Environmental Effects Monitoring Program

Quarterly Report: April - June 2018

June 29th, 2018

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Executive Summary

The Fundy Ocean Research Center for Energy (FORCE) is Canada's leading research centre for the demonstration and evaluation of tidal in-stream energy conversion (TISEC) technology. This technology (commonly known as "in-stream tidal turbines") is part of an emerging sector designed to generate electricity from the ebb and flow of the tide. It also has application in river systems and has the potential to introduce another non-carbon emitting source of electricity to the Nova Scotia electrical grid.

The first demonstration in-stream tidal energy turbine was operational at the FORCE site for a short time in 2009 and removed in 2010. There had been no turbines present at FORCE until Cape Sharp Tidal Venture (CSTV) deployed a two-megawatt demonstration turbine in November 2016 and began a commissioning process. This turbine was disconnected in April 2017 and recovered in June 2017. CSTV is intending to re-deploy a second improved and more efficient two-megawatt demonstration turbine at the FORCE site in summer 2018. Additional deployments by other FORCE berth holders are scheduled to follow CSTV; however, firm dates have not yet been provided, and turbine-specific monitoring programs will be developed and submitted to regulators for review.

Baseline studies began at FORCE in 2009 and Environmental Effects Monitoring Programs (EEMPs) were implemented in 2016; to-date, over 90 tidal-related research studies have been completed or are underway with funding from FORCE and the Offshore Energy Research Association (OERA). This EEMP consists of mid-field monitoring activities (100 m - 1000 m from the turbine) that are led by FORCE, and near-field monitoring activities (< 100 m) that are led by individual developers, or 'berth holders.'

FORCE's mid-field EEMP has continued in 2018. The design and completion of data collection and analysis is being conducted with academic and research partners, including the Nexus Coastal Resource Management (Halifax, NS), University of Maine (Orono, Maine, USA), the Sea Mammal Research Unit Consulting (Canada) (Vancouver, BC), Envirosphere Consultants (Windsor, NS), Acadia University (Wolfville, NS), Luna Ocean Consulting (Shad Bay & Freeport, NS), JASCO Applied Science (Dartmouth, NS), Ocean Sonics (Great Village, NS), and GeoSpectrum Technologies Inc. (Dartmouth, NS)

A near-field EEMP was initiated by CSTV in 2016 upon turbine deployment and was conducted throughout the operation period from November 2016 to April 2017. The 2016/2017 program focused on marine mammals, fish, and turbine sound. Data analysis was led by Ocean Sonics, JASCO Applied Sciences, Acadia University (Acadia Center for Estuarine Research), and Tritech Ltd. (Aberdeenshire, United Kingdom)

This report provides a summary of monitoring and data analysis completed at the FORCE site by both FORCE and CSTV up to the second quarter of 2018 (April 1st – June 30th, 2018). CSTV does not currently have a turbine deployed (the next deployment date is planned for later in 2018);

however, an update on the 2018 EEMP planning and an operational update for CSTV is provided in Appendix 1.

Since the commencement of the latest monitoring programs at the FORCE site in 2016, FORCE has completed approximately 336 hours of hydroacoustic fish surveys, 1,800 'C-POD days,'[1] bi-weekly shoreline observations, 35 observational seabird surveys, four drifting marine noise surveys, and 11 days of lobster surveys using 48 traps. In addition, CSTV has undergone turbine sound monitoring, and early monitoring of fish and marine mammals. Lessons learned from that first deployment, around monitoring devices, and data transfer and analyses, has been implemented into the updated EEMP for 2018.

Lobster monitoring: FORCE's Lobster EEMP consists of a lobster catchability study in collaboration with NEXUS Coastal Resource Management. The goal of this study is to measure whether the presence of a turbine affects the number of lobsters entering traps. Commercial lobster traps are used to compare catch volumes in different proximity to the turbine location.

A catchability study was completed at the FORCE site in October - November 2017, while no turbine was deployed. This study provides baseline catchability rates in the absence of a turbine.

Initial results indicate that catchability rates are high in the FORCE site, with catch rates ranging from 1.00-20.17 kg trap^{-1}. Catch rates declined slightly during the study period, likely in relation to increasing tidal velocities. The survey design consists of two concentric rings that increase in distance from where the turbine was located in 2016-2017. Preliminary qualitative analyses indicated that there were no differences between treatment rings, or with direction from the turbine location (North, East, South, West).

The next lobster catchability study will take place in October-November 2018, to coincide with the timing of the survey completed in 2017. The 2018 survey is contingent on the presence of a turbine at the site, which is needed to fully evaluate the effects of in-stream tidal turbines on lobster catchability rates.

Fish monitoring: Surveys have been completed using a downward facing hydro-acoustic echosounder to describe and quantify fish distributional changes that reflect behavioural responses to the presence of a deployed turbine. Results to date have shown that the density of fish at turbine height was highly variable across tidal stage, time of year, and location within the FORCE site. Preliminary findings suggest no significant effect of the turbine on the density of fish in the mid-field of the turbine or on fish vertical distributions, but more data collection during additional turbine deployments is needed evaluate impacts to fish. A report outlining these preliminary findings can be found in FORCE's 2017 annual report, located at: www.fundyforce.ca/environment/monitoring

This work continued in 2018 with a survey completed February 15th – 16th, April 10th – 11th, and May 8th - 9th to coincided with the operation of a subsea platform configured with similar

[1] 'C-POD days' refers to the number of days total each individual C-POD was deployed and collecting data.

instrumentation known as 'FAST-3.' An additional survey was completed June 7th - 8th after recovery of the FAST-3 platform on May 23rd.

Berth holder fish monitoring: With no turbines presently deployed at the FORCE site, there are no updates to provide on data collection and analysis related to fish in the near-field environment. CSTV, in preparation for the next deployment, is working on the development of an updated 2018 monitoring program that will incorporate lessons learned and recommendations from the 2016/2017 deployment in relation to monitoring fish in the near-field using a Gemini sonar device on the turbine structure. The 2018 monitoring program will also include the incorporation of a supplemental program for fish monitoring using a subsea cabled platform, the Fundy Advanced Sensor Technology – Environmental Monitoring System (FAST-EMS). In partnership with FORCE, CSTV has been performing tests of the FAST-EMS platform during Q2 to refine marine operations, ensure data transfer, and test the capabilities of the set-up and the monitoring instrumentation.

Marine mammal monitoring: The goal of the near-field and mid-field marine mammal monitoring programs is to detect changes in the distribution of marine mammals (predominately harbour porpoise at the FORCE site) in relation to operational in-stream turbines.

In collaboration with the Sea Mammal Research Unit (SMRU Consulting), FORCE monitors marine mammal presence using C-PODS deployed on a near-continuous basis in the mid-field of the turbine location. Initial results provide no evidence of permanent avoidance in the mid-field of the turbine, but there was a temporary decline in detection rates post turbine installation (41-46%), likely due to vessel activity. Tidal height was a more important factor in driving variation in porpoise abundance, with a 12-fold greater impact on detection rate than the presence of the turbine. A report outlining these preliminary findings can be found in FORCE's 2017 Annual Report, located at: www.fundyforce.ca/environment/monitoring.

In 2018, five C-PODs were recovered in January and redeployed two weeks later following a period of annual maintenance. During this time, beacons were added to aid with re-location in the event of premature resurfacing. All five C-PODs were recovered in early May and re-deployed following battery replacement to coincide with fish tagging efforts in the Gaspereau and Shubenacadie Rivers.

In addition, FORCE has continued its beach walk and public observation program for marine mammals.

Berth holder marine mammal monitoring: With no turbines presently deployed at the FORCE site, there are no updates to provide on data collection and analysis related to marine mammals in the near-field environment. However, in preparation for the next deployment, CSTV is working on the development of an updated 2018 monitoring program that will incorporate lessons learned and recommendations from the 2016/2017 deployment in relation to monitoring of marine mammals in the near-field using icListen hydrophones mounted on the turbine rotor and on the subsea base. The 2018 monitoring program will also include the incorporation of a supplemental program for fish monitoring using a subsea cabled platform, the Fundy Advanced Sensor Technology – Environmental Monitoring System (FAST-EMS). In partnership with FORCE, CSTV has been performing tests of the FAST-EMS platform during Q2 to refine marine operations, ensure data transfer, and test the capabilities of the set-up and the monitoring instrumentation.

Seabird monitoring: The main objectives of the mid-field seabird monitoring program are to obtain site-specific species abundance and behaviour data, which can be used to establish whether the presence of a turbine causes displacement of surface-visible seabirds and marine mammals from habitual waters and to identify changes in behaviour. Initial results show seasonal peaks in water-associated birds in spring and fall, consistent with known migratory patterns of species of loons, cormorants, gulls, waterfowl, and alcids. Initial results suggest no significant effect of turbine operations on seabird abundance. Eight surveys have been completed to-date in 2018, increasing the total number since 2016 to 35.

Sound monitoring: The goal of the sound monitoring program is to measure both ambient (in the immediate surroundings) and operational sound generated by in-stream turbines to understand the potential effects on marine life. An analysis completed by JASCO Applied Sciences that considered data collected from multiple hydrophones in and around the FORCE demonstration site concluded that turbine-produced sound could be audible at certain frequencies detectable by fish and porpoise; however, data collection during additional turbine deployments is needed to more fully characterize sounds from the turbine and verify predictions that sounds from in-stream turbines have minimal impacts on marine life.

Berth holder sound monitoring: With no turbines presently deployed at the FORCE site, there are no updates to provide on data collection and analysis related to operational sound in the near-field environment. However, finalization of analysis of the data collected during 2016/2017 was completed in Q2 with the objective of providing a clear description of the sound produced by the turbine relative to ambient (i.e., background) sound. This report has been attached as Appendix 3.

In preparation for the next deployment, CSTV is developing the scope for a new sound monitoring program, which will include the deployment of an acoustic (sound) recorder prior to deployment to capture additional baseline sound of the ambient environment in the area of the CSTV deployment site (Berth D). The updated 2018 monitoring program will incorporate the lessons learned and recommendations from the 2016/2017 deployment in relation to monitoring of turbine sound in the near-field.

Other activities: Independent of EEM programs, FORCE also conducts and supports additional research efforts, including fish tagging efforts in collaboration with Acadia University and Ocean Tracking Network, radar projects, and subsea instrument platform deployments through the Fundy Advanced Sensor Technology (FAST) program.

The FAST-EMS ('Environmental Monitoring System') platform is currently in trials to test directional sensors to collect data from a specific target, including the face of a turbine. Sensors currently include a Tritech Gemini imaging sonar, dynamic mount to position the sonar, and subsea cabling to allow for real-time data collection. Testing began March 22nd and continued periodically in Q2 2018 between the FORCE beach and Black Rock.

The FAST-3 platform underwent two 2-month deployments thus far in 2018. This subsea platform contains two hydroacoustic sonars and various environmental sensors to monitor fish densities in the mid-field of the turbine. FORCE will complete a comparative analysis of data collected by bottom (FAST-3) and ship-mounted hydroacoustic sonars (used as part of FORCE's fish EEMP) to evaluate the spatial and temporal representativeness of both instrument configurations and determine the degree to which results are corroborative. This project is supported by the Offshore Energy Research Association, the Province of Nova Scotia, and Natural Resources Canada.

Final reports prepared by EEMP contractors are published on FORCE's (www.fundyforce.ca/environment) and CSTV's website (www.capesharptidal.com) following review by FORCE's independent Environmental Monitoring Advisory Committee and regulators.

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Appendices

Acronyms

AAM	Active Acoustic Monitoring
ACER	Acadia Center for Estuarine Research
ADCP	Acoustic Doppler Current Profiler
AMAR	Autonomous Multichannel Acoustic Recorder
dB	Decibel
CFI	Canadian Foundation for Innovation
CLA	Crown Lease Area
CPUE	Catch Per Unit Effort
CSTV	Cape Sharp Tidal Venture
DFO	Department of Fisheries and Oceans (Canada)
EA	Environmental Assessment
EEM	Environmental Effects Monitoring
EEMP	Environmental Effects Monitoring Program
EMAC	Environmental Monitoring Advisory Committee
EMP	Environmental Management Plan
EMS	Environmental Monitoring System
FAST	Fundy Advanced Sensor Technology
FAST-EMS	Fundy Advanced Sensor Technology - Environmental Monitoring System
FORCE	Fundy Ocean Research Center for Energy
Hz	Hertz
MET	Meteorological
MREA	Marine Renewable-electricity Area
MW	Megawatt
NRCan	Natural Resources Canada
NSE	Nova Scotia Department of Environment
NSERC	Natural Sciences and Engineering Research Council
OERA	Offshore Energy Research Association
ONC	Ocean Networks Canada
OSC	Ocean Supercluster
OTN	Ocean Tracking Network
PAM	Passive Acoustic Monitoring
Q1/2/3	Quarter (1, 2, 3), based on a quarterly reporting schedule
RPM	Rotations Per Minute
TCC	Turbine Control Centre
TISEC	Tidal In-Stream Energy Converter
VEC(s)	Valuable Ecosystem Component(s)

Introduction

About FORCE

FORCE was created to lead research, demonstration, and testing for high flow, industrial-scale in-stream tidal energy devices, sometimes referred to as TISECs: tidal in-stream energy converters. Located near Parrsboro, Nova Scotia, in the Minas Passage of the Bay of Fundy, FORCE is a not-for-profit facility that has received funding support from the Government of Canada, the Province of Nova Scotia, Encana Corporation, and participating developers.

The FORCE project currently consists of five undersea berths for subsea turbine generators, four subsea power cables that will connect the turbines to land-based infrastructure, an onshore substation and power lines connected to the Nova Scotia power transmission system, and a visitors/operations center. The marine portion of the project is located in a leased area from the province (FORCE's Crown Lease Area, or 'CLA'), 1.6 km by 1.0 km in area, in the Minas Passage, and is also considered a 'Marine Renewable-electricity Area' (MREA) under the Province's *Marine Renewable-energy Act*. FORCE's onshore facilities, including its Visitor/Operations Centre and electrical substation, are located approximately 10 km west of Parrsboro, Nova Scotia.

Subsea 'berths' within the marine portion of the project are leased to tidal energy companies who are selected by the Nova Scotia Department of Energy. These companies are:[2]

Berth A: Minas Tidal
Berth B: Black Rock Tidal Power
Berth C: Atlantic Operations (Canada) Ltd. (DP Energy)
Berth D: Cape Sharp Tidal Venture (CSTV)
Berth E: Halagonia Tidal Energy[3]

The FORCE demonstration project was approved on September 15th, 2009 by the Nova Scotia Minister of Environment, and the conditions of its environmental assessment (EA) approval[4] provide for comprehensive, ongoing, and adaptive environmental management.

FORCE has two central roles:

1. Host: providing the technical infrastructure to allow demonstration devices to connect to the transmission grid; and
2. Steward: research and monitoring to better understand the interaction between devices and the environment.

Monitoring and reporting of any environmental effects from tidal turbines at the FORCE site is fundamental to FORCE's mandate—to assess whether in-stream tidal energy turbines can operate in the Minas Passage without causing significant adverse effects on the environment or

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[2] Further information about each company may be found online at: www.fundyforce.ca/technology

[3] Berth E does not have a subsea cable provided to it.

[4] FORCE's Environmental Assessment Registration Document and conditions of approval are found online at: www.fundyforce.ca/environment/enviromental-assesment.

electricity rates, and other users of the Bay. In this way, FORCE has a role to play in supporting informed, evidence-based decisions by regulators, industry, the scientific community, and the public. As deployments are expected to be phased in over the next several years, FORCE and regulators will have opportunity to adapt environmental monitoring approaches over time as lessons are learned.

The monitoring being conducted at the FORCE test site is part of an international effort to evaluate the risks tidal energy poses to marine life (Copping et al., 2016). Countries that are investigating tidal energy include China, France, Italy, Netherlands, South Korea, the United Kingdom, and the United States (Marine Renewables Canada, 2018). While the impacts from a single device or small arrays of devices are generally anticipated to be low, our understanding of these potential impacts on a global level is based on only a few deployments to date (Copping, 2018). A full evaluation of the risks of tidal energy will not be possible until more devices are tested, with monitoring programs that document local impacts, consider far-field and cumulative effects, and add to our growing global knowledge base.

BACKGROUND

Since 2009, FORCE has been conducting an Environmental Effects Monitoring Program ('EEMP') to better understand the natural environment of the Minas Passage and the potential effects of turbines as related to fish, seabirds, marine mammals, lobster, marine sound, benthic habitat, and other environmental variables. All reports on the site monitoring are available online at: www.fundyforce.ca/environment.

Presently, monitoring at the FORCE site is focused on lobster, fish, marine mammals, seabirds, and marine sounds and is partially divided into 'near-field' (less than 100 m from a turbine) and 'mid-field' (100 m+ from a turbine). Individual berth holders conduct near-field monitoring in direct vicinity of each berth as they are occupying, and FORCE completes mid-field monitoring activities as well as supporting integration of data analysis between these monitoring 'zones,' where applicable. All near-field and mid-field monitoring programs are reviewed by FORCE's environmental monitoring advisory committee (EMAC), which includes representatives from scientific, First Nations, and local fishing communities,[5] as well as federal and provincial regulators prior to turbine installation. In addition, FORCE and berth holders also submit an Environmental Management Plan (EMP) to regulators for review prior to turbine installation. EMPs include: environmental management roles and responsibilities and commitments, environmental protection plans, maintenance and inspection requirements, training and education requirements, reporting protocols, and more.

FORCE's present mid-field EEMP was developed in consultation with SLR Consulting (Canada)[6] and strengthened by review and contributions by national and international experts and scientists, Fisheries and Oceans Canada (DFO) and the Nova Scotia Department of Environment (NSE), and its EMAC. The mid-field EEMP is designed to:

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[5] Information about EMAC may be found online at: www.fundyforce.ca/about/advisory-committees

[6] This document is available online at: www.fundyforce.ca/environment/monitoring.

- address the predictions of the FORCE environmental assessment by monitoring the potential environmental effects of operating turbines; and
- be adaptive, based on monitoring results and input from regulators and EMAC, as well as ongoing turbine operations.

In addition, CSTV developed a near-field monitoring program focusing on marine mammals, fish, and turbine sound in collaboration with experts in the field of in-stream tidal energy and with input from DFO, NSE, and other in-stream tidal energy interests including the Offshore Energy Research Association of Nova Scotia (OERA), and FORCE's EMAC.

In 2016/2017, near-field monitoring was completed by CSTV in relation to its 2-megawatt, 16-metre diameter OpenHydro turbine at Berth D at the FORCE site. During turbine commissioning, CSTV conducted a near-field monitoring program that focused on fish, marine mammals, and turbine sound. Prior to this deployment, the only turbine present at the site was a 1-megawatt, 10-metre diameter in-stream tidal energy turbine, which operated for a short time in 2009. Since removal of this unit in 2010, no tidal turbines were present at the FORCE site until 2016. Consequently, the environmental studies conducted up to 2016 have largely focused on the collection of baseline data.

Monitoring Objectives

As part of its mandate, FORCE is tasked with monitoring and understanding the potential environmental effects of the activities undertaken at its site and reporting on these effects. The present EEMPs are based on the best available scientific advice regarding monitoring approaches and instrumentation and experience in the Minas Passage. The EEMPs will continue to evolve as results and research efforts suggest new approaches or different instruments, and as developments and lessons learned are ascertained, both at the FORCE site and internationally.

Since FORCE's creation in 2009, an adaptive management approach has been used to evaluate monitoring data and make informed, science-based decisions to modify monitoring and assess mitigation measures as necessary. This approach is necessary due to the unknowns and difficulties inherent with gathering data in tidal environments such as the Minas Passage and allows for adjustments and constant improvements to be made as knowledge about the system and environmental interactions become known.

Outcomes are continuously reviewed with regulators, EMAC, and others; where required, approaches and methodologies are revised on the basis of accumulated experience and observed progress toward achieving the monitoring objectives. This approach assists with resolving gaps in the knowledge of the potential effects and usefulness of mitigation measures.

In general, the present FORCE EEMP was designed to guide monitoring over the next five years, but it remains responsive to changes in turbine deployment schedules, regulatory guidance, and as data is collected and analyzed. Further, as more devices are scheduled for deployment at the FORCE site, and as monitoring techniques are improved at the site (through FORCE's Fundy Advanced Sensor Technology (FAST) program), the EEMPs will be revisited, keeping with the adaptive management approach followed at the FORCE site.

The overarching purpose of environmental monitoring is to verify the accuracy of the environmental effect predictions made in FORCE's original EA, submitted in 2009. These predictions were generated through an evaluation of existing physical, biological, and socioeconomic conditions of the study area, and an assessment of the risks the project poses to components of the ecosystem. One of the conditions of the EA approval is that FORCE conduct environmental effects monitoring in the near and mid-field of the FORCE site in collaboration with its berth holders.

Specifically, EEMPs are aimed at effects monitoring in relation to an operating tidal turbine and will provide a fuller understanding of turbine/marine life interactions when integrated. Multi-year data collection done in proximity to operational turbine(s) will be required to consider seasonal variability at the site and appropriate and statistical analysis of this data will help to obtain a fuller understanding of marine life/turbine interactions.

Table 1 outlines the objectives of the respective mid-field monitoring activities conducted at the FORCE demonstration site. Individual near-field monitoring objectives are outlined in appendices (Appendix 1 outlines CSTV's near-field monitoring objectives) and will be updated as additional turbines are deployed at the FORCE demonstration site. To address these objectives and to make conclusions about marine life/turbine interactions, continual efforts will be made to integrate the results of these monitoring activities, where applicable.

Mid-Field Environmental Effects Monitoring VEC	***Objectives***
Lobster	● to determine if the presence of an in-stream tidal energy turbine affects commercial lobster catches
Fish	● to test for indirect effects of in-stream tidal energy turbines on water column fish density and fish vertical distribution ● to estimate probability of fish encountering a device based on fish density proportions in the water column relative to turbine depth in the water column
Marine Mammals	● to determine if there is permanent avoidance of the mid-field study area during turbine operations ● to determine if there is a change in the distribution of a portion of the population across the mid-field study area
Marine Sound (Acoustics)	● to conduct ambient sound measurements to characterize the soundscape prior to and following deployment of the in-stream turbines
Seabirds	● to understand the occurrence and movement of bird species in the vicinity of in-stream tidal energy turbines ● to confirm FORCE's Environmental Assessment predictions relating to the avoidance and/or attraction of birds to in-stream tidal energy turbines

Table 1: The objectives of each of the 'mid-field' environmental effects monitoring activity, which consider various Valued Ecosystem Components (VECs), led by FORCE.

At this time and considering the scale of deployment in the near-term at the FORCE, it is unlikely that significant effects in the far-field will be measurable (SLR, 2015). Given this, far-field studies, such as sediment dynamics, will be deferred until such time that as scale requires. These studies will be developed in consultation with FORCE's EMAC, regulators, and others.

Mid-Field Monitoring Activities

FORCE's latest monitoring effort focuses on the 'mid-field area' (i.e., 100 m+ from a turbine). It is currently examining lobster, fish, marine mammals, seabirds, and marine sound. This latest effort was initiated in 2016 and has continued into 2018. The objectives of the mid-field monitoring activities are found in Table 1. FORCE's mid-field EEMP is available online at: www.fundyforce.ca/environment/monitoring.

The following sections provide a summary of the mid-field monitoring activities conducted at the FORCE site up to June 30th, 2018, including data collection, data analyses performed, initial results, and lessons learned. Where applicable, this report also presents analyses that have integrated data collected through the near-field and mid-field monitoring programs in an effort to provide a fuller understanding of turbine/marine life interactions.

There was no turbine operating at the FORCE site during this reporting period.

Lobster

PROGRAM SUMMARY

FORCE's mid-field lobster monitoring program consists of 'catchability surveys' in the mid-field, where modified commercial lobster traps are deployed on two rings increasing in distance from the turbine location (as depicted in Figure 1). The objective of this study is to determine if the presence of an in-stream tidal energy turbine affects commercial lobster catches within the Minas Passage, and to verify the prediction of the EA, which is that in-stream turbines will have minimal impacts on lobster populations within the test site. This is based on the following characteristics of the site:

- Species diversity and population density is low;
- The substrate is scoured bedrock;
- The in-stream turbine and equipment have a small footprint in the area; and
- With minimal impact, populations will recover to baseline levels in the short-term (AECOM, 2009).

FORCE contracted NEXUS Coastal Resource Management Ltd. (Halifax, NS) to conduct the catchability studies, analysis, and reporting. The first catchability study was completed in fall 2017 over 11 days of operations from October 23rd to November 15th, with a one-week break that suspended operations during the spring tide. Trap recovery rates were high during the survey (98%), and trap drift was minimal (~60 m average across traps). Lobsters retrieved from traps were measured (carapace length), the sex was designated (male, female, and berried female), and shell condition was evaluated. Upon completion of these measurements, lobsters were returned to the waters from which they were fished.

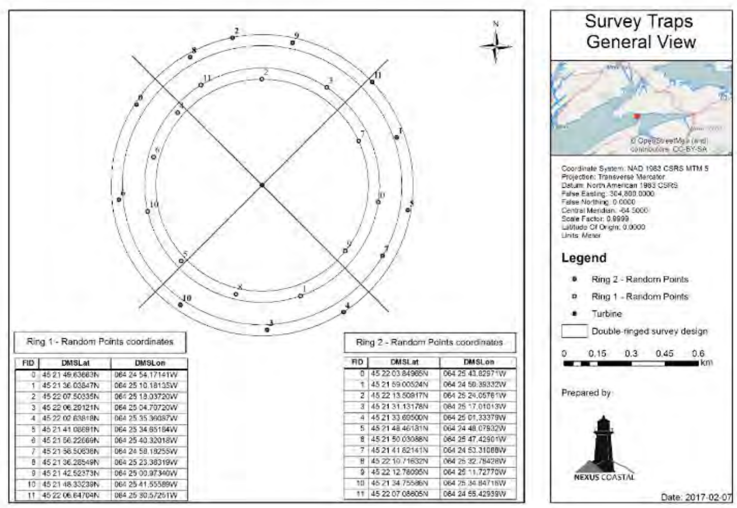

Figure 1: Double-ringed survey design proposed by Bayley (2010), with the dark centre representing the turbine and smaller circles representing lobster traps to be deployed (approximate distances shown) for the lobster monitoring program.

2018 Activities

No additional lobster monitoring work has been conducted in Q1 of 2018, but data analysis and further operational planning have continued in anticipation of a fall 2018 study, to enable comparison with the 2017 survey that occurred during the same time period. This study will only be completed, however, if a turbine is deployed at the site during that time. Following this deployment, statistical analyses will be completed to test EA predictions of minimal impacts of in-stream turbines on lobster catchability rates.

Initial Results & Lessons Learned

As highlighted in Appendix 2, catchability rates were 'high' (> 2.7 kg/trap) in nearly all traps during the study period, according to the following designation provided by DFO:

- Low: 0-0.7 kg CPUE (Catch Per Unit Effort)
- Moderately low: 0.8-1.1 kg CPUE
- Moderate: 1.2-1.7 kg CPUE
- Moderately high: 1.8-2.3 kg CPUE
- High: 2.4-10.7 kg CPUE (Serdynska & Coffen-Smout, 2017)

There was only one trap retrieved with catch ranked as 'moderately low' on the DFO scale, at 1.00 kg trap. The highest catch recorded was 20.17 kg trap. In total, 351 lobsters were caught and released during the study. Based on a carapace length to weight conversion, this amounted an estimated total weight of ~281.16 kg. Catch rates averaged across traps per day ranged from 4.79-8.99 kg trap (n= 7-8 traps per day for 6 days) across both study rings.

Preliminary qualitative analyses indicate that catch rates declined during the study period, likely due to increasing tidal velocities during the progression of the study. There was a statistically significant negative relationship between catch rates and maximum tidal range (m), indicating lower catch at higher flow rates. Catch rates did not increase significantly with depth, and qualitative analyses suggested that there was no significant difference in catch rates between the inner and outer survey rings. Survey rings were also divided by quadrant (i.e., North, South, East, and West quadrants) to track any directional effects of the turbine; qualitative comparisons did not reveal any differences between quadrants.

The EA prediction of minimal impacts of in-stream tidal turbines on lobster catchability rates relies, in part, on the condition of low population densities at the FORCE test site. Initial results showing high catchability rates in the FORCE test site may indicate that the impacts of turbines on lobster catchability is higher than anticipated. However, data collection in the presence of a deployed turbine is needed to fully verify EA predictions.

Significant lessons were learned during the survey operations. These lessons learned relate to survey design, logistical planning, and additional data collection, and were described in detail in the 2017 FORCE Annual Report.[7]

Fish

PROGRAM SUMMARY

The goals of the mid-field fish monitoring program led by FORCE and the University of Maine[8] (Orono, Maine, USA) are to test for indirect effects of in-stream tidal energy turbines on water column fish density and fish vertical distribution and to estimate the probability of fish encountering a device based on any 'co-occurrence' relative to turbine depth in the water column. These goals were laid out to test the EA prediction that in-stream turbines are unlikely to cause significant impacts (i.e., shifts in distribution) to marine fish within the project area. This prediction is based on the relatively small scale of the project (Copping et al., 2016) (i.e., a single turbine occupies 0.1% of the cross-section of Minas Passage).

The program uses a downward-facing hydro-acoustic echosounder (sonar) mounted onto a vessel,[9] which traverses transects across the FORCE site while collecting data on fish density and vertical distribution. Fish densities and distributions at the FORCE site are compared to those at a reference, or unimpacted site, located across the Minas Passage. Any changes occurring at the FORCE test site, and not at the reference site, are interpreted to possibly be attributed to turbine operations.

[7] This report is available online at www.fundyforce.ca/environment/monitoring.

[8] Previous work completed by the University of Maine in relation to the Ocean Renewable Power Corporation's project in Cobscook Bay, Maine looked at evasion and avoidance behaviours of fish and marine mammals in relation to the turbine. This work found that the probability of a fish encountering the turbine's blade would be less than 2.9% (Shen et al., 2015; Viehman and Zydlewski, 2015) and that there was no difference in marine mammal behaviour in response to a turbine (ORPC, 2014).

[9] The echosounder used is a Simrad EK80 (transducer and desktop unit). The EK80 transducer is attached onto the pole mount off the side of the vessel Nova Endeavor. This 'scientific grade' equipment uses sonar technology (split beam echosounder) to detect fish within the water column. GPS is used to verify location of the pole mount during data collection. This technology is preferred over single and multi-beam systems because it provides more detailed information on the 3D position of fish relative to a single beam sounder, and can survey over a further distance with higher resolution than a multi-beam system.

These ‘mobile surveys’ consist of a calibration period, followed by an approximate 24-hour survey to include two tidal cycles and day/night periods. Each transect is 1.8 km in length and is conducted twice—with and against the tidal current. The survey design is depicted in Figure 2.

Figure 2: Transects completed for the fish hydroacoustic surveys. The green square indicates the FORCE test site whereas the white lines highlight the transects completed through the test site and control site (bottom of image) near Cape Split.

The window to complete these hydroacoustic surveys is limited to neap tides, which occur approximately twice per month. FORCE’s surveys are completed during the neap tide of the month that has the lowest tidal range (e.g., less than 10 m tidal range, optimally 8 m – 9 m) to reduce the amount of entrained air in the water column, standardize tidal state across sampling periods, and overlap with previous sampling efforts. As a result, there is typically a five-day window per month suitable for completion of these surveys. This window may be further limited, or eliminated, due to weather conditions (winds must below 10 - 15 knots). Therefore, if weather conditions are unsuitable during the optimal five-day neap tide window, the survey is not completed. This may result in some information loss of particular months of the year and result in the completion of fewer than the nine target surveys per year, but will still maintain seasonal coverage, which is generally more important biologically than maintaining monthly coverage.

Data processing is done using the software Echoview® (version 7.1.35; Myriax, Hobart, Australia). For details on data processing and analysis, please consult FORCE’s 2017 annual report.

2018 Activities

Surveys have continued in Q1 of 2018 as conducted previously in 2016-2017. A survey scheduled for January 2018 was postponed due to weather limitations (high winds during the appropriate tide times as described above) and conducted on February 15th - 16th instead. A survey was also planned for March 2018, but not completed due to unfavourable weather conditions during the survey window. The survey was rescheduled for the first neap tide of April (10th - 11th), which provided an important data point during spring fish migrations. Another survey was completed in early May (8th - 9th) to coincide with the preferred neap tide conditions. In addition to the standard sampling array (Figure 2), these surveys included transects over the CSTV turbine location ('Berth D') as well as the FAST-3 Platform that houses similar instrumentation as the mobile surveys. This is part of a project funded by the OERA, Natural Resources Canada (NRCan), and the Nova Scotia Department of Energy.[10]

A fifth hydroacoustic fish survey was completed June 7th - 8th after the recovery of the FAST-3 platform on May 23rd.

Initial Results & Lessons Learned

Analyses include data collected during baseline studies in 2011 and 2012 (Melvin & Cochrane, 2014) and data collected during surveys conducted as part of FORCE's EEMP from March 2016 - August 2017. Across the contemporary (2016-2017) and historical (2011-2012) study periods, fish densities have been similar between the FORCE test site and reference site, including similar patterns of seasonal change. The highest fish densities were observed in May at both sites, likely driven by the spring migrations of alewife (*Alosa pseudoharengus*), Atlantic herring (*Clupea harengus*), striped bass (*Marone saxatilus*), Atlantic sturgeon (*Acipenser oxyrhynchus*), American shad (*Alosa sapidissma*), American mackerel *(Scomber scombrus*), and rainbow smelt (*Osmerus mordax*) (Baker et al., 2014, Stokesbury et al., 2016). High densities were also observed at both sites in November and January, likely due to migrations of Atlantic herring, river herring (*Alosa aestivalus*), and alewife out of Minas Passage during that time (Townsend et al., 1989). High densities in January could be caused by Atlantic herring that remain resident in Minas Passage throughout the winter. Fish densities were also greater during the ebb than the flood tide. Analyses evaluate changes in fish density in association with month (i.e., season), year, site (FORCE site vs. reference site), diel stage (day/night), tidal stage (ebb/flood), and turbine presence/absence using 2-stage linear models (for details, please consult Appendix 1 of FORCE's 2017 Annual Report).

Results to-date support the EA prediction that in-stream turbines have a minimal impact on marine fish, but data during spanning the full seasonal cycle from multiple years of deployments are needed to verify this prediction. However, confidence in these conclusions will be greatly strengthened following the next deployment of a turbine in Berth D. In addition, there may be opportunities to validate this echosounder data with near-field monitoring data collected by berth holders at the FORCE site. Additional sampling will be required to verify this prediction, as each device may have different impacts to fish.

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[10] See: www.oera.ca/press-release-research-investments-in-nova-scotia-in-stream-tidal-technology-research/

Marine Mammals

MID-FIELD PROGRAM SUMMARY

FORCE's marine mammal monitoring program in the mid-field involves two main components, aimed at verifying the EA prediction that project activities and components are not likely to cause significant adverse residual effects on marine mammals within the project area (AECOM, 2009):

1. The monitoring of the presence of click-producing mammals using C-POD receivers; and
2. An observation program that includes shoreline, stationary, and (at times) vessel-based observations to locate any marine mammals in destress in the vicinity of the FORCE site.

The first component of FORCE's marine mammal monitoring program involves the use of passive acoustic monitoring (PAM) mammal detectors known as 'C-PODs' (Figure 3), which record the vocalizations of toothed whales, porpoises, and dolphins.[11] C-PODs are deployed on SUBS packages between 200 m - 1,710 m from where the CSTV turbine was deployed in 2016-2017 (Figure 4). The goal of this program is to understand if there is a change in marine mammal presence in proximity to deployed in-stream tidal energy turbines and builds upon baseline C-POD data collection within the Minas Passage since 2011. Comparability with previous baseline research was a key rationale for the selection of C-PODs for FORCE's present marine mammal monitoring program. Analysis of C-POD data is completed by Sea Mammal Research Unit Consulting (SMRU Consulting; Vancouver, British Columbia).[12]

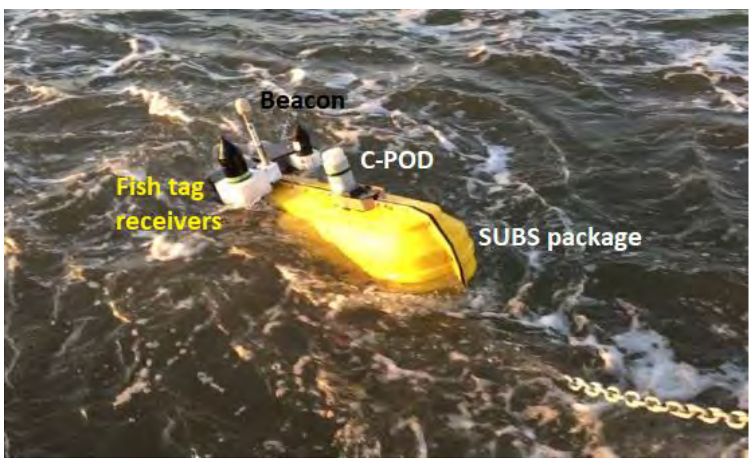

Figure 3: Recently deployed SUBS package containing two fish tag receivers, a beacon from MetOcean Telematics, and C-POD.

[11] The C-PODs, purchased from Chelonia Limited, are designed to passively detect marine mammal 'clicks' from toothed whales, dolphins, and porpoises. The species that C-PODS can potentially detect in the FORCE region are Killer Whale (Orca), Northern Bottlenose Whale, Dall's Porpoise, Harbour Porpoise and Pacific White-Sided Dolphin.

[12] SMRU Consulting, based in Vancouver, British Columbia, is a global leader in marine mammal research and has been involved in Fundy tidal energy research for marine mammals since 2009 (Tollit et al., 2011; Tollit and Redden, 2013).

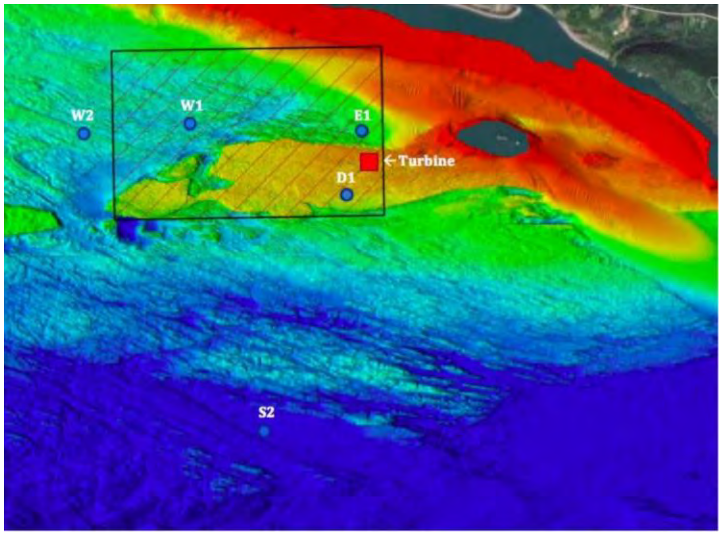

Figure 4: The five C-POD deployment locations in the mid-field of the turbine at the FORCE site, as deployed 2016 – present.

A second component of this program is a visual observation program that includes observations through beach walks, stationary observations at the FORCE Visitor Centre, and, at times, marine-based observations during marine operations. In addition, Envirosphere Consultants records any observations of marine mammals during its shore-based seabird monitoring surveys. These observations are shared with SMRU Consulting to support validation efforts of subsea-based C-POD marine mammal monitoring program and are presented in Envirosphere's reports.

2018 Activities

Upon recovery of on January 9th, the five SUBS packages that house the C-PODs, acoustic releases, and fish tag receivers underwent a period of annual maintenance. In addition, the SUBS packages were outfitted with additional fish tag receivers (see 'Other Activities' below) and beacons from MetOcean Telematics (Dartmouth, NS) to support recovery efforts in the event a SUBS package surfaces prematurely. The fully-furnished SUBS were re-deployed on January 22nd and recovered May 1st. Upon May recovery, the tail of SUBS package located at E1 was discovered to be damaged, with the beacon and tag receivers missing.

The SUBS packages were inspected, regular maintenance and data-recovery activities were completed, new battery packs installed, and were redeployed on May 3rd to ensure continuous deployment during spring tagging efforts led by Acadia University (Wolfville, NS) in the Shubenacadie and Gaspereau Rivers (see 'Fish Tracking' below). The damaged SUBS package was replaced with a spare and deployed with only the recovered C-POD. FORCE staff are presently undertaking repairs to the damaged SUBS package.

Also during Q2, the previously unrecovered C-POD deployed in location S2 was returned to FORCE anonymously (all SUBS packages and C-PODs are labelled with FORCE contact information in the event of loss). FORCE staff are in the process of inspecting the C-POD and are working with SMRU to assess if data is recoverable from the instrument and its suitability for future deployments.

Video: View online (https://twitter.com/fundyforce/status/963499152867983360): FORCE staff ballast a new sub configuration in the pool at Falck Safety Services in Dartmouth. A new addition includes a VEMCO fish receiver that will work in partnership with Dr. Mike Stokesbury's tagged fish research at Acadia University. The wand-looking device is an Iridium Beacon from MetOcean Telematics in Dartmouth; it's able to send a satellite signal to a cell phone with the SUBS package's exact location...in case we can't find it.

FORCE has also continued shoreline observations along areas of the Cumberland shore in proximity to the FORCE site, along with community volunteers. In addition, on June 8th (World Oceans Day), FORCE participated in the Great Canadian Shoreline Clean-up, an initiative of the Vancouver Aquarium and World Wildlife Fund Canada.[13] During these surveys, species of seabirds are typically observed with locations and behaviours are recorded. Abundances were observed to be low in Q1 and increased in Q2. Common species observed are gulls, cormorants and shorebirds along the coast including crows.

FORCE staff also make note of any observed marine mammals during marine operations and shoreline surveys. On June 22nd, FORCE staff observed a harbour porpoise surfacing near Black Rock Island during CSTV marine operations. No observations have been reported via FORCE's public reporting tool, https://mmo.fundyforce.ca/ in 2018.

Initial Results & Lessons Learned

Updated results and lessons learned were provided in Appendix 3 of FORCE's 2017 Annual Report. Preliminary analyses found no evidence that porpoise permanently avoided the site while a turbine was in operation in 2016-2017. There was, however, a reduction in porpoise detections (41-46%) following turbine installation in November 2016 at the site closest to the east of the turbine and the two sites west of the turbine location. Another closely located C-POD did not, however, notice a temporary decline in detection rates.

Initial results to-date support the EA prediction that project activities are not likely to cause significant adverse residual effects on marine mammals within the project area, but additional data collection spanning multi-year turbine deployments and various device technologies is needed to fully verify this prediction. Consideration of turbine produced sound and its trajectory could also help to explain variability amongst C-POD detections.

Integrated Analysis

Through the course of Q2, FORCE, CSTV, and researchers have further examined and compared the recordings for harbour porpoise data sets collected by C-PODs (mid-field) and the icListen hydrophones (near-field) from the 2016/2017 deployment. This examination was prompted by the difference in Days with Detected Porpoise Clicks between the turbine-mounted icListen hydrophones and the Chelonia C-PODs deployed in proximity to the CSTV turbine. Given that C-POD data files are not comparable with icListen data files (Porskamp et al., 2015), direct analysis is not possible; however, interferences may be made regarding the differences between the instruments' findings.

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[13] For further information about the Great Canadian Shoreline Clean-up, visit www.shorelinecleanup.ca.

In the Year 1 Monitoring Report for deployments May 2016 – January 2017, SMRU found that harbor porpoise were detected at all five monitoring locations (depicted in Figure 4 above) on 71 of 73 days post-installation of the CSTV turbine (up to January 18th, 2017), equaling 97.3% of days deployed. There was a temporary reduction in porpoise detections at the two sites west of the turbine (1,140m and 1,710m from the turbine) and site closest to the east of the turbine (210m) (declines were between 41% - 46%); however, another C-POD at a similar depth and ~200m away from the turbine showed no significant turbine effect. The decline detections observed likely represent disturbance from vessel activity associated with installation of the turbine and connection to the subsea cable; however, the exact reason for the differences among C-POD sites is not known. This variance could be attributable to turbine sound propagation, inter-site variability, or distribution of harbour porpoise.

Analysis for January 2017 to the post-recovery period is presently underway by SMRU; however, preliminary analysis shows a presence at 99% of days across all locations with an average percent time lost due to sediment interference (producing non-biological 'clicks' as sediment moves across the seafloor) at 17% - 36%, similar to previous study results including baseline collection periods.

These findings stand in contrast to the findings from the turbine-mounted icListen hydrophones, which recorded 9 days of porpoise detections over the same period (Ocean Sonics, 2018). As noted in the quarterly reporting last year (Cape Sharp Tidal Venture, 2018), the original sampling rates set up on the icListen hydrophones were incorrect and were not suitable for separating and identifying porpoise click trains from the natural soundscape, in particular during high flows. A lag in data transfer from the monitoring devices meant that the issue was not identified until late in February 2017. The sampling rates were adjusted remotely to the correct sampling rate in late March 2017. Further issues were experienced in relation to cabling and damage of the devices.

For the period after the sampling rate adjustment to the time of turbine disconnection in mid-April, one of the icListen hydrophones successfully recorded data.

The differences in detection rates between the C-PODs and the icListen devices is directly related to the functioning of the different devices. It is possible that the C-POD units are recording false positive detections as described above whereas the icListen devices and associated software programs have been developed to separate out the different high frequency sounds to make a positive identification. The continued use of C-PODs is important as it provides a direct comparison to baseline data that was collected at the FORCE site prior to any turbine deployments within the mid-field study area.

For both types of monitoring devices, further data collection will be required to cover seasonal and inter-annual variation to consider broad-scale avoidance/attraction behaviours of marine mammals in relation to an operational turbine (i.e., 'mid-field') as well as consider finer-scale behaviours in direct proximity to a turbine (i.e., 'near-field'). The issues experienced during the 2016/2017 deployment have been mitigated through a series of pre-deployment commissioning tests of the icListen devices, new protocol for transfer and management of data, and increased protection and new cabling for all icListen devices.

Seabirds

Program Summary

The main objectives of the near and mid-field seabird monitoring program are to obtain site-specific species abundance, composition, and behaviour (including temporal and spatial distribution) data, which can be used to verify the EA prediction that project activities are not likely to cause significant adverse residual effects on marine birds within the FORCE project area. More specifically, these abundance estimates are used to establish whether the presence of a tidal energy device causes displacement of surface-visible seabirds from habitual waters and to identify changes in behaviour.

The surveys use a geographic grid system to record observations in relation to various areas of the FORCE demonstration site and surrounding areas as depicted in Figure 5 below. The surveys are typically completed over a six-hour period, coinciding with the ebb tide, and are conducted by a professional bird observer and a biologist. Weather conditions, including precipitation, wind, and temperature are also recorded.

Envirosphere Consultants (Windsor, NS) was contracted to complete data collection, analysis, and reporting activities under FORCE's mid-field seabird monitoring program and has been conducting seabird and marine mammal monitoring at the FORCE site since 2008 (Envirosphere Consultants Limited, 2009 – 2013).

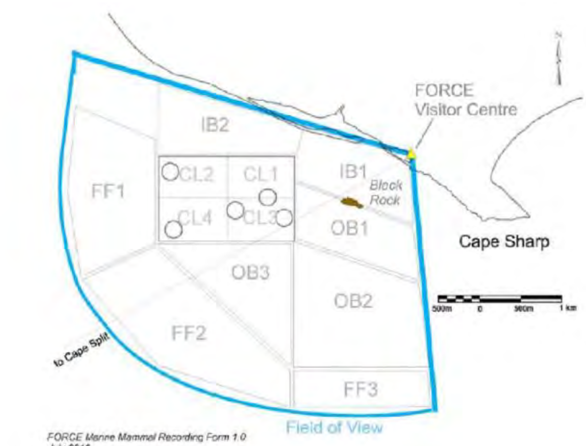

Figure 5: Subdivisions of the FORCE Crown Lease Area for the seabirds monitoring program where 'CL' indicates Crown Lease area; 'IB' indicates Inside Black Rock; 'OB' indicates Outside Black Rock; and 'FF' indicates Far-Field area.

2018 Activities

In 2018, 8 shore-based observational surveys have been completed with increased efforts in known migratory periods (April, May, November). Surveys were completed:

- January 16th;
- February 13th;
- March 19th;
- April 5th;
- April 19th;

- May 10th;
- May 29th; and
- June 12th.

Surveys generally took place over an approximate six-hour period with the outgoing tide, consistent with earlier surveys to help reduce statistical variability. Environmental factors expected to affect bird abundance were also recorded.

INITIAL RESULTS & LESSONS LEARNED

FORCE's 2017 Annual Report (see Appendix 2 of the Annual Report) provides information on species abundance and composition collected in the monitoring program from May 2016 – May 2017, providing qualitative and quantitative assessments of abundance patterns at the FORCE site. Results to-date indicate seasonal peaks corresponding to migratory movements in spring (March - April) and fall (October - November) with Black Rock being the focal point for bird activity in the survey area. These seasonal patterns have also been observed by FORCE staff and volunteers conducting shoreline surveys.

These initial findings support the EA prediction that project activities are not likely to cause significant adverse residual effects on marine birds within the FORCE area. However, data from at least one additional turbine operation spanning the full seasonal cycle is needed to perform a formal statistical analysis of the data to look for a turbine effect. Further, technologies that are surface-piercing may be more likely to cause impacts to birds, so additional data collection during operations of those tidal energy devices are needed to verify the EA prediction.

Additional analysis for Year 2 of the latest monitoring program is underway by Envirosphere Consultants.

Marine Sound

PROGRAM SUMMARY

Marine sound (otherwise referred to as 'acoustics') monitoring efforts are designed to characterize the soundscape at and around the FORCE test site prior to and during the operation of in-stream tidal turbine(s). Data collected from these monitoring efforts will be used to test EA predictions that operational sounds produced from in-stream turbines are unlikely to cause mortality, physical injury, or hearing impairment to marine animals (AECOM, 2009). Data will also be useful for increasing knowledge of the general soundscape of the Minas Passage.

While marine sound monitoring has occurred at the FORCE site for a number of years, the most recent monitoring activities began in anticipation of the deployment of the CSTV turbine in 2016, using Passive Acoustic Monitoring (PAM) devices known as hydrophones (i.e., underwater recorders) in various configurations. In 2016 - 2017, mid-field sound monitoring was completed using 'drifters' - hydrophones connected to a drifting buoy system. These drifters were deployed from a vessel, which moves away from the drifter and shuts off, and the drifters are allowed to travel with the current across the FORCE demonstration site, recording sound measurements along the way. FORCE completed data collection before and during the time the CSTV turbine was present.

Near-field sound data was collected through two methods of PAM—using turbine-mounted icListen high frequency hydrophones from Ocean Sonics (Great Village, NS) and a stationary, bottom-mounted system known as an 'AMAR' (Autonomous Multichannel Acoustic Recorder) and designed by JASCO Applied Sciences (Dartmouth, NS). The AMAR contained hydrophones and was moored in close proximity to the turbine (i.e., within 100 m) and recorded turbine sound. Further information about near-field monitoring instrumentations and methodologies may be found in Appendix 1, and the results of the sound monitoring during the 2016/2017 turbine deployment are provided in the final report in Appendix 3.

2018 Activities

Data analysis that integrates and compares sound data from these various PAM recorders in the Minas Passage was completed by JASCO Applied Sciences. The purpose of this analysis was to:

- compare turbine sound to flow noise relative to the existing environment, turbine state (generating, free-spinning, or not spinning), and measurement method;
- estimate the possible effects of turbine sound on marine life;
- evaluate the relative utility of the instrument configurations' use to record short-term (i.e., hours to days in duration) and long-term (i.e., weeks to months in duration) sound data in the Minas Passage; and
- provide guidance on methodologies for future acoustic measurements at the FORCE site.

In Q2 2018, the JASCO report underwent review by FORCE's EMAC. The final report is included in Appendix 3.

Integrated Analysis, Initial Results & Lessons Learned

JASCO's analysis found that sound levels increase with the current speed in the Minas Passage and are higher during flood tide than during ebb tide. With the turbine present at the site (regardless of operating state), it was observed that current direction did not influence sound levels, but current speed did. This was evidenced in increases in sound by 20 - 30 decibels (dB) in the generating and free-spinning states as the current speed increases. Likewise, the turbine was found to emit a band of sound in the 3150 – 4000 Hertz (Hz) while generating, and sound levels increased by ~10 dB as the current speed increased in this state.

Like current speed, the different turbine states (e.g., generating, free-spinning, or not spinning) were determined to have differing sound levels.[14] The JASCO study (Appendix 3) found that in

[14] When the turbine is in a generating mode, it is turning while generating electricity. In 'free-spin,' the turbine rotor is turning but is not generating electricity. Whether generating or in free-spin, the speed of the turbine will vary with the velocity of the current, thereby changing the level of sound produced. Under normal operating conditions, the amount of time the turbine rotor is in free-spin is minimal, typically less than 1% of the time for each tide. There is a short period of approximately 30 to 60 seconds between when the turbine rotor starts moving and when the turbine starts generating. The same is true, although typically for a shorter period, at the end of the generating cycle. Short periods of free-spin (i.e., less than 60 secs) are a regular part of the turbine operation.

the generating state, the turbine omitted a band of sound in the 1000–1250 Hz range that is nearly constant, and that when the turbine was in a free-spinning state, the sound produced was observed to be 5 - 25 dB quieter than the generating state.

It was found that turbine sound only exceeded the threshold for behavioural disturbance to fish at very short ranges and only at the highest current speeds on the flood tide. The turbine could, however, be audible to herring (or mask sounds a herring could hear) up to 1000 m away, but was typically in the range of 500 m or less. Additional data collection when a turbine is reinstalled at the FORCE site will provide information regarding seasonality and upon device commissioning, further data in relation to an operational tidal energy turbine.

For porpoise, the sound range of the turbine was found to be up to 800 m; however, this distance was generally less than 300 m in the generating state. In the free-spinning state, the turbine did not generate sound levels in the porpoise hearing frequency band that were measurable above ambient sediment noise. The range where the turbine could cause temporary hearing shifts in porpoise, if one stayed beside the turbine for 24 hours, was 150 – 250 m on most days and increased to 500 m during spring tides. It is highly unlikely, however, that a porpoise would remain near the turbine for longer than one hour. Overall, it was found that the sound amplitude of vessels and the turbine were found to be at similar ranges for porpoise. As with fish monitoring, further data collection is required to make conclusions regarding sound impacts on marine mammals; however, initial results like those from the mid-field mammals program indicate no evidence that porpoise permanently avoided the site while the CSTV turbine was deployed in 2016 - 2017.

Finally, JASCO provided an evaluation of the relative utility of different measurement methods used in acoustic monitoring (i.e., turbine-mounted, autonomously-stationed, and drifting PAM recordings) and provided further recommendations for monitoring when the CSTV turbine is redeployed at the FORCE site. Presently, FORCE and CSTV are reviewing these recommendations and developing plans for future sound data collection.

These free-spin periods typically occur at the start and end of each generating cycle and have a low rotations per minute (RPM) (i.e., less than 7 RPM).

Other FORCE Research Activities

Fish Tracking

To enhance fish monitoring and to expand its data collection capacity, in partnership with the Ocean Tracking Network (OTN),[15] FORCE staff attached one VEMCO[16] fish tag receiver (a VR2 receiver) to each C-POD mooring/SUBS package (see 'Marine Mammal Program' above). These receivers are used to supplement OTN's ongoing data collection program within the Minas Passage and are referred to as 'Buoys of Opportunity.' Upon retrieval of the C-PODs and receivers, instruments are shared with OTN, where data is offloaded prior to redeployment. This effort will support increased knowledge of fish movement within the Minas Passage, which has applicability beyond tidal energy demonstration, as well as complement FORCE's hydroacoustic data collection, which currently does not allow for species identification.

