FORCE Echolocating Marine Mammal EEMP 2nd Year Monitoring Report

Prepared for FORCE

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2nd Year (2018) Monitoring Report

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Prepared by SMRU Consulting

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Executive Summary

Tidal inlets such as the FORCE demonstration site are dynamic regions that provide important habitat for harbour porpoise (*Phocoena phocoena*). Harbour porpoise use echolocation to hunt and communicate (Kastelein et al. 2002), and they are known to be susceptible to noise disturbance (Tougaard et al. 2009). Few studies to date have focused on exposure to continuous low frequency noise 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). C-PODs can detect echolocating cetacean species including dolphins, but not whales. Monitoring began on 5 May 2011 and is ongoing. This report encompasses monitoring up to May 1, 2018, and includes the 160 day Cape Sharp Tidal Venture (CSTV) turbine trial at Berth D of FORCE test site. The installation of the CSTV tidal turbine occurred on 7 November 2016. The cable connection to the turbine was disconnected on April 21, 2017 (during which time the turbine had the ability to free-spin) and the turbine Was removed June 15, 2017.

This report firstly summarizes the dynamic temporal patterns in porpoise presence in Minas Passage from 2011-2018 related to key environmental covariates, notably annual, seasonal, tidal and day versus night variability. It is important to note that temporal coverage was intermittent over this seven year period, with just two winter-early spring periods of baseline that overlapped with the CSTV turbine trial. We provide a statistical analysis of the distribution and activity of harbour porpoise around the FORCE demonstration area in response to the installation and operation of the turbine using data from 2 mid-range C-PODs (within 230 m), and three located at least 1 km away.

From May 2011 through to May 2018, there have been 1210 monitoring days and 4651 C-POD days, spread across eight locations within and immediately adjacent to the FORCE site. Overall, harbour porpoises have been detected on 98.9% of days at a median of seven detection positive minutes per day and maximum of 44 minutes. When the turbine was operating, porpoises were detected on 82% of days. No dolphins were detected during any of the C-POD deployments at any of the eight C-POD locations. C-PODs a reported to have an effective porpoise click detection range 188 m (Nuuttila et al. (2018), with decreased performance reported when ambient noise exceeds 105 dB re. 1 µPa (rms) and false alarm rates less than 2% (Clausen et al. 2018). Comparison of porpoise detection rates using C-PODs and post-deployment analysis of broadband recordings using alternate click detection software such as PAMGuard (Porskamp et al. 2015, Sarnocinska et al. 2016, Jacobsen et al. 2017) are subject to the effects of variable hydrophone sensitivities, issues with determining false classifications and variability in deployment methods. Nevertheless, these studies do highlight porpoise detection probabilities using buoy-mounted C-PODs should be considered minimum estimates.

A statistical model using data from the five C-PODS that overlapped in time with the CSTV turbine trial was built to test the effects of the turbine while accounting for the natural dynamics of the FORCE test

site. The model results confirmed an effect on porpoise presence at the closest two mid-field monitoring stations. Additionally, porpoise presence varied significantly by time of year (i.e., peak period May/June and lower secondary peak October/November), by current speed and tidal height (i.e., preference for 0-2.5 m/s ebb tides), by time of day (i.e., higher activity at night) and across the lunar cycle (i.e., affected by the position in the spring-neap tidal cycle). CPODs monitor underwater noise each minute, however, in each minute, the units will only 'listen' until a maximum buffer is reached (called the ClickMax buffer). If this buffer is reached then the remainder of the minute monitoring is lost (termed Percent Time Lost). C-POD performance restrictions (Percent 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. Percent Time Lost had little effect on data quality between an ebb current speed of <2.4 m/s (95% of 10-minute periods) and a flood current speed of <2 m/s (71% of 10-minute periods). At ebb current speeds up to 2.9 m/s (99% of 10-minute periods) and flood current speeds up to 3.5 m/s (95.5% of 10-minute periods), Percent Time Lost does not exceed 65%. Despite the use of statistical methods to take Percent Time Lost into account, C-POD monitoring performance above these current speeds is clearly less reliable, noting that these speeds only occur a very small fraction of the tidal cycle.

During the CSTV turbine trial, porpoises were detected at all five monitoring locations on 128 of the 130 days, and 106 of 129 days at D1, and 76 of 130 days at East1. Declines in daily porpoise presence with the operating turbine from similar time periods of baseline monitoring equated to ~35% for East1 and ~7% for D1. 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 (that accounted for the environmental variables and Percent Time Lost) tested for changes in the distribution and activity of harbour porpoise in relation to the installation and operation of the turbine. The overall effect of turbine operations on porpoise detection rates were found to be significant (P<0.01). East1, a site 210 m north of the turbine at 41 m depth, and D1, a site 230 m south of the turbine at 33 m depth both showed statistically fewer porpoise detections post installation of the turbine. Both these sites had overall lower activity levels both with and without the turbine, whereas the sites > 1 km west and south of the turbine had overall higher activity levels and showed no decrease in porpoise detections with the turbine. The obvious and immediate drop in detections observed during the previous analysis of the first 73 days post-installation at East1 as well as West1 and West2 are believed to represent disturbance from vessel activity and initial turbine installation, while subsequent dips observed after this period considered to reflect continued winter and also 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 short (166) post-installation period, result in the overall conclusion that further C-POD data collection is required before robust inferences can be drawn, but preliminary statistical results suggest a mid-range turbine effect within 230 m. Continued C-POD monitoring will allow for a better understanding of the variables that inform the environmental dynamics of the FORCE demonstration area.

Table of Contents

List of Figures

List of Tables

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-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

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: 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 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).

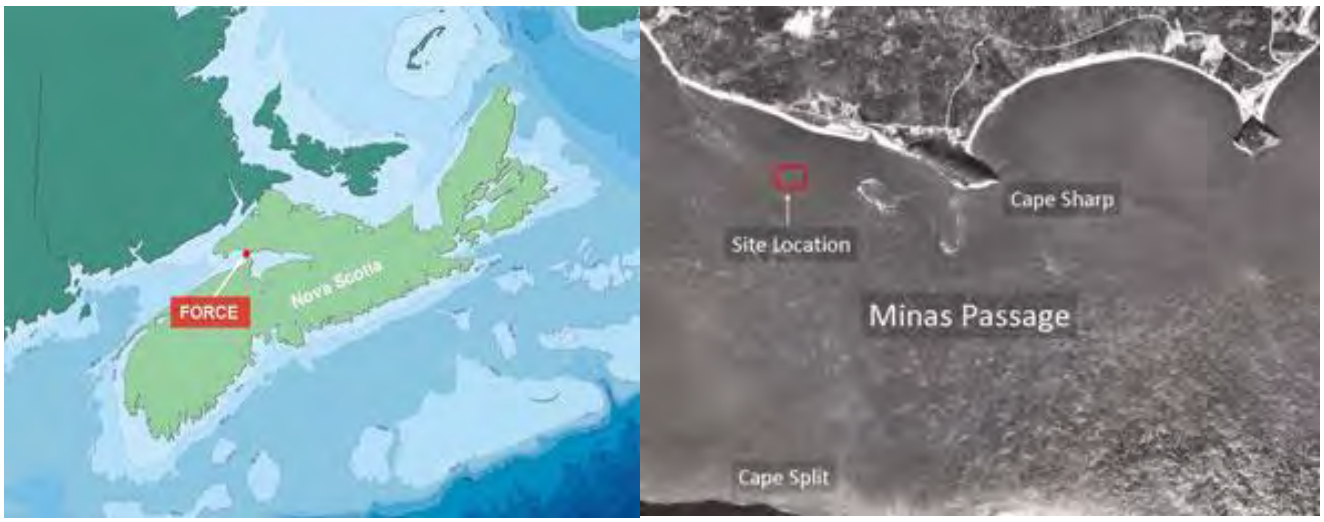

Figure 1. Regional location of FORCE test site (Left Panel) and the location of the test site in Minas Passage (Right Panel).

Harbour porpoise (*Phocoena phocoena*), the numerically dominant marine mammal species in Minas Passage, use high frequency echolocation clicks to hunt and communicate (Kastelein et al. 2002) and are known to be 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 harbour porpoise) at the FORCE tidal demonstration site in relation to operational in-stream turbines. This 2018 Marine Mammal EEMP Report describes the results of the second year 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 to provide a statistical analysis of porpoise activity and site use, including an assessment of turbine removal 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 harbour 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 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 seven 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 has since continued to collect C-POD marine mammal detection data at four of the seven 2011-2014 baseline sites, as well as the additional site adjacent to Berth D. Temporal coverage was intermittent over this baseline 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. Selected 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 locations close to the turbine berths as well as locations at increasing distances away from the turbine berths (i.e. a gradient design. A part of the wider FORCE EEMP, monitoring of distances nearer the turbine (<100m) were considered the responsibility of the berth holder.

On November 7, 2016, a single 2 MW Open Hydro turbine was installed at Berth D by Cape Sharp Tidal Venture (CSTV). It was recovered on June 15, 2017. Sporadic survey and recovery related vessel activity occurred from mid-April until recovery. The CSTV turbine was present until June 15, 2017, but only operational until April 21, 2017, after which the cable was disconnected, and the unit allowed to go into free-spin (when currents were strong enough). The year 1 EEMP monitoring began on June 7, 2016 and concluded on January 18, 2017, encompassing two C-POD deployment periods with monitoring periods of 84 and 118 days respectively (Joy et al. 2017). Harbour 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 study area post-installation. However, significant (41-46%) and immediate drops in porpoise detections observed at E1, W1 and W2 after turbine installation were noted and likely represent disturbance from turbine installation and vessel activity, with subsequent dips observed after this period reflecting continued lunar-scale fluctuations related to lower detection performance of C-PODs during all spring tides (higher % lost time), as well as seasonal decreases that are known to occur during winter. These observations coupled with high levels of inter-annual and site variability and the very short post-installation period so far analyzed, resulted in the conclusion that further C-POD data collection is required before inferences can be drawn and preliminary statistical results of mid-range turbine effects substantiated (Joy et al. 2017).

The Year 2 EEMP began February 8, 2017 and concluded on May 1, 2018, encompassing four deployments in time, each lasting 98, 104, 104 and 99 days. Since 2011, a total of 1210 days of C-POD monitoring has been completed. In this report, we firstly provide a summary of all data collected at all sites over all time periods (664,197 10-minute periods across 8 sites). Secondly, we focus on the five monitoring sites included in the FORCE EEMP (562,620 10-minute periods) and develop statistical models to investigate any avoidance or change in behavior linked to the turbine deployment while accounting for natural shifts in porpoise presence over time. We provide summary data across the 166-day period and then test to assess the effect of an operational turbine (November 7, 2016 to April 21, 2017).

