FORCE Marine Mammal EEMP 1st Year Monitoring Report

Prepared for FORCE

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1st Year (2017) Monitoring Report

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Executive Summary

Tidal inlets such as the FORCE demonstration area are dynamic regions that provide important habitat for h arbor porpoise (*Phocoena phocoena*). Harbor porpoise use echolocation to hunt and communicate (Kastelein et al. 2002), and they are known to be very susceptible to noise disturbance (Tougaard et al. 2009). Few studies to date have focused on exposure to continuous low frequency noise sources such as that emitted by tidal turbines. The tidal dynamics inform the presence of porpoises in these areas in complex ways. Hence, long-term and ongoing monitoring of this variability has been an important component of understanding the impacts of installing tidal turbines at this site. FORCE contracted SMRU Consulting (Canada) to complete equipment calibration and click detection data analysis relating to the deployment of passive acoustic monitors (C-PODs) in support of its marine mammal environmental effects monitoring program (EEMP). The most recent EEMP-specific monitoring began on 7 June 2016 and concluded on 18 January 2017, encompassing two C-POD deployment periods with monitoring periods of 84 and 118 days respectively. The installation of the Cape Sharp Tidal Venture's (CSTV) tidal turbine occurred on 7 November 2016, with associated vessel activity also occurring the next day.

This report firstly summarizes the dynamic temporal patterns in porpoise presence in Minas Passage 2011-2017 related to key environmental covariates, notably annual, seasonal, tidal and day vs night variability. It is important to note that temporal coverage was intermittent over this period, with only one winter-early spring period of baseline. Spring through fall data was better represented with two or three years of data collection. We then use this information to provide a statistical analysis of the distribution and activity of harbor porpoise around the FORCE demonstration area in response to the installation and operation of the turbine during the 2nd of the 2016/2017 C-POD deployments, for which data from 5 C-PODs was available.

From May 2011 through to January 2017, there have been 805 monitoring days and 2847 C-POD days, spread across 8 locations within and immediately outside the FORCE area. Overall, harbor porpoises have been detected on 98.4% of days at a median of 6 detection positive minutes per day and maximum of 44 minutes. No dolphins were detected during any of the C-POD deployments at any of the 8 C-POD locations. A statistical model using all C-POD monitoring days confirmed porpoise presence varied significantly by time of year (peak period May/June and lower secondary peak October/November), by current speed and tidal height (preference for 0-2.5 m/s ebb tides), by time of day (higher activity at night) and across the lunar cycle (affected by the position in the spring-neap tide cycle). C-POD performance (termed % time lost) also varied due to noise effects, notably due to non-biological clicks associated with sediment transfer during periods of relatively high current velocity.

During the 2nd of the 2016/2017 C-POD deployments, porpoises were detected at all five monitoring locations on each of the 45 pre-installation days (median 4 detection positive minutes per day) and on 71 of 73 (97.3%) days post-installation of the turbine (median 3 detection positive minutes per day). Consequently, there was no evidence of porpoise exclusion of the mid-range (210 – 1710 m) study area post-installation, noting that changes in the overall distribution of porpoise within the vicinity of the turbine is considered of higher importance.

A statistical model of this period tested for changes in the distribution of harbor porpoise in relation to the installation and operation of the turbine. East1, a site 210 m north of the turbine at 41 m depth, showed statistically fewer porpoise detections post installation of the turbine, whereas D1, a site 230 m northwest of the turbine at 33 m depth, on the rock shelf on which the turbine was also installed, showed no significant effect on porpoise detection rates. Both these sites had overall lower activity levels pre- and post-turbine installation, whereas the sites > 1 km west and south of the turbine had overall higher activity levels. West1, located inside the FORCE demonstration area (1,140 m from the turbine), and West2 (1,710 m away just outside of the FORCE demonstration area), both statistically declined in porpoise detections post installation, while South2 (1,690 m away, south of the FORCE demonstration area) and the deepest site at 68 m depth, had similar detections rates pre and post installation (i.e., no turbine effects). Declines in post installation detection rates were between 41-46%. The obvious and immediate drop in detections observed at East1, West1 and West2 likely represent disturbance from vessel activity, while subsequent dips observed after this period may reflect continued lunar-scale fluctuations related to lower detection performance of C-PODs during all spring tides (higher % lost time). These observations coupled with high levels of inter-annual and site variability and the very short post-installation period so far analyzed, result in the overall conclusion that further C-POD data collection is required before robust inferences can be drawn and preliminary statistical results of mid-range turbine effects at some sites can be substantiated. In particular, continued C-POD monitoring will allow for a better comparison with previous baseline data collected.

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List of Acronyms

ACF: autocorrelation function

AR-1: First order Auto-regressive, used to describe the form of the autocorrelation function

BinDPM: Binomial (0 or ≥1) Detection Positive Minute

BinDPM=0: No porpoise detected within a consecutive 10-minute period

BinDPM=1: At least one porpoise detected within a consecutive 10-minute period

P(BinDPM=1): Probability of there being at least 1 detection positive minute of 10 consecutive minute period.

CSTV: Cape Sharp Tidal Venture

CV: Coefficient of Variation

DPM: Detection Positive Minutes (a count of the number of minutes a porpoise is detected in a fixed period of time

E1: C-POD location East 1

D1: C-POD location specific to berth D.

EEMP: Environmental Effects Monitoring Program

FORCE: Fundy Ocean Research Center for Energy

GEE-GLM: Generalized Estimating Equation with a General Linear Model

IQR: Interquartile Range

OERA: Offshore Energy Research Association

QIC: Quasi Information Criteria

S2: C-POD location South 2

SPL: Sound Pressure Levels in units of Pascal

W1: C-POD location West 1

W2: C-POD location West 2

1. Introduction and EEMP Objectives

Tidal energy is a largely untapped renewable energy source. Worldwide, only a small number of in-stream tidal turbines have been deployed to date. The Fundy Ocean Research Center for Energy (FORCE) is a Canadian non-profit institute that owns and operates a facility in the Bay of Fundy, Nova Scotia (Figure 1), where grid connected tidal energy turbines can be tested and demonstrated. It enables developers, regulators and scientists to study the performance and interaction of tidal energy turbines with the environment. The FORCE test site is in the Minas Passage area of the Bay of Fundy, near Cape Sharp and roughly 10 km west of the town of Parrsboro (Figure 1).

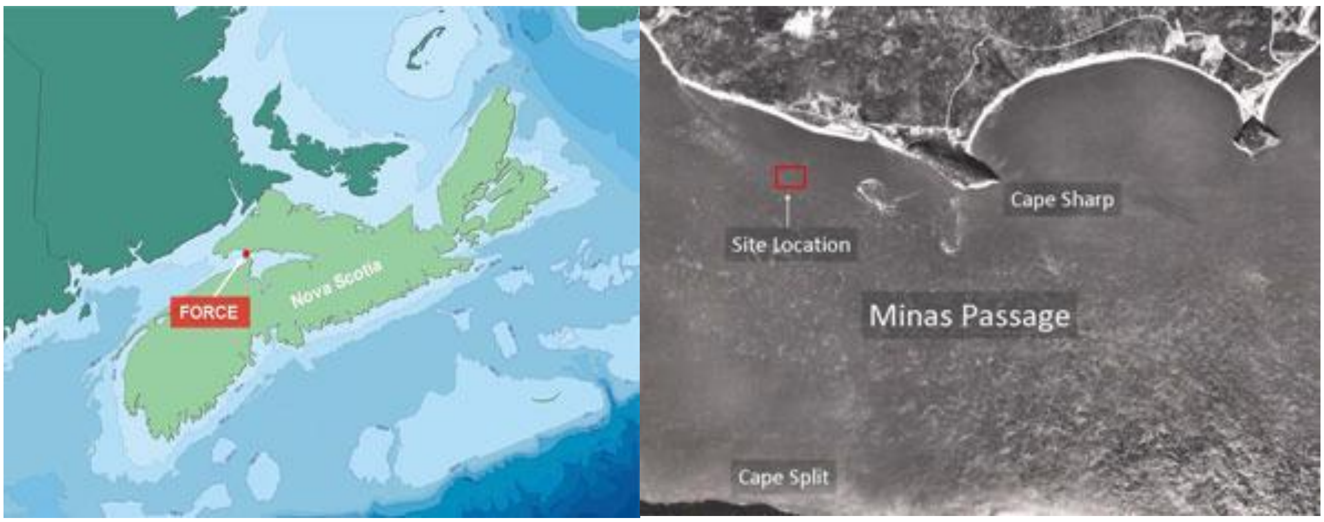

Figure 1. Reginal location of FORCE test site (Left Panel) and the location of the test site in Minas Passage (Right Panel).

Harbor porpoise (*Phocoena phocoena*), the key marine mammal species in Minas Passage, use high frequency echolocation clicks to hunt and communicate (Kastelein et al. 2002) and are known to be very susceptible to pulsed noise disturbance (Tougaard et al. 2009). FORCE contracted SMRU Consulting (Canada) to complete equipment calibration and data analysis relating to the deployment of passive acoustic monitors (C-PODs) in support of its marine mammal environmental effects monitoring program (EEMP). The goal of this program is to detect changes in the distribution and activity of echolocating cetaceans (predominately harbor porpoise) at the FORCE tidal demonstration site in relation to operational in-stream turbines. This 2017 Marine Mammal EEMP Report describes the results of the first nearly eight months of the C-POD monitoring program as part of FORCE's 2016-2021 EEMP at its marine demonstration and testing facility in Minas Passage. The report aims to describe the current program's objectives, methodology, problems encountered, and a statistical analysis of porpoise activity and site use, including an assessment of turbine installation and operational effects.

The main objectives of the larger multi-year FORCE marine mammal EEMP are to assess medium-term effects of direct and indirect stressors on harbor porpoise by monitoring porpoise activity and site use, with the primary objectives to assess (SLR 2015): 1) Permanent avoidance of the mid field (considered

100-1000m) study area during turbine installation and operation; 2) Large magnitude (~50%) change in the distribution (echolocation activity levels) of a portion of the population in the study mid field area. While the marine mammal EEMP was designed to have sufficient power to detect large magnitude changes in distribution (SLR 2015), smaller scale change should not be considered insignificant.

SMRU Consulting previously undertook the design, analysis and interpretation of marine mammal acoustic monitoring studies to collect 2011-2014 baseline information in the FORCE tidal demonstration site (e.g. Tollit et al. 2011). These baseline studies were completed in collaboration with Dr. Anna Redden at Acadia University and funded by FORCE and the Offshore Energy Research Association (OERA) of Nova Scotia. Following a pilot effects assessment study associated with the Open Hydro deployment in 2009-2010 (Tollit et al. 2011), a gradient passive acoustic monitoring design was developed deploying up to 7 C-PODs to collect long-term baseline data and to assess reliability of methodologies (Wood et al. 2013, Porskamp et al. 2015). Beginning in June 2016, the EEMP added an additional C-POD monitoring location next to Berth D, and collected a further 4 months of C-POD marine mammal detection data at five sites in total (including four sites previously monitored) to contrast with the 2011-2014 baseline data. This additional baseline data was collected to improve the turbine effects analysis, not least in capturing the scale of inter-annual variability in porpoise presence in Minas Passage, but also in exploring the consistency of key seasonal, tidal and diurnal trends detected in previous (2011-2014) analyses (e.g., spring and fall peaks in presence, variability linked to tidal phases, and higher night-time activity). A statistical model was used to describe changes in harbor porpoise presence in response to the variability in the environmental effects observed across the monitoring stations in the Minas Passage area of the Bay of Fundy. It is important to note that temporal coverage was intermittent over this period, with only one winter-early spring period of baseline. Spring through fall data was better represented with two or three years of data collection.

On 7 November 2016, a single 2 MW Open Hydro turbine was installed at Berth D by Cape Sharp Tidal Venture (CSTV). Passive acoustic monitoring using five C-PODs originally deployed on 23 September continued throughout the turbine installation period and for up to 73 days post-installation until 18 January 2017. Two C-POD sites were located within 230 m of the turbine, while the remaining three C-POD sites varied between 1,140-1,710 m from the turbine site. These locations represented safe deployment and retrieval distances from Berth D, as well as previously used baseline monitoring locations within and outside the FORCE site, which were selected to represent a gradient design in monitoring turbine noise effects (i.e., locations close to the turbine berths as well as locations at increasing distances away from the turbine berths). A part of the wider FORCE EEMP, monitoring of distances nearer the turbine (<100m) were considered the responsibility of the berth holder.

A statistical model was fit to the time series of porpoise echo-location data detected at these 5 C-POD locations during the September to January deployment focusing on an assessment of turbine installation and operational effects.