OTN data managers are in the process of acquiring information, including species information, and sharing with FORCE. Initial results show that the OTN receivers deployed by FORCE have detected tags from the following projects:

- Maritimes Region Atlantic salmon marine survival and migration (Hardie, D.C., 2017);
- MA Marine Fisheries Shark Research Program (Skomal, G.B., Chisholm, J., 2009);
- Curry Atlantic Sturgeon and Striped Bass (Curry, A., Linnansaari, T., Gautreau, M., 2010);
- Inner Bay of Fundy Atlantic Salmon (Bradford, R., LeBlanc, P., 2012);
- Movement patterns of American lobsters in the Minas Basin, Minas Passage, and Bay of Fundy Canada (2017);
- Gulf of Maine Sturgeon (Zydlewski, G., Wippelhauser, G. Sulikowski, J., Kieffer, M., Kinnison, M., 2006);
- OTN Canada Atlantic Sturgeon Tracking (Dadswell, M., Litvak, M., Stokesbury, M., Bradford, R., Karsten, R., Redden, A., Sheng, J., Smith, P.C., 2010); and
- Darren Porter Bay of Fundy Weir Fishing (Porter, D., Whoriskey, F., 2017).

Further information about these Buoys of Opportunity, and the projects listed above, can be found on OTN's website: https://members.oceantrack.org/project?ccode=BOOFORCE

In 2018, FORCE has worked in collaboration with Dr. Mike Stokesbury at Acadia University to install additional VEMCO receivers of a new design on FORCE's C-POD moorings/SUBS packages. These new receivers are expected to be even more effective in picking up acoustic detections in high flow environments, where tag signals can be obscured by noise. This partnership will contribute additional information regarding movement patterns of Atlantic Salmon, sturgeon, striped bass, and Alewife in Minas Passage and Basin. This work is sponsored by the OERA,

[15] Ocean Tracking Network's website: www.oceantrackingnetwork.org.

[16] VEMCO is "the world leader in the design and manufacture of acoustic telemetry equipment used by researchers worldwide to study behaviour and migration patterns of a wide variety of aquatic animals." Learn more: www.vemco.com.

NRCan, the Nova Scotia Department of Energy, the Natural Sciences and Engineering Research Council of Canada (NSERC), and the Canadian Foundation for Innovation (CFI).[17]

As mentioned above, the SUBS packages were recovered in early May 2018 and were redeployed shortly thereafter to coincide with tagging efforts in the Shubenacadie and Gaspereau Rivers.

Fundy Advanced Sensor Technology (FAST) Program

FORCE's Fundy Advanced Sensor Technology Program ('FAST') is designed to advance capabilities to monitor and characterize the FORCE site. Specifically, the FAST Program was designed to achieve the following objectives:

1) To advance capabilities of site characterization;
2) To develop and refine environmental monitoring standards and technologies; and
3) To develop marine operating methodologies.

FAST combines both onshore and offshore monitoring assets. Onshore assets include a meteorological (MET) station and radar system; the MET station broadcasts data live on the Ocean Networks Canada (ONC; Victoria, BC) website[18] while the radar system works to monitor surface currents and seabirds. Offshore assets include three subsea data collection platforms for both autonomous and cabled data collection; cabled data collection is broadcasted live on the ONC website.

Online Feature: Working at the Bottom of the Bay, describes two contractors' experience in working on the FORCE project, including FAST marine operations. Link: (https://marineenergy.biz/2018/05/04/working-at-the-bottom-of-the-bay)

Platform Projects

The first and largest of the FAST subsea platforms, 'FAST-1,' houses an instrument referred to as the 'Vectron.' Developed in partnership with Nortek Scientific (Halifax, NS), Memorial University (St. John's, NL), and Dalhousie University (Halifax, NS), the Vectron is the world's first stand-alone instrument to remotely measure turbulence at mid-water column. Measurements and analysis from the Vectron will help tidal energy companies to better design devices, plan marine operations, and characterize a site.

A second, smaller platform is presently dedicated to a project called 'FAST-EMS' (Fundy Advanced Sensor Technology-Environmental Monitoring System). This platform holds directional sensors to collect data from a specific target, including the face of a turbine. Specifically, the sensor suit includes an active acoustic monitoring (AAM) device--a Tritech (Aberdeenshire, Scotland) Gemini imaging sonar, a dynamic mount to position the sonar, from Kongsberg Maritime (Halifax, NS), an acoustic Doppler current profiler (ADCP) to understand water speeds from Norteck Scientific (Halifax, NS), a Sculpin HDC (Clarenville, Newfoundland

[17] Information about this project, and others funded through this program, is available online at: www.oera.ca/press-release-research-investments-in-nova-scotia-in-stream-tidal-technology-research/

[18] This is available online at: www.oceannetworks.ca/observatories/atlantic/bay-fundy

and Labrador) subsea camera, and subsea cabling with multiplexer from MacArtney (Dartmouth, NS) to allow for real-time data collection. In 2018, FAST-EMS has undergone two 'wet tests' between Black Rock Beach and Black Rock Island. The first test ran in Q1 into and a second test was initiated in May 26th and continues to date in the same area, but within deeper water. Data collected from these tests was provided to researchers at the Acadia Centre for Estuarine Research (ACER).

Online Feature: Measuring an Underwater Hurricane, describes the need for FAST in supporting monitoring innovations. Link: http://www.under-water.co.uk/measuring-an-underwater-hurricane/

Moving forward, the FAST-EMS platform will be tested within the deeper and faster flows of the FORCE demonstration site and will be outfitted to include icListen hydrophones to measure marine sound in addition to the present instrument configuration. When tested within the FORCE site, the platform is intended to provide supplemental and/or contingency monitoring for the near-field monitoring program for CSTV[19].

The 'FAST-3' platform houses two hydroacoustic and various environment sensors, and is currently in use at the FORCE site to monitor fish densities in the mid-field of the turbine. FORCE has received funding from NRCan and OERA to complete a comparative analysis of data collected by bottom (FAST-3) and ship-mounted hydroacoustic sonars (used as part of the mid-field fish EEMP). The goals of this project are to evaluate the spatial and temporal representativeness of both instrument configurations and determine the degree to which results are corroborative. Data collection and the development of analysis techniques for this project are currently underway. In 2018, the platform has been deployed:

- December 12th, 2017 - February 22nd, 2018; and
- March 28th - May 23rd, 2018.

Radar Projects

In cooperation with Acadia University, a standard marine radar is located on the FORCE Visitor Centre (pictured in Figure 6). This radar (similar to those used on fishing vessels) is used to support bird tracking research led as well as to map surface velocities and eddies through northwestern Minas Passage. In 2018, in cooperation with the Canadian Coast Guard, a second radar was installed on Cape Sharp headland, which maps the eastern Minas Passage.

A radar has previously been used within the outer Bay of Fundy to track bird movements and is being used presently to assess bird movement around the FORCE turbine site. This work is led by Dr. Phil Taylor at Acadia University.

[19] For details of the CSTV Contingency Program and the CSTV Supplemental Program of the EEMP please refer to the CSTV website (www.capesharptidal.com) for an updated EEMP for 2018.

Figure 6: The radar is located on the top right corner of the FORCE Visitor Centre.

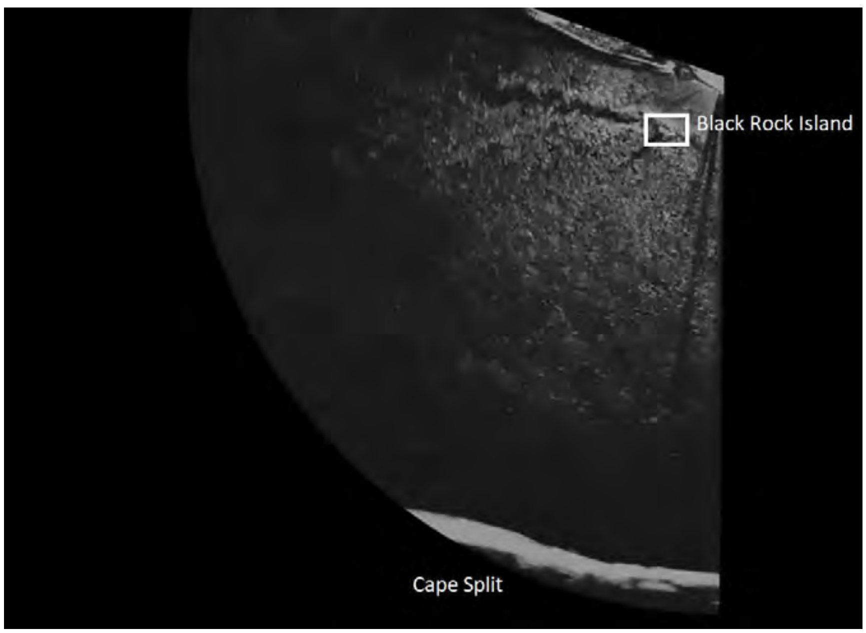

Figure 7: A screenshot of an X-band radar image with labels indicating land-based features. This radar is located on top of the FORCE Visitor Centre.

Presently, the radar is also being used to characterize the Black Rock Island wake, a key constraint on turbine placement and operation in the FORCE region and surrounding waters. With the addition of the radar at Cape Sharp headland, this data will be used to improve velocity resolution and accuracy—an international first. This work is done in collaboration with the National Oceanography Centre in the United Kingdom (Dr. P. Bell), CulOcean Consulting (Dr. J. Culina), and Acadia University (J. Locke, Dr. R. Karsten).

Resource: Melissa Oldreive, Dr. Joel Culina, and Jeremy Locke lead a webinar hosted by the OERA on the radar project. Available online:: http://www.oera.ca/meetingsevents/webinar-series/oera-webinar-series-joel-culina-fundy-ocean-research-center-for-energy/

Environmental Monitoring Advisory Committee (EMAC)

The purpose of FORCE's Environmental Monitoring Advisory Committee (EMAC) is to provide advice on monitoring programs, and to review and advise on monitoring results. Membership includes representatives from scientific, First Nations, and fishing communities. EMAC continues to meet in 2018, provide advice to FORCE on third-party EEM reports and results, and provide advice to FORCE on berth holder EEMPs as they are submitted to FORCE.

In 2018, EMAC has reviewed reports from the near-field monitoring program, provided comments and advice to CSTV and its research partners, and reviewed an integrated analysis of marine sound data (see Appendix 3).

More information on EMAC, including objectives, terms of reference, membership, and summary minutes from these meetings are available on the FORCE website: www.fundyforce.ca/about/advisory-committees.

Research Networks

It is also important to note that additional research projects are occurring within the Bay of Fundy, particularly the Minas Passage and the Minas Basin outside of the jurisdiction of FORCE. FORCE works closely with many research partners, such as the Acadia Tidal Energy Institute,[20] Dalhousie University, Nova Scotia Community College, and others to keep up-to-date on these activities and how they may contribute to the growing understanding of the monitoring turbine effects.

In addition, FORCE also participates in research forums to understanding the growing local and international knowledge of tidal energy effects monitoring. This includes the Fundy Energy Research Network (FERN), a research forum designed to "coordinate and foster research collaborations, capacity building and information exchange"[21] and Annex IV,[22] an international body connects those actively involved in marine renewable energy projects to share information and discuss progress in environmental monitoring efforts. In June 2018, FORCE and CSTV participated in a workshop led by Annex IV regarding data transferability – the process of using data and models from one project and/or location to inform potential effects from another, ensuring consistency across data collection methods across sites, and in standardizing approaches across multiple projects/locations to inform conclusions about marine life/turbine interactions.

Ocean Supercluster

The Government of Canada's February 2018 announcement of an Atlantic Canada-based Ocean Supercluster (OSC) supported a mandate to "better leverage science and technology in Canada's ocean sectors and to build a digitally-powered, knowledge-based ocean economy",

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[20] The Acadia Tidal Energy Institute is the lead organization behind the Nova Scotia Tidal Energy Atlas (http://tidalenergyatlas.acadiau.ca/). FORCE is a project partner to the Atlas.

[21] Source: http://fern.acadiau.ca/about.html. FORCE participates in the Natural Sciences, Engineering, and Socio-Economic Committees of FERN

[22] Annex IV is an initiative of the International Energy Agency's Ocean Energy Systems. Information about Annex IV is available online at https://tethys.pnnl.gov/about-annex-iv

and included marine renewables as part of its scope. OSC has also declared its intent to create cross-sector opportunities for activities such as the “customization of underwater sensors and communications systems to provide real-time data.” Within OSC, it may be possible to create partnership opportunities to further enhance environmental effects monitoring efforts in the Minas Passage. Additional info is available at www.oceansupercluster.ca.

Near-Field Monitoring Activities

As highlighted above, while FORCE completes site-level or 'mid-field' monitoring activities at the FORCE site, near-field monitoring (i.e., device-specific monitoring within 100m of a turbine) is completed by individual berth holders. Like the mid-field monitoring programs, the near-field monitoring programs undergo review by FORCE's EMAC and regulators.

Moving forward, each berth holder's monitoring activities will be included as appendices below. Since CSTV is preparing for turbine redeployment in 2018, an update prepared by CSTV is included in Appendix 1 of this report.

Updates from future berth holder will be provided as others develop and implement near-field, device-specific environmental effects monitoring programs.

Summary

The environmental effects monitoring programs conducted at the FORCE test site continue to build a collective understanding of the potential risks tidal energy poses for marine life in the Minas Passage. Findings to-date follow the international body of research in the field, which has documented few negative impacts of in-stream tidal turbines on marine life (Copping et al., 2016; Copping, 2018). It is still too early to draw conclusions, particularly because of the challenges of working in high-flow, turbid environments and due to limited experience with operating turbines.

There have, however, been some encouraging findings: there have been no significant changes in the distribution and behavior of fish and seabirds at the FORCE site in relation to a deployed turbine, indicating that there is no evidence to suggest fish and seabirds avoid the near and mid-field area while a turbine is in operation. This is similar to studies elsewhere that have documented no changes in behavior of fish in the vicinity of an operating turbine (Bevelheimer et al., 2015). At finer scales (i.e., in the direct vicinity of the turbine), international research has shown that fish generally avoid turbines while they are in operation (Copping et al., 2016).

Similarly, mid-field monitoring has also documented temporary declines in the presence of harbour porpoise during turbine installation, likely due to vessel activity at the FORCE site in association with the installation of the OpenHydro turbine by CSTV in late 2016. Marine mammals are known to be impacted by anthropogenic sounds, including those emitted by underwater construction and vessels, leading to injury or changes to behaviour and distribution (Gotz et al., 2009). Though analysis shows sounds from marine renewable energy projects are detectable by marine mammals at certain distances and in certain tidal conditions at the FORCE site, it is considered unlikely for turbines to cause injury; however, more information is needed to evaluate how sounds from these projects might affect animal behaviours (Copping et al., 2016). Further work will aim to increase understanding of porpoise use of the Minas Passage and to evaluate the impacts of sounds from vessels and turbines on marine life in the vicinity of the FORCE site.

The monitoring technologies currently available for assessing fish behaviors around turbines and associated collision risk are limited, and many that are traditionally used (e.g., video cameras, SCUBA) are largely not effective in Minas Passage. Multi-beam imaging sonars and acoustic tagging technologies have demonstrated their utility in this environment, and methods are currently under review and development at the FORCE site by staff and associated research collaborators. As these technologies and techniques are improved internationally and through efforts like FAST research projects, they will become increasingly accessible for near-field and mid-field monitoring at the FORCE site. Similarly, experience with operating turbines will help to improve instrumentation design, configuration, and housing as well as data transfer, processing, and analysis methodologies, in keeping with the adaptive management approach used at the FORCE site.

The information gained during future turbine deployments at the FORCE test site in 2018 and beyond will be important towards evaluating the EA prediction that the project is unlikely to cause significant harm to marine life. While the deployment in 2016 - 2017 provided important preliminary findings to support this prediction, monitoring in association with an additional deployment of the same turbine technology will add significantly to our understanding of the potential impacts of this specific device. In the near-term, monitoring efforts will help to provide comparisons to baseline data collected such as the comparisons that will be made amongst lobster catchability surveys conducted in 2017 (without a turbine) and 2018 (with a turbine); in the longer-term, monitoring will need to be conducted over the full seasonal cycle and in association with multiple different turbine technologies in order to understand if tidal energy can be a safe and responsibly-produced energy source.

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Appendix 1:
Cape Sharp Tidal Monitoring Program Update

Cape Sharp Tidal Monitoring Program Update

Cape Sharp Tidal (CST) is preparing for turbine redeployment in mid-2018 and does not currently have a turbine deployed at Berth D at the FORCE demonstration site. A number of activities towards preparing for and improving the 2018 near-field environmental effects monitoring activities continued during Q2 2018 and are outlined in this update.

About Cape Sharp Tidal

Cape Sharp Tidal is a joint venture between tidal energy technology developer, OpenHydro, a Naval Energies company and Halifax-based energy company Emera Inc. The CST project uses OpenHydro's Open-Centre Turbine (Figure A.1). This turbine technology has four key components:

- a horizontal axis rotor;
- a magnet generator;
- a hydrodynamic duct; and
- a subsea gravity base foundation.

Simplicity is a key advantage of this device, resulting in reduced maintenance requirements and eliminating the potential for environmental biofouling. Seawater is used for both generator cooling and for lubrication. The turbine possesses one moving part, the rotor, which is bi-directional (i.e., the turbine is capable of extracting energy in both the ebb and the flood flow). There are 10 fins, each approximately 2.4 m wide x 4.8 m long, and manufactured from glass-reinforced plastic. The thickness of each fin ranges from 21 cm at the root (outer diameter) to 1.5 cm at the tip (inner diameter). The turbine is supported by a triangular-shaped gravity foundation subsea base structure. The entire unit sits on the sea floor without requiring drilling or any preparation to the substrate.

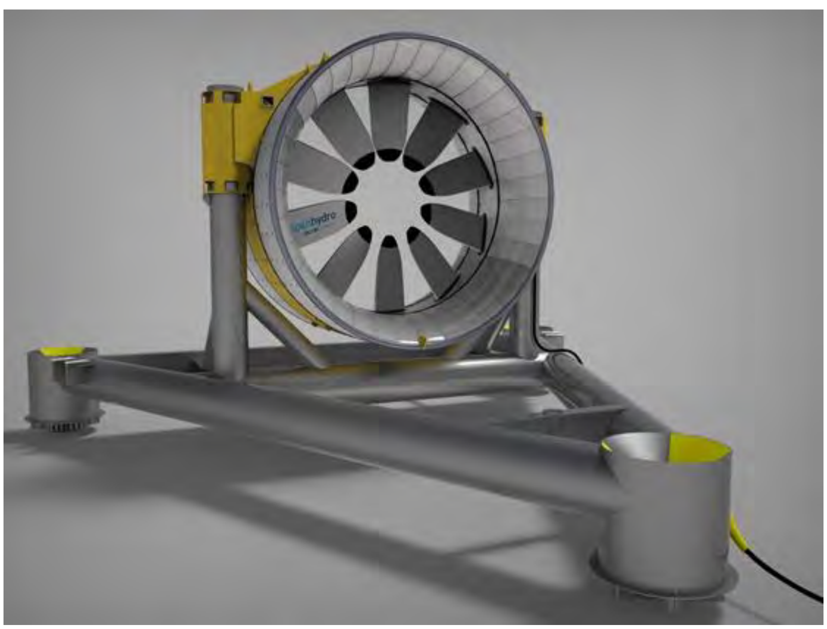


Figure A.1: An image of the OpenHydro Open-Centre Turbine design.

CST deployed a 2-megawatt (MW) in-stream tidal energy turbine at the FORCE site on November 7th, 2016. This turbine was retrieved on June 15th, 2017. Following retrieval, the turbine and subsea base were towed to port facilities in Saint John, New Brunswick. Details of the marine operations around the retrieval were provided in the 2017 Q2 and Q3 Environmental Effects Monitoring (EEMP) Reports (www.capesharptidal.com/eemp/).

Q2 Operational Update

The focus of operations during this reporting period (April 1st – June 30th, 2018) has been preparing for a 2018 deployment (this date has not yet been confirmed). This includes continued preparation of the environmental monitoring devices removed from the recovered turbine and applying lessons learned from the past deployment, including the refinement of the data transfer and analysis processes with researchers.

CST has continued to work to improve the turbine technology and increase the operating efficiency of the next turbine to be deployed at the FORCE site at Berth D in 2018. During Q2, the turbine deployed in 2016 and recovered in 2017 (the 'wet turbine') was removed from the subsea base on May 1st, 2018. The subsea base remained on the purpose-built *Scotia Tide* barge throughout this process as it will be used again in the 2018 deployment.

During the first week of June 2018, the turbine control centre (TCC) was re-mounted onto the subsea base and the upgraded turbine (the 'dry turbine') was moved to the barge and installed on the subsea base during the week of June 4th.

CST continues to collaborate with local and international scientists, universities and independent research and technology companies to reach its goals of increased knowledge and environmental protection. As noted in previous reports, the retrieval of the turbine provided an opportunity for CST and researchers involved in monitoring studies to inspect all monitoring devices, evaluate and improve device protection where needed and implement improvements based on what was learned during the first deployment. A root cause analysis report was developed, and the results were used to adjust and improve the use and positioning of the monitoring instruments for the 2018 deployment.

Near-Field Environmental Effects Monitoring – 2018 Update

The near-field environmental effects monitoring activities, related to the CST device, were developed in collaboration with experts in the field of in-stream tidal energy and with input from government agencies, including Fisheries and Oceans Canada (DFO) and Nova Scotia Environment (NSE), as well as other in-stream tidal energy interests including the Offshore Energy Research Association, technology experts and researchers. The near-field environmental effects monitoring objectives are designed to be updated on an annual basis, in keeping with the adaptive management approach at the FORCE site.

The overarching purpose of near-field environmental effects monitoring is to verify the accuracy of the environmental effect predictions made in the environmental assessment (EA) for the FORCE site. These predictions were generated through an evaluation of existing physical, biological and socioeconomic conditions of the study area, and an assessment of the risks the project poses to components of the ecosystem.

Near-field environmental effects monitoring for the 2016/2017 deployment focused on fish, marine mammals and turbine sound. It commenced upon connection of the CST turbine to FORCE's subsea power cable in early November 2016. The near-field environmental effects monitoring program and related reports submitted to regulators in 2016/17 and January 2018 are available on the CST website: www.capesharptidal.com/eemp.

Updates and revisions to the near-field monitoring program continue throughout Q2. Although the main components of study remain the same (i.e., marine fish, marine mammals and turbine sound), the process of defining the objectives was revisited and refined with greater focus on alignment with the EA predictions. The updated EEMP will also take into consideration the lessons learned from the last deployment, recommendations from researchers and FORCE's Environmental Monitoring Advisory Committee (EMAC), and requirements and recommendations of regulators. Another key focus of the monitoring program will be a better integration and analysis of near-field CST results with the results collected under the mid-field monitoring program activity for a better understanding of the test site area, where applicable. An updated EEMP for 2018 will be posted on the CST website following review by regulators and prior to the 2018 deployment.

Following the deployment from 2016/2017 and discussions with regulators, CST developed additional plans to address key areas in preparation for the 2018 deployment. These additional plans will supplement the near-field EEMP. The protocol related to the plans was finalized in Q2 with researchers and presented to regulators and include the following:

- A **Commissioning Plan** to plan to document the testing and results of all monitoring devices prior to deployment;
- A **Data Management Plan** to document procedures for ensuring timely access and transfer of data from the monitoring devices on the turbine and subsea base to researchers for processing and analysis; and
- A **Contingency Plan** to provide details of planned contingency measures that can be implemented immediately in the event of a monitoring device failure (i.e., Gemini sonar or hydrophones) that results in the inability to meet the objectives of the monitoring program. The contingency plan was field-tested in Q2 2018. These tests also served to test sensor operation and data management access and transfer capabilities.

More information on these plans is provided below.

NEAR-FIELD MONITORING PROGRAM SUMMARIES & UPDATES

MARINE FISH INCLUDING SPECIES AT RISK

The focus for CST on fish monitoring in Q2 2018 has been ongoing evaluation of the devices for the 2018 monitoring program. This includes input from sensor device developers and researchers.

The Tritech Gemini imaging sonar will be used for fish monitoring. This device is an active acoustic device: a high frequency multi-beam sonar technology that uses reflected sound (similar to an echo) to build up a picture of an underwater environment. Images created by high-frequency sonars are low resolution when compared with contemporary video technologies. However, when there is insufficient light or high turbidity (due to cloudiness or haziness of water caused by suspended solids [sand]), high-frequency sonars are preferred because video cameras lose the ability to create a clear image.

As noted in the 2018 Q1 report, CST continued evaluation and testing of this sensor with a focus on improving the link quality. At the end of Q1, CST achieved 100% link quality with all instruments. In Q2 2018, the Gemini device was re-mounted within the protective frame and re-positioned onto the subsea base. Further tests were conducted, as part of the commissioning plan, to ensure proper functioning (refer to commissioning plan section below for a list of all the tests conducted).

An additional Gemini unit was acquired in Q2 2018 and has also undergone testing to be used in the contingency program for the near-field monitoring (see contingency plan section below).

Marine Mammals (Harbour Porpoise) including Marine Mammal Species at Risk

The focus for CST on marine mammal monitoring in Q2 2018 has been ongoing evaluation of the hydrophones for the 2018 monitoring program. This includes input from sensor device developers and researchers to ensure a successful monitoring program during the next deployment.

The marine mammal monitoring program for CST will utilize four icListen high frequency hydrophones mounted in four different locations: one on the top of the rotor, and three on the subsea base. The hydrophones act as underwater microphones able to detect and record marine mammal vocalizations.

During Q2 2018, CST continued evaluation and testing of the four icListen hydrophones. This builds off the inspections, evaluations and tests completed in late 2017 following turbine retrieval and is part of the 2018 commissioning plan. In Q2 2018, the hydrophones were mounted onto the subsea base and the turbine and further tests were conducted to ensure proper functioning (see commissioning plan section below for a list of all the tests conducted).

An additional two high-frequency hydrophones were acquired in Q2 2018 to be used in the contingency program (see contingency plan section below).

Turbine Sound

Phase 2 of turbine sound analysis from the 2016/2017 deployment was completed in Q2 2018. This report provides a full analysis of the source level of the turbine as a function of the operational state and flow speed, and addresses the sound produced by the turbine relative to ambient (i.e., background) sound. The report has been reviewed by FORCE's EMAC and findings and recommendations will be directed toward additional turbine sound monitoring planned for the 2018 deployment.

The study results, which consider the integration of multiple hydrophones throughout the FORCE site, are highlighted in the main body of the Q2 2018 report.

Commissioning Plan

CST's commissioning plan for the monitoring devices was finalized in Q2 2018, and tests on the monitoring devices continued. The commissioning plan details a systematic process of tests to ensure that all monitoring devices are performing as expected in varying scenarios from "bench tests" onshore before the devices are installed on the turbine, up to the final test that will take place in the Minas Passage just prior to deployment. During Q2, the following tests were conducted:

- Bench test – confirmation of correct operation of sensors through test cables to laptop; confirmation of cable assembly integrity;
- Integrated Systems Test (IST) 04 – Confirmation sensors are tested through sensor pod flange connections with their permanent cable assemblies;
- Installation – Properly installed following approved protocol; and
- IST06 – Confirmation sensors are functional post-installation on the barge at quayside.

The final test remaining to be completed is the IST07. This test is planned for Q3 2018 and involves confirmation of the functionality of all sensors during tow trials. A final test of all sensors (IST08) will take place immediately post-deployment at the FORCE test site; however, this date has not yet been confirmed.

Data Management Plan

The data management plan was finalized in Q2 2018. The plan addresses two main components of monitoring infrastructure improvements that will facilitate the data collection and transfer at the FORCE site. The plan also addresses data issues and lessons learned from the 2016/2017 deployment.

The first component of the plan was the investigation of an upgrade to the bandwidth available at the FORCE site for uploading monitoring data. This was achieved with the acquisition of increased capacity from the FORCE substation. The second element of infrastructure improvement involved the addition of computers at the FORCE substation to move data from the sensors and allow for remote access to devices from onshore. These items were completed in Q2 2018 and facilitate the movement of large amounts of data, improve the ability to remote adjust the processing software, and provide direct data access.

Set-up will take place prior to the 2018 deployment. The data management plan provides the following benefits for the CST project:

1. Reduction of the volume of data collected, and accordingly, the data to be analyzed, so that data sets collected will be focused on key relevant 'events;'
2. Maintains data quality;
3. Direct upload of data from the FORCE substation;
4. Remote access to data for equipment providers and analysts; and

5. Improved back-up facility: The data collected on hard drives is no longer the means of transmitting the information but is a dedicated back-up facility allowing for increased capacity and longer fix time, if required.

CONTINGENCY PLAN

A contingency plan that was initiated in Q1 2018, was finalized in Q2.

Contingency planning is necessary to address specific conditions that may occur during the operation of the CST project that might lead to a temporary halt of environment monitoring or a disruption that affects the objectives of the near-field monitoring efforts. An essential element of contingency planning is preparing processes and plans that can be activated if these events occur.

The following unexpected events require contingency planning:

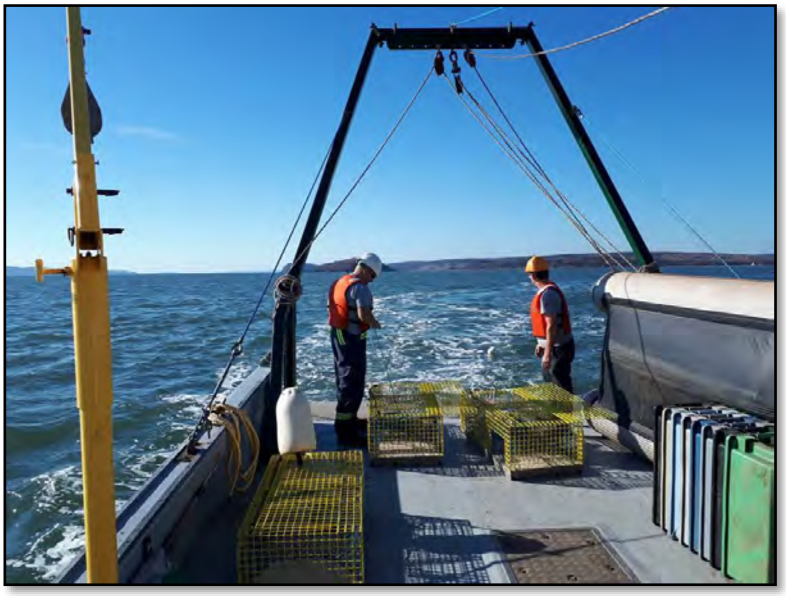
- Damage or loss of environmental monitoring devices;
- Gaps in the collection of monitoring data that are caused by activities related to deployment and/or retrieval operations; and
- Other unexpected events that lead to a disruption in the collection of monitoring data.

The scope of the contingency plan must be measurable to the scope of the monitoring program. For that reason, the contingency plan incorporates both a Gemini device and two hydrophones on a cabled Fundy Advanced Sensor Technology (FAST) platform. The set-up and initial tests (onshore and intertidal zone tests) were completed under a joint program between FORCE and OpenHydro. In Q2, CST worked with FORCE to test the platform in the Minas Passage between the Black Rock Beach and Black Rock. These tests will extend into Q3 to prepare the program for immediate use, if required, following the 2018 deployment.

Testing associated with the contingency plan also provided the opportunity to test specific devices (i.e., the Gemini sonar), to test elements of the data management program and to make improvements to the analytical algorithms including aspects of the *SeaTec* software used in conjunction with the Gemini sonar data. The *SeaTec* software uses specific algorithms to identify and track marine life and objects in open water environments around tidal turbines. The FAST platform test that was conducted during Q2 has allowed researchers to ensure the functionality of the Gemini in the Minas Passage on the platform, and the opportunity to collect pre-deployment data to facilitate algorithm improvements and the refinement of a subsampling methodology. These algorithm improvements and subsampling methodology will be used for both the instruments mounted on the FAST platform, and for the instruments mounted on the turbine, once deployed.

The Contingency Plan will be finalized prior to deployment and further details will be provided as part of the final CST 2018 near-field EEMP. The EEMP and all associated documents will be posted on the CST website.

Appendix 2:
Mid-field Lobster Monitoring Report



LOBSTER CATCHABILITY STUDY REPORT

PREPARED FOR: FORCE

NEXUS Coastal Resource Management Ltd. | December 2017

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SECTION I: OBJECTIVES SUMMARY

The purpose of this study is to monitor lobster catchability within the FORCE Crown Lease Area (CLA; Figure 1). Lobster catchability is represented as catch per unit effort (CPUE), or catch per trap, which functions as a proxy measure for population density. Surveying prior to TISEC turbine deployment establishes initial data for future comparison. Comparing data collected during TISEC turbine deployment against the initial data assesses the level of impact the technology may have on lobster catchability. This research will also test the assumptions of the initial environmental assessment (EA). The AECOM (2009) report assumes minimal TISEC turbine impacts on lobster populations within the CLA, based on the following prescriptive characteristics:

- Species diversity and population density is low;
- The substrate is scoured bedrock;
- The TISEC turbine and equipment has a small footprint in the area;
- With minimal impact, populations will recover to baseline levels in the short-term (AECOM, 2009).

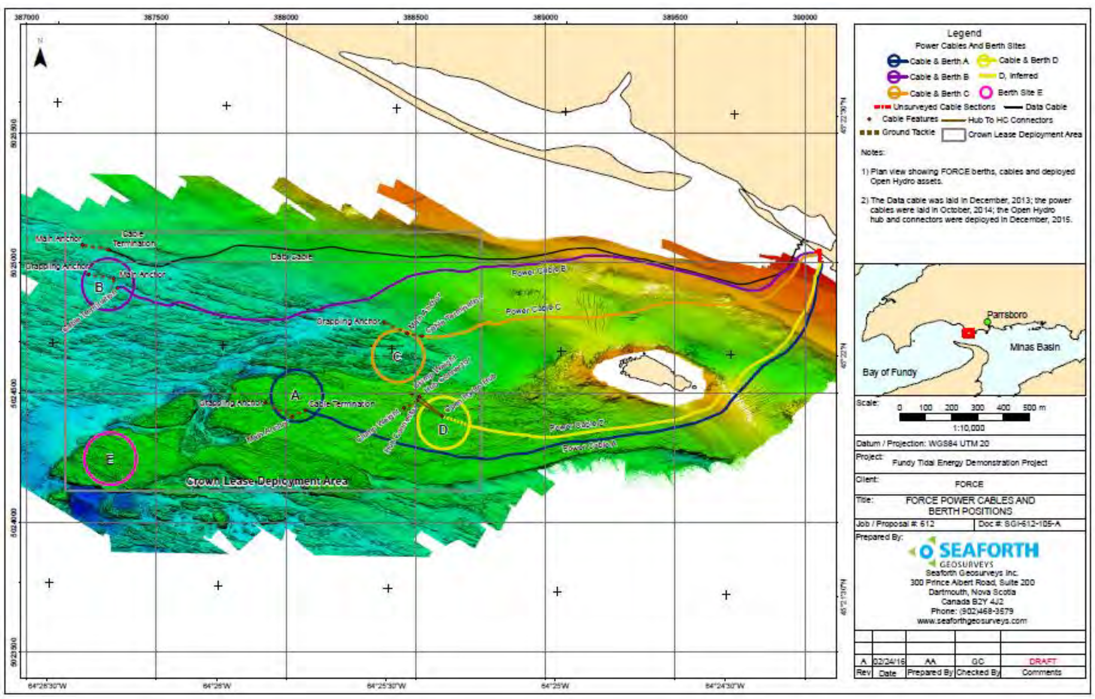


Figure 1. Map of Proposed TISEC device deployment berths (FORCE, 2016).

This study provided opportunity to test sampling methodologies and provided a reference point for comparison of the catchability statistics recorded within the CLA against the general fishery in the Minas Passage, as determined by Fisheries and Oceans Canada (DFO

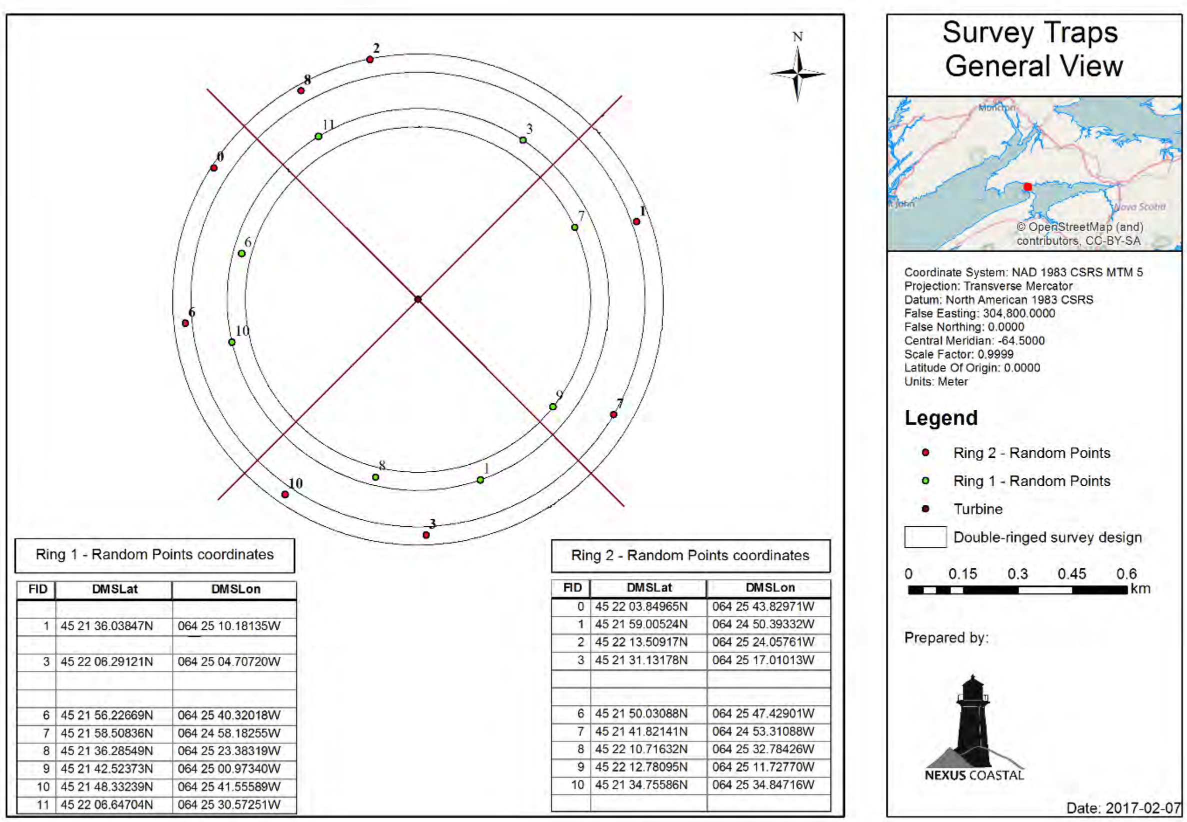
2014). According to the DFO 2014 report, lobster population density in the broader Minas Passage (outside the CLA) as high, using the following catchability gradients:

- 0 - 0.7 kg CPUE (low)
- 0.8 - 1.1 kg CPUE (moderately low)
- 1.2 - 1.7 kg CPUE (moderate)
- 1.8 – 2.3 kg CPUE (moderately high)
- 2.4 – 10.7 kg CPUE (high) (p. 22, Serdynska & Coffen-Smout, 2017)

SECTION II: OVERVIEW OF METHODS

FALL, IN-SEASON SURVEY

The survey plot (Figure 2) is a design modification proposed by Bayley (CEF, 2011). The plot consists of two interval rings centered around the turbine. The inner 'treatment' ring is 50m wide, positioned 475m-525m from the turbine. The 475m exclusion zone over compensates for trap drift due to currents and allows a broad buffer to protect against trap interference with the turbine. The outer 'control' ring is also 50m wide, positioned 575m-625m away from the turbine. In the Bayley design, each ring is comprised of 12 randomized, fixed stations – 24 stations in the entire survey plot. Bayley also recommended sampling stations 3 times for one complete survey (to correct against gear foul or loss), ensuring useable data is collected for each station. Bayley also proposed a soak time parameter of no longer than 24 hours after trap deployment. The survey plot is divided into North, East, South, and West quadrants.



Ring 1 - Random Points coordinates

FID	DMSLat	DMSLon
1	45 21 36.03847N	064 25 10.18135W
3	45 22 06.29121N	064 25 04.70720W
6	45 21 56.22669N	064 25 40.32018W
7	45 21 58.50836N	064 24 58.18255W
8	45 21 36.28549N	064 25 23.38319W
9	45 21 42.52373N	064 25 00.97340W
10	45 21 48.33239N	064 25 41.55589W
11	45 22 06.64704N	064 25 30.57251W

Ring 2 - Random Points coordinates

FID	DMSLat	DMSLon
0	45 22 03.84965N	064 25 43.82971W
1	45 21 59.00524N	064 24 50.39332W
2	45 22 13.50917N	064 25 24.05761W
3	45 21 31.13178N	064 25 17.01013W
6	45 21 50.03088N	064 25 47.42901W
7	45 21 41.82141N	064 24 53.31088W
8	45 22 10.71632N	064 25 32.78426W
9	45 22 12.78095N	064 25 11.72770W
10	45 21 34.75586N	064 25 34.84716W

Figure 2. Adapted double-ringed survey plot.

Local fishing industry representatives advised that it would be difficult to sample more than 12 stations per day, based on tidal cycle and currents. Thus, the survey plot designed was adapted - comprising 16 randomized fixed stations, 8 traps per ring (Table 1).

Table 1. Corresponding coordinates for the 16 randomly selected fixed survey stations. Fixed identification (FID) numbers are also included.

Ring 1 – Coordinates			**Ring 2 - Coordinates**		
FID	DMSLat	DMSLon	FID	DMSLat	DMSLon
1-1	45 21 36.03847N	064 25 10.18135W	0	45 22 03.84965N	064 25 43.82971W
3-1	45 22 06.29121N	064 25 04.70720W	1-2	45 21 59.00524N	064 24 50.39332W
6-1	45 21 56.22669N	064 25 40.32018W	2	45 22 13.50917N	064 25 24.05761W
7-1	45 21 58.50836N	064 24 58.18255W	3-2	45 21 31.13178N	064 25 17.01013W
8-1	45 21 36.28549N	064 25 23.38319W	6-2	45 21 50.03088N	064 25 47.42901W
9	45 21 42.52373N	064 25 00.97340W	7-2	45 21 41.82141N	064 24 53.31088W
10-1	45 21 48.33239N	064 25 41.55589W	8-2	45 22 10.71632N	064 25 32.78426W
11	45 22 06.64704N	064 25 30.57251W	10-2	45 21 34.75586N	064 24 55.42939W

The team used modified commercial American lobster traps made with 2.5 cm wire mesh and measuring 1.21 m (48”) x 0.38 m (15”) x 0.61 m (24”), with two 12.7 cm rings, and one blocked biodegradable escape vent (Figure 3). The traps were weighted with a 150kg concrete slab to minimize movement from the strong tides of the Bay of Fundy. Each trap was connected to a 75m buoy line and corresponding marked buoy (with vessel name and licence number). Each trap was freshly baited with 1.5 kg of redfish during each deployment to align with standard fishing industry practice in the area and affixed with DFO-approved identification tags (Table 2).

Figure 3. Study trap configuration.

Table 2. Documented DFO Science ID tag numbers for each survey trap placed by NEXUS Coastal, which correspond to each survey station. Nexus mooring codes and survey traps are regulated by the provisions of DFO science license #347451.

NEXUS mooring codes	
R1-00-A-3018300	**R2-00-A-3018324**
R1-01-A-3018301	**R2-01-A-3018325**
R1-02-A-3018302	**R2-02-A-3018326**
R1-03-A-3018303	**R2-03-A-3018327**
R1-04-A-3018304	**R2-04-A-3018328**
R1-05-A-3018305	**R2-05-A-3018329**
R1-06-A-3018306	**R2-06-A-3018330**
R1-07-A-3018307	**R2-07-A-3018331**
R1-08-A-3018308	**R2-08-A-3018332**
R1-09-A-3018309	**R2-09-A-3018333**
R1-10-A-3018310	**R2-10-A-3018334**
R1-11-A-3018311	**R2-11-A-3018335**
R1-00-B-3018312	**R2-00-B-3018336**
R1-01-B-3018313	**R2-01-B-3018337**
R1-02-B-3018314	**R2-02-B-3018338**
R1-03-B-3018315	**R2-03-B-3018339**
R1-04-B-3018316	**R2-04-B-3018340**
R1-05-B-3018317	**R2-05-B-3018341**
R1-06-B-3018318	**R2-06-B-3018342**

NEXUS mooring codes	
R1-07-B-3018319	**R2-07-B-3018343**
R1-08-B-3018320	**R2-08-B-3018344**
R1-09-B-3018321	**R2-09-B-3018345**
R1-10-B-3018322	**R2-10-B-3018346**
R1-11-B-3018323	**R2-11-B-3018347**

The field team conducted a Fall, in-season survey from October 24th to November 15th, 2017. Logistically, only 8 stations could be deployed and retrieved in one day. Marine operations in the CLA are greatly impacted by tidal speed, tidal range, and depth; therefore, stations were deployed and retrieved in the most efficient manner possible depending on these factors.

Station positions were entered into the vessel's (*Nova Endeavor*) Nobeltec® GPS plotter to ensure all traps were deployed appropriately. During trap deployment, date, time, station FID, latitude, longitude, ID tag number, and surface temperature were recorded in a logbook. During trap retrieval, ID tag numbers were used to verify station FID, and all other fields were recorded in the logbook. For each station retrieved, the following data was recorded on data sheets (Figure 4):

- Station FID
- Position
- Depth
- Time retrieved
- Species name
- Sex codes (e.g. male – 1; female – 2; and berried female – 3)
- Carapace length for relevant Crustacea– using standard issue calipers
- Total length for relevant fin fish – using a 1 cm offset measuring board
- By-catch total number of individual – for all other species

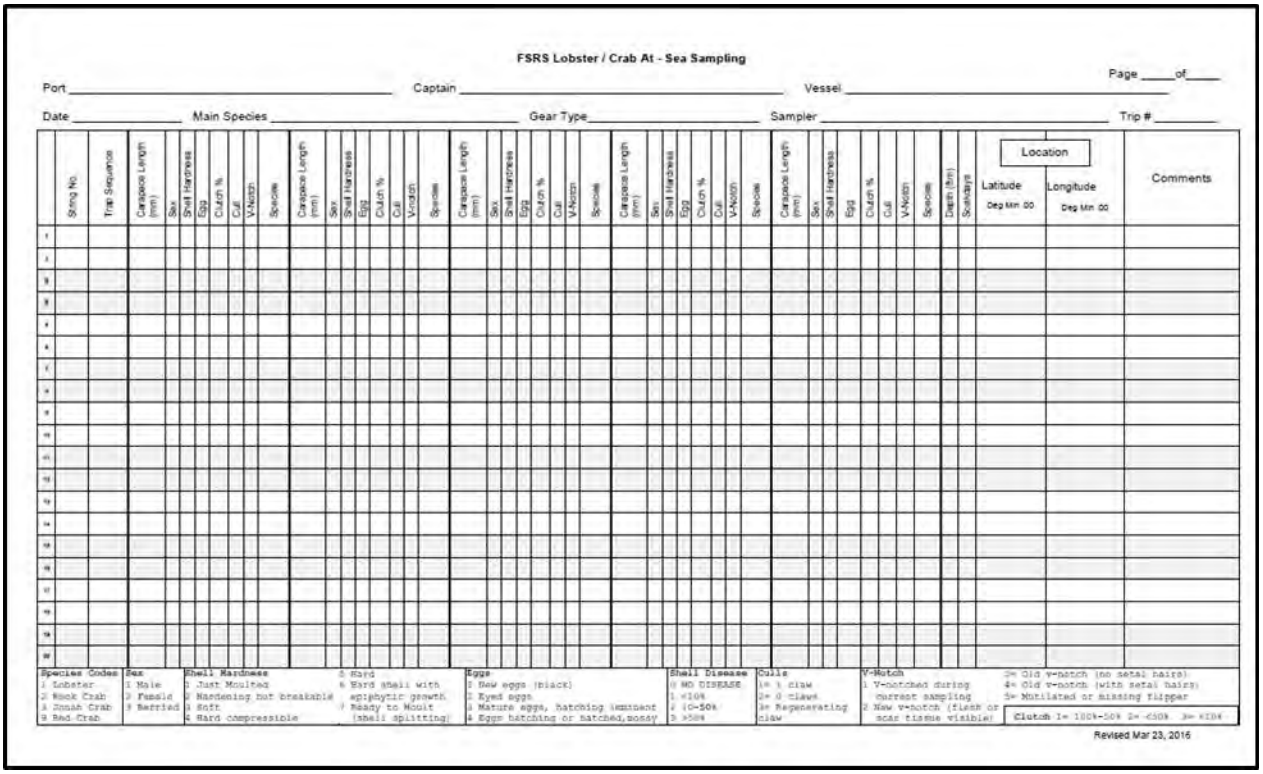


Figure 4. Lobster/Crab At-Sea Sampling data sheet.

Data was entered into the DFO Crustacean Research Information System (CRIS) and an output excel created. The analysis examines catch (kg) per trap by date, station FID, quadrant, and ring (i.e. inner vs. outer).

Section III: Preliminary Results

Fall, In-Season Survey

Eight survey stations were successfully deployed on seven days between October 24th and November 15th, 2017. During this period three survey plot replications were completed with a retrieval success rate of 97.9% (47 of 48 traps). All stations were successfully retrieved within a soak period of 24 hours except for one station on October 24th. Due to weather conditions all stations set on October 25th were left for a longer soak period. Stations retrieved beyond the 24-hour soak period have been omitted from further analysis.

Within the survey period, daily catchability for survey stations within the CLA plot are categorized as high (>2.7 kg/trap), with one exception. On November 13th, 2017 the field team recorded 1.00kg of lobster caught at station 7-1 – which is moderately low on the DFO catchability scale. Although mean station catchability was high throughout the period, there appears to be a declining trend over time (Figure 5). Catch variability between stations appears to have lowered in the later period. Although we may glean a semblance of trends from these results, currently, the limited time scale prevents broader trend analysis.

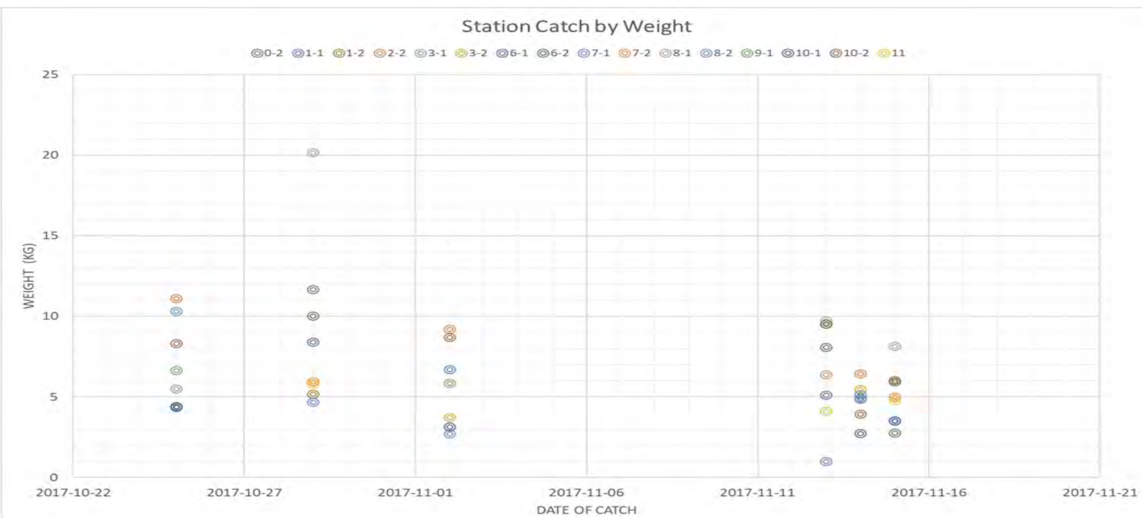


Figure 5. Daily station catchability.

In Figure 6, maximum tidal ranged between 10.5m to 12.3m, throughout the study. The figure depicts a strong negative relationship (R^2 = 0.75) between the two variables – as tidal height increases, catches decrease. Our team infers that lobsters limit their movements during periods of high tidal velocity. There was also increased rock debris and trap damage during high tidal velocity – which provides supporting evidence that it may be difficult for lobsters to move during these periods. In contrast, the team found no relationship (R^2 = 0.0845) between catch and depth (at mean tide) (Figure 7).

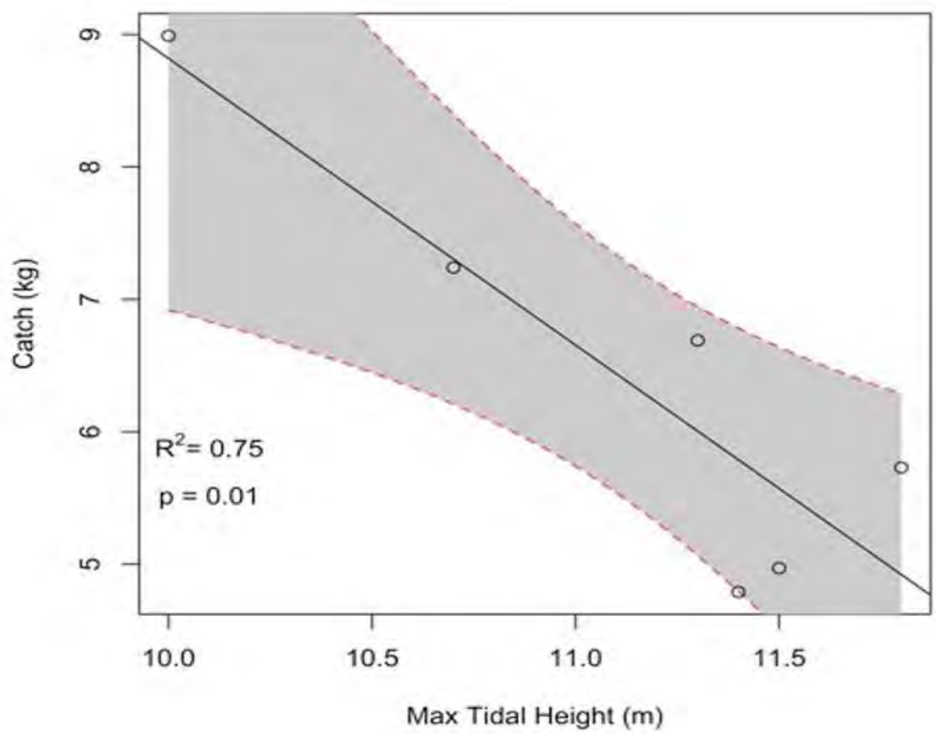


Figure 6. Mean daily station catchability relative to maximum daily tidal height.