2. Methods

2.1 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 23 February 2017 (period #1), 2 or 22 June 2017 (period #2), 9 September 2017 (period #3) and on 22 January 2018 (period #4). The deployments took place in a single tide over roughly 3 hours on the following day. Each cylindrical shaped C-POD is assembled into a "subs package" (approximately 1.21 m (4 ft.) long and approximately 40 cm (16") in diameter) 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 2).

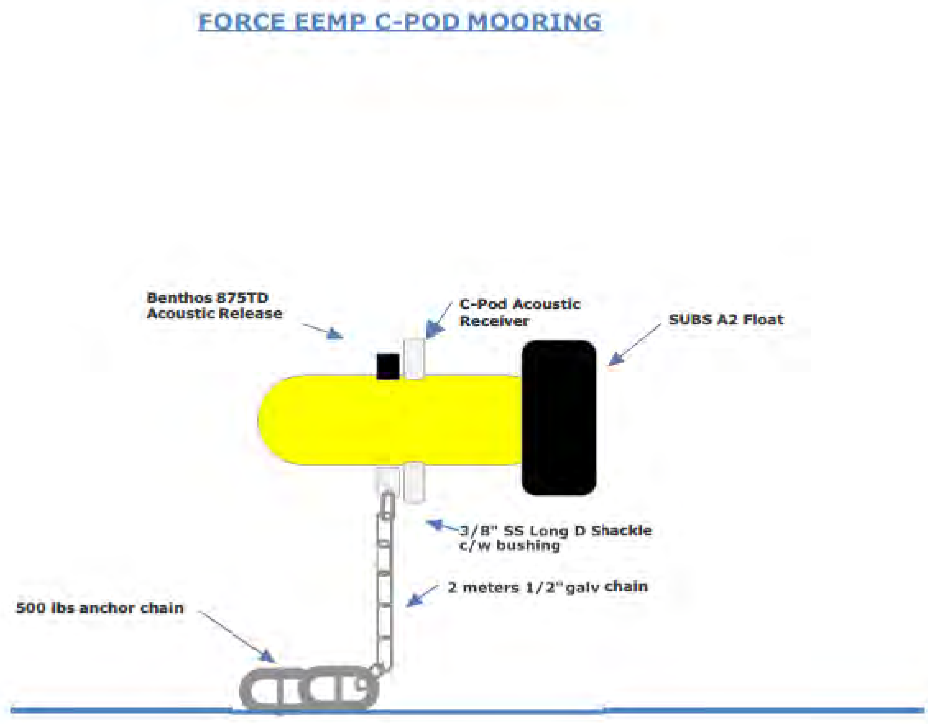

Figure 2. Diagram of FORCE C-POD mooring.

The approximate spatial location of EEMP C-PODs and CSTV turbine are depicted in Figure 3. Figure 4 provides an overview of the temporal and spatial coverage across all C-POD deployments and includes periods of turbine operation and free-spinning presence (denoted by pink cross and square hatch respectively). Further details of the 2017/2018 deployment locations and related information are provided in Table 7 in Appendix 1.

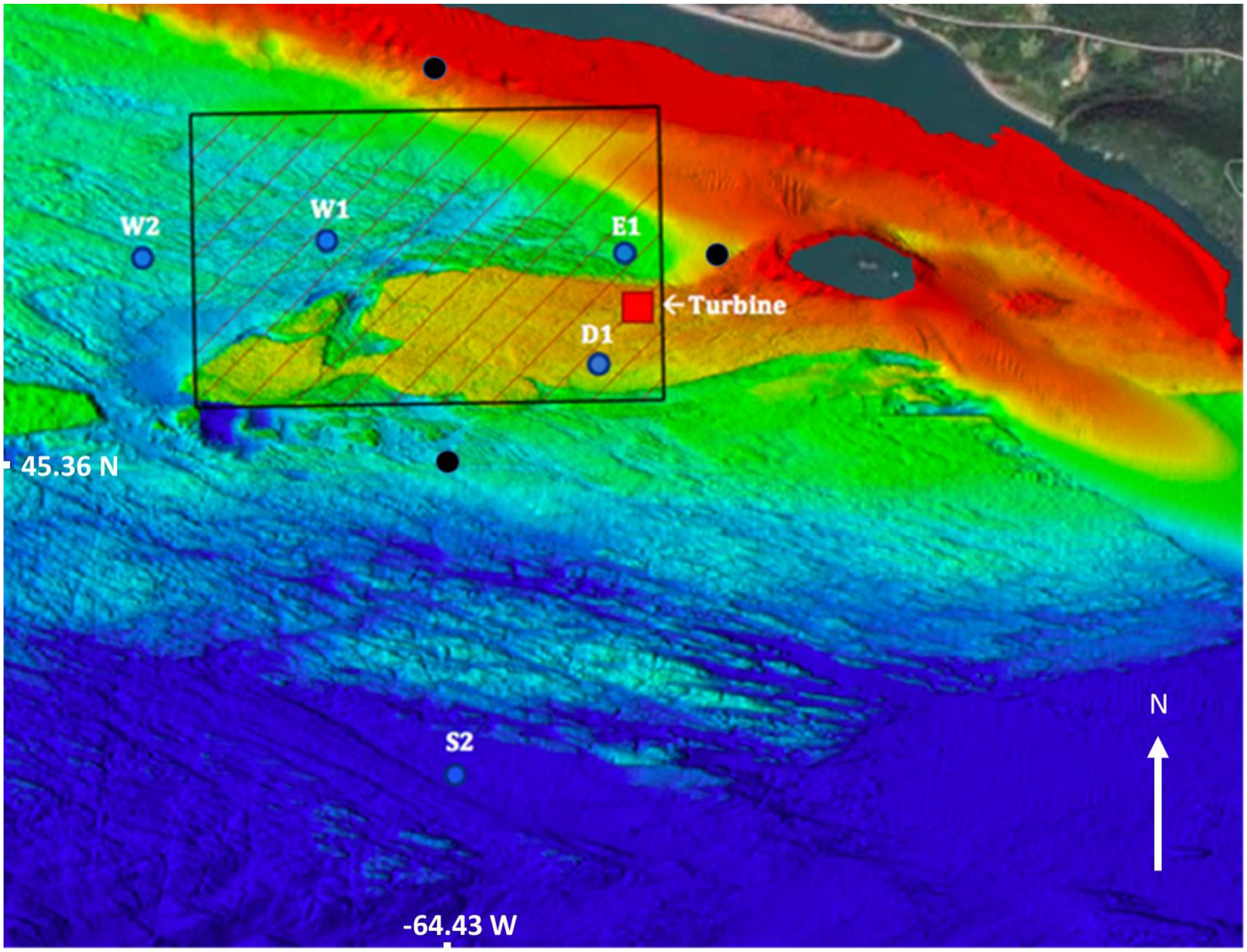

Figure 3. Locations of five long-term monitoring C-PODs (E1, D1, W1, W2, and S2), previously used C-POD locations (N1, E2, S1; black circles) and CSTV turbine installation location. The hatched box denotes the 1 x 1.6 km FORCE demonstration area. Shallow water is depicted by warmer colours.

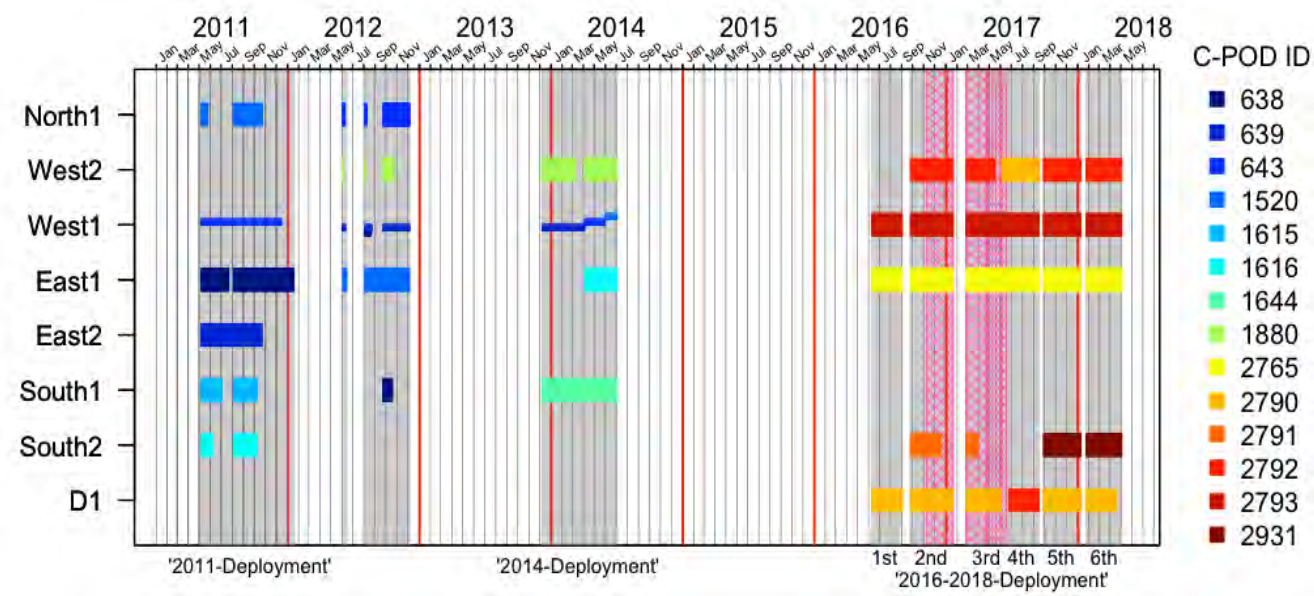

Figure 4. Entire C-POD deployment history at eight monitoring locations between 5 May 2011 and 1 May 2018. FORCE's EEMP (2016-2018) currently involves six deployment periods denoted by the labels on the bottom x-axis and five monitoring locations. The pink cross-hatch represent the presence of an operating turbine (termed 'turbine on'), while the pink square hatch represents turbine presence in free-spinning mode. The grey shading denotes when at least one C-POD was operating.

Site selection was based on the decision to continue monitoring the two core long-term baseline sites within the FORCE demonstration area (Sites West1 and East1, Figure 3). These sites represent the best baseline coverage for comparable C-POD studies undertaken 2011-2014 with 535 and 470 days of pre-turbine 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 3) – 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. 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 42-50 m in 2017/18, with D1 slightly further away (230 m) and shallower (32-39m). West1 was 1,090-1,140 m away at a depth of 47-55 m, West2 was 1,710 m away at a depth of 46-54 m and South2 was 1,690 m from the turbine and the deepest deployment at 70-80 m (Table 7). In other words, D1 and East1 are within the 100 – 1000 m mid field monitoring distance, whereas West1, West2 and South2 are all located outside at a distance >1000 m and <1700 m.

2.2. 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.