2. Methods

2.1 C-POD Calibration

As recommended for the FORCE Marine Mammal EEMP, SMRU Consulting and FORCE staff conducted an echolocation click[1] sensitivity calibration of all 5 available C-POD units to determine reliability and consistency, and to make recommendations for the first deployment. The C-PODs were configured with settings to match Wood et al. (2013) and the hydrophone elements soaked overnight in water. The calibration trials were conducted at the Ocean Sonics Ltd tank facility in Great Village, Nova Scotia. We played back sequences of 5 successively louder 130 kHz clicks from an Ocean Sonics *icTalk* projector (an all-in-one projector that produces a complex range of tones and sweeps) located at the center of the test tank (Figure 2), and recorded >100 clicks at each amplitude on each unit. C-PODs were mounted around the periphery of the tank (Figure 2). This was undertaken twice to test all 5 C-PODs, with one unit tested twice, to ensure between test compatibility.

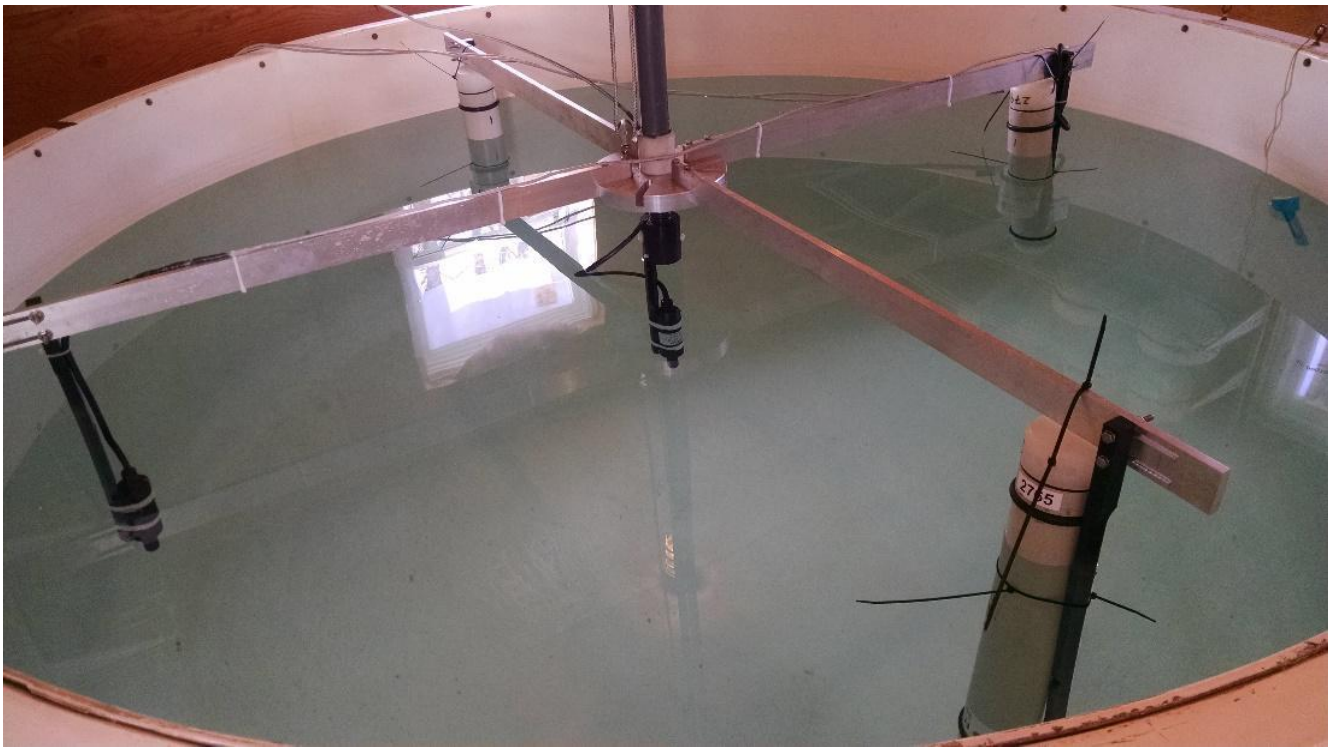

Figure 2. Experimental setup with the Ocean Sonics *icTalk* projector in the center of the tank, 3 C-PODs around the periphery and an Ocean Sonics *icListen* reference hydrophone, also at the periphery.

All five C-PODs operated and detected clicks as expected. The time and amplitude of each detected click was exported from the C-POD software for further analysis in R (version 3.3.2, R Core Team 2016). Figure 3 shows the distribution of click Sound Pressure Levels (SPL) in units of Pascal for each C-POD unit and round (C-POD 2973 was tested in both round 1 and 3), for each of the 5 amplitude clicks (left to right on

[1] C-PODs have been designed to record the echolocation clicks produced by toothed cetaceans. Echolocation, or bio-sonar is used by animals that have evolved to listen for the echoes of their returning calls to learn about their environment (e.g. navigate, detect, and catch prey). Harbor porpoise have evolved to produce narrow band high frequency (NBHF) clicks in series, commonly referred to as a click train.

the X-axis). Mean SPL were calculated and then converted to dB re 1µPa. Some clicks were not detected by the C-POD unit and this is reported as % clicks missed. The coefficient of variation (CV) is reported for each click amplitude and averaged across all amplitude levels.

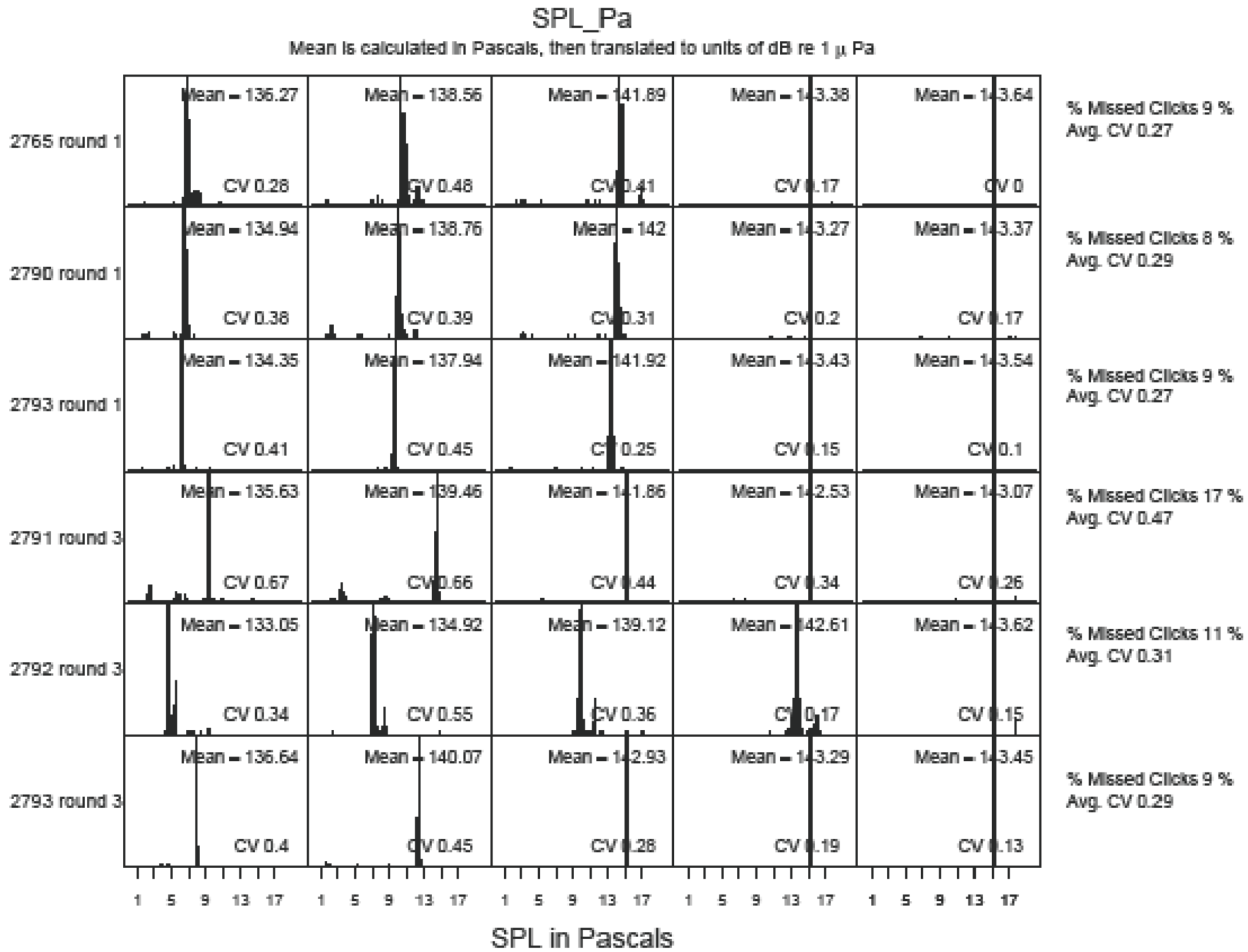

Figure 3. Distribution of click received levels (Sound Pressure Level reported in Pascals). Each column corresponds to each of the 5 amplitude levels of clicks generated by the *icTalk*. The loudest 2 sets of clicks exceeded the input level of the C-PODs and were thus recorded at the maximum SPL of the system. Each row corresponds to a C-POD number and the round of testing. Round 2 data were ignored as the *icListen* did not record during that period.

C-PODs 2765, 2790 and 2793 consistently report similar SPL levels, and have the lowest CV and % missed clicks. These C-PODs were recommended for use in period one and for sites within the FORCE demonstration area. The sensitivity of C-POD 2791 was clearly lower than all other C-PODs with % clicks missed at 17% compared to 8-11% for the remaining C-PODs. C-POD 2791 was deployed at location South2 and this scale of differences was noted in comparison to environmental levels and other C-PODs.

2.2. Deployment and Recovery Information

C-PODS and associated moorings and buoys were loaded onto the modified lobster fishing boat *Nova Endeavor* in Parrsboro, Nova Scotia on 6 June 2016 (period #1) and 21 September 2016 (period #2). The deployments took place in a single tide over roughly 3 hours on the following day. Each cylindrical shaped C-POD is approximately 1.21 m (4 ft.) long and approximately 40 cm (16") in diameter. The C-PODs are assembled into a "subs package" containing the acoustic release mechanism and recovery buoy. This is connected by a 2.5 m long chain to an anchor made of several lengths of chain (Figure 4).

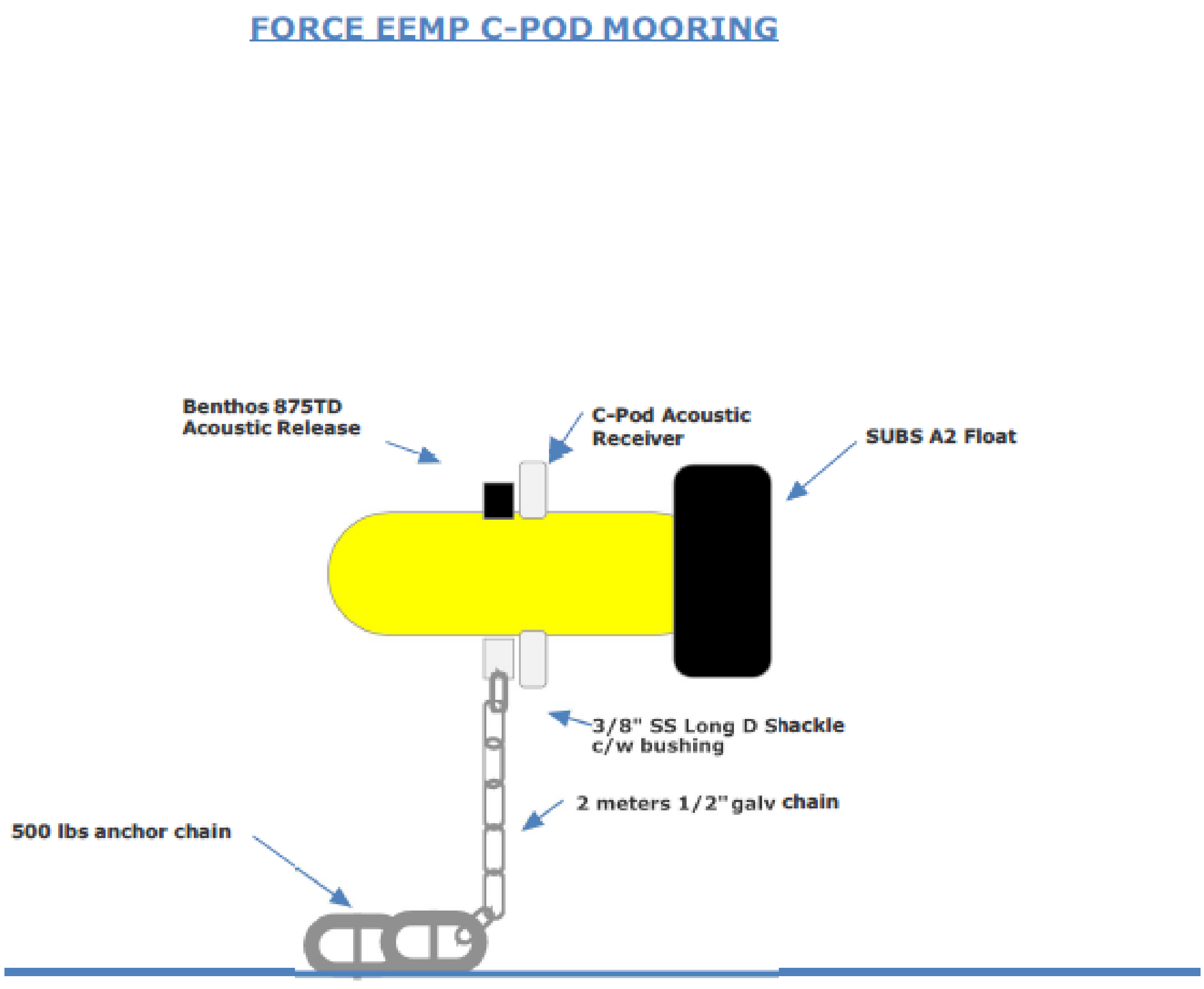

Figure 4. Diagram of FORCE C-POD mooring.