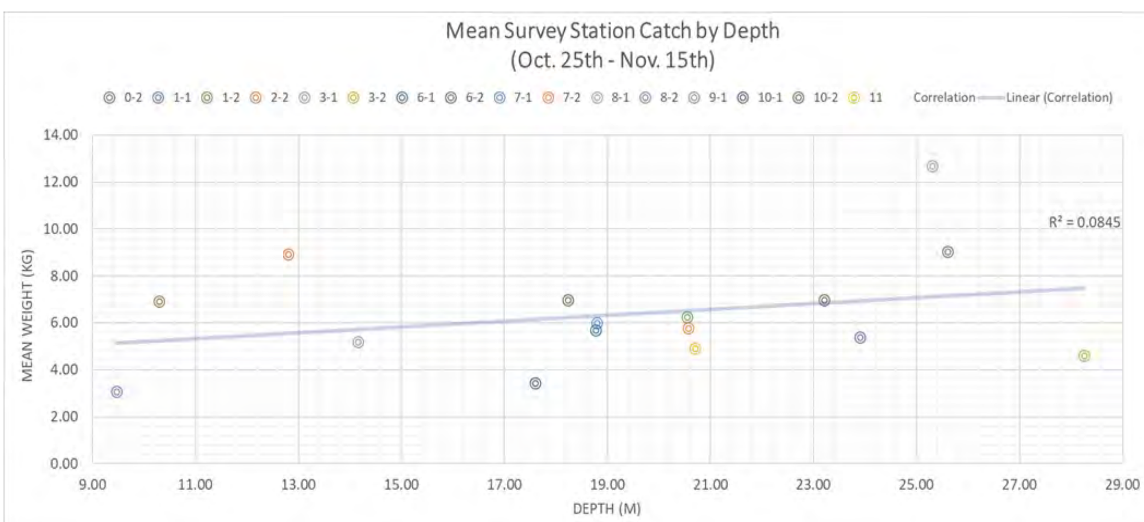


Figure 7. Mean station catchability relative to depth throughout the survey period.

Daily mean catchability for ring 1 was also high (> 2.7kg/trap) throughout the survey period (Figure 8). Ring 1 catch rates diminished slightly over time, and variability fluctuated with no clear trend. In figure 9, ring 2 daily catchability was also greater than 2.7kg/trap for the period. In contrast to ring 1, ring 2 mean catch rates reduced by a larger degree and variability also diminished. On November 2nd, 2017, ring 2 variability was almost negligible (0.13) and cannot be depicted on the chart.

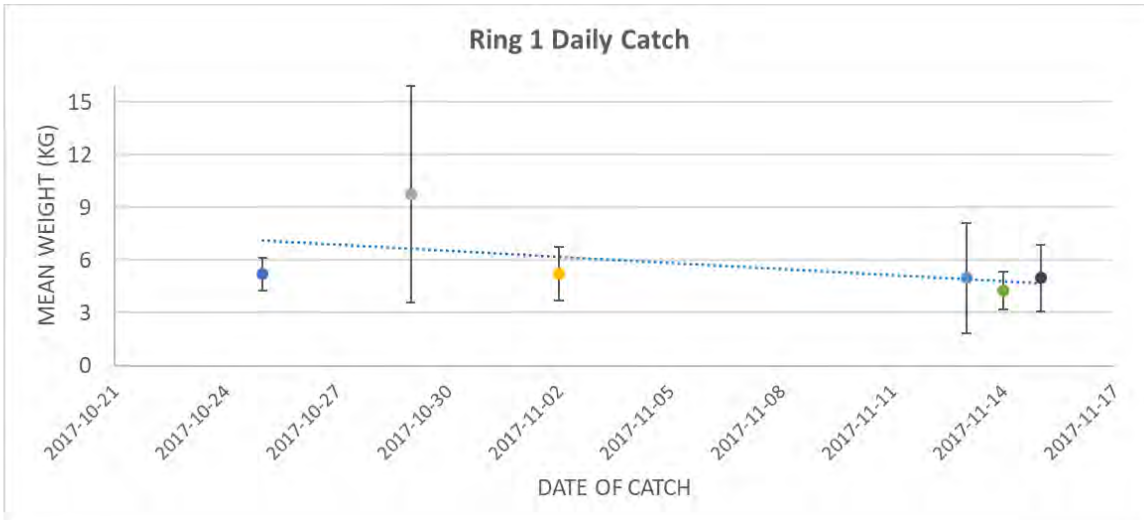


Figure 8. Mean daily ring 1 catchability and associated daily catch variability.

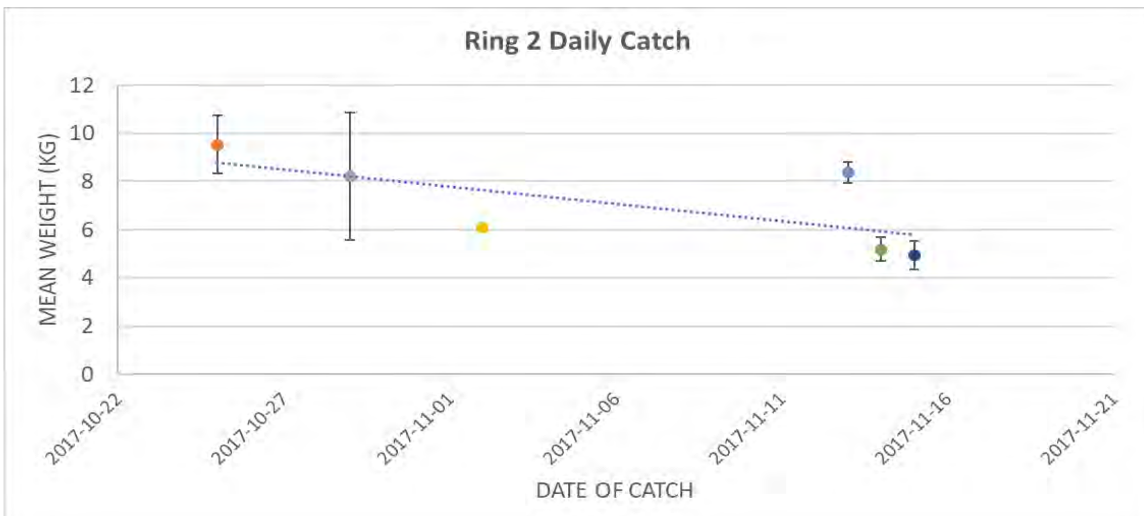


Figure 9. Mean daily ring 2 catchability and associated daily catch variability.

Mean ring 1 catchability for remained above 2.7kg/trap, for each quadrant throughout the period (Figure 10). Variability was high for the South quadrant (5.29) and moderate to low for the other quadrants. All quadrants in ring 2 also displayed high catchability throughout the period and variability was moderate. Catchability and variability trends are not depicted since these datasets are averaged across the survey period.

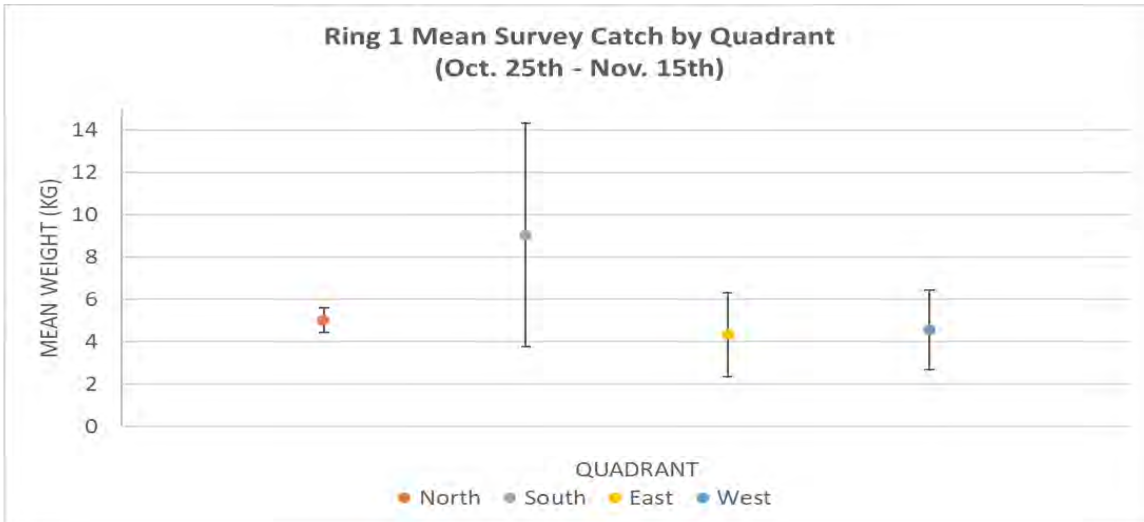


Figure 10. Mean ring 1 catchability and catch variability by corresponding quadrant.

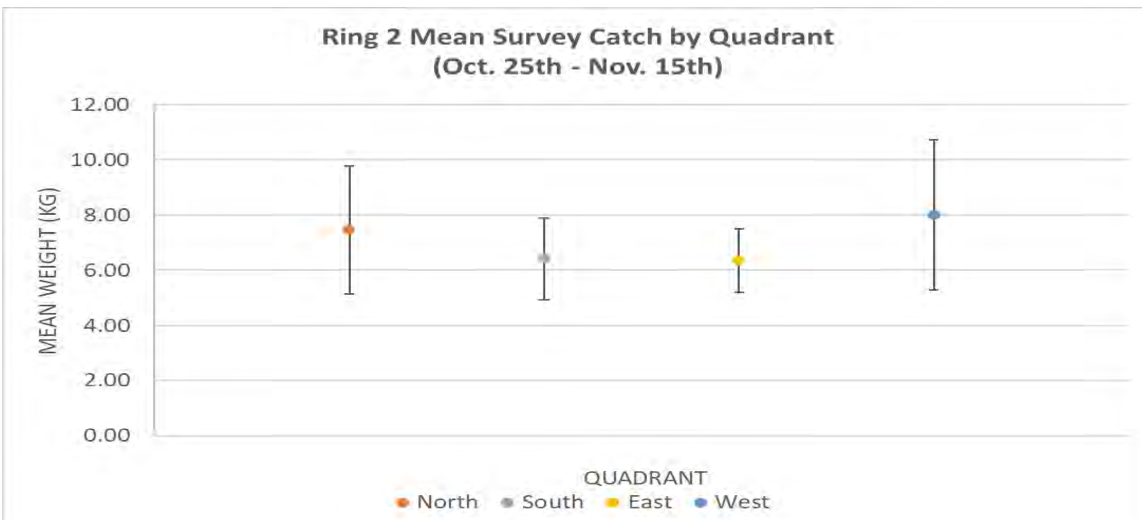


Figure 11. Mean ring 2 catchability and catch variability by corresponding quadrant.

SECTION IV: DISCUSSION OVERVIEW

FALL, IN-SEASON SURVEY

There is high catchability within the CLA, which indicates high lobster population density. Although catchability recorded by DFO is 2014 (above) is based on traps fished with open escape panels, the mean catchability for the CLA Fall survey trended within the baseline range of the broader Minas Passage fishery (DFO, 2017).

The following factors contribute to lobster population dynamics:

- Depth
- Temperature
- Currents (e.g. velocity and direction)
- Season
- Lobster mobility
- Lobster molt cycle
- Reproductive cycles (i.e. mating)
- Salinity
- Dissolved oxygen
- Photoperiod
- Natural mortality
- Fishing mortality (Factor, 1995)

Since mean tidal height trended within a narrow range of 0.10m, it is assumed that this tidal height will be a more significant factor to determine effect on catchability and will be used as a co-variant in the analysis of subsequent surveys. The potential effect of tidal height on future catchability studies can be mitigated by surveying within the same tidal period (neap tides; least variability between tides).

If we assume that the level of fishing efforts remains constant throughout the season (where all harvesters fish 300 traps per licence), then it may reasonable to assume this factor will not affect catchability if the survey is conducted during same period (commencing near the start of the fall lobster fishing season - October 15th). This will also enable inter-annual catch comparisons.

Sampling the same random fixed stations during each survey mitigates any effects of changing trap depth on catchability. Surface temperature data was collected for each station; however, the temperature-catchability relationship was deemed outside of the scope of this initial study and not analyzed. Subsequent studies will include covariant analysis of catch with temperature, as well as salinity, data collected at the site by FORCE

The following factors constrained the operational execution of the survey: high current velocity affecting vessel mobility, buoy resurfacing (which is dependent on depth and buoy length,) and short tidal window (approximately 1 hour straddling low slack tide). Buoy resurfacing time can be reduced by increasing the length of buoy line from 75m to 100m –

thus, increasing length of time buoys remain on the surface, which should improve operational efficiency. Unfortunately, due to the area's oceanography, and the constraints on the vessel to dock and depart straddling high tides, the other factors affecting operations cannot be mitigated.

Geological features of the CLA also had an impact on operations. The vessel experienced difficulties maneuvering to survey stations near Black Rock during high current velocities. The field team mitigated this by ensuring traps at these survey stations were deployed and retrieved during low velocity (during slack tide; 15-minute window). Station 9 was fixed near Black Rock and there was a risk to trap retrieval. Additionally, the bathymetry of the Minas Passage Plateau constrains the spatial bounds of the survey plot. Station 3-2 was fixed along the plateau's edge, which presented a risk to trap retrieval. Subsequent studies (after deployment of the Turbine) will focus sampling along the flow axis, by increasing the number of stations in instream quadrants and reducing the number of stations in lateral quadrants.

SECTION V: RECOMMENDATIONS

The 2017 Fall survey provided information on the nature and abundance of lobster in the immediate area around the FORCE site that will be essential for systematic evaluation on lobster catchability effects after future deployment of turbines at the site. The survey also provided an opportunity to test the methodology and survey design. Therefore, based on the findings from the survey the following recommendation are offered:

1. ***Modify survey design to ensure continued statistical validity of the study.***
2. ***Collect additional environmental information, specifically, temperature, salinity, turbidity.***
3. ***Adapt overall program design to consider cumulative effects of multiple pilot tidal energy projects.***

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Appendix 3:
Acoustic Data Analysis of the OpenHydro Open Center Turbine at FORCE

Acoustic Data Analysis of the OpenHydro Open-Centre Turbine at FORCE

Final Report

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28 June 2018

P001292-002
Document 01588
Version 3.0b

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Document Version Control

Version	Date	Name	Change
1.0	2018 Mar 28	B. Martin	Draft released to client for review.
2.0	2018 Apr 11	B. Martin	Final released to client.
3.0b	2018 Jun 27	C. Whitt	Updated version released to client. Includes static spectrograms in Section 4.1.

Suggested citation:

Martin, B., C. Whitt, and L. Horwich. 2018. *Acoustic Data Analysis of the OpenHydro Open-Centre Turbine at FORCE: Final Report.* Document 01588, Version 3.0b. Technical report by JASCO Applied Sciences for Cape Sharp Tidal and FORCE.

Disclaimer:

The results presented herein are relevant within the specific context described in this report. They could be misinterpreted if not considered in the light of all the information contained in this report. Accordingly, if information from this report is used in documents released to the public or to regulatory bodies, such documents must clearly cite the original report, which shall be made readily available to the recipients in integral and unedited form.

Contents

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Executive Summary

Cape Sharp Tidal (CST), a joint venture of Emera Ltd and OpenHydro, is evaluating the potential for generating electrical power from tidal water flow with OpenHydro's Open-Centre Turbine technology. A demonstration project is currently being conducted at the Fundy Ocean Research Centre for Energy (FORCE) test site in the Minas Passage, NS. The demonstration project aims to improve the turbine technology for long-term efficient generation of electricity from tidal currents and to understand and assess the potential effects of turbines on the environment. As required under the Environmental Assessment (EA) Approval, CST and FORCE developed Environmental Effects Monitoring Plans (EEMPs) to address the predictions of the EA. A key element of the EEMPs is the potential effects of turbine sound on fish and marine mammals.

The scope for the turbine sound component of the EEMPs is two-fold: 1) investigations to determine the best way to record operational and ambient sounds in the Minas Passage (both short and long term); and 2) subsequent data analysis to characterize the tidal turbine sound relative to the existing environment.

Acoustic data collection at the FORCE test site has been ongoing since 2012. Comprehensive measurements began in fall 2016 when CST deployed the first grid-connected Open-Centre Turbine on 7 Nov 2016, in the FORCE Crown Lease Area (the study area, Figure 1). After a six-month engineering evaluation, the turbine was disconnected from its subsea cable in April 2017, recovered in June 2017, and taken to Saint John, NB, for further design improvements. During the engineering evaluation, long-term acoustic recordings were made with hydrophones mounted on the turbine platform, as well as an autonomous hydrophone housed in a protective flow-shield on the seabed 167 m from the turbine. Short-term drifting hydrophone measurements were made before the turbine was installed on 18 Oct and 20 Oct 2016, and with the turbine in place on 27 Mar 2017. Two methods of hanging the hydrophone below the drifting float were evaluated: one with an 'S'-shaped catenary cable and one with an elastic cable and baffles to minimize movement.

This report, jointly funded by CST and FORCE, analyzes the 2016–2017 short- and long-term data to:

1. Compare tidal turbine sound to flow noise and how it depends on current speed, turbine state, and measurement method.
2. Estimate the possible effects of the turbine sound on marine life.
3. Evaluate the relative utility of instrument configurations to be used moving forward when measuring the effects of new turbine configurations on the acoustic environment.
4. Provide guidance on methodologies for performing acoustic measurements near tidal turbines and processing of acoustic data to mitigate effects of flow noise.

Based on these measurements, we find that at most frequencies the turbine has a lower source level than vessels that might be typical in the area. For porpoises, the sound amplitude of vessels and the turbine will be similar at similar ranges, and we can expect that pressure-sensing fish will detect and be affected by vessels at 7–10 times the range as the turbine.

The estimated ranges for sound to have various effects on animals is summarized in Table 1 and discussed in Section 4.3.

Table 1. The typical and maximum ranges to the selected thresholds for effects on marine life.

Acoustic effect	Typical range (m)	Maximum range (m)
Fish disturbance	< 30	30
Herring masking	500	1000
Porpoise masking	300	800
Porpoise TTS after 24 h	200	500

From these measurements we observed that autonomous recorders near the seabed provided the best data quality and best characterization of the turbine and ambient sound through all tidal and turbine operating states. Drifter measurements provided useful validation of turbine sound at various ranges but were insufficient to develop a model of the turbine sound in all tidal and operating states. Drifter hydrophone suspensions must include an effective means of isolating the hydrophone from surface wave action, and drifters should have a GPS logger attached to record the location at least twice per minute. Hydrophones on the turbine platform need to be more carefully isolated from flow noise and electrical noise.

Based on the results, we recommend:

- Autonomous recorders in high-flow shielded moorings be considered as the primary method of assessing turbine sound levels.
- Cabled hydrophones on turbine platforms should be located as close as possible to the seabed, and they should be protected by a stream-lined flow-shield.
- The sound signature of the Open-Centre Turbine should be re-assessed during the next deployment.
- At least one lunar cycle of ambient sound should be recorded before or after the next deployment, to quantify the ambient sound levels at all current speeds. An Acoustic Doppler current profiler should be deployed at the same time as the acoustic recorder.
- The detection performance for porpoise should be compared during a simultaneous deployment of the autonomous recorder and the turbine mounted hydrophones.

1. Introduction

To evaluate the potential for generating electrical power from tidal water flow with OpenHydro's Open-Centre Turbine technology, Cape Sharp Tidal (CST) is conducting a demonstration project at the Fundy Ocean Research Centre for Energy (FORCE) test site in the Minas Passage, NS. As part of the Environmental Assessment (EA) Approval, CST and FORCE developed Environmental Effects Monitoring Plans (EEMPs). A key element of the EEMPs is the potential effects of turbine sound on fish and marine mammals.

The turbine sound component of the EEMPs aims to: 1) determine the best way to record short- and long-term operational and ambient sounds in the Minas Passage and 2) analysis the collected data to characterize the tidal turbine sound relative to the environment.

Acoustic data collection at the FORCE test site has been ongoing since 2012. Comprehensive measurements began in fall 2016 when CST deployed the first grid-connected Open-Centre Turbine on 7 Nov 2016 in the study area (Figure 1). During an engineering evaluation, long-term acoustic recordings were made with hydrophones mounted on the turbine platform, as well as an autonomous hydrophone housed in a protective flow-shield on the seabed 167 m from the turbine. Short-term drifting hydrophone measurements were made before the turbine was installed and with the turbine in place.

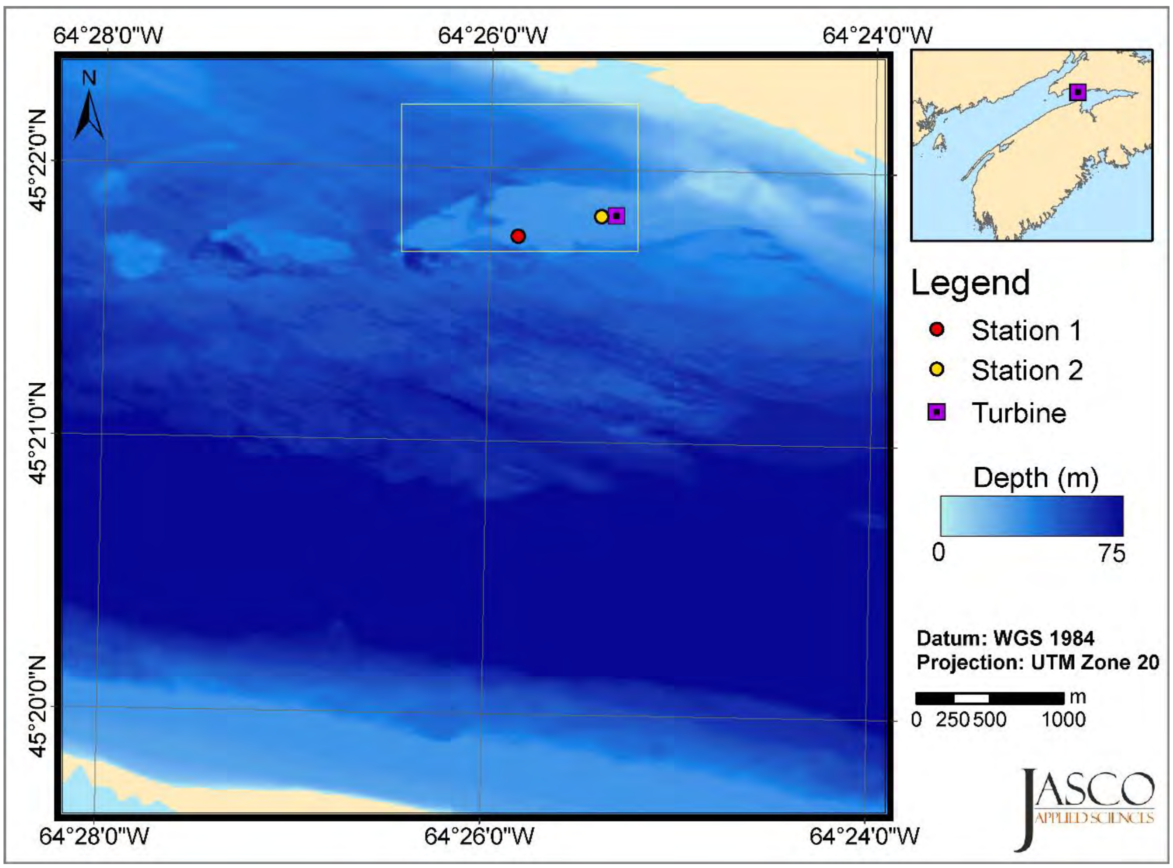

Figure 1. The study area, including locations of turbine and acoustic recorders at two 'stations'. Station 1 was the control site 680 m from the turbine. Station 2 was 167 m from the turbine. The FORCE test site is outlined in yellow.

This report analyzes the 2016–2017 short- and long-term data to:

1. Compare tidal turbine sound to flow noise and how it depends on current speed, turbine state, and measurement method. Specifically, to:
   a. Characterize the frequency content (i.e., spectrum) of the flow noise in relation to that of the tidal turbine sound and its correlation with the current speed.
   b. Determine the cut-off frequency below which the flow noise contaminates the acoustic measurements.
   c. Compare the received sound spectra between recording methods (drifting hydrophones versus hydrophones on the turbine platform versus autonomous recorders on the seabed).
2. Estimate the possible effects of the turbine sound on marine life. Specifically, to:
   a. Determine the total received sound level, as a function of frequency, for each increment of the tidal cycle,
   b. Determine the source level of the turbine as a function of frequency, tidal states, and turbine states,
   c. Determine the range from the turbine where the sound has the potential to injure marine life, and
   d. Determine the range from the turbine where the sound has the potential to mask biologically relevant sounds.
3. Evaluate the relative utility of instrument configurations to be used moving forward when measuring the effects of new turbine configurations on the acoustic environment.
4. Provide guidance on methodologies for performing acoustic measurements near tidal turbines and processing of acoustic data to mitigate effects of flow noise.

This report is divided into two parts. The first part of the report contains:

- Section 2: A summary of underwater sound and the effects of sound on marine life.
- Section 3: A summary of the methods used to collect and analyze the acoustic data for this project.
- Section 4: High-level results that address items 1 and 2 above and a discussion of the results and guidance on future acoustic data collection efforts.

The second part of the report is comprised of technical appendices providing detailed analysis results that support the summaries in the main report.

2. Effects of Underwater Sound on Marine Life

Underwater sound in the ocean is generated by four types of sources [1, 2]:

1. Natural geologic sources: Earthquakes, breaking waves, rain, ice, and sediment moving in high current conditions.
2. Man-made sources: Ships, sonars, seismic airgun surveys, and in-water activities such as drilling, pile-driving, dredging, and generating power.
3. Biologic sources: A wide variety of marine life makes and listens to sounds for social communicating, mating, mother-calf bonding, foraging, avoiding predators, and selecting habitat.
4. Measurement artifacts: Signals that are not caused by sound propagating in the water but instead are the result of how the measurements are made, including signals generated by water flowing around a hydrophone (flow noise), electrical noise from recording hardware, and sounds reflecting off recorders or moorings, which add to the sound travelling from the source to the hydrophone.

Different sources of sound can overlap in time, location, and frequency. The capacity for marine life to perceive and be affected by a sound depends how the sound's frequency content overlaps with the animal's hearing range (see Section 2.3). As a result, a source's frequency range is often used as the primary characteristic for assessing its possible effects (Figure 2).

The subsections below introduce how marine life uses underwater sound, the hearing capabilities of marine life, and the effects of sound on marine life. For more information on these topics that is geared toward a general audience, we recommend the website *Discovery of Sound in the Sea* (https://dosits.org).

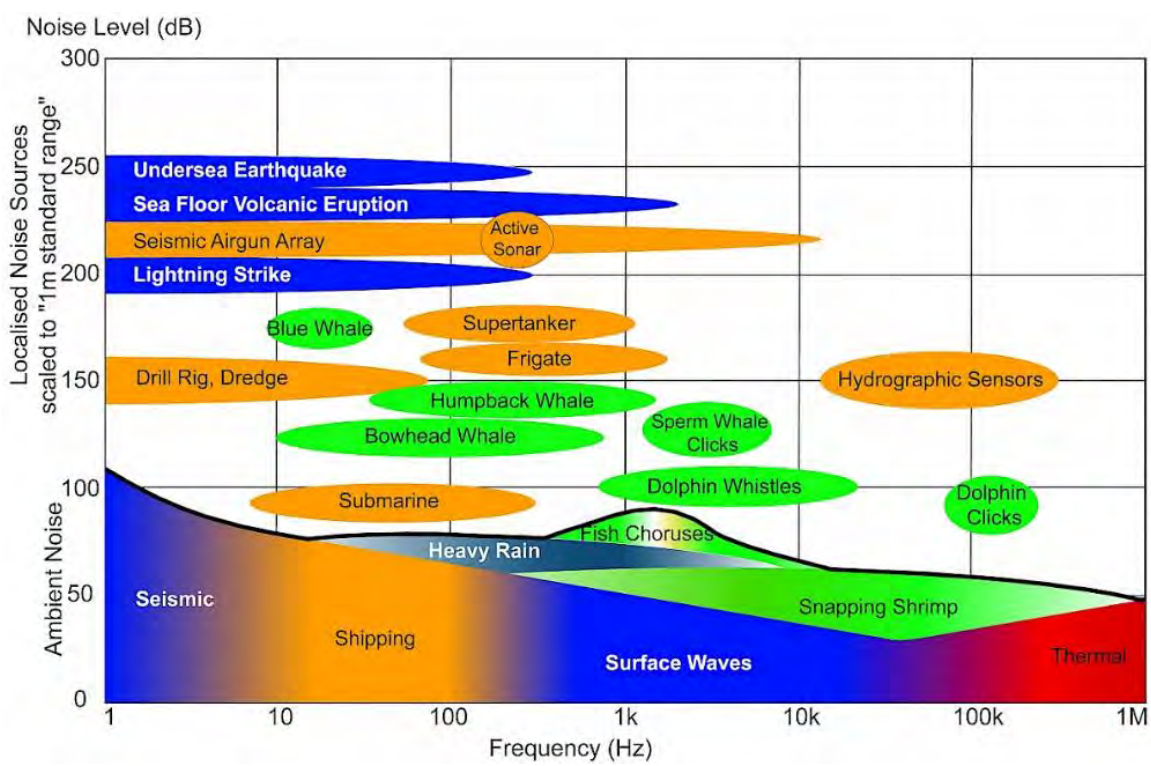

Figure 2. Sounds in the ocean. The spectral level of typical sound source, when measured at 1 m from the source, and the typical ambient noise levels measured by a recorder. Yellow sound sources are man-made, blue are geologic, and green are biologic. Thermal noise is the limit of what can be measured at high frequencies due to electronic self-noise (from https://www.ospar.org/work-areas/eiha/noise).

2.1. How Marine Life uses Underwater Sound

Hearing is one of the most important senses for marine life because light does not penetrate very far into the ocean. Sounds that are ecologically relevant to marine animals include conspecific calls, predator and prey sounds, natural sounds used for orientation, and echolocation calls from odontocetes (toothed whales) [3].

We know that marine mammals use sound for foraging and navigating [4-6], social communicating [e.g. 7], mother-calf bonding [8], and mating displays [9]. Populations of odontocetes that live together, such as dolphins, beluga, and pilot whales, have signature whistles that identify individuals to the group. Many populations of odontocetes have dialects used to communicate within their group, including sperm whale 'codas' [10] and the whistles of killer whales [11]. The Minas Passage is frequented by harbour porpoise that use the Passage as a feeding area. Porpoise emit a very high frequency echolocation click (~130 kHz) and listen for the echoes to navigate and to find food [12, 13].

All fish and sea turtles have hearing organs, and all individuals measured to date responded to sound in some way [14]. In fish, there have been multiple evolutions of sound production for courtship and agonistic displays [15], which implies a significant advantage is gained by being able to produce sound. Some reef fish select or avoid habitat based on sound [16], and it appears that both coral and fish larvae use the intensity and transient content of the soundscape to select settlement locations [17, 18]. This shows that sound is important to these species at all life stages. Invertebrates also produce and perceive sound. For example, oysters have a valve closing response to sound [19], as do scallops, which also make distinctive 'cough' sounds associated with clearing sediment from their valves [20]. Snapping shrimp generate bubbles by rapidly moving their claws; these bubbles are believed to be used for signalling and hunting. These sounds vary widely in space and time [21]. Lobsters and many other crustaceans sense sound and generate sounds that are believed to be associated with breeding [22].

2.2. Hearing Capabilities of Marine Life

The potential effects that a sound could have on an animal depend greatly on how well the animal can hear the sound. Marine mammals have two ears whose structure is very similar to that of land mammals. Their ears are sensitive to acoustic pressure in the water. Different groups of mammals have evolved their hearing for specific purposes, and they hear at different frequencies and with different minimum sound levels.

Marine fish have different hearing structures—three dense masses of bone, called otoliths, that respond differently to sound waves than the tissue around them. As a result, fish hearing is sensitive to the acceleration of the water caused by a sound rather than the acoustic pressure. In most cases, particle acceleration is only large enough to be perceived very close to a sound source [23]. Some fish, however, have adaptations that connect their swimbladder to the otoliths, which enhances their sensitivity to sound pressure. Fish and sea turtles can be organized into five large groups with respect to hearing and sensitivity to man-made sounds. The groups, arranged in order from most to least sensitive are: 1) fish with swimbladders involved in hearing, 2) fish with swimbladders not involved in hearing, 3) fish without swimbladders, 4) sea turtles, and 5) eggs and larvae. The grouping of the key species for the Minas Passage monitoring programs are shown in Table 2.

Table 2. Hearing groups of fish in the Minas Passage.

Hearing group	Key species in the Minas Passage
Fish with swimbladders involved in hearing	Atlantic herring (*Clupea harengus*) Alewife/Gaspereau (*Alosa pseudoharengus*) River herring (*Alosa aestivalis*) Shad (*Alosa sapidissima*)
Fish with swimbladders not involved in hearing	Atlantic salmon (*Salmo salar*) Atlantic cod (*Gadus morhua*) Pollock (*Pollachius pollachius*) Silver hake (*Merluccius bilinearis*) Red hake (*Urophycis chuss*) Striped bass (*Morone saxatilus*) Atlantic sturgeon (*Acipenser oxyrhynchus*)
Fish without swimbladders	Mackerel (*Scomber scombrus*) Wolffish (*Anarhichas lupus*) Sea raven (*Hemitripterus americanus*) Grubby (*Myoxocephalus aenaeus*) Summer flounder (*Paralichthys dentatus*) Witch flounder (*Glyptocephalus cynoglossus* Lump fish (*Eumicrotremus spp*.) Plaice (*Hippoglossoides platessoides*) Spiny dogfish (*Squalus acanthias*) Thorny skate (*Amblyraja radiata*) White shark (*Carcharodon carcharias*)

Invertebrates have a different sensory organ called a statocyst that is also believed to be sensitive to acceleration from water movement, gravity, and sound; however, there is limited data on the response of these structures.

The hearing sensitivity of a species, the threshold of hearing (akin to the level at which a sound becomes audible) as a function of frequency, is commonly referred to as an audiogram. Figure 3 shows examples of sound pressure audiograms for fish (left) and odontocete mammals (i.e., toothed whales (right) and harbour porpoises). Herring are fish whose swimbladders are involved in hearing and, as a result, they can sense acoustic pressure at relatively low levels over a wide frequency range. In contrast, salmon, cod, and dab (a flatfish) have swimbladders that are not involved in hearing and are therefore less sensitive to acoustic pressure. Their audiograms are elevated compared to those of herring and span a smaller frequency range. The odontocete audiograms show a wide range of sensitivities across species, but in general odontocetes are most sensitive in the range of 20 kHz and above, which is the band they use for echolocation. Their sensitivity at 200 Hz is lower than that of the salmon. Sea turtles have hearing like that of salmon shown in Figure 3 (left). Shark hearing is restricted to low frequencies (less than ~400 Hz), [e.g., 24], and, because they lack swimbladders, shark hearing relies on detecting the particle motion aspect of sound. There are no audiograms for marine invertebrates, but invertebrates lack air-filled cavities so these groups are presumed to respond primarily to particle motion, and only at low frequencies.

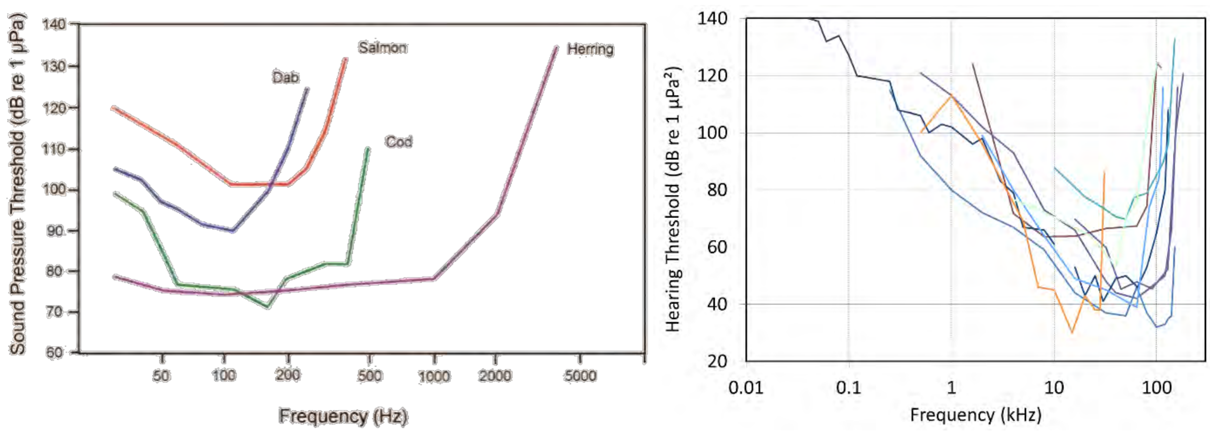

Figure 3. Example audiograms for fish (left [25]) and odontocete mammals (right, courtesy of H. Yurk and C. Gomez, extracted from the literature).

When determining potential effects of a sound source, audiograms are used to inform the process of frequency weighting received sound. Frequency weighting scales the importance of sound components at particular frequencies according to an animal's sensitivity to those frequencies. For human hearing, we use the 'A-weighting' auditory weighting function to filter sounds before estimating the effects [26]. The weighting function is an inversion of the audiogram (or equal-loudness curves when they exist), normalized to have a gain of zero at the frequencies of peak sensitivity. For marine mammal hearing, species are separated into five hearing groups, each with its own auditory weighting function (Figure 4). These weighting functions, developed by Finneran [27], are based on detailed analysis of existing audiogram data and other inputs and have been incorporated into the Technical Guidance issued by American regulators for assessing effects of noise on marine mammals [28]. No such generalized weighting functions exist for fish or invertebrates; however, inverted audiograms (i.e., Figure 3, left) have been used for individual species.

To determine the potential effects of tidal turbine sounds on relevant species, sound levels are compared with known thresholds for effects, or compared to ambient sound levels. In this analysis, we compare the high-frequency cetacean (e.g., porpoise) marine mammal weighted sound and the herring auditory filter-weighted sound pressure levels to the weighted background sound levels. We did this because porpoise and herring are the two most sound-sensitive species in the study area.

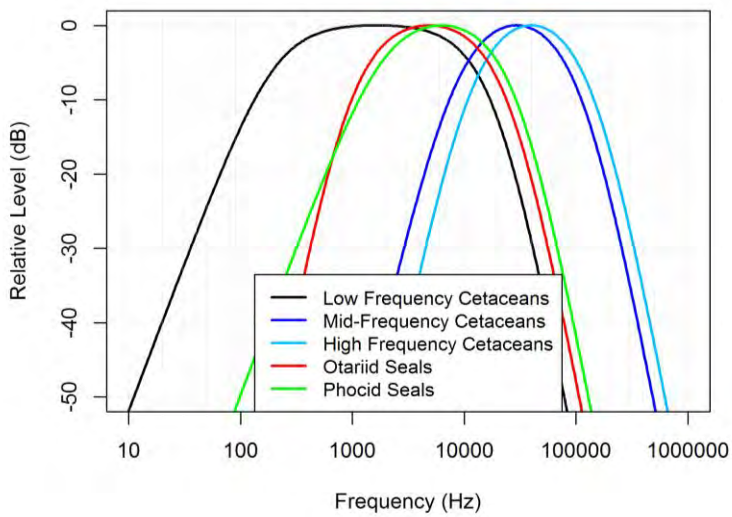

Figure 4. Auditory weighting functions for the marine mammal hearing group [28]. Low-frequency cetaceans include the large baleen whales (e.g., blue, fin, and humpback whales). Mid-frequency cetaceans are dolphins, sperm whales, and beaked whales that whistle and echolocate in the band of ~1000–80000 Hz. High-frequency cetaceans are dolphins, sperm whales, and porpoises that echolocate at ~130 kHz. Otariid seals are sea lions and fur seals, whereas phocid seals are considered 'true' seals, characterized by short fore flippers and the absence of external ears.

2.3. Effects of Underwater Sound on Marine Life

Short- and long-term studies of passive acoustic data in conjunction with observations of marine life behaviour have shown a wide range of impacts of man-made underwater sound on marine life. In general, impulsive sounds (brief, intermittent sound with a rapid rise and decay) have greater potential to damage hearing than non-impulsive sounds (broadband sound without a high peak pressure with rapid rise) because of their short rise time and high pressures . Non-impulsive sounds may present greater masking potential and greater behavioural effects due to their, typically, longer duration signals. Examples of observed effects of impulsive sounds include: diversion of migrating of bowhead whales around seismic surveys [29]; a change in bowhead whale calling rates in response to seismic surveys [30]; porpoise avoiding areas within 20 km of impact pile driving [31, 32]; seismic survey noise affecting scallops, lobsters, and zooplankton months after exposure [33, 34]; alarm and startle reactions in fish and squid to seismic surveys [35]; a variety of responses by benthic animals to substrate borne vibrations [36]; beaked whales responding and stranding when exposed to naval sonars [37-39]; blue whales changing behaviour and calling patterns when exposed to naval sonars [40, 41] or seismic surveys [42]; pile driving sounds injuring fish [43, 44]; blue mussels changing their metabolic state when exposed to pile driving [45]; and a marked difference in beaked whale echolocation clicks in the presence of vessels with active echosounders [46].

Known effects of non-impulsive sounds include: small boat noise affecting the settlement of larvae fish [47], affecting fishes orientation responses [48], and increasing fish cortisol (stress) levels [49]; vessel noise restricting the communication space for baleen whales [50]; vessel noise reducing the communication space of mating cod and haddock [51]; fish avoiding or changing behaviour in the presence of vessels [14, section 7.5.5] and stress hormones decreasing in right whales when shipping was reduced after 9/11 [52]. Adverse effects from noise on marine fish may also in turn affect other ecosystem components that rely on marine fish as a food source.

The effects of sound on humans and animals is generally visualized as a series of four zones, or concentric rings, around the sound source (Figure 5). In Zone 1, the sound exposure leads to barotrauma injury [for examples see 53] or permanent threshold shift (PTS), meaning that hearing is damaged and does not recover. In Zone 2, the sound exposure causes a temporary threshold shift (TTS) where hearing recovers after some duration (e.g., the morning after a rock concert). In Zone 3, the sound source masks the ability of an animal to hear another sound of importance (e.g., conspecifics, predators, prey, environmental queues). In Zone 4, the sound is still audible and may evoke a behavioural response (e.g., orientation, movement) or physiological response (e.g., stress hormones).

The first noise mitigation regulations based on noise thresholds were based on keeping the sound pressure level below the level associated with measured injuries to the hearing of marine life [54-56]. Evidence has since demonstrated that the total sound exposure level and the peak sound pressure levels are better indicators of injury than the sound pressure level [14, 57]. As a general rule, noise regulations are imposed on human activities to minimize injury to marine mammals and other endangered marine life rather than to reduce disturbance [58]. Understanding the effects of acoustic disturbance remains an important area of research [59, 60].

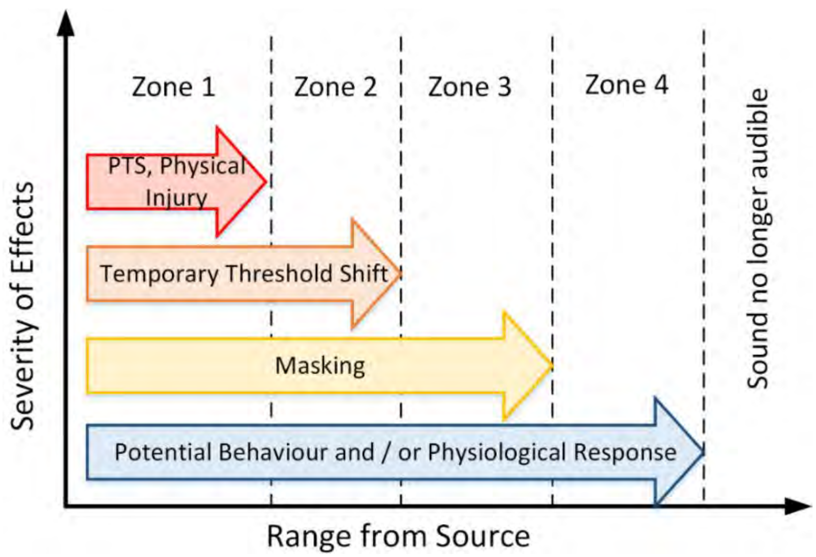

Figure 5. General principles of noise exposure (after Dooling, Leek and Popper [61]).

For assessing the potential of a project, such as the development of tidal energy in the Minas Passage, to affect marine wildlife it is useful to have numeric thresholds to compare with the project's emitted sounds. For fish, Canadian regulations include the protection of fish and fish habitat under the federal *Fisheries Act* and additional protection of specific species under the *Species at Risk Act.* No numeric thresholds are specified. Our best available information on effects of underwater noise on fish indicates that exposure to a sound pressure level of 158 dB re 1 μPa for 12 hours (194 dB re 1 μPa²·s sound exposure level) can cause temporary shifts in hearing thresholds (TTS) for fish with swimbladders [62], and exposure to a sound pressure level of 170 dB re 1 μPa for 48 hours (220 dB re 1 μPa²·s sound exposure level) causes recoverable injury for fish with swimbladders [63]. For behavioural reactions, 150 dB re 1 μPa² sound pressure level is often cited as the threshold for effects, as well as the minimum sound level at which injury effects begin to accumulate (known as 'effective quiet'), and it is assumed to apply to all hearing groups [64].

For marine mammals, Canadian regulations focus on critical habitats for species that are listed under Schedule 1 of the *Species at Risk Act;* the only noise thresholds that are specified apply to these habitats. American regulatory criteria provide the best available guidance for assessing potential hearing injury to marine mammals. The criteria use weighted functions based on frequency hearing range of the species (Figure 4) and calculate a daily sound exposure level (SEL; total daily sound energy) for predicting injury. For near continuous sound sources, such as tidal turbines, the daily exposure limit for porpoise is 153 dB re 1 μPa²·s to avoid temporary hearing threshold shifts, and 173 dB re 1 μPa²·s to avoid permanent hearing threshold shifts [28].

3. Methods

Collection and analysis of turbine and ambient sound used both long-term and short-term recording methods. Long-term acoustic recordings are weeks to months in duration using hydrophones that are held stationary on the turbine platform or on the seabed nearby. Short-term acoustic recordings are made using drifters that move with the currents past the turbine. The drifters typically travel 2–3 km in 10 minutes. At a speed of 12 km/h (6.5 knots), a drifter would spend 1 minute within ±100 m of the turbine.

3.1. Data Collection

In accordance with the EEMPs, CST and FORCE gathered extensive acoustic data during the deployment of the Open-Centre turbine from November 2016 to June 2017. This data set includes:

- Drifting hydrophone measurements made by FORCE on 18 and 20 Oct 2016 before the turbine was installed. Two types of drifters were evaluated—a drifter with a catenary 'S' shaped hydrophone suspension and a drifter with a simple elastic rope and damper to minimize hydrophone vertical movement. The drifter with the catenary used a JASCO AMAR recorder in a duty cycled setting sampling at 32 and 375 kHz (see technical details in Appendix A.1.4). The drifter with the elastic rope and damper used an Ocean Sonics icListen recorder sampling at 512 kHz (see technical details in Appendix A.1.3).
- Ocean Sonics icListen hydrophones were mounted on the turbine platform and transmitted their data to shore, as indicated in the 2017 EEMP annual report, up until cable disconnection in April 2017. The sample rates varied from 32 to 512 kHz over the measurement period (see technical details in Appendix A.1.2).
- An autonomous acoustic recorder (JASCO AMAR) in a specially designed high-flow mooring recorded data at the seabed 167 m from the turbine from 18 Nov 2016 to 19 Jan 2017. The JASCO AMAR recorder used a duty cycled setting sampling at 32 and 375 kHz (see technical details in Appendix A.1.1).
- Drifting hydrophone measurements made by FORCE on 27 Mar 2017 with the turbine free-spinning during a flood tide. The simple elastic-rope and damper drifter was used for these measurements. These measurements used an Ocean Sonics icListen recorder sampling at 512 kHz (see technical details in Appendix A.1.3).

Two autonomous recorders were originally deployed near the turbine. The second autonomous recorder was intended as a control measurement to capture ambient sound. That recorder was not recovered. We were able to extract enough information about ambient sound from the first autonomous recorder to sufficiently distinguish turbine sound from ambient sound and develop a model of turbine sound.

For contextual comparison of the Minas Passage measurements to the sound levels in the wider project area, the results of a four-month acoustic recording underneath the shipping lanes at the Grand Manan Basin are provided. Details of the measurement equipment configurations, calibrations, and mooring designs are contained in Appendices A.1 and A.2.

To help interpret the acoustic data, current speed and direction were measured at the turbine platform continuously during the deployment and CST logged turbine state data throughout the evaluation. The turbine states are categorized as: not-spinning, free-spinning, and generating.

3.2. Data Analysis

The objectives of this data analysis were to determine the frequency band affected by flow noise, the frequency band of the sounds emitted by the Open-Centre Turbine, and then comparing how these bands changed with turbine operating state, current speeds, and measurement technique (drifters versus turbine-mounted hydrophones versus autonomous bottom-mounted hydrophones), as well as investigate the potential relationship between turbine sound and marine life. The acoustic metrics used for these analyzes were 1-minute broadband sound pressure level (SPL), pressure spectral density, and decidecade-band SPL (see Appendix A.3). The decidecade sound pressure levels were weighted to also provide the high-frequency cetacean (Figure 4) and herring-auditory-filter weighted (Figure 3) sound pressure levels. We used 1-minute statistics to match the time resolution of the current speed and turbine state data set. One-minute averaging also smooths the random effects of turbulence and sediment movement sounds.

The metrics used throughout this report are *level* quantities. This means that they are ten times the logarithm of an acoustic measure divided by its reference value, and the units have the form 'dB re 1 μPa^2'. A result, a 10 dB increase in the level is equivalent to multiplying the acoustic measurement by 10. Details of the acoustic metrics are provided in Appendix A.3.

An automated odontocete click-detector (see Appendix A.7) was used to find periods when porpoise were vocalizing in the long-term data sets.

The analysis results were used to train models that provide the source level of the turbine as it changed with frequency, operating state, and current speed. Generalized Additive Models (GAMs) were used for the source levels modelling (see Appendix A.5), along with simplified acoustic propagation models (see Appendix A.6).

3.3. Data Quality

All JASCO instrumentation used in this study were calibrated before and after each use (see Appendix A.2). Data from other instrumentation were analyzed according to manufacturer-supplied calibration information. Calibrations were validated after data collection and before data analysis to verify instrument performance, as a standard part of JASCO's ISO 9001 Quality Management System. During processing and analysis, relevant ISO standards were used for acoustic metrics (see Appendix A.3).

4. Results

This section addresses the first two questions identified in Section 1. Recommendations for future measurement programs are contained in Section 4.3. Detailed results are contained in Appendix B, Appendix C, and Appendix D.

In this analysis, the current speeds are in units of normalized current speed, which is the percent of maximum current. To help interpret the acoustic measurements, it is important to note that the current speeds in the ebb tide are ~70% of those in the flood tide. The maximum daily current speed depends on the long-term tidal cycle and can vary from 65–100% of the absolute maximum (see Appendix B.1).

4.1. Comparing Tidal Turbine Sound to Flow Noise and Dependence on Current Speed, Turbine State, and Measurement Method

The data indicates that turbine sound is dependent on the current speed and the operating state of the turbine. Flow noise depends on the measurement method and current speed. Overall, the turbine and flow sound levels increase with the current speed and are higher in the flood tide than the ebb tide, similar to the current speeds.

In Figure 6, the full recording period of the autonomous seafloor AMAR recorder has been aligned so that the left edge of the data is at high tide. The first ~6 hours of the recording are median pressure spectral densities for each minute of the ebb tide, and the last ~6 hours are for the flood tide. The data from Figure 6 are presented slightly differently in Figure 7, which shows the decidecade sound pressure levels as a function of time since high tide and turbine state. From these figures, we identify four frequency bands of interest:

1. Primary flow noise: Up to ~60 Hz is dominated by flow noise (for the autonomous seafloor recorder). Increasing current speed increases both the magnitude of the flow noise effects and the range of frequencies affected.
2. Turbine Band 1: From ~60–250 Hz, there is a band of sound generated by the turbine in both free-spinning and generating states that intensifies with current speed.
3. Turbine Band 2: From ~600–1600 Hz, there is a band of sound from the turbine that is present only in the generating state. The amplitude of this sound does not depend on current speed.
4. Turbine Band 3: From ~3000–4500 Hz, there is a band of sound that is only present during the generating state whose amplitude depends weakly on current speed.

The data in Figure 7 has gaps in the generating and free-spinning curves near slack tide and in the not-spinning curves during the flood tide. This is due to the operating parameters for the turbine during the engineering evaluation: at least 15% normalized current was required to start the turbine spinning, and the turbine was always at least free-spinning during high current flows.

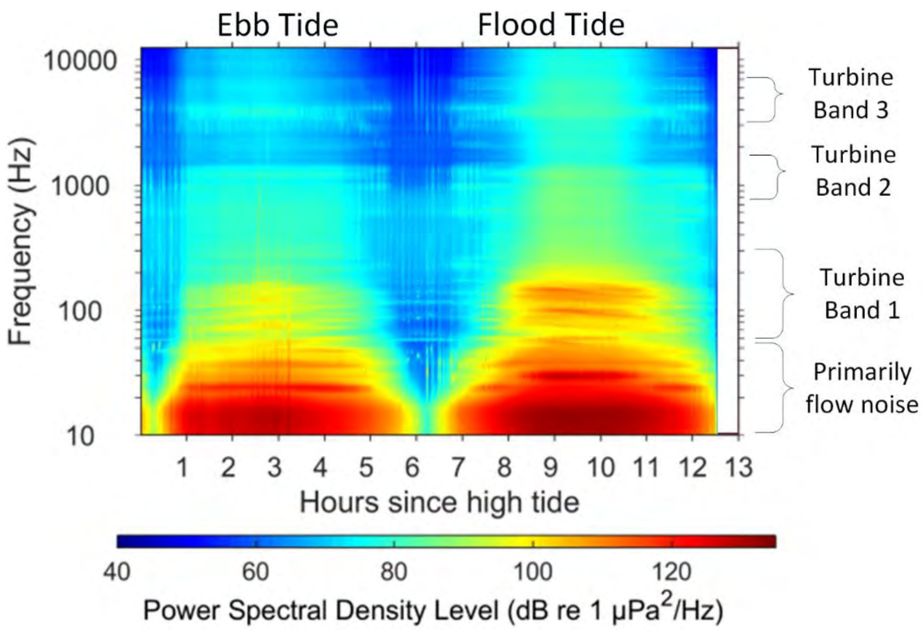

Figure 6. Pressure spectral density versus tidal increment time as measured by the AMAR 167 m from the turbine 18 Nov 2016 to 19 Jan 2017. The horizontal axis is time in hours since high tide.