C-PODs were time synced when started and checked for clock drift after retrieval. Clock drift was estimated at less than 1 minute during these deployments. There was no evidence of data corruption in either of the 2017/2018 deployment periods, except data from 2791, 35 days after its deployment on 23 February 2018, resulting in up to 63 days of lost data. 2790 and 2792 were recovered by fishermen two weeks post recovery operations, while 2791 was not found until even later.

2.3 Statistical Analysis

The statistical analysis was limited to the five monitoring sites included in the FORCE EEMP, which covered 562,620 10-minute periods, across 1210 unique dates spread across every day of the 365-day (366 leap year) calendar. This data analysis includes data from 2011 through 2018, with the primary goal of assessing the influence of the 130-day tidal turbine deployment in porpoise habitat while controlling for natural environmental variability over time. It is important to bear in mind the current EEMP aims to assess turbine effects over multiple years, thus on-going objectives additional to the primary objective above as outlined in the 2015 SLR are to make a preliminary assessment of: 1) whether there was evidence of permanent avoidance by harbour porpoise of the mid field study area during turbine installation and operation, and 2) if large magnitude (~50%) changes were observed in the distribution (echolocation activity levels) of a portion of the porpoise population in the study mid field area.

Porpoise were generally detected for just a few minutes per day of monitoring, and often logged in consecutive minutes. The number of DPM within a 10-minute window was therefore not a measure of independent observations but instead consecutive time windows were autocorrelated. As well, the distributional form of the detections was zero-heavy with a right-skewed tail for consecutive detections. We have therefore 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, and chosen to report median and inter-quartile ranges (Zar 1999) of detection positive minutes (DPM) per day of C-POD detections. These are described in detail below. Data from C-PODs given known limitations should be considered minimum estimates of porpoise presence.

2.4.1 Logistic Regression with Correlated Time Series

We modelled the probability of porpoise occupancy within range of a C-POD detector using a GEE framework. We assumed a binomial distribution with a logit-link function for modelling the presence or absence of porpoise detections for each 10-minute period (i.e., BinDPM). The BinDPM data is continuously collected at each C-POD deployment location, and as such, this kind of time-series data is highly correlated across time. Therefore, the data required modeling methods that could accommodate this form of auto-correlation. Models with correlation structures built directly into them were considered; as well models with high-rank smoothers such as splines can help remove correlation across continuous covariates. Our approach included both of these techniques.

2.4.2 Fitting GEE Models with AR-1 Correlation Structure

We used a Generalized Estimating Equation within a Generalized Linear Model framework (GEE) 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[1] 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, 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 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 12, 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.

Using the full EEMP location dataset back to 2011, there were 562,620 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 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 non-linear

[1] 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).

relationships 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 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 focused significance testing on detecting differences in porpoise detections collected while the turbine was present and operational, and comparing this period to turbine absent and turbine present but stationary. This modeling approach removes confounding effects such as differences between locations, while accounting for natural (baseline) environmental variability, thus allowing the model to compare the 'population-averaged' effect of the turbine on porpoise presence with and without an operational turbine.

3. Results

3.1 Overall Porpoise Detection Rates (2011-2018)

Across all years of the Minas Passage C-POD monitoring study, there have been a total of 4,651 C-POD days across 1,210 calendar days, with a total of 664,197 10-minute periods (Tables 1 and 2). A total of 130 C-POD monitoring days were collected when the turbine was operational. Porpoise were detected on 98.9% of days across all pods combined, 86.5% of days by pod and detected for median 7 minutes per day (Tables 1 and 2). When the turbine was operating, porpoises were detected on 82% of days by pod and detected for median 3 minutes per day, noting that the turbine was operating only over winter and early spring (a period of lower baseline porpoise presence). Similar to previous C-POD deployments (e.g., Wood et al. 2013), there were no acoustic-operator confirmed dolphin detections during the 2017/2018 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).

Table 1. Definitions of deployment scenarios and associated summary of C-POD monitoring effort, turbine status, and EEMP details. The turbine operational period is highlighted in black (*), and the Year 2 EEMP deployments highlighted in italics (+).

Deployment Scenario and Turbine Status	**Deployment Dates**	**Number of Monitored Days**	**Number of Pod-Days (# Days x # C-Pods)**	**Num. 10-Min Intervals**
2011 Deployment: Absent	2011-05-05 - 2012-01-17	258	958	136446
2012 Deployment: Absent	2012-05-31 - 2012-12-03	137	391	56795
2014 Deployment: Absent	2013-12-06 - 2014-07-01	208	689	99108
2016 Deployment 1: Absent	2016-06-08 - 2016-08-30	84	252	35775
2016 Deployment 2: Absent	2016-09-23 - 2016-11-06	45	225	32065
***2016 Deployment 2: Operational**	**2016-11-07 - 2017-01-18**	**73**	**332**	**47403**
+*2017 Deployment 3: Operational	**2017-02-24 - 2017-04-21**	**57**	**262**	**37229**
+2017 Deployment 3: Free-spinning	*2017-04-22 - 2017-06-01*	41	146	20756
+2017 Deployment 4: Free-spinning	*2017-06-03 - 2017-06-15*	13	39	5382
+2017 Deployment 4: Absent	*2017-06-16 - 2017-09-14*	91	357	51009
+2017 Deployment 5: Absent	*2017-09-27 - 2018-01-08*	104	520	74135
+2018 Deployment 6: Absent	*2018-01-23 - 2018-05-18*	99	480	68094

* turbine operational
+ year 2 EEMP deployment

[Type here]

Table 2. FORCE site monitoring summary: Percent of monitoring days with and without porpoise (all pods combined), and for each location during each deployment scenario. Number of days in region without porpoise (all pods combined), and median number of minutes when present (Interquartile Range) for each deployment scenario. The turbine operational period is highlighted in black and the Year 2 EEMP deployments highlighted in italics.

Deployment Scenario and Turbine Status	% Days Porpoise Present	% Days Pods Detect Porpoise	Days Without Porpoise (Days Monitored)	Median (IQR) of Minutes if Present
2011 Deployment: Absent	99.2	83.2	2 (258)	7 (2, 17)
2012 Deployment: Absent	95.6	82.9	6 (137)	5 (1, 13)
2014 Deployment: Absent	99.0	87.5	2 (208)	9 (3, 16)
2016 Deployment 1: Absent	98.8	92.5	1 (84)	7 (3.75, 14)
2016 Deployment 2: Absent	100.0	76.4	0 (45)	4 (1, 10)
***2016 Deployment 2: Operational**	**97.3**	**73.8**	**2 (73)**	**3 (0, 7)**
+*2017 Deployment 3: Operational	***100.0***	***92.4***	***0 (57)***	***7 (3, 14.75)***
+2017 Deployment 3: Free-spinning	*100.0*	*95.2*	*0 (41)*	*7 (4, 12)*
+2017 Deployment 4: Free-spinning	*100.0*	*100*	*0 (13)*	*12 (7, 18.5)*
+2017 Deployment 4: Absent	*100.0*	*96.9*	*0 (91)*	*12 (6, 21)*
+2017 Deployment 5: Absent	*100.0*	*88.3*	*0 (104)*	*8 (2.75, 20)*
+2018 Deployment 6: Absent	*100.0*	*88.3*	*0 (99)*	*7 (2, 16)*
All Deployment data	98.9	86.5	13 (1210)	7 (2, 16)

* turbine operational

+ year 2 EEMP deployment

Harbour porpoise were present in Minas Passage on 100% of days (i.e., detected on at least one C-POD) during deployments 3,4,5 and 6 of EEMP Year 2 (Table 2). The percent of days porpoise are present and median minutes present are similar or higher than 2011-2016 baseline. Deployment 2 of EEMP Year 1 remains the period in which fewest porpoise days and minutes present were detected (Table 2).

Porpoises were detected at all sites, with highest rates of detection in the deeper water site at South2 and lowest at sites North1 and East2 (Figure 5). The Percent Time Lost on each C-POD also varied by site, with very high values notable at East2, a site close to Black Rock that was discontinued for this reason (Figure 6) and is a function of C-POD memory restrictions coupled with the amount of non-target (likely mobile seafloor sediment-related) clicks. This can result in lost recordings at the end of each minute and was consequently required as an explanatory factor within subsequent GEE models, with greater time lost associated with fewer detections of porpoises. Percent Time Lost was previously linked to periods of high tidal velocity (esp. spring tides) and model predictions are less accurate when high rates occur. Overall, however there is no evidence of permanent avoidance of the mid field study area by porpoise during turbine operations, nor while it was free-spinning, nor after turbine recovery (Tables 2 and 4, Figure 8). 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.

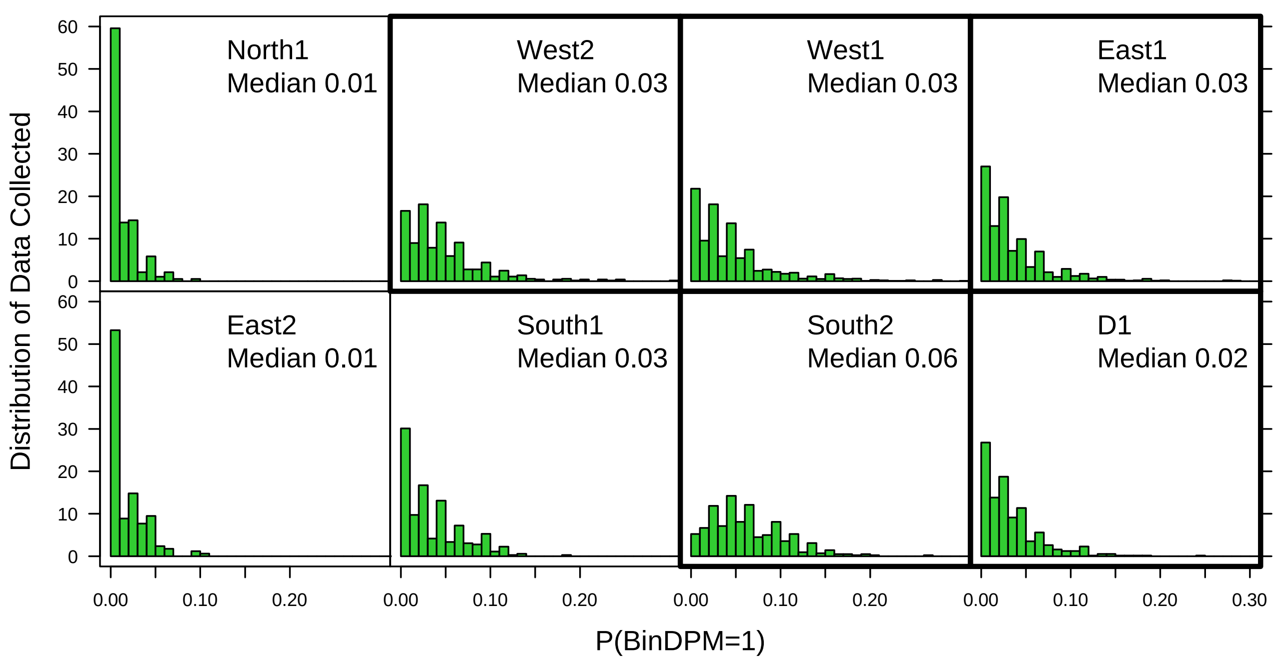

Figure 5. Distribution of the daily sums of porpoise detection positive minutes per day from all C-POD locations across all deployments (includes all eight locations 2011-2018). Statistical analysis was conducted using data from West2, West1, East1, South2, and D1 (shown as bold panel boxes).