The 2016/2017 deployment locations and related information are provided in Table 1 with deployment times and locations relative to previous deployments depicted in Figure 5. The spatial location of C-PODs and turbine are depicted in Figure 6.

Table 1. C-POD deployment and retrieval information for 2016/2017 deployment #1 (top 3 rows) and #2 (bottom 5 rows). Depth is standardised to tidal height at deployment. Times are in UTC.

Site	C-POD ID	Depth (m)	Distance to turbine (m)	Deployment (date, time)	Retrieval (date, time)	Longitude (ºW)	Latitude (ºN)
D1	2790	31	230	7 June 2016 18:08	30 Aug 2016 13:58	-64 25.388	45 21.766
East1	2765	40	200	7 June 2016 17:59	30 Aug 2016 13:50	-64 25.333	45 21.973
West1	2793	53	1090	7 June 2016 17:52	30 Aug 2016 14:09	-64 26.125	45 21.944
D1	2790	33	230	22 Sept 2016 13:59	18 Jan 2017 14:54	-64 25.366	45 21.759
East1	2765	41	210	22 Sept 2016 14:07	18 Jan 2017 14:48	-64 25.360	45 21.975
West1	2793	46	1140	22 Sept 2016 14:12	18 Jan 2017 14:02	-64 26.163	45 21.947
West2	2792	44	1710	22 Sept 2016 14:17	18 Jan 2017 13:50	-64 26.601	45.21.963
South2	2791	68	1690	22 Sept 2016 13:49	18 Jan 2017 13:38	-64 25.835	45 21.039

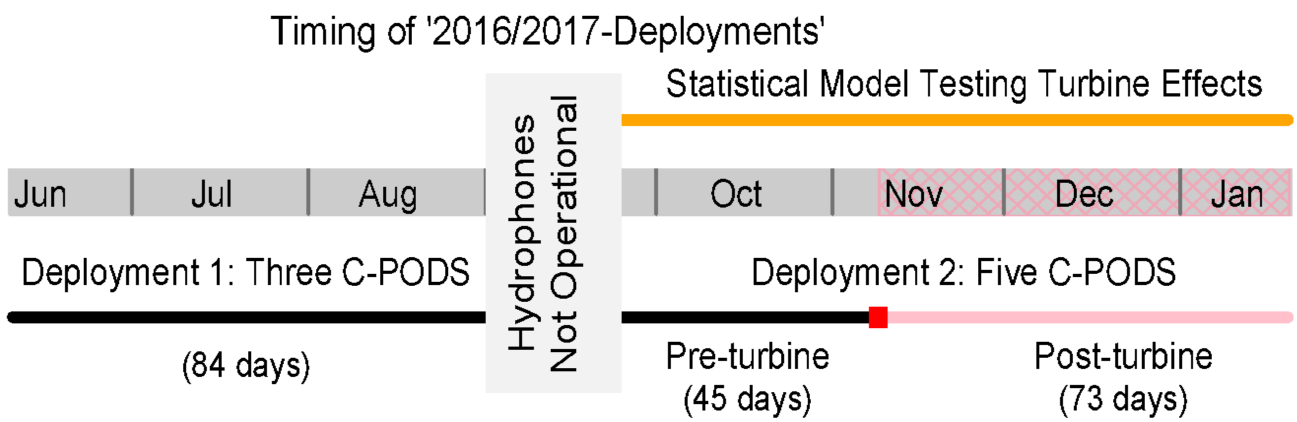

Figure 5. Timing of 2016/2017 deployments in which there were two periods of C-POD deployment to allow for retrieving acoustic data and for changing batteries. Deployment 1 included three C-PODS at D1, East1 and West1. Deployment 2 included an additional 2 C-PODS added to locations West2 and South2 (Figure 6), for a total of five C-PODS (Table 1).

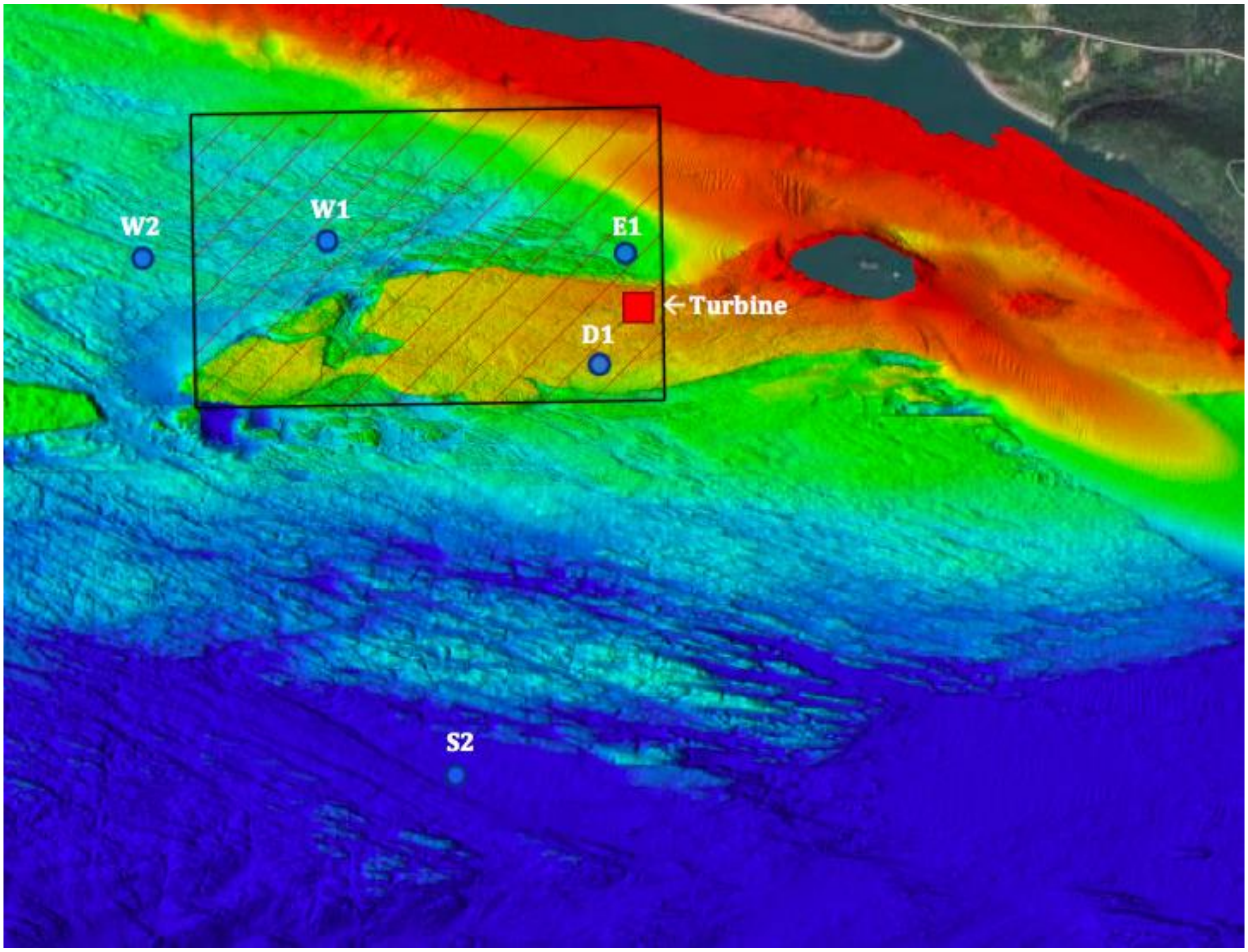

Figure 6. Locations of five monitoring C-PODs and CSTV turbine installed at Berth D. The hatched box denotes the FORCE demonstration area. Shallow water is depicted by warmer colours.

Site selection was based on continuing to monitor the two core long-term baseline sites within the FORCE demonstration area (Sites West1 and East1, Figure 6). These sites represent the best baseline coverage for comparable C-POD studies undertaken 2011-2014 with 535 and 470 days of coverage, noting that coverage was poor across winter months. The third site selected was D1, in the vicinity and on the rock shelf of Berth D (Figure 6) – where CSTV planned to install an Open Hydro turbine in fall 2016. A vertical cone of safety plan developed by Joel Culina (*cf.* Tollit et al. 2017) was used to determine how far a C-POD should be deployed in relation to a turbine and the ability to safely recover a C-POD. These precautionary calculations were undertaken by FORCE staff and are fully described in the process to receive a Marine Access Permit. Two extra sites outside the FORCE demonstration area (West2 and South2) were selected to provide additional area coverage in the 2nd deployment. Both these sites had previously been used to collect baseline C-POD data during the 2011-2014 deployments. Site East1 was closest to the turbine (200-210 m) at a depth of 40-41 m, with D1 slightly further away (230 m) and shallower (31-33m). West1 was 1,090-1,140 m away at a depth of 46-53 m, West2 was 1,710 m away at a depth of 44 m and South2 was 1,690 m from the turbine and the deepest deployment at 68 m (Table 1).

2.3 Data Quality Assessment

C-POD software V2.044 was used to process the data and custom Matlab (R2016a) and R (version 3.3.2, R Core Team 2016) scripts were used to calculate statistical outputs and create data plots using presence/absence of porpoise detections per 10-minute period. We refer to this as BinDPM (as in binary detection positive minutes). The data quality assessment specifically assesses 1) if non-biological interference has occurred, 2) determines whether the porpoise click detector is operational, 3) ensures no clock drift occurred, and 4) assesses the scale of % time lost due to internal memory restrictions. Non-target noise from sediment movement and moorings can result in periods of lost recording time in each minute, due to exceeding the C-PODs click maximum buffer.

To allow for the hydrophone elements to reach their typical underwater sensitivity, data from the first 2016 deployment resulted in 82 days, 19 hours and 30 minutes of data at each location spread across 84 calendar days (Julian days 159-243). Data were collected throughout this period on each of the three C-PODs. C-PODs were time synced when started and checked for clock drift after retrieval. Clock drift was estimated at less than 1 minute during this deployment cycle. There was no evidence of data corruption in either of the 2016/2017 deployment periods. During the 2nd of the 2016/2017 deployments, the batteries at two locations ran out before the scheduled end of the monitoring period (South2: 32 days lost, D1: 1 day lost). The remaining C-PODs monitored for 118 calendar days. No clock drift greater than 1 minute was observed in the units that monitored the entire deployment.

2.4 Statistical Analysis

To fulfill the goals of this current study, we fit two different statistical models. The first was a statistical model of all C-POD data dating back to 5 May 2011, noting that temporal coverage is incomplete across years and seasons (Figure 7). This was to understand the variability in porpoise activity across years, and within years across the seasons. It was not used to test the impacts of the turbine deployment, but was used to identify important environmental covariates. The second statistical model was specifically tailored to testing the effects of the installation of the turbine using only the 2nd of the 2016/2017 deployments, while controlling for larger scale environmental variability identified using all C-POD data in the first model. These variables were time of year and day, lunar cycle, tidal height and velocity as well as percent lost time (a proxy for environmental noise). Both models used the same general statistical approach, which we discuss next. While only the 2nd deployment has been currently used to directly assess turbine effects, as more post-installation data is collected for time periods where C-POD baseline coverage overlaps, then the ability to incorporate this C-POD baseline data in the analysis is justified.