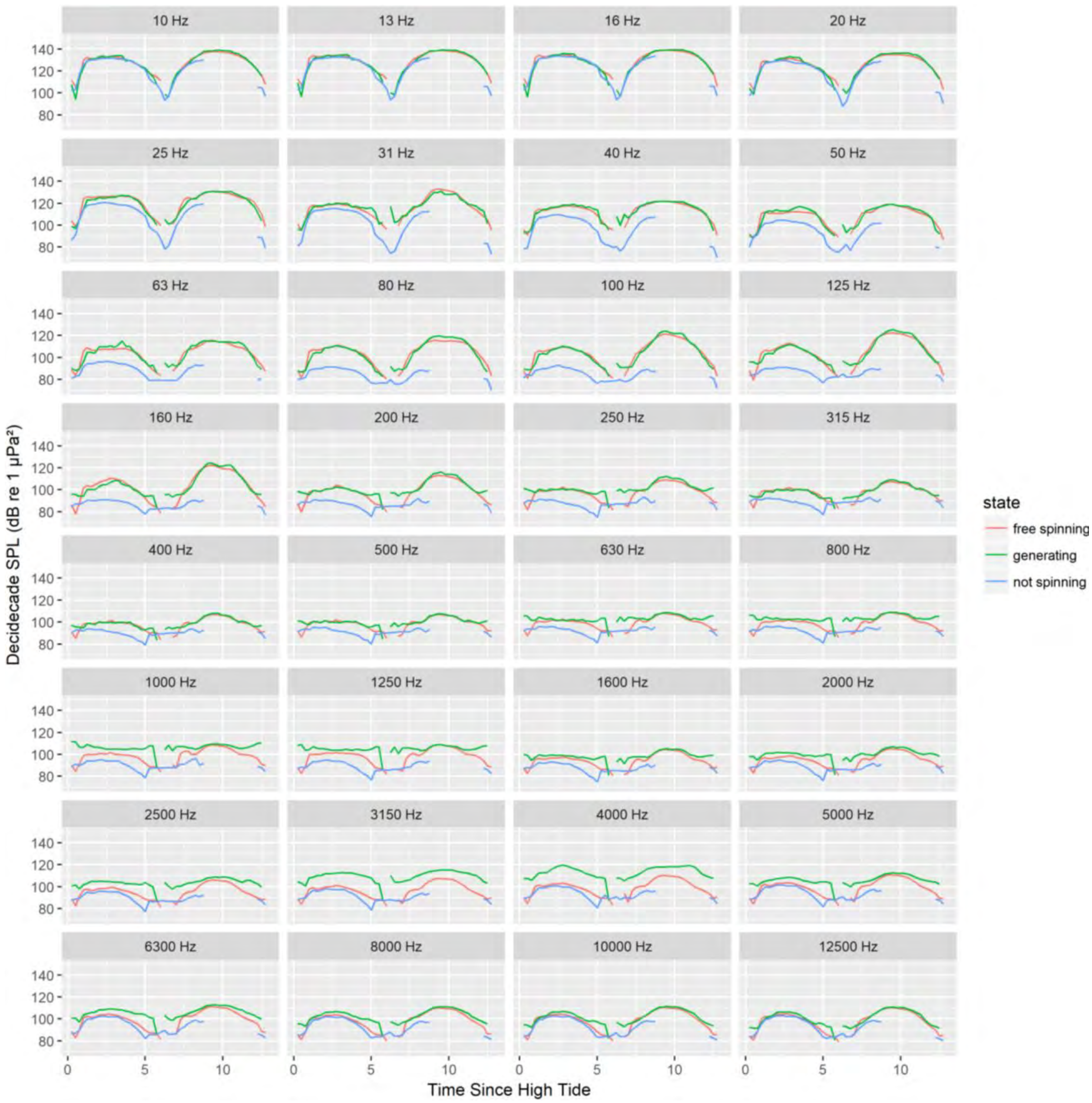

Figure 7. Median decidecade band SPL for each decidecade using data from the autonomous AMAR 167 m from the turbine. The turbine state is shown by the curve colours.

Figures 8 and 9 provide examples of the sounds created by the Open-Centre turbine. The generating state produced broadband rasping sounds (Figure 8). The free-spinning operating state produced a knocking and vibrating sound, as well as tones in the 50–200 Hz range (Figure 9). Throughout the recordings, occasional impulsive sounds were observed, possibly produced by sediment striking the metal housing of the turbine or the recorder (e.g., at ~15 sec in Figure 9). The examples in Figures 8 and 9 are typical of sounds in the different operating states and how the sound transitioned between states. However, a wide variety of onsets and transitions were found. These depended on how the OpenHydro engineers configured the turbine control centre, which was tested and evaluated during these recordings.

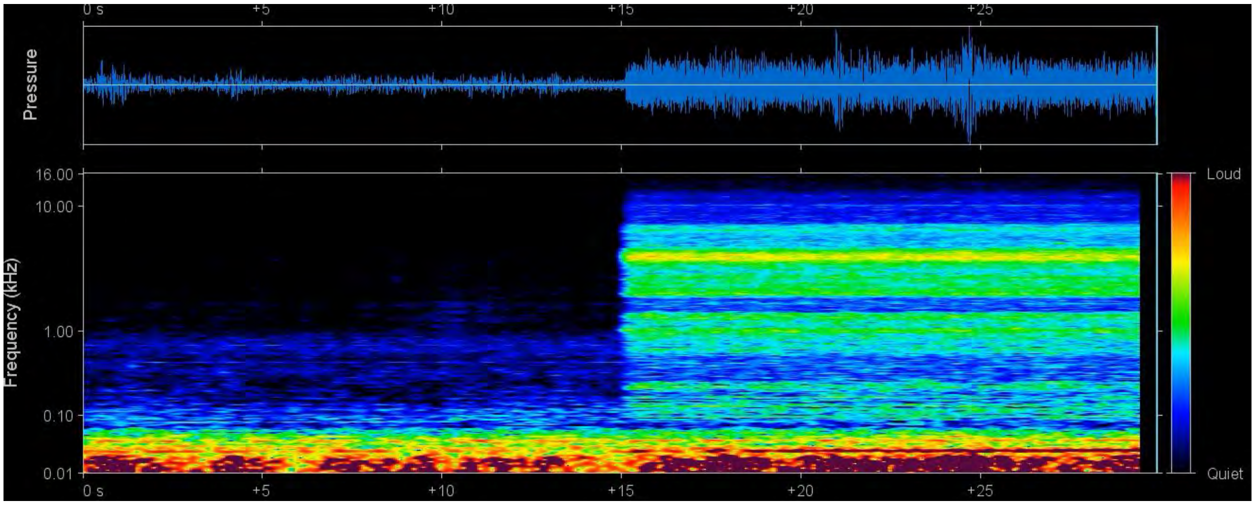

Figure 8. Spectrogram from 30 second MP4 movie containing the sound recorded by the AMAR 167 m from the OpenHydro turbine when it switched from not spinning to generating in a 20% normalized speed flood current at 14:39 on 17 Jan 2017.

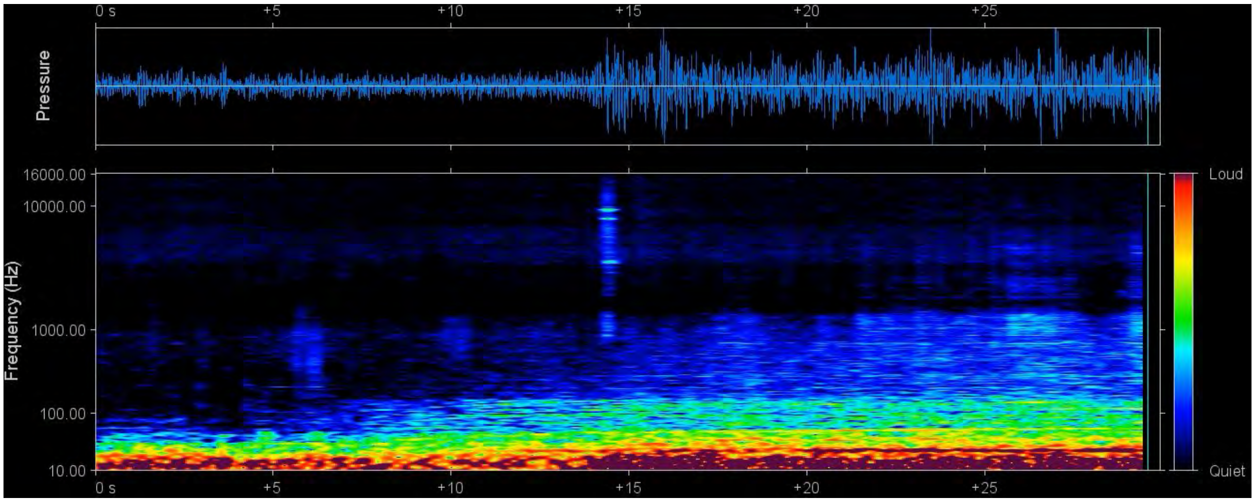

Figure 9. Spectrogram from 60 second MP4 movie containing the sound recorded by the AMAR 167 m from the OpenHydro turbine when it switched from not spinning to free wheeling in a 50% normalized speed ebb current at 21:29 on 5 Dec 2019. The knocking/vibrating sound at the end of the clip was typical for the free-spinning state.

To determine how the measurement method affects the flow noise, we compared median pressure spectral densities as an indicator of the effectiveness of different long-term recording positions (Figure 10). In Figure 10, two spectra are shown from the hydrophones on the turbine platform—the hydrophone on the forward-port leg of the platform and the hydrophone on top of the turbine (hydrophone mounting arrangements are shown in Figure 27). These are compared to the seabed AMAR located 167 m from the turbine, the icListen drifter data from 27 Mar 2017, and reference data from the outer Bay of Fundy. Turbulent flow noise is expected to have a slope of frequency$^{-5/3}$; this noise is included in Figure 10 for comparison [65, 66].

The similarity of slope of all the measured data to the frequency$^{-5/3}$ line at low frequencies shows that all recording methods considered are affected by flow noise to varying degrees. For frequencies greater than 60 Hz, the autonomous AMAR data appears to be representative of sounds in the water rather than flow noise. The autonomous, shielded, and bottom mounted location of AMAR was 5–20 dB quieter than the hydrophone in the forward-port location, and 10–40 dB quieter than the turbine top location. The icListen drifter data from 27 Mar 2017 had similar median sound levels to the AMAR from ~90–1000 Hz; however, we found that there was vertical movement noise up to ~150 Hz when comparing sound levels as a function of current speeds. Above 1000 Hz, measured sound levels in the Minas passage were up to 5 dB higher than the outer Bay of Fundy because of sediment impact noise hitting the instrumentation or surrounding structures. The sediment noise may have had higher levels on recordings made above the seabed compared to the autonomous bottom mounted recorder.

The analysis of the turbine sound levels used the autonomous recordings because flow noise affected a much wider range of frequencies on the turbine platform hydrophones. The 63 Hz decidecade was chosen as the lowest frequency band where the turbine sound levels were sufficiently above the flow noise for analysis.

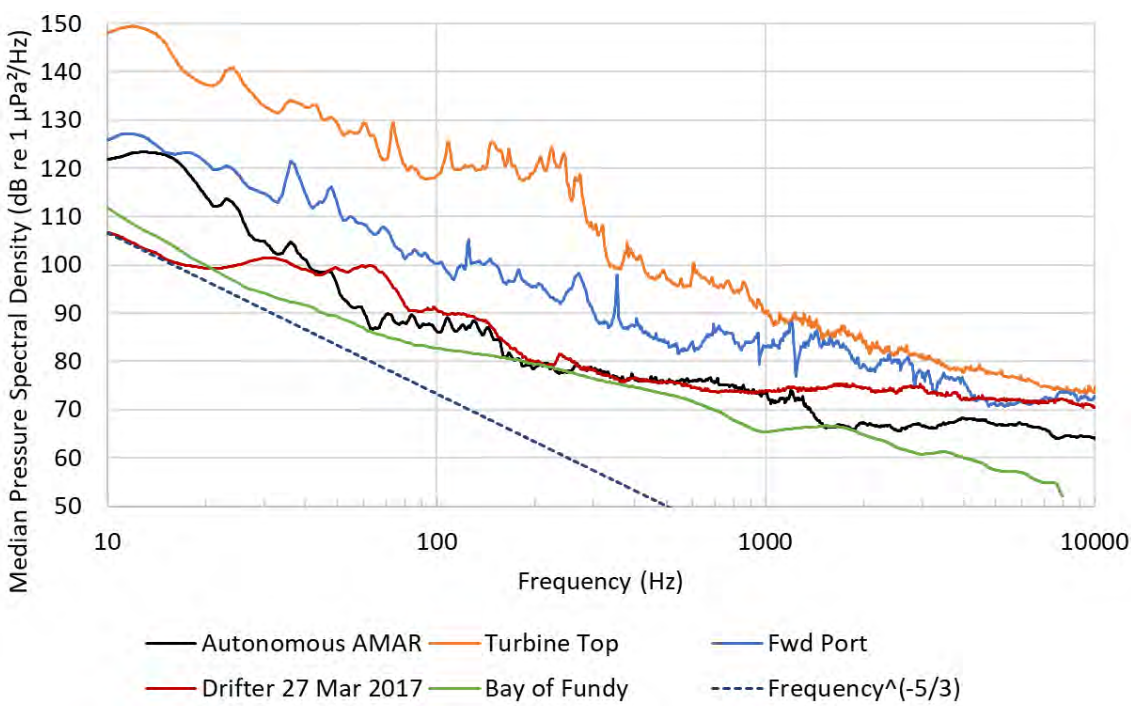

Figure 10. Median pressure spectral densities for three different long-term recording positions, as well as the icListen drifter measurements from 27 Mar 2017

4.2. Turbine Sound Level Modelling

We used the data from the autonomous recorder to train models of the decidecade received sound pressure levels that depended on the current speed for each of the operating states (not spinning, free spinning, and generating), as well as the two current directions (ebb and flood). Figure 11 shows examples of the predicted levels from the model and how they compare to the median decidecade sound pressure levels from the outer Bay of Fundy. The model analysis shows:

- The sound levels in all three turbine states does not depend strongly on the current direction, only on the current speed.
- The ambient conditions in the Minas Passage at frequencies below 1 kHz are up to 25 dB quieter than the sound levels in the outer Bay of Fundy.
- The turbine emits a band of sound in 60–250 Hz range in the generating and free-spinning states that increases by 20–30 dB as the current speeds increases.
- The turbine emits a band of sound in the 1000–1250 Hz range while generating that is nearly constant sound level, regardless of currents speeds.
- The turbine emits a band of sound in the 3150–4000 Hz while generating whose sound levels increase by ~10 dB as the current speed increases.
- The free spinning state is 5–25 dB quieter than the generating state, especially at low current speeds.
- At normalized currents of 80%, the sound levels are 10–30 dB above the levels recorded in the outer Bay of Fundy.

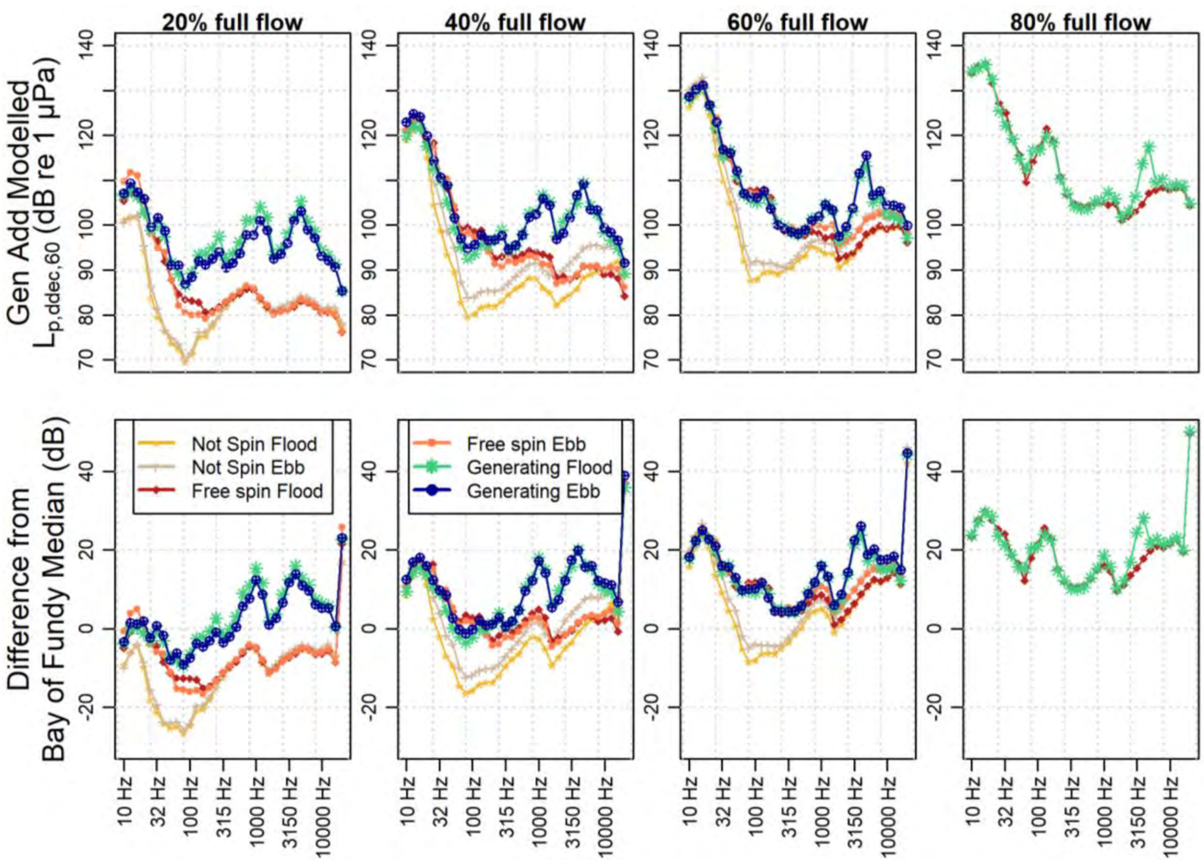

Figure 11. General additive modelled decidecade sound pressure levels received at the autonomous AMAR for normalized current speeds of 20, 40, 60, and 80% of full flow. (Top row) the modelled sound pressure levels. (Bottom row) the difference between the median decidecade sound pressure level measured under the shipping lanes in the Bay of Fundy and the conditions measured in the Minas Passage

The models were validated by looking at boxplots of their predictions compared to the measurements. The not-spinning case had the largest measured-modelled errors of ~−3 dB for turbine speeds below ~25% of full speed, which is due to the presence of additional sound sources (such as wind and waves) that are not part of the models. As the current speeds increase above 25% of full speed, the models have ~0 dB mean error compared to the measurements and progressively smaller interquartile ranges as the speed increases. This implies that the turbine sound becomes highly predictable as the speed increases and it is well characterized by the autonomous recordings (Appendix C.2.2).

The model was then converted to a *source level* model by adding $20 \cdot \log_{10}(167\ \text{m})$ to the received levels since the recorder was 167 m from the turbine. The source level model was then verified by using it to predict the expected sound levels from the icListen drifter during the drift that passed closest to the turbine on 27 Mar 2017. Using a restricted frequency band of 63–400 Hz, the agreement was excellent, both for the background noise levels and the turbine levels (see Appendix D.1).

We recommend only the source level model of turbine sound for specific frequency ranges and flow speeds. The measured data did not allow a useful model to be created for other conditions. For the free-spinning case, the valid frequency range of the model is the 63–400 Hz decidecade bands, and the model is only recommended for normalized flow speeds from 20–100%. For the generating case, the valid frequency range is the 63–10000 Hz decidecade bands, and the model is only recommended for normalized flow speeds from 20–70%.

Appendix D.3 presents spreadsheets that contain the median modelled sound pressure levels as a function of decidecade band and normalized flow speed.

4.3. Ranges to Effects of Sound on Marine Life

The verified source level model estimated ranges to thresholds for possible effects on marine life:

- The range where sound levels drop below the fish behavioural effects threshold (150 dB re 1 μPa²).
- The range where the herring auditory filter weighted sound levels drop below the median herring auditory filter weighted ambient noise levels for the Minas Passage.
- The range where the high-frequency cetacean (HFC) marine mammal hearing weighted sound pressure levels drop below the HFC weighted ambient sound levels.
- The range where the daily HFC weighted sound exposure level drops below the temporary threshold shift (TTS) criteria of 153 dB re 1 μPa²·s.

We found that:

- The turbine sound only exceeds the threshold for behavioural disturbance to fish (150 dB re 1 μPa²) at ranges less than 30 m and only at the highest current speeds on the flood tide (Figure 12).
- The range where the turbine could be audible to herring, or mask sounds a herring could hear, was less than 1000 m (upper inter-quartile values in Figure 13). For most turbine states and current speeds, the range was less than 500 m.
- The range where the turbine could be audible to porpoise, or mask sounds porpoises could hear, was less than 800 m (Figure 14). Ranges were generally less than 300 m in the generating state. In the free-spinning state, the turbine did not generate sound levels in the porpoise hearing frequency band that were measurable above ambient sediment noise at a range of 167 m (at the autonomous recorder).
- The range where the turbine could cause TTS in porpoises, if one stayed beside the turbine for 24 hours, was 150–250 m on most days and increased to 500 m during spring tides (Figure 15).

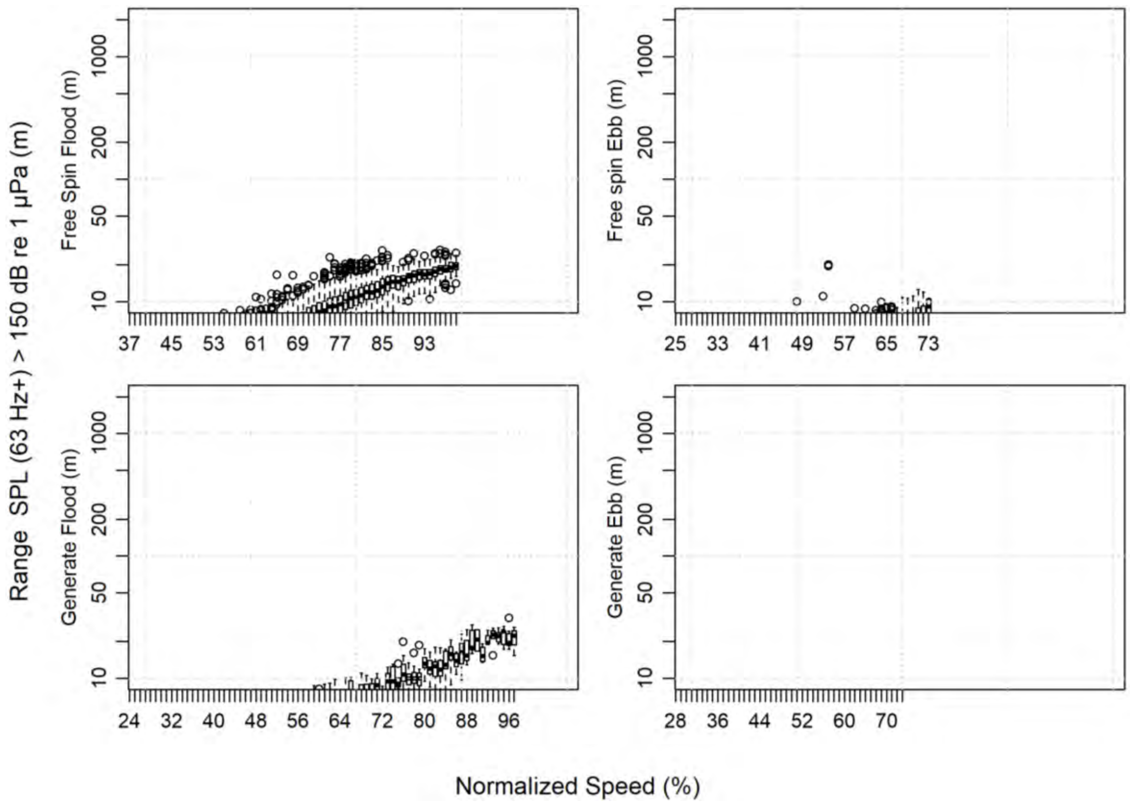

Figure 12. Threshold ranges for possible behavioural disturbance to fish.

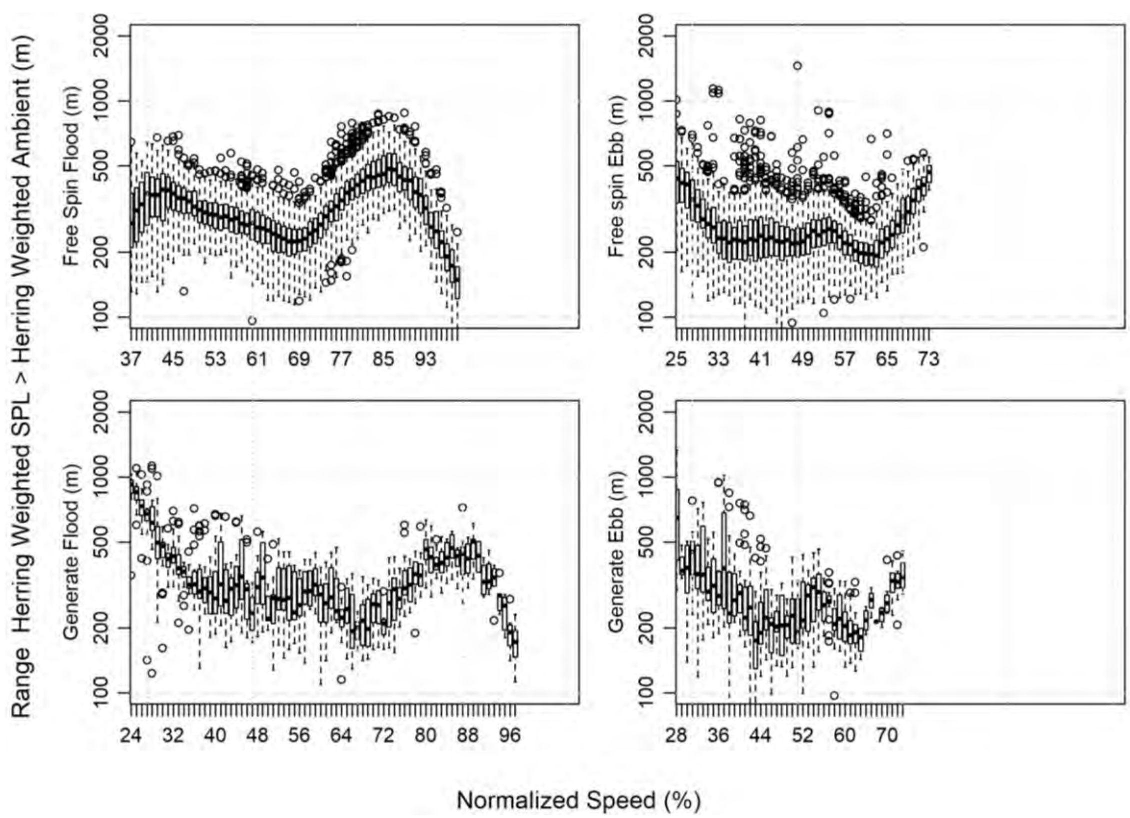

Figure 13. Threshold ranges where the herring-weighted turbine sound exceeds ambient herring weighted background.

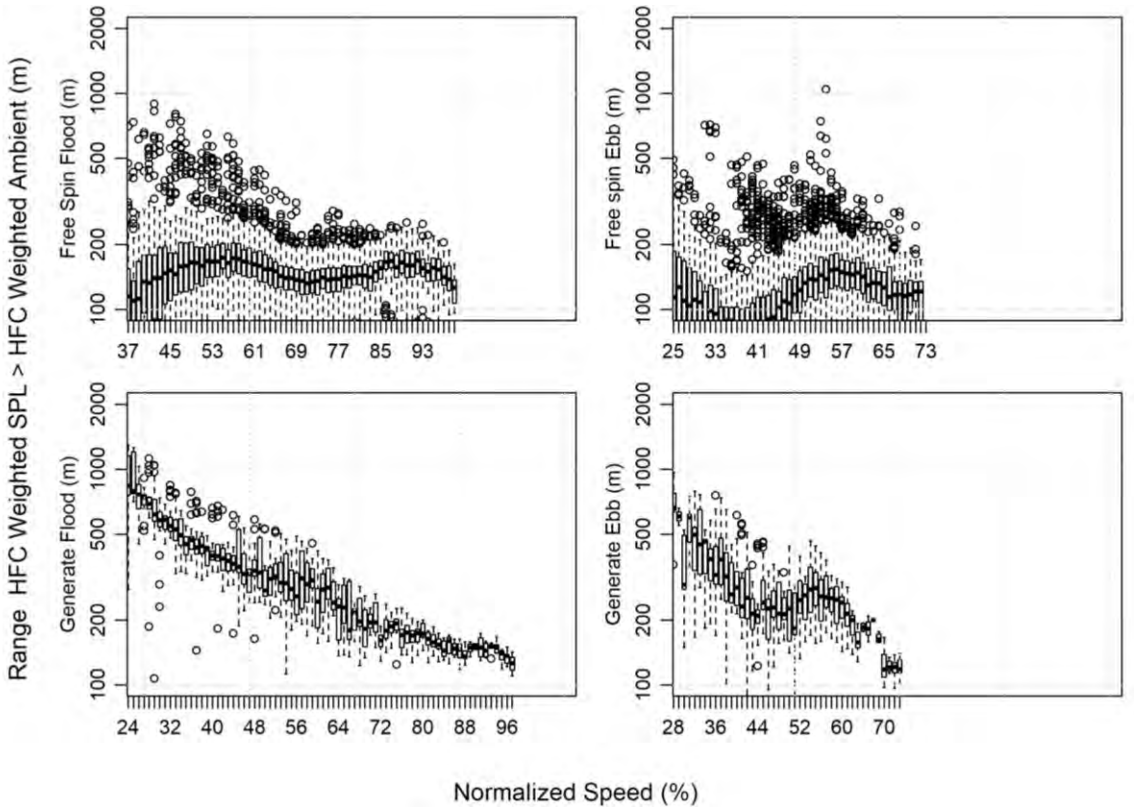

Figure 14. Threshold ranges where the high-frequency cetacean auditory-filter weighted turbine sound exceeds the high-frequency cetacean auditory-filter weighted background.

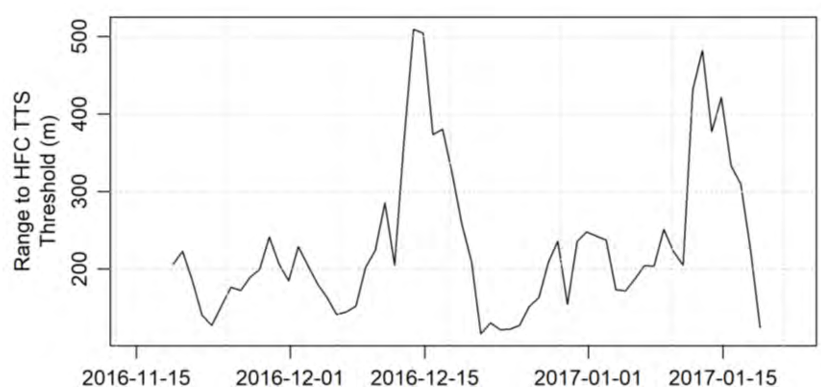

Figure 15. High-frequency cetacean weighted daily sound exposure levels and range to possible temporary threshold shift (TTS). Porpoises would need to stay within this range of turbine for a full 24 hours to accumulate enough acoustic energy for the onset of temporary hearing injury.

5. Discussion

5.1. Open-Centre Turbine Sound, Ambient Sound and Typical Vessels

We have compared the turbine sound to a typical fishing vessel at 10 knots and a typical tugboat at 10 knots (Figure 16) [67] to put the amplitude of turbine sound in context of other sounds typical of the area. Below 4 kHz, the turbine has a lower source level than the vessels. In the generating case, the 4000 Hz decidecade has a similar source level as the typical vessel. Since the maximum source level of the turbine is ~165 dB re 1 μPa² and the vessels are ~180 dB re 1 μPa² at low frequencies, we can expect that pressure-sensing fish will detect and be affected by vessels at 7–10 times the range as the turbine. For porpoises, the sound amplitude of vessels and the turbine will be similar at similar ranges.

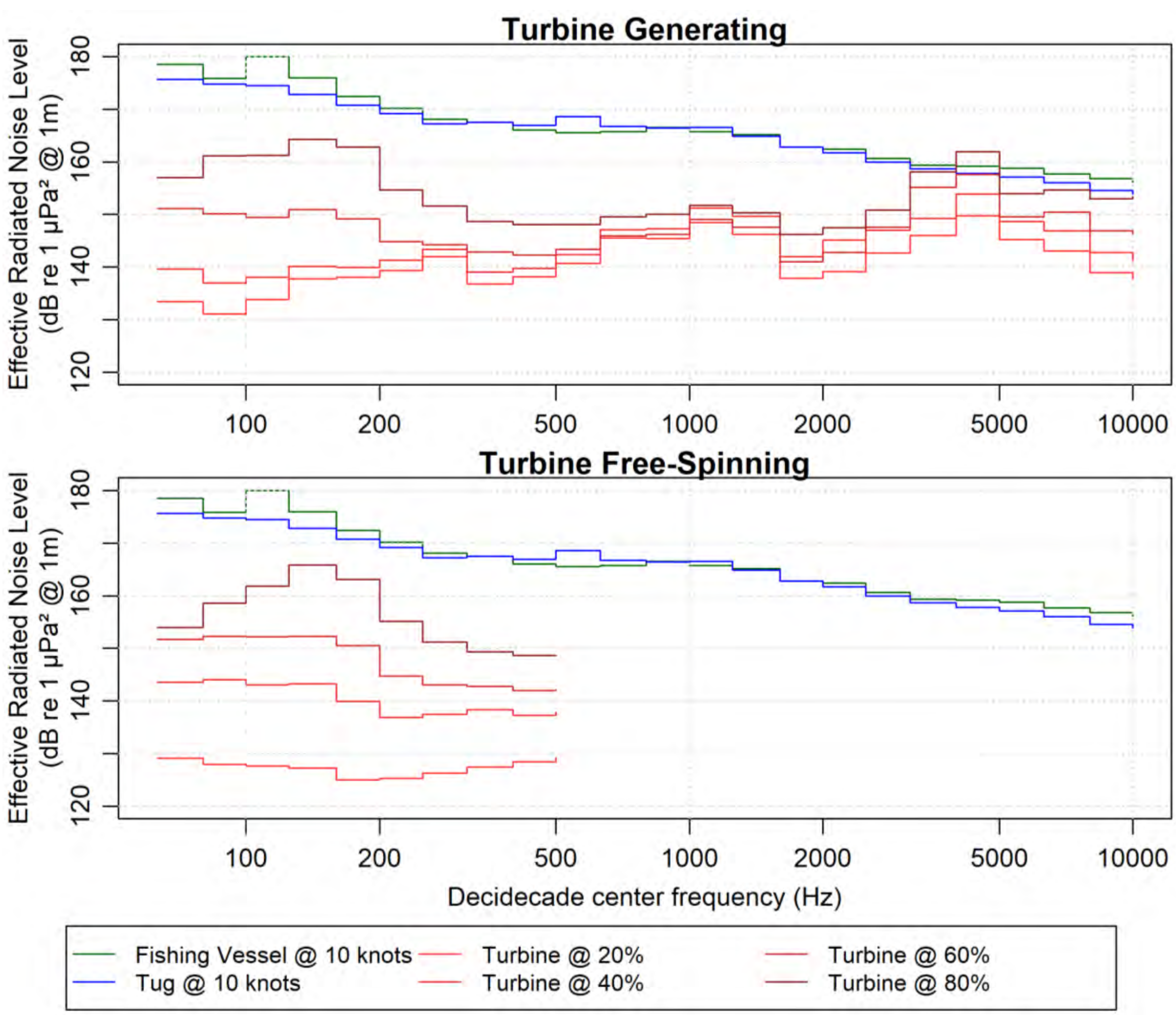

Figure 16. Comparing the turbine source levels to typical fishing and tugboat source levels at 10 knots. Above 400 Hz the turbine does not generate sounds in free-spinning mode that are measurable above background at 167 m.

Table 3. Comparing broadband and weighted effective radiated noise levels (dB re 1 µPa² @ 1 m)

Vessel class	Broadband effective radiated sound level (63 Hz–10000 Hz generating & vessels, 63–400 Hz free spinning)	Herring audiogram weighted (including sound below 63 Hz for all sources)	High-frequency cetacean weighted
Free spinning 40% current speed	153	160	--
Generating 40% current speed	160	158	144
Free spinning 80% current speed	170	173	--
Generating 80% current speed	171	173	155
Fishing vessel @ 10 knots	186	186	155
Tug @ 10 knots	184	184	153
Recreational @ 12 knots	172	164	155
Large ferry @ 20 knots	194	194	158
Tanker @ 14 knots	191	192	154
Container @14 knots	190	192	156

Notes: 63 Hz is the lowest frequency that is consistently above flow noise for the autonomous recorder. The free-spinning turbine only emits sound in the band of 63–400 Hz (which does not overlap with the high-frequency cetacean auditory filter; see Figure 4).

5.2. Turbine Sounds and Marine Life

We cannot say what the effects of sound were, only what the effects of turbine sound on marine life might be. The estimated ranges for sound to have various effects on animals is summarized in Table 1. Results are presented in Section 4.3 and Appendix D.2.

In general, the range from the turbine to each of the identified thresholds is typically much shorter than the maximum range. This is because turbine and ambient sounds are at a maximum only at peak current speeds at spring tides, for short periods of time during the day, and only for a few days each lunar cycle.

The typical and maximum ranges for each threshold described in Table 1, Section 4.3, and Appendix D.2 are shown in subsequent figures to illustrate the ranges relative to the size of the Minas Passage. Figure 17 shows the range until the sound decreases to below the threshold for behavioural disturbance to fish. At the scale shown in Figure 17, the range is indistinguishable from the turbine location. Figure 18 shows the range until sound decreases below the threshold for masking any sound a herring could hear. Figure 19 shows the range until turbine sound levels decrease below the level audible to porpoises, or mask sounds porpoises could hear. Figure 20 shows the range where the turbine could cause TTS in porpoises, if one stayed within that range for 24 hours.

The range where the turbine could cause TTS in porpoises was calculated by accumulating the sound exposure level over multiple tide cycles, so it accounts for variations in both turbine sound and ambient sound. To exceed the exposure threshold would require an individual animal to stay within that range for the entire 24 hours. It is highly unlikely that a porpoise would remain near the turbine for longer than one hour, and therefore TTS is not expected to occur.

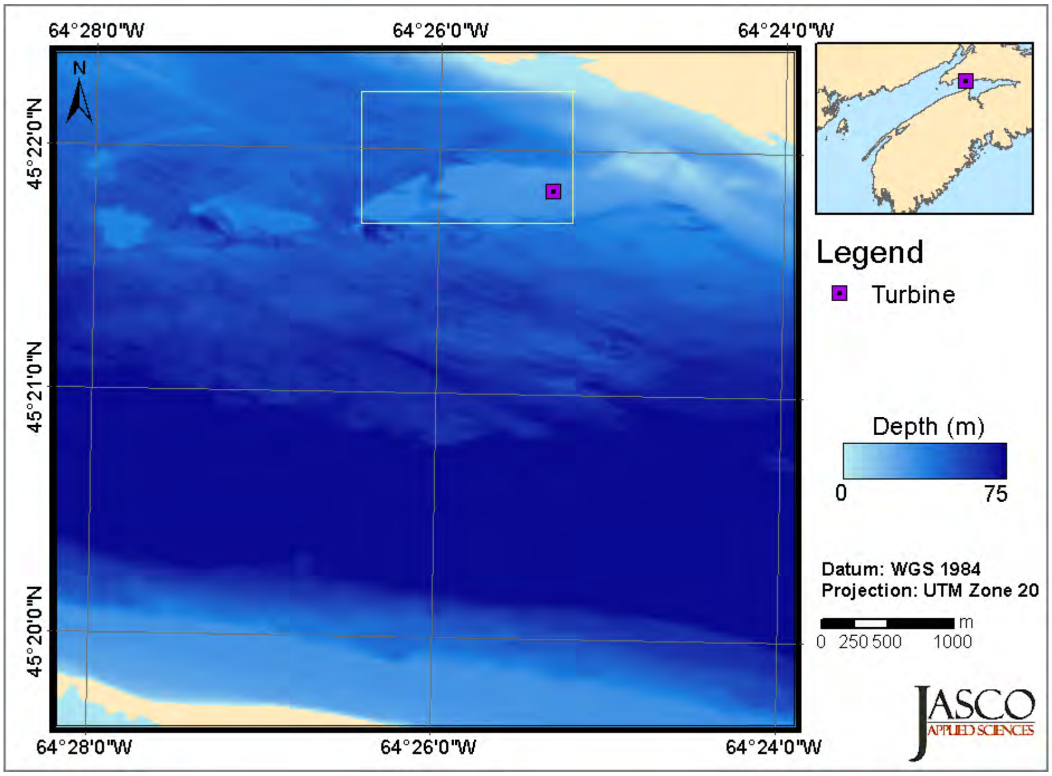

Figure 17. The range for the turbine sound to drop below the threshold for behavioural disturbance to fish. The inner ring is the typical range. The outer ring is the maximum range at spring tides, once per lunar cycle.

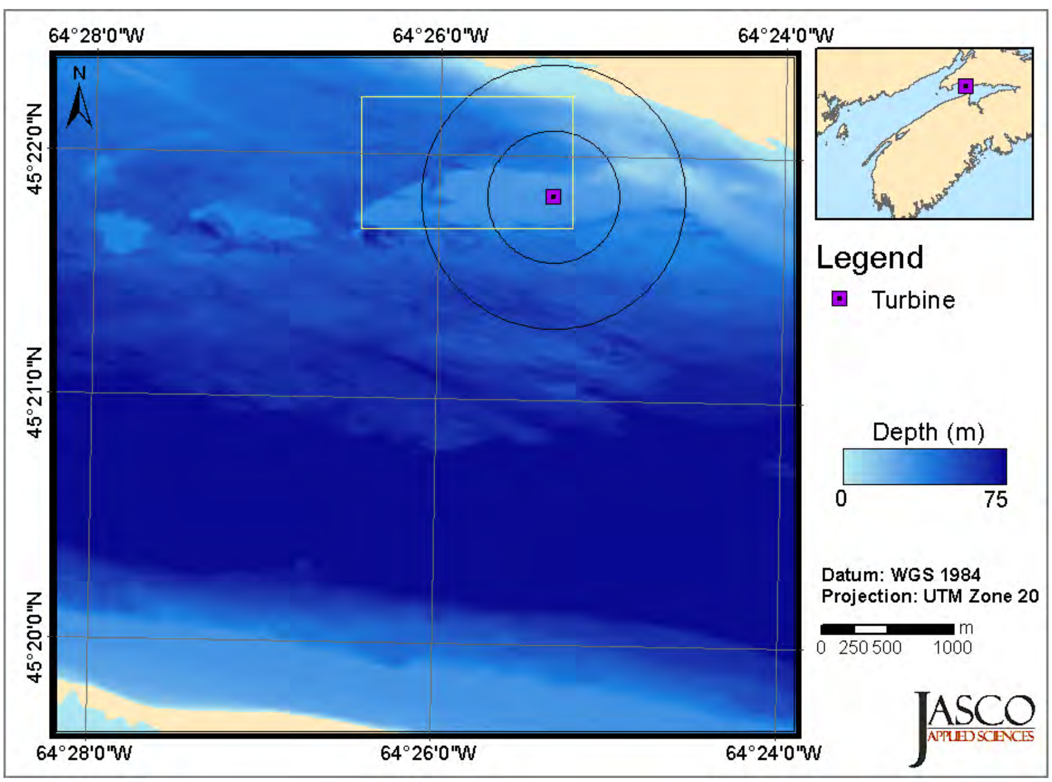

Figure 18. The range for the turbine sound to drop below the threshold for herring masking. The inner ring is the typical range. The outer ring is the maximum range at spring tides, once per lunar cycle.

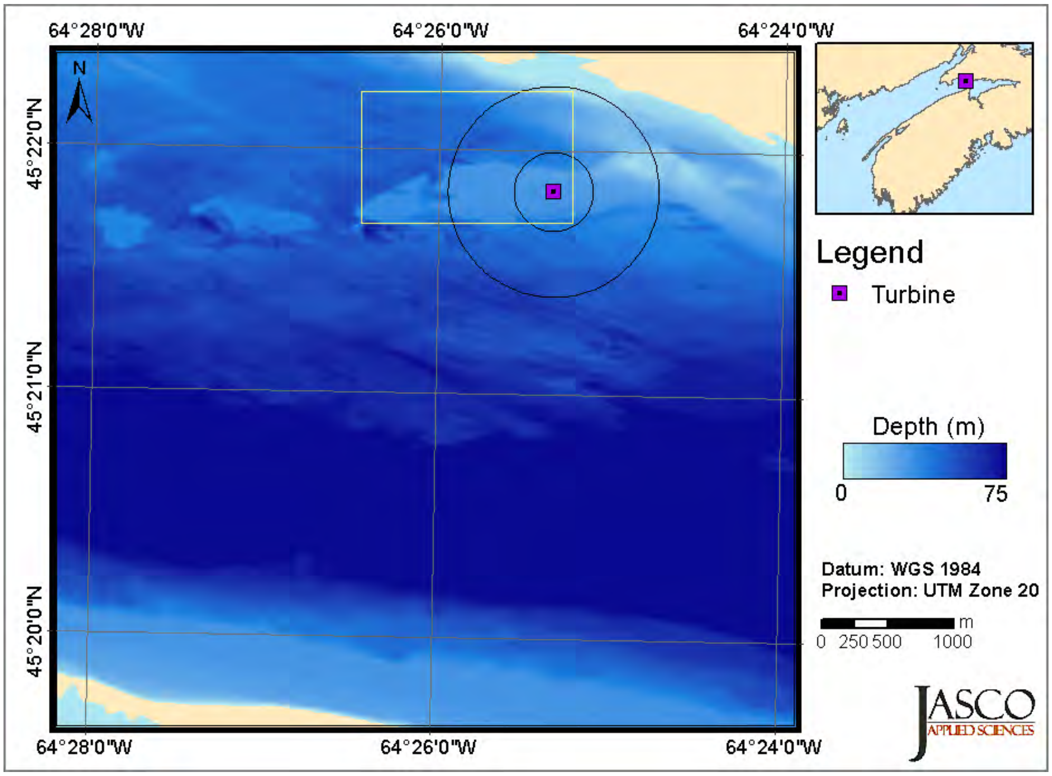

Figure 19. The range for the turbine sound to drop below the threshold for porpoise masking. The inner ring is the typical range. The outer ring is the maximum range at spring tides, once per lunar cycle.

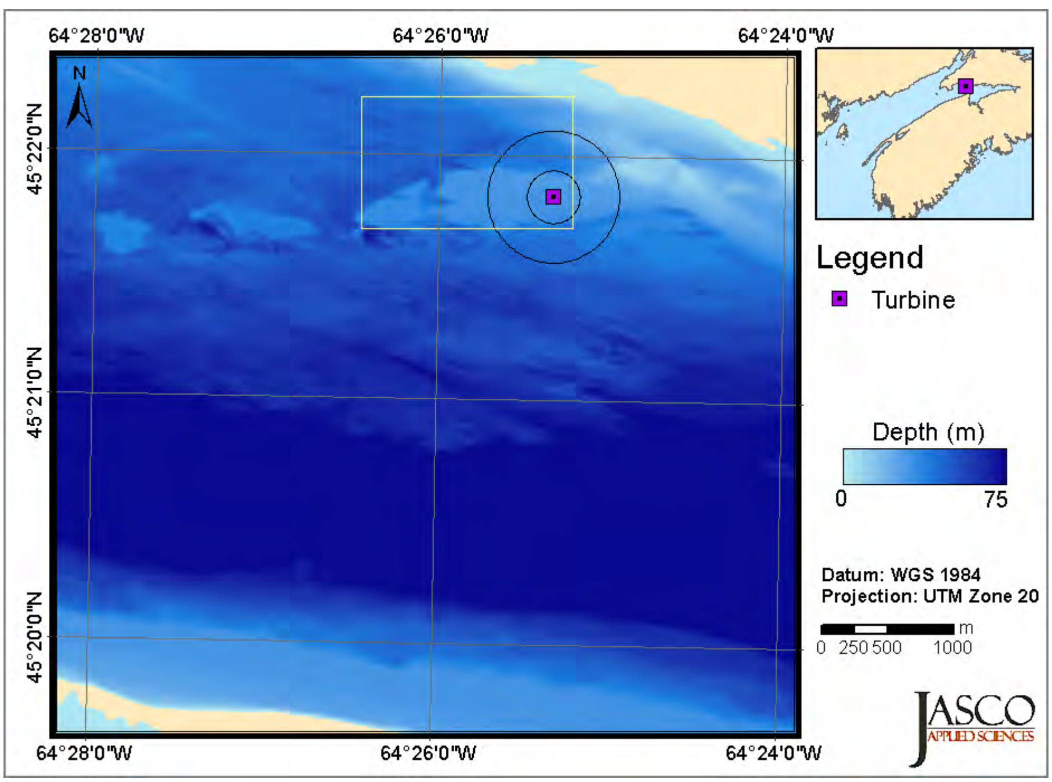

Figure 20. The range for the turbine sound to drop below the threshold for porpoise TTS. The inner ring is the typical range. The outer ring is the maximum range at spring tides, once per lunar cycle.

5.3. Relative Utility of Different Measurement Methods

Appendices B.2, B.3, B.4, and C.1 contain numerous comparisons between the measurement methods that show:

- The value of drift measurements is in obtaining the sound level versus range to validate source level models.
- Ignoring the drifter suspension, either acoustic recorder (Ocean Sonics icListen or JASCO AMAR) is suitable for drift measurements.
- Drifter suspensions must include an effective means of isolating the hydrophone from surface wave action. The relatively simple elastic isolation used on the Ocean Sonics icListen drifter in this study was inadequate for measurements below 150 Hz on 27 Mar 2017 because waves and weather caused flow noise that masked the sounds being measured. Data quality with the elastic hydrophone suspension was acceptable on 20 Oct 2017, because weather was calmer on that day.
- Drifters must have a GPS logger attached to record the location at least twice per minute; higher logging rates are recommended
- Hydrophone(s) on the turbine platform had much higher flow noise levels than the drifters and the autonomous recorder, and the effects were larger when the hydrophone was higher in the water column.
- The flow noise for some positions of hydrophones on the turbine platform hydrophones varied according to the current direction. Noise was louder when the hydrophone was downstream of turbine, even for the not-spinning turbine state (i.e., during the ebb tide for the forward-port hydrophone).
- Hydrophones on the turbine platform need to be more carefully isolated from electrical noise.
- Porpoise detections varied by time period. Porpoises were detected sporadically by the autonomous AMAR in November and December 2016 and detected regularly in cabled icListen data from 24 Mar to 13 Apr 2017. Simultaneous measurements are needed to determine if the differences are due to recording method, recording location, or recording time frame.

Based on the results, we recommend:

- Autonomous recorders in high-flow shielded moorings be considered as the primary method of assessing turbine sound levels. A recording of at least one full lunar cycle should be made while simultaneously logging of the current speed and turbine state. The 1-minute decidecade sound levels should be used to train generalized additive models of the turbine source levels, which can then be used to predict 1) the range where the turbine sound could injure marine life and 2) the range where the turbine is audible above background. $20\log_{10}$(range) acoustic propagation attenuation models are adequate around tidal turbines in the Minas Passage.
- Drifters should be used occasionally to measure the sound level versus range to the turbine to verify the sound level models developed from the autonomous recorders.
- Cabled hydrophones on turbine platforms should be located as close as possible to the seabed, and they should be protected by a stream-lined flow-shield.

5.4. Additional Recommended Measurements of the Open-Centre Turbine

In summer 2018, the Open-Centre Turbine will be redeployed in the Minas Passage. It is possible that the sound signature of the turbine will change, and it should therefore be re-assessed. As well, the turbine platform hydrophones mounts have been updated, increased protection has been provided, and the transmission system has been updated. We recommend that CST use this next deployment to address the following points related to acoustic monitoring of the turbine:

- Record the soundscape in the Minas Passage for at least one lunar cycle before deploying the turbine using an autonomous recorder. This baseline measurement will quantify the ambient sound levels at all current speeds. An Acoustic Doppler current profiler should be deployed at the same time as the acoustic recorder. We suggest the following duty cycle:
  - 64 kHz for 300 seconds
  - 375 kHz for 60 seconds
  - Sleep for 300 seconds.

  An autonomous AMAR will record for 120 days on this duty cycle. This cycle will record both more time and a wider bandwidth than the measurement in 2016 by using only one hydrophone instead of two to conserve storage space. The purpose of 64 kHz data is to check if the turbine emits any sounds above 10 kHz that have been missed in the earlier analysis (with a 32 kHz sampling rate). The 375 kHz sampling is intended for porpoise detection.
- Assuming the autonomous recorder remains deployed after turbine installation, the data should be used to develop a source level model for the refurbished turbine.
- The detection performance for porpoises should be compared for the simultaneous deployment of the autonomous recorder and the turbine mounted hydrophones.
- Consider applying flow shields to at least one of the lower-level turbine mounted hydrophones (Figure 27, locations 1, 2, or 4) to compare with the autonomous recorder as well as the locations that are not shielded.
- Consider making measurements of the turbine using two autonomous recorders, one that is perpendicular to the turbine, as was done previously, and one that is in-line with the turbine to check if the axial source levels are higher.
- A different suspension mechanism (Figure 21) that places the hydrophone at 5–8 m depth should be evaluated. Two types of drifters have been used at the FORCE test site to date. The icListen-based drifters are easy to deploy and have shallow draught, but they tend to have high levels of surface wave noise. The AMAR-based drifters solve the surface noise problem but are too cumbersome for rapid deployment. They also would place the hydrophone at 15 m depth, which could tangle with the turbine at low tide.
- During the next round of reporting, consider performing a literature review that compares the Open-Centre Turbine measurements with other devices worldwide to determine if any other measurement techniques might provide better results, a simpler implementation, or both.
- During the analysis and reporting of the next measurements, consider reporting the pressure spectral densities as a function of current speed with confidence intervals around each curve (e.g., Figure 22). This will demonstrate statistical validity of the characterization of the turbine sound and support the conclusion that reported sound levels are truly representative of the turbine sounds.

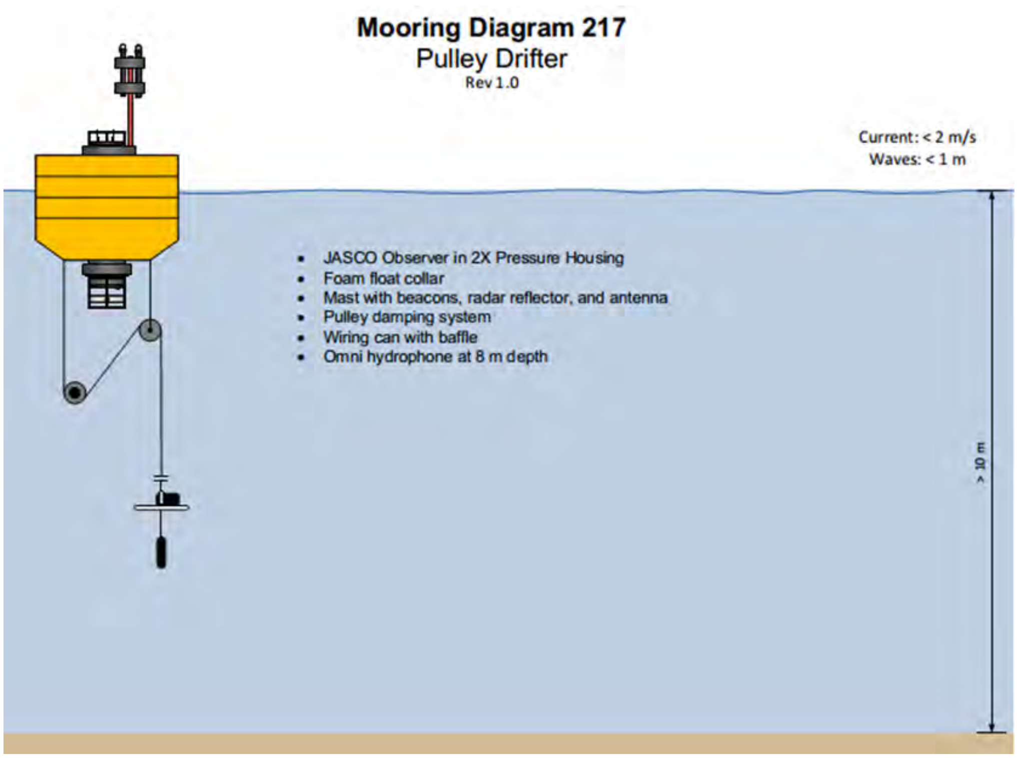

Figure 21. Proposed pulley drifter with localization beacons.