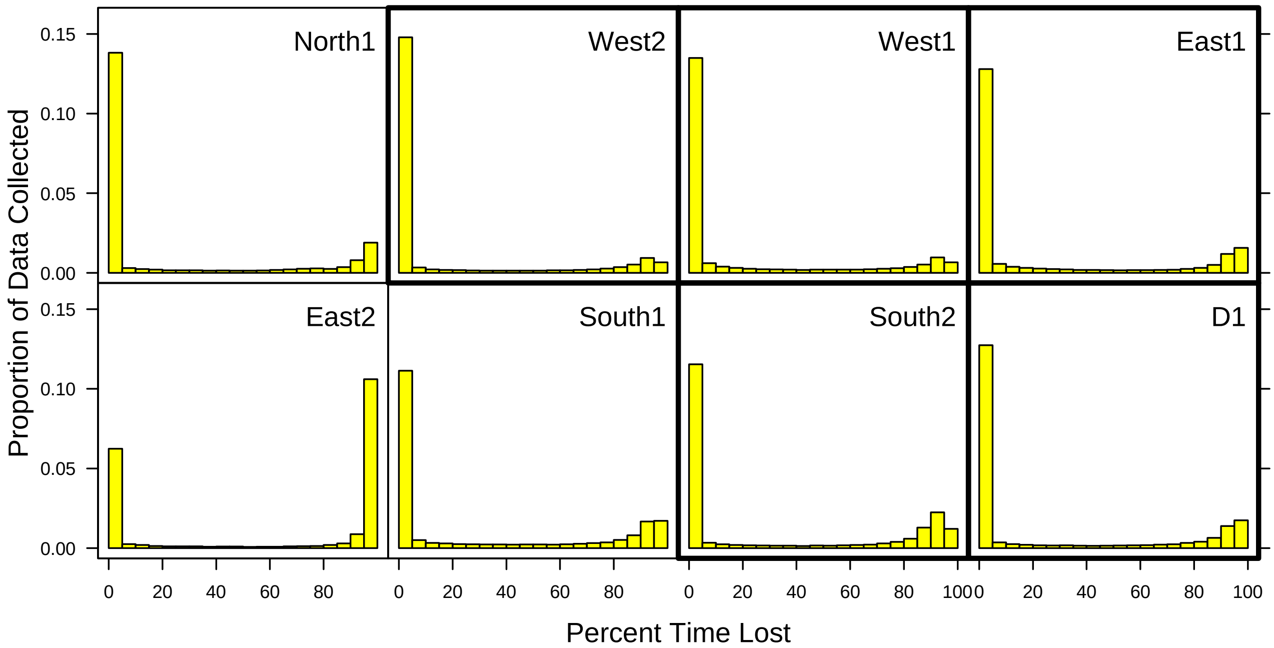

Figure 6. Distribution of Percent Time Lost data from all C-POD locations across all deployments (2011-2018). For comparing between sites, both the X- and Y- axes are standardized to have the same limits. Statistical analysis was conducted using data from West2, West1, East1, South2, and D1 (shown as bold panel boxes).

3.2 Porpoise Detection Rates at EEMP Sites (2011-2018)

The next section provides information relating only to the five EEMP C-POD monitoring sites. The mean percent probability [95% CI] of detecting a porpoise in a 10-minute Interval (P(BinDPM=1)) across all deployments was lowest at D1 (3.3 [3.18, 3.43], followed by East1 (3.54 [3.45, 3.64]), then West 1 (4.43 [4.33, 4.53]) and West2 (4.77 [4.64, 4.9]). Highest rates were observed at South2 (6.33 [6.14, 6.53]). The total sum of detection positive minutes per day at each EEMP monitoring site provided a similar picture (Figure 7). Across all EEMP monitoring sites the mean P(BinDPM=1) was 4%, with a median of 8 daily detection positive minutes. Median Percent Time Lost was 0.0%, but the mean Percent Time Lost of 22.3% (Figure 8), highlighting the left-handed skew of the data.

Figure 9 provides site-specific raw counts of porpoise detection minutes per day for all periods with turbine absent (No Turbine), turbine present but in free-spinning mode (Turbine free-spin), and turbine operational (Turbine on). Values are lowest at every site for Turbine On, most notable for East1, as well as D1 and West1. Again, caution is required in interpreting this raw detection data without accounting for confounding environmental variables, such as time of year, site variability and Percent Time Lost.

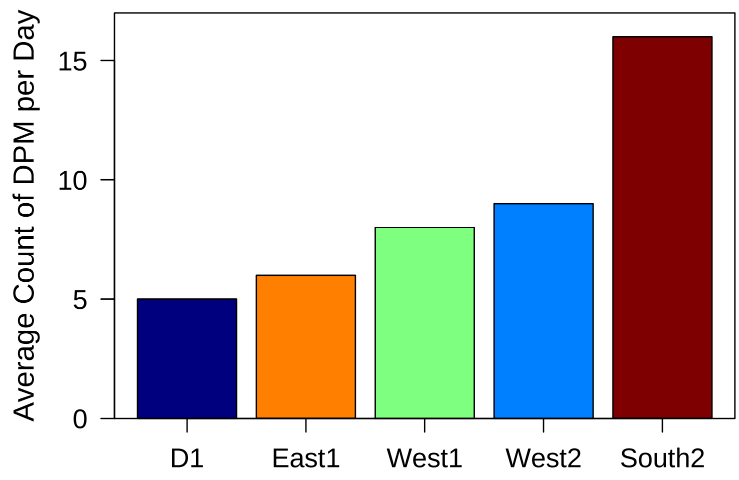

Figure 7. Average sum of detection positive minutes per day at each EEMP monitoring site (2011-2018). D1 and East1 are monitoring the mid-range adjacent to Berth D (210 and 230 m respectively), while West2, West1, South2 are all beyond the mid-field range (>1 km).

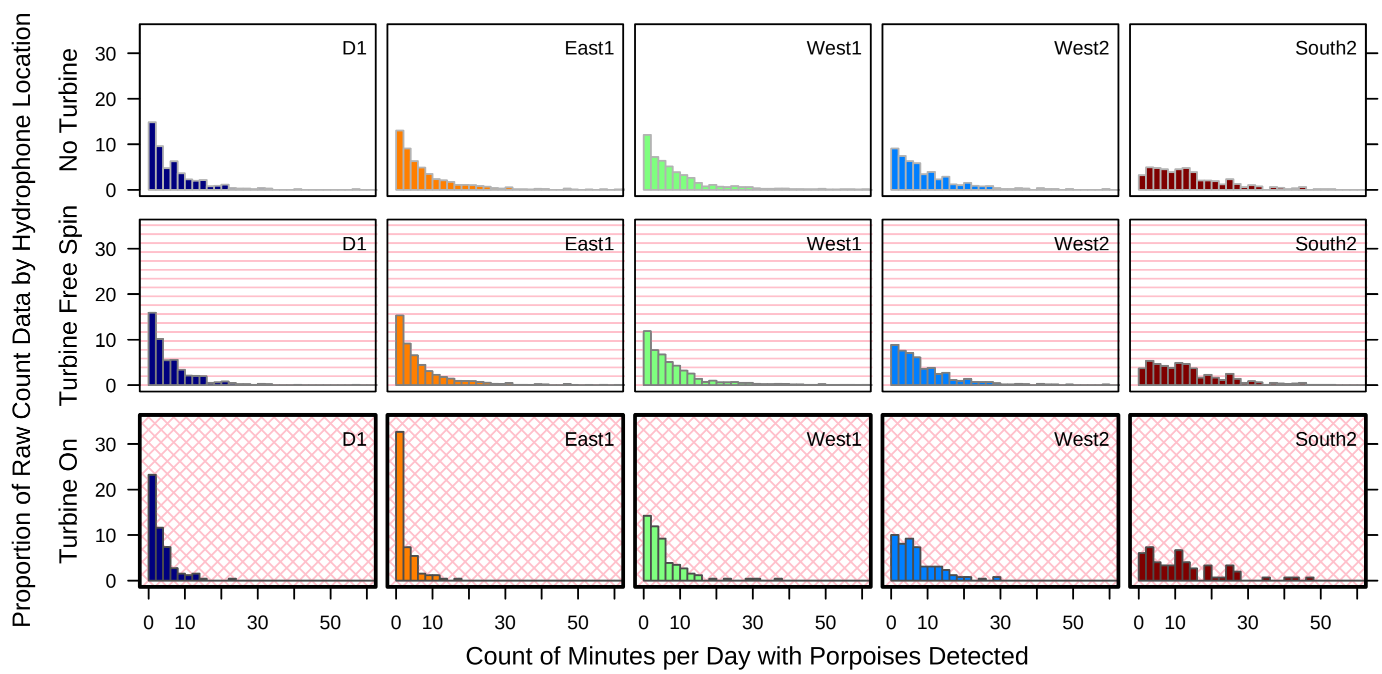

Figure 8. Site specific counts (median and Interquartile Range) of porpoise detection minutes per day for all periods with turbine absent (No Turbine), turbine operational (Turbine on) and turbine present but in free-spinning mode (Turbine Free Spin).

3.3. GEE Model results for EEMP Sites (2011-2018)

The primary analysis focuses on assessing the influence of the 166-day tidal turbine deployment in porpoise habitat while controlling for natural environmental variability over time. To this end, we compare changes at each of the five EEMP monitoring sites (2011-2018; Figure 9) to a range of the smoothed (b-splines) functions of environmental variability (Figure 10) both during and in the absence of turbine installation and operations. We additionally provide a preliminary assessment of: 1) whether there was evidence of permanent avoidance by harbour porpoise of the mid field study area (D1 and E1) during turbine installation and operation, and 2) if large magnitude (~50%) changes were observed in the distribution (echolocation activity levels) of a portion of the porpoise population in the study mid field area.

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, 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.

3.2.1.1. Annual Cycle over 365 Julian Day (Figure 10; Panel a)

The annual cycle has two peaks in porpoise detections, a late spring/early summer cycle that peaks around 30 June, and another lower peak in the fall around 6 November. November 6th is the day before the date that the turbine was deployed at the FORCE demonstration site in 2016. Prior to Year 2 EEMP data, the late spring cycle peak was May 30th.