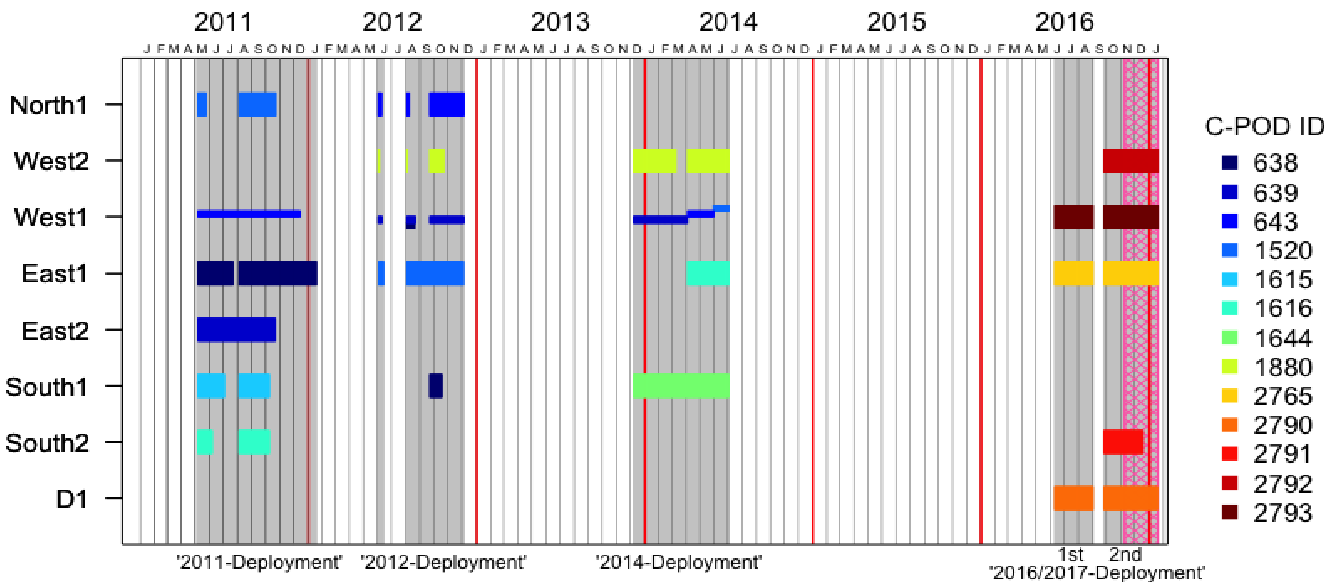

Figure 7. C-POD deployment history at 8 locations between 5 May 2011 and 18 January 2017. For descriptive purposes, this report describes four deployment periods denoted by the labels on the bottom x-axis. The 2nd of the 2016/2017 deployments includes the turbine installation on 7 November 2016 and covers the far right (most recent) 73 days of post-turbine monitoring from 7 November 2016 to 18 January 2017, denoted in this figure (and following figures) by pink hatching (also see Figure 7). The grey shading denotes when at least one C-POD was operating.

Porpoise were generally detected for just a few minutes per day, and often logged in consecutive minutes. The number of DPM within a 10-minute window was therefore not a measure of independent observations (i.e., it was autocorrelated). As well, the distributional form was zero-heavy with a right-skewed tail for consecutive detections. We have therefore reported median and inter-quartile ranges (Zar 1999) for DPM per day. We analysed the presence or absence of porpoise detections per 10-minute period (BinDPM) as a binary response variable (i.e., when porpoise detected, BinDPM=1; when porpoise not detected or absent, BinDPM=0) in the comparative statistical models. These are described in detail below.

2.4.1 Logistic Regression with Correlated Time Series

We used statistical models for comparing the BinDPM C-POD data using a logit link function to accommodate the Binomial distribution of the BinDPM 0 or 1 data. The BinDPM data is continuously collected at each C-POD deployment location (Table 1). This kind of time-series data is highly correlated across time, and this data structure requires modeling methods that accommodate the autocorrelation. Correlated data can be incorporated using models with correlation structures built directly into them, or by using high-rank smoothers such as splines to help remove correlation across continuous covariates in a model. We used both approaches.

2.4.2 Fitting GEE Models with AR-1 Correlation Structure

We used a Generalized Estimating Equation within a Generalized Linear Model framework (GEE-GLM) approach as it allows both a logit link function to accommodate the Binomial distribution of the BinDPM data, and allows for the inclusion of autocorrelation[2] functions (ACFs) to accommodate the correlation structure in the data. A model with an ACF assumes a parameterized correlation matrix to down-weight adjacent time points to avoid pseudo-replication and artificial inflation of p-values. We examined the autocorrelation at lags between 1 and 50 time steps to ensure that sequential dependence declined across time (Figure 8), and a first order auto-regressive (AR-1) form to the autocorrelation function (ACF) was appropriate. The AR-1 ACF has a sparse structure with a single parameter to estimate that allows the function to decay exponentially towards 0 as the time lag increases.

The GEE-GLM models with an assumed AR-1 correlation structure were fit to clusters of 10-minute data. The time interval length for each cluster is based on examining the auto-correlation in residuals that originates from a model fit without accommodating the auto-correlation. In this dataset, the autocorrelation fell to negligible levels after 3 hours as depicted in Figure 9, therefore the limit at which data could be assumed independent was 3 hours, and the grouping structure of our model is thus based around 3-hour windows of data.

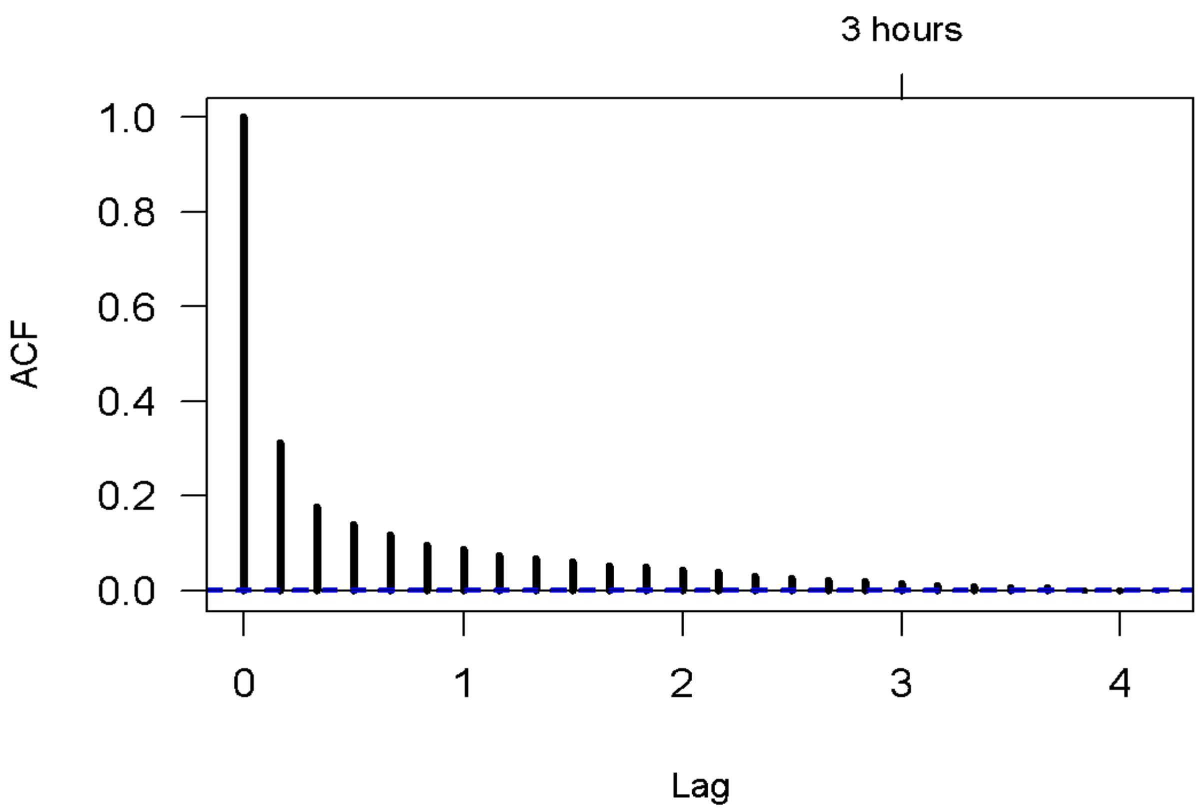

Figure 8. ACF of the model residuals without considering autocorrelation. This was used to set the autocorrelation structure of the GEE-GLM model, in which independence was assumed after a lag of 3 hours (after 18 time windows ACF=0.01).

[2] Autocorrelation in relation to time quantifies the extent of the linear relation between values at time points that are a fixed interval apart (e.g., behavior for a one minute sample is likely related to behavior in the next minute sample).

Using the full dataset back to 2011, there were 407,592 10-minute intervals (rows of data in the dataset), and timely convergence of candidate models was an important consideration. With non-linear functional relationships between environmental covariates and the response variable, this meant not only solving the regression coefficients, but also optimizing the number and placement of smoothing knots, a task which can easily become intractable when there are multiple non-linear relationships between environmental covariates and the response variable.

Therefore, the smoothing spline describing the relationship between porpoise response variable and each environmental covariate was optimized separately outside of the GEE-GLM model using the "*bs*", and "*gam*" function in the R-package "*mgcv*". The number and location of knots in each smoothing spline is optimized via a penalty term that has the effect of penalizing steep slopes by reducing the degrees or freedom (or wiggliness) in the smoothing function. The advantage of using this regression spline approach is that the analysis stays within the linear model framework, with the same linear model theory and computational methods as any other linear model. This additionally ensures that data from outside of the target analysis period could be included to describe porpoise response to normal stochastic changes in the regional environment.

These smoothed basis functions were then adopted as the covariate data into the design matrix of the GEE-GLM models. From a modeling perspective, fitting the smoothing splines external to the optimization of the AR-1 ACF ensures identifiability in parameters as both autocorrelation terms and the degrees of freedom of a spline compete to describe the complexity of the data series as correlation between observations increases.

We fit the smoothing functions to the following environmental covariates: annual cycle, the lunar cycle, the day/night cycle, as well to two components of the tidal cycles: the tidal height, and current speed, and examined the relationship to the amount of time lost at the C-POD hydrophone due to internal memory restrictions.

The GEE-GLM fit to all the data from 2011 through 2017 was undertaken to assess the influence of changes in porpoise habitat in the FORCE demonstration tidal area due to environment variability over time. Until more data is collected (especially in winter for which only one year is represented), the main results of this first model were thus to determine the environmental covariates important in describing porpoise detection across the seasons, and control where possible for this natural source of variability in our key GEE-GLM model that covers the 118 monitoring days of the 2nd of the 2016/2017 C-POD deployments.

It is important to bear in mind that only 73 days of C-POD data were collected after a delayed turbine installation and that the current EEMP aims to assess turbine effects over multiple years. Nevertheless, the objective of this report (as per SLR 2015) was to make a preliminary assessment of, 1) Permanent avoidance by harbor porpoise of the mid field study area during turbine installation and operation, and 2) Large magnitude (~50%) change in the distribution (echolocation activity levels) of a portion of the porpoise population in the study mid field area. To achieve these objectives, we fit a GEE-GLM with focused significance testing on data collected in deployment 2. This modeling approach removes confounding effects such as differences between C-PODs, while accounting for natural (baseline) environmental variability, thus allowing the model to compare the 'population-averaged' effect of the turbine on porpoise presence before and after its installation. Optimally, this approach should be undertaken with an extended post-installation period that includes a long enough time series to distinguish seasonal variability from turbine effects.

3. Results

3.1 Annual Porpoise Detection Rates (2011-2017)

Across all years of the Minas Passage C-POD monitoring study, there have been a total of 2,847 C-POD days across 805 calendar days. Porpoise were detected on 98% of days and detected for 6 minutes per day on average (Table 2). Similar to previous C-POD deployments (e.g., Wood et al. 2013), there were no acoustic-operator confirmed dolphin detections during the more recent 2016/2017 EEMP deployments (i.e., a scientist analyzed all periods that each C-POD had recorded as a 'possible' dolphin and found that on all occasions these were false positives). C-PODs do not detect non-echolocating whales (e.g., Right whales or minke whales).