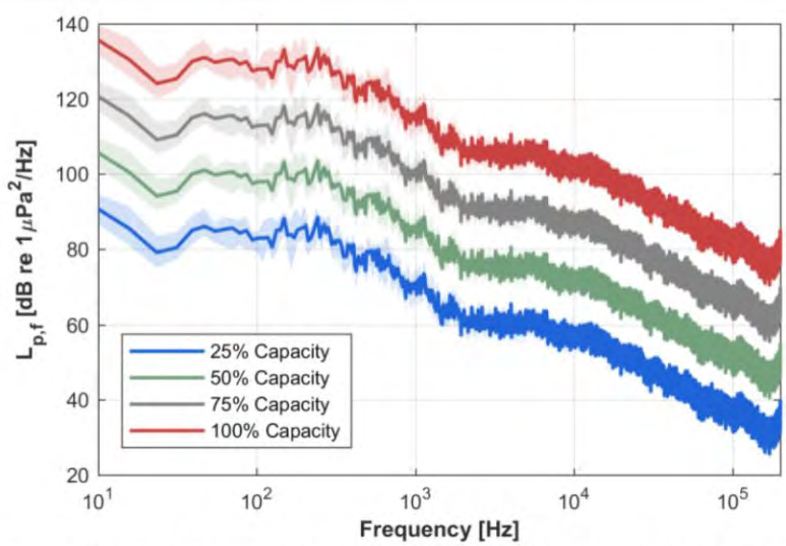

Figure 5: Example of median mean-square sound pressure spectral density level variations as a function of sea state for a single spatial position. Shaded region denotes interquartile range.

Figure 22. Example of turbine pressure spectral densities as a function of current speed, with interquartile confidence intervals [Figure 5 from IEC 68].

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Appendix A. Method Details

A.1. Recorder Configurations

A.1.1. AMARs–The Minas Passage and Outer Bay of Fundy

To measure sound pressure levels (SPL), two bottom-mounted Autonomous Multichannel Acoustic Recorders (AMARs, JASCO Applied Sciences) were deployed, Station 2 at a range of 167 m from the turbine as the measurement site and Station 1 at 680 m as a control site. The turbine was located at Easting: 388662 m, Northing: 5024422 m (UTM 20N).Due to the exceptionally high current in the area, hydrodynamic high-flow moorings were used with floats that submerged during tidal flows and surfaced at slack tide (Figures 24 and 25). The recorders were deployed near the OpenHydro turbine on 18 Nov 2016 (Table 4). Station 2 was retrieved on 19 Jan 2017, but Station 1 was not retrieved due to difficulties in locating the surface float of this unit. For the remainder of this document, the recorder at 167 m from the turbine will be referred to as the autonomous AMAR or autonomous recorder.

Each AMAR was fitted with two M36-V35-100 hydrophones (GeoSpectrum Technologies Inc.), sampling for 250 seconds at 32,000 samples per second (sps) giving an acoustic bandwidth of 10 to 16 kHz, with a nominal sensitivity of −165 dB re 1 V/µPa. Hydrophone 1 was located near the front, or 'bow' of the high flow mooring, and hydrophone 2 was located near the lifting plate at the centre of the high flow mooring (Figure 24). Hydrophone 1 also sampled for 65 seconds at 375,000 sps, giving an acoustic bandwidth of 10 to 187.5 kHz, also with a nominal sensitivity of −165 dB re 1 V/µPa. There was a 165 second sleep cycle in the recording schedule to preserve battery life and memory. The lower sample rate can capture most mechanical noise from the turbine and vessels, as well as potential vocalizations from most large marine mammals. The high sample rate can capture high-frequency vessel sound sources, such as sonars and acoustic positioning systems. It can also capture high-frequency echolocation clicks from marine mammals. Two hydrophones were used to determine if there were differences in flow-noise reduction inside the high flow mooring

A similar AMAR recorder to the ones used in the Minas Passage was deployed at 143 m water depth underneath the inbound Bay of Fundy shipping lane, adjacent to the North Atlantic Right Whale critical habitat (Table 4, Figure 26). This recorder is referred to as the outer Bay of Fundy recorder. Its data will be used as a reference for 'normal' conditions in the larger Bay of Fundy.

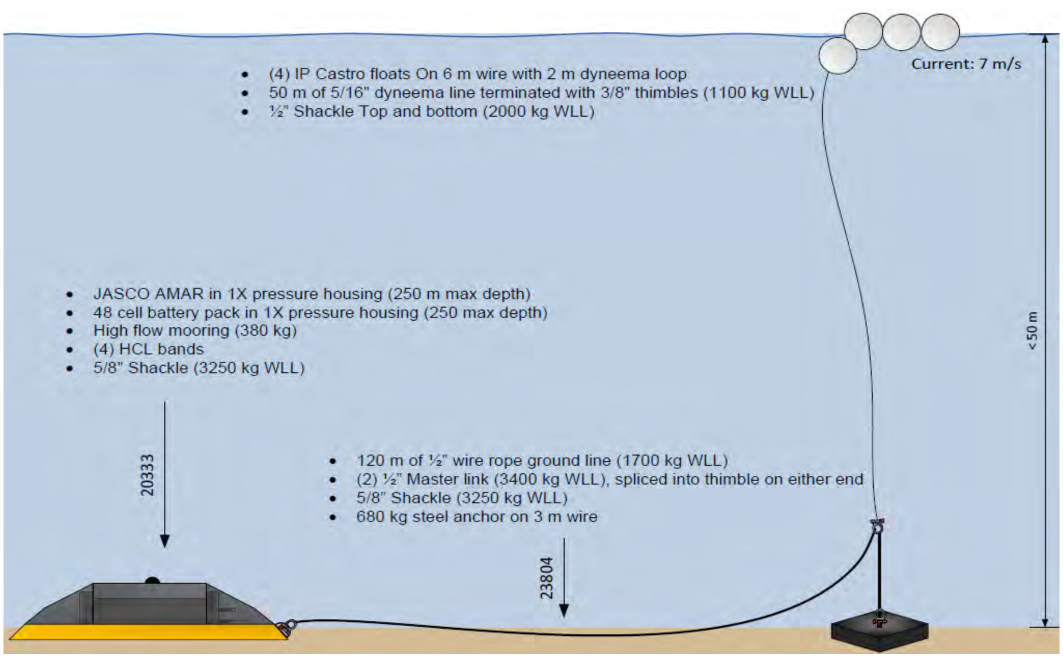


Figure 23. Configuration for the high-flow mooring.

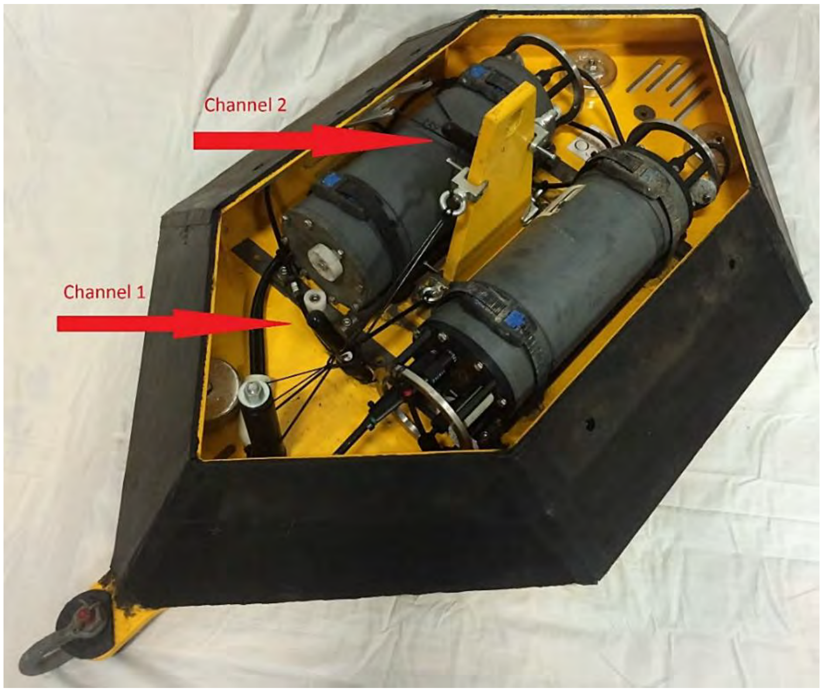


Figure 24. Inside the high-flow mooring. Hydrophones are shown with red arrows.

Figure 25. Cover of the JASCO High Flow Mooring. (Left) top view of the neoprene cover. (right) View from underneath showing cut-outs in the metal structure to allow for sound transmission.

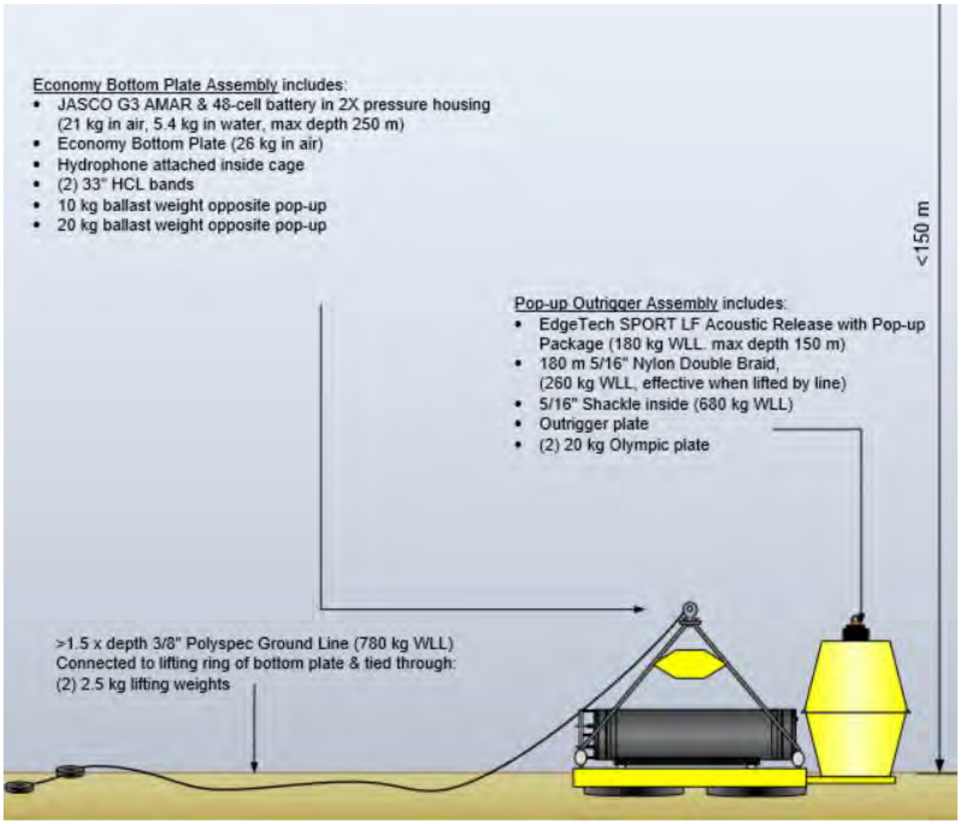


Figure 26. Mooring configuration used in the outer Bay of Fundy.

Table 4. Recorder locations and deployment details from the OpenHydro study. Sensor depths are relative to mean high water.

Device	Latitude (N)	Longitude (W)	Deployment	Retrieval	Horizontal range from source (m)	Sensor depth (m)
AMAR 200, Station 2	45° 21’ 49.51 N	64° 25’ 24.78 W	18 Nov 2016	19 Jan 2017	167	43
AMAR 227, Station 1	45° 21’ 45.12 N	64° 25’ 50.88 W	18 Nov 2016	Not retrieved	680	46
Outer Bay of Fundy AMAR Stn 1	44° 33’ 46.50' N	66° 20’ 9.90' W	3 Dec 2015	28 Apr 2016	--	143

A.1.2. icListen Real-time data stream

Four icListen Smart Hydrophones (Ocean Sonics Ltd.) were secured to the turbine platform (Figure 27) and interfaced to the fibre optic data cable connecting the turbine platform to shore. The data from the icListen was recorded at the visitor's centre in Parrsboro, NS, and used for subsequent analysis, including this report. Of the four hydrophones installed on the platform, only Hydrophone 1 (icListen 1404) provided data throughout the turbine deployment (Table 5). Data from two of the hydrophones were not transmitted due to issues with the telemetry system, and one hydrophone suffered physical damage. The telemetry system on the turbine platform, as well as physical protection for the hydrophones, have been improved in anticipation of the turbine's redeployment.

icListen 1404 in the Forward-Port location sampled at 32 kHz until 8 Mar 2017, increased in sample rate to 64 kHz until 24 Mar 2017, and then increased again to 512 kHz until turbine recovery on 13 Apr 2017.

The icListens were equipped with hydrophone ceramics from GeoSpectrum Technologies Inc. and had a nominal sensitivity of −169 dB re 1V/µPa.

Table 5. Data from the turbine-mounted icListen.

icListen ID	Data start	Data end
Hydrophone 1–1404–Forward-Port	12 Nov 2016	13 Apr 2017
Hydrophone 2–1407–Forward-Starboard	8 Nov 2016	9 Nov 2016
Hydrophone 3–1405–Top	10 Nov 2016	20 Nov 2016
Hydrophone 4–1406–Aft	--	--

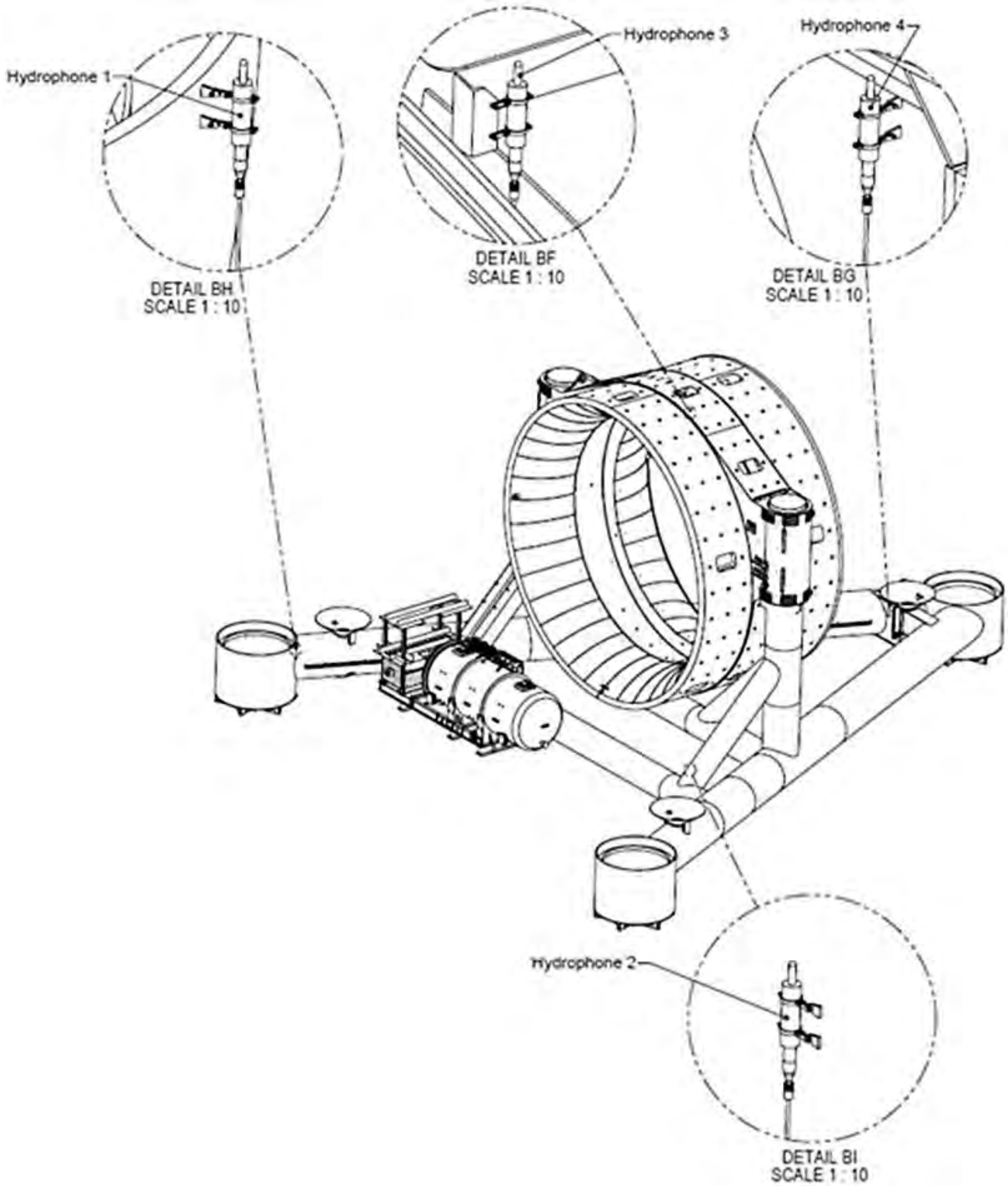


Figure 27. General arrangement drawing for the Open-Centre Turbine showing the locations of the icListen hydrophones. Hydrophone 1 was 8 m from the turbine rim. The cylinder at the lower left side of the turbine rim is the Turbine Control Centre.

A.1.3. icListen drifters

Hydrophone drifters based on the icListen were deployed by FORCE on 31 Aug 2016, 20 Oct 2016, and 27 Mar 2017. The icListen drifter is a lightweight device that uses a compliant suspension to hang the recorder 5 m below the surface. Some isolation from surface movement is provide by a compliant strength member and dampers (black cable and bristles in Figure 28).

All icListen trials employed two separate drifters sampling at 512 kHz. Each drift was 1–3 km long for which the start and stop locations and times are known. The 2016 drifts occurred before the turbine was deployed. Drifts on 20 Oct 2016 were interleaved with AMAR drifts (Appendix A.1.4) and occurred across the low tide slack tide. On 27 Mar 2017, eleven trials with two separate drifters were conducted throughout a flood tide while the turbine was free-spinning.

Figure 28. The icListen drifter being unloaded from the Tidal Runner (photo courtesy of Ocean Sonics Ltd.).

A.1.4. AMAR drifters

An AMAR recorder integrated into a drifting mooring was deployed by FORCE on 18 and 20 Oct 2016, before the installation of the OpenHydro turbine (Table 6).

The mobile recorder assembly employed a catenary mooring in a free-drifting arrangement (Figure 29). The mooring was designed to keep the acoustic recorder from moving in the vertical axis due to wave motions, since 1 cm of vertical motion results in a 120 dB re 1 µPa pressure change, which is 10-times the background sound pressure level in most ocean areas. If the design was successful, then the recorder would effectively be a water 'particle' drifting with the water mass and recording the actual sound levels rather than artificial pressure changes caused by the interaction of the recorder and the environment. Temperature depth (TD) loggers were included in the mooring (Figure 29) to verify that different aspects of the mooring were moving as expected. Unfortunately, these devices were not properly activated during deployment, so no TD data was recorded.

The catenary mooring consisted of a buoyant surface unit and an AMAR acoustic recorder (JASCO) attached below it on an alternately weighted and buoyed line 35 m long. The surface unit comprised a large spherical float with an upper mast and a counterweight below at the end of a rigid rod. A satellite beacon and VHF/strobe beacon were mounted on the upper mast to facilitate tracking and retrieval. A pick-up line with floats and a fabric sea anchor (not shown in Figure 29) were also attached to the surface float.

The AMAR was fitted with an M8E-35dB hydrophone (GeoSpectrum Technologies Inc.), duty cycled between 32,000 samples per second (sps) for 680 seconds (acoustic bandwidth: 10 Hz to 16 kHz) and 375,000 sps for 130 seconds (acoustic bandwidth: 10 Hz to 187 kHz, nominal sensitivity: −165 dB re 1 V/µPa).

Table 6. Deployment and retrieval locations and times of 8 recordings made by the AMAR catenary drifter on 18 and 20 Oct 2017. Data start and end times indicate the timeframe where no deployment/retrieval related noise occurred. The total data is the number of minutes during the recording where data was not impacted by deployment/retrieval related noise.

Date	ID	Deployment		Retrieval		Data start (UTC)	Data end (UTC)	Total data (min)
		Location	Time (UTC)	Location	Time (UTC)			
18 Oct 2017	18–01	45.368° N 64.443° W	12:32	45.357° N 64.408° W	13:01	12:36:30	12:54:30	18.00
	18–02	45.377° N 64.452° W	14:00	45.356° N 64.397° W	14:18	14:01:30	14:11:30	10.00
	18–03	45.372° N 64.455° W	15:35	45.352° N 64.389° W	15:54	15:36:00	15:47:30	11.50
	18–04	45.377° N 64.452° W	16:55	45.354° N 64.395° W	17:21	16:56:30	17:13:00	16.50
	18–05	45.361° N 64.421° W	18:17	45.364° N 64.445° W	19:06	18:19:15	19:00:00	40.75
20 Oct 2017	20–01	45.359° N 64.408° W	10:50	45.362° N 64.425° W	11:13	10:52:00	11:07:30	15.50
	20–02	45.363° N 64.419° W	12:27	45.365° N 64.428° W	12:45	12:27:45	12:40:00	12.25
	20–03	45.368° N 64.443° W	14:03	45.356° N 64.405° W	14:40	14:05:30	14:29:00	23.50

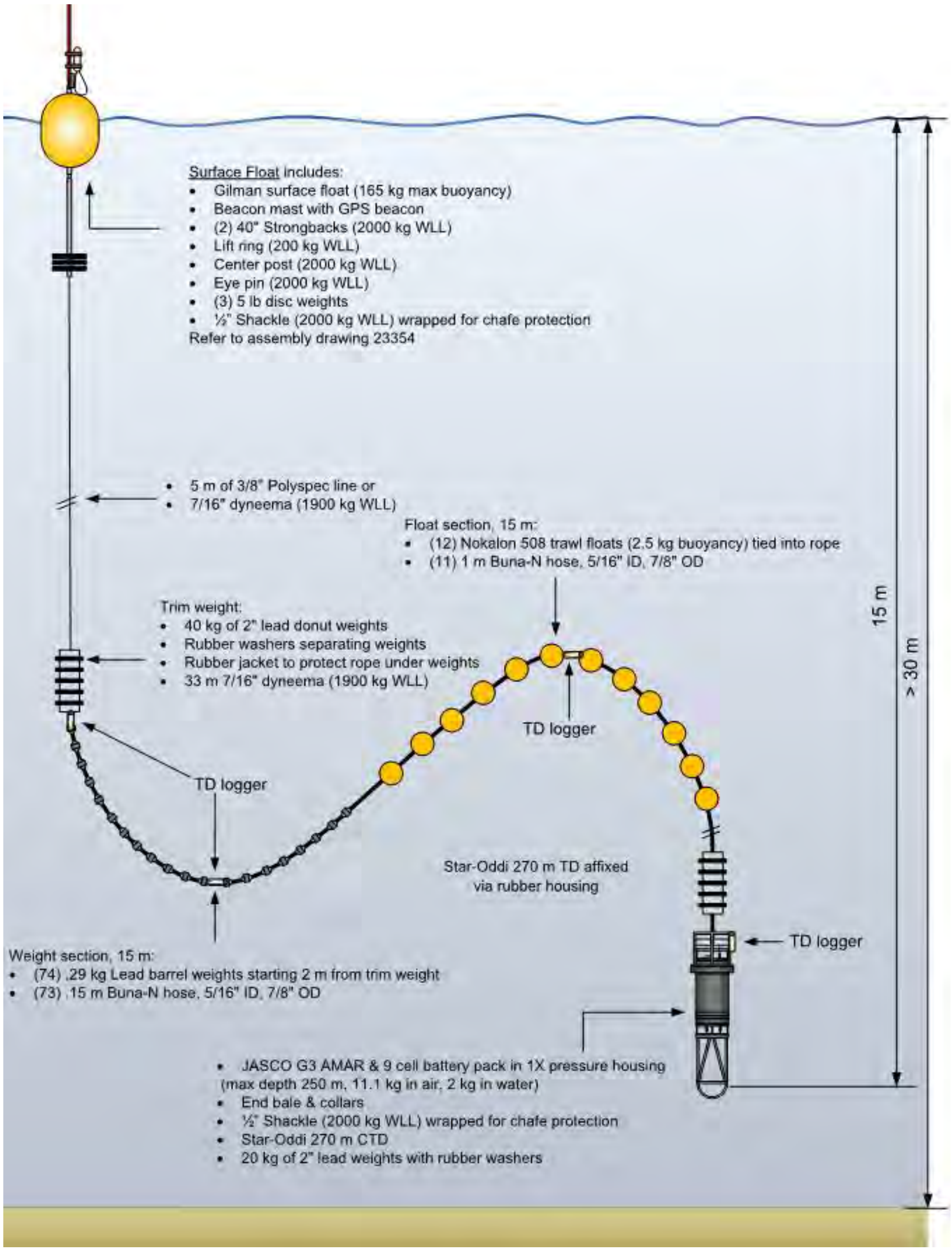


Figure 29. Catenary mooring diagram

A.2. Recorder Calibrations

Each AMAR was calibrated before deployment and upon retrieval with a pistonphone type 42AC precision sound source (G.R.A.S. Sound & Vibration A/S; Figure 30). The pistonphone calibrator produces a constant tone at 250 Hz at a fixed distance from the hydrophone sensor in an airtight space with known volume. The recorded level of the reference tone on the AMAR yields the system gain for the AMAR and hydrophone. To determine absolute sound pressure levels, this gain is applied during data analysis. Typical calibration variance using this method is less than 0.7 dB absolute pressure.

Figure 30. Split view of a G.R.A.S. 42AC pistonphone calibrator with an M36 hydrophone Manufacturers' calibrations were used for the icListen data.

A.3. Acoustic Metrics

This report uses the symbols and definitions for acoustic metrics from ISO standard 18405 [69]. An important element of the standard is the distinction between field quantities, such as sound pressure, and *level* quantities that are 10 times the logarithm of the field quantity, i.e., sound pressure l*evel*.

The most important metrics employed in this analysis are (see Table 7):

- Peak sound pressure level ($L_{p,pk}$) (note that the term peak SPL is deprecated).
- Sound pressure level over an averaging duration T ($L_{p,T}$), which may be referred to as the SPL;
- Sound exposure level over some period T ($L_{E,T}$), which may be referred to as the SEL; and
- Weighted sound pressure levels ($L_{p,W,T}$) where 'W' is a frequency band or frequency weighting function. The frequency bands employed are the decidecade bands (below), the marine mammal function hearing group auditory filters (Figure 4), and the inverted herring audiogram.

For most of the analysis in this report, a one-minute averaging time is employed. This duration is aligned with the time resolution of the tide and turbine state information, and it provides a tractable data size for analysis. Shorter time periods have high sound level variances than the one-minute integration time, and this information is not relevant for analysis of a continuous sound source such as the Open-Centre Turbine. For some analysis, a one-second averaging time is employed for understanding of effects that have shorter time durations, such as the sound levels versus range to the turbine when analyzing drifter data.

The distribution of a sound's pressure with frequency is described by the sound's spectrum (absolute value of the Fourier transform of the sound's time series), which shows the fine-scale features of the frequency distribution of a sound. The sound spectrum is split into of adjacent frequency bands whose width depends on the duration of the time series input to the Fourier transform. There are many excellent texts on Fourier Analysis; we recommend *Principles of Marine Bioacoustics* [70], which includes chapters on hearing, use and production of sound by marine life, and other relevant background information. Splitting a spectrum into 1 Hz wide bands, yields the pressure spectral density of the sound. These values directly compare to the Wenz curves, which represent typical deep ocean sound levels (Figure 2 [71]; note that Wenz averaged spectra over 200 seconds, and to be strictly comparable current projects should use similar durations).

In general animals perceive exponential increases in frequency rather than linear increases [72, 73]. Therefore, splitting the spectrum into 1 Hz bands is not representative of how animals perceive sound;

rather analyzing a sound spectrum with bands that increase exponentially in size gives data that are more meaningful. In underwater acoustics, a spectrum is commonly split into bands that are 1/10th of a decade where each decade represents a 10-fold increase in frequency. The centre frequency of the ith decidecade band, $f_c(i)$, is defined as

$$f_c(i) = 10^{i/10}, \tag{1}$$

and the low (f_{lo}) and high (f_{hi}) frequency limits of the ith decidecade-band are defined as:

$$f_{lo} = f_c(i) \cdot 10^{-1/20} \text{ and } f_{hi} = f_c(i) \cdot 10^{1/20} \ . \tag{2}$$

This definition is the same as the ANSI definition for 1/3-octave-bands (base 10) [69, 74]. The decidecade bands become wider with increasing frequency, and on a logarithmic scale the bands appear equally spaced (Figure 31).

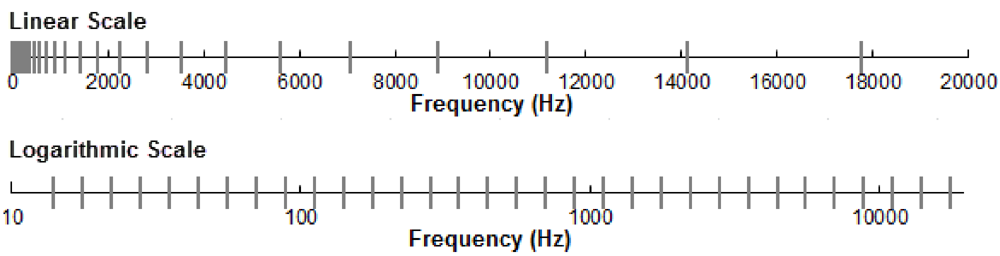


Figure 31. Decidecade bands shown on a linear frequency scale (top) and on a logarithmic scale (bottom).

The sound pressure level in the ith decidecade-band $L_{p,\text{ddec } i,T}$ is computed from the power spectrum $S(f)$ between f_{lo} and f_{hi}:

$$L_{p,ddec\ i,T} = 10\log_{10}\left(\frac{1}{T}\int_{f_{lo}}^{f_{hi}} S^2(f)df/p_o^2\right),$$

where T is the duration of time used to compute the power spectrum S(f) and p_o is the reference pressure. Summing the sound pressure level of all the decidecade bands yields the broadband sound pressure level:

$$\text{Broadband SPL} = 10\log_{10}\sum_i 10^{L_{p,ddec\ i}/10} \ .$$

Table 7. Symbols and Abbreviations

Symbol/abbreviation	Definition	Units
Fundamental Values		
λ	Wavelength of a sound = c/f	m
c	Sound speed in water, nominally 1500 m/s	m/s
f	Frequency of a sound	Hz = 1/s
Acoustic Metrics [see 69]		
Peak sound pressure level ($L_{p,pk}$)	Ten times the logarithm of the ratio of the maximum instantaneous sound pressure level in a stated frequency band attained by an acoustic pressure signal, *p*(*t*) divided by the reference value, P_{02} (normally 1 µPa²): $$10\log_{10}\frac{max(p^2(t))}{p_0^2}.$$ Note that L_{pk} is a poor indicator of a sound's loudness because the peak signal duration is often very short. The sound exposure level is a better indicator of loudness.	dB re 1 µPa²
Sound pressure level (SPL or $L_{p,T}$)	Ten times the logarithm of the ratio of the mean-square pressure level in a stated frequency band over a time window (T, s) containing the acoustic event to a reference value, P_{02}: (normally 1 µPa²) $$10\log_{10}\frac{1}{T}\int_T\frac{(p^2(t))}{p_0^2}dt.$$	dB re 1 µPa²
Sound exposure level (SEL, $L_{E,T}$)	The sound exposure level is ten times the logarithm of the ratio of the time-integral of the squared pressure over the analysis duration (T), divided by the reference time T_0 (normally 1 s) and reference square pressure value P_{02} (normally 1 µPa²): $$10\log_{10}\left(\int_{T100} p^2(t)dt \Big/ T_0 p_0^2\right)$$ where T_0 is a reference time interval of 1 s. The SEL represents the total acoustic energy received at some location during an acoustic event. By Parseval's theorem, this is also the variance in the signal assuming a mean pressure of zero.	dB re 1 µPa²·s
Weighted sound pressure level ($L_{p,W,T}$)	The sound pressure level computed using a frequency weighted spectrum (of data with time duration *T*) $$10\log_{10}\left(\frac{1}{T}\int_f\frac{(w(f)S(f))^2}{p_0^2}df\right),$$ where w(f) is the frequency weighting function and S(f) is the Fourier transform of p(t).	dB re 1 µPa²
Mean-square sound pressure spectral density level ($L_{p,f,t}$)	Ten times the logarithm of the ratio of the distribution as a function of non-negative frequency of the mean-square sound pressure per unit bandwidth of a sound having a continuous spectrum, divided by the reference value reference square pressure value p02 (normally 1 µPa²): $$10\log_{10}\left(S(f)^2/p_0^2\right).$$	dB re 1 µPa²/Hz

Note: The units for sound pressure level in this table are given as dB re 1 µPa², however, many references continue to use dB re 1 µPa which is equivalent. The difference reflects how the analysis was performed. Here we show the calculation as $10\log_{10}$(pressure²), whereas many practitioners compute the sound pressure level as $20\log_{10}$(sqrt(pressure²))–which yields the same value but has units of dB re 1 µPa. Some of the figures in this report were generated with older versions of JASCO's analysis software that used the dB re 1 µPa units. Similarly, the pressure spectral density level is also called the power spectral density in some figures.

A.4. Cadence Analysis

Cadence analysis aligns the acoustic data with an external cadence such as the time of day, time of week or tidal cycle. For this project cadence analysis begins by referencing each minute of data to a point in the tidal cycle. Tide predictions are generated using the TBone web service (http://tbone.biol.sc.edu/tide/index.html). For these data the Cape Sharp, NS, (45.3667° N, 64.3833° W) station was used.

For the high-resolution cadence images, data were plotting for up to 780 minutes (13 hours) after a given tide reference point (low, high, or slack tide). Each available minute of data is compared to the tide prediction and then assigned to the bin corresponding to the same number of minutes following the chosen reference point. The cadence analysis was performed on the 1 Hz pressure spectral density data. Each time and frequency bin is divided by the total number of data points to get the average pressure spectral density for that bin. Pressure spectral density is plotted on a logarithmic frequency axis, so low frequencies are interpolated between the 1 Hz FFT points, and high frequencies are averaged across all 1 Hz bins that correspond to each pixel in the image.

This same underlying data is separately averaged across 15-minute time periods, again relative to the same tide reference points (low, high, or slack tide). Then the 15-minute average 1 Hz data is used to compute decidecade band values. These 15-minute decidecade values are stored in a comma-separated value (CSV) file for subsequent analysis and reporting.

A.5. General Additive Modelling of Received Levels

A General Additive Model is a statistical tool used to make inferences about an unknown function using known predictor variables. In this study, General Additive Models were fit to the long term acoustic measurements to predict turbine sound at all operating conditions and flow rates, using the available measurements at only some turbine conditions and flow rate. The models were created using the software package 'mgcv' [75] for the 'R' programming language. Additive models are sometimes referred to as 'smoothers' because they are spline functions that smoothly follow the measured data rather than being traditional linear models. The model used was 'decidecade SPL ~ s(normalizedCurrentSpeed)'. Individual models were run for the six-identified tide and turbine states:

1. Turbine not spinning, flood tide.
2. Turbine not spinning, ebb tide.
3. Turbine free spinning, flood tide.
4. Turbine free spinning, ebb tide.
5. Turbine generating, flood tide.
6. Turbine generating, ebb tide.

The models were then used to predict the median sound levels for each decidecade band at normalized flow rates of 20, 40, 60, and 80% of the full flow. The models are only valid above 70% flow for the flood direction since the ebb flow rarely exceeds 70% of the maximum flood flow. Similarly, the sound levels at 100% of full flow were not included because we did not have sufficient examples of this operating state to develop a reliable model.

The models were used to create tables of expected sound pressure levels as a function of the six tide-turbine states and the normalized flow speed (1–99). These tables are included in this report in Appendix D.3.

A.6. Acoustic Propagation Modelling

Acoustic propagation modelling was used for two purposes in this analysis: 1) to estimate the propagation loss of the turbine signals arriving at the recorders; and 2) to estimate the ranges from the turbine that the turbine sounds would be above the ambient levels.

Our original intention was to employ high fidelity acoustic propagation modelling to estimate the propagation losses. This type of modelling accounts for the water depth, bottom shape and composition as well as sound speed profile in the water column to estimate the losses as a function of range and direction. The FORCE site is exceptionally challenging to model because:

- The seabed around the turbine is weathered basalt, which has a great deal of structure (ripples and boulders on the order of 2–3 m high) that is difficult to model.
- The basalt platform stands up above the local seabed that is composed of mixed rock and sediment with uncertain geoacoustic parameters
- The sound speed profile is poorly known.
- The water depth varies over a wide range due to the tides which would require a great many propagation modelling 'runs' to account for. Once the runs were completed the depth-appropriate transmission loss would need to be selected from moment to moment to estimate the losses.

The analysis of received sound levels from the icListen drifters deployed on 27 Mar 2017 performed by GTI (reported dated 5 Jan 2018) demonstrated that the distance from the turbine that the sound could be detected was on the order of 100's of meters, and that spherical spreading ($20Log_{10}$(Range)) was an appropriate propagation model (Figure 32). Therefore, we choose to use simple geometric spreading with an attenuation of $20Log_{10}$(Range) for this analysis.

The propagation ranges under consideration here are less than 1 km, and the frequency range of interest is below 10 kHz. Therefore, we did not include an absorption term in the propagation modelling since it is at most 1 dB/km at 10 kHz, which is far below the uncertainty in other elements of our analysis.

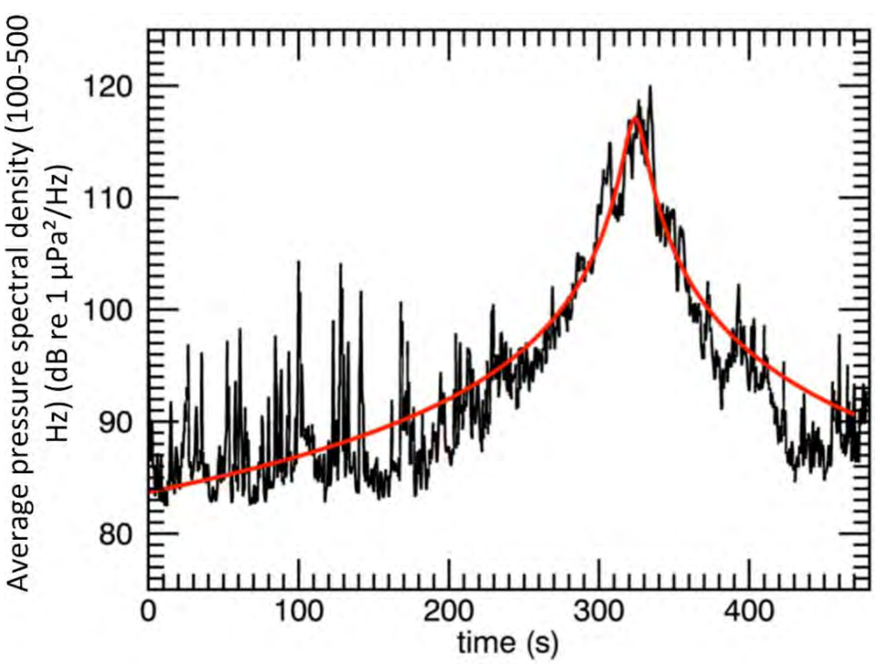


Figure 32. Average Pressure Spectral Density in the frequency range of 100–500 Hz vs time in file for icListen drifter 1658 on trial 7 on 27 Mar 2017. The drifter moved at ~4 m/s. The estimated range to the turbine at the closest range was 30 m. The red line is a best-fit of 20log10(range) (Figure 9 from GeoSpectrum Technologies Inc FORCE Turbine Analysis Report dated 5 Jan 2018).

A.7. Automated Click Detector for Porpoises

We applied an automated click detector/classifier to the high-frequency data from the autonomous AMAR data sampled at 375 kHz and the icListen data sampled at 512 kHz to detect clicks from porpoises (Figure 33). This detector/classifier is based on the zero-crossings in the acoustic time series. Zero-crossings are the rapid oscillations of a click's pressure waveform above and below the signal's normal level (e.g., Figure 33). Clicks are detected by the following steps (Figure 33):

1. The raw data is high-pass filtered to remove all energy below 8 kHz. This removes most energy from other sources such as shrimp, vessels, wind, and cetacean tonal calls, while allowing the energy from all marine mammal click types to pass.
2. The filtered samples are summed to create a 0.334 ms rms time series. Most marine mammal clicks have a 0.1–1 ms duration.
3. Possible click events are identified with a split-window normalizer that divides the 'test' bin of the time series by the mean of the 6 'window' bins on either side of the test bin, leaving a 1-bin wide 'notch'.
4. The maximum peak signal within 1 ms of the detected peak is found in the high-pass filtered data.
5. The high-pass filtered data is searched backwards and forwards to find the time span where the local data maxima are within 9 dB of the maximum peak. The algorithm allows for two zero-crossings to occur where the local peak is not within 9 dB of the maximum before stopping the search. This defines the time window of the detected click.
6. The classification parameters are extracted. The number of zero crossings within the click, the median time separation between zero crossings, and the slope of the change in time separation between zero crossings are computed. The slope parameter helps to identify beaked whale clicks, as beaked whale clicks increase in frequency (upsweep).
7. The Mahalanobis distance between the extracted classification parameters and the templates of known click types is computed. The covariance matrices for the known click types, computed from thousands of manually identified clicks for each species, are stored in an external file. Each click is classified as a type with the minimum Mahalanobis distance, unless none of them are less than the specified distance threshold.

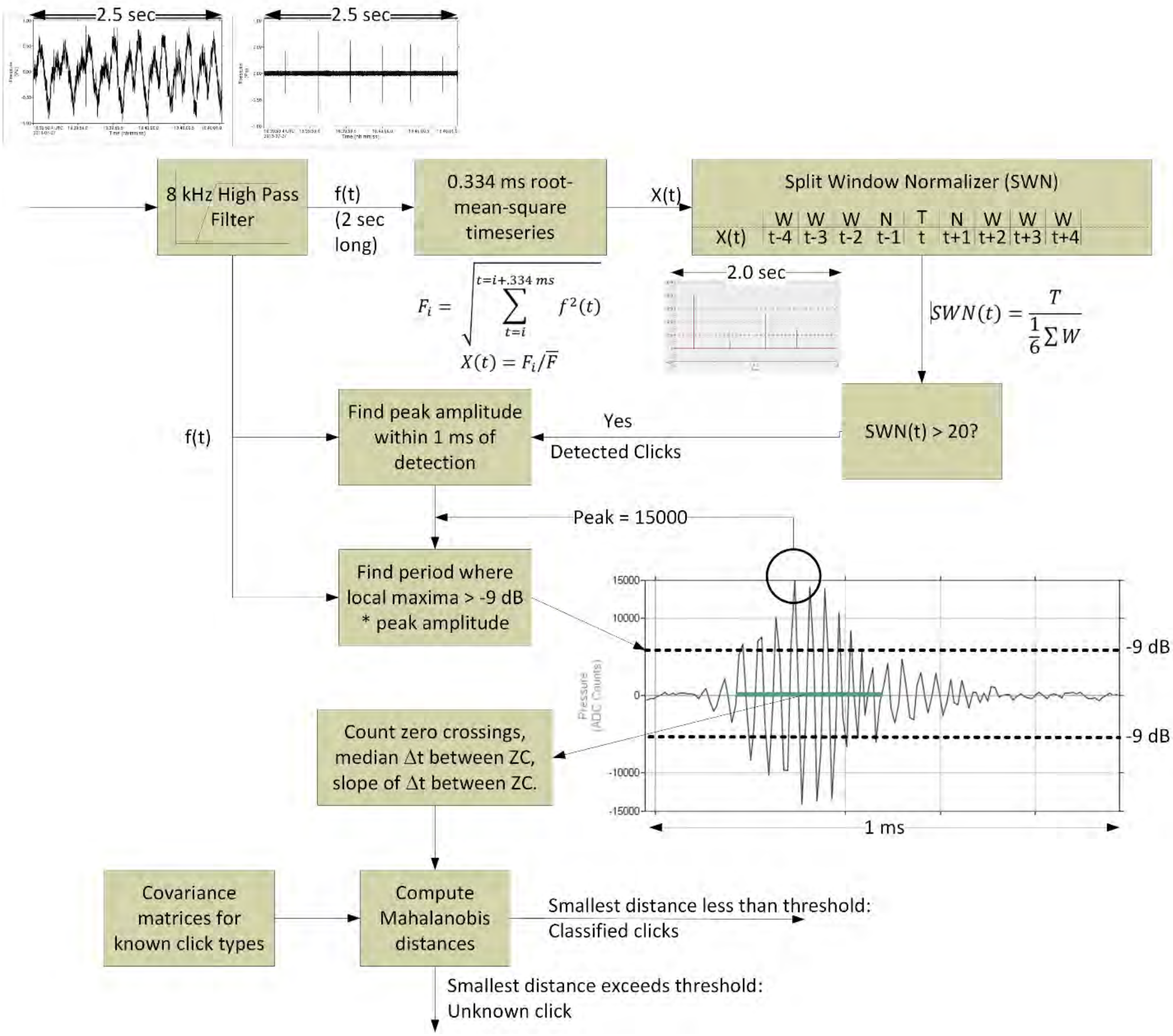


Figure 33. The click detector/classifier block diagram.

Appendix B. Results–Total Sound Levels

B.1. Non-Acoustic Data

Emera provided data with the minute-by-minute normalized current speeds (Figure 34), direction, and the turbine operating state (not spinning, free spinning, generating). Using this information, three time periods were selected for detailed analysis of sound levels while both the AMAR and icListen recordings are available:

- 24 Dec 2016–the maximum current speed on this day was 68% at 09:50 and represents a neap tide day.
- 16 Dec 2016–the maximum current speed was 100% at 02:43 and is a maximum spring tide.
- 01 Dec 2016–the maximum current speed was 83% at 02:43 and was chosen as a representative 'normal' day.

For each time the modelled (see Appendix C.2.2.2) and measured sound levels are compared. The range to the 150 dB SPL isopleth and the sound levels exceeding background levels are also estimated. The comparisons are made from the high tide time preceding the maximum current until the low tide following.

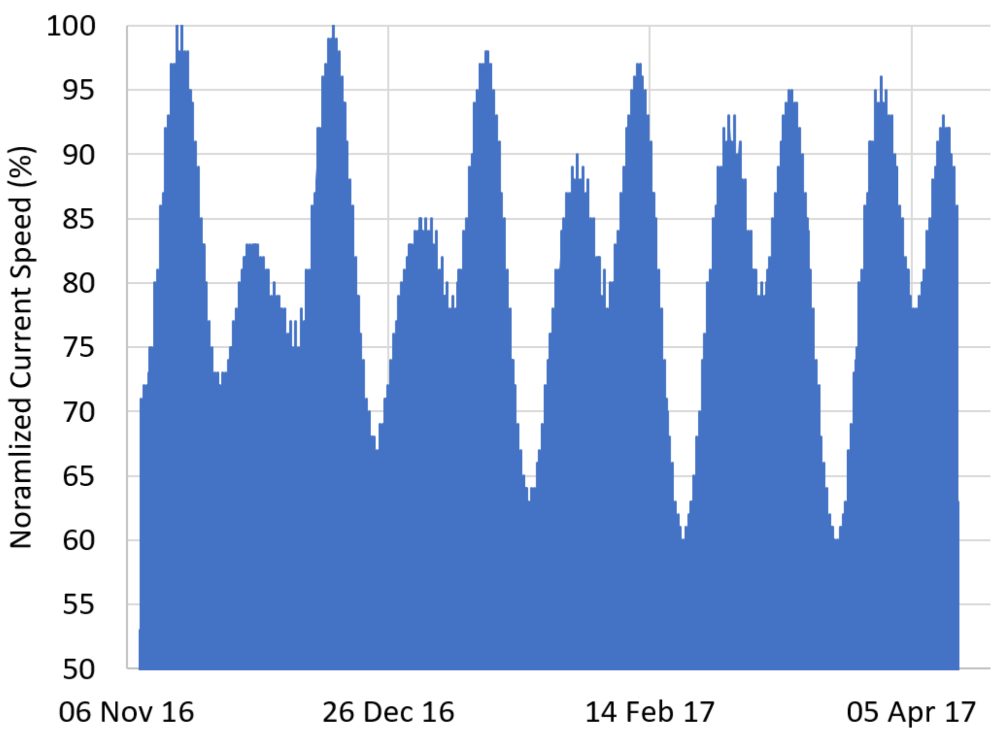


Figure 34. Normalized current speed data provided by Emera. Due to the large amount of data (by minute) this figure shows the maximum normalized current speed per tidal cycle.

B.2. Static Recorders

This section contains the total sound levels and variability in sound levels recorded at the autonomous AMAR (Stations 1 and 2), on two of the turbine mounted icListens, and the outer Bay of Fundy reference AMAR (Stn 1).

This section demonstrates that:

- Flow noise affects acoustic recordings in the Bay of Fundy. The effects are proportional to the current velocity. Similarly, the effects increase with height off the seabed.
- The Open-Centre Turbine generates sounds at frequencies as low as 60 Hz that can be easily distinguished from the background noise using a bottom mounted recorder 167 m from the turbine. There we chose to use the decidecade bands of 63 Hz and above for analysis and modelling of the turbine and environment.
- The Minas Passage environment has much higher sound levels in the kilohertz region than are recorded in low energy environments. This is due to sediment interaction noise, i.e., gravel and rock striking each other.

B.2.1. Outer Bay of Fundy Stn1

The long-term recording made under the traffic lanes in the outer Bay of Fundy is used as a reference for a 'normal' acoustic environment in the Bay of Fundy (Figures 35 and 36). The overall trend in the data are periods of low-frequency noise associated with variations in tidal current strength, as well as short periods of low-frequency noise associated with passing vessels. At frequencies above 1 kHz, the pressure spectral density (Figure 36 bottom) and decidecade sound pressure levels (Figure 36 top) both tend to decrease in amplitude as the frequency increases. Note that the decidecade levels above 1 kHz have a small quartile range (~6 dB) and are in the range of 90 dB re 1 µPa². We will see in the following sections that the decidecade levels in the Minas Passage are much higher and have greater inter-quartile ranges.

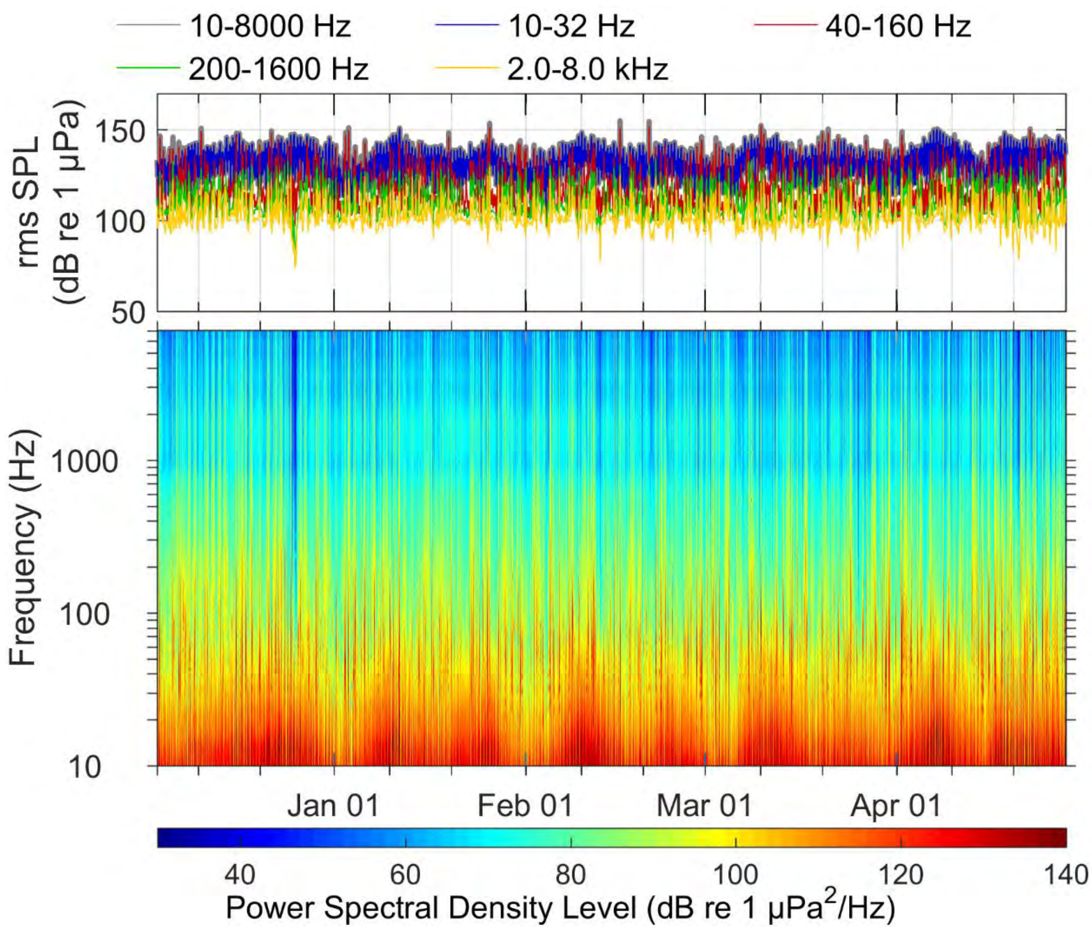


Figure 35. (Top) in-band SPL and (bottom) spectrogram for the AMAR deployed in the Bay of Fundy in 2015.

