%, 2-way ANOVA with Tukey HSD: p=0.0002) or Seeley's Cove aquaculture site (4.1%, 2-way ANOVA with Tukey HSD: p=0.0003; Table 11). At Charlie's Cove, average presence was 9.2%, and did not significantly differ from the other sites.

C-PODs report the total number of click trains detected, regardless of whether those click trains are classified as harbour porpoise. The metric allows identification of times when the system was overloaded by looking for the maximum number of click trains able to be detected in one min (4096). This occurred 4.7% of the time, on average. The

Table 10. Echolocation activity (average number of click trains per min) and percent presence (from Detection Positive Minutes) of harbour porpoise during the Day and Night, detected between October 2011 and December 2012 at the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) aquaculture sites.

Trial	Echolocation activity		Percent presence	
	Day	Night	Day	Night
LNG				
Oct_2011	12.0	4.0	22.6	10.3
Nov_2011	11.8	8.9	18.2	15.9
Feb_2012	1.7	1.9	3.5	4.0
Mar_2012	4.1	11.3	14.7	32.8
Apr_2012	4.4	7.9	7.3	13.3
Jul_2012	3.9	6.1	8.2	13.8
Aug_2012	25.4	26.0	38.5	33.5
Oct_2012	0.6	1.1	2.1	3.9
Dec_2012	20.5	22.1	25.1	28.0
SJH				
Dec_2011	1.1	12.2	3.7	21.4
Feb_2012	1.2	13.7	3.7	24.1
May_2012	0.2	0.3	1.6	1.3
Jun_2012	0.1	0.4	0.2	1.3
Aug_2012	0.1	0.3	0.6	1.1
Sep_2012	0.0	0.0	0.0	0.0
Dec_2012	0.1	1.9	0.3	4.1
SC				
Oct_2011	1.5	6.8	2.3	8.1
Dec_2011	3.6	15.1	9.3	20.3
Jan_2012	0.0	9.6	0.0	8.9
Jul_2012	0.0	0.1	0.0	0.3
Aug_2012	0.2	0.8	0.2	1.1
Sep_2012	0.1	0.4	1.4	2.7
Nov_2012	0.7	0.9	2.2	0.1
CC				
Oct_2011	4.7	9.2	11.2	18.8
Nov_2011	7.9	11.5	11.0	17.6
Jan_2012	0.7	3.5	3.1	9.0
Jun_2012	0.2	0.8	1.0	3.0
Jul_2012	1.3	10.9	4.7	26.7
Nov_2012	0.1	0.4	1.0	2.7

Table 11. ANOVA table comparing percent porpoise presence during the day and night, and among four industrial sites: the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) aquaculture sites.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-statistic	p-value
Site	3	0.6215	0.20717	9.348	5.19×10^{-5}
Day/Night	1	0.1103	0.11027	4.976	0.0302
Site*Day/Night	3	0.0256	0.00852	0.384	0.7646
Residuals	50	1.1081	0.02216		

trial with the largest percentage of overload (28%) was September 2012 at Seeley's Cove. The next largest percentage was much lower (4.8%) during May 2012 at the Saint John Harbour.

The proportion of Detection Positive 10 Minutes within each hr may be seen in Figures 9-12. These hourly figures allow visualization of more fine-scale day/night trends. Residence time was another metric of day/night trends. This was defined as the number of consecutive minutes of porpoise presence (Table 12). The ten longest intervals of consecutive presence were all found outside of working hours (defined as 9:00-17:00), with the exception of two instances (October 2011 and August 2012) at the LNG terminal. Within each site, the longest interval was always found between the hours of 1:00 and 9:00. The longest interval of consecutive presence (147 min) was seen at the Seeley's Cove aquaculture site during December 2011.

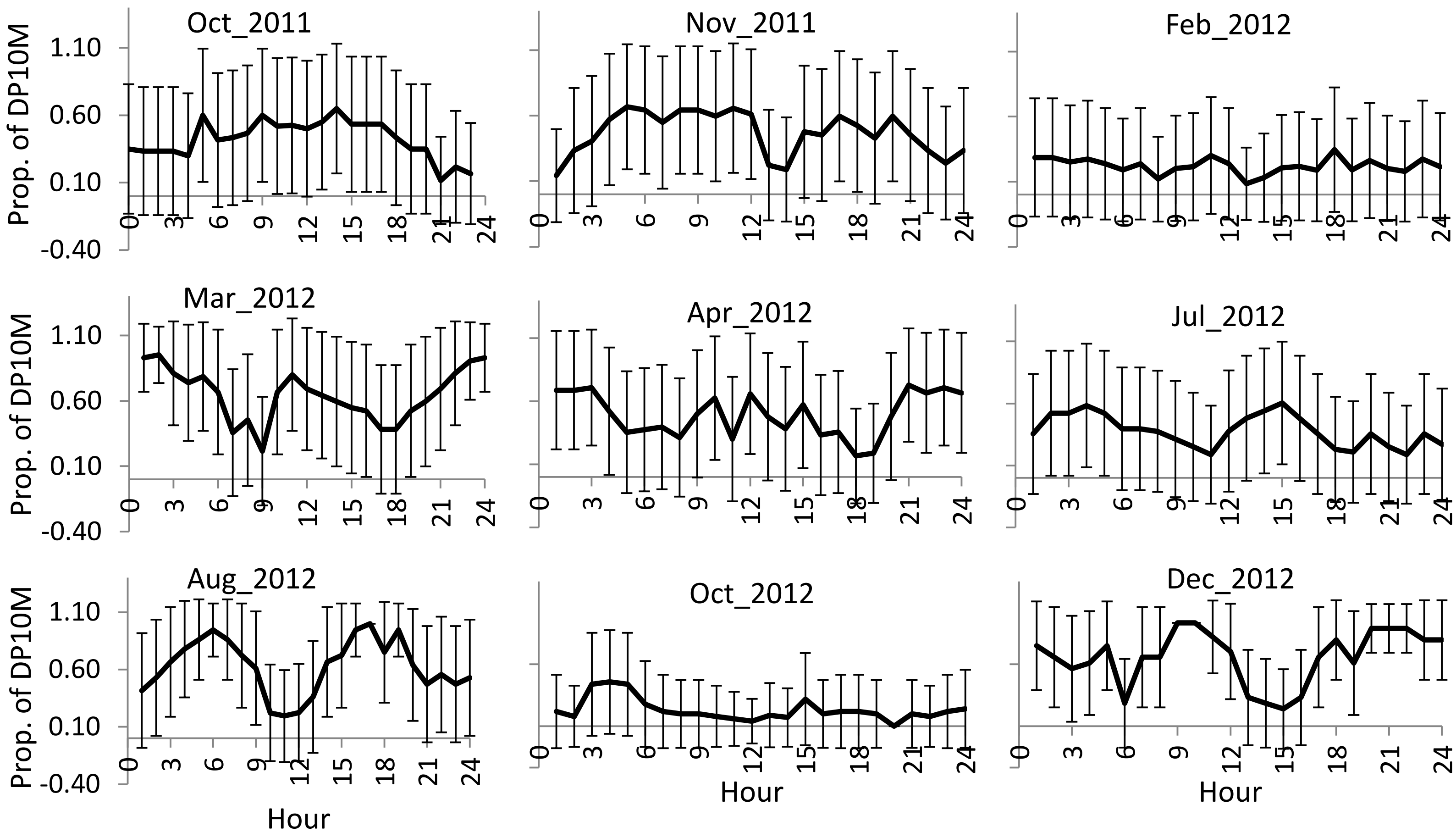

Figure 9. Hourly proportion of Detection Positive 10 Minutes (DP10M) between October 2011 and December 2012 at the Liquefied Natural Gas (LNG) terminal. Error bars measure one standard deviation.

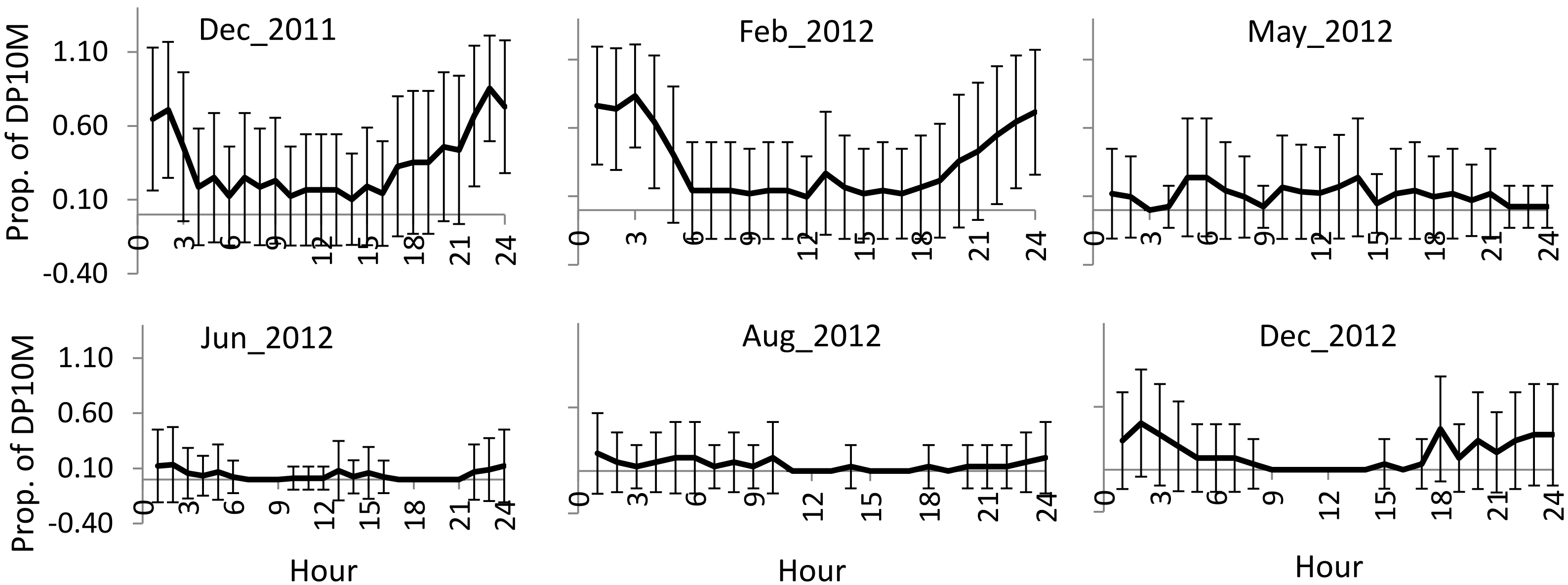

Figure 10. Hourly proportion of Detection Positive 10 Minutes (DP10M) between December 2011 and December 2012 at the Saint John Harbour (SJH) site. Error bars measure one standard deviation.

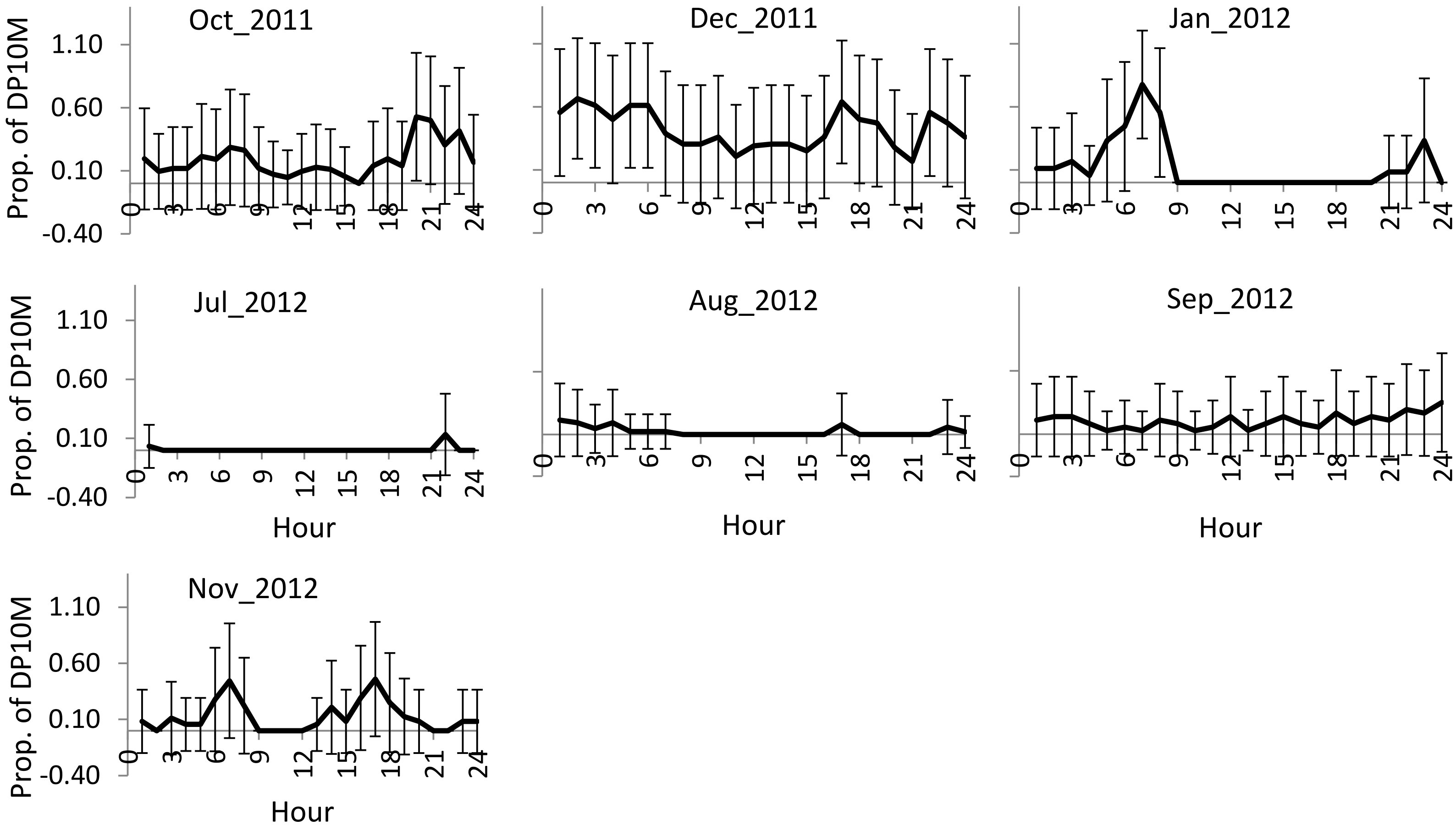

Figure 11. Hourly proportion of Detection Positive 10 Minutes (DP10M) between October 2011 and November 2012 at the Seeley's Cove (SC) aquaculture site. Error bars measure one standard deviation.

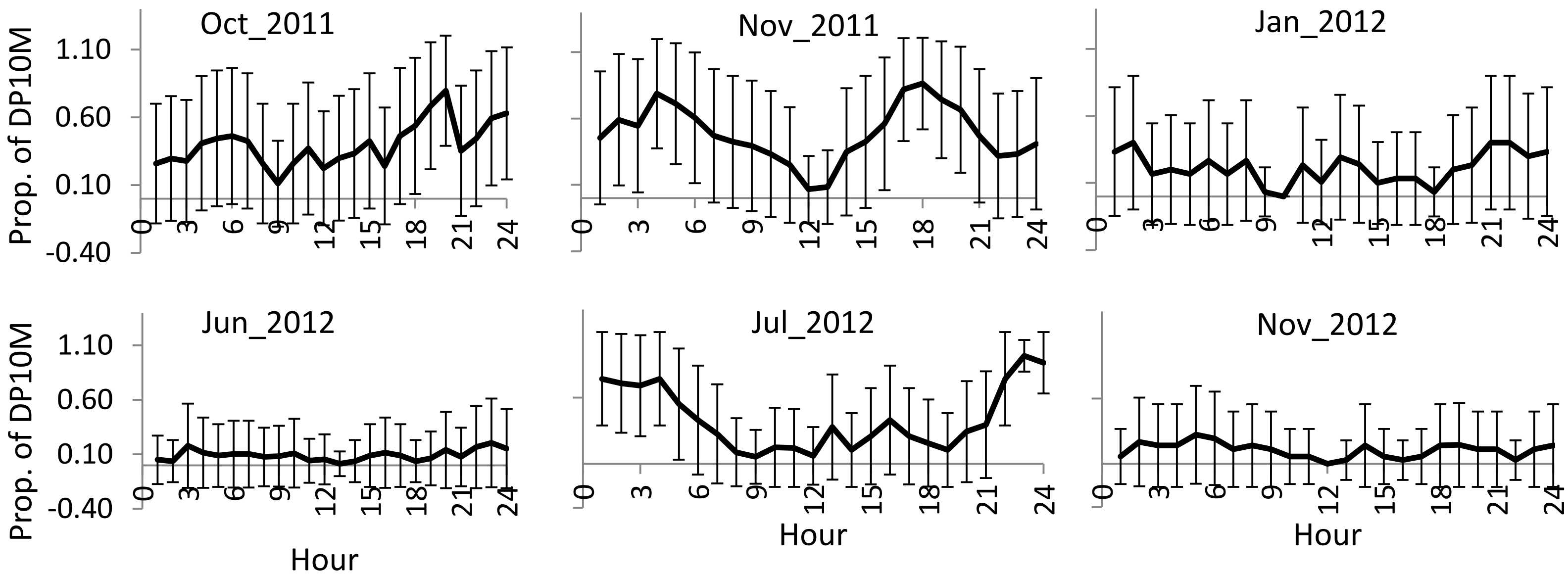

Figure 12. Hourly proportion of Detection Positive 10 Minutes (DP10M) between October 2011 and November 2012 at the Charlie's Cove (CC) aquaculture site. Error bars measure one standard deviation.

Table 12. Mean (SD) and maximum residence times (number of consecutive minutes of presence) of harbour porpoise detected between October 2011 and December 2012 at the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) aquaculture sites.

Trial	Mean (SD)	Maximum
LNG		
Oct_2011	3 (4.3)	91
Nov_2011	2 (1.6)	13
Feb_2012	1 (0.7)	8
Mar_2012	2 (2.1)	25
Apr_2012	1 (0.7)	7
Jul_2012	2 (1.3)	11
Aug_2012	5 (10.7)	117
Oct_2012	1 (0.7)	5
Dec_2012	2 (2.1)	19
SJH		
Dec_2011	3 (6.0)	83
Feb_2012	3 (6.2)	83
May_2012	1 (0.5)	3
Jun_2012	1 (0.5)	4
Aug_2012	1 (0.5)	3
Dec_2012	1 (0.8)	6
SC		
Oct_2011	2 (2.4)	24
Dec_2011	3 (7.2)	147
Jan_2012	2 (2.1)	12
Jul_2012	1 (0.5)	2
Aug_2012	1 (1.4)	9
Sep_2012	1 (0.6)	4
Nov_2012	1 (0.9)	5
CC		
Oct_2011	2 (3.5)	42
Nov_2011	2 (1.7)	22
Jan_2012	2 (3.2)	29
Jun_2012	1 (1.2)	9
Jul_2012	2 (1.9)	19
Nov_2012	1 (0.6)	4

The environmental data provided by the Liquefied Natural Gas terminal were also examined for a relationship with percent porpoise presence (from Detection Positive Minutes) through regressions. It should be noted that these data were sometimes temporally correlated. Wind speed was only found to have a significant relationship ($p=0.004$) with percent presence in July 2012, and although the r^2 value was highest in this month, it was still quite low ($r^2=0.05$). July 2012 was also the only month in which water temperature was found to be significantly related to porpoise presence, and had the largest r^2 value of 0.19.