3.2.1.2. Lunar Cycle and Spring Neap Tides (Figure 10; 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.

3.2.1.3. Diurnal Patterns (Figure 10; 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.

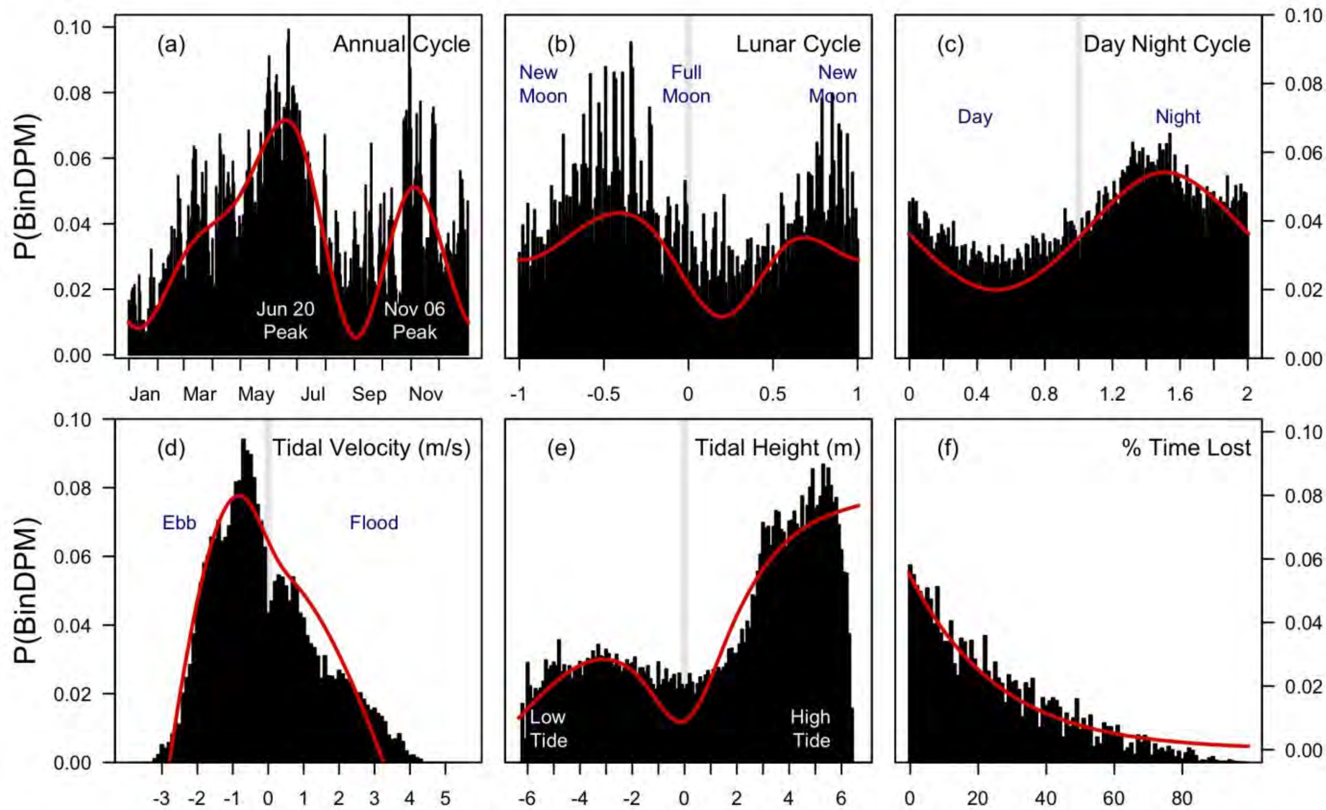

Figure 9. Shape of smoothing functions overlaid over the domain of a set of environmental variables. Black bars are P(BinDPM=1) frequency bars of raw data provided as a means to check the performance of the smoothing splines. Coloured lines are the cyclic (a, b, c) and non-cyclic (d, e) cubic regression 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 2011-2018 from 5 EEMP 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.

3.2.1.4. Tidal Current Speed and Tidal Height (Figure 10; 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 10; 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 as an explanatory variable. There is a simple linear relation on the logit scale between Percent 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 Percent Time Lost for each C-POD location are presented in Table 3 and Figure 10. Distribution of % Time Lost data from all C-POD locations across all deployments (2011-2018). For comparing between sites, both the X- and Y- axes are standardized to have the same limits.

Figure 11 provides a monitoring site summary (2011-2018) with observed mean probability of porpoise detection per time bin (PBinDPM) over time at 5 of the C-POD locations used in the analysis; West2, West1, East1, South2, and D1. The variability over short time intervals is readily seen in all years, with longer time-dependent processes observable over each of the years of data. The effect of the environmental variables is clearly complex with porpoise presence consistently low but also highly variable. Overall, these data do not support any indication of either permanent avoidance of the mid field study area during turbine installation and operation (Tables 2 and 4) nor large magnitude (~50%) change in the distribution of a portion of the population in the study mid-field area. A statistical analysis of this general impression was completed in the following section.

Table 4. Percent probability (95% C.I.'s) of porpoise presence at each location during the turbine deployment. These detection probabilities show that porpoise were detected at all locations during the deployment including D1 and East1 which are within 250 m of the turbine at Berth D. 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 **During** Turbine Deployment	Number of 10-Minute Intervals
D1	1.79 (1.63, 1.96)	24796

W2	3.93 (3.69, 4.18)	24942
W1	3.02 (2.81, 3.24)	24942
E1	1.15 (1.02, 1.29)	24942
S2	4.7 (4.39, 5.03)	17075

. The most time lost was observed at South2. 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. Appendix 2 describes additional analyses assessing influence of current speed on Percent Time Lost. Percent Time Lost had little effect on data quality between an ebb current speed of <2.4 m/s (95% of 10-minute periods) and a flood current speed of <2 m/s (71% of 10-minute periods). At ebb current speeds up to 2.9 m/s (99% of 10-minute periods) and flood current speeds up to 3.5 m/s (95.5% of 10-minute periods), Percent Time Lost does not exceed 65%, but quickly increases at higher speeds. The highlights the value of including Percent Time Lost in addition to other environmental variables to assess the potential effects of the turbine installation

Table 3. Proportion of Percent (%) Time Lost by C-POD location (averaged across time). At West 2, we observed the highest % of data with '0 Percent Time Lost', whereas at South we observed the least amount of observed '0 Percent Time Lost'. D1 had highest rank in Percent Time Lost greater than 95%.

Location Site	Time Lost=0 %	Time Lost>50 %	Time Lost>95 %
D1	61.37	27.40	8.74
West2	71.22	17.95	3.33
West1	64.01	19.54	3.32
East1	60.84	23.48	7.86
South2	55.28	33.84	6.07

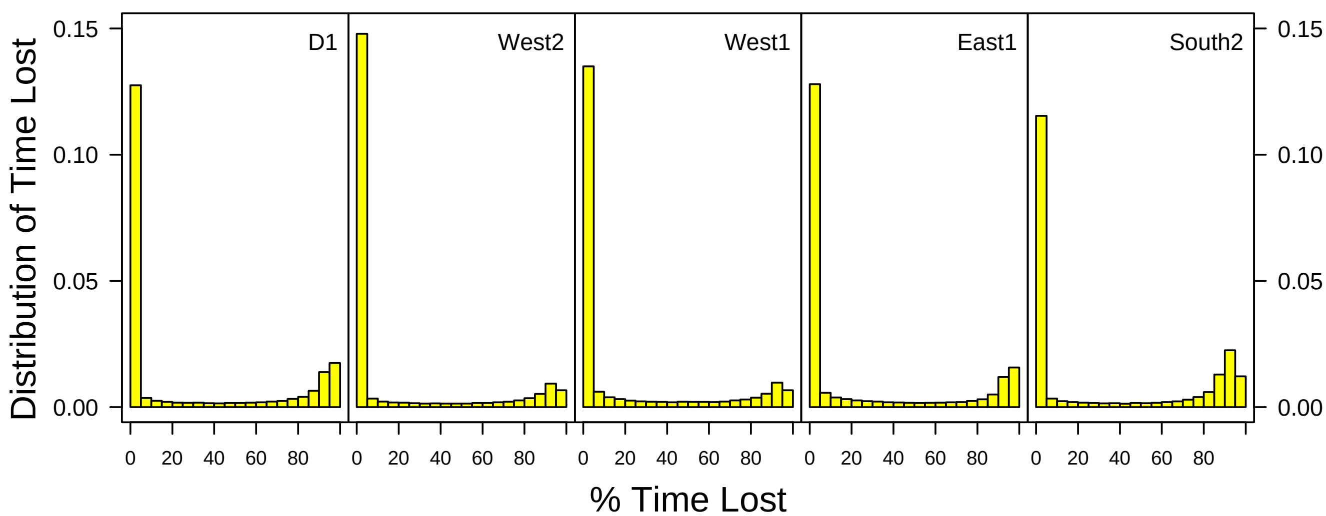

Figure 10. Distribution of % Time Lost data from all C-POD locations across all deployments (2011-

2018). For comparing between sites, both the X- and Y- axes are standardized to have the same limits.

Figure 11 provides a monitoring site summary (2011-2018) with observed mean probability of porpoise detection per time bin (PBinDPM) over time at 5 of the C-POD locations used in the analysis; West2, West1, East1, South2, and D1. The variability over short time intervals is readily seen in all years, with longer time-dependent processes observable over each of the years of data. The effect of the environmental variables is clearly complex with porpoise presence consistently low but also highly variable. Overall, these data do not support any indication of either permanent avoidance of the mid field study area during turbine installation and operation (Tables 2 and 4) nor large magnitude (~50%) change in the distribution of a portion of the population in the study mid-field area. A statistical analysis of this general impression was completed in the following section.