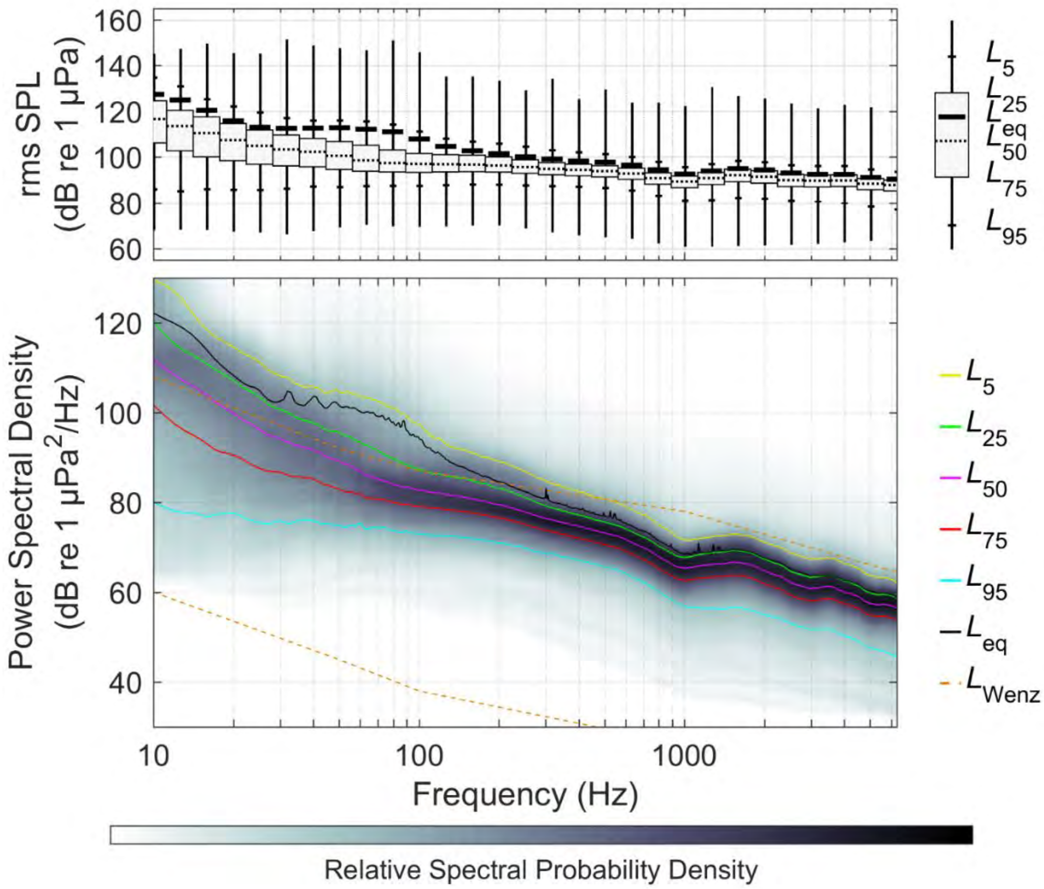


Figure 36. (Top) Exceedance percentiles and mean of the decidecade band SPLs and (bottom) exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962) for the AMAR deployed under the shipping lanes in the Bay of Fundy in 2015.

B.2.2. Autonomous AMAR

The complete measurement results for the autonomous AMAR are presented in Figures 37 and 38 for the deployment period (18 Nov 2016 to 19 Jan 2017). All results presented in this section are from hydrophone 1. The spectrogram and band level plot (Figure 37) shows that low-frequency noise contributed the most energy to the recordings, and that the highest low-frequency sound levels occurred on the days with the highest tidal currents (Figure 34). The differences over a short time in the band level plot indicate that there were large variations due to tide. Figure 38(bottom) shows the pressure spectral density (PSD) compared to the expected limits on prevailing noise. Typically, we compare the median, or L_{50}, to the prevailing noise limits to describe ambient noise conditions. In this area, the L_{50} exceeded or was very close to the upper limit on prevailing noise for all frequencies. There are peaks in the PSD in the range of 60–300 Hz and ~4 kHz that are likely associated with the turbine operations (see Appendix C). Based on Figure 38, data from frequencies less than 50 Hz are affected by flow noise most of the time; however, the flow noise can reach to ~200 Hz and above.

The decidecade band levels above 1 kHz are ~10 dB higher than in the outer Bay of Fundy and have an interquartile range of ~20 dB. This variability is due to the energy from sediment interactions, which is an important source at full tidal flows and stops at slack tide.

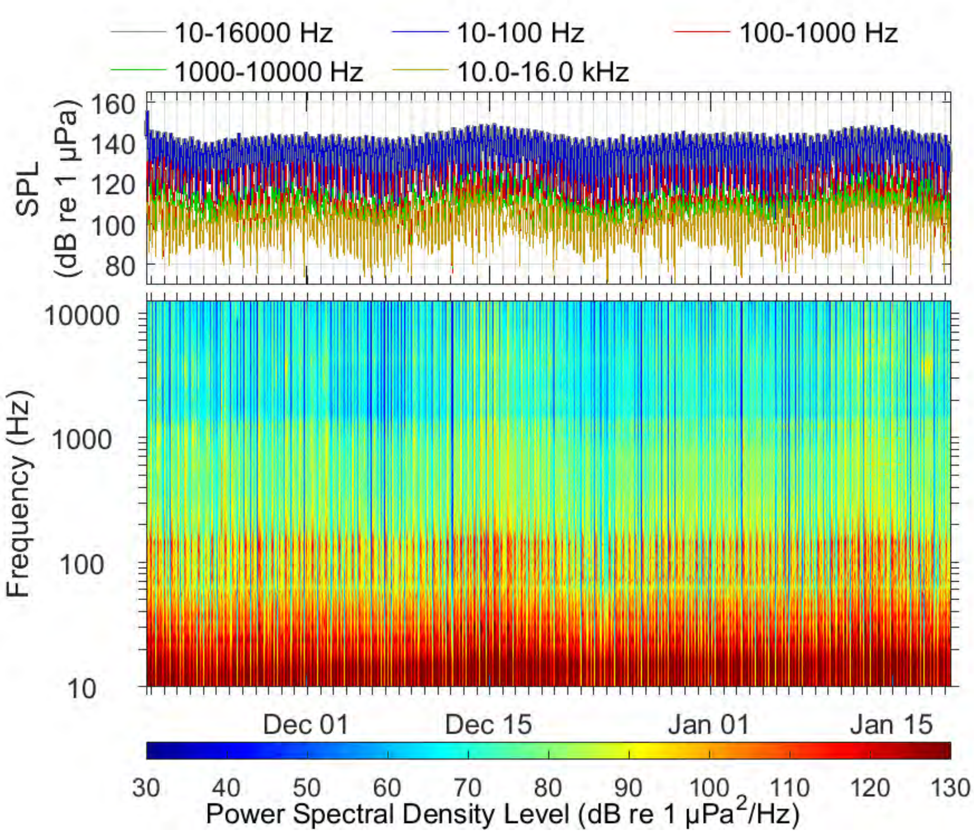


Figure 37. (Top) in-band SPL and (bottom) spectrogram for the autonomous AMAR.

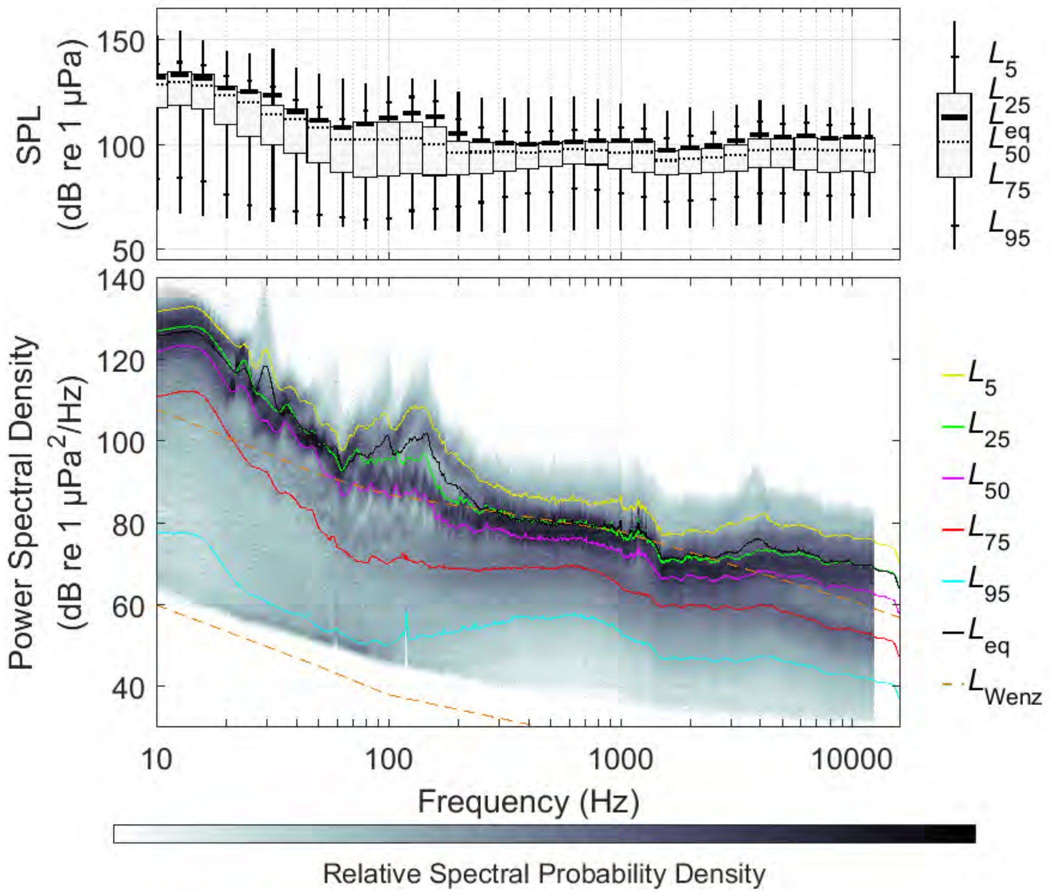


Figure 38. (Top) Exceedance percentiles and mean of the decidecade band SPLs and (bottom) exceedance percentiles and probability density (grayscale) of 1-min PSD levelscompared to the limits of prevailing noise (Wenz 1962) for the autonomous AMAR.

B.2.3. Turbine mounted hydrophones

B.2.3.1. icListen 1404-Forward-Port

The complete measurement results for the Forward-Port icListen are presented in Figure 39 and Figure 40 for the period sampled at 32 kHz (12 Nov 2016 to 08 Mar 2017). The spectrogram and band level plot (Figure 39) shows that low-frequency noise contributed the most energy to the recordings, and that the highest low frequency sound levels occurred on the days with the highest tidal currents (Figure 34). Figure 38(bottom) shows the pressure spectral density (PSD) compared to the expected limits on prevailing noise. Typically, we compare the median, or L_{50}, to the prevailing noise limits to describe ambient noise conditions. In this area, the L_{50} was 5–10 dB above the upper limit of prevailing noise for all frequencies. The peaks in the PSD in the range of 60–300 Hz and ~4 kHz that are likely associated with the turbine operations are less pronounced on the icListen than they are on the AMAR (Figure 38; also see Appendix C). Based on Figure 40, data from frequencies less than 200 Hz are affected by flow noise most of the time, however, the flow noise can reach to ~500 Hz. The high PSD levels above 1000 Hz are likely generated by real sound in the water from sediment interaction noise.

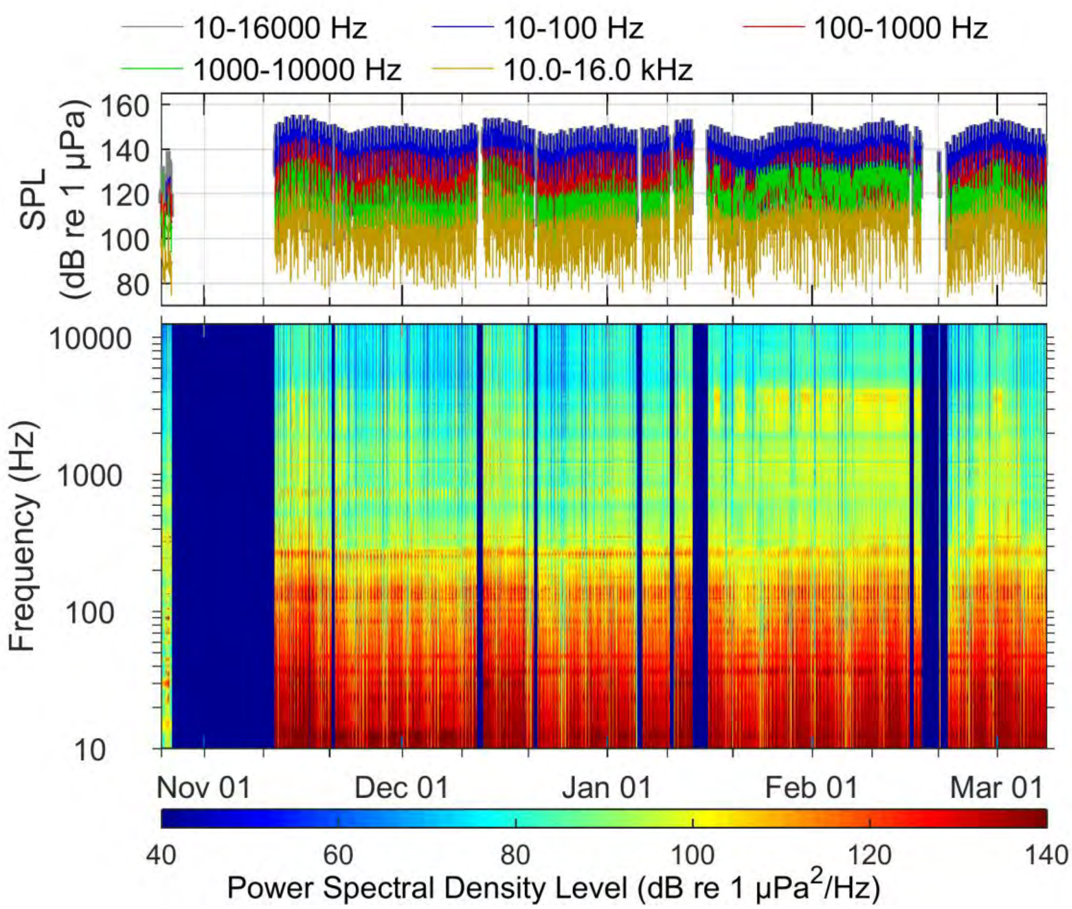


Figure 39. (Top) in-band SPL and (bottom) spectrogram for icListen 1404 hydrophone in the Forward-Port position.

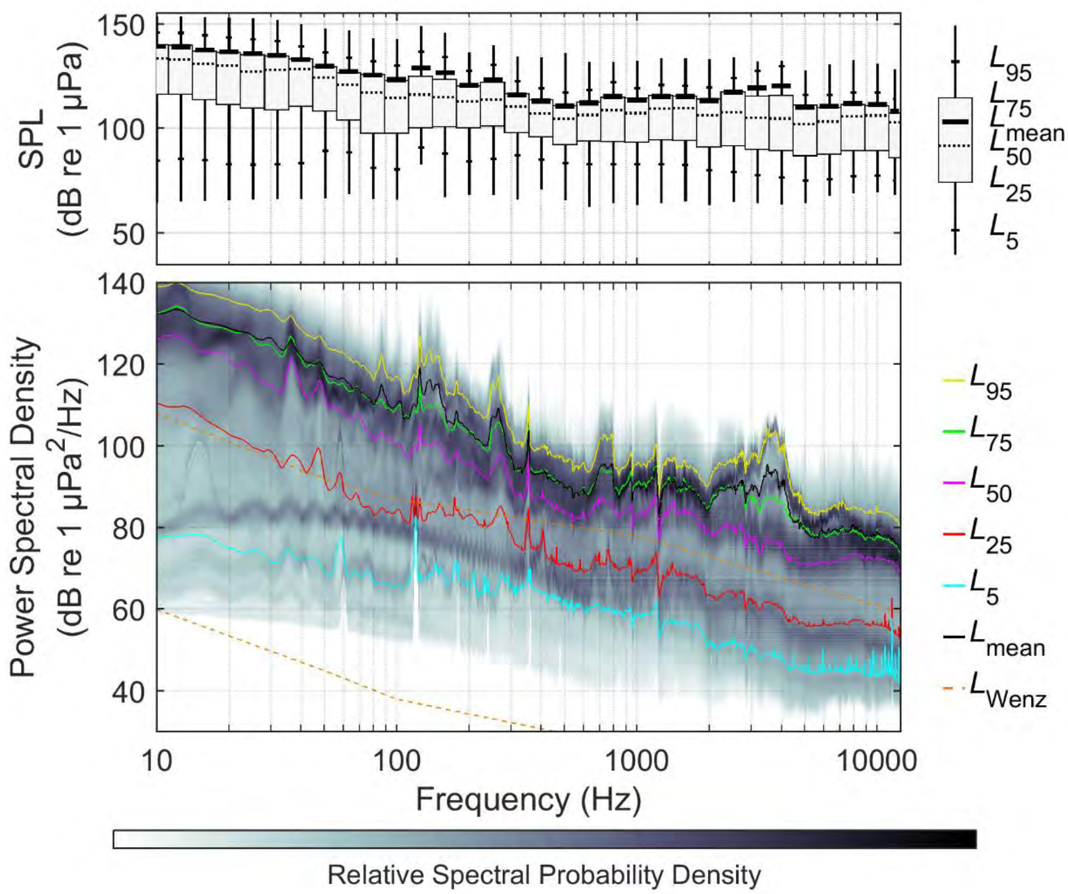


Figure 40. (Top) Exceedance percentiles and mean of the decidecade band SPLs and (bottom) exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962) for icListen 1404 hydrophone in the Forward-Port position

B.2.3.2. IcListen 1405–Turbine Top

The hydrophone placed at the top of the turbine (hydrophone 3, Figure 27) was operational for ~13 tidal cycles (Figure 41). The long-term spectrogram for this hydrophone has a short enough total duration that the differences between the ebb and flood tide speeds and its effect on flow noise is easily seen. The flow noise at this location affected the recorded sound levels up to 16 kHz (Figures 41 and 42). The decidecade bands above 1 kHz on this hydrophone (Figure 42) continue to decrease in amplitude with frequency, unlike those on the forward-port hydrophone (Figure 40) and the autonomous AMAR (Figure 38). This shows that the flow noise is still dominant at these frequencies and the effects of sediment interaction are not important in the recordings at this position. This data from this recording position are of limited value for assessing the sound emitted by the turbine.

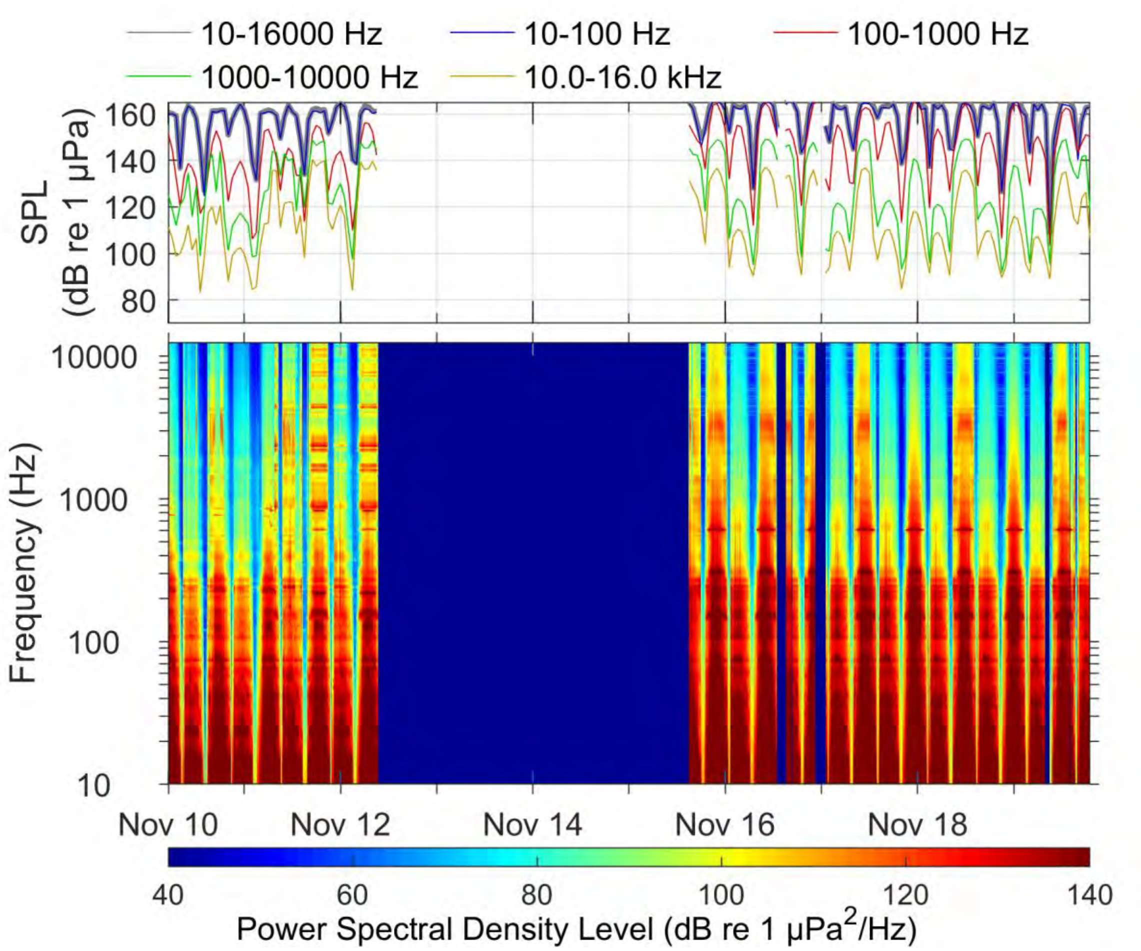


Figure 41. (Top) in-band SPL and (bottom) spectrogram for icListen 1405 hydrophone on top of the turbine.

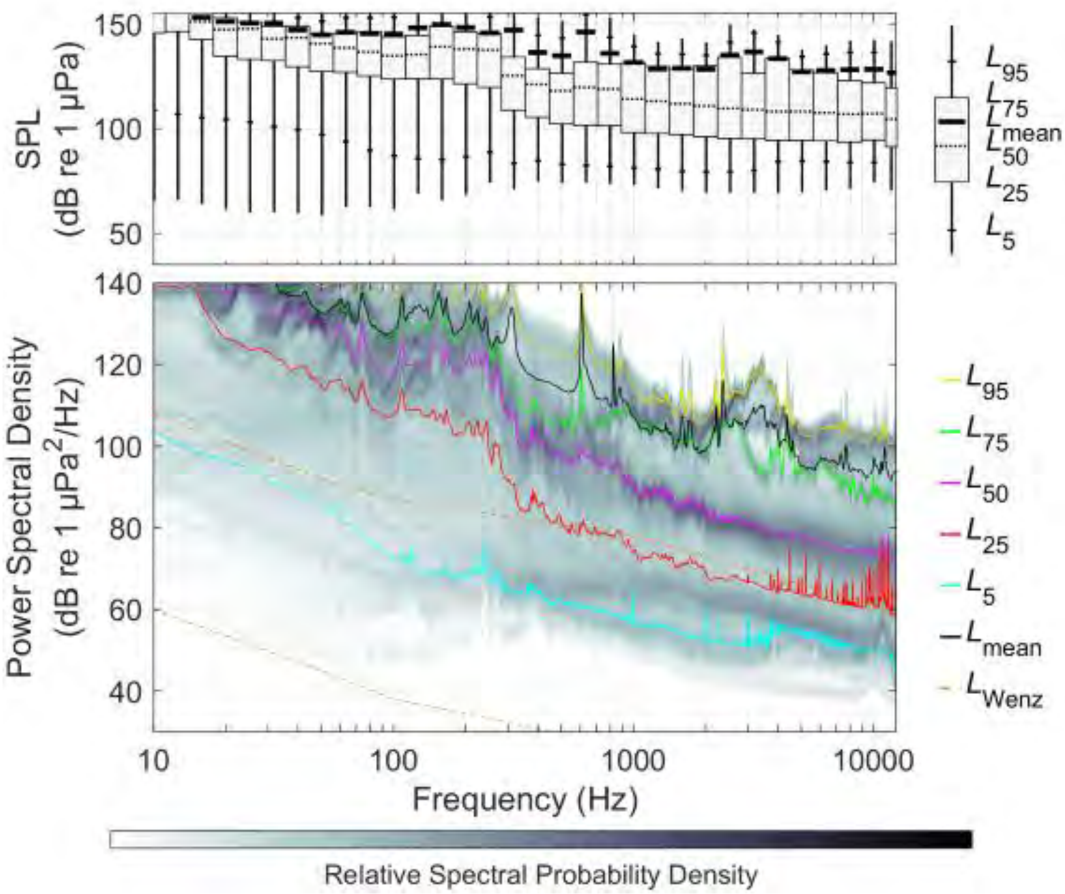


Figure 42. (Top) Exceedance percentiles and mean of the decidecade band SPLs and (bottom) exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962) for icListen 1405 hydrophone on top of the turbine.

B.2.3.3. High Frequency Noise Issues on the Cabled icListen

The icListen sampling rate was increased to 512 kHz on 24 Mar 2017. This high sampling rate data can be used to detect porpoises, whose clicks are centred near 130 kHz [13]. During meetings with Emera, concerns about the detection rate of porpoises on the icListen compared to CPOD detectors (Chelonia Ltd) lead us to investigate the high sample rate data. It was found that in the frequency band of 60–150 kHz the noise levels on the cabled icListen hydrophone were 15–25 dB above those on the on the drifting icListen hydrophone or the AMAR (Figures 43–47). The nature of the noise leads us to believe that the source is from switching power supplies that are providing power to the icListen. Further investigation of this noise is recommended before the turbine is redeployed. There were also impulsive sounds present in the data that were likely from the Gemini sonar.

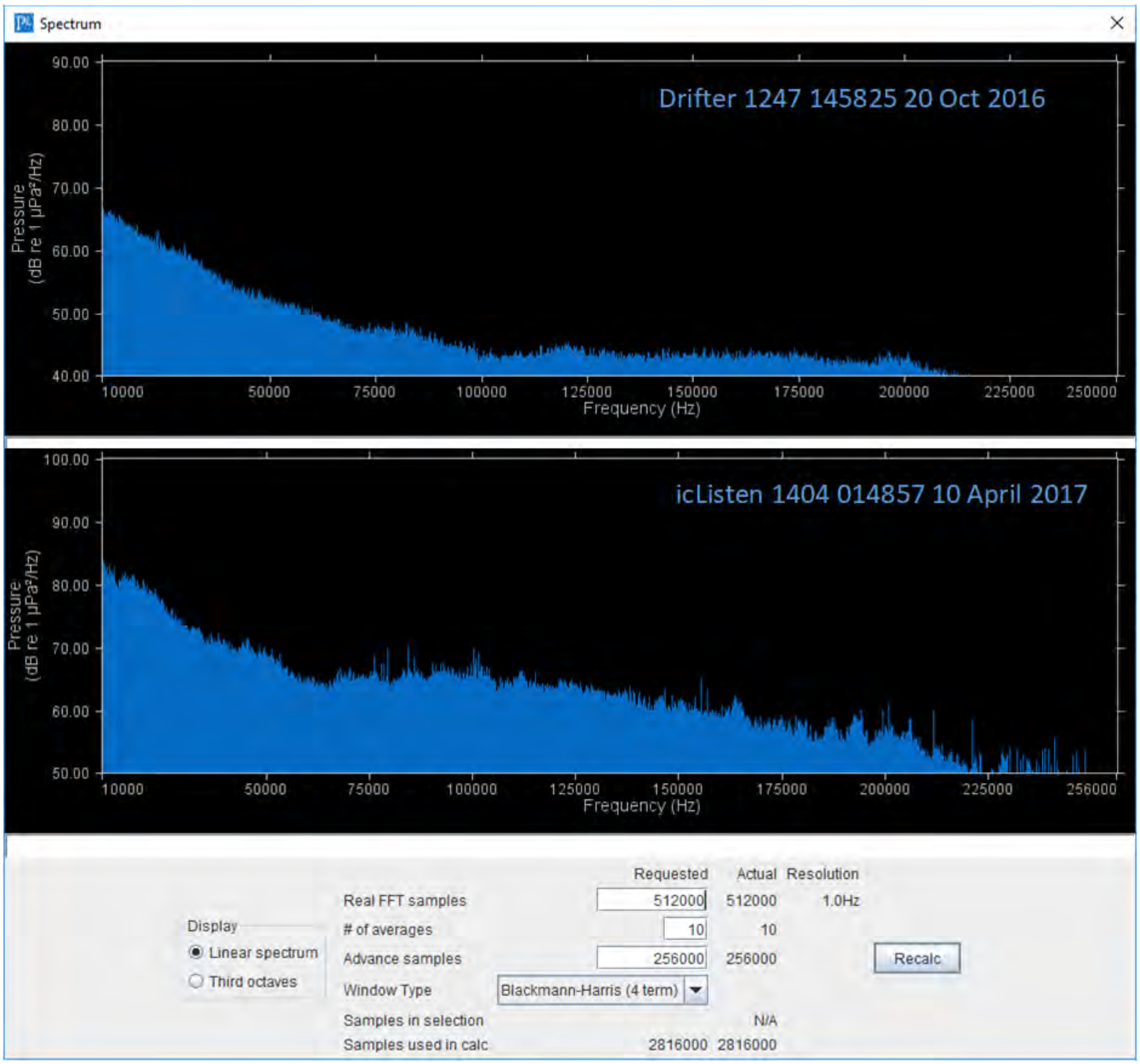


Figure 43. Comparing icListen noise floors. (top) icListen 1247 in a drifter mooring on 20 Oct 2016. (middle) icListen 1404 attached to the OpenHydro turbine platform. (Bottom) Processing Parameters.

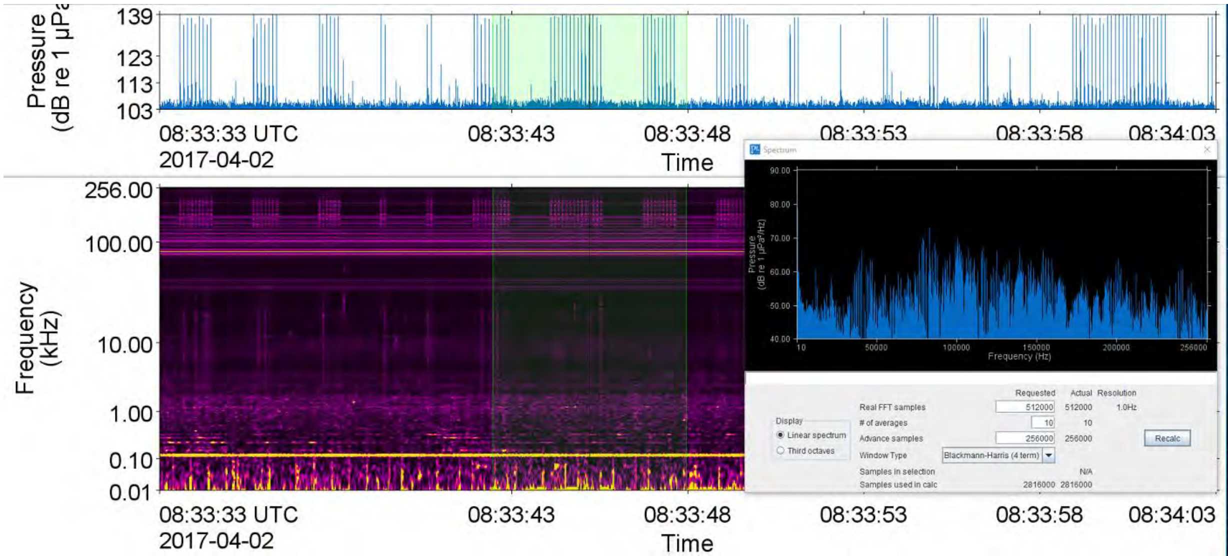


Figure 44. icListen 1404 data sampled at 512 kHz at slack tide on 2 April, showing impulsive signals (likely from the Gemini sonar) and continuous tones at high frequencies.

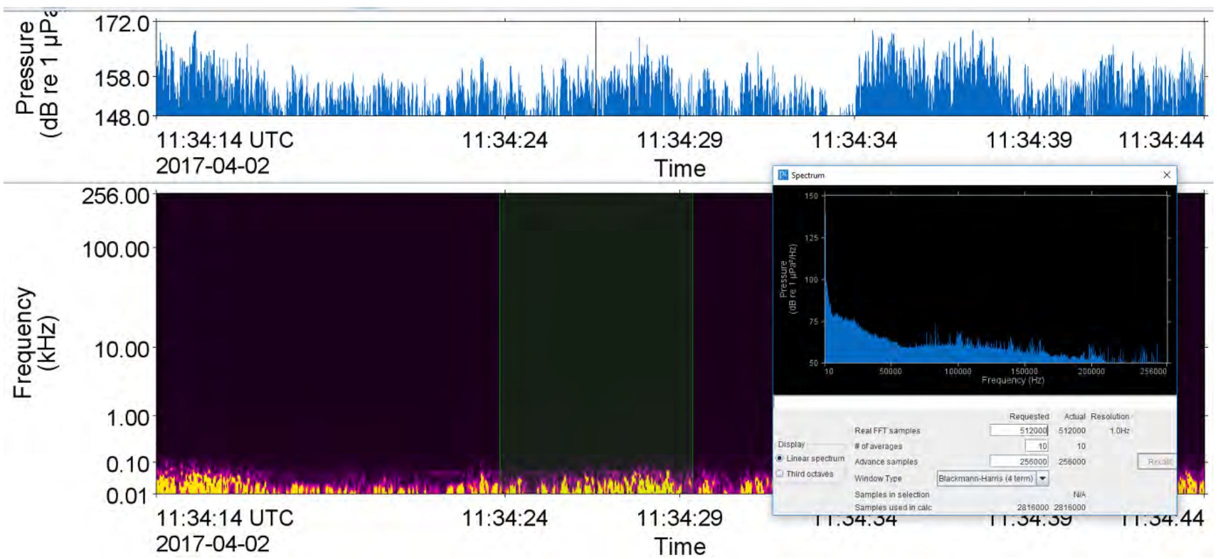


Figure 45. icListen 1404 data at full tidal flow 3 hours after the data in Figure 44; the increase in energy seen in Figure 43 is still present. This effect is not replicated for the AMAR (Figure 47)

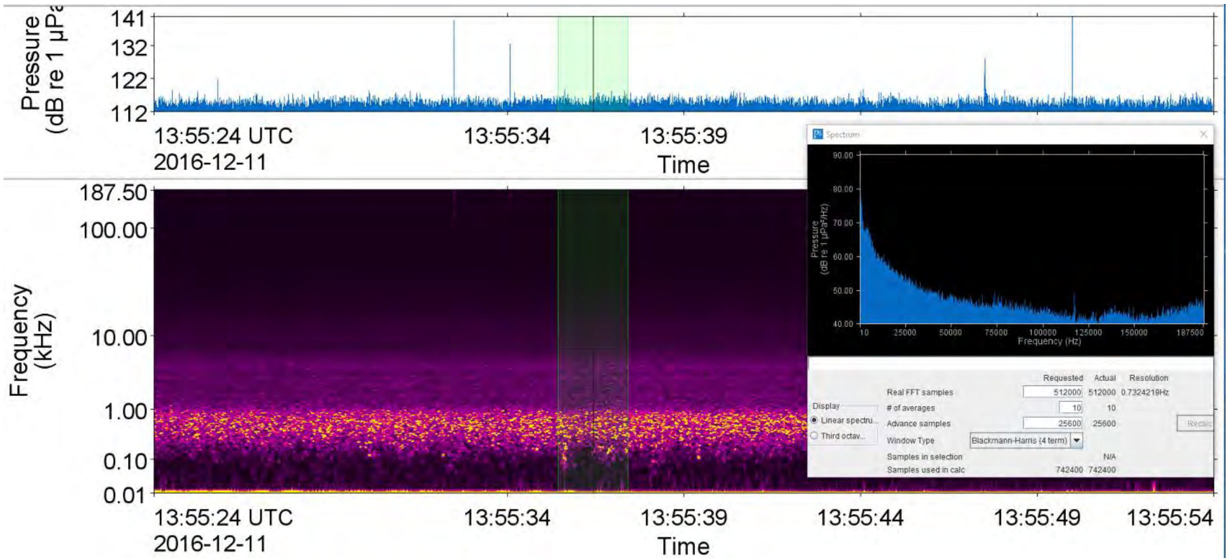


Figure 46. Autonomous AMAR data at slack time on 11 Dec 2016. The noise levels above 60 kHz are similar to those from the drifting icListen (Figure 43)

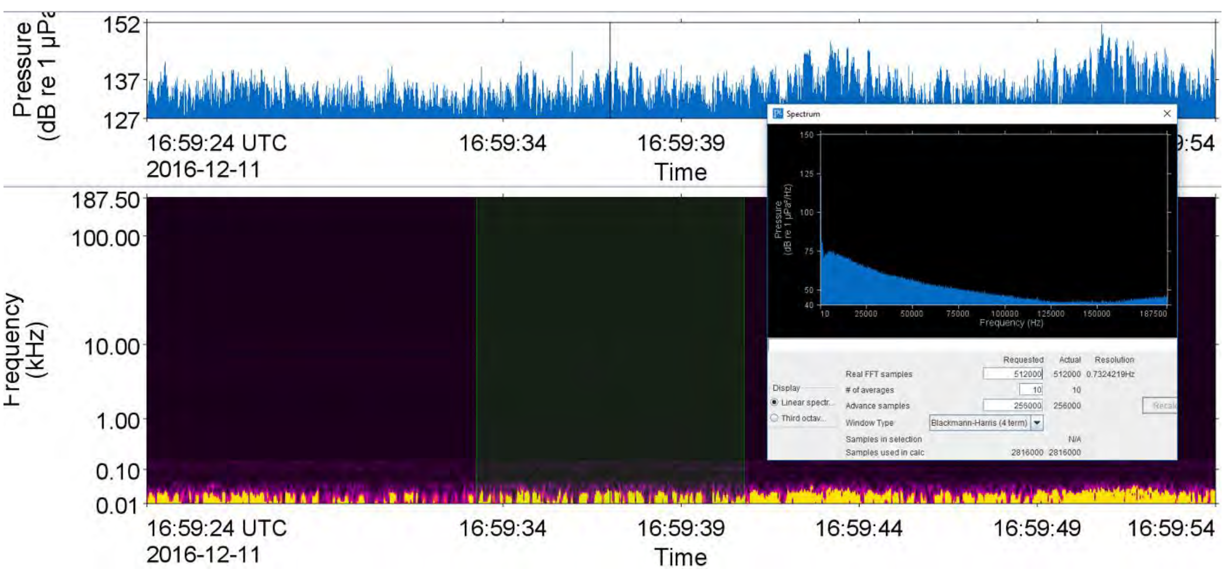


Figure 47. Autonomous AMAR data at full tidal flow on 11 Dec 2016, 3 hours after the data in Figure 46. The noise levels above 60 kHz did not change significantly.

B.2.4. Porpoise Detections

The autonomous AMAR sampled at 375 kHz for 1-minute out of every 8, and the forward-port icListen was switched to 512 kHz sampling on 24 Mar 2017; these data sets are suitable for detecting porpoises. Porpoise were detected sporadically in November 2016 to January 2017 on the bottom mounted recorder (Figure 49). Porpoise were detected on almost all days in the spring using the turbine mounted hydrophone (Figure 48). Further work will be needed to determine if the differences in detection are related to the recording method or the seasons. The AMAR high flow mooring cover may not allow the porpoise click frequencies to propagate to the hydrophone. We have verified its performance up to 32 kHz only. The CPOD data collected intermittently since 2012 appears to show that porpoise presence peaks in the spring and is at its lowest levels in December/January [76].

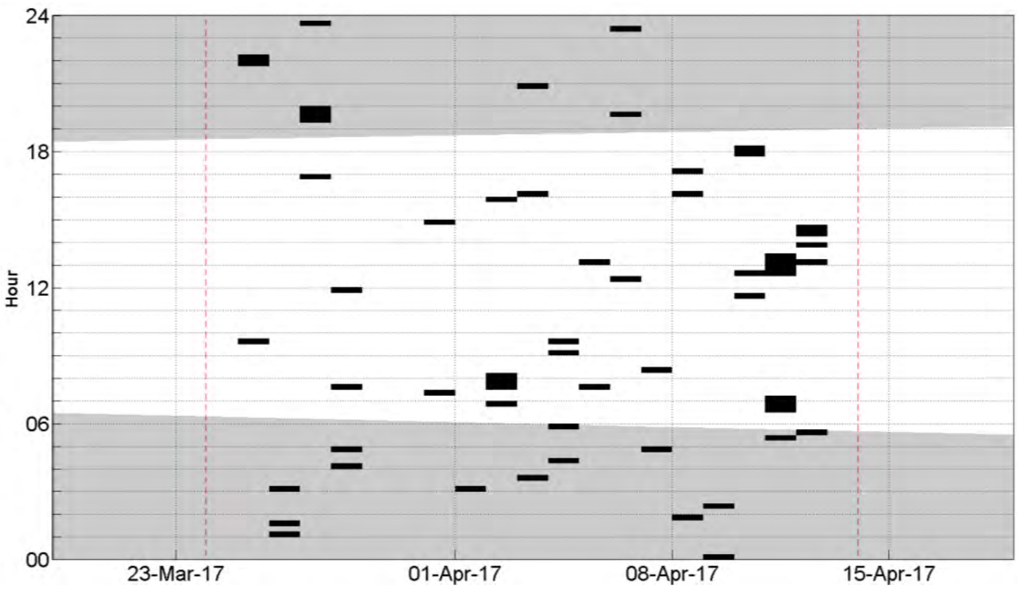


Figure 48. Automated porpoise click-trains detections on the 512 kHz sampled forward-port hydrophone data (24 Mar 2017 to 13 Apr 2017).

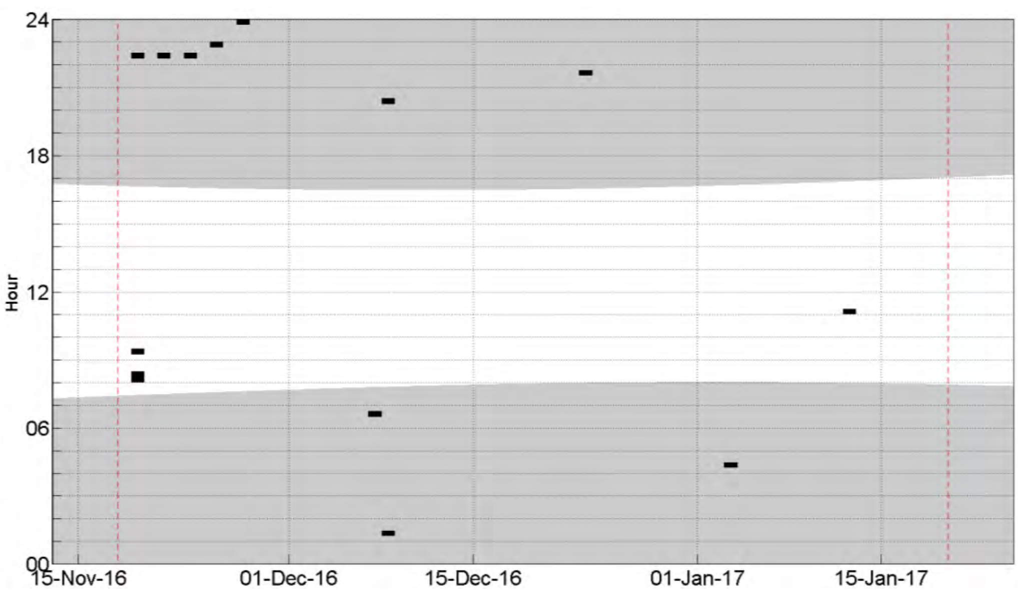


Figure 49. Automated porpoise click-trains detections on the 375 kHz sampled autonomous AMAR data (16 Nov 2016 to 19 Jan 17).

B.3. Drifters

Acoustic recordings are made with hydrophones that are sensitive to the small changes in pressure from sound waves travelling in the water. Large pressure changes can occur when water flows around the hydrophone—a problem for stationary hydrophones that is overcome by using drifters. However, drifters can move up-and-down in the water due to waves, which also causes large pressure changes. These pressure changes from hydrophone movement and currents are called flow noise. It is a measurement artifact that must be minimized during data collection and accounted for during data analysis.

Two sets of drifter measurements were considered in this analysis–the combined icListen and AMAR drifts on 20 Oct 2016 and the icListen drifts on 27 Mar 2017. The data are summarized in Figure 50.

On 20 Oct 2016, the AMAR and icListen measured similar sound levels (Figure 50 left). In this data set, the high-frequency cetacean mammal weighted sound pressure levels (frequency > ~10 kHz, see Figure 4) rise in parallel with the low frequencies are only a few decibels below the broadband sound levels for most of the tidal cycle. This means that the strongest source of sound is at high frequencies, i.e., from sediment interactions. Near slack tide, vessel noise caused the low-frequency sound levels to increase independently of the high frequencies. In this data set, the icListen drifter had regular, low intensity and low-frequency impulsive sounds (Figure 51). We believe the source of this sound is movement of the hydrophone due to surface wave action that couples to the hydrophone (mooring shown in Figure 28). The AMAR drifter, which has a catenary mooring (Figure 29) did not have these impulses (Figure 52).

On 27 Mar 2017, the icListen data showed a nearly constant low-frequency sound level while the high-frequency sound level rises and falls with the tidal cycle (right hand side of Figure 50). The seventh drift, at around 14:00, was analyzed in detail both by GeoSpectrum and in this report (see Appendices A.6 and D.1) to assess the turbine sound level as a function of range. These data proved valuable for validating the sound level model derived from the autonomous AMAR data (Appendix C.2). The increase in sound levels as the drifter passed the hydrophone is not apparent here because Figure 50 uses data with a 1-minute averaging time. The source of the low-frequency noise on 27 Mar 2017 appears to be far higher levels of surface-wave induced noise that made data below 150 Hz unsuitable for analyzing environmental or turbine sound levels (Figure 53).

From these data sets, we conclude:

1. The value of drift measurements is in obtaining the sound level versus range to validate source level models.
2. Either acoustic recorder is suitable for drift measurements. If the AMAR is used in the future, it should be programmed to record continuously at the higher sampling rate rather than duty cycling.
3. Drifters must include an effective means of isolating the hydrophone from surface wave action.
4. Drifters must have a GPS logger attached that records the location at least once per minute, higher logging rates are recommended.

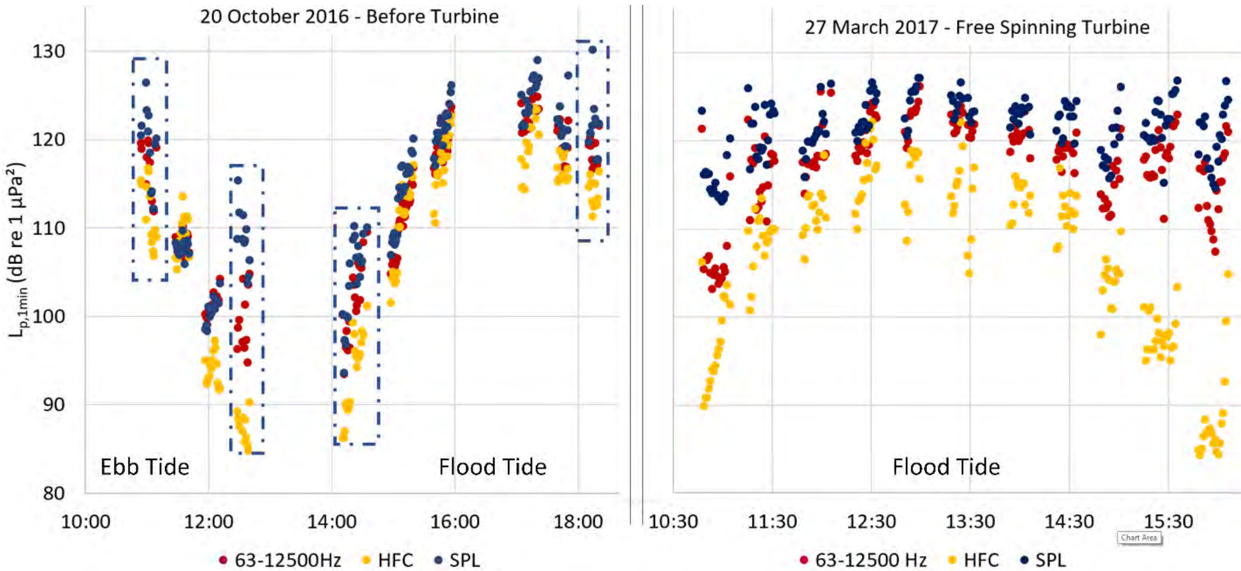


Figure 50. Comparing drifting hydrophones results. (left) one-minute SPL measured on 20 Oct 2016 before the turbine was installed. Drifts with boxes around them were made with the AMAR drifter. (Right) the 11 drift trials made on 27 Mar 2017 using the icListen drifters with the turbine free-spinning.

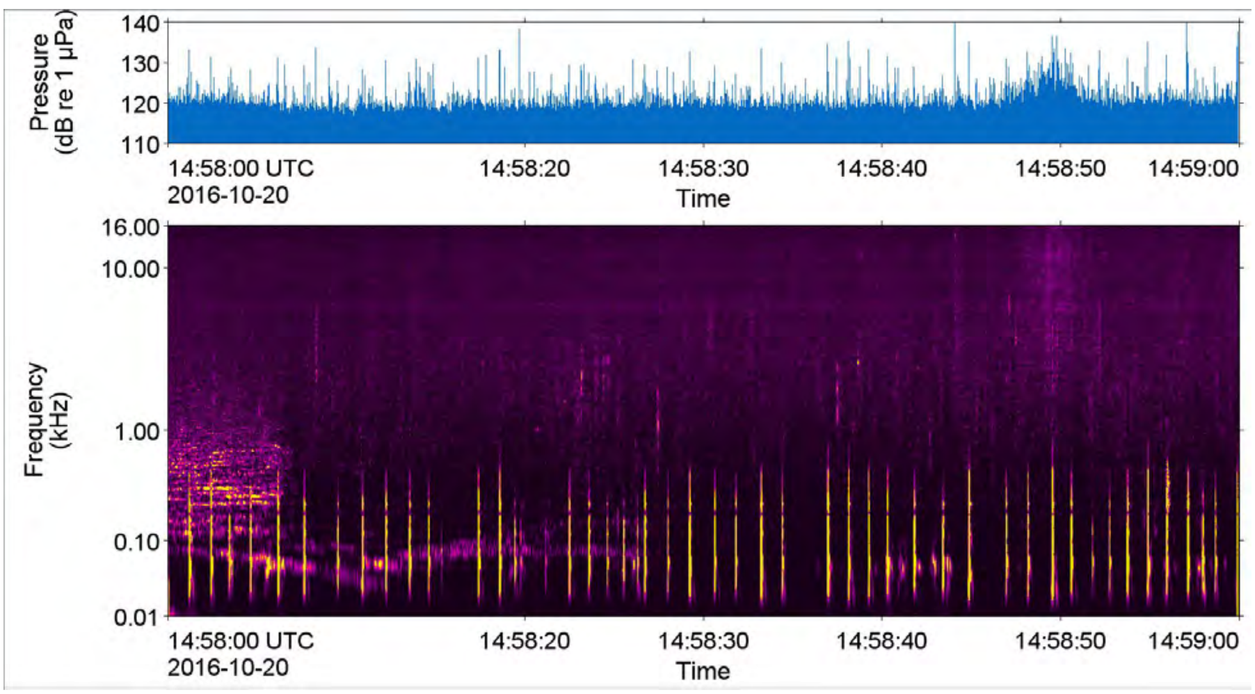


Figure 51. Time-series (top) and spectrogram (bottom) of one-minute of data from icListen drifter 1247 at 14:58 on 20 Oct 2016. The data were high-pass filtered at 5 Hz to remove the extreme low-frequency noise that was present. The vertical yellow impulses from ~10 Hz–300 Hz are likely due to the mooring line coming tight and the hydrophone moving upwards in the water column.

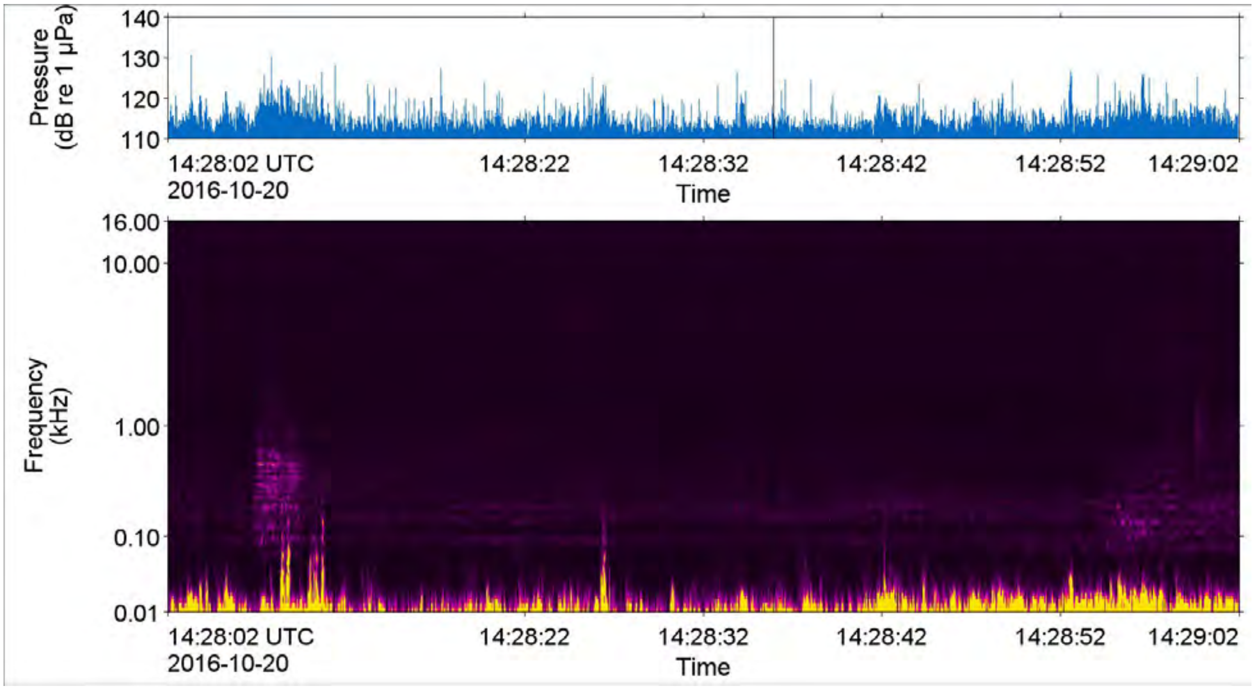


Figure 52. Time-series (top) and spectrogram (bottom) of one-minute of data from the AMAR drifter at 14:28 on 20 Oct 2016.