3.3 *Effects of Underwater Noise on Harbour Porpoise Presence and Echolocation Activity Analyses*

The underwater noise and porpoise presence datasets were time-matched for investigation of the main objective of this study, which is to determine if higher underwater noise levels in these industrial areas of the Bay of Fundy displace harbour porpoise from potential habitat. Time-matching was done by determining if there were porpoise present within the 30 min after the beginning of a noise recording. The resulting matched datasets had 3,831 samples. The sample sizes within each trial may be seen in Table 13.

Underwater noise samples were reported as linear levels (dB_{lin}), and as levels adjusted according to harbour porpoise hearing thresholds (dB_{ht} (*Pp*); see Methods). The range and averages of the two noise levels measures may be seen in Figure 13. The average 1/3 octave band noise levels of all 8,145 samples were approximately 100 dB_{lin} re 1µPa across the frequency range examined. The dB_{ht} (*Pp*) adjustment dropped the average by about 80 dB at the lowest frequency (100 Hz). The hearing threshold

Table 13. Number of time-matched samples between underwater noise samples (30 min intervals) and porpoise detections from the beginning of noise recordings to 30 min after. Data recorded at the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) sites between October 2011 and December 2012.

	LNG	SJH	SC	CC
October 2011	285		16	44
November 2011	39			26
December 2011		184	83	
January 2012			67	
February 2012	169	112		
March 2012	83			
April 2012	244			
May 2012		214		
June 2012		12		560
July 2012	327		240	284
August 2012	73	33	303	
September 2012		46	78	
October 2012	23			
November 2012			51	
December 2012	97	138		
Total	1,340	739	838	914

adjustment then increased by approximately 3 dB per 1/3 octave frequency band until the levels were comparable at the highest frequency (16 kHz). Descriptive statistics of dB_{ht} (*Pp*) noise levels may be seen in Table 14.

The percentage of dB_{ht} (*Pp*) samples with high noise levels (>120 dB re 1µPa) during the day and night, and among sites, were then compared (Table 15). Overall, there was a higher percentage of high noise samples found during the day (2.6%) than night (1.0%; Kruskal-Wallis p=0.007). Interestingly, Charlie's Cove now had the highest overall percentage of high noise values (3.6%); however, this is mostly due to

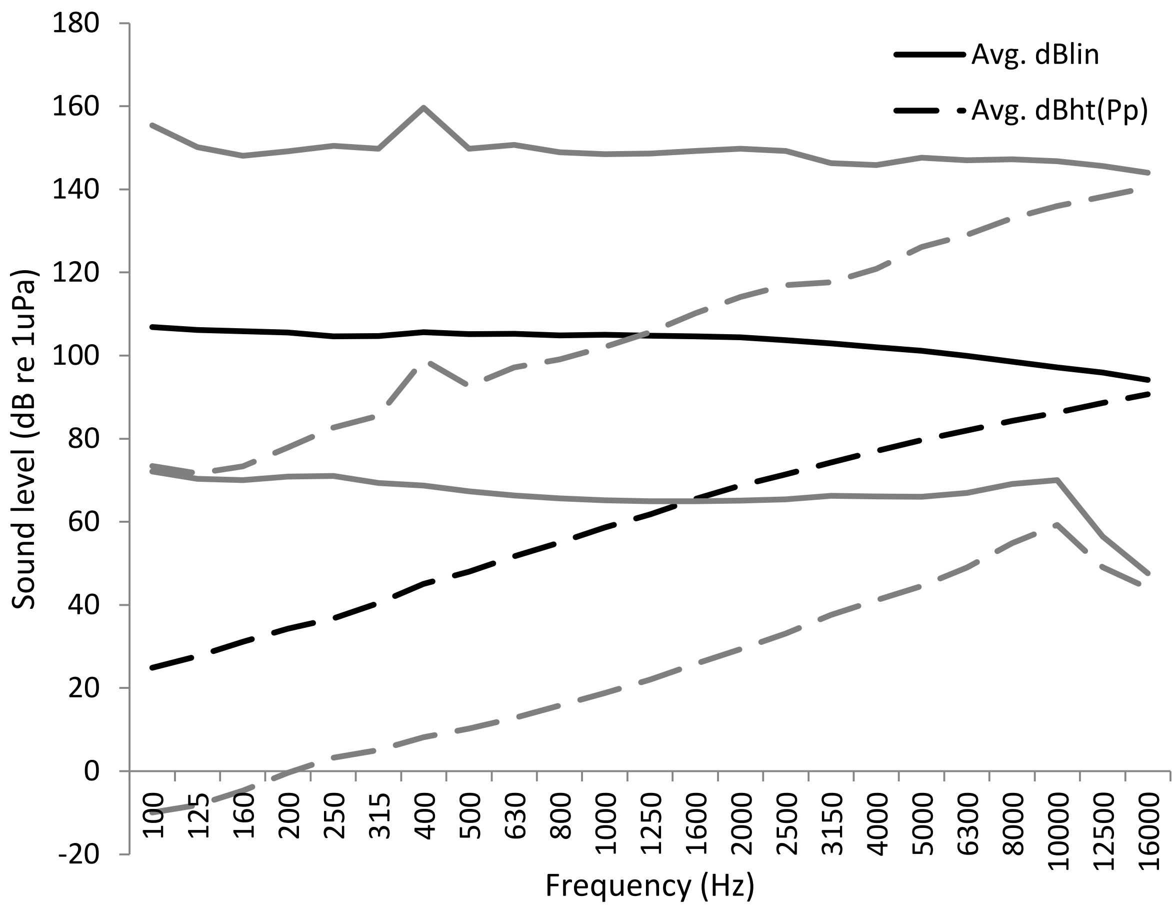

Figure 13. Average and range of linear noise levels (dB_{lin}; solid lines) and noise levels adjusted for harbour porpoise hearing abilities (dB_{ht} (*Pp*); dashed lines). Calculations were made from all 8,145 noise samples recorded at the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) aquaculture sites.

one month (October 2012). This indicates that the linear high noise samples found at the LNG terminal are mostly driven by low frequencies. The percentage of high dB_{ht} (*Pp*) noise samples found at Charlie's Cove was significantly higher (at the 10% significance

Table 14. Descriptive statistics of broadband (0.1-16 kHz) underwater sound levels (dB_{ht} (*Pp*) re 1µPa) from 1/3 octave bands recorded between October 2011 and December 2012 at the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) aquaculture sites.

Trial	Range	Mean	SD
LNG			
Oct_2011	85-111	96	4.8
Nov_2011	98-117	103	4.2
Feb_2012	80-129	106	10.9
Mar_2012	89-120	112	6.3
Apr_2012	89-135	98	8.0
Jun_2012	90-127	100	7.8
Jul_2012	90-117	101	6.4
Aug_2012	93-112	97	3.4
Oct_2012	80-90	87	3.0
Nov_2012	91-118	99	6.3
Dec_2012	90-118	99	6.9
SJH			
Dec_2011	86-120	91	6.5
Jan_2012	73-96	87	5.9
Feb_2012	94-128	97	4.2
Apr_2012	82-122	112	8.4
May_2012	90-127	99	7.9
Jun_2012	87-134	99	14.4
Aug_2012	89-117	96	7.0
Sep_2012	85-125	92	8.9
Oct_2012	85-137	102	10.4
Dec_2012	87-132	100	8.0
SC			
Oct_2011	71-110	94	8.6
Dec_2011	69-107	85	10.5
Jan_2012	84-118	94	7.4
Feb_2012	83-116	97	5.6
Jul_2012	84-141	92	7.8
Aug_2012	82-144	94	9.4
Sep_2012	87-122	99	5.4
Nov_2012	86-116	97	5.1
Dec_2012	97-112	101	3.5
CC			
Oct_2011	82-99	85	4.8
Nov_2011	79-95	87	2.9
May_2012	82-130	95	13.8
Jun_2012	81-138	90	10.4
Jul_2012	76-134	86	9.6
Sep_2012	84-128	88	5.2
Oct_2012	82-141	93	11.3
Nov_2012	82-133	92	7.9

level) than Seeley's Cove (0.6%, Wilcox: p=0.06). Charlie's Cove did not significantly differ from Saint John Harbour (2.7%), but Saint John Harbour had significantly more high dB_{ht} (*Pp*) noise samples than both the LNG terminal (0.7%) and Seeley's Cove aquaculture site (Wilcox: p=0.03).

To examine the effect of underwater noise levels on porpoise presence, average echolocation activity was calculated for each 10 dB noise bin (Figures 14-17), and percent presence was compared between the bottom (quietest) and top (loudest) third of noise sample amplitudes (Table 16). Linear and dB_{ht} (*Pp*) noise levels were used in the comparisons. Measures of porpoise echolocation activity were calculated separately for Day and Night as percent presence was typically higher during the night, and noise levels were sometimes higher during the day. If higher underwater noise levels displaced harbour porpoise, then higher percent presence should be found at the bottom 30% of noise samples as compared to the top 30%.

There were no consistent patterns of echolocation activity decreasing with increasing noise level bins. This was confirmed using Friedman's test to statistically compare percent presence (arcsine-squareroot transformed) in the bottom and top 30% of noise samples, with day and night as a covariate. For both dB_{lin} and dB_{ht} (*Pp*) noise levels, and at all sites, porpoise presence did not differ between low (average 40.5% presence for dB_{lin} and 38.6% for dB_{ht} (*Pp*)) and high (average 39.2% for dB_{lin} and 40.2% for dB_{ht} (*Pp*)) noise levels. This result did not differ when percent presence with more extreme noise levels (25%, 20%, 15%, 10%, and 5%) were compared ($x^2<1.5238$, $p>0.217$).

Table 15. Number of high noise samples (> 120 dB_{ht} (*Pp*) re 1µPa) in the Day and Night recorded between October 2011 and December 2012 at the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) aquaculture sites.

Trial	# high noise/total Day	# high noise/total Night
LNG		
Oct_2011	0/134	0/151
Nov_2011	0/12	0/31
Feb_2012	4/65	2/104
Mar_2012	1/55	0/29
Apr_2012	1/168	4/105
Jun_2012	4/296	0/149
Jul_2012	0/203	0/125
Aug_2012	0/48	0/25
Oct_2012	0/15	0/8
Nov_2012	0/132	0/199
Dec_2012	0/35	0/62
SJH		
Dec_2011	1/56	0/128
Jan_2012	0/31	0/38
Feb_2012	0/42	1/70
Apr_2012	1/33	1/26
May_2012	7/140	1/75
Jun_2012	1/12	
Aug_2012	0/19	0/14
Sep_2012	6/159	1/168
Oct_2012	12/176	10/179
Dec_2012	5/70	3/116
SC		
Oct_2011	0/60	0/97
Dec_2011	0/27	0/56
Jan_2012	0/108	0/166
Feb_2012	0/141	0/189
Jul_2012	8/253	0/170
Aug_2012	23/417	0/297
Sep_2012	1/38	0/41
Nov_2012	0/39	0/95
Dec_2012	0/10	0/17
CC		
Oct_2011	0/15	0/29
Nov_2011	0/13	0/13
May_2012	34/364	34/220
Jun_2012	25/366	0/200
Jul_2012	6/177	0/108
Sep_2012	1/106	0/115
Oct_2012	23/152	0/164
Nov_2012	4/70	0/109

The effect of noise levels on porpoise activity was also investigated by examining the number of minutes between each noise sample and the last and next occurrence of a Detection Positive Minute. The average time-to-last and time-to-next presence within each 10 dB_{lin} and dB_{ht} (*Pp*) noise bin were investigated for trends, but no consistent trends arose. There was high variability in the dataset, with the standard deviations often exceeding average values. However, it was found that porpoise were present at levels as high as 150 dB_{lin} re 1µPa and 118 dB_{ht} (*Pp*) re 1µPa.

3.3.1. *Case Study: LNG Shagra underwater noise effects on porpoise presence*

The LNG tanker Shagra docked and began offloading at the Liquefied Natural Gas terminal on February 18th 2012 while the noise recording and porpoise detecting equipment were deployed, providing a case study for the effects of ship noise on porpoise presence. This tanker was built in 2009, is 354 m long with a deadweight of 130,102 tons, and a draught of 12 m (www.marinetraffic.com). Docking began at 7:30 am, and was assumed to last 3 hr based on information within the terminal's Environmental Impact Assessment (Jacques Whitford Environmental Limited 2009). Therefore, six noise samples separated by 30 min intervals were used to determine underwater noise levels during docking (7:47-10:17). The ship was recorded to have disembarked at 22:48 on February 19th 2012. The EIA also estimated this to take 3 hr, encompassing six noise samples (19:56-22:27). In the interim, the tanker was considered to be offloading, during which engines would have been minimally running or stopped. This time period encompassed 66 noise samples (10:47-19:26). Approximately 36 hr (72 noise samples) were available before docking began (19:37-7:16), and approximately 5.5 hr (11 noise samples) were available after the tanker disembarked

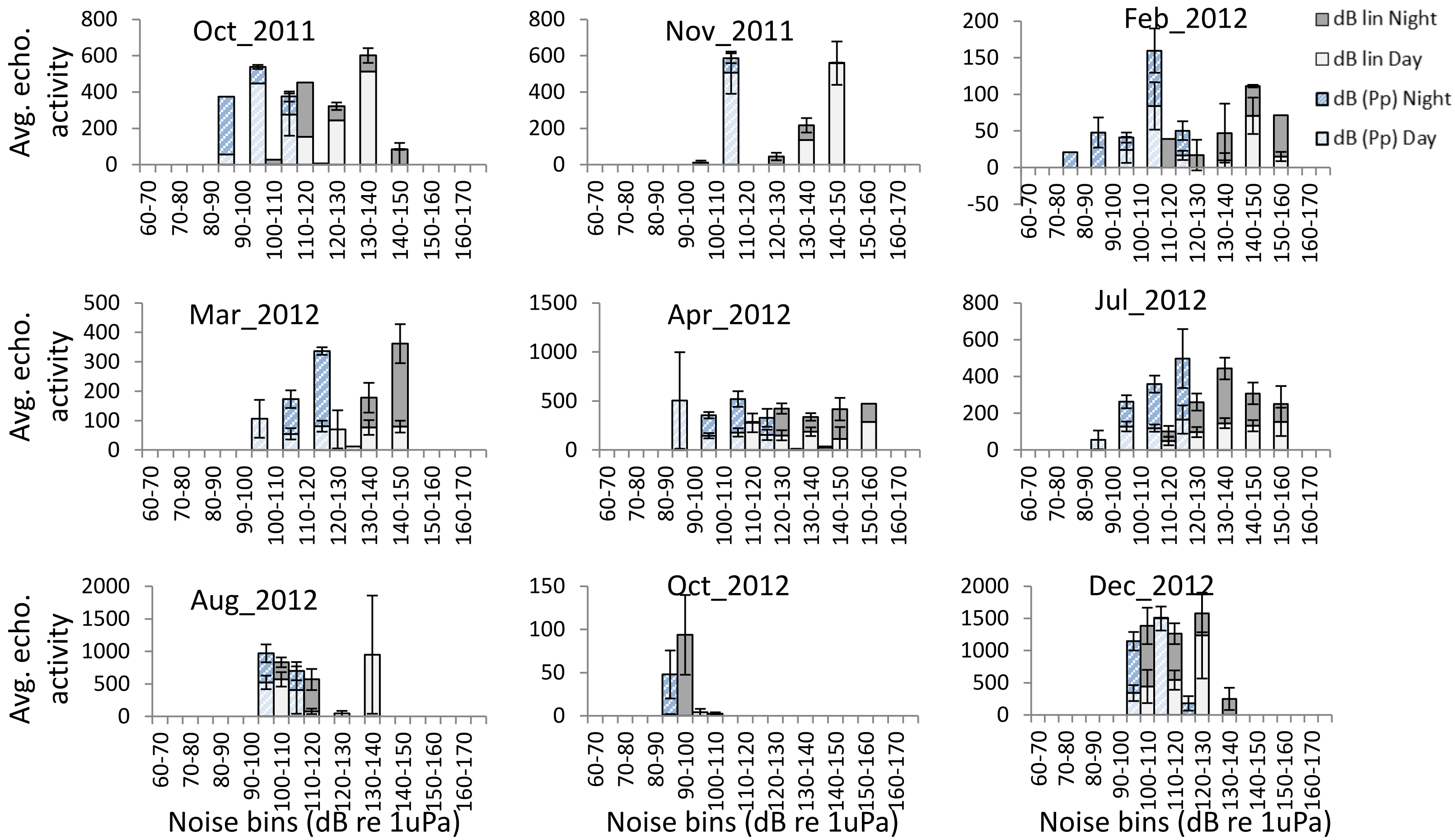

Figure 14. Average echolocation activity (number of click trains per min) of harbour porpoise in 10 dB noise bins (dB_{lin} grey bars, and dB_{ht} (*Pp*) hatched blue bars). Data recorded between October 2011 and December 2012 at the Liquefied Natural Gas (LNG) terminal. Error bars measure the standard error of the mean.