Table 4. Percent probability (95% C.I.'s) of porpoise presence at each location during the turbine deployment. These detection probabilities show that porpoise were detected at all locations during the deployment including D1 and East1 which are within 250 m of the turbine at Berth D. 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 **During** Turbine Deployment	Number of 10-Minute Intervals
D1	1.79 (1.63, 1.96)	24796
W2	3.93 (3.69, 4.18)	24942
W1	3.02 (2.81, 3.24)	24942
E1	1.15 (1.02, 1.29)	24942
S2	4.7 (4.39, 5.03)	17075

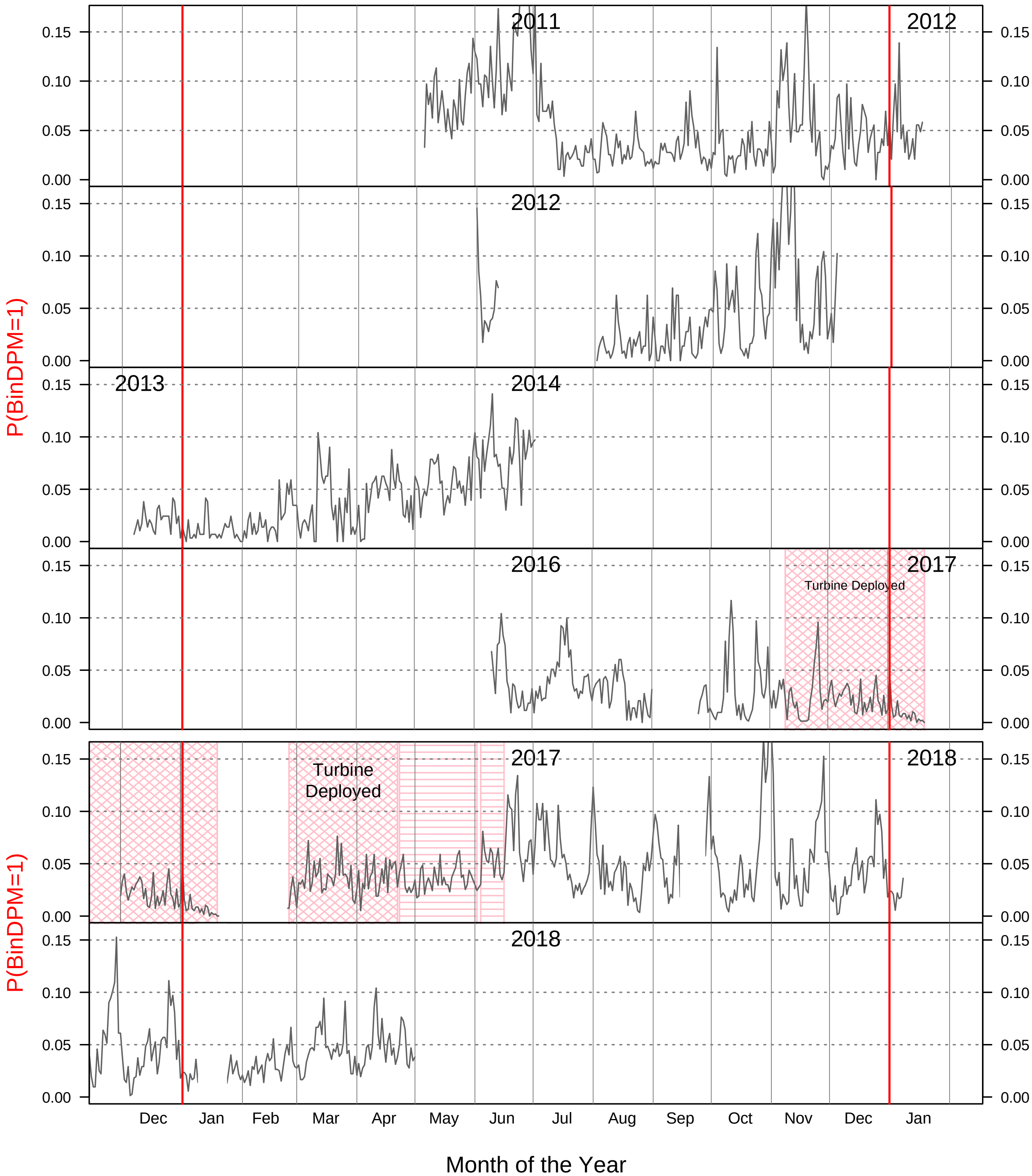

Figure 11. Long-term time series summary of porpoise presence at 5 key locations from 2011 to 2018. The pink cross-hatch (Nov 7, 2016 – April 21, 2017) represents the presence of an operating turbine while the pink square hatch (April 22 – June 15, 2017) represents turbine is present but in free-spin mode. The upper four panels represent C-POD data collected prior to Year 2 EEMP, while the lower two panels represent both years of EEMP monitoring. Note: there were no C-POD deployments in 2015.

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

A set of candidate binomial GEE models were fit to the hydrophone data collected at locations West2, West1, East1, South2, D1 for 130 days of the 166-day turbine operational period. This subset of locations was selected as they provided a dataset with active C-POD deployments during the `turbine-deployment' period: November 7, 2016 to April 21, 2017. This ensured the design was balanced across possible locations adjacent and non-adjacent to the turbine, and therefore optimized for comparing any immediate effects of the turbine deployment at local sites in the region while controlling for the sources of variability in porpoise detections related to the annual, daily and tidal cycles in the Bay of Fundy.

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. As well, the model included a linear term to control for the amount of time lost at the hydrophone due to internal memory buffer restrictions from excessive ambient noise (Percent Time Lost). C-POD location was treated as a categorical variable, and the model coded 'D1' as the reference group (and 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 and 6).

Model predictions from the GEE selected are compared to the patterns in the observed data throughout the study period, for each of the 5 C-POD locations (Figure 12), and in finer detail for the turbine deployment period (Figure 13). The main feature of Figure 13 is the variability in the detection probabilities over both short and long time frames. Secondly, the figure also shows an initial decline following a recovery during the turbine operational phase.

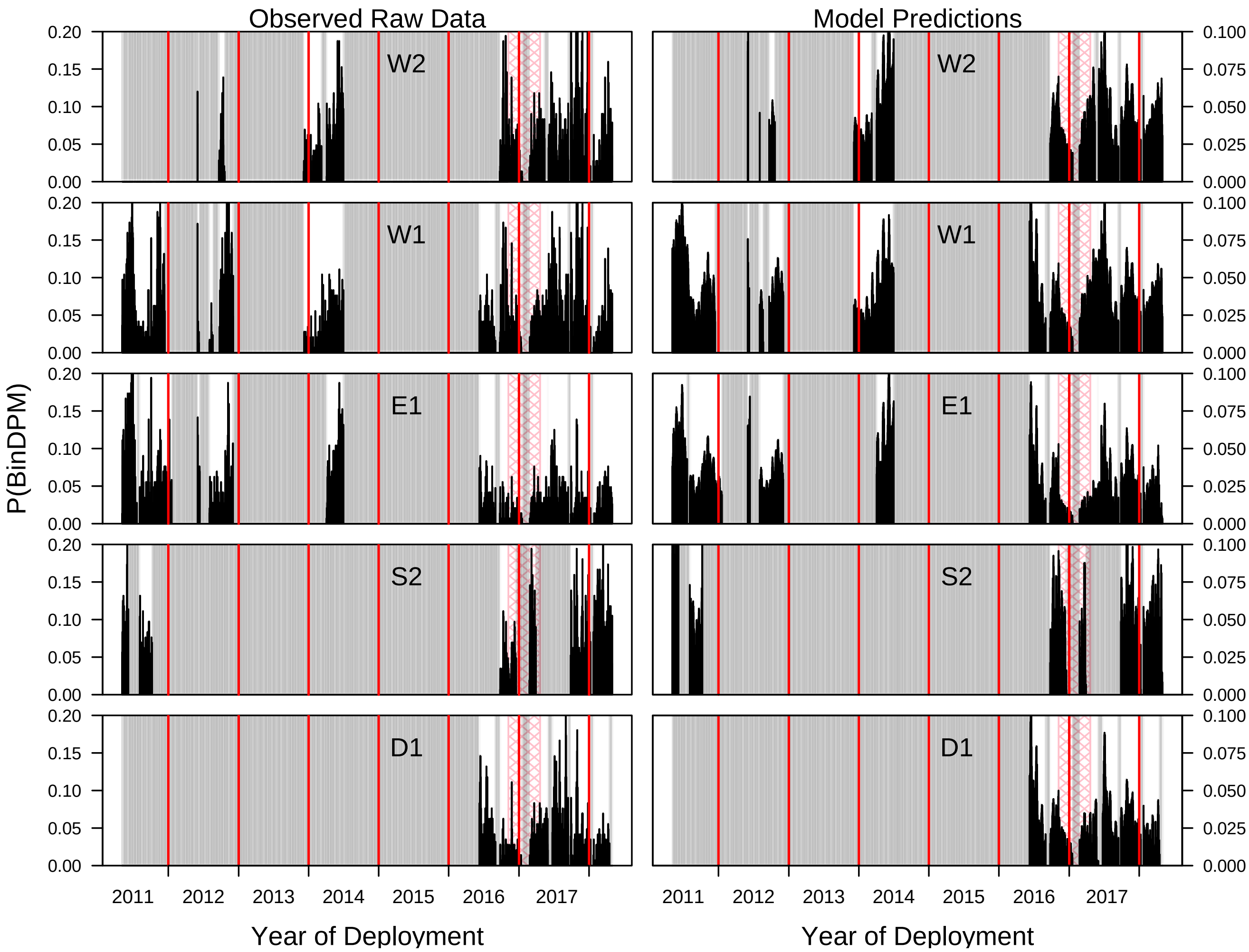

Figure 12. Site summary EEMP C-POD data (2011-2018). Observed raw data BinDPM per day (left panels) are compared against GEE model predictions of the overall mean probability of porpoise detection per time bin (PBinDPM) over time (right panel). There were statistically fewer porpoise at E1 (East1) and D1 during the turbine deployment, compared to no-turbine periods between 2011 and 2018. The pink cross-hatch represents the presence of an operating turbine while the pink square hatch represents turbine is present but in free-spin mode. Plots are grey when no C-PODs were collecting data at the location.