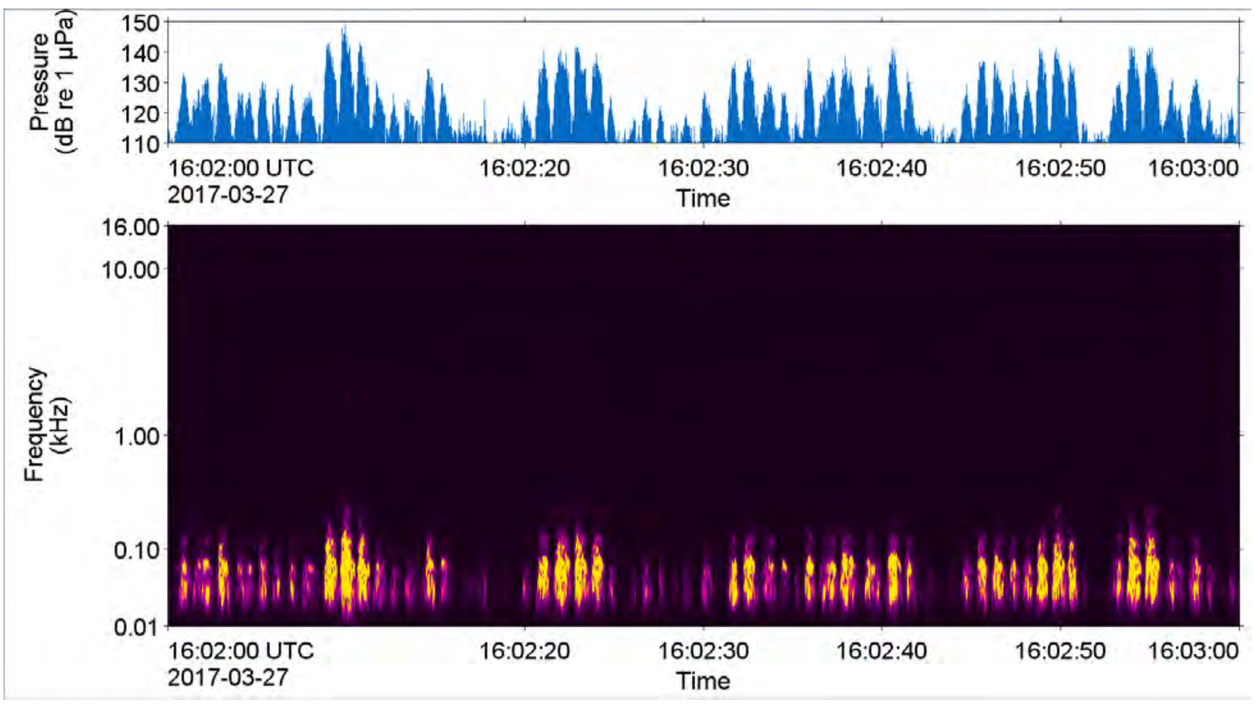


Figure 53. One-minute SPL time-series and spectrogram from icListen drifter 1658 at 16:02 on 27 Mar 2017. Conditions on this day resulted in longer movement noises than were observed on 20 Oct 2016. These data were high pass filtered at 5 Hz.

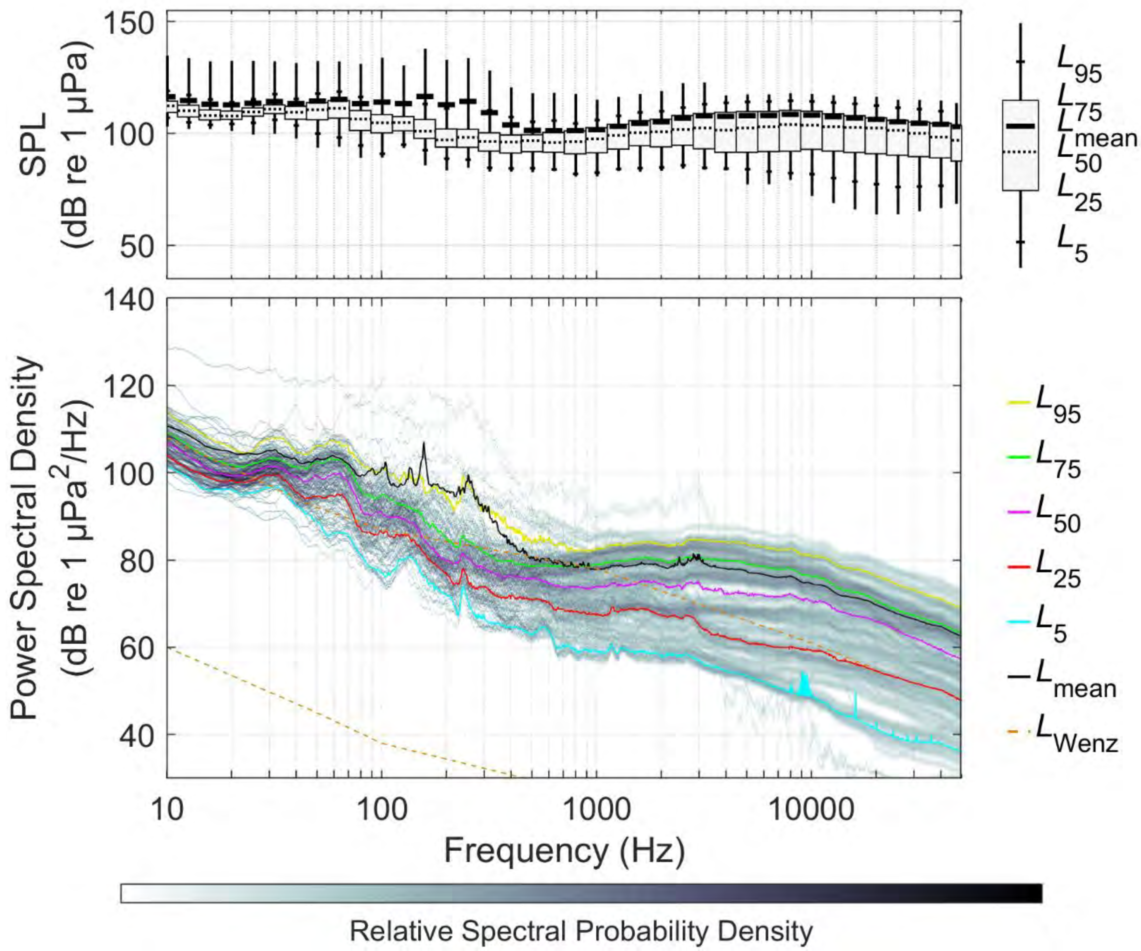


Figure 54. (Top) Exceedance percentiles and mean of the decidecade band SPLs and (bottom) exceedance percentiles and probability density (grayscale) of 1-min PSD levels compared to the limits of prevailing noise (Wenz 1962) for icListen 1658 drifter hydrophone deployed on 27 March. This figure is based on 158 minutes of data across a single flood tidal cycle shown on the right side of Figure 50.

B.4. Comparing Median Spectra

We compared median pressure spectral densities (from Figures 36, 38, 40, 42, and 54) as an indicator of the flow noise recorded at with different monitoring methods (Figure 55). Turbulent flow noise is expected to have a slope of frequency$^{-5/3}$ which is included in the figure for comparison [65, 66].

It is clear from Figure 55 that all recording locations considered are affected by flow noise to varying amounts. For frequencies greater than 60 Hz, the autonomous AMAR data appears to be representative of sounds in the water rather than flow noise. The autonomous, shielded, and bottom mounted location of the autonomous AMAR was 5–20 dB quieter than the hydrophone in the forward-port location, and 10–40 dB quieter than the turbine top location. The drifter was affected by vertical movement noise up to ~150–200 Hz on 27 March (Figure 53), but it had similar sound levels to the AMAR from ~50–1000 Hz. Above 1000 Hz sediment movement noise in the Minas Passage increased measured sound levels compared to the outer Bay of Fundy. The sediment noise may have had higher levels on recordings made above the seabed compared to the autonomous bottom mounted recorder. For quiet long-term recordings, the high flow mooring AMARs appear to be the preferred monitoring solution.

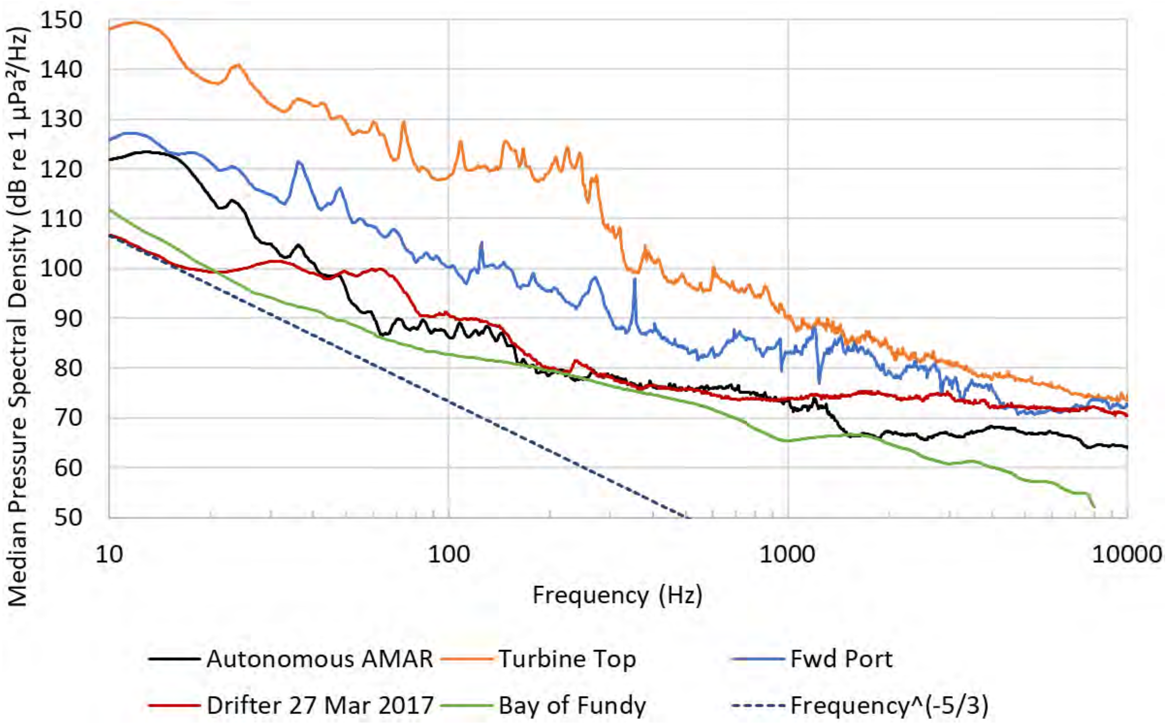


Figure 55. Median pressure spectral densities for three different long-term recording positions, the reference recording from the outer Bay of Fundy as well as the drifter measurements from 27 Mar 2017. Frequency$^{-5/3}$ is the expected slope for turbulent flow noise.

Appendix C. Received Turbine Sound Levels

The sound levels received at autonomous AMAR and the forward-port icListen were analyzed in detail to determine the received sound levels from the Open-Centre Turbine. The objective of the analysis was determining the sound level for each combination of turbine operating and tidal states. The received levels will be converted to source levels that can then be used for predicting the noise footprint of the turbine (Appendix D).

The turbine operating states are not spinning, free spinning and generating. The tidal state is composed of two variables–the tidal direction (ebb and flood) and the current speed (Figure 34). Thus, there were six basic cases–ebb and flood tides for the three tidal states. Two types of analysis to group the data as a function of tidal speed were completed. In the first case the current speed was ignored and only the tidal increment time (e.g., time since high tide, see Appendix A.4) was used to collect similar data (Section Appendix C.1). In the second case the tidal increment time was ignored and only the current speed was used to collect similar data (see Appendix C.2).

C.1. Collecting Data by Tidal Increment

The data were collected by tidal increment (i.e., time since high tide) in two ways–by the median power spectral density for each minute, and by the median decidecade sound pressure level for every fifteen minutes after high tide. The 1-minute power spectral density analysis provides insights into variability of individual frequencies; however, it is more difficult to employ for forward modelling of the range at which the turbine sound exceeds the background levels and thresholds for effects of noise on marine life. The decidecade values for every 15 minutes are more appropriate for forward modelling.

C.1.1. Median Power Spectral Densities by Minute

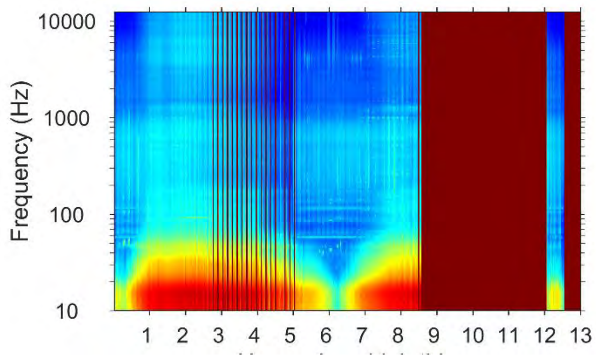
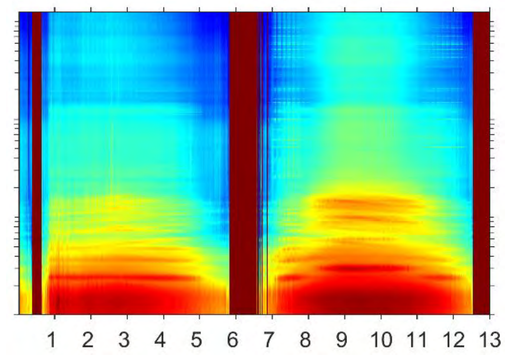
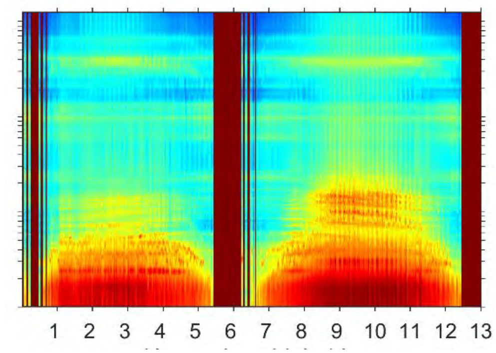
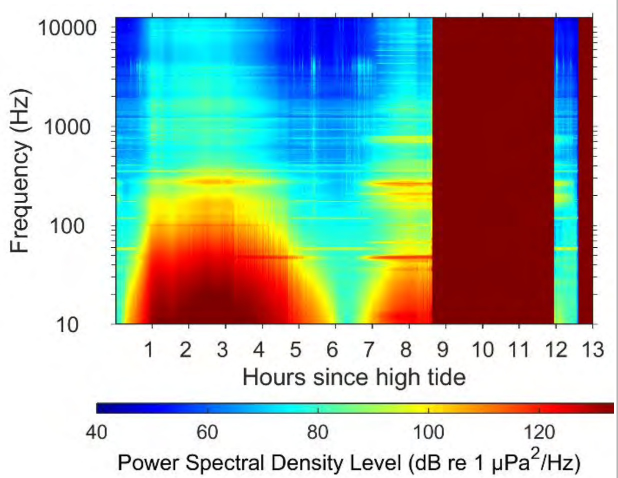
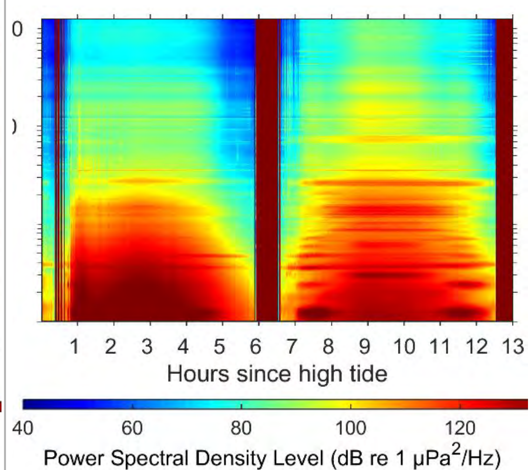
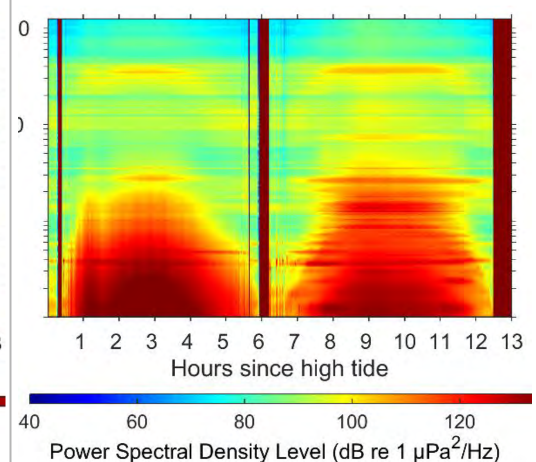
Table 8 contains six long-term-spectral-average figures where the horizontal axis is time since high tide. The *predicted* high tide times for Parrsboro were used to generate these figures, and they will be updated using the FORCE tidal gauge data in the future. All figures were generated using the same colour-to-PSD mapping. The columns of Table 8 are for the three turbine operating states. The top row of Table 8 are the measurements made at 167 m from the turbine at the autonomous AMAR. The bottom row are the measurements made by the forward-port cabled hydrophone that was 8 m from the turbine rim.

Each figure includes two energy peaks, where the first period is the ebb tide and the second is the flood tide. Times without sufficient data samples are blocked out in red. Important results in these figures are:

1. In all turbine operating states, the flood tides have higher sound levels than the ebb tides
2. The generating state produces sounds in the 1–4 kHz range that are not present in the free-spinning state.
3. The large block of red in the not-spinning data shows that the turbine was always free spinning at high currents (i.e., during flood tides).
4. The blocked-out times near slack tide for the free-spinning and generating cases indicate that the turbine needs approximately 15% normalized current speeds to begin rotating. In the range of 20–300 Hz the turbine produces discrete tonal sounds that are shown as the horizontal bands of energy

5. The turbine produces discrete tones in the frequency range of 20–300 Hz that are shown in the figures as horizontal bands of energy in the forward-port hydrophone recordings. On the autonomous AMAR recordings, the lines are inclined, which is due to multipath interference where the sound arriving directly from the turbine adds constructively and destructively with the sound reflected from the surface. The frequencies with constructive interference create higher energy. Those frequencies depend on the wavelength of the sound and its relationship to the difference in path length for the direct and reflected energy. As the tide goes out, the water depth decreases, and the path length difference becomes shorter. Thus, the interference happens at lower frequencies (deeper water) at high tide than low tide, which makes the inclined lines ‘point’ upwards toward the middle of the figures which is low tide.
6. There is an indication that during the first hour of the ebb tide the turbine sound increases then drops slightly before increasing again, especially when measured by the forward-port hydrophone.

Table 8. Power spectral density versus tidal increment time, turbine state, and recorder. The horizontal axis is time in hours since high tide. Times with less than 30 samples of data are blocked out in red.

	Not spinning	Free spinning	Generating
AMAR Stn 2			
IcListen 1404			

C.1.2. Decidecade Band Levels by 15-minute Increment

The pressure spectral density figures in Appendix C.1.1 have a frequency resolution of 1 Hz, and a time resolution of 1 minute–this is too fine a resolution to be managed for most visualizations and subsequent use in acoustic footprint modelling. Decidecade band levels at a lower time resolution are much easier to manage and visualize. In particular, we want to understand how the three turbine operating states sound levels compare across time, across frequency, and by recording location (the autonomous AMAR and forward-port icListen). For the autonomous AMAR, Figure 56 (ebb tide) and Figure 57 (flood tide) have a panel for each 15-minute time increment, and the horizontal axis for each panel is the decidecade frequency. Figure 58 has a panel for each decidecade and the horizontal axis is time across the full tidal cycle with high tide at the left-hand edge of each panel. Figures 59, 60, and 61 repeat these figures for the forward-port icListen hydrophone. Each panel in all figures has three curves corresponding to the different turbine operating states.

Important results from these figures are:

1. For the autonomous AMAR recordings (Figures 56–58), the sound generated by the turbine is distinct from the ambient noise for decidecades of at least 40 Hz and above. The turbine sound is most pronounced in the bands of 63–250 Hz for both free spinning and generating states, and in the band 100–1250 Hz and 3150–4000 Hz for generating only.
2. At the turbine mounted hydrophone, the low-frequency sound (63–250 Hz) does not separate from the flow noise. The higher-frequency sound is well separated from the background noise levels in the frequency band of 1000–6300 Hz but is most prominent in 1000–1250 Hz and 3150–4000 Hz bands.
3. The 63–250 Hz sound increases over a 40-dB range as a function of current speed, whereas the 1000–1250 Hz sound has a nearly constant sound level. The 3150–4000 Hz sound levels vary over a 10-dB range as function of current speed.
4. For all frequency bands, the data recorded on the bottom mounted hydrophone has higher sound levels during flood tide than during ebb. During the ebb tide the turbine mounted hydrophone has higher sound levels for frequencies of 63 Hz and below than during the flood tide. We propose that this is due to additional turbulence in the water mass as it exits the turbine and interacts with the hydrophone (see Figure 27 for hydrophone placement). This reversal of the low-frequency energy pattern can also be seen in Table 8.

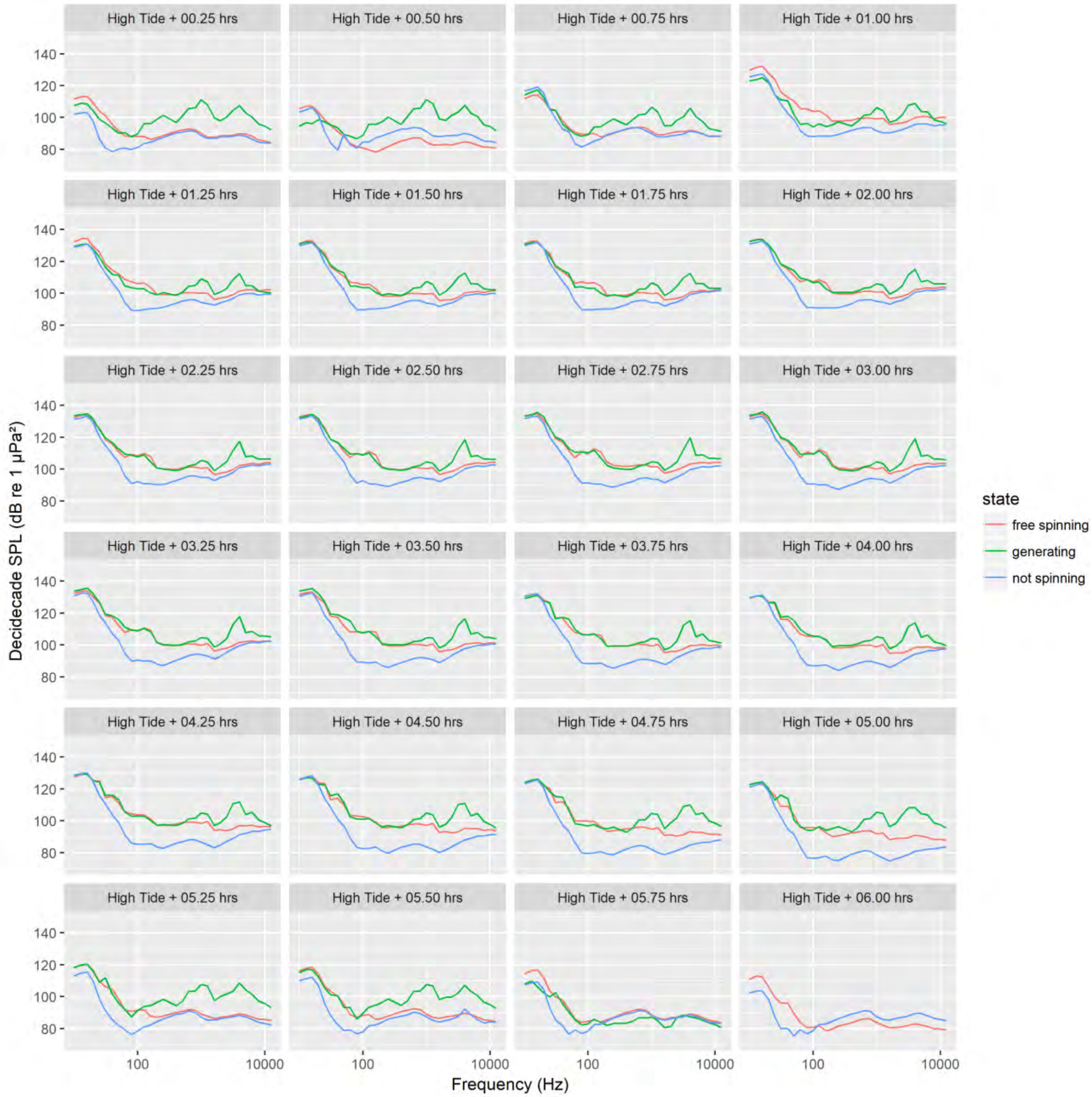


Figure 56. Median decidecade band SPL for each 15-minute time increment during ebb tide using data from the autonomous AMAR. The turbine state is shown by the curve colours.

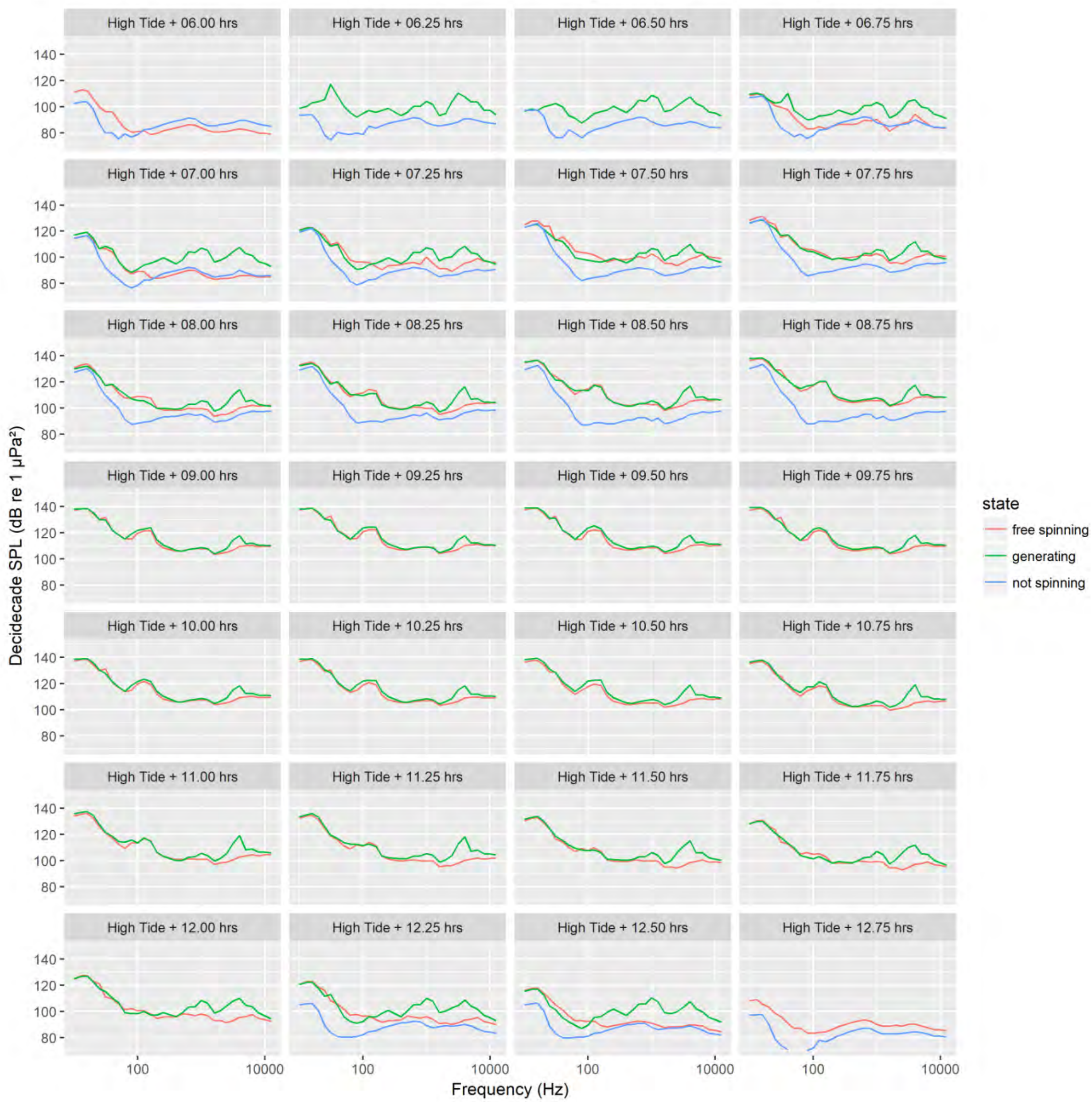


Figure 57. Median decidecade band SPL for each 15-minute time increment during flood tide using data from the autonomous AMAR. The turbine state is shown by the curve colours.

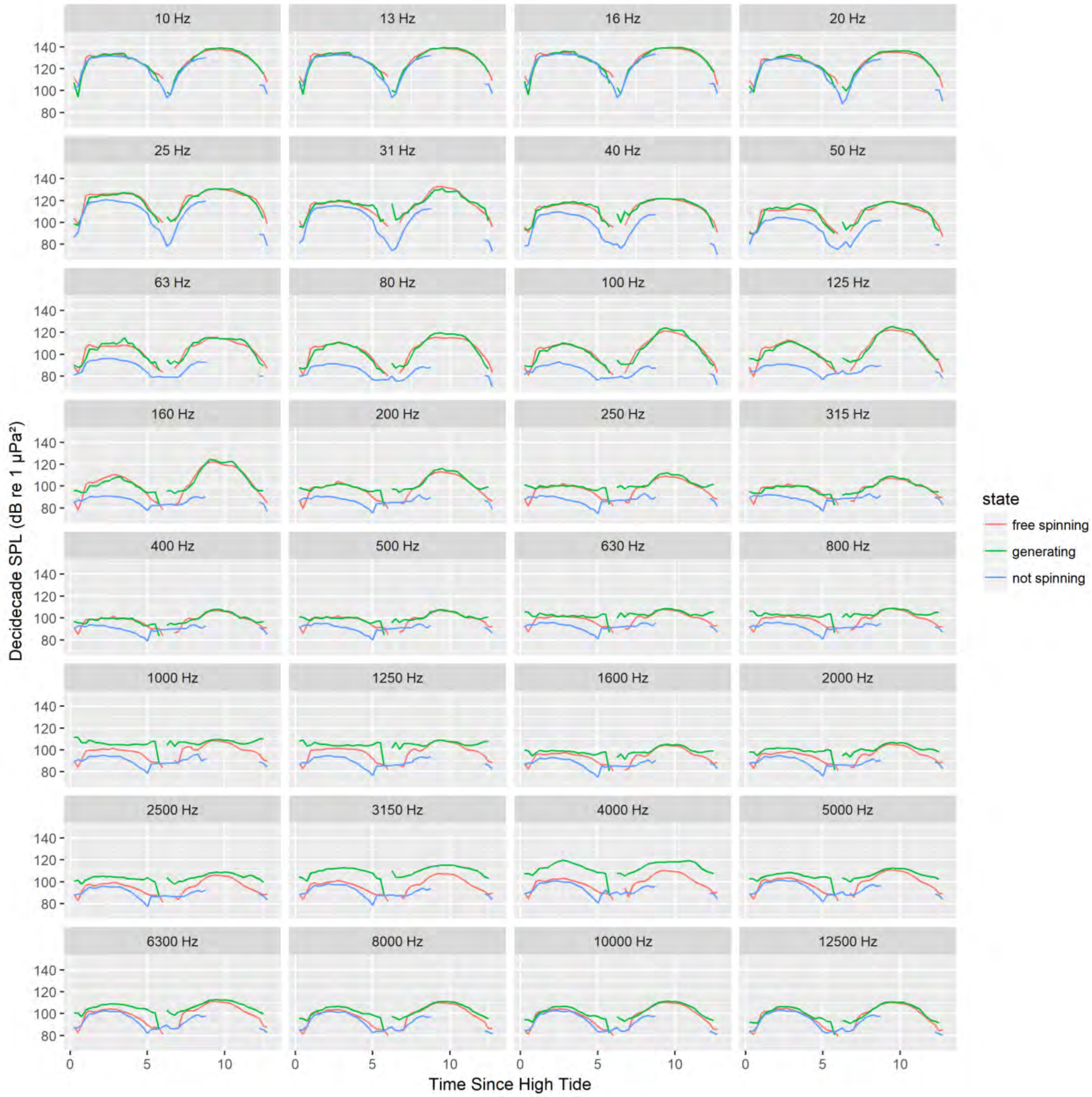


Figure 58. Median decidecade band SPL for each decidecade using data from the autonomous AMAR. The turbine state is shown by the curve colours.

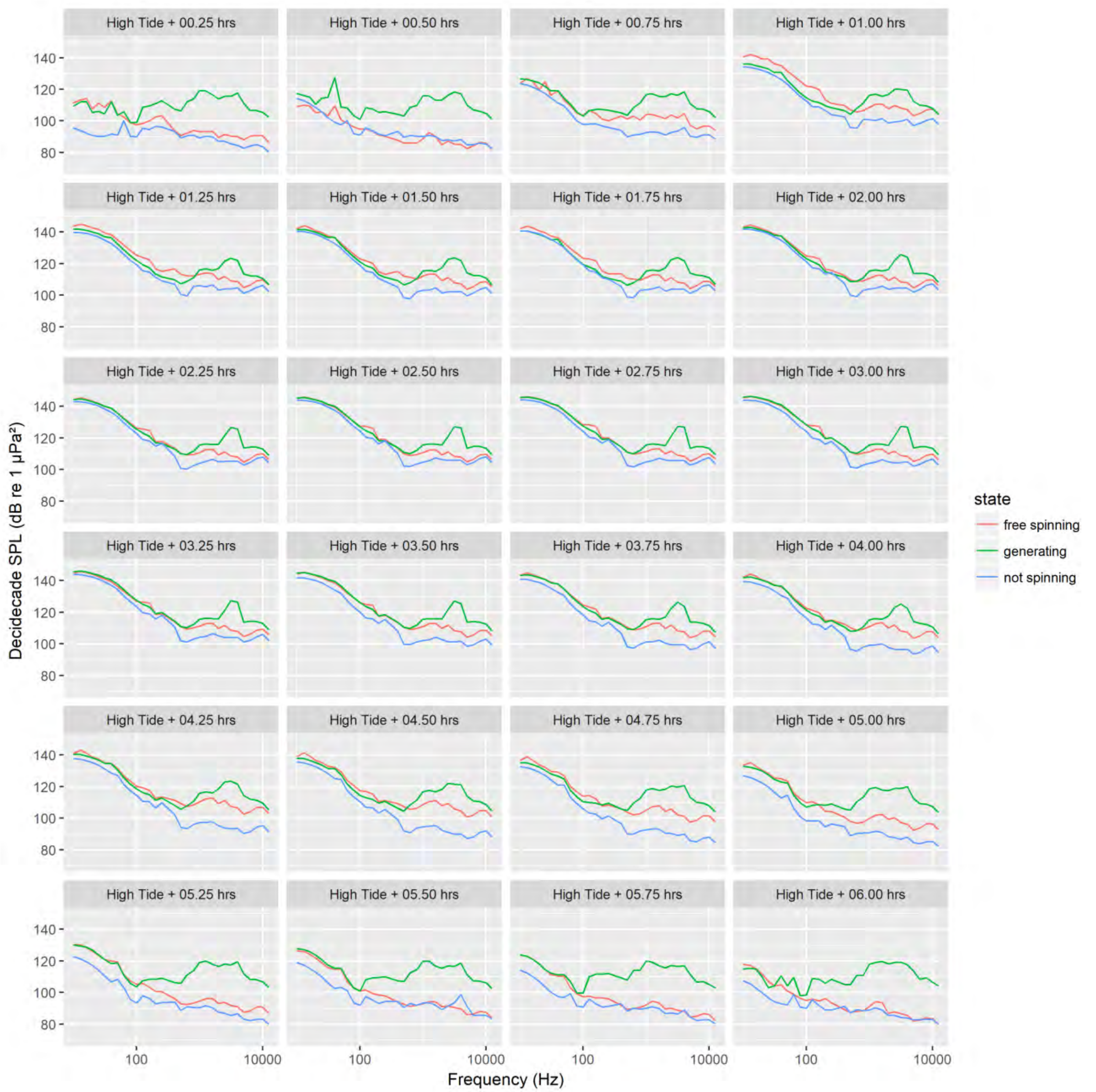


Figure 59. Median decidecade band SPL for each 15-minute time increment during ebb tide using data from the forward-port icListen hydrophone. The turbine state is shown by the curve colours.

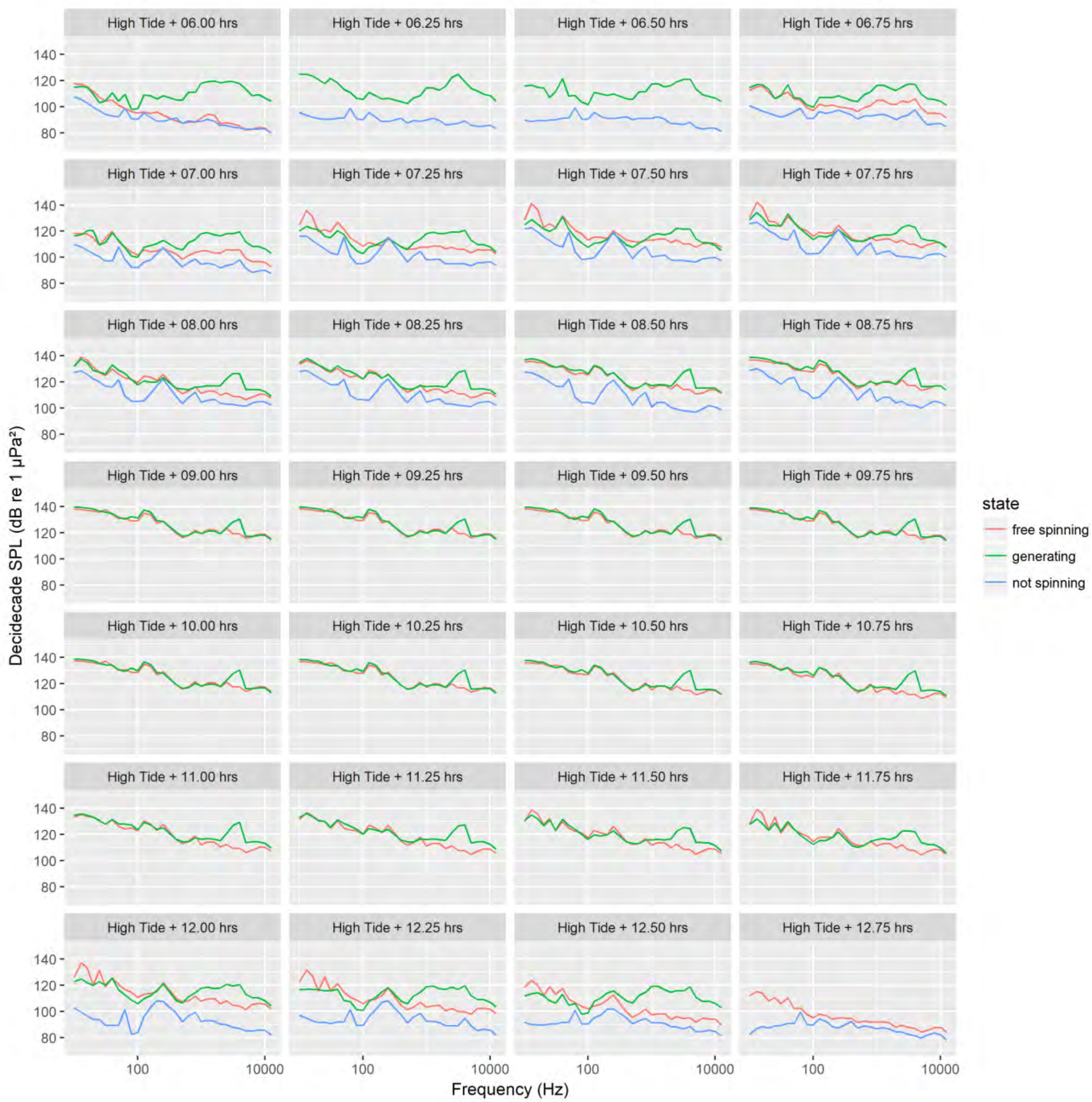


Figure 60. Median decidecade band SPL for each 15-minute time increment during flood tide using data from the forward-port icListen hydrophone. The turbine state is shown by the curve colours.

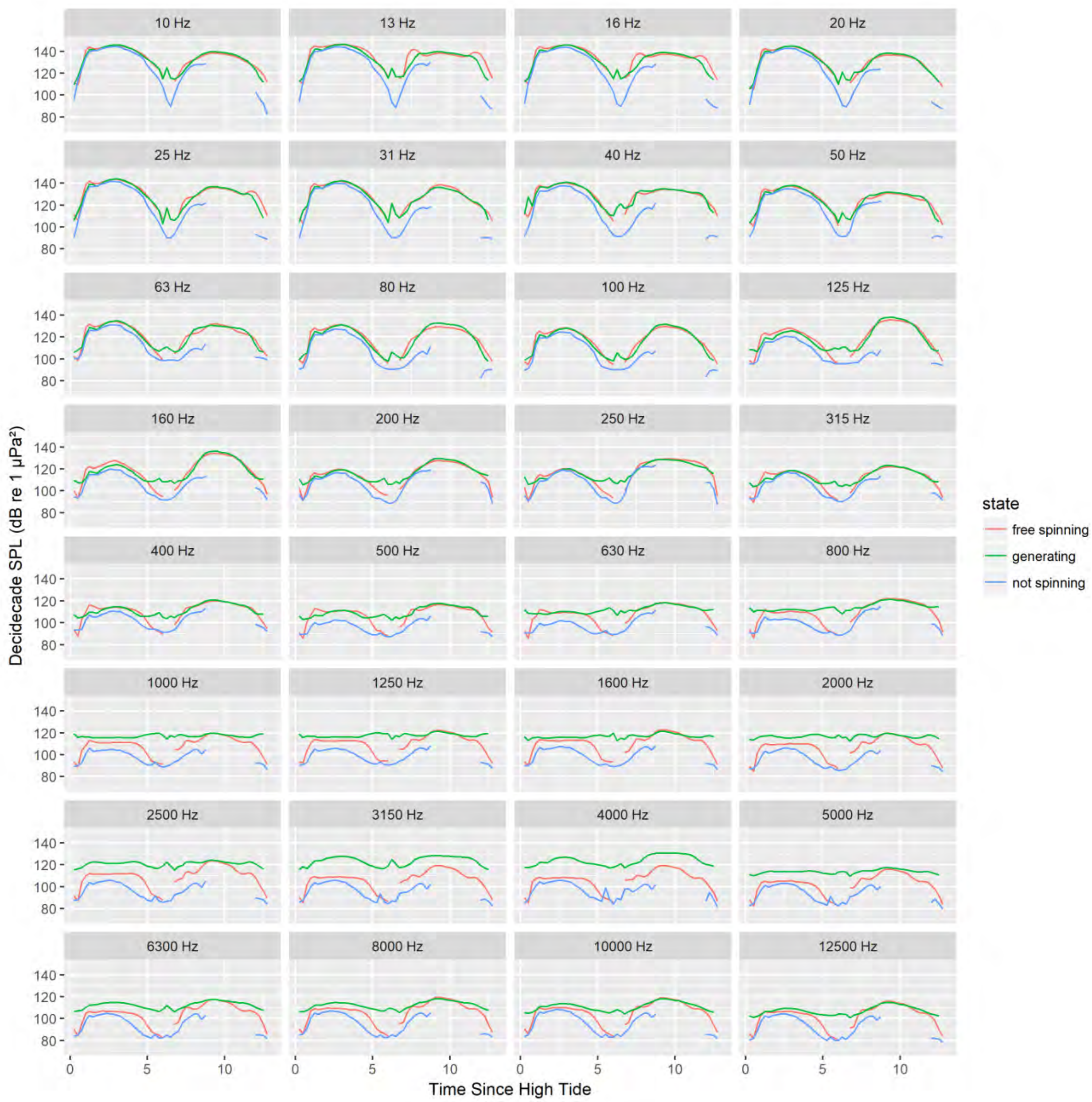


Figure 61. Median decidecade band SPL for each decidecade using data from the forward-port icListen hydrophone. The turbine state is shown by the curve colours.

C.2. General Additive Models of Decidecade Sound Pressure Levels

C.2.1. Model Development

The results from Appendix C.1 showed that the sound levels from the environment (flow noise and sediment interaction noise) and from the turbine depend on current speeds. However, the current speeds are highly variable in time both within the lunar cycle and across lunar cycles (see Figure 34). Therefore, an analysis based on the current speed rather than tidal time increment has the potential to provide more accurate representations of the sound levels.

As described in Appendix A.5, Generalized Additive Models (GAMs) of the 1-minute decidecade band sound pressure levels vs current speed were created for each combination of tide direction (ebb, flow) and each turbine operating state (not spinning, free spinning, generating). Typical result are shown in Figures 62–64 which provide an overview of the sound levels received at the autonomous AMAR. The red curves through the data are the general additive models. The reasons for choosing the GAMs vs a linear model are evident from the results–the not spinning sound pressure level appear to increase linearly with current speed, however the free spinning and generating sound levels do not. The black dots in Figures 62–64 are the measured data; the relative density in the measured data clouds indicate that for 18 Nov 2016 to 19 Jan 2017 the turbine was free-spinning much more that it was generating.

The differences in behaviour of the sound pressure levels as a function of frequency that were observed in the time increment analysis are also evident in the current speed analysis. For example, at 160 Hz (Figure 62) the flood generating sound levels increase over a 30-dB range, are nearly flat at 1000 Hz (Figure 63), and increase over a 10 dB range at 4000 Hz (Figure 64).

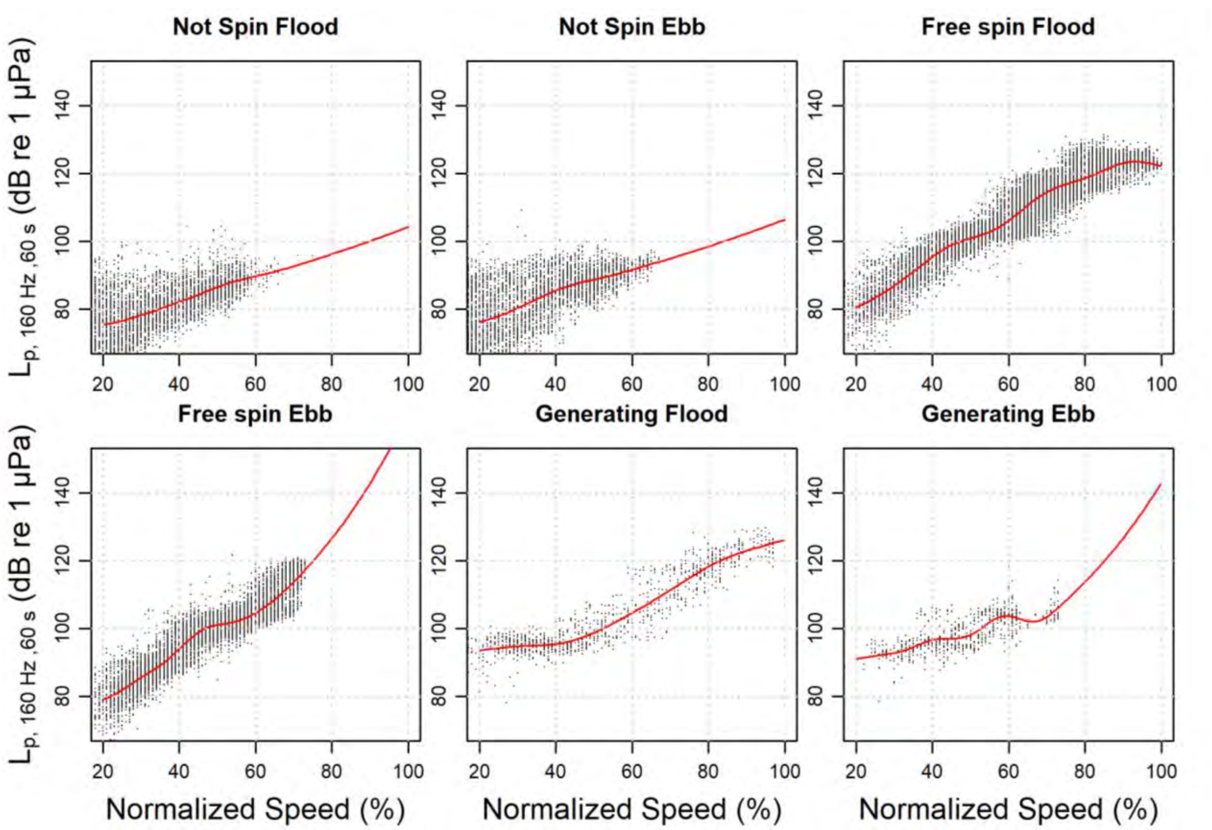


Figure 62. Received 160 Hz decidecade band sound pressure levels from the autonomous AMAR (18 Nov 2016 to 19 Jan 2017) plotted versus normalized current speed for each tide-turbine state. Red lines are the general additive model SPL ~ s(normalizedCurrentSpeed).

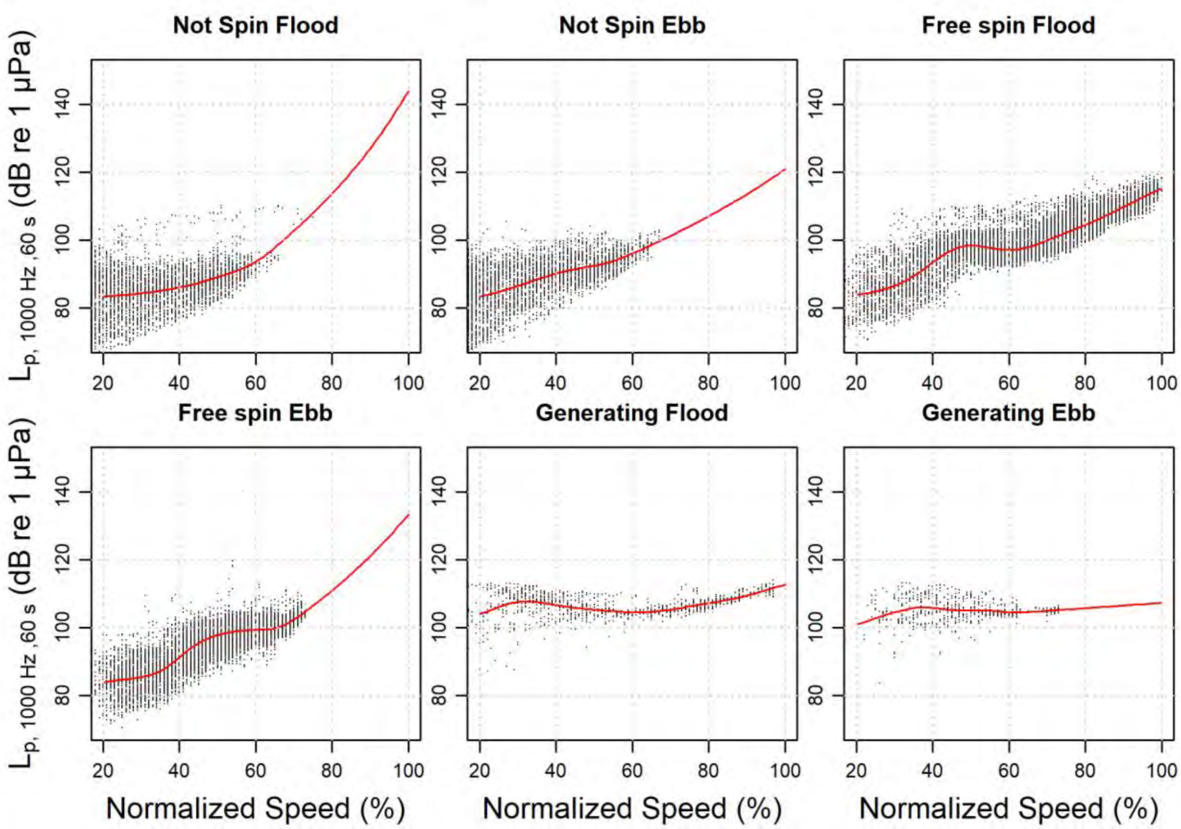


Figure 63. Received 1000 Hz decidecade band sound pressure levels from the autonomous AMAR (18 Nov 2016 to 19 Jan 2017) plotted versus normalized current speed for each tide-turbine state. Red lines are the general additive model SPL ~ s(normalizedCurrentSpeed).

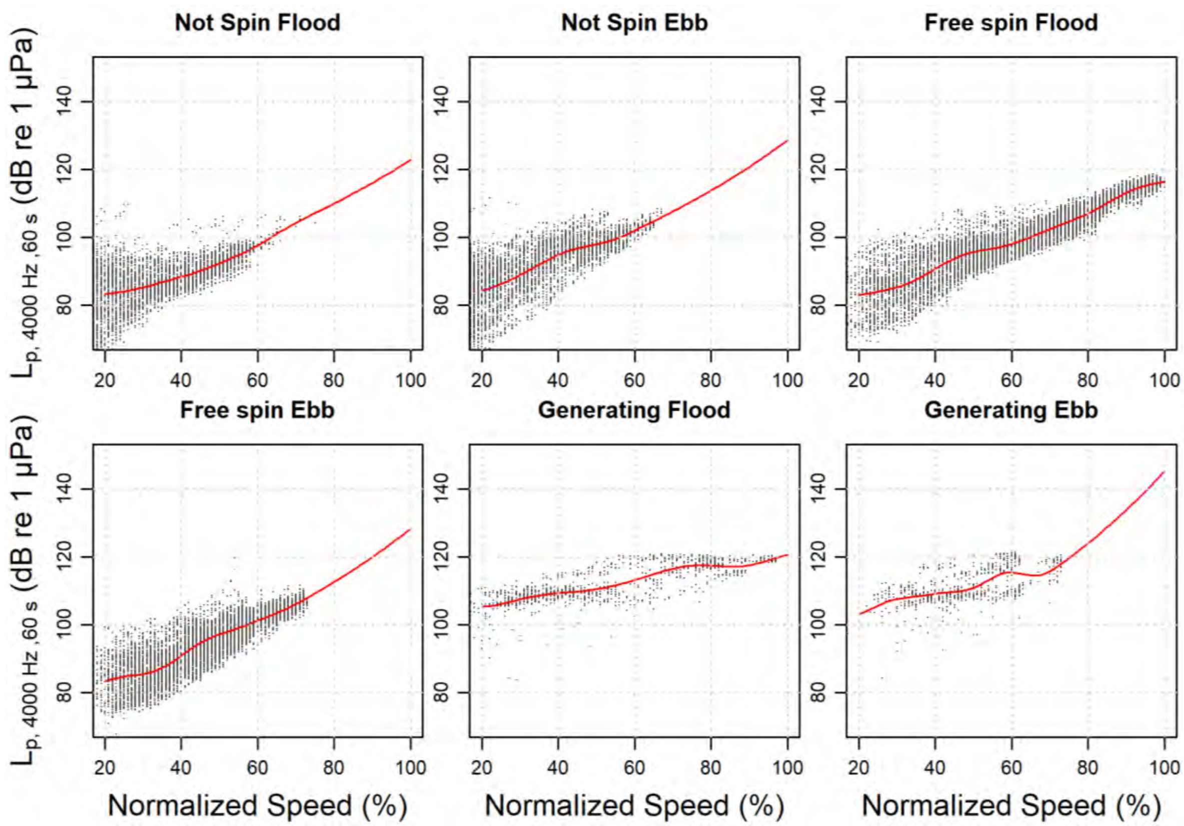


Figure 64. Received 4000 Hz decidecade band sound pressure levels from the autonomous AMAR (18 Nov 2016 to 19 Jan 2017) plotted versus normalized current speed for each tide-turbine state. Red lines are the general additive model SPL ~ s(normalizedCurrentSpeed).

C.2.2. Assessing Model Accuracy

Two approaches were used to assess the received sound pressure level model accuracy: 1) plotting the distributions of model-measured sound pressure level errors and 2) plotting an example of the modelled and measured sound levels for three sample tidal cycles described in Section B.1.