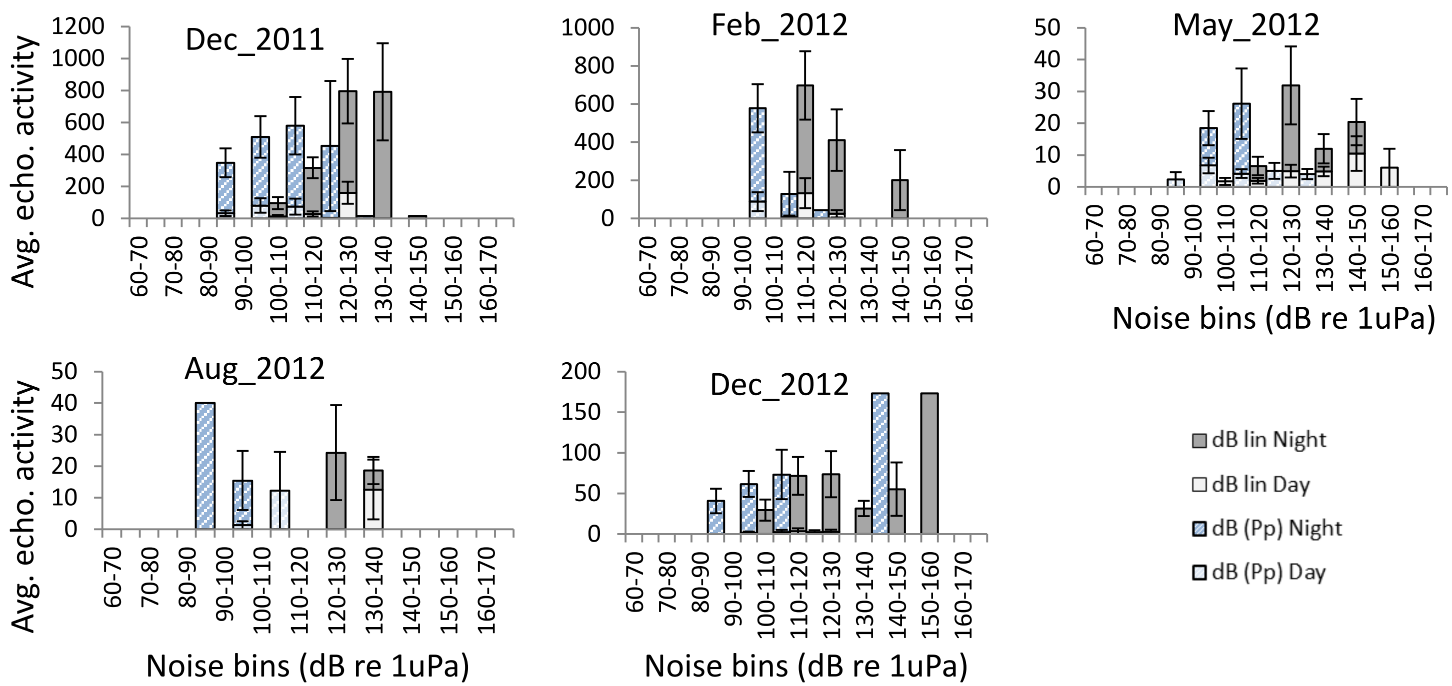

Figure 15. Average echolocation activity (number of click trains per min) of harbour porpoise in 10 dB noise bins (dB_{lin} grey bars, and dB_{ht} (*Pp*) hatched blue bars). Data recorded between December 2011 and December 2012 at the Saint John Harbour (SJH) site. Error bars measure the standard error of the mean.

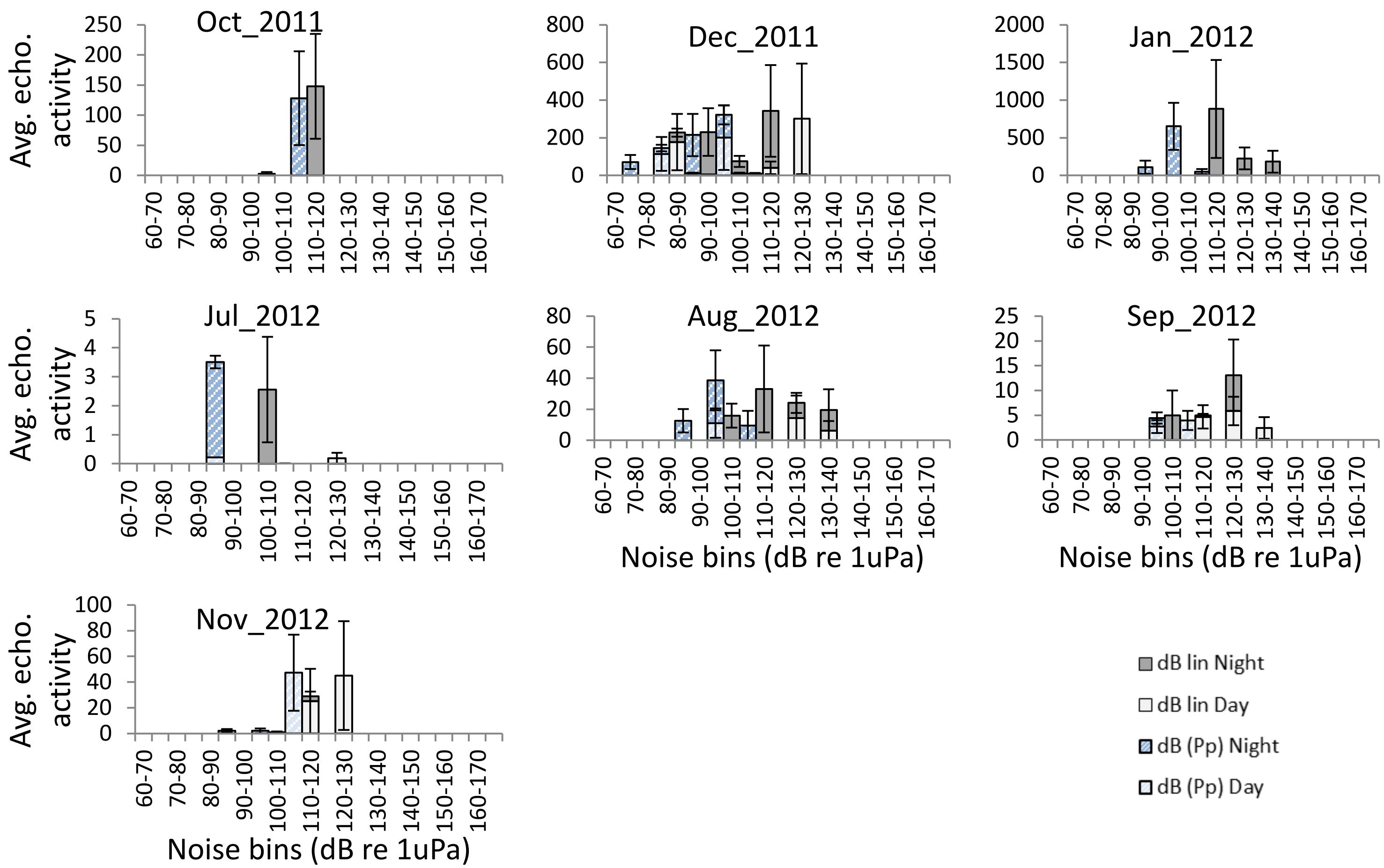

Figure 16. Average echolocation activity (number of click trains per min) of harbour porpoise in 10 dB noise bins (dB_{lin} grey bars, and dB_{ht} (*Pp*) hatched blue bars). Data recorded between October 2011 and November 2012 at the Seeley's Cove (SC) aquaculture site. Error bars measure the standard error of the mean.

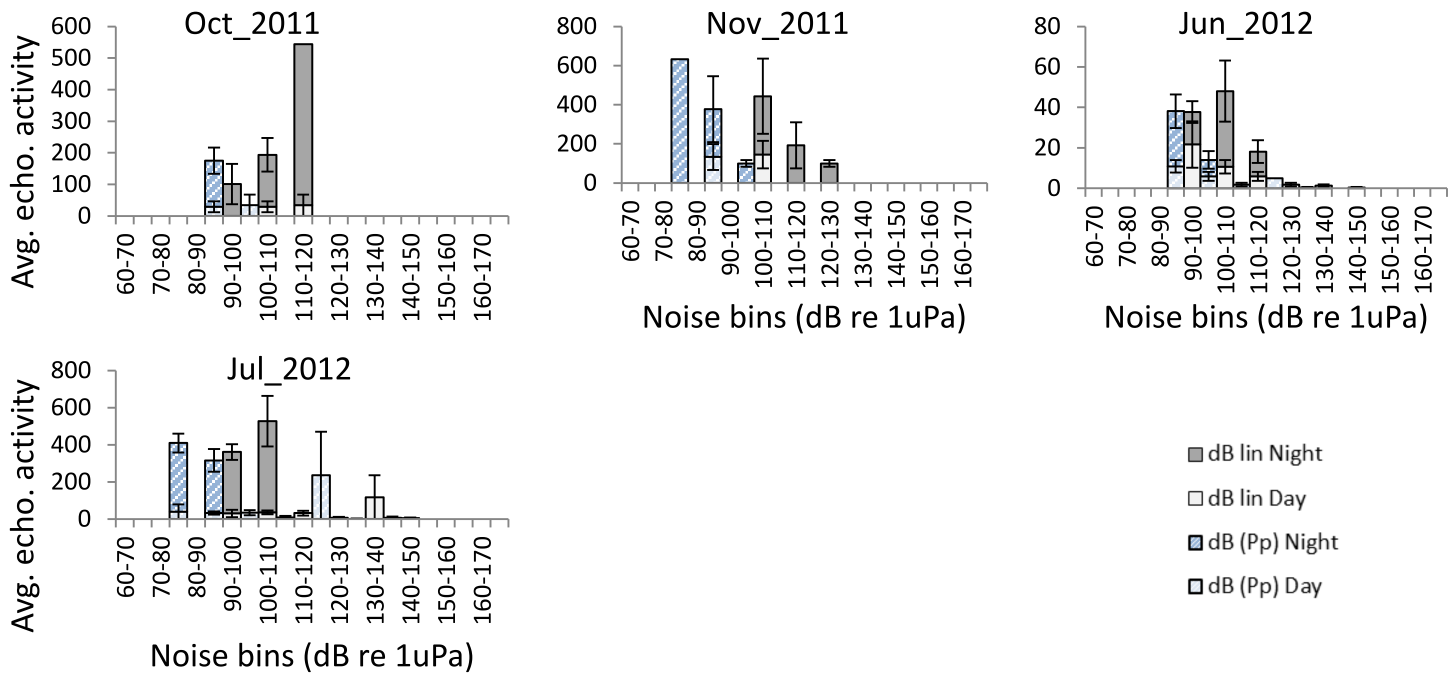

Figure 17. Average echolocation activity (number of click trains per min) of harbour porpoise in 10 dB noise bins (dB_{lin} grey bars, and dB_{ht} (*Pp*) hatched blue bars). Data recorded between October 2011 and July 2012 at the Charlie's Cove (CC) aquaculture site. Error bars measure the standard error of the mean.

Table 16. Percent presence of harbour porpoise during the Day and Night in the bottom and top 30% of noise samples (dB_{lin} and dB_{ht} (*Pp*)). Porpoise detections taken between October 2011 and December 2012 at the Liquefied Natural Gas (LNG) terminal, Saint John Harbour (SJH), Seeley's Cove (SC) and Charlie's Cove (CC) aquaculture sites. Dashes indicate where no noise recording samples were taken at that time of day, and were not included in the analyses.

	dB_{lin}				dB_{ht} (*Pp*)			
	Bottom 30%		Top 30%		Bottom 30%		Top 30%	
	Day	Night	Day	Night	Day	Night	Day	Night
LNG								
Oct_2011	79.5	61.7	60.1	51.1	80.5	46.7	60.1	51.1
Nov_2011	-	25.0	85.7	20.0	0.0	16.7	100.0	50.0
Feb_2012	33.3	58.3	28.6	26.7	23.1	47.4	24.0	26.9
Mar_2012	70.6	75.0	83.3	100.0	64.7	62.5	80.0	100.0
Apr_2012	63.4	78.1	61.4	79.3	64.3	77.4	66.7	78.6
Jul_2012	57.4	43.2	60.6	62.5	55.0	42.1	65.5	79.1
Aug_2012	76.5	100.0	66.7	76.9	83.3	75.0	70.0	91.7
Oct_2012	0.0	75.0	14.3	-	0.0	60.0	33.3	0.0
Dec_2012	63.6	88.9	100.0	65.0	75.0	100.0	100.0	68.2
SJH								
Dec_2011	38.5	28.6	63.6	84.1	53.9	23.7	46.7	80.8
Feb_2012	33.3	80.0	23.1	47.6	45.5	87.0	28.6	50.0
May_2012	22.5	25.0	34.9	28.6	22.0	21.7	36.2	35.3
Jun_2012	0.0	-	0.0	-	0.0	-	0.0	-
Aug_2012	0.0	50.0	40.0	40.0	0.0	40.0	20.0	100.0
Sep_2012	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dec_2012	0.0	39.4	0.0	66.7	11.1	46.9	4.6	47.4
SC								
Oct_2011	-	0.0	0.0	33.3	-	0.0	-	40.0
Dec_2011	100.0	90.5	63.2	83.3	100.0	90.9	53.9	66.7
Jan_2012	0.0	35.3	0.0	41.7	0.0	13.3	0.0	52.9
Jul_2012	0.0	1.8	1.4	0.0	0.0	2.3	0.0	0.0
Aug_2012	0.0	17.7	1.4	5.6	0.0	16.3	1.6	20.7
Sep_2012	-	8.7	9.1	0.0	-	8.7	13.6	0.0
Nov_2012	-	13.3	27.3	25.0	0.0	14.3	37.5	0.0
CC								
Oct_2011	-	23.1	14.3	83.3	-	23.1	25.0	80.0
Nov_2011	83.3	100.0	0.0	100.0	100.0	66.7	0.0	100.0
Jun_2012	19.2	24.0	21.5	40.0	16.7	26.5	22.4	42.9
Jul_2012	0.0	88.1	28.2	-	25.0	88.9	28.2	-

(22:57-4:29). Percent presence of harbour porpoise (from Detection Positive 10 Minutes) were calculated for the five time periods (Before, Docking, Offloading, Disembarking, After) to determine if dB_{lin} or dB_{ht} (*Pp*) noise levels had any effect (Figure 18). There appears to be a pattern of porpoise presence being depressed during high noise periods. The highest proportion of porpoise presence was seen before the tanker arrived. Linear noise levels during this time were variable, but the average was relatively high. When porpoise hearing thresholds were considered, the average level dropped considerably; therefore, low frequencies must have been driving the high linear levels. Porpoise presence dropped to zero shortly before docking and remained suppressed into the first 3 hr of offloading. Noise levels increased by over 15 dB_{lin}, and 20 dB_{ht} (*Pp*) during docking. Porpoise presence then steadily increased during offloading (when average noise levels had dropped 7-8 dB), disembarking (when average noise levels increased 3-5 dB), and after the tanker left (when average noise levels dropped about 14 dB). Noise levels before and after the presence of the LNG tanker were more variable than those when the tanker were present, likely because the natural levels included some quiet samples which were masked by the presence of a tanker and tugs.

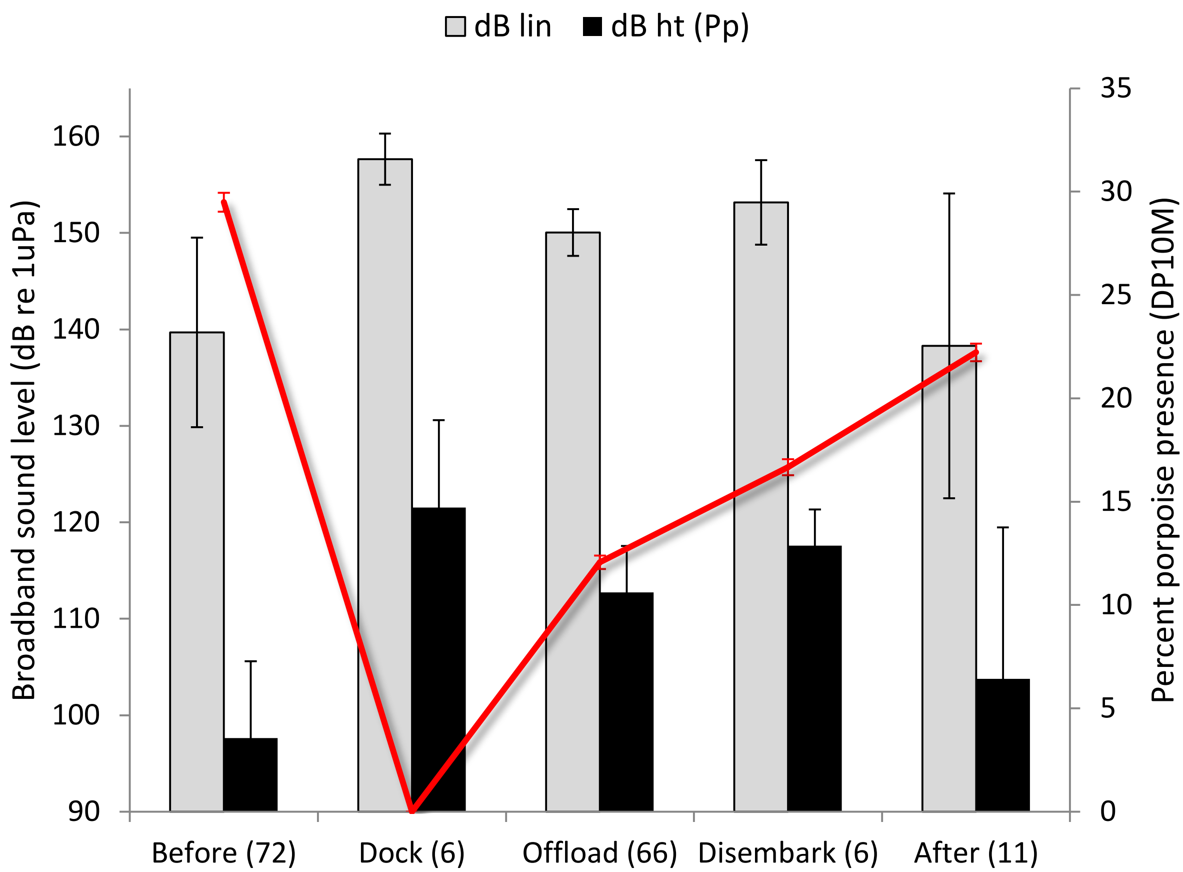

Figure 18. Linear (dB_{lin}; grey bars) and porpoise hearing adjusted (dB_{ht} (*Pp*); black bars) noise levels (dB re 1µPa) before, during, and after the LNG tanker Shagra visited the Liquefied Natural Gas (LNG) terminal, and the relationship with harbour porpoise presence (percentages calculated from Detection Positive 10 Minutes). Sample sizes of noise samples are in parentheses; error bars measure one standard deviation.

4.0 Discussion

Underwater noise pollution has become a concern for marine mammal conservationists and regulators as the potential for harm has been demonstrated (Richardson *et al.* 1995, Nowacek *et al.* 2007). Harm may be direct, as is the case when impulsive noise damages hearing ability (Southall et al. 2007). Indirect harm is likely more common, through increased stress levels (Rolland *et al.* 2009), or sustained avoidance of potentially important habitat (Carstensen *et al.* 2006). This study is concerned with underwater noise in industrial areas of the Bay of Fundy, Canada, and its potential to displace harbour porpoise. The main three objectives were to: 1) describe underwater noise levels at these sites over a year, 2) detect harbour porpoise throughout the year to determine if individuals were present year round, and 3) determine if porpoise presence was found to be lower at higher noise levels, indicating displacement. As a brief summary, noise levels are reported and did not exceed 162 dB_{lin} re 1µPa, harbour porpoise are present year-round, there were day/night differences in noise level and porpoise presence at some sites but not others, and noise levels were not found to affect porpoise presence; however, there was evidence for short-term displacement.

4.1 *Underwater Noise*

Noise levels were highly variable within and between sites (Table 2). On average, LNG was the loudest site (128 dB re 1µPa) with levels being significantly louder than Seeley's Cove (117 dB re 1µPa), and Charlie's Cove (110 dB re 1µPa) aquaculture sites. Average levels at the Saint John Harbour site (124 dB re 1µPa) were comparable to those at the LNG terminal, but were significantly higher than those at Charlie's Cove.