Harbor porpoise were present in Minas Passage on 83 of the 84 calendar days (98.8%) during deployment 1 of 2016, and 116 of 118 calendar days (98.3%) during deployment 2. These 2016/2017 rates and other descriptive statistic are provided in Table 2, and can be compared to previous 2011-2014 baseline deployments here. The lowest daily presence was observed during the 2012 deployment (95.6%), and the highest rate during the 2011 deployment (99.2%), however, porpoises were observed for the fewest minutes per day during both pre- and post-turbine periods of the 2016/2017 deployment period compared to all other deployments. Porpoise were present for 7 minutes of the day during deployment 1, and for 4 and 3 minutes during the pre-turbine and post-turbine deployment periods respectively for deployment 2 in 2016/2017. Porpoises were present 97.3% of days post installation, highlighting no evidence of permanent avoidance of the mid field study area by porpoise. Clearly, caution is required when interpreting this simple raw data synthesis, especially as it does not incorporate different timing of deployments within a year and lunar cycle, as well as the specific site locations available in each year and the level of associated percent time lost metrics. This is of particular note given baseline studies have identified strong seasonal variations, with lower activity noted during one previous baseline winter period, which is coincident with the timing of this recent turbine installation.

As part of the EEMP to specifically monitor the turbine in Berth D, D1 was added for the 2016/2017 deployments. C-POD locations East1 and West1 were consistently used in the 2011-2014 baseline monitoring program and both are located within the FORCE demonstration area. These 2 sites were therefore selected for monitoring in both the 1st and 2nd periods of the 2016/2017 C-POD deployments (noting West2 and South2 were selected for the 2nd deployment period only), and allow for direct comparison of daily porpoise detections to previous deployments.

Table 2. Percent of calendar days with at least one porpoise present at one or more monitoring locations, and the number of minutes per day porpoise were there, when present. Monitoring effort is reported in three ways; the number of calendar days reported for each monitoring period, the number of pod days in which each location considered a "Day" (number of days multiplied by the number of locations), and the number of 10 minute monitoring periods.

Deployment	% Days Porpoise Present	Median (IQR) of DPM if Present/Day	Number of Calendar Days	Number of POD-Days	Number of 10 Min. Intervals
2011 Deployment	99.2	7 (2, 17)	258	958	136,446
2012 Deployment	95.6	5 (1, 13)	137	391	56,795
2014 Deployment	99.0	9 (3, 16)	208	689	99,108
2016/2017:					
1st Deployment	98.8	7 (3.75, 14)	84	252	35,775
2nd Deployment:					
Pre Turbine	100.0	4 (1, 10)	45	225	32,065
Post Turbine	97.3	3 (0, 7)	73	332	47,403
All Data	**98.4**	**6 (2, 15)**	**805**	**2847**	**407,592**

We provide a direct comparison of daily porpoise detection rates at these two key sites, comparing 2011-2014 baseline with the recent 2016/2017 deployments, noting that C-POD units used across these two studies vary. In terms of seasonal timing of previous C-POD deployments at East1 and West1 compared to 2016/2017, there was good temporal overlap with the 2011 and 2012 deployments, but poor temporal overlap with the 2014 deployment (Figure 9). Direct comparison of previously collected data with the 73-day turbine installation period was notably low, one of the reasons for focusing on data from the 2nd deployment only to assess potential turbine effects. Variability within years and across years can be observed at both sites (Figure 9), with detection rates visibly lower in 2016/2017. The environmental factors driving these effects were investigated further using GEE-GLM modelling.

As part of the seabird EEMP, Envirosphere Consultants Limited made concurrent observations of marine mammals from a shore-based observation site above Minas Passage. Recorded sightings of porpoise on four days in which C-POD deployments were concurrent were 2 August 2016, 1 October 2016, 17 November 2016 and 16 January 2017). On each day, C-PODs also detected porpoise, though none of the four visual sightings were concurrent to the hour of detection by C-PODs.

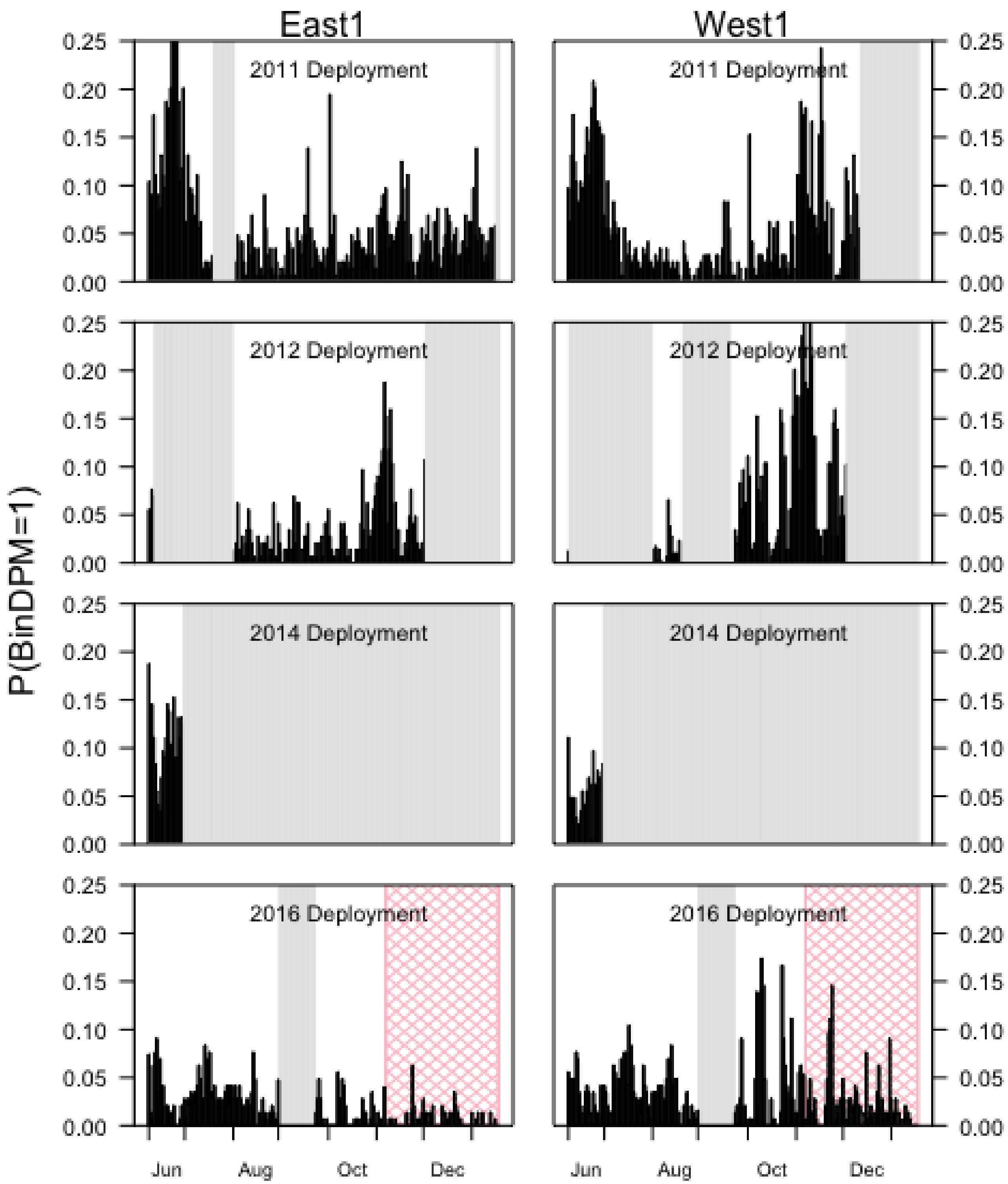

Figure 9. Comparing daily porpoise detections (P(BinDPM=1)) between 8 June and 18 January across 4 years of deployment. Grey periods denote when the hydrophones were not operational. The pink hatching on the bottom 2 panels denote the period when the turbine was installed.

3.2. GEE-GLM Models

We fit a comprehensive GEE-GLM model to all the C-POD data from 2011 to 2017 (Figure 10) to compare the observed patterns in porpoise detections in this region between and within years. It is important to note that temporal coverage is intermittent over this period, with only one winter-early spring period of baseline. Spring through fall data is better represented with two or three years of data collection. As illustrated for West1 and East1 in Figure 9, there was considerable variability both between year and within year in porpoise detections, but consistency in seasonal peaks: one in the May/June and one in October/November. The model predictions for the post turbine installation period does not support any permanent avoidance of the mid field study area by porpoise. However, we are cautious about making further inferences about turbine effects using this model due to the lack of consistency across C-POD deployment locations and time (Figure 7). For example, in the 2011 deployment, there was only one C-POD operational during 37 of the 73 day post-turbine installation period. In the 2012 deployment, there is C-POD coverage for only the first 28 of 73 days, and in the 2014 deployment there is C-POD coverage for the last 45 days of the 73 days (but no overlap with that of the 2012 deployments). This complex deployment history combined with the inter-annual variability introduces unintended bias to those sites and time periods where the majority of data were collected, and until more data is collected in 2017 for direct comparison renders this model's predictions unreliable for testing turbine-related effects for the same period in 2016/2017.

These previous deployments (2011-2014) and the 2016/2017 deployments allowed us to better understand the variability in porpoise detections explained by the natural cycles in the Minas Passage environment. There is clearly a complex interaction between tidal cycles and current speed that can influence the presence of porpoise (e.g., Tollit et al. 2011, Porskamp et al. 2015), as well as processes happening at both larger annual scales and smaller local processes (Figure 10). The impact of time lost due to internal memory limitations also needs to be quantified. These relationships are best understood and described through smoothing functions, which we describe in the following sections. The model also ranks the importance of these factors in describing variability in porpoise detections.

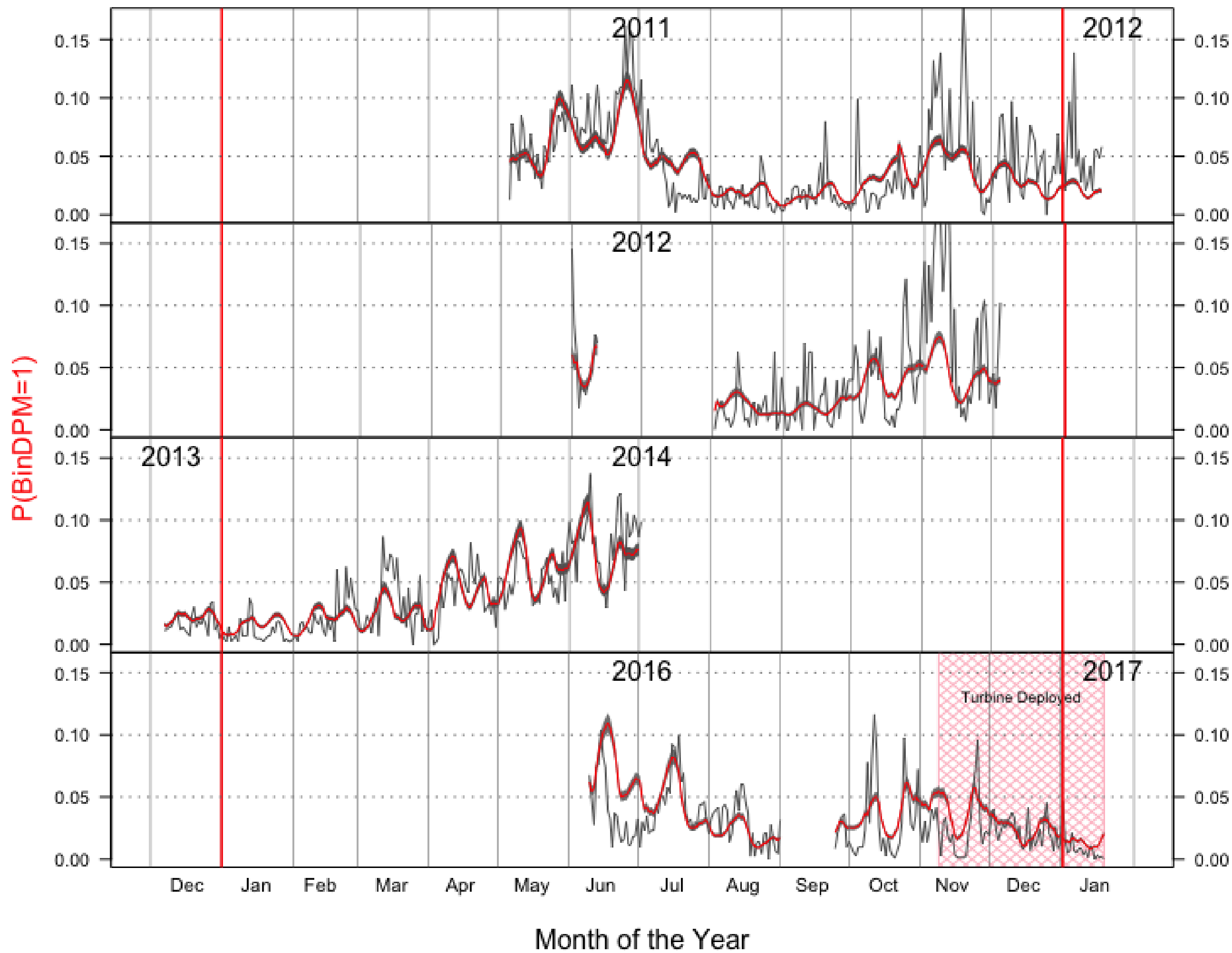

Figure 10. FORCE baseline data 2011-2017. Raw data BinDPM per day (grey lines) versus GEE-GLM model predictions of the overall mean probability of porpoise detection per time bin (PBinDPM) over time (red line).