C.2.2.1. Model-Measure sound pressure level Errors

The GAMs were used to predict the received sound pressure level for each turbine state, decidecade band and percent normalized flow (1 to 99). For each minute of data from the autonomous AMAR the predicted sound pressure level was extracted from this table. The measured sound pressure level was subtracted from the modelled sound pressure level to compute the error. Boxplots of these error distributions were then generated for three sound pressure levels:

1. 63 Hz and above (Figure 65), which is the sum of the 63–12500 Hz decidecade bands; 63 Hz was chosen as the lower cut-off for the frequency band containing turbine sounds well above the background sound level (See Appendices B.2 and C.1).
2. High-frequency cetacean Weighted (HFC, Figure 66): the sum of the decidecade bands from 10–16000 Hz weighted by the HFC auditory filter which is relevant for the ability of porpoise to hear the turbine (see Section 2.2 and [28])
3. The sound pressure level weighted by the inverted herring audiogram (Figure 67), which represented the sound levels herring, gaspereau, and shad are likely to hear.

The error figures for each of the measurements show median errors of ~5 dB when the turbine is not spinning for normalized flows rates below 20%. This makes sense because other factors, such as wind, waves and vessel presence contribute to the sound levels when the currents are low and the model does not account for these factors. For the free-spinning and generating states, the modelled sound pressure levels are within 1–2 dB of the median measurements for normalized flow speeds above ~15%, which is 90% of the tidal cycle (based on the data provided by Emera, see Appendix B.1). The figures also indicate that there is very little free spinning or generating data for normalized flow speeds below 15%, as expected. From these results we conclude that the models may be used to estimate the turbine sound levels and the ambient sound levels for normalized flow rates above 20%.

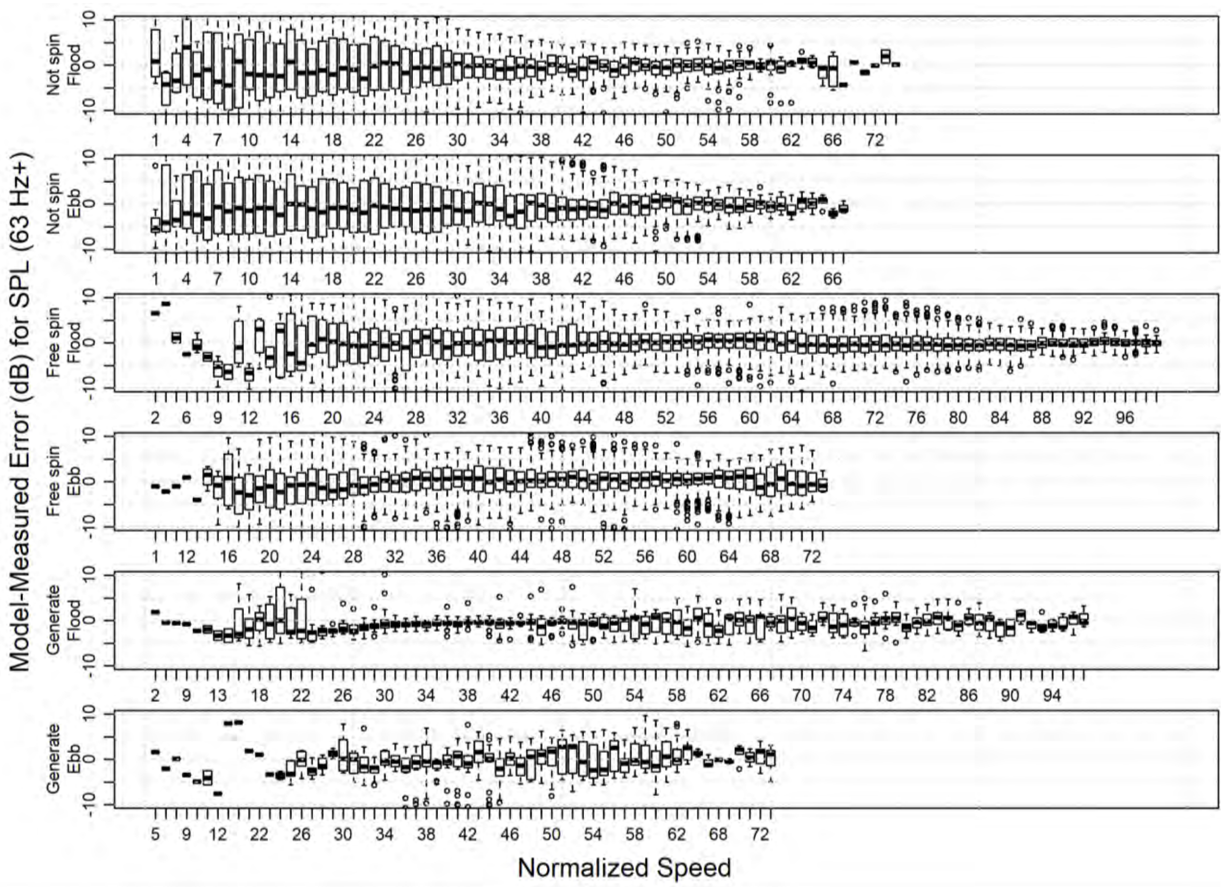


Figure 65. Difference between modelled sound pressure levels from 63–12500 Hz and all the per-minute data measured on the autonomous AMAR for each tide-turbine state combination.

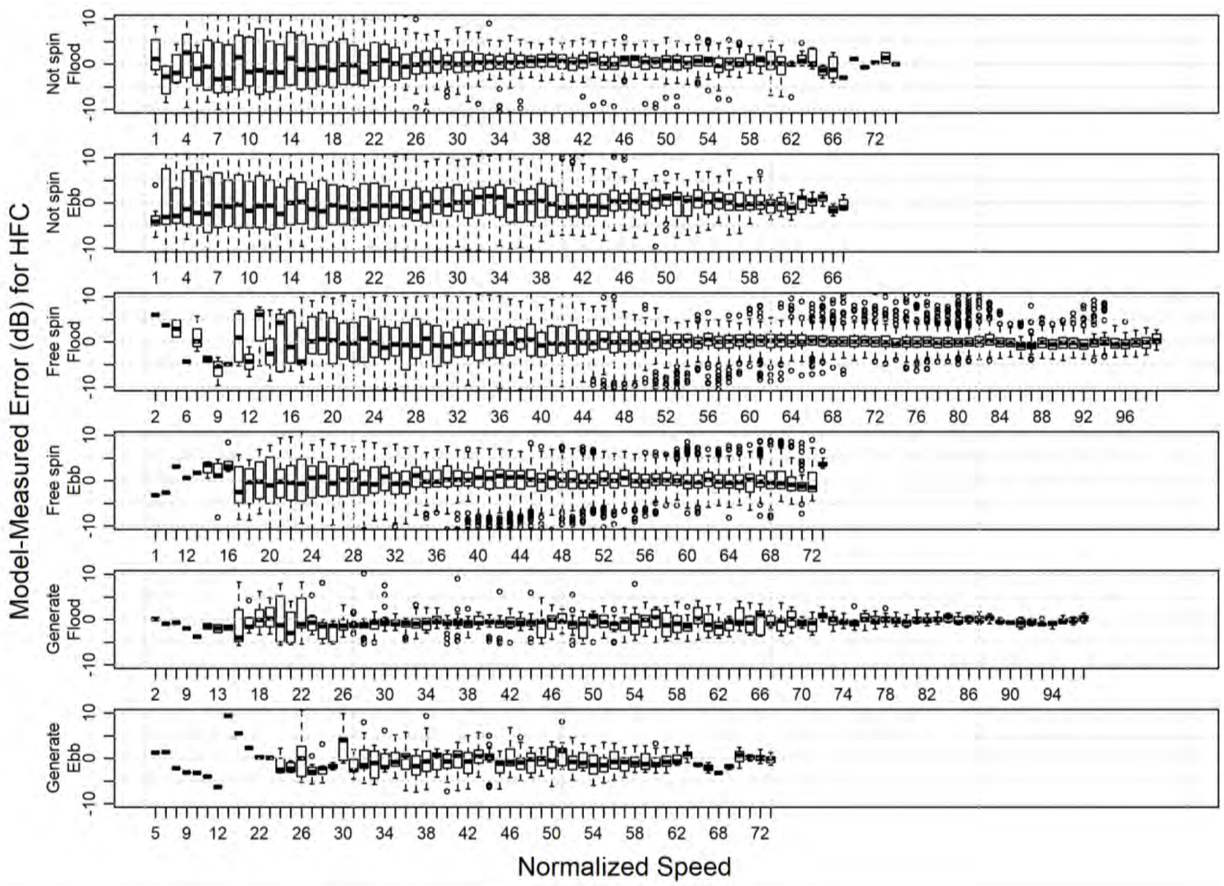


Figure 66. Difference between modelled high-frequency cetacean weighted sound pressure levels and all the per-minute data measured on the autonomous AMAR for each tide-turbine state combination.

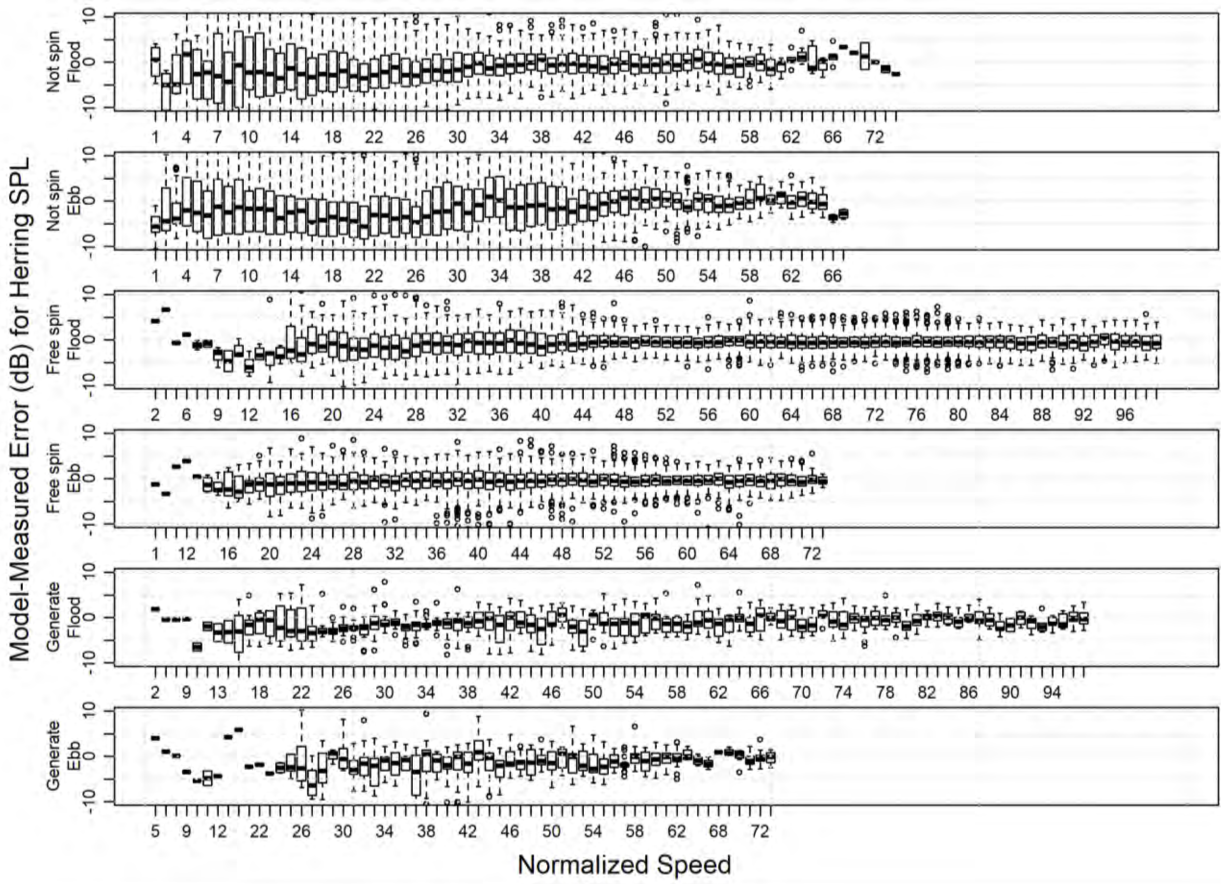


Figure 67. Difference between modelled sound pressure levels from 10–12500 Hz and all the per-minute data measured on the autonomous AMAR for each tide-turbine state combination

C.2.2.2. Representative Model-Measure Data

This section provides representative examples of the measured per-minute sound pressure levels and the predicted levels for three tidal cycles, selected to represent neap (Figure 68), normal (Figure 69), and spring (Figure 70) tides (see Appendix B.1). As shown by the boxplots in Appendix C.2.2.1, the agreements are very good for periods with higher flow speeds but less accurate around slack tide.

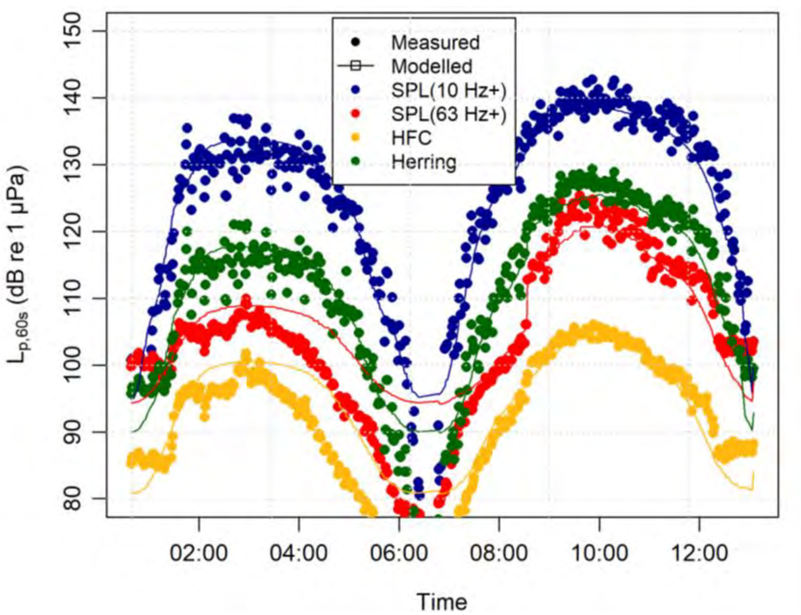


Figure 68. Neap tides on 24 Dec 2016: Comparing the modelled sound pressure levels (lines) and measured sound pressure levels (points). High tide shown on the left side.

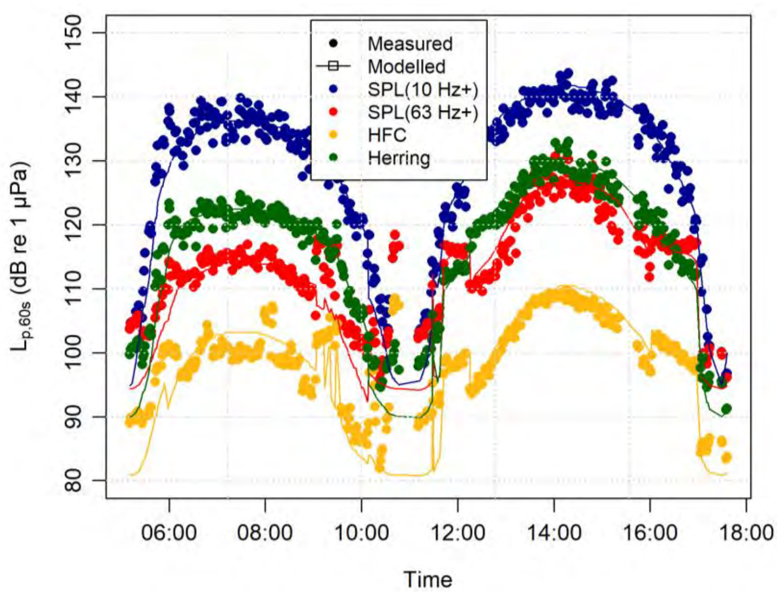


Figure 69. 'Normal' tides on 16 Dec 2016: Comparing the modelled sound pressure levels (lines) and measured sound pressure levels (points). High tide shown on the left side.

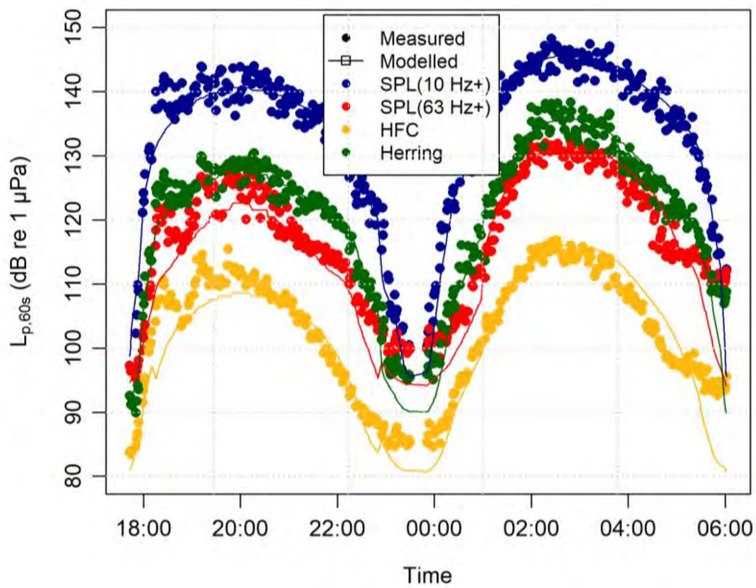


Figure 70. Spring tides on 30 Nov–1 Dec 2016: Comparing the modelled sound pressure levels (lines) and measured sound pressure levels (points). High tide shown on the left side.

C.2.3. Modelled Sound Pressure Levels

The models were used to predict the median sound pressure levels for each decidecade band for normalized current speeds of 20, 40, 60, and 80%, which were then plotted for all six tide-turbine state combinations (Figures 71 and 72). The sound pressure levels are plotted in the top row of each figure, and as a difference from the sound pressure levels measured under the traffic lanes of the outer Bay of Fundy (see Appendix B.2.1) in the bottom rows.

The important results derived from these figures are:

1. The sound levels in all three turbine states does not depend strongly on the current direction, only on the current speed.
2. The free spinning state is 5–25 dB quieter than the generating state, especially at low current speeds.
3. The ambient conditions in the Minas Passage at frequencies below 1 kHz are up to 25 dB quieter than the sound levels in the outer Bay of Fundy underneath the shipping lanes.
4. The 1000–1250 Hz sound produced by the turbine while generating shows a nearly constant sound level, a result similar to what was found from the tidal time increment analysis. The 3150–4000 Hz sound levels increases with current speed.
5. At normalized currents of 80% the sound levels are 10–30 dB above the levels recorded in the outer Bay of Fundy.
6. The differences in sound levels on the icListen hydrophone that depend on current direction (i.e., sound levels are higher during ebb tide at low frequencies) applies to the not spinning case, as well as the spinning cases. This suggests that the turbine is adding turbulence to the water column.
7. The icListen hydrophone on the turbine platform has energy at electrical power generation frequencies that are not present on the AMAR (e.g., 60, 120, and 300 Hz). The relative amplitude of the signals at these frequencies appears to change with flow speeds.
8. The turbine sound levels received at the icListen are higher than those on the autonomous AMAR, which makes sense since the icListen is much closer to the turbine.

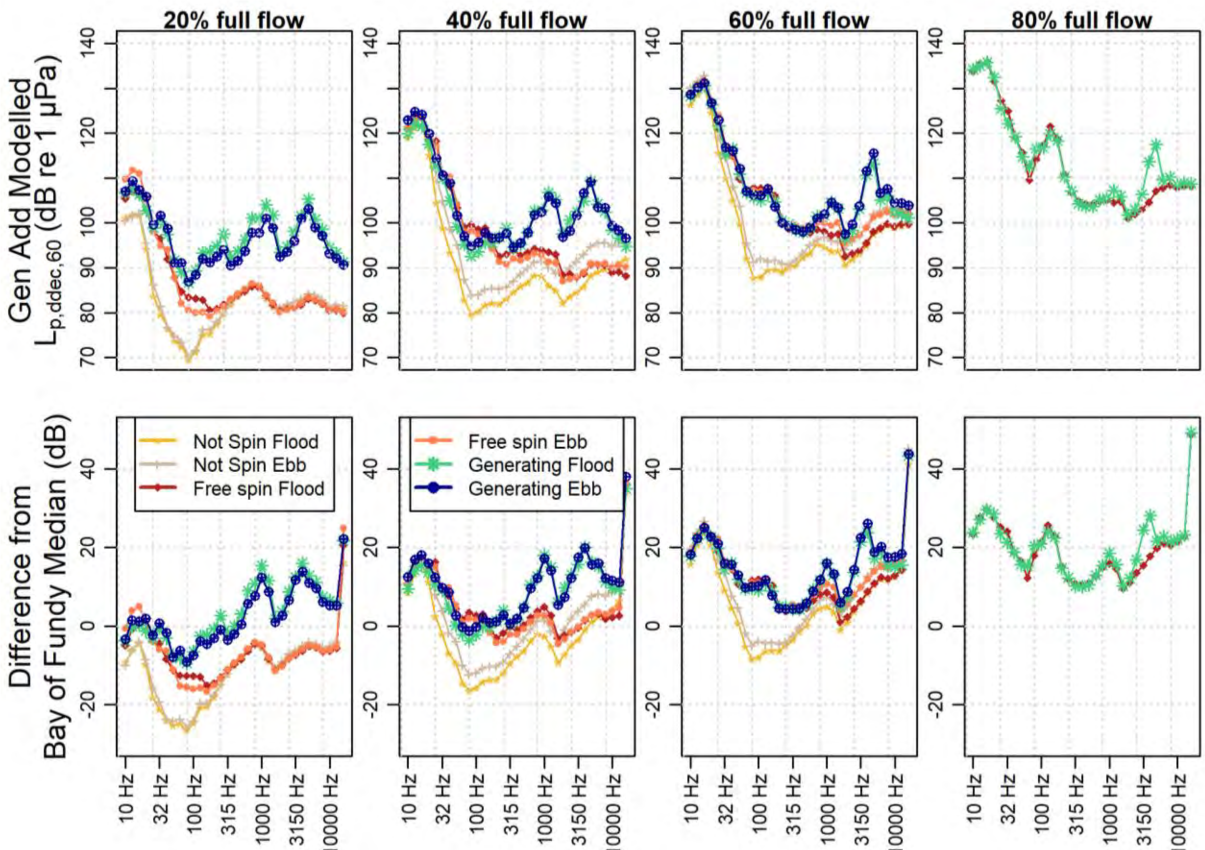


Figure 71. General additive modelled decidecade sound pressure levels received at the autonomous AMAR for normalized current speeds of 20, 40, 60, and 80% of full flow. (Top row) the modelled sound pressure levels. (Bottom row) the difference between the median decidecade sound pressure level measured under the shipping lanes in the Bay of Fundy and the conditions measured in the Minas Passage.

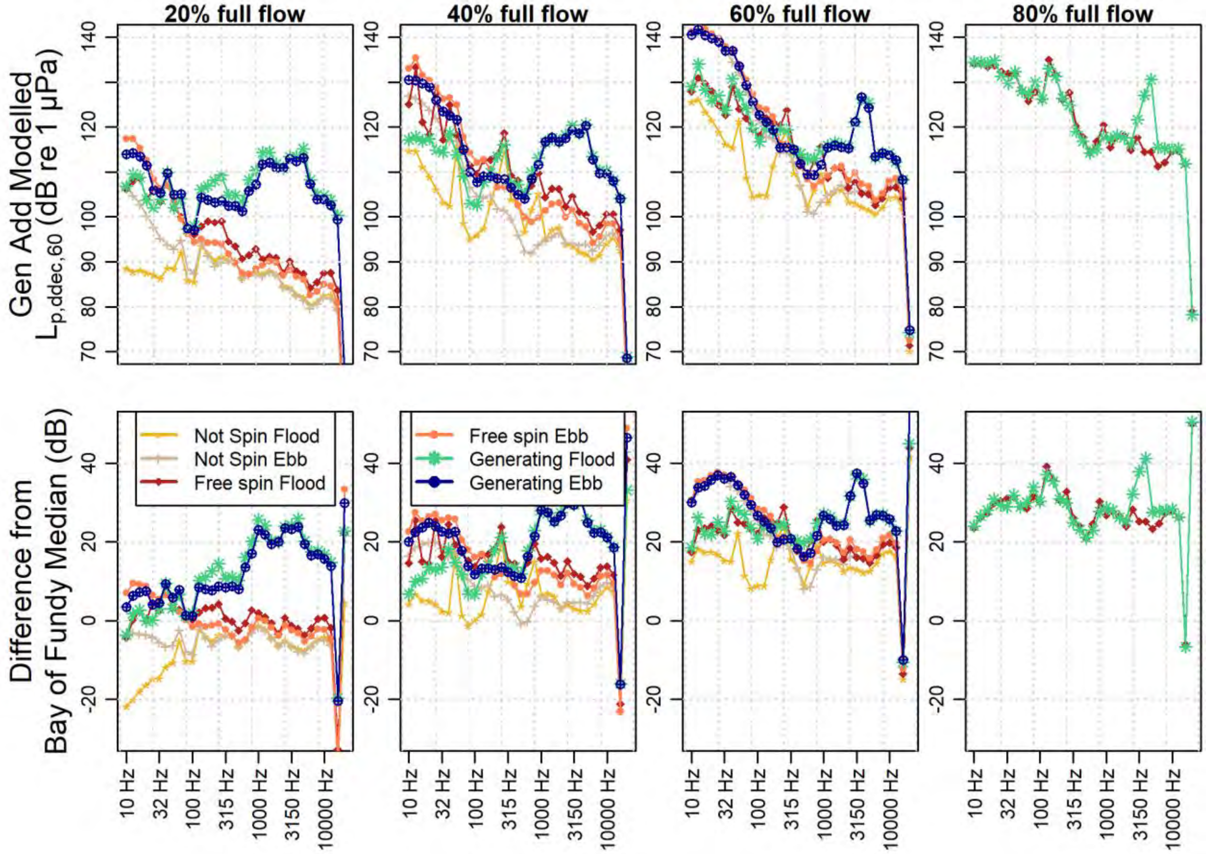


Figure 72. General additive modelled decidecade sound pressure levels received the forward-port hydrophone location for normalized current speeds of 20, 40, 60, and 80% of full flow. (Top row) the modelled sound pressure levels. (Bottom row) the difference between the median decidecade sound pressure level measured under the shipping lanes in the Bay of Fundy and the conditions measured in the Minas Passage.

Appendix D. Open-Centre Turbine Source Levels

A highly desirable outcome of this analysis is a turbine source level model that may be used to estimate the radius around the turbine where the turbine could affect marine life, as well as where the sound exceeds the background sound levels. The GAM received level models developed in Appendix C.2 were converted to source level models by adding $20\log_{10}$(range), where the range from the turbine to the autonomous AMAR was 167 m.

D.1. Model Evaluation

To evaluate whether the model is accurate, the icListen 1658 drifter pass on Trial 7 of 27 Mar 2017 was analyzed. This data had previously been analyzed by GTI (see Appendix A.6) which indicated that the drifter likely passed within 30 m of the turbine. Given that this measurement was made near high tide, this range means that the drifter passed directly over the turbine. To assess the model the track of the drifter was linearly interpolated between the known start and end points, which predicted a closest point of approach to the turbine of 30 m–in agreement with the GTI model. The 1-second sound pressure levels were computed and plotted as function of estimated range to the turbine (Figure 73). During those drift measurements the turbine was free-spinning in a flood tide. The modelled sound levels were computed from the sum of the not-spinning and free-spinning flood tide median sound pressure levels estimated for the known current speed for each minute. The free spinning source levels were used, minus $20\log_{10}$(range). Only the 63–400 Hz decidecades were summed which is the overlap of the frequencies where turbine is well separated from the environmental noise while free spinning.

In summary, Figure 73 indicates that the modelled sound level for the turbine and environmental noise closely tracked the sound levels measured by a drifter. This is a remarkable success given the uncertainties in the analysis:

- The models were developed using a bottom mounted recorder, but the measurements were made with a drifter.
- The range from the AMAR to the turbine is likely only accurate to ±20 m;
- The track of the drifter was highly uncertain because we only had the start and end points of the track; and
- The drifter recorded significant surface/movement noise.

The measured data in Figure 73 contains two peaks, one ~100 m before the turbine CPA and one ~250 m after CPA. These are due to multipath interference between the direct path and surface reflected path (Lloyd's mirror effect), as well as changes in the turbine sound emissions (see Figure 74).

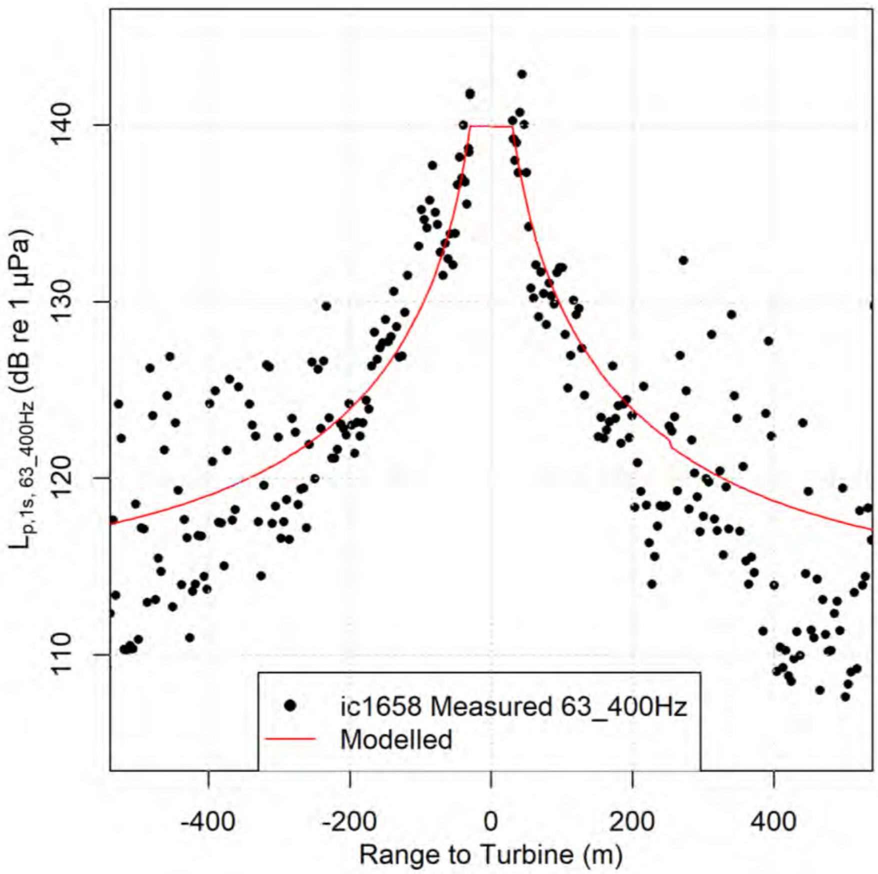


Figure 73. Received and modelled sound pressure levels for Trial 7 of icListen drifter 1658 on 27 Mar 2017.

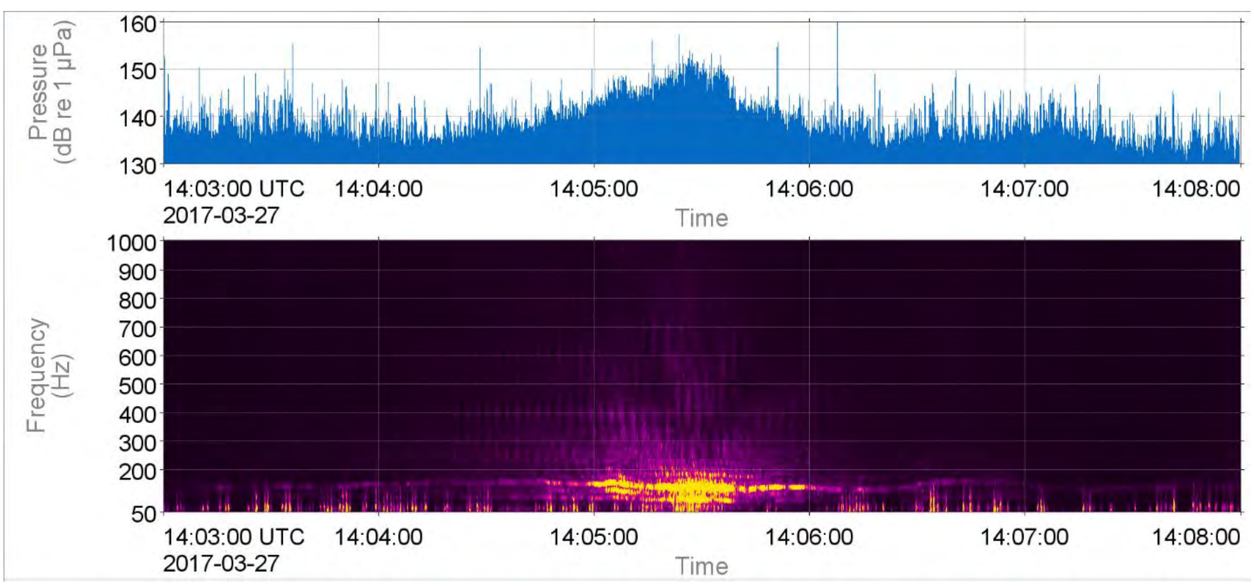


Figure 74. Five minutes of data centred on the closest point of approach of the ic1658 drifter to the turbine during trial 7 on 27 Mar 2017. The banding pattern in the data is due to multipath interference and is often called the Lloyd's mirror effect.

The comparison with the drifter demonstrates the reliability of the model when used within it's bounds. For the free-spinning case the valid frequency range are the 63–400 Hz decidecade bands. For the generating case, the range is the 63–10000 Hz decidecade bands. To understand the amplitude of the turbine source levels, we have compared it to a typical fishing vessel at 10 knots and a typical tugboat at 10 knots (Figure 75) [67]. Below 4 kHz the turbine has a much lower source level than the vessels. In the generating case the 4000 Hz decidecade has a similar source level as the typical vessel. Since the maximum source level of the turbine is ~165 dB re 1 μPa² and the vessels are ~180 dB re 1 μPa² at low frequencies we can expect that fish will detect and be affected by vessels at 7–10 times the range as the turbine.

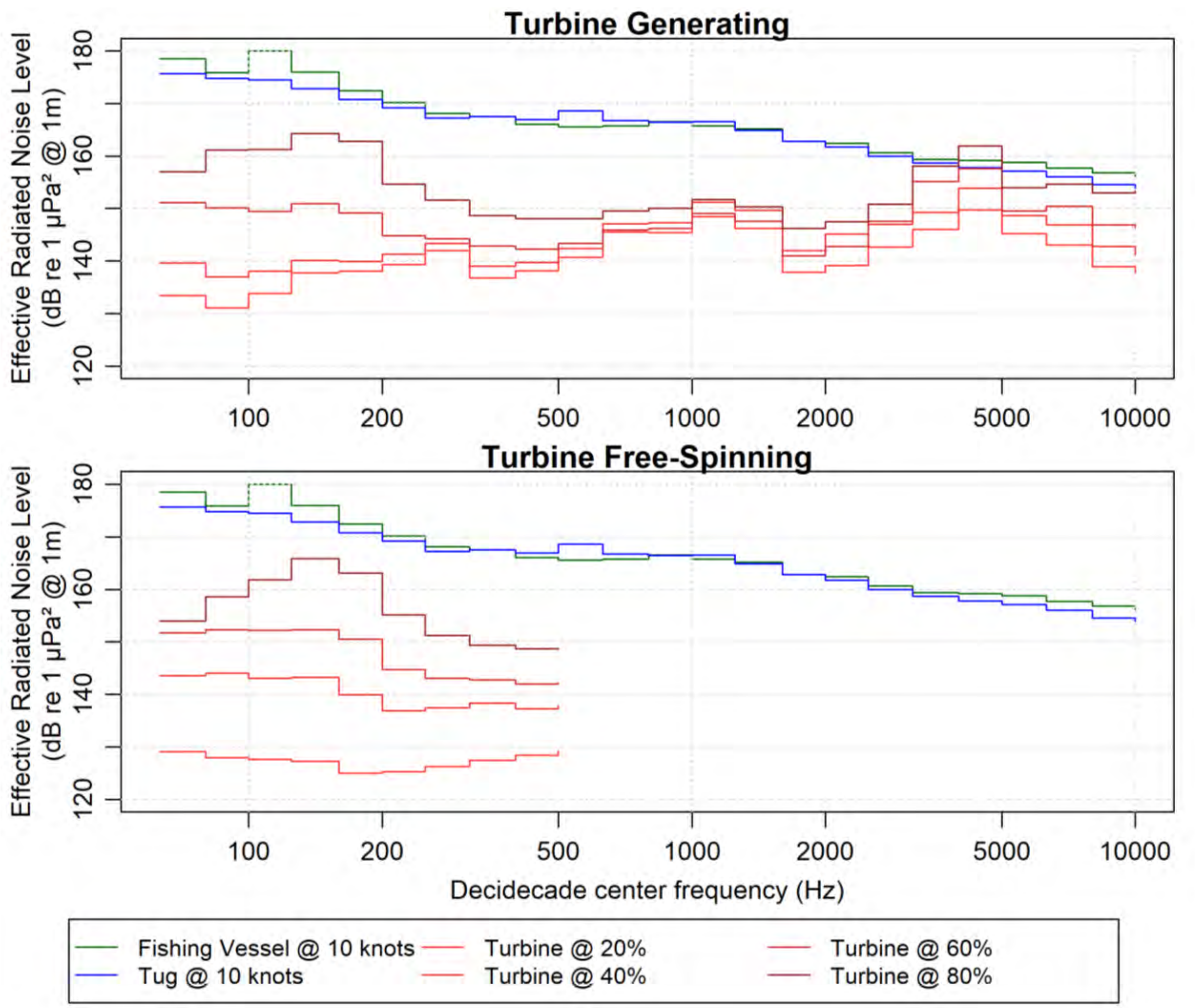


Figure 75. Comparing the turbine source levels to typical fishing and tugboat source levels. Above 400 Hz the turbine does not generate sounds in free-spinning mode that are measurable above background at 167 m.

D.2. Distances to Effects of Sound Radii

The model was used to estimate the distance to five threshold conditions:

1. The range where the 63 Hz and above sound pressure levels exceed 150 dB re 1 µPa which the range often specified for behavioural disturbance of fish.
2. The range where the 63 Hz and above sound pressure levels exceed the ambient background.
3. The range where the herring auditory filter weighted turbine sound levels exceed the herring-auditory-filter-weighted ambient background.
4. The range where the high-frequency cetacean marine-mammal auditory filter weighted sound pressure level exceeds background, which is the maximum range at which turbine sound could mask sounds a porpoise may hear.
5. The daily high-frequency cetacean weighted sound exposure level and the range to the temporary threshold shift criteria of 153 dB re 1 µPa²·s.

Both the environmental sound levels and turbine sound levels are highly variable due to the turbulence in the tidal flows. To capture this variability in the threshold ranges, we treated the sound levels measured at the AMAR as a variable source level. The calculations were:

1. Each minute of recordings where the normalized flow speed was greater than 20%, we assumed the signal at the AMAR was dominated by the turbine, and $20\log_{10}(167\text{ m})$ was added to the received level to convert the sound to as a source level (SL).
2. The ambient noise for the flow direction and normalized flow speed was extracted from the received level tables for the 'not spinning' turbine state (AN).
3. The threshold range is:

   $$R_T = 10^{(SL-AN)/20} .$$

   In the case of the 150 dB re 1 µPa² threshold the AN term is replaced by 150. The factor of '20' accounts for the spherical spreading in this environment (see Figure 73 and Appendix A.6).

The large set of results obtained may then be plotted using boxplots to provide an estimate of the variability in the threshold ranges (Figures 76–80). These figures show that:

1. The turbine sound only exceeds the threshold for behavioural disturbance to fish (150 dB re 1 µPa) at very short ranges and only at the highest current speeds on the flood tide (Figure 76).
2. The range where the turbine could be audible to herring, or mask sounds a herring could hear, was 1000 m (upper inter-quartile values in Figure 78). For most turbine states and current speeds, the range was 500 m or less.
3. The range where the turbine could be audible to porpoise, or mask sounds a porpoise could hear, was 800 m (Figure 79). The ranges were generally less than 300 m in the generating state and 150 m in the free-spinning state.
4. In the free-spinning state, the turbine was detectable above the background at a maximum of 500 m (Figure 77).
5. The high-frequency content in the generating sound results in longer ranges where the sound is greater than the ambient background than the free-spinning case; however, the sound is very constant, which results in a limited variability in the ranges where the turbine sound is above ambient for both the broadband and high-frequency cetacean weighted sound pressure levels.
6. The range where the turbine could cause temporary hearing shifts in porpoise, if one stayed beside the turbine for 24 hours, was 150–250 m on most days and increased to 500 m during spring tides (Figure 80). Based on the porpoise detection durations (Figure 49), it is highly unlikely that a porpoise would remain near the turbine for longer than one hour, and therefore TTS is not expected to occur.

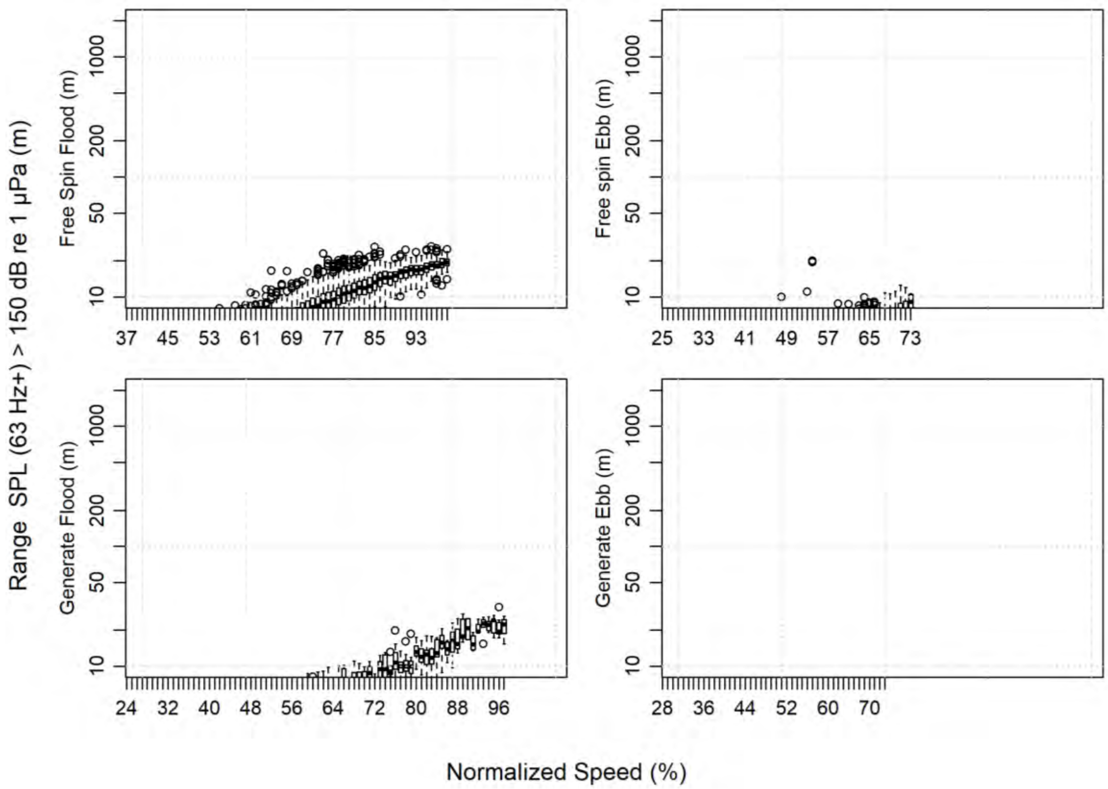


Figure 76. Threshold ranges for possible behavioural disturbance to fish.

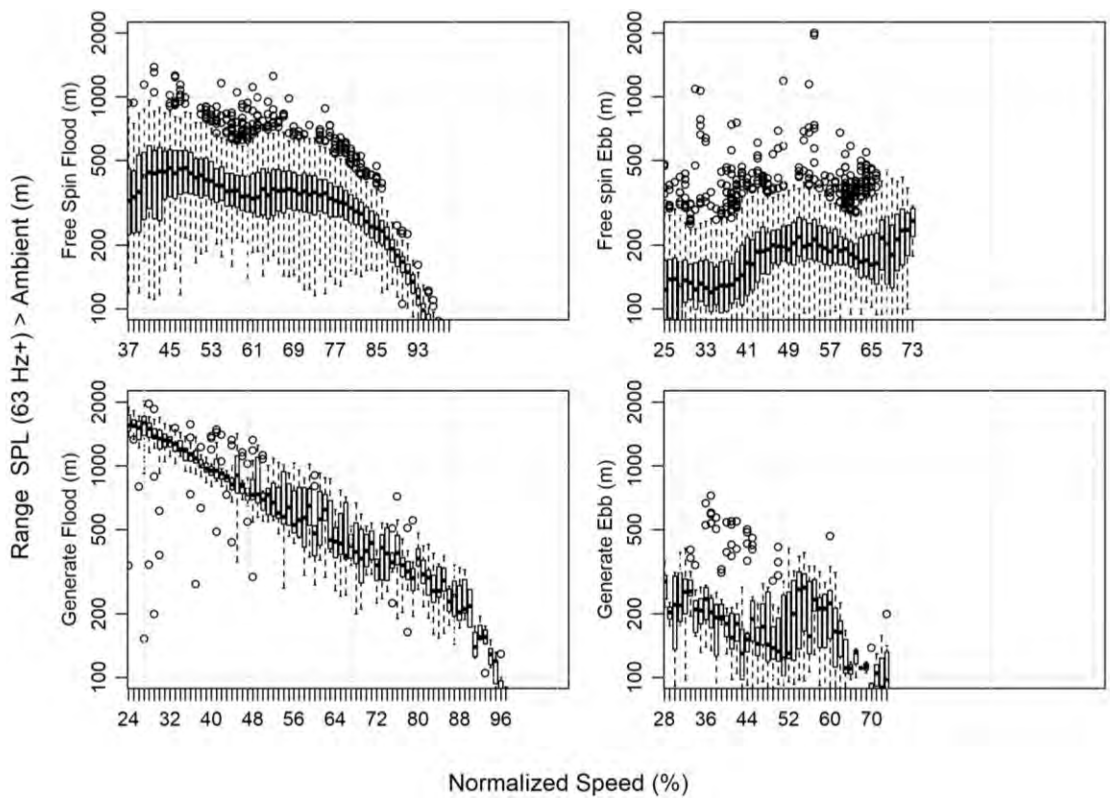


Figure 77. Threshold ranges where the turbine sound exceeds ambient background (63 Hz and above).

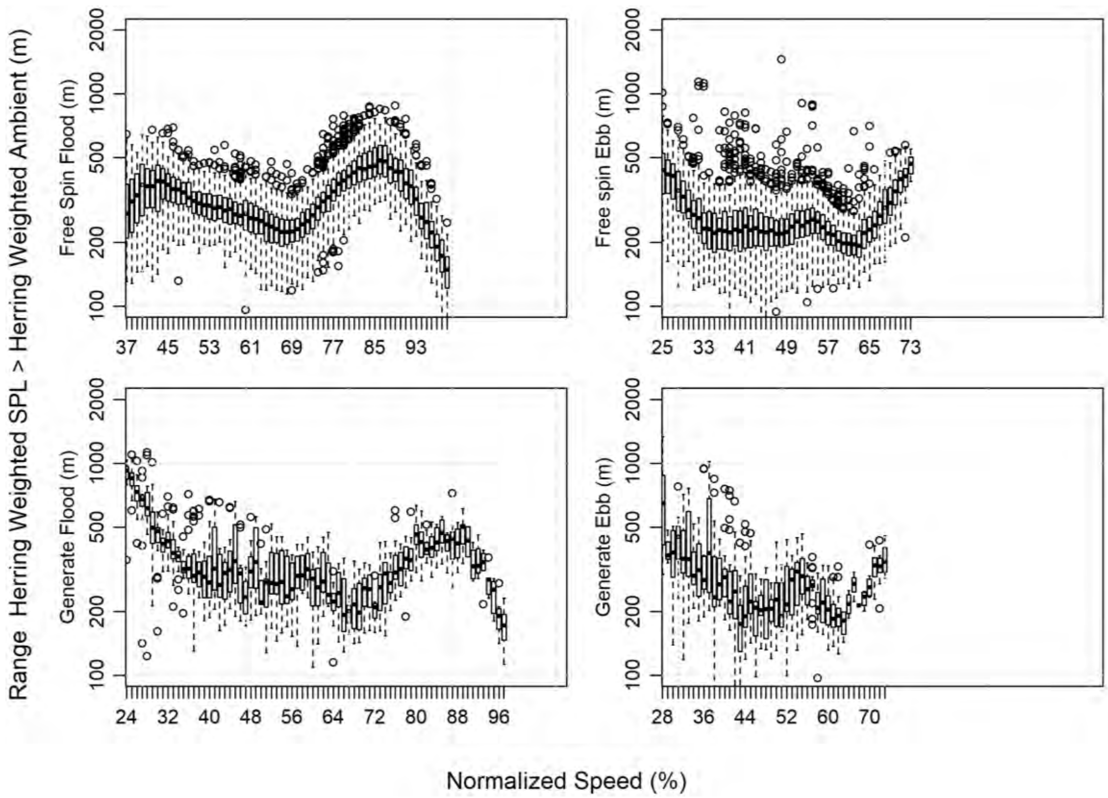


Figure 78. Threshold ranges where the herring audiogram weighted turbine sound exceeds the herring audiogram weighted background

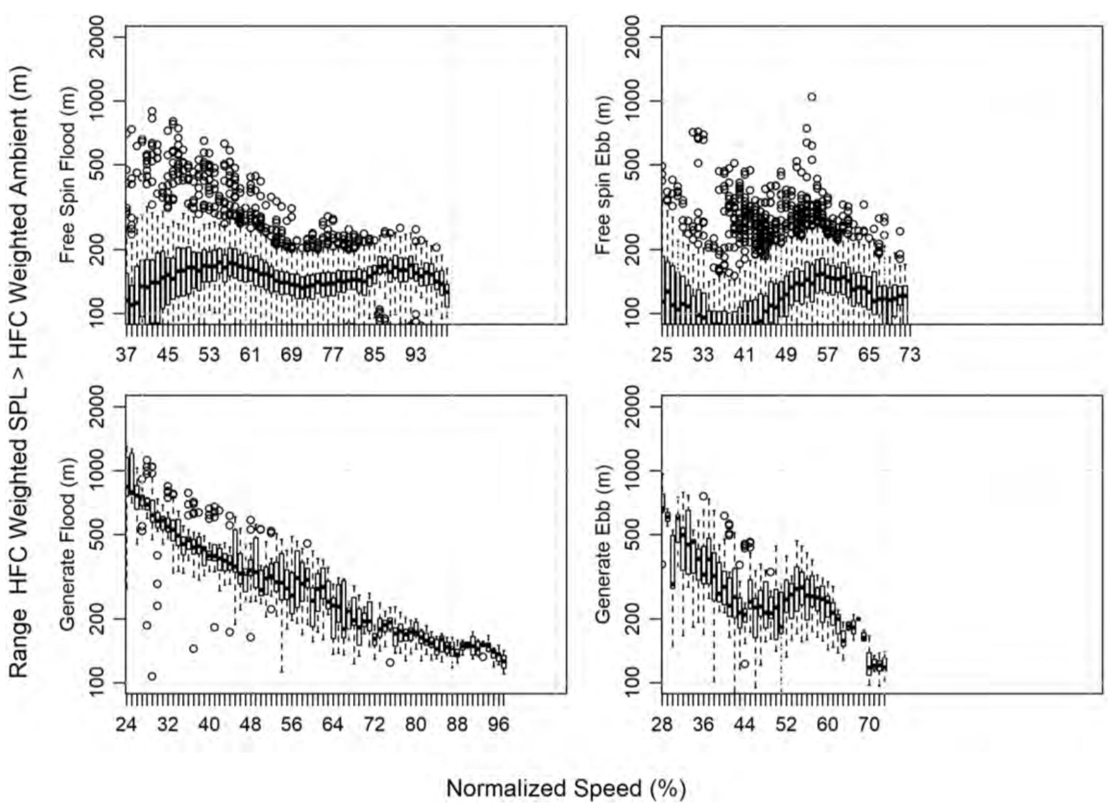


Figure 79. Threshold ranges where the HFC weighted turbine sound exceeds the HFC weighted background.

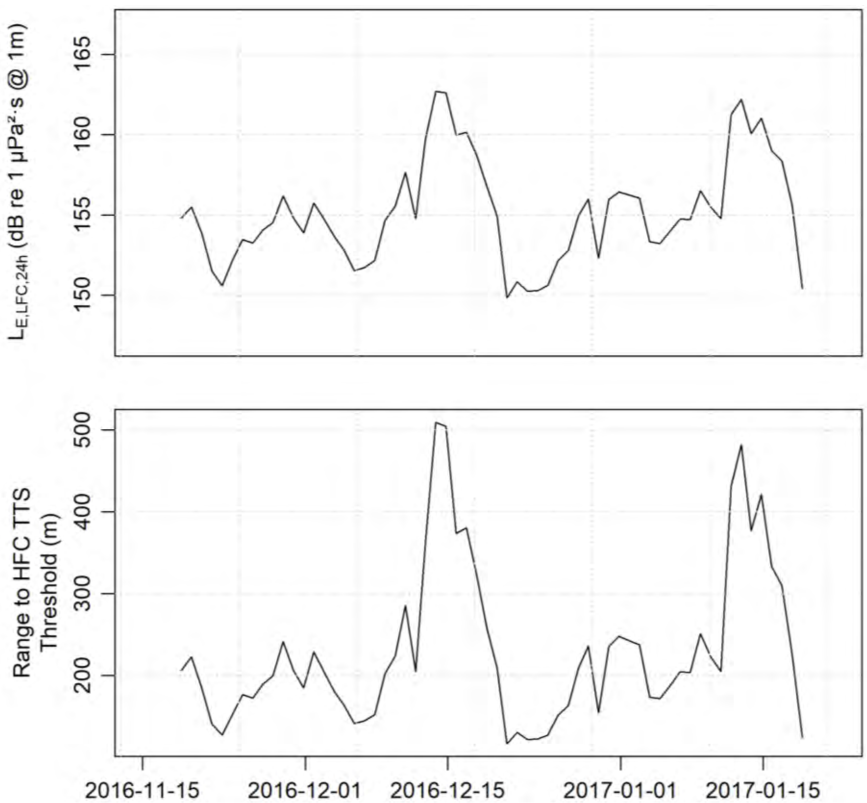


Figure 80. High-frequency cetacean weighted daily sound exposure levels and range to possible TTS.

D.3. Model Tables

This section contains embedded spreadsheets with the median sound pressure levels for each decidecade band and flow speed. The limits on using these models are:

- The free-spinning and generating models are only recommended for flow speeds above 20%.
- The not-spinning flood tide model should be used cautiously above 50% flow speeds.
- For ebb tides only use the data for flow speeds up to 70%.
- For the free-spinning state only use decidecades from 63–400 Hz; above 400 Hz the model is mostly environmental noise.
- For the generating state only use the decidecades from 63–10000 Hz.

D.3.1. Not Spinning Ebb

modelledSLsEbbNo
tSpinning_modelR_

D.3.2. Not Spinning Flood

modelledSLsFloodN
otSpinning_modelR

D.3.3. Free Spinning Ebb

modelledSLsEbbFre
eSpinning_modelR_

D.3.4. Free Spinning Flood

modelledSLsFloodF
reeSpinning_model

D.3.5. Generating Ebb

modelledSLsEbbGe
nerating_modelR_1

D.3.6. Generating Flood

modelledSLsFloodG
enerating_modelR_1