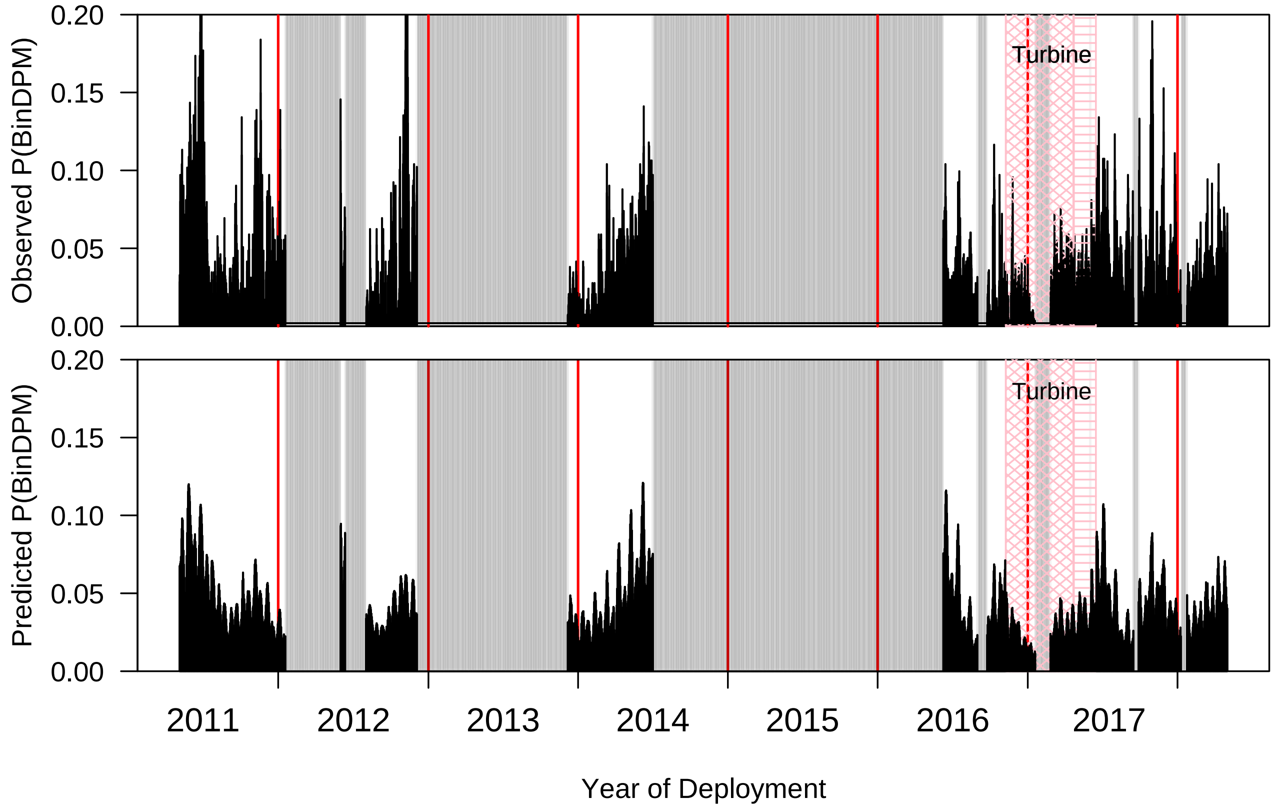

Figure 13. Overall summary EEMP C-POD data (2011-2018). Observed raw data BinDPM per day (top panel) is compared against GEE model predictions of the overall mean probability of porpoise detection per time bin (PBinDPM) over time (bottom). The pink cross-hatch represent the presence of an operating turbine. The pink cross-hatch represents the presence of an operating turbine while the pink square hatch represents turbine is present but in free-spin mode.

Results of the overall test that all locations have coefficients of zero, and that all locations are unaffected by the turbine presence are presented in the following table (Table 5). The significant interaction between location and turbine in (Table 5), indicates that turbine effects were not equal across all locations.

Table 5. Statistical summary of GEE Model results reporting overall effect of Location and Turbine, and the interaction of these factors on porpoise detection rates. All main effects as well as the interaction term are significant, indicating the operational turbine has some effect at one or more of the C-POD listening locations.

Variable	Degrees of Freedom	Chi square	P-value
Location	4	403.12	<0.01
Turbine	1	209.23	<0.01
Location:Turbine	4	77.46	<0.01

In Table 6 we present the locations-by-turbine regression coefficients for each C-POD location with Chi-square tests, and p-values to indicate significance. The model 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). We then compare the conditional (modeled) mean of D1 to all other locations before and after the turbine is deployed (Table 6), and determine which locations are driving model significance. The model predicts, 1) no effect of the turbine at West1 (p-value = 0.98) or West2 (p-value = 0.51), 2) a significant negative effect at East1 and D1 (p-values < 0.01), and 3) a significant positive effect at South2 (p-value < 0.01). Therefore, the lower porpoise detections at locations East1, and D1, and higher rates of detections at South2 account for the significant interactions term in Table 5.

Table 6. Statistical results of GEE regression coefficient 'Estimates' comparing turbine effects at each of the 5 hydrophone locations for the 2016/2017 turbine deployment. Significance at α <0.01 is denoted by '**'. The model predicts, 1) no effect of the turbine at West1 (p-value = 0.98) or West2 (p-value = 0.51), 2) a significant negative effect at East1 and D1 (p-values < 0.01), and 3) a significant positive effect at South2 (p-value < 0.01).

Model Term	Estimate	Standard Error	Wald Chi-square	P-value
D1	-3.13	0.02	-130.86	<0.01**
East1	-0.05	0.03	-1.68	0.09
West1	0.07	0.03	2.61	<0.01**
West2	0.21	0.03	7.37	<0.01**
South2	0.75	0.03	24.76	<0.01**
D1:Turbine	-0.44	0.05	-8.89	<0.01**
East1:Turbine	-0.61	0.07	-8.41	<0.01**
West1:Turbine	0	0.06	0.03	0.98
West2:Turbine	0.04	0.06	0.66	0.51
South2:Turbine	0.3	0.07	4.42	<0.01**

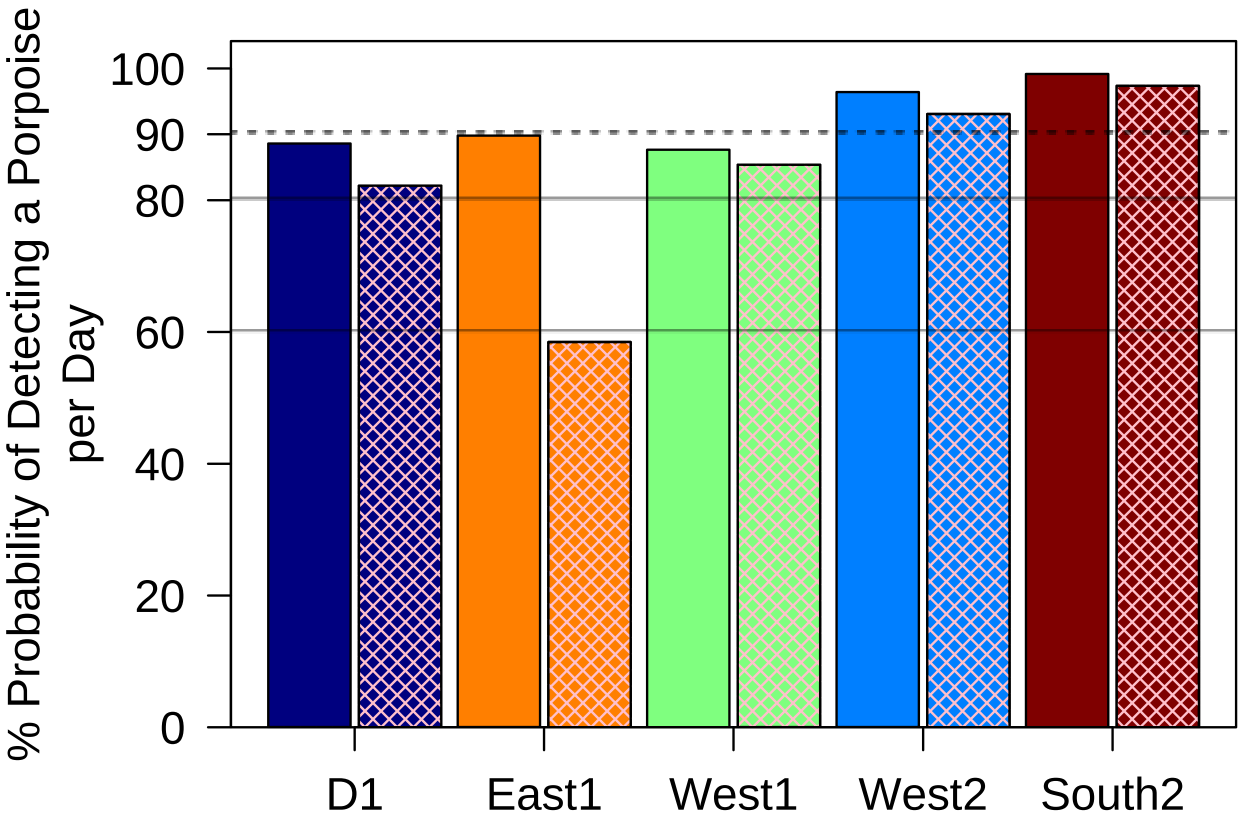

Figure 14 Probability of Detecting a Porpoise per Day at each of 5 C-POD locations. Bars with pink hatching correspond to dates the turbine was operational (130 days, Nov 7, 2016 – Apr 21, 2017). Bars without hatching represent the same days of the year, but for 'baseline years' (no CSTV turbine; 318 days matched between Nov 7 and Apr 21).

Finally, we compared the probability of detecting a harbour porpoise during the 130 days we monitored of the 166-day turbine operation trial to the same Julian Days but for two baseline years when the turbine was absent (Figure 14). This is a cruder approach than the modeling approach, as it just takes into account time of year, but doesn't account for differences in tidal conditions, or other variables that were significant sources of variability in our data. Results were similar, with D1 and East1 having the biggest decline in detectability with the turbine present (particularly seen at East1). The measure at South2 is opposite to the model result which predicted an increase with turbine, this is because "per Day" is a very course measure of detectability compared to "per 10-minute" time window. Overall, this crude calculation provides an alternate way of summarizing the data, and supports the model conclusion of a negative porpoise response at the mid-field sites, D1 and East1.

The relative importance of the predictive value of the covariates was assessed within the model, and the 'Annual Cycle over 365 Julian Days' was the most important covariate, and motivated the data summary seen in Figure 14. This was followed by tidal speed, time lost, time of day, location, presence of turbine, and lastly influence of the lunar cycle. Day of the year was 2.1 fold more important in predicting porpoise detection than the C-POD location, and 5.7 fold more important than turbine presence.

In summary, the data highlights that porpoise were not excluded by turbine installation and operations over the mid-field study area. East1 and D1 had significantly fewer detections than West1, West2, and South2 either both with and without the turbine present. There was a significant decrease in porpoise activity at the two sites closest to Berth D of the five C-POD monitoring sites. These decreases were all less than a 50% reduction and occurred at ranges of 200 – 230 m from the turbine. Two sites that were more than a kilometre away sites did not show a significant turbine effect (West1 and West2), while a third site at 1690 m distant, and in deeper water to the South increased in porpoise activity.

4. Discussion

Harbour porpoise use echolocation to hunt and communicate (Kastelein et al. 2002), and they are known to be 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 harbour porpoise echolocation clicks occurred for 732 calendar days spread across four years between May 5, 2011 and November 6, 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 November 7, 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 166 days of turbine operation and C-POD monitoring.

The main objectives of FORCE’s marine mammal EEMP are to assess long-term effects of direct and indirect stressors on harbour porpoise by monitoring their activity and spatial use around Berth D and other tidal turbine berth deployments. We detected harbour porpoise in the Minas Passage study area on 98.9% of days. However, porpoise use and movement into and around the study area varies over both long (seasonal peaks, lunar cycles) and short (nocturnal preference, tide state) timescales. Porpoise detections also varies temporally and spatially, requiring sophisticated modeling techniques to assess residual effects. 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 tidal 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 monitoring performance (Percent Time Lost) also varied spatially and temporally, associated with excessive non-biological clicks and potentially mooring performance and was notably poor during very high (e.g., spring tide) tidal speeds (Appendix 2). Percent Time Lost had little effect on data quality between an ebb current speed of <2.4 m/s (95% of 10-minute periods) and a flood current speed of <2 m/s (71% of 10-minute periods). At ebb current speeds up to 2.9 m/s (99% of 10-minute periods) and flood current speeds up to 3.5 m/s (95.5% of 10-minute periods), Percent Time Lost does not exceed 65%. The effects of these covariates were controlled for within the GEE modelling frame. Despite the use of statistical methods to take Percent Time Lost into account, C-POD monitoring performance above these current speeds is clearly less reliable, noting that these speeds only occur a very small fraction of the tidal cycle.