3.2.1. Porpoise Detection Rates in Response to Environmental Variables

We included a set of environmental variables that have profound biological influence in the marine environment and, in our models statistical power to describe the variability in our porpoise activity response variable (BinDPM). We assumed all processes had a fixed (and known) periodicity and acted independently from other cyclic processes and therefore were well described by additive components in the GEE. We considered a 365-day annual cycle (366 for leap years), a 29.6-day lunar cycle (IQR: 29.1, 30.2; www.timeanddate.com/moon/phases/canada/halifax), a 24-hour day-night cycle, and an approximately twice-daily (M2) tidal cycle. Each of these processes was described either by a cyclic or by a non-cyclic cubic regression spline smooth (Figure 11), such that the environmental predictor variables are considered random smooth functions.

The shape of these functional relationships, the rationale for including them, and the relative importance of each in the GEE models are explained in the following sections.

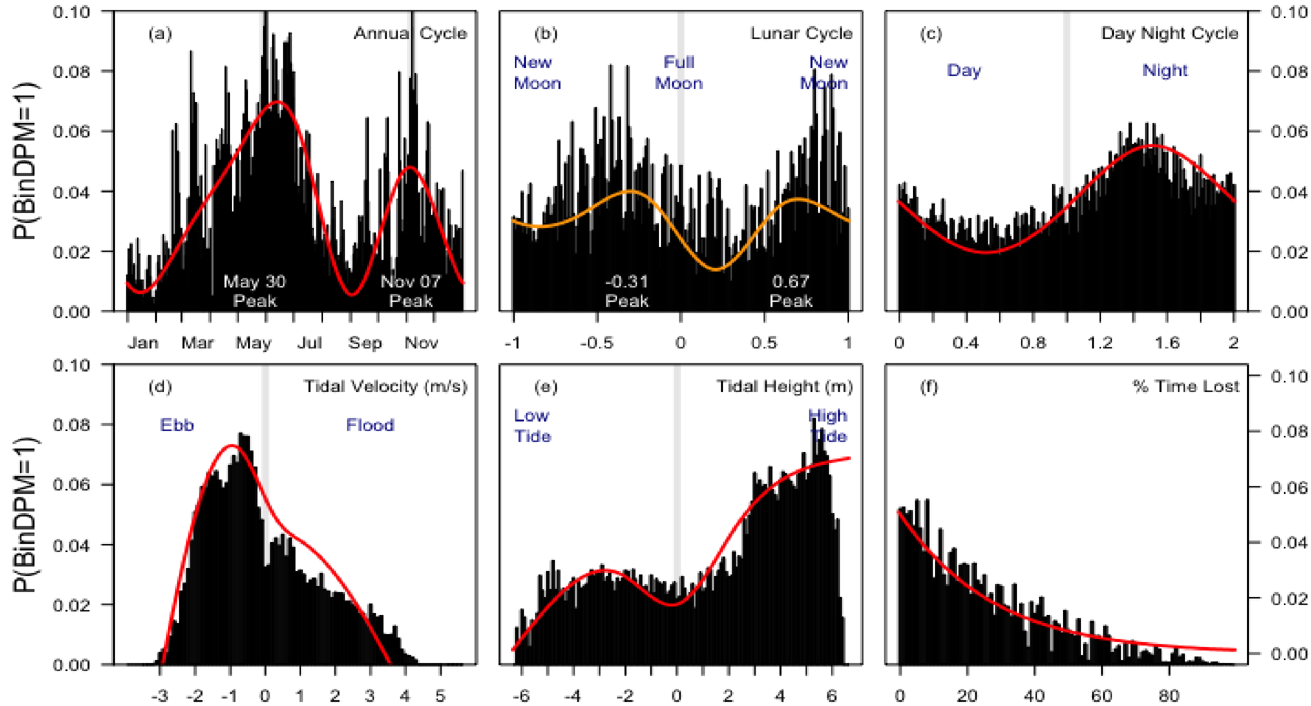

Figure 11. Shape of smoothing functions overlaid over the domain of a set of environmental variables. Black bars are P(BinDPM=1) frequency bars of raw data provided as a way to check the performance of the smoothing splines. Coloured lines are the cyclic (a, b, c) and non-cyclic (d, e) cubic regression smoothing splines. In all panels, the y-axis denotes the probability of detecting at least one porpoise in a 10-minute window, i.e., P(BinDPM=1), and how this varies over the range of the environmental variable denoted on the x-axis. Data includes all data collected during 2011-2017 from 8 hydrophone locations over all deployment dates. In Panel (a), the x-axis is Julian Day starting with January 1st, and ending on December 31st. In Panel (b), the x-axis denotes the phase of the moon with new moons at both ends of the axis (at '-1' and '1'), and full moon in the middle (at '0'). In Panel (c), sunrise is set to occur at the beginning and end of the x-axis (at '0' and '2'), with sunset occurring at '1'. In Panel (d), the x-axis is simply the tidal velocity measured in m/s, while the x-axis of Panel (e) is the height of the tide in m. Panel (f) represents the (logit) linear relation of porpoise presence to % time-lost due to C-POD internal memory space limitations.

3.2.1.1. Annual Cycle over 365 Julian Day (Figure 11; Panel a)

The annual cycle has two peaks in porpoise detections, a late spring cycle that peaks around 30 May, and another lower peak in the fall around 7 November. November 7th is also notable as this is the date that the turbine was deployed at the FORCE demonstration site in 2016.

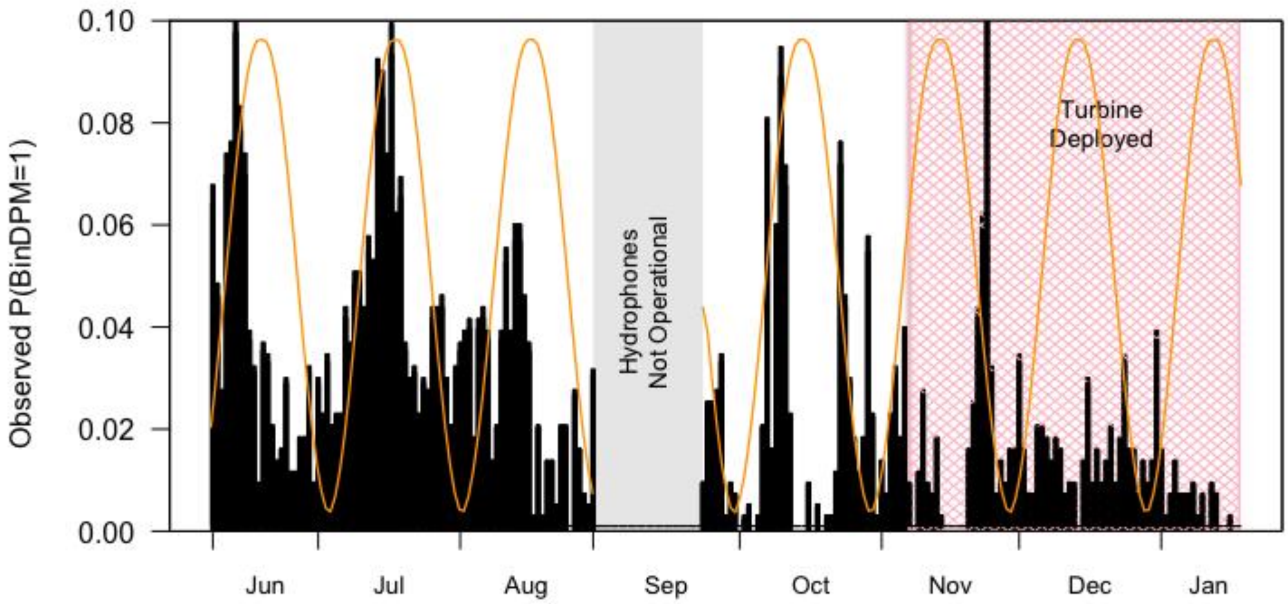

Figure 12. Raw Data from both time periods of 2016/2017 deployments: Lunar Cycle is overlaid in orange with spring tides at both the maximum and minimum of the cyclic function. Porpoise detections are maximized at just before (~70% along) the spring tide cycle.

3.2.1.2. Lunar Cycle and Spring Neap Tides (Figure 11; Panel b)

There was a strong signal observed in porpoise detections in response to the lunar cycle with two peaks per lunar cycle. This dual cycle reflects the spring tides that occur every full and new moon. Peaks occurred when the tidal amplitude was 70% that of a full spring tide on both the full moon, and the new moon. These trends are also seen in a time series plot of the raw data plotted for the full 2016/2017 C-POD deployments (Figure 12).

3.2.1.3. Diurnal Patterns (Figure 11; Panel c)

Porpoise were most often detected at night, peaking in the middle of the night, with the least number detected during the middle of the day.

3.2.1.4. Tidal Current Speed and Tidal Height (Figure 11; Panels d and e)

Porpoise detections changed with the tidal conditions of the M2 tidal cycle observed in the Bay of Fundy. Porpoise are more likely to be detected during the ebb tide compared to the flood tide, with most detections during moderate ebb current speeds (between 0 and -2.5 m/s). Porpoise are most likely present when the tidal heights are moderately high (>2.5 m). To summarize, porpoise in the Minas Channel therefore prefer the first few hours after tides have turned to ebb when water velocities are flowing at low to moderate speeds.

3.2.1.5. Percent Time Lost (Figure 11; Panel f)

The amount of data recording time lost on the C-POD is a function of the internal memory restrictions coupled with the amount of non-target clicks recorded at each site. These lost recording times happen when the allowable memory fills up prior to the completion of a 60 second time window and the remaining detection time within that minute is lost due to the turning off the C-POD recorder to conserve memory (that is otherwise assumed to be taken up by non-target noise from sediment movement and mooring). Percent time lost due to sediment interference varied by site and was also included in the GEE-GLM as an explanatory variable. There is a simple linear relation on the logit scale between % time lost and detection of porpoises, with the greater the time lost, the fewer detections of porpoises. This makes intuitive sense as the less time the C-POD is actively recording data, the lower the probability a porpoise would be detected.

Summaries of differences in % time lost for each C-POD location are presented in Table 3, and each location's distribution of % time lost is plotted in Figure 13. West2 had the least amount of time lost (highest percentage of data with 0% time lost, and lowest with >95% time lost), and therefore was the best at listening for porpoise detections. The most time lost was observed at South2 with only 51.83% of the data with 0% time lost, and the greatest amount of data with >95% time lost. This is also the location that ran out of battery 32 days before the retrieval of the C-POD unit, highlighting the limitations of monitoring certain sites that are subject to large amount of sediment noise (more echo-location clicks also require more battery power). In previous monitoring periods (prior to 2016), there were far higher rates of time lost reported for South1 and East2 and as a consequence these sites were omitted for C-POD deployment in this EEMP. As found in previous C-POD studies (Tollit et al. 2011), periods of spring tides (especially around the full moon) were associated with higher relative levels of non-porpoise sediment-related clicks. This leads to a decreased performance in porpoise detection ability. Percent time lost was included in addition to other environmental variables to assess the potential effects of the turbine installation.

Table 3. Proportion of % Time Lost by C-POD location (averaged across time). At West 2, we observed the highest % of data with '0 % time lost', whereas at South we observed the least amount of observed '0 % time lost'.