This trend is also seen when comparing average ambient levels between sites. Ambient levels at the LNG terminal were comparable with those at the Saint John Harbour, and were significantly higher than those at both aquaculture sites. When examining only noise levels above 120 dB re 1µPa, both LNG and Saint John Harbour sites had significantly more high noise samples than Charlie's Cove, but were comparable with Seeley's Cove.

These differences may be attributed to the different types of activities found at each site, and the time of day in which they are performed. At the Liquefied Natural Gas terminal, large LNG tankers dock about every month with the help of tug boats, and crude oil tankers regularly dock at the monobuoy only 1 km away. The loudest noise level was recorded at the LNG terminal in February 2012 at 162 dB re 1µPa. During this recording, a LNG tanker was disembarking from the terminal. More information about this vessel, its noise levels and their effect on porpoise presence will be discussed as a case study. There is also a dredging material disposal site located 1.5 km away. The area around the LNG terminal is frequented by fishing and recreational vessels, and it has open fetch to the main body of the Bay of Fundy. This 24 hr activity is reflected in the fact that ambient and high (>120 dB re 1µPa) noise levels did not significantly differ between day and night.

The day and night presence of shipping activity was also the case at the Saint John Harbour (SJH) site. Both ambient and high noise levels did not significantly differ between day and night. This site is not as exposed as the LNG terminal, and the recording equipment was located on one side of a 400 m wide channel with large concrete walls lining each side. This port harbour is visited by scrap metal ships and cruise ships often, as well as fishing and recreational vessels. In the summer months, it is dredged to increase draft. Dredging has been reported to create noise levels of 160 dB_{rms} re 1µPa at 1 m at 100 Hz (Richardson *et al.* 1995).

At the aquaculture sites, noise levels were much lower. The quietest noise level (85 dB re 1µPa) was recorded at the Seeley's Cove (SC) aquaculture site in December 2011 at 2:45 in the morning. Sea lice treatments, requiring the use of 15 m long barges, were performed at Seeley's Cove during the September and December 2012 recordings. These months were found to have two of the highest mean noise levels recorded at this site. At both aquaculture sites, ambient levels were recorded more often at night than during the day, but no day/night differences were seen for high noise levels. The quietest time found among all site-day/night combinations was Charlie's Cove at night. These trends are likely seen because the majority of anthropogenic noise sources are present during working hours. These sites are frequented by vessels smaller than those seen at the LNG and Saint John Harbour sites, for the purpose of maintaining aquaculture facilities, or for fishing scallop and lobsters. At the Saguenay-St. Lawrence Marine Park, underwater noise levels were 8 dB louder during the day than night due to the presence of a car ferry and whale watching vessels (Gervaise *et al.* 2012).

Hourly wind speeds were provided for the LNG terminal, and were examined with respect to the ambient noise levels. No significant relationships were found. Low frequency ambient noise is reported to increase rapidly with increasing wind speeds in shallow water (Madsen *et al.* 2006). All of these sites are considered to be shallow by the definition given by Richardson *et al.* (1995), which is a depth less than 200 m. However, there were some trends seen. The quietest months at the LNG terminal

(August and October 2012) coincided with the lowest maximum wind speeds. November 2011 also had low maximum wind speeds, but the noise levels were comparable with the other months, perhaps due to higher minimum wind speeds (Figure 8).

4.2 *Harbour porpoise activity*

Porpoise were detected with a passive acoustic monitoring tool developed for this purpose. There were many observational confirmations of harbour porpoise being seen at these industrial sites. Porpoise presence was common but variable (Table 10). Average percent presence (9%) was comparable to the Minas Basin observations where porpoise were detected 11% of the time (Tollit *et al.* 2011). However, the average percent of time in which C-PODs reached the maximum value of click trains per min (4.7%) was less than that in the Minas Basin (8.7%). On average, percent presence (16.4%) was higher at the LNG terminal than at Saint John Harbour (4.7%) or the Seeley's Cove (4.1%) aquaculture site. Percent presence (9.2%) at the Charlie's Cove aquaculture site fell between LNG and Saint John Harbour/ Seeley's Cove values. Peak porpoise detection at another aquaculture facility in the Bay of Fundy during the summers of 2006 and 2007 occurred in August (Haarr *et al.* 2009). This was also the case at the LNG terminal. The second highest porpoise detection occurred in July at the Charlie's Cove aquaculture site. Other high porpoise detections were observed in the winter months (SJH-December 2011 and February 2012, SC – December 2011, CC-November 2011).

The second objective of this study was to determine if harbour porpoise remain in the Bay of Fundy during the winter months, or migrate south to the Gulf of Maine (Neave and Wright 1968, Gaskin *et al.* 1985). When considering all measures: echolocation activity, percent presence, and residence time, it is clear that at least some of the harbour porpoise population is present in the Bay of Fundy through all months of the year, and at all sites investigated. It is now known that there is no time during the year when porpoise will not be present in the Bay, and thus subject to disturbance. Regulators and construction planners should be aware of this when planning marine construction activities, such as pile driving. This finding supports that of the Fundy Ocean Research Centre for Energy, which detected harbour porpoise in the Minas Basin (inner Bay of Fundy) in the winter of 2011 (Tollit *et al.* 2011). Harbour porpoise presence in the Bay of Fundy year round may reflect a change in their distribution and behavior since the late 1960s (Neave and Wright 1968), or the advent of better detection technology. Off western Greenland, harbour porpoise have diversified their diet, presumably to adapt to increased sea surface temperatures (Heide-Jørgensen *et al.* 2011). Perhaps this is also occurring in the Bay of Fundy.

Percent presence was found to be higher during the night than the day at the Saint John Harbour and both aquaculture sites, but not at the LNG terminal. Porpoise are known to reside in areas of upwelling and eddies formed by strong tidal currents. These areas concentrate prey species, such as herring, which are attracted to concentrated plankton (Diederichs *et al.* 2008). In fact, herring distribution has been identified as the most important factor affecting porpoise distribution in the Bay of Fundy (Gaskin *et al.* 1985). Nighttime presence is thought to be higher as porpoise follow the vertical migration of herring (*Clupea harengus*) to surface waters at night (Gaskin *et al.* 1985). Many studies have found porpoise presence to be higher during the night than day (Cox *et al.* 2001, Haarr *et al.* 2009, Todd *et al.* 2009, Tollit *et al.* 2011); however, there is some evidence to the contrary (Cox and Read 2004). PODs are often deployed near land where they may be accessed easily, such as in this study. Therefore, they would detect porpoise in surface waters more often than porpoise at depth.

Herring distribution was not assessed in this study, and environmental factors (wind speed and water temperature) provided for the LNG terminal did not correlate with percent porpoise presence. According to Department of Fisheries and Oceans personnel, the industrial areas of interest no longer have active herring populations, but do have many anadromous fishes such as shad (*Alosa sapidissima*) which frequent the Saint John River. Charlie's Cove would be likely to have the highest herring population of these sites since the main nursery ground is from Saint Andrews to the Wolves islands and Grand Manan (Gary Melvin, pers. comm.[2]).

The number of consecutive minutes of presence was considered an index of porpoise residence time (Table 12). Higher values indicate that the porpoise were using the area for some purpose, such as feeding or resting, whereas lower values indicate they were navigating through the area (Diederichs *et al.* 2008). Within each site, the maximum values always fell within the late night to early morning time period (1:00-9:00). Also, the ten longest intervals of consecutive presence always fell outside of work hours (defined as 9:00-17:00), with the exception of two instances at the LNG terminal.

[2]Gary Melvin, Research Scientist, Fisheries and Oceans Canada, 506-529-5874

These observations support the idea that harbour porpoise are using surface waters for feeding during the night.

The maximum distance between sites was 70 km, therefore it is possible that some porpoise were detected at different sites within a sampling period since tagging data indicated they can travel 14-28 km a day on average (Read and Westgate, 1997).

Many studies have utilized PODs to assess porpoise presence using the measure Detection Positive Minutes. It is widely accepted that porpoise echolocate almost constantly, and so this measure confidently reports true presence, but not necessarily absence (Akamatsu *et al.* 2007). The POD will only detect a click that is directed toward the device, and since porpoise have a narrow echolocation beam (11-13°; Koblitz *et al.* 2012), or could swim above or below the POD, it is likely that porpoise presence is underestimated by these devices (Dudzinski *et al.* 2011). Also, the PODs are limited to ranges of 600 m^2 (T-POD; Diederichs *et al.* 2008) and 300 m^2 (C-POD; Tougaard *et al.* 2006 in Tollit *et al.* 2011) or a radial range 170 m (Carstensen *et al.* 2006).

4.3 *Underwater noise effects on harbour porpoise presence*

The third and main objective of this study was to determine if ship noise and other anthropogenic noise at the industrial sites studied had an effect on porpoise activity. Porpoise presence was compared with varying noise levels on both a linear scale, and on an adjusted scale. The adjusted scale applied a weighting function (dB_{ht} (*Phocoena phocoena*)) to the linear levels in order to estimate broadband perceived levels.

It has been generalized that marine mammals will tend to avoid an area when noise levels exceed 120 dB re 1µPa (Richardson *et al.* 1995, Southall *et al.* 2007). The industrial sites investigated in this study exceeded 120_{lin} dB re 1µPa approximately 50% of the time, on average, but exceeded 120 dB_{ht} (*Pp*) re 1µPa only 3% of the time. This difference reflects the proportion of low frequencies in the broadband noise levels at the four study sites, and the porpoises' reduced abilities to detect these frequencies. The high linear noise levels were found 82% of the time on average at the LNG terminal, 59% at the Saint John Harbour, 38% at Seeley's Cove, and only 19% of the time at Charlie's Cove. When levels were adjusted, Charlie's Cove had the highest percentage of noise samples over 120 dB_{ht} (*Pp*) re 1µPa (3.6%), indicating that the high percentage of samples over 120 dB_{lin} re 1µPa found at the LNG terminal were mostly driven by low frequencies. The occurrence of these high linear noise levels did not differ from day to night. However, high dB_{ht} (*Pp*) noise levels occurred more often during the day (2.6%) than the night (1.0%), overall. More specifically, harbour porpoise have been reported to have sustained avoidance behavior when exposed to noise levels of 140 dB re 1µPa (Southall *et al.* 2007). Noise levels exceeded 140_{lin} dB re 1uPa 11% of the time, most often at LNG (28%) and in decreasing amounts at the other sites (SJH-10%, SC-3%, CC-2%).

AHDs or seal scarers are used on fishing nets, aquaculture nets, and at construction sites for the purpose of deterring seals and porpoise from an area (Johnston 2002). For 2 d in May 2012 at the Charlie's Cove aquaculture site, an acoustic harassment device (AHD) was heard in the noise recordings. This AHD had a fundamental frequency of 10 kHz. During the time period that the AHD was detected, noise levels averaged 136 dB_{lin} re 1µPa or 124 dB_{ht} (*Pp*) re 1µPa, which is 22 dB_{lin} and 33 dB_{ht} (*Pp*) louder, on average, than the remainder of the trial's noise levels. Although the time period in which the

AHD was detected only accounted for little more than 10% of the noise samples recorded in this trial, the average noise level (117 dB re 1µPa) was the highest recorded at this site. Also, the density plot (Appendix C) for this trial shows the highest densities over the broadest range of noise levels than any other month at this site. Similar AHDs have been reported to reach source levels greater than 180 dB re 1µPa at 1 m (Johnston 2002).

Unfortunately, due to equipment malfunction, porpoise presence data was not available during the time period that the AHD was active at Charlie's Cove. A similar study off Grand Manan in the Bay of Fundy, Canada, found that porpoise stayed 645 m away from an active AHD (Johnston 2002). Also in the Bay of Fundy, harbour porpoise bycatch was reduced 77% when less intense alarms (source level 133-145 dB re 1µPa) were activated, without compromising the catch rate of target fish species (Kraus *et al.* 1997, Trippel *et al.* 1999). In Retreat Passage, British Columbia, Canada, the activation of an AHD had an immediate and severe effect, displacing harbour porpoise to a distance of 200 m according to observational data (Olesiuk *et al.* 2002). Aquaculture operations, such as cleaning nets with high-pressure hoses, were also found to temporarily displace porpoise (Haarr *et al.* 2009). These examples demonstrate that harbour porpoise can be displaced by some high amplitude sounds.

Hearing structures in the mammalian ear may be temporarily or permanently injured through threshold shifts. A temporary threshold shift is defined as a decrease in hearing sensitivity of at least 6 dB (Southall *et al.* 2007). However, statistically significant decreases in hearing sensitivity have been found for a captive harbour porpoise at lesser amounts. When exposed to octave band white noise centered at 4kHz, temporary threshold shifts were observed at levels as low as 124 dB re 1µPa (Kastelein *et al.* 2012). The National Marine Fisheries Service (2003) has set an injury threshold for cetaceans at 180 dB_{rms} re 1µPa (Madsen *et al.* 2006). Levels this high were not observed in the current recordings.

When percent presence was statistically compared between the bottom and top 30% of noise samples, no differences were detected. This was true for both dB_{lin} and dB_{ht} (*Pp*) noise levels, and when the gap between low and high levels was increased (most extreme comparison involved the bottom and top 5% of noise samples). Also, porpoise were found to be present for noise levels as high as 150 dB_{lin} re 1µPa and 118 dB_{ht} (*Pp*) re 1µPa. Therefore, it is concluded that the moderate noise levels found at these industrial areas do not affect porpoise activity by displacing them from the area, however they may shift locations on small scales. Under spherical spreading conditions, sound levels drop by 40 dB over a distance of 100 m. This study cannot determine if such short range displacements of porpoise occurred. The porpoise could have been displaced a short distance from particularly high noise level sources, such as the LNG tanker Shagra.

An opportunistic case study occurred when the LNG tanker Shagra visited the LNG terminal while recording equipment was deployed. This case study shows the effect of tanker noise on porpoise activity at a much finer scale than the previous comparisons. The noise recording equipment and POD were positioned closest to the aft of the tanker, thus being subject to the highest level of propeller noise. However, it is important to note that the noise levels reported are not source levels. As can be seen in Figure 18, linear levels were much less variable during time periods of tanker presence than before and after its presence, due to the tanker masking lower ambient noise levels. This is also true for the dB_{ht} (*Pp*) noise levels but to a lesser extent, indicating the tanker is emitting noise in lower frequency 1/3 octave bands to which porpoise are less sensitive. However, the tanker must have been emitting broadband components which reached higher frequency 1/3 octave bands since average dB_{ht} (*Pp*) noise levels were higher when the tanker was present as compared to before or after. Average noise levels were highest (158 dB_{lin} re 1µPa, 122 dB_{ht} (*Pp*) re 1µPa) during docking of the tanker, which requires the use of 2-3 tugs. During this time period, the percent porpoise presence dropped to zero from the 30% presence that was observed before the tanker arrived. However, percent presence began to recover within 3 hr of this noise event, even though average noise levels remained fairly high (150-153 dB_{lin} re 1µPa, 113-118 dB_{ht} (*Pp*) re 1µPa). Fully loaded ships tend to produce higher noise levels than offloaded vessels (Richardson *et al.* 1995), which may be why noise levels during disembarking were lower than those during docking despite similar maneuvering.

Harbour porpoise are most sensitive to sounds in the 16-140 kHz range (Figure 1), with thresholds increasing by 10.7 dB per octave below 16 kHz (Terhune 2013). Since shipping noise is most intense between 20-300 Hz (Richardson *et al.* 1995), it is likely that porpoise would be somewhat insensitive to most ship noise.

It will be important to take the noise levels as perceived by harbour porpoise into account when assessing possible displacement related to anthropogenic noise disturbances. For humans, the C-weighting function (dB(C)) was developed to measure the broadband perception of high amplitude sound levels, and the A-weighting function (dB(A)) was developed to approximate lower sound levels as perceived by humans.

Southall *et al.* (2007) developed M-weighting functions for five marine mammal groups, which are analogous to C-weighting functions. Nedwell *et al.* (2007) developed the concept of dB_{ht} (*Species*) weighting, where ht stands for hearing threshold. This metric allows amplitudes to be reported as levels above the hearing threshold. Terhune (2013) applied this concept to the harbour porpoise (dB_{ht} (*Phocoena phocoena*)) by extrapolating known hearing thresholds below 250 Hz, standardizing to 0 dB at 20 kHz, and obtaining an equation with a 10.7 dB per octave slope. The purpose of the dB_{ht}(*Pp*) weighting function is to account for the frequency response of the harbour porpoise hearing system, and is analogous to A-weighting. The intention is to provide a practical metric of broadband noise perception that may be used by industry and government regulators.

Harbour porpoise were not completely displaced from these industrial areas due to underwater noise levels. The generalized threshold of 120 dB re 1µPa related to displacement (Southall *et al.* 2007) appears to be too conservative for this species. The noise levels at the four industrial areas reported herein were moderate enough as to not reach a general disturbance level for harbour porpoise. The potential displacement of a marine mammal species whose hearing is sensitive at lower frequencies will likely differ. Also, responses by marine mammals to noise disturbance are known to be highly variable due to a number of factors, such as individual variation, whether there is a perceived threat, or a benefit for being tolerant (Richardson *et al.* 1995, Ellison *et al.* 2011). It is also possible that porpoise are ecologically bound to these areas as income feeders, and so have no choice but to be chronically exposed to anthropogenic noise (Richardson *et al.* 1995).

Physiological effects may be occurring even though behavioural avoidance was not observed beyond the fine scale. It is possible that porpoise may be experiencing increased stress levels (Weilgart *et al.* 2007).Temporary threshold shifts may also be a concern, as their degree depend on duration of noise exposure in addition to the noise level (Kastelein *et al.* 2012). The long exposures to anthropogenic noise levels found herein may affect the hearing abilities of harbour porpoise.

The noise levels reported for these industrial areas of the Bay of Fundy are novel to the literature, and will be useful for future acoustic research and for industrial and government regulators concerned with noise pollution of developing waterways and coasts. Reporting these levels according to the frequency response of harbour porpoise hearing abilities will be useful for regulators so as to avoid setting noise level limits too conservatively.

Bibliography

Akamatsu, T., Teilmann, J., Miller, L.A., Tougaard, J., Dietz, R., Wang, D., Wang, K., Siebert, U., and Naito, Y. 2007. Comparison of echolocation behavior between coastal and riverine porpoises. Deep-Sea Research II 54: 290-297. doi:10.1016/j.dsr2.2006.11.006

American Cetacean Society. 2006. Harbor Porpoise (*Phocoena phocoena*) fact sheet. Accessed online 20 September 2011 at <acsonline.org>

Andersen, S. 1970. Auditory sensitivity of the harbour porpoise *Phocoena phocoena*. In *Investigations on Cetacea*, G. Pilleri eds. Institute for Brain Research, Bern. Vol. 2, pp. 225-259

Au, W.W.L., and Hastings, M.C. 2008. Principles of Marine Bioacoustics. Spinger Science+Business Media, LLC, New York, NY. ISBN-10: 0387783644

Bailey, G., Senior, B., Simmons, D., Rusin, J., Picken, G., and Thompson, P.M. 2010. Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals. Marine Pollution Bulletin 60: 888-897. doi:10.1016/j.marpolbul.2010.01.003

Brandt, M.J., Diederichs, A., Betke, K., and Nehls, G. 2011. Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. Marine Ecology Progress Series 421: 205-216. doi: 10.3354/meps08888

Carstensen, J., Henriksen, O.D., and Teilmann, J. 2006. Impacts of offshore wind farm construction on harbour porpoises: acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). Marine Ecology Progress Series 321: 296-308.

Castellote, M., Clark, C.W., and Lammers, M.O. 2012. Acoustic and behavioural changes by fin whales (*Balaenoptera physalus*) in response to shipping and airgun noise. Biological Conservation 147: 115-122. doi:10.1016/j.biocon.2011.12.021

Clark, C.W., Ellison, W.T., Southall, B.L., Hatch, L., van Parijs, S.M., Frankel, A., and Ponirakis, D. 2009. Acoustic masking in marine ecosystems: intuitions, analysis, and implication. Marine Ecology Progress Series 395: 201-222.

Cox, T.M., and Read, A.J. 2004. Echolocation behavior of harbor porpoises *Phocoena phocoena* around chemically enhanced gill nets. Marine Ecology Progress Series 279: 275-282.

Cox, T.M. 2001. Will harbour porpoises (*Phocoena phocoena*) habituate to pingers? Journal of Cetacean Research and Management 3(1): 81-86.

Dahne, M., Gilles, A., Luke, K., Peschko, V., Adler, S., Krügel, K., Sundermeyer, J., and Siebert, U. 2013. Effects of pile-driving on harbour porpoises (*Phocoena phocoena*) at the first offshore wind farm in Germany. Environmental Research Letters 8: 1-16. doi:10.1088/1748-9326/8/2/025002

Diederichs, A., Hennig, V., and Nehls, G. 2008. Investigations of the bird collision risk and the responses of harbour porpoises in the offshore wind farms Horns Rev, North Sea, and Nystead, Baltic Sea, in Denmark. Part II: Harbour porpoises. Final Report for the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Germany. pp. 15-34.

Dudzinski, K.M., Brown, S.J., Lammers, M., Lucke, K., Mann, D.A., Simard, P., Wall, C.C., Rasmussen, M.H., Magnúsdóttir, E.E., Tougaard, J., and Eriksen, N. 2011. Trouble-shooting deployment and recovery options for various stationary passive acoustic monitoring devices in both shallow-water and deep-water applications. Journal of the Acoustical Society of America 129(1): 436-448.

Ellison, W.T., Southall, B.L., Clark, C.W., and Frankel, A.S. 2011. A new context-based approach to assess marine mammal behavioral responses to anthropogenic sounds. Conservation Biology 26(1): 21-28. doi: 10.1111/j.1523-1739.2011.01803.x

Gaskin, D.E., Read, A.J., Watts, P.F., and Smith, G.J.D. 1985. Population dispersal, size, and interactions of harbour porpoises in the Bay of Fundy and Gulf of Marine. Canadian Technical Report of Fisheries and Aquatic Sciences No. 1291.

Gervaise, C., Simard, Y., Ray, N., Kinda, B., and Ménard, N. 2012. Shipping noise in whale habitat: Characteristics, sources, budget, and impact on belugas in Saguenay- St. Lawrence Marine Park hub. Journal of the Acoustical Society of America 132(1): 76-89.

Haarr, M.L., Charlton, L.D., Terhune, J.M., and Trippel, E.A. 2009. Harbour porpoise (*Phocoena phocoena*) presence patterns at an aquaculture cage site in the Bay of Fundy, Canada. Aquatic Mammals 35(2): 203-211. doi: 10.1578/AM.35.2.2009.203

Heide-Jørgensen, M.P., Iversen, M., Nielsen, N.H., Lockyer, C., Stern, H., and Ribergaard, M.H. 2011. Harbour porpoises respond to climate change. Ecology and Evolution 580-586. Open Access doi: 10.1002/ece3.51

Jacques Whitford Environmental Limited. 2004. Environmental Impact Statement: Liquefied Natural Gas Marine Terminal and Multi-Purpose Pier.

Johnson, S.C. 1967. Sound detection thresholds in marine mammals. In *Marine Bioacoustics*. W.N. Tavolga eds. Pergamon, New York. Vol. 2, pp. 247-260

Johnston, D.W. 2002. The effect of acoustic harassment devices on harbour porpoises (*Phocoena phocoena*) in the Bay of Fundy, Canada. Biological Conservation 108: 113-118.

Johnston, D.W., Westgate, A.J., and Read, A.J. 2005. Effects of fine-scale oceanographic features on the distribution and movements of harbour porpoises *Phocoena phocoena* in the Bay of Fundy. Marine Ecology Progress Series 295: 279-293.

Kastelein, R.A., Bunskoek, P., Hagedoorn, M., Au, W.W.L., and de Haan, D. 2002. Audiogram of a harbor porpoise (*Phocoena phocoena*) measured with narrow-band frequency-modulated signals. Journal of the Acoustical Society of America 112(1): 334-344. doi: 10.1121/1.1480835

Kastelein, R., Hoek, L., Jennings, N., de Jong, C., Terhune, J., and Dieleman, M. 2010. Acoustic Mitigation Devices (AMDs) to deter marine mammals from pile driving areas at sea: Audibility and behavioural response of a harbour porpoise and harbour seals. COWRIE Ref: SEAMAMD-09, Technical Report. ISBN 978-0-9565843-7-3

Kastelein, R.A., Grandier, R., Hoek, L., and de Jong, C.A.F. 2012. The hearing threshold of a harbor porpoise (*Phocoena phocoena*) for impulsive sounds. Journal of the Acoustical Society of America 132(2): 607-610.

Koblitz, J.C., Wahlberg, M., Stilz, P., Madsen, P.T., Beedholm, K., and Schnitzler, H.-U. 2012. Asymmetry and dynamics of a narrow sonar beam in an echolocating harbor porpoise. Journal of the Acoustical Society of America 131(3): 2315-2324. doi: 10.1121/1.3683254

Kraus, S.D., Read, A.J., Solow, A., Bladwin, K., Spradlin, T., Anderson, E., and Williamson, J. 1997. Acoustic alarms reduce porpoise mortality. Nature 388: 525.

Kyhn, L.A., Tougaard, J., Thomas, L., Duve, L.R., Stenback, J., Amundin, M., Desportes, G., and Teilmann, J. 2012. From echolocation clicks to animal density – Acoustic sampling of harbor porpoises with static dataloggers. Journal of the Acoustical Society of America. 131(1): 550-560. doi: 10.1121/1.3662070

Lucke, K., Siebert, U., Lepper, P.A., and Blanchet, M.-A. 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. Journal of the Acoustical Society of America 125(6): 4060-4070. doi: 10.1121/1.3117443

Lucke, K., Lepper, P.A., Blanchet, M.-A., and Siebert, U. 2011. The use of an air bubble curtain to reduce the received sound levels for harbor porpoises (*Phocoena phocoena*). Journal of the Acoustical Society of America 130(5): 3406-3412. doi: 10.1121/1.3626123

Madsen, P.T., Wahlberg, M., Tougaard, J., Lucke, K., and Tyack, P. 2006. Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. Marine Ecology Progress Series 309: 279-295.

McDonald, M.A., Hildebrand, J.A., and Wiggins, S.M. 2006. Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California. Journal of the Acoustical Society of America 120(2): 711-718. doi: 10.1121/1.2216565

McKenna, M.F., Katz, S.L., Wiggins, S.M., Ross, D., and Hildebrand, J.A. 2012. A quieting ocean: Unintended consequence of a fluctuating economy. Journal of the Acoustical Society of America 132(3): EL169-EL175.

National Marine Fisheries Service. 2003. Taking marine mammals incidental to conducting oil and gas exploration activities in the Gulf of Mexico. *In* Madsen, P.T., Wahlberg, M., Tougaard, J., Lucke, K., and Tyack, P. 2006. Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. Marine Ecology Progress Series 309: 279-295.

Neave, D.J., and Wright, B.S. 1968. Seasonal migrations of the harbor porpoise (*Phocoena phocoena*) and other cetaceans in the Bay of Fundy. Journal of Mammalogy 49(2): 259-264.

Nedwell, J., Workman, R., and Parvin, S.J. 2005. The assessment of likely levels of piling noise at Greater Gabbard and its comparison with background noise, including piling noise measurements made at Kentish Flats. *In* Tougaard J., Carstensen, J., Teilmann, J., Skov, H., and Rasmussen, P. 2009. Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (*Phocoena phocoena* (L.)) (L). Journal of the Acoustical Society of America 126(1): 11-14. doi: 10.1121/1.3132523

Nedwell, J.R., Turnpenny, A.W.H., Lovell, J., Parvin, S.J., Workman, R., Spinks, J.A.L., and Howell, D. 2007. A validation of the dB_{ht} as a measure of the behavioural and auditory effects of underwater noise. Subacoustech Ltd. Document Ref: 534R1232.

Nowacek, D.P., Thorne, L.H., Johnston, D.W., and Tyack, P.L. 2007. Responses of cetaceans to anthropogenic noise. Mammal Review 37: 81-115.

National Research Council (NRC). 2005. Marine mammal populations and ocean noise: Determining when noise causes biologically significant effects. National Academic Press.

Olesiuk, P.F., Nichol, L.M., Sowden, M.J., and Ford, J.K.B. 2002. Effect of the sound generated by an acoustic harassment device on the relative abundance and distribution of harbor porpoises (*Phocoena phocoena*) in Retreat Passage, British Columbia. Marine Mammal Science 18(4): 843-862.

Palka, D. 2000. Abundance of the Gulf of Maine/ Bay of Fundy harbor porpoise based on shipboard and aerial surveys during 1999. Northeast Fisheries Science Center Reference Document 00-07.

Parks, S.E., Urazghildiiev, I., and Clark, C.W. 2009. Variability in ambient noise levels and call parameters of North Atlantic right whales in three habitat areas. Journal of the Acoustical Society of America 125(2): 1230-1239. doi: 10.1121/1.3050282

R Development Core Team. 2005. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN: 3-900051-07-0 <http://www.R-project.org>

Read, A.J., and Westgate, A.J. 1997. Monitoring the movements of harbour porpoises (*Phocoena phocoena*) with satellite telemetry. Marine Biology 130: 315-322.

Richardson, W.J., Greene, Jr., C.R., Malme, C.I., and Thomson, D.H. 1995. Marine Mammals and Noise. Academic Press Inc., California. ISBN: 9780125884419

Rolland, R.M., Parks, S.E., Hunt, K.E., Castellote, M., Corkeron, P.J., Nowacek, D.P., Wasser, S.K., and Kraus, S.D. 2012. Evidence that ship noise increases stress in right whales. Proceedings of the Royal Society Biological Sciences. doi: 10.1098/rspb.2011.2429

Southall, B.L., Schusterman, R.J., and Kastak, D. 2003. Auditory masking in three pinnipeds: Aerial critical ratios and direct critical bandwidth measurements. Journal of the Acoustical Society of America 114(3): 1660-1666.

Southall, B.L., Bowles, A.E., Ellison, W.T., Finneran, J.J., Gentry, R.L., Greene, Jr., C.R., Kastak, D., Ketten, D.R., Miller, J.H., Nachtigall, P.E., Richardson, W.J., Thomas, J.A., and Tyack, P.L. 2007. Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals 33(4): 411-509. ISSN 0167-5427

Terhune, J.M. 2013. A practical weighting function for harbor porpoise underwater sound level measurements. Journal of the Acoustical Society of America. In press.

Thompson, P.M., Lusseau, D., Barton, T., Simmons, D., Rusin, J., and Bailey, H. 2010. Assessing the responses of coastal cetaceans to the construction of offshore wind turbines. Marine Pollution Bulletin 60: 1200-1208. doi:10.1016/j.marpolbul.2010.03.030

Todd, V.L.G., Pearse, W.D., Tregenze, N.C., Lepper, P.A., and Todd, I.B. 2009. Diel echolocation activity of harbour porpoises (*Phocoena phocoena*) around North Sea offshore gas installations. Open Access article: 734-745.

Tollit, D., Wood, J., Broome, J., and Redden, A. 2011. Detection of marine mammals and effects monitoring at the NSPI (OpenHydro) turbine site in the Minas Passage during 2010. Final report prepared for Fundy Ocean Research Centre for Energy (FORCE).

Tougaard, J., and Henriksen, O.D. 2009. Underwater noise from three types of offshore wind turbines: Estimation of impact zones for harbor porpoises and harbor seals. Journal of the Acoustical Society of America 125(6): 3766-3773.

Tougaard, J., Poulsen, L.R., Amundin, M., Larsen, F., Rye, J., and Teilmann, J. 2006. Detection function of T-PODs and estimation of porpoise densities. *In* Tollit, D., Wood, J., Broome, J., and Redden, A. 2011. Detection of marine mammals and effects monitoring at the NSPI (OpenHydro) turbine site in the Minas Passage during 2010. Final report prepared for Fundy Ocean Research Centre for Energy (FORCE).

Tougaard, J., Carstensen, J., Teilmann, J., Skov, H., and Rasmussen, P. 2009. Pile driving zone of responsiveness extends beyond 20 km for harbor porpoises (*Phocoena phocoena* (L.)) (L). Journal of the Acoustical Society of America 126(1): 11-14. doi: 10.1121/1.3132523

Trippel, E.A., Strong, M.B., Terhune, J.M., and Conway, J.D. 1999. Mitigation of harbour porpoise (*Phocoena phocoena*) by-catch in the gillnet fishery in the lower Bay of Fundy. Canadian Journal of Fisheries and Aquatic Sciences 56: 113-123.

Tyack, P.L., Zimmer, W.M.X., Moretti, D., Southall, B.L., Claridge, D.E., Durban, J.W., Clark, C.W., D'Amico, A., DiMarzio, N., Jarvis, S., McCarthy, E., Morrissey, R., Ward, J., and Boyd, I.L. 2011. Beaked whales respond to simulated and actual Navy Sonar. PLoS ONE 6(3): e17009. doi:10.1371/journal.pone.0017009

Verfuβ, U.K., Miller, L.A., and Schnitzler, H.-U. 2005. Spatial orientation in echolocation harbour porpoises (*Phocoena phocoena*). The Journal of Experimental Biology 208: 3385-3394. doi:10.1242/jeb.01786

Weilgart, L.S. 2007. The impacts of anthropogenic ocean noise on cetaceans and implications for management. Canadian Journal of Zoology 85: 1091-1116. doi:10.1242/jeb.01786

MarineTraffic: Shagra. Accessed on 27 February 2013 at <marinetraffic.com>

Yuen, M.M.L., Nachtigall, P.E., Breese, M., and Supin, A.Y. 2005. Behavioral and auditory evoked potential audiograms of a false killer whale (*Pseudorca crassidens*). Journal of the Acoustical Society of America 118(4): 2688-2695. doi: 10.1121/1.2010350

Appendix A: Calibrations

Automatic Recording Devices (ARDs) were calibrated with multiple hydrophones to aid direct comparisons. Three constructed ARDs (Black, Orange, Grey) were paired with five hydrophones (Vemco Ltd., Nova Scotia, model VLHT). The hydrophones were identified by their colour-coding and length: Long Green, Long Red, Short Red/White, Short Red/Yellow, Short Red/Green/White. Two commercial ARDs (Wildlife Acoustics Inc, Massachusetts, Song Meter SM2+ firmware version 3.1.9) with built-in hydrophones (8 m and 30 m long) were included in the calibrations.

Many sources of variation exist within the recording systems, including the sensitivity of the hydrophone, the cable length, the computer sound card settings, and the variable resistor of the hydrophone impedance matching device. The entire system using all ARD-hydrophone combinations was calibrated as a single unit to include all of these variables.

Underwater ambient pressure has no effect on received levels since the hydrophone is a pressure detector, allowing it to be used in both air and water. The source levels during calibration were received in-air (dB re 20µPa), and therefore needed to be adjusted to the underwater reference pressure (1µPa) by adding 26 dB. Using the NoiseLAB program (v 3.0) and the accompanying NoiseLAB Batch Processor (v 3.1), 1/3 octave band levels relative to the adjusted in-air sound levels were determined, and used as calibration readings.

Setup

Four hydrophones (Vemco Ltd., Nova Scotia, model VLHT), the two Wildlife Acoustic (WA8m and WA30m), and a calibration hydrophone (Sensor Tech Ltd. SQ31-02) were hung side-by-side from a horizontal bar approximately one meter above a desktop. The fifth hydrophone (Long Red) was used in the field between October 2011 and April 2012, but ceased functioning properly between December 2011 and April 2012. Therefore, levels from a previous calibration session were used (December 2011). The hydrophone cables were extended to a distance approximating what was used in the field to avoid an electric field being produced by wound cable. The variable resistor of the impedance matching device was set to approximately the same level for the constructed Automatic Recording Devices (ARDs), and the computer and Ishmael (v 2.0) program setting were also standardized. All ARD and analysis equipment settings remained constant throughout the recording and calibration procedures.

A sound field was created with speakers facing the far end of a large room so that echoes may dissipate before reaching the hydrophones multiple times. Two loudspeaker systems were used to output a signal, depending on the signal frequency. An Eminence 7442 subwoofer (38.5 cm diameter) was used to output 1/3 octave signals from 0.025-1 kHz, and a five-speaker box (1.5 m long, housing 18 cm diameter speakers) was used to output signals from 1-20 kHz. In all cases, the signals were produced by a Tabor Electronics 50 Ms/s waveform generator, and were amplified by a Brüel and Kjær Type 2706 power amplifier. The waveform generator had a modulating function which frequency modulated the sinusoidal signals at 40 Hz to help eliminate standing waves.

A Gould 20 MHz Digital Storage OS1420 oscilloscope was used to visualize the signal waveform and approximate the wavelength variation of each signal. The sample click deviation of the waveform generator was increased from 10 Ks/s at 25 Hz to 2,000 Ks/s at 20 kHz to maintain a proportional frequency modulation range for each 1/3 octave frequency band.

1 kHz Calibration

A 1/3 octave 1 kHz signal was received by the calibration hydrophone, the Wildlife Acoustic ARDs, and the five hydrophones rotated with each of the three constructed ARDs. A sound level meter was placed next to the hydrophones to read the received level. This was 95.5 dB re 20μPa at 1 kHz. Adding 26 dB provided the received level in reference to underwater pressure, 121.5 dB re 1μPa.

The 1/3 octave root-mean-square (rms) sound levels between 0.02 and 16 kHz were output from NoiseLAB. The frequency responses of the subwoofer and five-speaker box were calculated in reference to 1 kHz, and applied to the sound levels of each ARD-hydrophone pair (Table A 1). The 0 dB amplitudes for the 1 kHz one-third octave band for each ARD-hydrophone pair was then determined in relation to 121.5 dB re 1μPa.