Location Site	Time Lost= 0 %	Time Lost>50 %	Time Lost>75 %	Time Lost>95 %
D1	62.34	26.25	21.17	7.37
East1	55.66	28.11	22.98	10.36
West1	58.23	24.91	18.51	5.20
West2	75.52	15.94	12.80	4.50
South2	51.83	36.79	31.86	18.81

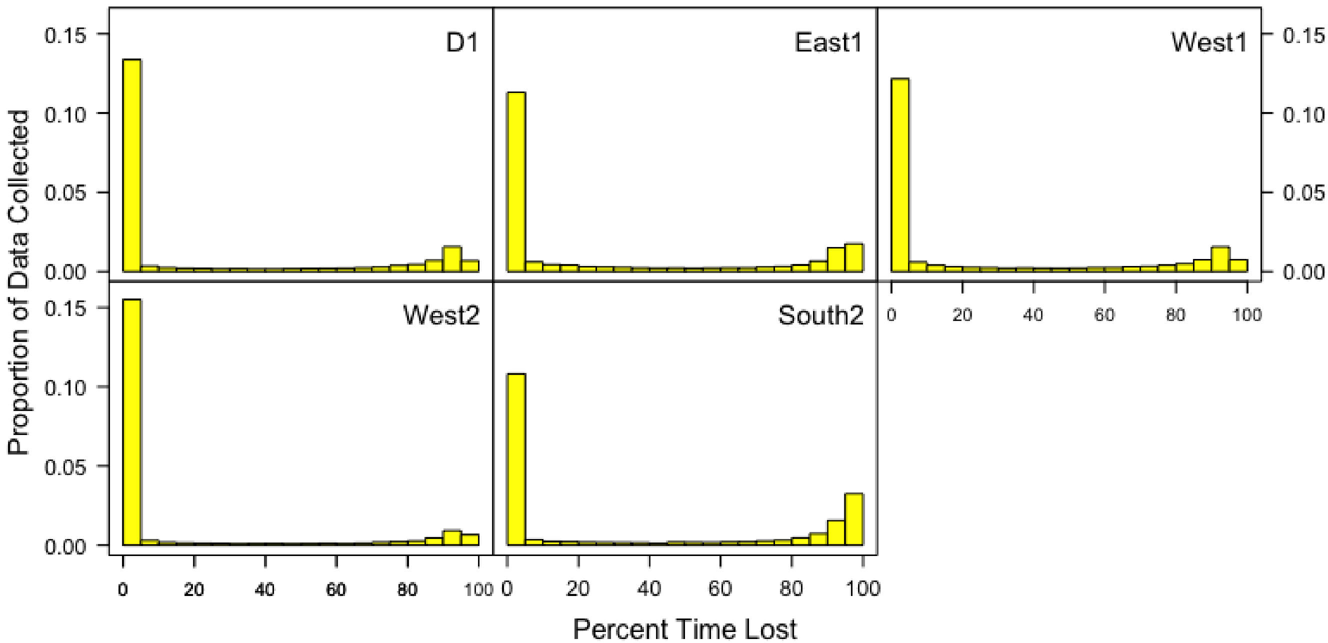

Figure 13. Distribution of % time-lost data from 5 hydrophone locations in the 2016/2017 deployments. For comparing between sites, both the X- and Y- axes are standardized to have the same limits.

3.3 Assessing the Effect of the Turbine Installation on Porpoise Detection Rates

Observed probabilities (from raw data) of porpoise presence in the 2nd of 2016/2017 deployments varied by location and are presented as percentages in Table 4. The highest porpoise presence was found at West2, the same location with the least % time lost. Despite a somewhat lower click sensitivity of the C-POD located at South2, detection rates at the shallower sites at D1 and East1 were lowest. As the same C-PODS were used in the same locations both pre-and post-turbine installation (i.e., a balanced design); these rates are comparable between locations, but because the season is advancing through time, the reduction post turbine installation in the observed probabilities are confounded with the expected lower presence in the area due to seasonal winter lows. Subsequent GEE-GLM modelling of on-going data collections covering seasonal variability will aim to take this into account. The raw data reductions (41-46%) in porpoise activity after turbine installation can be observed for the three sites (East1, West1 and West2) out of five. In all three cases, the 95% Confidence Intervals of porpoise presence during pre and post turbine installation do not overlap. The activity at site D1 increases by 10% with overlapping 95% confidence intervals, while site South2 activity levels are within 1%. Statistical data analyses using a GEE-GLM model (Table 5) accounts for seasonal variability, % time lost and early battery power loss at D1, and South2 (not accounted for in these raw observed probabilities).

Table 4. Percent probability (95% C.I.'s) of porpoise presence from the 2nd period of the 2016/2017 C-POD deployments. Observed probabilities are the sum of BinDPM=1 divided by the total number of 10-minute intervals then multiplied by 100 to translate to % probability.

Location Site	% Probability **Before** Turbine	Number of 10-Minute Intervals	% Probability **After** Turbine	Number of 10-Minute Intervals
D1	1.29 (1.04, 1.61)	6413	1.42 (1.21, 1.67)	10273
East1	1.20 (0.95, 1.51)	6413	0.67 (0.53, 0.85)	10419
West1	4.01 (3.55, 4.52)	6413	2.17 (1.9, 2.47)	10419
West2	5.11 (4.59, 5.69)	6413	3.02 (2.71, 3.37)	10419
South2	3.31 (2.89, 3.78)	6413	3.27 (2.84, 3.76)	5873

In order to compare porpoise activity pre-turbine to the post-turbine installation, only the second period of the 2016/2017 deployment was selected. This period provided the most balanced design in which there was approximately equal effort at the 5 locations, with the same C-POD units deployed at each location across the 45 days pre-installation, and for the 73 days post turbine installation. Selecting this restricted 118 day subset of data therefore provided the optimal design for comparing any immediate effects of the turbine installation at local sites in the mid field area of the turbine (Figure 11). Currently the model includes the two day installation and connection period during which project vessels were operating in the area. Full use of baseline data is recommended as further data is collected.

We compared candidate models using a model selection criteria (quasi information criteria: QIC), and the model with the lowest QIC was selected. The final model included smoothed terms to remove confounding effects of environmental variability associated with time of year, the spring-neap tidal cycle, the tidal height and current velocity, as well as the time of day. Finally, the model included a linear term to control for the recording time lost at the hydrophone due to internal memory restrictions (% Time Lost). C-POD location was treated as a categorical variable, and the model coded 'D1' as the reference group (forms the model's intercept) against which the other four locations are compared. The GEE model found significant differences between C-POD locations, as well as a significant effect of the turbine on porpoise detection (Table 5).

In terms of the relative importance of the predictive value of the covariates used within the model, tidal velocity was the most important, followed by time of day, location, lunar cycle, Julian day, % time lost and lastly turbine presence. In fact, tidal velocity was twelve fold more important in predicting porpoise detection than turbine presence.

Table 5. GEE Model statistical results on 2nd deployment porpoise detection rates pre and post turbine installation. Location effects have higher statistical significance than turbine effects.

Model Covariate	Degrees of Freedom	Chi-Square Statistic	P-value
Location	4	190.15	<0.01**
Turbine	1	18.83	<0.01**
Location*Turbine Interaction	4	11.58	0.02*

Table 6. GEE regression coefficients at each of the 5 hydrophone locations for the 2nd of the 2016/2017 deployments. Significance at α <0.05 is denoted by '*', and at <0.01 by '**'. The model predicts, 1) more porpoise detections at West1, West2 and South2 than D1 (all p-values < 0.01) and 2) fewer porpoise detections at East1, West1, and West2 after the turbine installation (all p-values 0.01), but no significant differences in porpoise detections between pre- and post-turbine installation at D1 (p-value = 0.55), or South2 (p-value = 0.35).

Model Term	Estimate	Standard Error	Wald Chi-Square Statistic	P-value
D1:Locaton	13.62	27.23	0.25	0.62
East1:Location	-0.11	0.21	0.29	0.59
West1:Location	1.11	0.21	28.29	<0.01**
West2:Location	1.28	0.18	50.9	<0.01**
South2:Location	1.03	0.17	36.07	<0.01**
D1:Turbine	-0.16	0.27	0.35	0.55
East1:Turbine	-0.68	0.28	5.96	0.01*
West1:Turbine	-0.67	0.26	6.56	0.01*
West2:Turbine	-0.58	0.23	6.42	0.01*
South2:Turbine	-0.22	0.23	0.89	0.35

The significant interaction between location and turbine in Table 5, indicates that turbine effects were not equal across locations. In Table 6, we present the location-by-turbine regression coefficients for each C-POD location with the Chi-square tests. This model fit to the 2nd of the 2016/2017 deployments, found that there were significantly more porpoise detections at West1, West2, and South2 (p-values<0.01) compared to D1 and East1 (Top 5 rows of Table 6). The model predicts significantly fewer porpoise detections post-turbine installation at East1, West1, and West2 (p-values=0.01), but with no significant differences in porpoise detections on account of the turbine at D1 (p-value=0.55) or South2 (p-value=0.35). Therefore, the lower porpoise detections at locations East1, West1, and West2 post-installation of the turbine are driving the overall significant result of the turbine installation as presented in Table 5.

Figure 14 compares raw detection rate data (left panels) against the GEE-GLM model predictions (right panels). This figure highlights firstly, an immediate decline in model predicted porpoise detection post turbine deployment at these three locations. FORCE representatives documented that vessel activity occurred around installation on 7 November as well as the following day. Thus, significant effects include the short-term effects likely caused by vessel presence during this period. Secondly, across all sites, there was a period of very low porpoise presence a week after turbine installation, similar to that observed a month prior (pre-turbine). Both these dips appear related to full moon spring tides (Figure 12), a period known to exhibit high levels of sediment transfer and decreased detection performance (Tollit et al. 2011, Porskamp et al. 2015). Notably, FORCE representatives reported no vessel activity associated with the significant operation of deployment/interconnection at the site during this mid-November dip. Lastly, there looks to be a longer term drop in porpoise presence at the time limit of the data series in mid-January. This may be because of natural seasonal variability, another spring tide dip or may be due to the turbine's presence. More data are needed to determine if this trend persists, or was just part of the natural variability in the Minas Passage environment.

In summary, the data highlights that porpoise were not excluded from the mid field study area either during the period of turbine installation nor from the subsequent days the tidal turbine was in operation. A model of these data identified a significant decrease in porpoise activity at three of the five C-POD monitoring sites. These decreases were all less than a 50% reduction and occurred at ranges of 200 – 1710 m. The site at D1, which is on the same shelf and within 230 m of the turbine, did not show a significant turbine effect, nor did a more (1690 m) distant, and deeper water site at South2.