Table A 1. Sound levels (dB on NoiseLAB) for each 1/3 octave between 0.025 and 16 kHz relative to 121.5 dB re 1μPa at 1 kHz for three constructed Automatic Recording Devices (ARD; Grey, Orange, Black), paired with five hydrophones (LG Long Green, LR Long Red, SRW Short Red/White, SRY Short Red/Yellow, and SRGW Short Red/Green/White), and two commercial ARDs (WA8m and WA30m) with built-in hydrophones.

	Grey					**Orange**					**Black**					**WA8m**	**WA30m**
	LG	**LR**	**SRW**	**SRY**	**SRGW**	**LG**	**LR**	**SRW**	**SRY**	**SRGW**	**LG**	**LR**	**SRW**	**SRY**	**SRGW**	**Built-in**	**Built-in**
25	2.27	8.25	-10.75	3.62	-7.54	3.64	-4.15	-11.92	2.73	-8.44	15.61	6.35	-0.01	16.88	3.68	33.38	3.96
31.5	16.51	22.49	3.91	17.19	6.28	17.88	10.09	2.74	16.30	5.38	29.85	20.59	14.65	30.45	17.50	38.04	7.64
40	15.75	21.73	3.39	14.23	14.90	17.12	9.33	2.22	13.34	14.00	29.09	19.83	14.13	27.49	26.12	46.75	13.69
50	52.17	58.15	19.76	53.80	37.88	53.54	45.75	18.59	52.91	36.98	65.51	56.25	30.50	67.06	49.10	56.73	17.39
63	75.76	81.74	35.95	77.37	48.59	77.13	69.34	34.78	76.48	47.69	89.10	79.84	46.69	90.63	59.81	64.33	28.47
80	53.04	59.02	31.65	53.50	51.44	54.41	46.62	30.48	52.61	50.54	66.38	57.12	42.39	66.76	62.66	58.23	42.57
100	47.20	53.18	29.59	48.93	50.31	48.57	40.78	28.42	48.04	49.41	60.54	51.28	40.33	62.19	61.53	51.39	33.65
125	47.04	53.02	34.49	51.23	52.21	48.41	40.62	33.32	50.34	51.31	60.38	51.12	45.23	64.49	63.43	47.68	40.03
160	58.43	64.41	45.22	60.99	52.84	59.80	52.01	44.05	60.10	51.94	71.77	62.51	55.96	74.25	64.06	52.96	41.86
200	61.75	67.73	48.82	64.32	52.11	63.12	55.33	47.65	63.43	51.21	75.09	65.83	59.56	77.58	63.33	49.52	39.13
250	49.51	55.49	49.26	52.69	57.66	50.88	43.09	48.09	51.80	56.76	62.85	53.59	60.00	64.95	68.88	49.35	38.75
315	50.45	56.43	52.27	54.10	55.19	51.82	44.03	51.10	53.21	54.29	63.79	54.53	63.01	67.36	66.41	50.11	41.15
400	48.68	54.66	57.65	52.15	61.46	50.05	42.26	56.48	51.26	60.56	62.02	52.76	68.39	65.41	72.68	47.46	43.32
500	50.69	56.67	50.33	53.96	55.21	52.06	44.27	49.16	53.07	54.31	64.03	54.77	61.07	67.22	66.43	49.69	36.21
630	52.22	58.20	54.55	54.25	57.77	53.59	45.80	53.38	53.36	56.87	65.56	56.30	65.29	67.51	68.99	49.85	43.58
800	43.27	49.25	47.21	51.55	51.52	44.64	36.85	46.04	50.66	50.62	56.61	47.35	57.95	64.81	62.74	48.33	42.38
1000	43.12	49.10	46.23	49.28	49.42	44.49	36.70	45.06	48.39	48.52	56.46	47.20	56.97	62.54	60.64	43.32	36.06
1250	49.02	55.00	51.56	51.52	53.55	50.39	42.60	50.39	50.63	52.65	62.36	53.10	62.30	64.78	64.77	47.04	42.48
1600	49.13	55.11	51.29	50.83	53.33	50.50	42.71	50.12	49.94	52.43	62.47	53.21	62.03	64.09	64.55	50.68	42.19
2000	45.91	51.89	45.21	47.93	49.59	47.28	39.49	44.04	47.04	48.69	59.25	49.99	55.95	61.19	60.81	44.20	39.05
2500	36.80	42.78	35.72	37.66	36.92	38.17	30.38	34.55	36.77	36.02	50.14	40.88	46.46	50.92	48.14	36.79	31.40
3150	48.56	54.54	42.78	46.56	47.25	49.93	42.14	41.61	45.67	46.35	61.90	52.64	53.52	59.82	58.47	40.64	32.27
4000	34.72	40.70	41.82	35.97	42.30	36.09	28.30	40.65	35.08	41.40	48.06	38.80	52.56	49.23	53.52	38.32	34.53
5000	45.34	51.32	42.45	48.34	47.23	46.71	38.92	41.28	47.45	46.33	58.68	49.42	53.19	61.60	58.45	47.89	42.29
6300	41.47	47.45	41.95	41.97	50.76	42.84	35.05	40.78	41.08	49.86	54.81	45.55	52.69	55.23	61.98	40.08	36.43
8000	35.41	41.39	38.09	34.17	37.23	36.78	28.99	36.92	33.28	36.33	48.75	39.49	48.83	47.43	48.45	38.72	33.79
10000	18.67	24.65	21.43	16.20	17.30	20.04	12.25	20.26	15.31	16.40	32.01	22.75	32.17	29.46	28.52	17.14	24.40
12500	-11.54	-5.56	-16.10	-5.17	-5.54	-10.17	-17.96	-17.27	-6.06	-6.44	1.80	-7.46	-5.36	8.09	5.68	-12.49	-14.70
16000	-14.88	-8.90	-13.89	-14.71	-8.41	-13.51	-21.30	-15.06	-15.60	-9.31	-1.54	-10.80	-3.15	-1.45	2.81	-18.97	-21.18

Frequency Response

Four of the hydrophones were rotated with the Grey ARD, and a 30 second recording was taken for each 1/3 octave signal between 0.025 and 16 kHz. WA8m and WA30m hydrophones were recording concurrently. In-air received levels for each 1/3 octave band was measured by comparing the received levels of the calibration hydrophone on a Marantz recorder (PMD 671) to the hydrophone's calibration data. This provided the sound levels presented to the hydrophone array. Sound levels for the Grey ARD-hydrophone pairs and the WA systems were then adjusted by these received levels to obtain equal sound levels in each 1/3 octave band.

Received 1/3 octave sound levels for the other two ARDs (Orange and Black; Table A 2) were then calculated according to the frequency response of each hydrophone, obtained from the Grey ARD recordings (after the addition of the speaker frequency responses). Note that the Long Green hydrophone was not properly connected to the Grey ARD during the 800 Hz signal recording, and so the sound level was averaged between the 630 and 1000 Hz levels. Also, the WA8m 16 kHz recording was undistinguishable from background noise levels, and so the sound level could not be measured in NoiseLAB. This sound level was calculated by taking the difference seen between the WA8m and WA30m 12.5 kHz level, and adding it to the WA30m 16kHz level. The Long Red hydrophone 1 kHz level from a previous calibration session was used as a starting point, then the frequency response of the Long Green hydrophone was applied to determine received levels of the other 1/3 octave bands. The Long Green hydrophone was used under the assumption that their similar lengths would dictate a similar frequency response.

Table A 2. Frequency response (dB) of each hydrophone (LG Long Green, LR Long Red, SRW Short Red/White, SRY Short Red/Yellow, SRGW Short Red/Green/White) relative to 1 kHz after adjustment for speaker frequency response.

	LG	LR	SRW	SRY	SRGW	WA8m	WA30m
25	-40.85	-40.85	-56.98	-45.66	-56.96	-9.94	-32.10
31.5	-26.61	-26.61	-42.32	-32.09	-43.14	-5.28	-28.42
40	-27.37	-27.37	-42.84	-35.05	-34.52	3.43	-22.37
50	9.05	9.05	-26.47	4.52	-11.54	13.41	-18.67
63	32.64	32.64	-10.28	28.09	-0.83	21.01	-7.59
80	9.92	9.92	-14.58	4.22	2.02	14.91	6.51
100	4.08	4.08	-16.64	-0.35	0.89	8.07	-2.41
125	3.92	3.92	-11.74	1.95	2.79	4.36	3.97
160	15.31	15.31	-1.01	11.71	3.42	9.64	5.80
200	18.63	18.63	2.59	15.04	2.69	6.20	3.07
250	6.39	6.39	3.03	3.41	8.24	6.03	2.69
315	7.33	7.33	6.04	4.82	5.77	6.79	5.09
400	5.56	5.56	11.42	2.87	12.04	4.14	7.26
500	7.57	7.57	4.10	4.68	5.79	6.37	0.15
630	9.10	9.10	8.32	4.97	8.35	6.53	7.52
800	0.15	0.15	0.98	2.27	2.10	5.01	6.32
1000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1250	5.90	5.90	5.33	2.24	4.13	3.72	6.42
1600	6.01	6.01	5.06	1.55	3.91	7.36	6.13
2000	2.79	2.79	-1.02	-1.35	0.17	0.88	2.99
2500	-6.32	-6.32	-10.51	-11.62	-12.50	-6.53	-4.66
3150	5.44	5.44	-3.45	-2.72	-2.17	-2.68	-3.79
4000	-8.40	-8.40	-4.41	-13.31	-7.12	-5.00	-1.53
5000	2.22	2.22	-3.78	-0.94	-2.19	4.57	6.23
6300	-1.65	-1.65	-4.28	-7.31	1.34	-3.24	0.37
8000	-7.71	-7.71	-8.14	-15.11	-12.19	-4.60	-2.27
10000	-24.45	-24.45	-24.80	-33.08	-32.12	-26.18	-11.66
12500	-54.66	-54.66	-62.33	-54.45	-54.96	-55.81	-50.76
16000	-58.00	-58.00	-60.12	-63.99	-57.83	-62.29	-57.24

The 0 dB amplitudes for each 1/3 octave band between 0.2 and 16 kHz for each ARD-hydrophone pair were then determined in relation to 121.5 dB re 1µPa (Table A 3). Final amplitudes were calculated by adding the calibration values for the respective

ARD-hydrophone pair to levels recorded in the field, and then adjusting for the frequency response of respective hydrophone.

Table A 3. Calibration values (0 dB in NoiseLAB = x dB re 1µPa) for each 1/3 octave between 0.025 and 16 kHz for three constructed Automatic Recording Devices (ARD; Grey, Orange, Black), paired with five hydrophones (LG Long Green, LR Long Red, SRW Short Red/White, SRY Short Red/Yellow, and SRGW Short Red/Green/White), and two commercial ARDs (WA8m and WA30m) with built-in hydrophones.

	Grey					**Orange**					**Black**					**WA8m**	**WA30m**
	LG	**LR**	**SRW**	**SRY**	**SRGW**	**LG**	**LR**	**SRW**	**SRY**	**SRGW**	**LG**	**LR**	**SRW**	**SRY**	**SRGW**	**Built-in**	**Built-in**
25	119.23	113.25	132.25	117.88	129.04	117.86	125.65	133.42	118.77	129.94	105.89	115.15	121.51	104.62	117.82	88.12	117.54
31.5	104.99	99.01	117.59	104.31	115.22	103.62	111.41	118.76	105.20	116.12	91.65	100.91	106.85	91.05	104.00	83.46	113.86
40	105.75	99.77	118.11	107.27	106.60	104.38	112.17	119.28	108.16	107.50	92.41	101.67	107.37	94.01	95.38	74.75	107.81
50	69.33	63.35	101.74	67.70	83.62	67.96	75.75	102.91	68.59	84.52	55.99	65.25	91.00	54.44	72.40	64.77	104.11
63	45.74	39.76	85.55	44.13	72.91	44.37	52.16	86.72	45.02	73.81	32.40	41.66	74.81	30.87	61.69	57.17	93.03
80	68.46	62.48	89.85	68.00	70.06	67.09	74.88	91.02	68.89	70.96	55.12	64.38	79.11	54.74	58.84	63.27	78.93
100	74.30	68.32	91.91	72.57	71.19	72.93	80.72	83.08	73.46	72.09	60.96	70.22	81.17	59.31	59.97	70.11	87.85
125	74.46	68.48	87.01	70.27	69.29	73.09	80.88	88.18	71.16	70.19	61.12	70.38	76.27	57.01	58.07	73.82	81.47
160	63.07	57.09	76.28	60.51	68.66	61.70	69.49	77.45	61.40	69.56	49.73	58.99	65.54	47.25	57.44	68.54	79.64
200	59.75	53.77	72.68	57.18	69.39	58.38	66.17	73.85	58.07	70.29	46.41	55.67	61.94	43.92	58.17	71.98	82.39
250	71.99	66.01	72.24	68.81	63.84	70.62	78.41	73.41	69.70	64.74	58.65	57.91	61.50	55.55	52.62	72.15	82.75
315	71.05	65.07	69.23	67.40	66.31	69.68	77.47	70.40	68.29	67.21	57.71	66.97	58.49	54.14	55.09	71.39	80.35
400	72.82	66.84	63.85	69.35	60.04	71.45	79.24	65.02	70.24	60.94	59.48	68.74	53.11	56.09	48.82	74.04	78.18
500	70.81	64.83	71.17	67.54	66.29	69.44	77.23	72.34	68.43	67.19	57.47	66.73	60.43	54.28	55.07	71.81	85.29
630	69.28	63.30	66.95	67.25	63.73	67.91	75.70	68.12	68.14	64.63	55.94	65.20	56.21	53.99	52.51	71.65	77.92
800	78.23	72.25	74.29	69.95	69.98	76.86	84.65	75.46	70.84	70.88	64.89	74.15	63.55	56.69	58.76	73.17	79.12
1000	78.38	72.40	75.27	72.22	72.08	77.01	84.80	76.44	73.11	72.98	65.04	74.30	64.53	58.96	60.86	78.18	85.44
1250	72.48	66.50	69.94	69.98	67.95	71.11	78.90	71.11	70.87	68.85	59.14	68.40	59.20	56.72	56.73	74.46	79.02
1600	72.37	66.39	70.21	70.67	68.17	71.00	78.79	71.38	71.56	69.07	59.03	68.29	59.47	57.41	56.95	70.82	79.31
2000	75.59	69.61	76.29	73.57	71.91	74.22	82.01	77.46	74.46	72.81	62.25	71.51	65.55	60.31	60.69	77.30	82.45
2500	84.70	78.72	85.78	83.84	84.58	83.33	91.12	86.95	84.73	85.48	71.36	80.62	75.04	70.58	73.36	84.71	90.10
3150	72.94	66.96	78.72	74.94	74.25	71.57	79.36	79.89	75.83	75.15	59.60	68.86	67.98	61.68	63.03	80.86	89.23
4000	86.78	80.80	79.68	85.53	79.20	85.41	93.20	80.85	86.42	80.10	73.44	82.70	68.94	72.27	67.98	83.18	86.97
5000	76.16	70.18	79.05	73.16	74.27	74.79	82.58	80.22	74.05	75.17	62.82	72.08	68.31	59.90	63.05	73.61	79.21
6300	80.03	74.05	79.55	79.53	70.74	78.66	86.45	80.72	80.42	71.64	66.69	75.95	68.81	66.27	59.52	81.42	85.07
8000	86.09	80.11	83.41	87.33	84.27	84.72	92.51	84.58	88.22	85.17	72.75	82.01	72.67	74.07	73.05	82.78	87.71
10000	102.83	96.85	100.07	105.30	104.20	101.46	109.25	101.24	106.19	105.10	89.49	98.75	89.33	92.04	92.98	104.36	97.10
12500	133.04	127.06	137.60	126.67	127.04	131.67	139.46	138.77	127.56	127.94	119.70	128.96	126.86	113.41	115.82	133.99	136.20
16000	136.38	130.40	135.39	136.21	129.91	135.01	142.80	136.56	137.10	130.81	123.04	132.30	124.65	122.95	118.69	140.47	142.68

Appendix B: Noise level adjustments to dB_{ht} (*Phocoena phocoena*)

Linear noise levels were adjusted according to harbour porpoise hearing thresholds. The dB_{ht} (*Species*) concept was proposed by Nedwell *et al.* (2007), and was developed for the harbour porpoise by Terhune (2013). Specifically, hearing thresholds were estimated for frequencies below 250 Hz as an audiogram had not been measured below this frequency (Kastelein *et al.* 2002). Using three audiograms, an equation with a 10.7 dB per octave slope was developed:

$$dB = 46.4 - 35.6 \log (kHz)$$

This equation provided the dB value to be subtracted from the linear 1/3 octave level at each frequency (Table B 1).

Table B 1. Frequency-specific decibel (dB) losses when adjusted for harbour porpoise hearing thresholds (dB_{ht} (*Phocoena phocoena*)).

Frequency (Hz)	dB to be subtracted	Frequency (Hz)	dB to be subtracted
100	82.00	1250	42.95
125	78.55	1600	39.13
160	74.73	2000	35.68
200	71.28	2500	32.23
250	67.83	3150	28.66
315	64.26	4000	24.97
400	60.57	5000	21.52
500	57.12	6300	17.94
630	53.54	8000	14.25
800	49.85	10000	10.80
1000	46.40	12500	7.35
		16000	3.53

Appendix C: Supplemental Figures

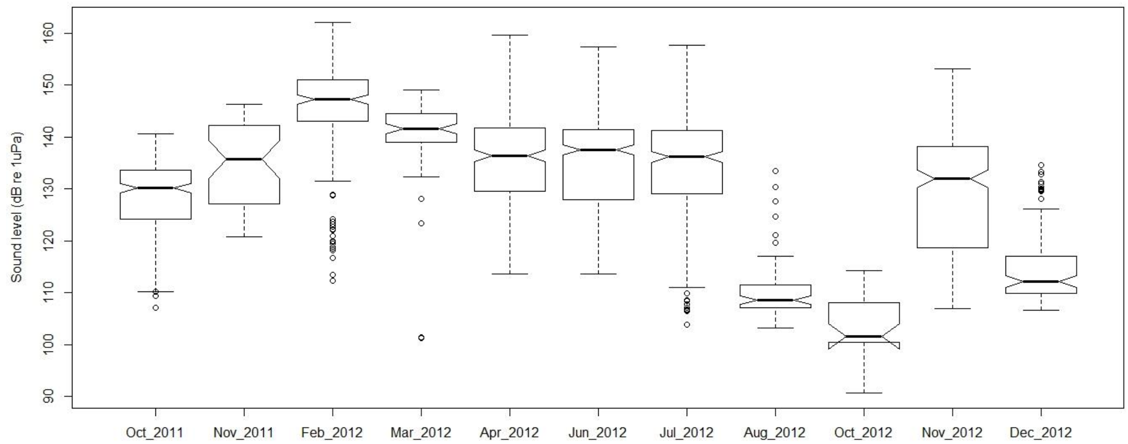

Figure C 1. Boxplot of broadband (0.1-16 kHz) sound levels (dB_{lin} re 1μPa) recorded from October 2011 to December 2012 at the Liquefied Natural Gas (LNG) terminal. Bold lines illustrate the medians, notches are defined as 1/√n and denote significant differences, boxes are lower and upper quartiles, tails are the minimum and maximums, and circles identify outliers.

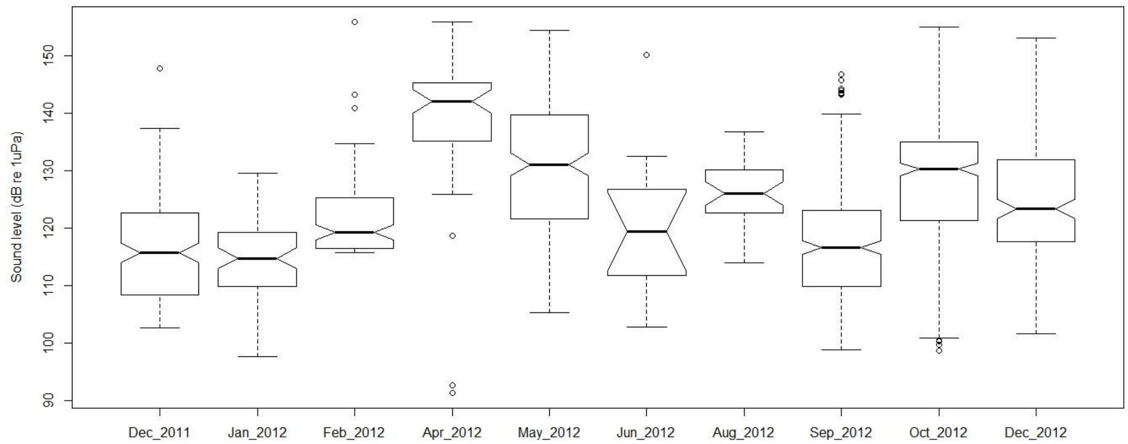

Figure C 2. Boxplot of broadband (0.1-16 kHz) sound levels (dB_{lin} re 1µPa) recorded from December 2011 to December 2012 at the Saint John Harbour (SJH) site. Bold lines illustrate the medians, notches are defined as $1/\sqrt{n}$ and denote significant differences, boxes are lower and upper quartiles, tails are the minimum and maximums, and circles identify outliers.

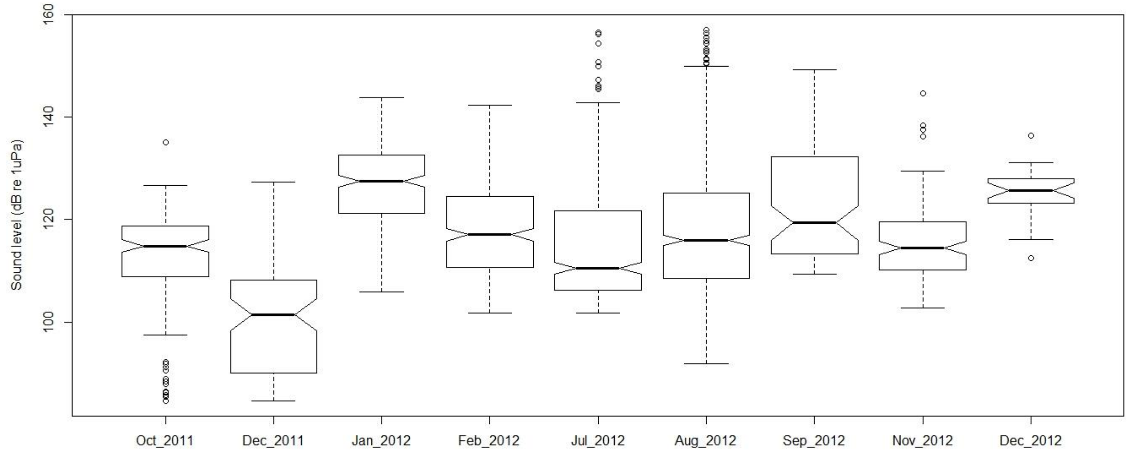

Figure C 3. Boxplot of broadband (0.1-16 kHz) sound levels (dB_{lin} re 1µPa) recorded from October 2011 to December 2012 at the Seeley's Cove (SC) aquaculture site. Bold lines illustrate the medians, notches are defined as $1/\sqrt{n}$ and denote significant differences, boxes are lower and upper quartiles, tails are the minimum and maximums, and circles identify outliers.

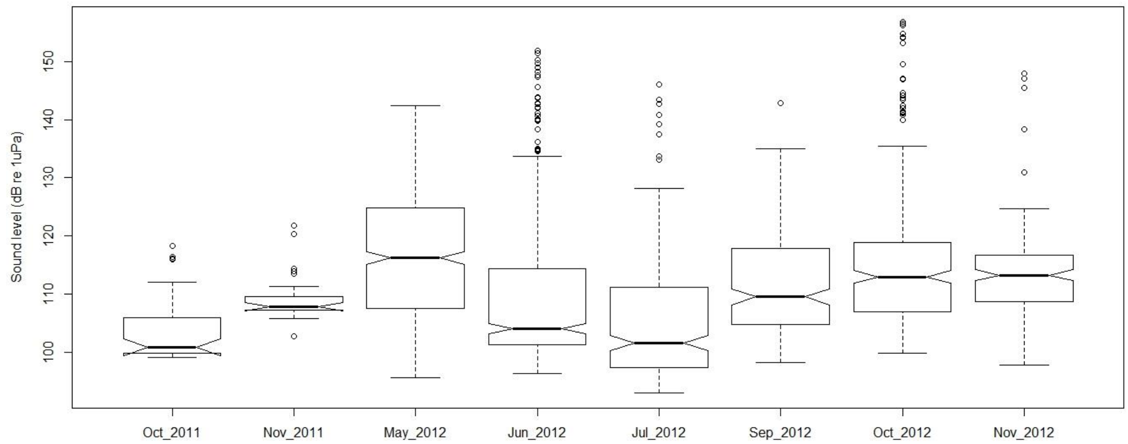

Figure C 4. Boxplot of broadband (0.1-16 kHz) sound levels (dB_{lin} re 1µPa) recorded from October 2011 to November 2012 at the Charlie's Cove (CC) aquaculture site. Bold lines illustrate the medians, notches are defined as 1/√n and denote significant differences, boxes are lower and upper quartiles, tails are the minimum and maximums, and circles identify outliers.

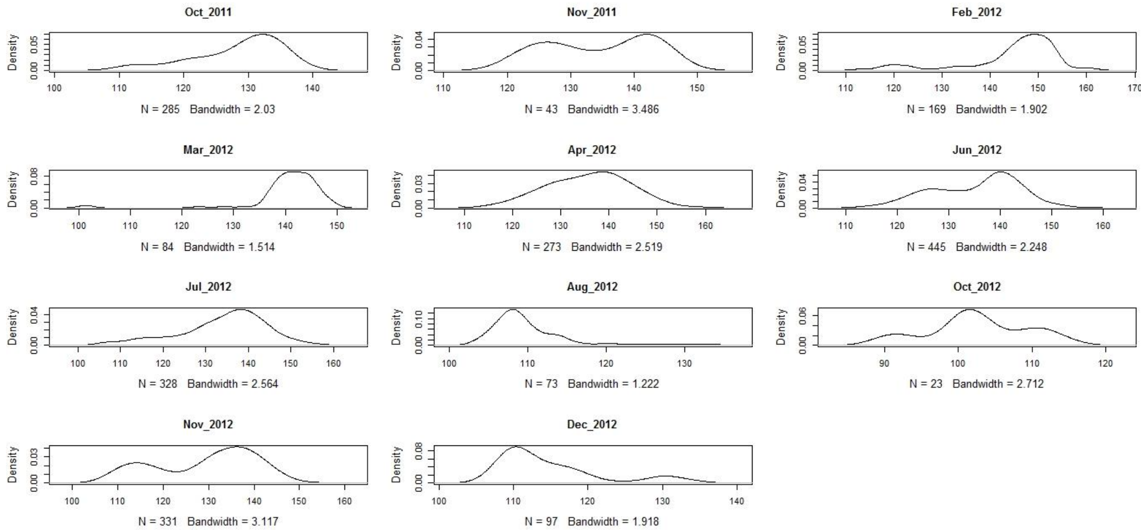

Figure C 5. Kernel density plot of broadband (0.1-16 kHz) sound levels (dB_{lin} re 1µPa) recorded from October 2011 to December 2012 at the Liquefied Natural Gas (LNG) terminal.

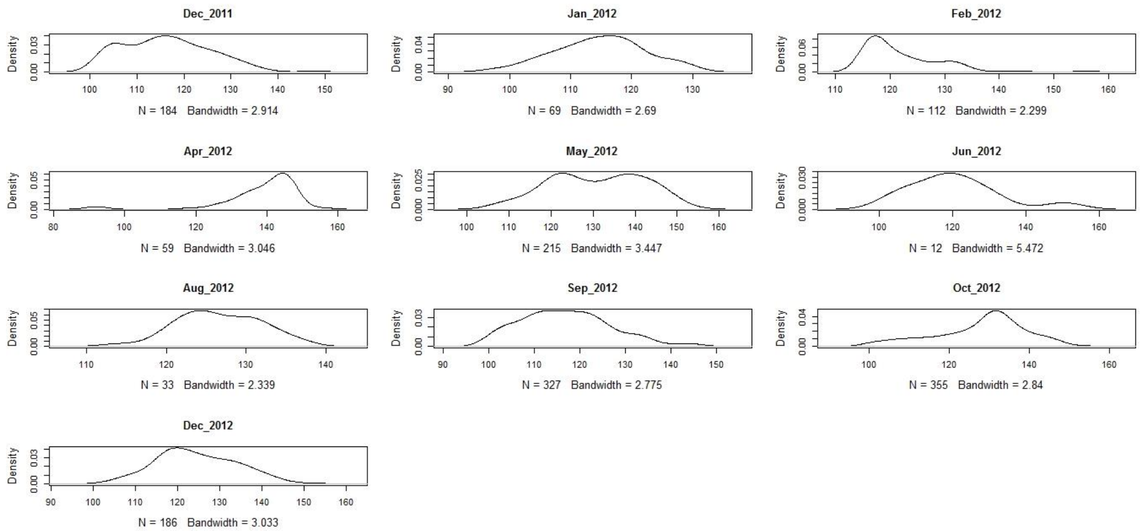

Figure C 6. Kernel density plot of broadband (0.1-16 kHz) sound levels (dB_{lin} re 1μPa) recorded from December 2011 to December 2012 at the Saint John Harbour (SJH) site.

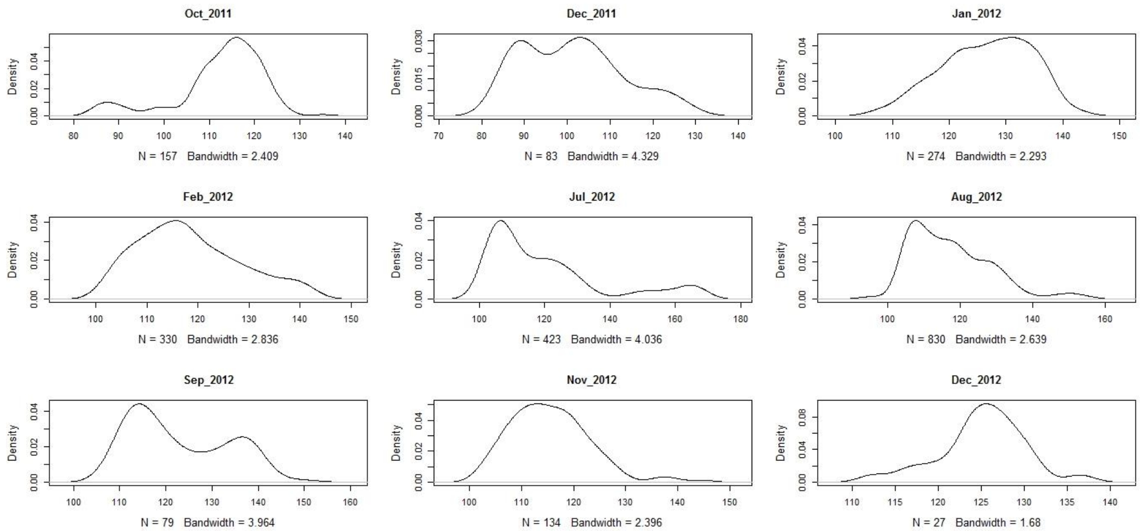

Figure C 7. Kernel density plot of broadband (0.1-16 kHz) sound levels (dB_{lin} re 1µPa) recorded from October 2011 to December 2012 at the Seeley's Cove (SC) aquaculture site.

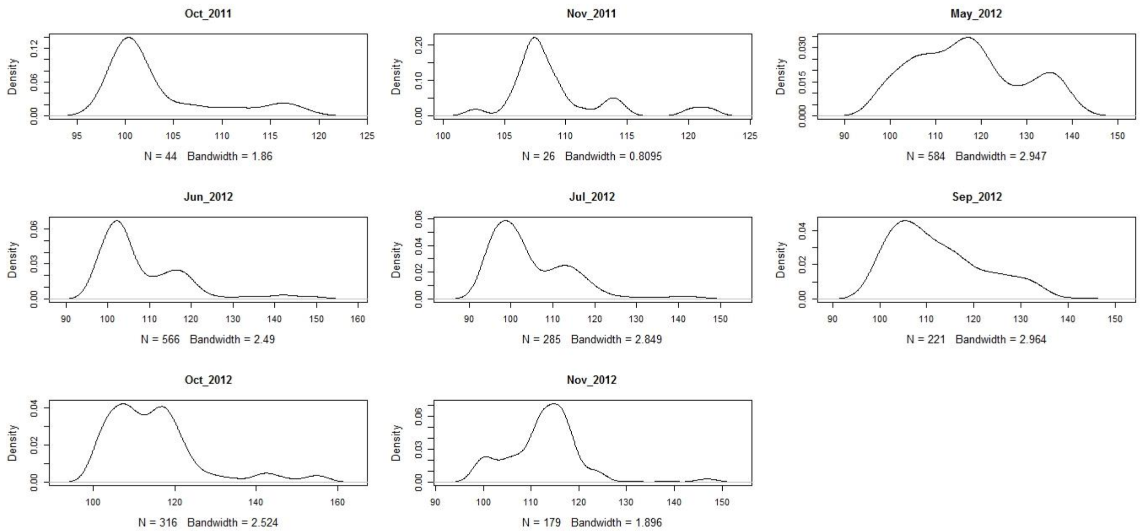

Figure C 8. Kernel density plot of broadband (0.1-16 kHz) sound levels (dB_{lin} re 1µPa) recorded from October 2011 to November 2012 at the Charlie's Cove (CC) aquaculture site.

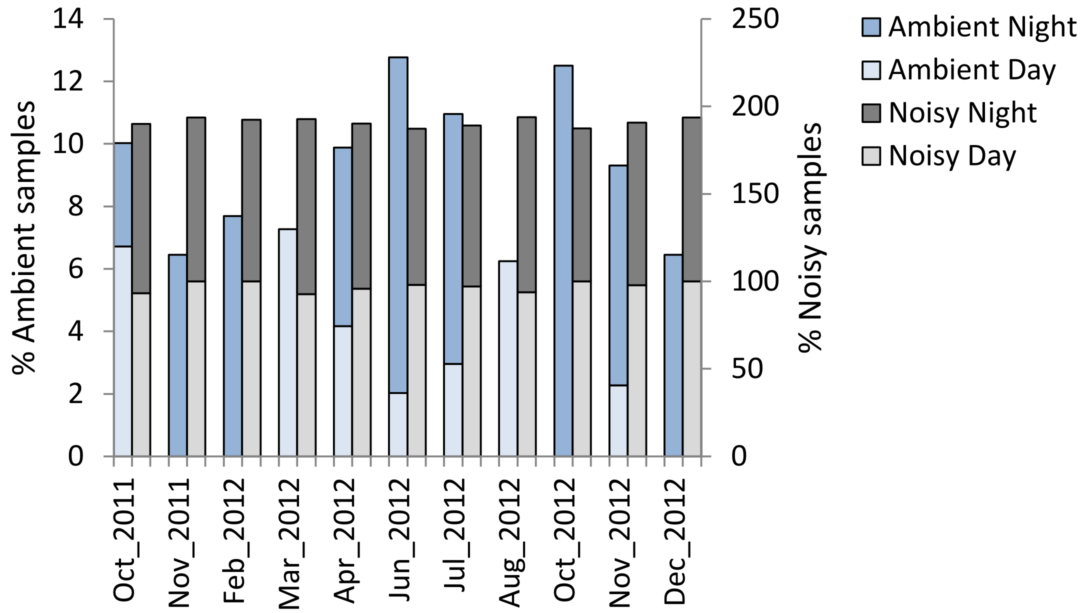

Figure C 9. Percentage of Ambient and Noisy samples during the Day and Night in each trial between October 2011 and December 2012 at the Liquefied Natural Gas (LNG) terminal.

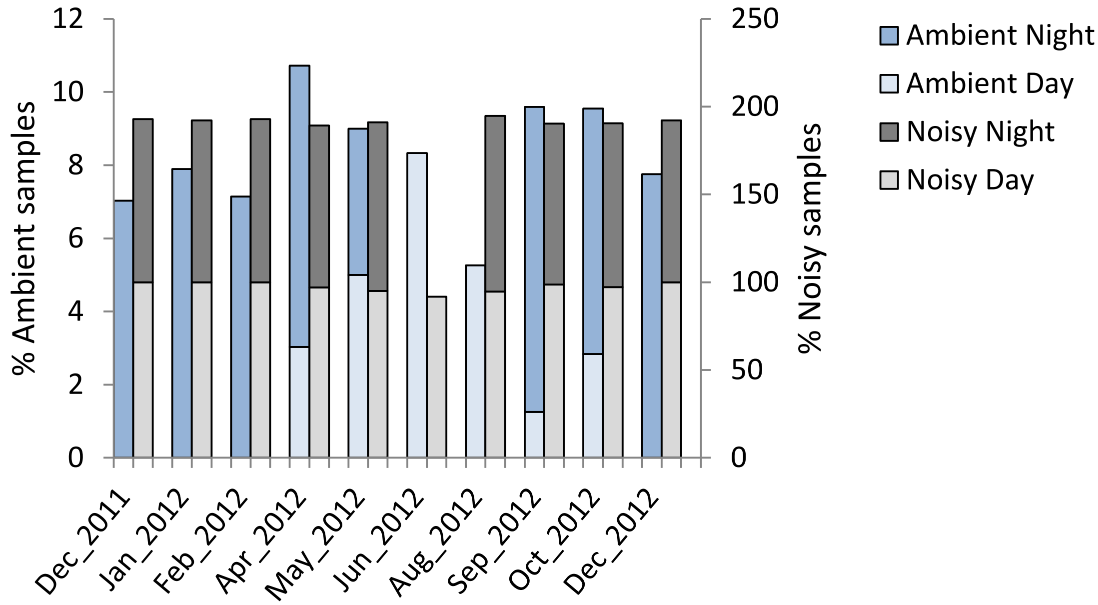

Figure C 10. Percentage of Ambient and Noisy samples during the Day and Night in each trial between December 2011 and December 2012 at the Saint John Harbour (SJH) site.