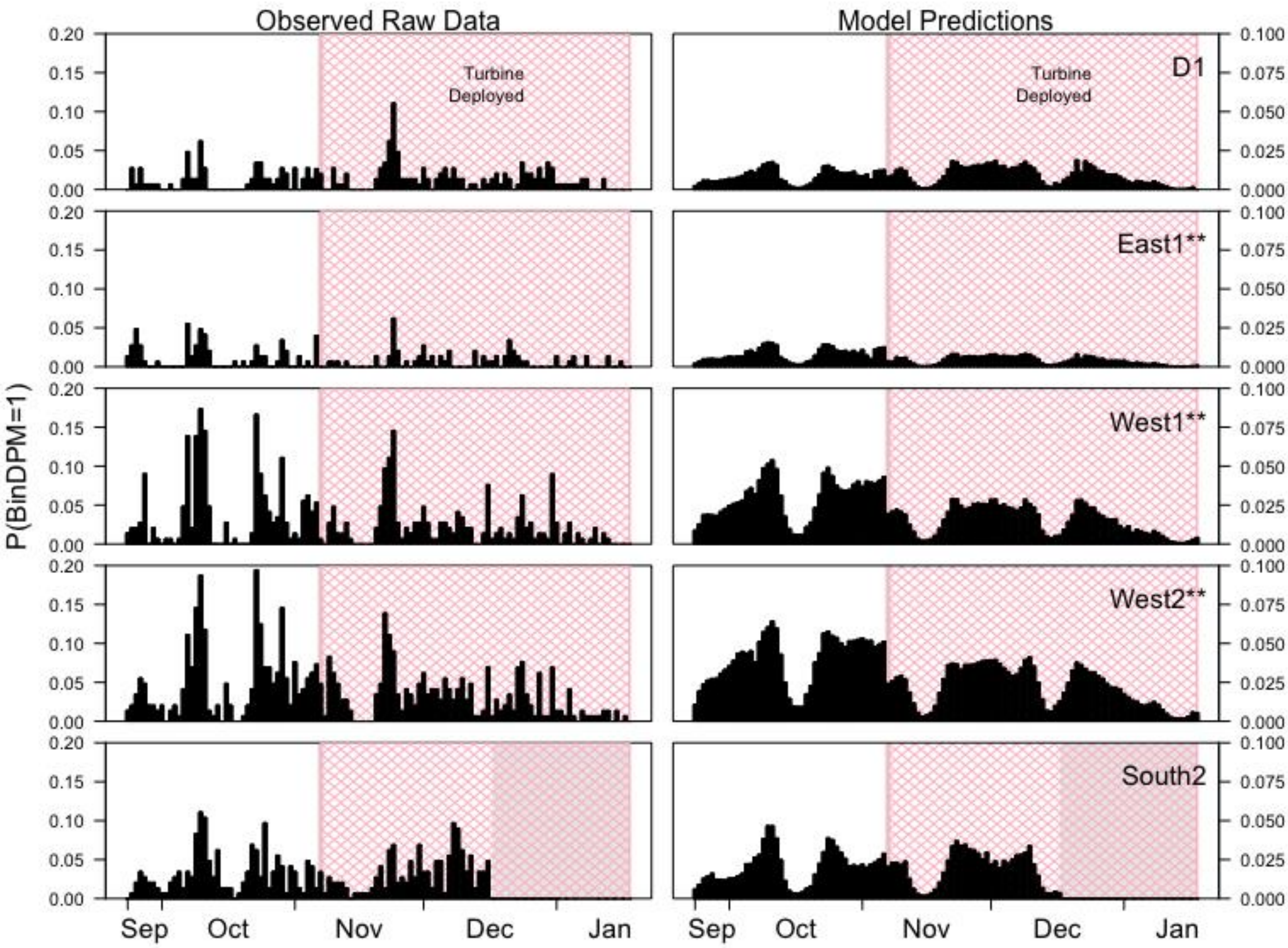

Figure 14. Probability of Porpoise detections, P(BinDPM=1) during the 2nd period of the 2016/2017 deployment. The left panels depict the raw data, the right panels depict the GEE model predictions for the same period. Locations with significantly lower probability in DPM post turbine installation are noted by '**'. The cross hatching denotes when the turbine was installed and working. The grey shading in the bottom panels shows when the C-POD at South2 was not collecting data for the last 32 days of the deployment (dead batteries).

4. Discussion

Harbor porpoise use echolocation to hunt and communicate (Kastelein et al. 2002), and they are known to be very susceptible to noise disturbance (Tougaard et al. 2009). Tidal turbines have the potential to cause acoustic effects on porpoise from continuous low-frequency noise, noting that emitted noise levels and range of effects will likely vary with current speed (Ellison et al. 2012, Polagye et al. 2011). In Minas Passage, baseline acoustic C-POD monitoring of harbor porpoise echolocation clicks occurred for 732 calendar days spread across four years between 5 May 2011 and 6 November 2016, and occurred at 8 different locations. C-PODs were deployed in a similar manner, used identical detection settings and analytical methodology and were therefore considered comparable. A single CSTV turbine was installed on 7 November 2016, and this report summarizes the factors that affect porpoise detection rates in the Minas Passage area and provides the preliminary effects analysis of the first 73 days of post turbine installation monitoring.

4.1 Annual Variability

Porpoise were detected on >95% of days across all monitoring deployments. However, in the 2016/2017 2nd deployment, porpoises were in the region for fewer minutes per day than in previous years (median 3.5 minutes compared to overall median of 7 minutes), noting importantly this period coincides with a previously recorded seasonal decrease in detection rates. However, baseline data was available for only one winter for comparison and additional data collection in this time period is recommended. Significant between-year variability has been previously reported in this region (Porskamp et al. 2015), and despite extensive baseline data, incomplete annual coverage combined with some inconsistency in monitoring locations, there remains uncertainty in applying the past to interpreting the patterns observed in the 2016/2017 dataset. It is clear that longer than 73 days of post-turbine installation monitoring is required to determine if these lower detection rates persist into the following seasons. C-POD monitoring at five sites is currently ongoing.

4.2 Time of Year Variability

In addition to between year variability, we observed strong within year (Julian day) cycles that influenced the presence of porpoise in the study area (as previously reported in Wood et al. 2013, Porskamp et al. 2015). This result is consistent with studies in other locations that have shown as much as three-fold changes in harbor porpoise abundance across the year (e.g., Hall 2011). Long-term satellite-tag monitoring of harbor porpoises have shown large habitat ranges in this species (7,738-11,289 km^2; Johnston et al. 2005), but the size of monthly focal areas were typically far smaller (122-415 km^2). This suggests that the within year variability in porpoise detections is a result of seasonal movements to favoured habitat (Wood et al. 2013). In our study region, porpoise presence peaked during May and June coinciding with the movement of spawning herring into the area, and was lowest during the late summer, presumably during the summer movement of the harbor porpoise population out into the more open waters of the Bay of Fundy. There was a secondary peak in porpoise occurring in late October/November, followed by low levels through the remainder of the winter period. The turbine was installed during this secondary peak. Although we might expect timing of these peaks to vary annually, a consistency across previous monitoring periods suggests that local porpoise density declines naturally over this post-installation period of 7 November to 18 January, even without any disturbance in the area.

4.3 Lunar and Flood/Ebb Tidal Variability

The tides are an alternating pattern of rising and falling sea level whose amplitude is influenced by both the moon and the sun. When the sun lines up with the moon and the earth, as during a new moon or full moon, we observe spring tides, thus there are two spring tides for each lunar cycle. The lunar cycle has been associated with harbor porpoise numbers in the Salish Sea with statistically more harbor porpoise associated with new moons (Hall 2011). Porpoise detection rates in our study region were clearly affected by lunar-related tidal patterns. Porpoise detection rates were highest in the transition period between neaps and springs. This result has been observed in Scotland where harbor porpoise detections were dependent on the position in the spring-neap tide, with highest detections when approaching peak spring tides (Embling et al. 2010). In Minas Passage, peak tidal exchanges and high current velocities associated with spring tides have been linked to C-POD % time lost and lower detection performance of C-PODS (e.g., Tollit et al. 2011, Section 3.2.1.5 in Porskamp et al. 2015).

On a shorter scale, the daily tidal cycle has long been associated with harbor porpoise habitat selection, with tidal variables such as tidal state (ebb/flood), tidal speed and tide height having an important influence on both the distribution (Marubini et al., 2009), and behaviour (Calderan, 2003, Johnston et al. 2005) of harbor porpoises. These dynamic spatio-temporal patterns in porpoise presence in Minas Passage related to tidal variables were likely because prey are known to also respond to these variables (e.g. Embling et al. 2010, Benjamins et al. 2016) by changing their distribution in the water column and/or by inducing schooling behaviour that could make them more accessible to predators (Embling et al. 2013). Notably, over the second deployment, tidal speed was the most important covariate in predicting porpoise detection (note that the analysis period covers 118 days, and therefore the seasonality described in 'JulianDay' has less of an effect than in the models with longer time series, e.g. Porskamp et al. 2015). Overall, we found porpoise were more likely to be detected during the ebb tide compared to the flood tide, with most detections during moderate ebb tidal flows between 0 and -2.5 m/s. Thus, porpoise in the Minas Passage were detected at highest rates in the first few hours after tides had turned to ebb when water velocities were flowing at low to moderate speeds.

4.4 Diel Patterns

In addition to annual, seasonal, and tidal variability, there are smaller daily processes that affect porpoise detection. We similarly found that porpoise detections were highest during the night, as shown in previous studies (Porskamp et al. 2015). Elsewhere, harbor porpoises have been shown to change their vocalisation behaviour with time of day (Carlström 2005), and the observed nocturnal pattern in Minas Passage may be a consequence of changes in behaviour, animal orientation and vocalisation rates rather than a change in porpoise presence (Williamson et al. 2017).

Alternatively, strong increases in after-midnight feeding has been reported across the range of this species (e.g., Carlström 2005, Todd et al. 2009, Linnenschmidt et al. 2013, Mikkelsen et al. 2013 and Brandt et al. 2014). The harbor porpoise is a highly mobile and a wide-ranging species that can move up to 50 km per day based on satellite tracking data (e.g., Johnston et al. 2005). Porpoise in the Baltic Sea have been shown to adapt their foraging strategy to prey behaviour, with daily movement patterns in a certain area depending on temporal changes in food availability. In Scotland, daily cycles of porpoise detection changed according to substrate type and water depth (Williamson et al. 2017). For this study, there was no prey field data to match to porpoise movements. However, it is reasonable to suppose that changes in prey distribution and abundance linked to darkness may cause important prey aggregations for porpoise in Minas Passage or that darkness makes hunting easier as porpoise are less visible. Either way, the distribution of prey and the ease with which it can be captured at different locations likely help explain the diel patterns in porpoise detections.

4.5 Location and Turbine Effects

The C-POD deployments were aligned according to a gradient design, with mid-field monitoring at the turbine site ranging outward from 200 to 1,710 m, with distances based mainly on predictive noise modelling undertaken by Polagye et al. (2011). However, depth varies over the FORCE demonstration area, with a steep drop-off to the south of the FORCE demonstration area. As a result, there were differences in the C-POD deployment depths. The two West locations were selected to ensure coverage of shallow waters west of the turbine, and the South location was included to monitor the deeper water where certain prey may concentrate (Wood et al. 2013). Depth and slope has been shown to be significant predictors of harbor porpoise distributions (Watts and Gaskin, 1985; Read and Westgate, 1997, Raum-Suryan and Harvey 1998) with porpoises generally found in the deeper water of their range. In Minas Passage, we observed the fewest detections in the shallow waters adjacent to the turbine at sites D1 and East1, with higher detection rates at the deeper depths of West1, West2, and South2. D1 and East1 were located not only in the shallowest water but also closest to the turbine with detection rates at less than half that of the other deeper sites during the 2nd of the 2016/2017 deployments. These potential differences in porpoise distribution due to differences in depth highlight the importance of good experimental design with balance in locations and redundancy at distances from the turbine at different depths to ensure the effects of the turbine are not confounded with C-POD location or depth.

Few studies to date have focused on exposure to continuous low frequency noise sources such as that emitted by tidal turbines, but one of the key goals of this study was to determine if the presence of the single operating turbine could cause porpoises to be displaced or excluded from their preferred habitat. Harbor porpoise were detected at all monitoring stations both before and after the turbine installation, thus it is clear that harbor porpoises were not excluded post-installation from the mid-range area monitored in this study. However, in our statistical GEE-GLM model fit to the 118 days of the 2016/2017 2nd deployment, we found the turbine (installation period and operational period) was a significant (p-value = 0.01) factor in the detection of porpoises at three of the five monitored sites, with reductions in detection probability of 41-46%. These sites included the closest C-POD site to the turbine (East1, 210 m away), as well as West1 and West2 (1,140 and 1,710 m from the turbine respectively) The site at D1 was located south of the turbine at Berth D, but at similar depth and distance from the turbine as East1, yet showed a small increase in observed (raw) detection probability (Table 4) but a non-significant turbine effect in the GEE-GLM model (Table 6). South2 detected no change in detection rates pre and post turbine installation. Noise propagation effects may explain observed differences across sites. However, to put the magnitude of the turbine related turbine effects into context, this effect was the least important in predicting changes in porpoise detection rates in our GEE-GLM model, with its influence 12 times less than that of tidal speed, the most important covariate.

5. Conclusions and Recommendations

Harbor porpoise use of the study area varies on both long (seasonal peaks, lunar cycles) and short (nocturnal preference, state of tide) timescales, as well as spatially (preference for deeper water). C-POD performance also varies temporally and spatially, requiring sophisticated modeling techniques to assess residual effects, while also noting that temporal coverage across years is intermittent and limited in winter. On average, porpoise clicks are detected in the Minas Passage study area almost every day (98.5% of days) for 0 to 44 minutes (median 7 minutes). Porpoise were detected at all five C-POD monitoring stations both immediately before (100% of days, median 4 minutes) and after (97.3%, median 3 minutes) the single CSTV turbine was installed. Overall, there was clearly no porpoise exclusion of the mid-range study area post-installation of the turbine. However, a significant (41-46%) drop in porpoise presence was found at three of the five monitoring sites, including the site at East1, 210 m south from the turbine, as well as the two sites 1140 and 1,710 m to the west. Currently this analysis includes the two day period of installation (with associated vessel activity) as well as 71 days of turbine operation. Interestingly, the site at D1, a site located close to the turbine (230 m to the northwest) on the rock shelf on which the turbine was also installed, showed no significant effect in porpoise detections post-installation of the turbine. The deeper-water site at South2 also showed no significant reduction in porpoise detections. Noise propagation effects may explain observed differences across sites. It is important to bear in mind the very short post-installation period analyzed to date, resulting in the overarching conclusion that further C-POD data collection is required before robust conclusions can be drawn and preliminary GEE-GLM model findings of potential mid-range turbine effects substantiated. This additional EEMP data will allow for a better comparison with previous baseline data collected.

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