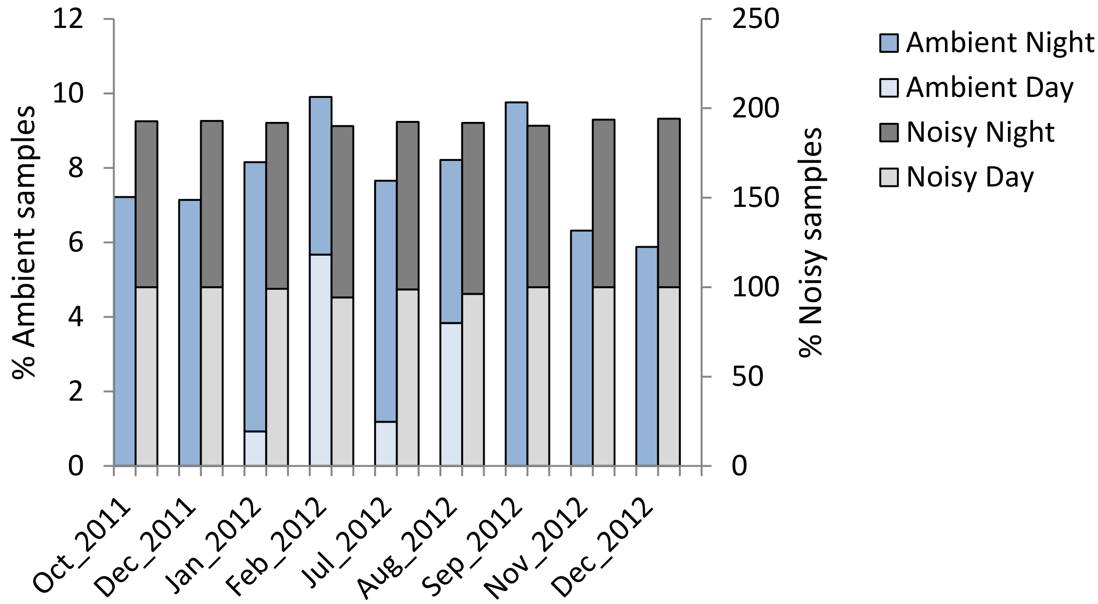

Figure C 11. Percentage of Ambient and Noisy samples during the Day and Night in each trial between October 2011 and December 2012 at the Seeley's Cove (SC) aquaculture site.

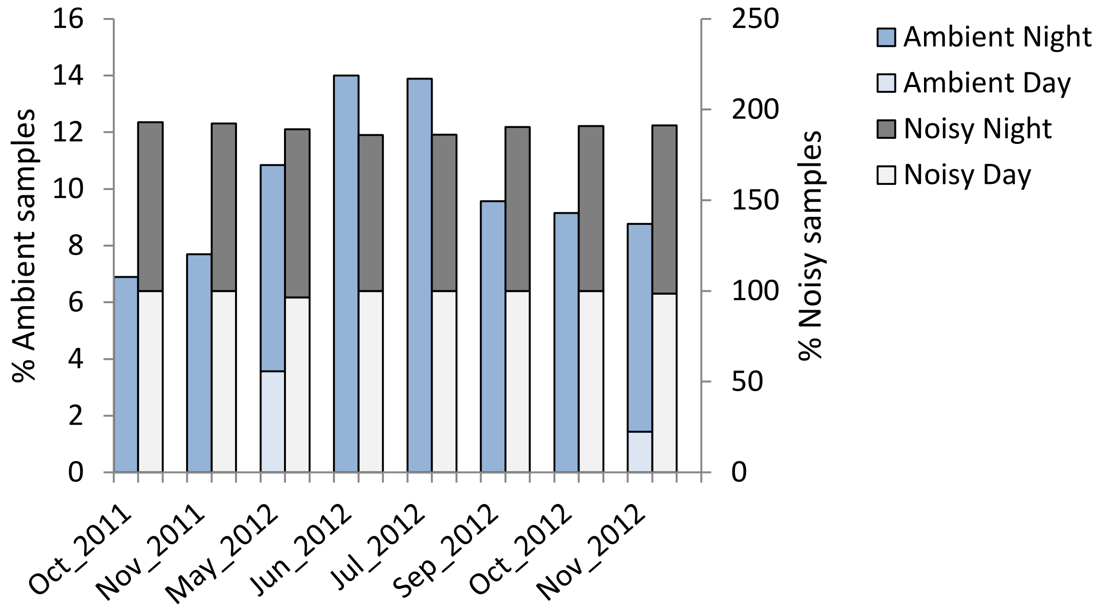

Figure C 12. Percentage of Ambient and Noisy samples during the Day and Night in each trial between October 2011 and November 2012 at the Charlie’s Cove (CC) aquaculture site.

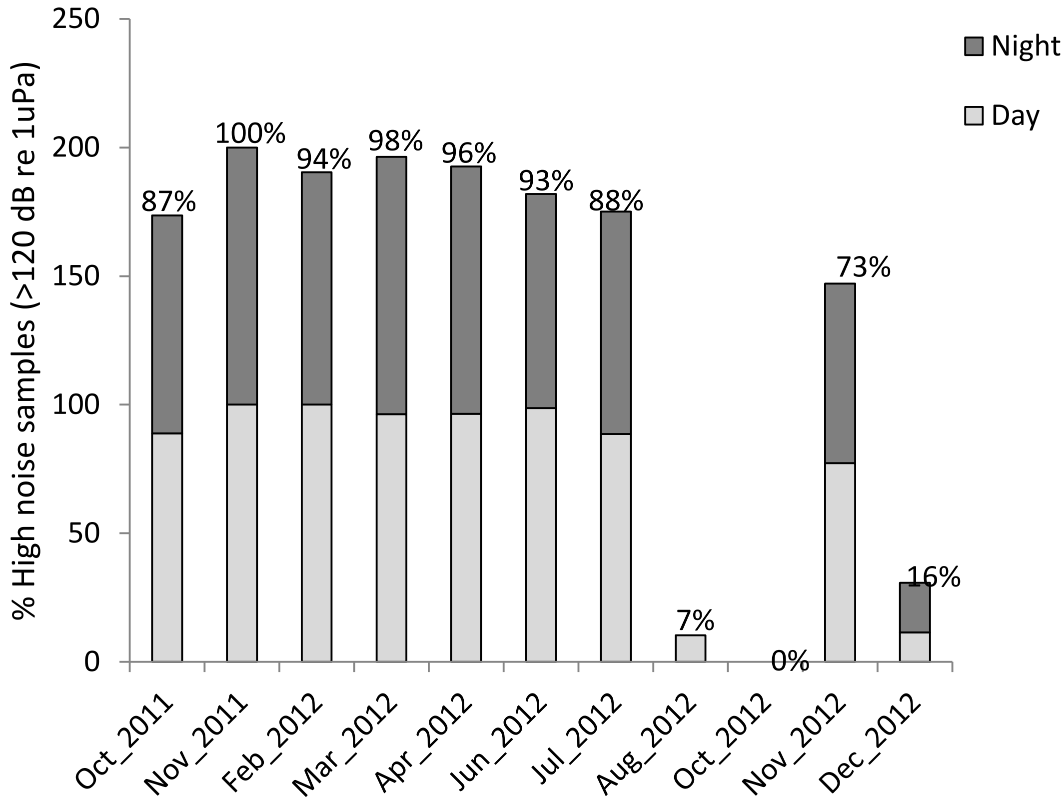

Figure C 13. Percentage of High noise (> 120 dB_{lin} re 1μPa) samples during the Day and Night in each trial between October 2011 and December 2012 recorded at the Liquefied Natural Gas (LNG) terminal. Percentages above bars denote total percent of high noise samples.

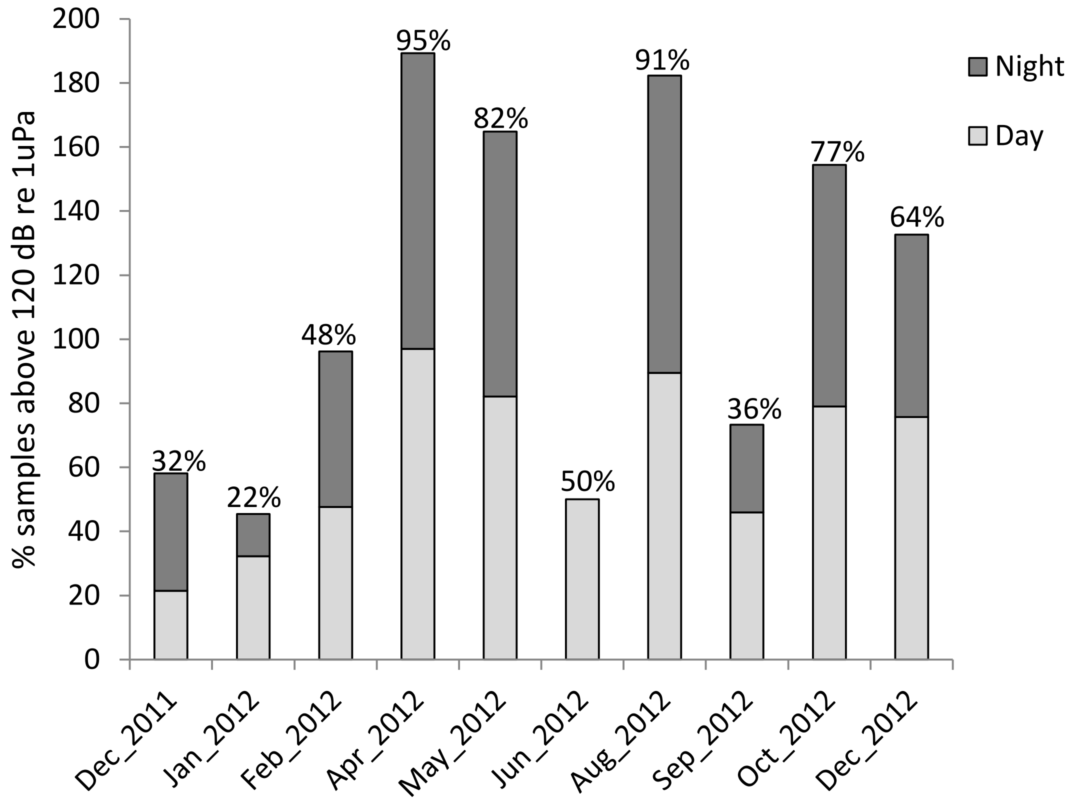

Figure C 14. Percentage of High noise (> 120 dB_{lin} re 1µPa) samples during the Day and Night in each trial between December 2011 and December 2012 recorded at the Saint John Harbour (SJH) site. Percentages above bars denote total percent of high noise samples.

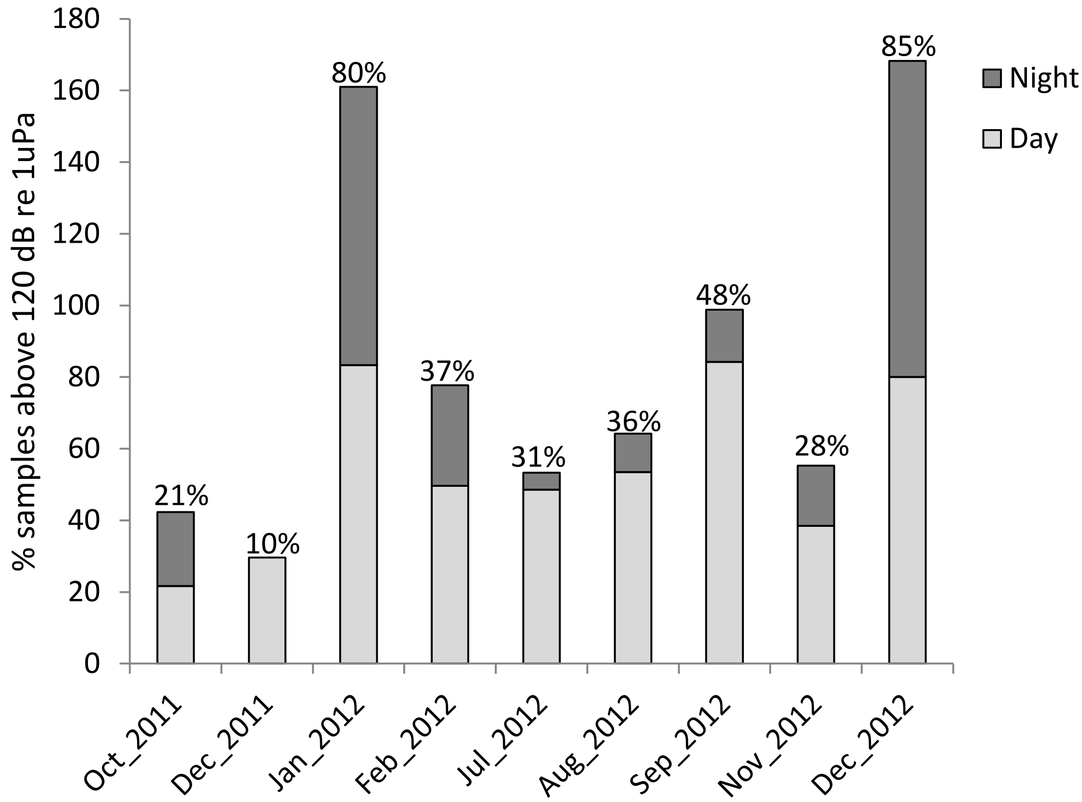

Figure C 15. Percentage of High noise (> 120 dB_{lin} re 1µPa) samples during the Day and Night in each trial between October 2011 and December 2012 recorded at the Seeley's Cove (SC) aquaculture site. Percentages above bars denote total percent of high noise samples.

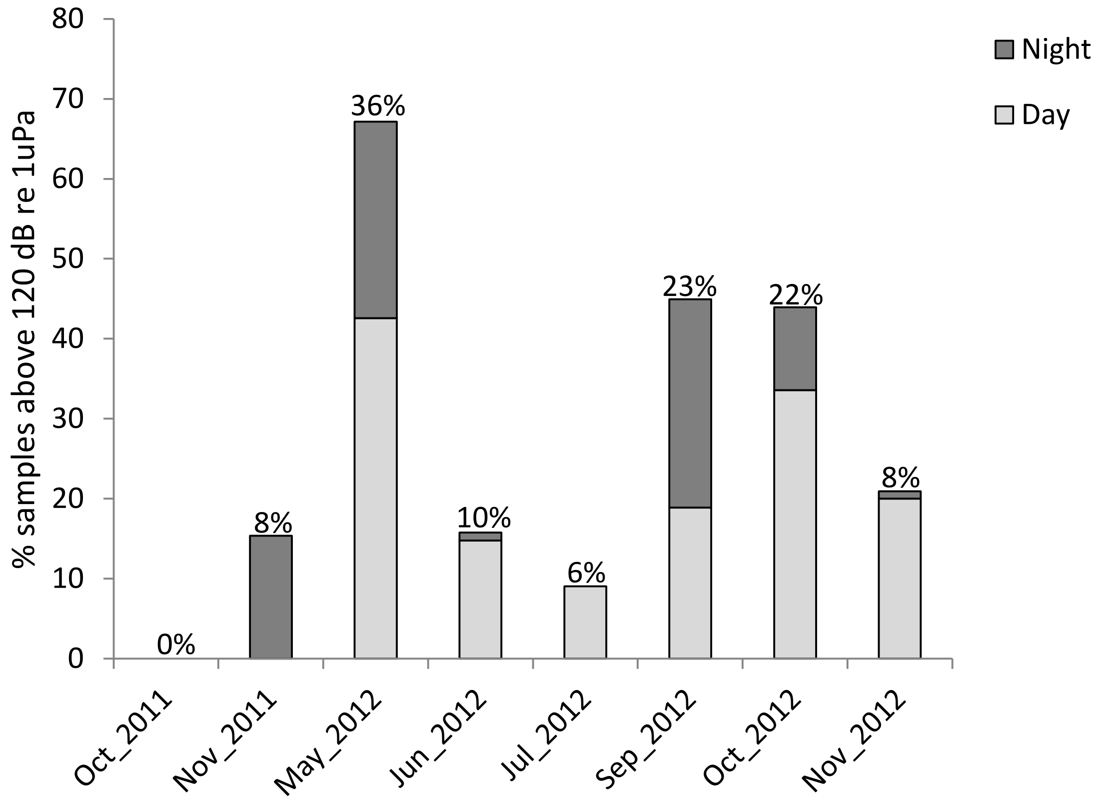

Figure C 16. Percentage of High noise (> 120 dB_{lin} re 1µPa) samples during the Day and Night in each trial between October 2011 and November 2012 recorded at the Charlie's Cove (CC) aquaculture site. Percentages above bars denote total percent of high noise samples.

Curriculum Vitae

Amanda Babin (nee. Mackenzie)

Mount Allison University (2005-2009, B.Sc. Honours)

Publications:

Mackenzie, A.B. 2011. Biological Synopsis of the Compound Sea Squirt *Diplosoma listerianum*. Can. Man. Rep. Fish. Aquat. Sci. issue no. 2966.

Mackenzie, A.B. 2011. Biological Synopsis of the Light Bulb Tunicate *Clavelina lepadiformis*. Can. Man. Rep. Fish. Aquat. Sci. issue no. 2967.

Mackenzie, A.B. 2011. Biological Synopsis of the European Sea Squirt *Ascidiella aspersa*. Can. Man. Rep. Fish. Aquat. Sci. issue no. 2968.

Conference Presentations:

A.Babin. 19th annual Graduate Research Conference. April 27th 2012. University of New Brunswick, Fredericton NB. [Oral Presentation]

A.Babin. 1st Annual Conference of the New England Student Chapter of the Society of Marine Mammology. April 20th 2012. University of Southern Maine, Portland ME. [Oral Presentation]

Dr. Catherine Hood, Amanda Mackenzie and Kraig Babin. 2011. Engaging Fishermen in Right Whale Stewardship in Southwestern New Brunswick. Fundy North Fishermen's Association in collaboration with LFA 36 fishermen. Completed with support from the Habitat Stewardship Program for Species at Risk (2010HSP5510). CURA Coastal People and Places conference. Saint Mary's University, Halifax, NS, June 2011. [Poster Presentation]

A.Mackenzie and R. Aiken. Examining encounter rates of the nudibranch *Onchidoris biamellata* (L.) in relation to Mosimann random motion and Search Theory models. Atlantic Canada Coastal and Estuarine Science Society Conference. St. Andrews, NB, May 2010. [Poster Presentation]

A.Mackenzie, R. Aiken. Examining encounter rates of the nudibranch *Onchidoris biamellata* (L.) in relation to Mosimann random motion and Search Theory models. 8th Bay of Fundy Ecosystem Partnership. Wolfville, NS, May 2009. [Oral Presentation]

A.Mackenzie and R. Aiken. Examining encounter rates of the nudibranch *Onchidoris biamellata* (L.) in relation to Mosimann random motion and Search Theory models. Northeast Undergraduate Research and Development Symposium. University of New England, ME, Mar 2009. [Oral Presentation]