C-PODs a reported to have an effective porpoise click detection range 188 m (Nuuttila et al. (2018), with decreased performance reported when ambient noise exceeds 105 dB re. 1 µPa (rms) and false alarm rates less than 2% (Clausen et al. 2018). Comparison of porpoise detection rates using C-PODs and post-deployment analysis of broadband recordings using alternate click detection software such as PAMGuard (Porskamp et al. 2015, Sarnocinska et al. 2016, Jacobsen et al. 2017) are subject to the effects of variable hydrophone sensitivities, issues with determining false classifications and variability in deployment methods. Nevertheless, these studies do highlight porpoise detection probabilities using buoy-mounted C-PODs should be considered minimum estimates.

4.1 Annual Variability

Porpoise were detected on ~99% of days across all monitoring deployments, but across pods and detection minutes per day interannual variability was more apparent (Table 2). During the turbine trial in 2016/2017 there were two C-POD monitoring periods, the first of which recorded porpoises for fewer minutes per day in the region than in previous years, but there was a general recovery observed for the second monitoring period for all but the two closest C-POD locations. It is worth noting that the trial period coincided with a previously recorded seasonal (winter) decrease in detection rates. Baseline data were available at these 5 C-POD locations for the two winter seasons 2013/2014 and 2017/2018. These were used to compare with the 2016/2017 turbine operational trial. There are inconsistencies in effort across time and location since monitoring began in 2011, but overall baseline effort is considered good. It should be acknowledged that there are notable between year differences (Wood et al. 2013, Porskamp et al. 2015) and the patterns observed in the 2016/2017 dataset should be viewed within this context.

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 harbour porpoise abundance across the year (e.g., Hall 2011). Long-term satellite-tag monitoring of harbour 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), and in response to the timing of herring runs, and the location of those pulses of prey.

In our study region, porpoise presence peaked during late 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 harbour 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 November 7, during this secondary peak, and operated through the late January trough into the start of the rebound back to peak levels (the turbine was disconnected on April 21, 2017). Although we expect timing of these peaks to vary annually, a consistency across previous monitoring periods suggests that local porpoise density declines naturally over the first post-installation monitoring period of 7 November to 18 January, even without any disturbance in the area. We would likewise expect an increase in porpoise detections during the second post-installation monitoring period, which we did observe in our data (Figure 13). If the peak is shifted later in time in this year due to natural annual variability in porpoise movements, then there is a potential confounding of the turbine effect with this movement. Our results suggest that all but East1 and D2 locations recovered from the declines reported in the EEMP Year 1 assessment (Joy et al. 2018). However, there remains some uncertainty in applying the past to interpreting the patterns observed in the 2016/2017 dataset.

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 harbour porpoise numbers in the Salish Sea with statistically more harbour 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 harbour 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 Percent 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, Appendix 2).

On a shorter scale, the daily tidal cycle has long been associated with harbour 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 harbour 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). Overall, we found porpoise were more likely to be detected during high tides and during the ebb tide compared, 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, harbour 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 harbour 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 m (East1) to 1,710 m (West2), 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 harbour porpoise distributions (Watts and Gaskin, 1985; Read and Westgate, 1997, Raum-Suryan and Harvey 1998, Benjamins et al., 2017) with porpoises generally preferring nearshore habitat in moderate (>50 m) water depths (e.g., Embling et al., 2010; Isojunno et al., 2012; Booth et al., 2013). In Minas Passage, we observed the fewest detections in the shallow waters adjacent to the turbine at sites D1 and East1 both <40 m depth, 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 even without the turbine in place. 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 of harbour porpoise 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. Polagye et al. (2018) found harbour porpoise to negatively respond to the presence of a boat playing low frequency turbine sounds, but the boat was absent during the control periods, thus there was a confounding of boat with playback signal. Harbour seals in dynamic tidal channels have shown avoidance behaviour at 400 m from a tidal turbine (Joy et al., 2018) and avoidance out to 500 m to low frequency playbacks (Hastie et al. 2018). In our study, harbour porpoise were detected at all monitoring stations both before and after the turbine installation, thus it is clear that harbour porpoises were not excluded post-installation from the mid-range area monitored in this study. However, in our statistical model, we found the turbine (installation period and operational period) was a significant factor (p-value = 0.01) in the detection of porpoises at three of the five monitored sites. At D1 and East1, the two locations within 230 m, had a negative effect on porpoise presence, and at South2 a much deeper site at 1690 m the turbine effect was positive.

This Year 2 EEMP analysis includes an additional 57 days of C-POD monitoring of the turbine operational phase over the previous 73 days reported in the Year 1 EEMP report (Joy et al. 2017). In Joy et al. (2017), it was previously reported that porpoise detections decreased at East1, West1, West2 during the initial 73 days post installation, but showed a weak but non-significant increase at D1. By using both post-installation C-POD monitoring periods and this longer data time series of 130 days, the negative general detection pattern at West1 and West2 was no longer detected. We can either assume these sites recovered from any turbine installation effect, or the initial decline should be attributed instead to only natural stochasticity of porpoise movement in and around the Bay of Fundy. The decrease in porpoise detections at East1 persisted, as well as a statistically important decline at D1. Given that harbour seals have shown avoidance behaviour to both playback noise (Hastie et al. 2018), and to operational turbines (Joy et al. 2018), and as harbour porpoise rely on detecting echoes of high-frequency clicks bouncing off prey at close range, it is certainly possible that porpoise are showing a preference to foraging farther from the noise of the turbine. Since the turbine trial occurred during the winter season when detection rates are typically low, any results remain preliminary in nature. Without additional observations, it remains difficult to know if porpoises are responding to noise levels, reduced prey fields around the turbine or reduced ability to hunt. Passive acoustic monitoring can not determine absolutely whether an absence of clicks is due to an absence of animals or that animals have stopped vocalizing, however tags placed on porpoises have shown that they echolocate almost continuously.

5. Conclusions and Recommendations

Harbour 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 the seven years is intermittent and limited in winter (though now up to two years of baseline). On average, porpoise clicks are detected in the Minas Passage study area almost every day (98.9% of days) for 0 to 44 minutes (median 7 minutes). Porpoise were detected at all five C-POD monitoring stations both immediately before and after (82% of days) the single CSTV turbine was installed. Overall, there was no porpoise exclusion of the mid-range study area post-installation of the turbine. However, a significant drop in porpoise presence was found at the two closest of the five monitoring sites, notably at East1 at 210 m south from the turbine, and also D1 at 230 m northwest. This analysis covers a total of 130 days of turbine operation and includes the two-day period of installation (with associated vessel activity). These two shallow water sites also have the lowest rate of porpoise detections due presumably to unattractive habitat, even without a turbine present. The deeper-water site at South2 showed a significant increase in porpoise detections. Noise propagation effects may explain observed differences across sites. It is important to bear in mind that this analysis and these results represents a short post-installation period and despite the significant baseline effort to characterize these dynamics observed at the FORCE site, there remains uncertainty in overinterpretation of these data. Therefore, the overarching conclusion is that further C-POD data collection is required during turbine operation before robust conclusions can be drawn, and these preliminary model findings of potential mid-range turbine effects can be substantiated.

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Appendix 1.

Table 7. Deployment and retrieval information of C-PODs in Minas Passage across Year 2 EEMP deployments. Depths are standardised to tidal height at deployment. Times are in UTC.

Deployment number	Location	C-POD ID	Depth (m)	Latitude (ºN)	Longitude (ºW)	Deployment date and time	Retrieval date and time
3	D1	2790	34	45.36268	-64.4234	2017-2-23 19:32	2017-06-15
3	E1	2765	44	45.3661	-64.4222	2017-2-23 19:25	2017-06-01 15:23
3	W1	2793	50	45.36653	-64.4352	2017-2-23 19:05	2017-06-01 14:11
3	W2	2792	49	45.36595	-64.4432	2017-2-23 18:58	2017-06-15
3	S2	2791	73	45.35013	-64.4293	2017-2-23 18:43	2017-03-29
4	D1	2792	35	45.36272	-64.42327	2017-06-02 06:05	2017-09-14 17:01
4	E1	2765	45	45.36612	-64.42212	2017-06-02 16:10	2017-09-14 15:29
4	W1	2793	50	45.36655	-64.43523	2017-06-02 15:13	2017-09-14 15:14
4	W2	2790	47	45.36602	-64.42657	2017-06-22 19:38	2017-09-14 16:43
4	S2	-	-	-	-	Not deployed	Not deployed
5	D1	2790	32	45.36278	-64.42352	2017-09-26 14:18	2018-01-08 14:44
5	E1	2765	42	45.36607	-64.42197	2017-09-26 14:14	2018-01-08 14:34
5	W1	2793	47	45.36653	-64.43518	2017-09-26 13:40	2018-01-08 14:52
5	W2	2792	46	45.36602	-64.44308	2017-09-26 13:46	2018-01-08 14:59
5	S2	2931	70	45.35017	-64.42945	2017-09-26 14:03	2018-01-08 15:17
6	D1	2790	39	45.36293	-64.42372	2018-01-22 21:02	2018-05-01 0:48
6	E1	2765	50	45.36627	-64.42230	2018-01-22 21:07	2018-05-01 10:22
6	W1	2793	55	45.36655	-64.43545	2018-01-22 20:52	2018-05-01 10:57
6	W2	2792	54	45.36597	-64.44332	2018-01-22 20:44	2018-05-01 11:04
6	S2	2931	80	45.34992	-64.42945	2018-01-22 20:33	2018-05-01 11:23

Appendix 2

This appendix provides additional information on the interaction of current speed and click max memory buffer limitations of C-PODs (defined as Percent (%) Time Lost). Porpoise clicks were detected above 3 m/s on the ebb and 4 m/s on the flood (Figure 9), with a steep drop off after 2 m/s on the ebb. This result may be due to memory buffer limitation or as a result of less porpoise vocalizations or presence. For this analysis we assessed 562,620 10-minute monitoring periods, noting model predicted maximum speeds of flood tides are stronger than ebb tides.

Figure A shows a heat map for each 0.1 m/s current speed bin (negative ebb, positive flood) with darker blue (>90% of data) and red (>65% of data) colouring indicating those cells with a high proportion of Percent (%) Time Lost at that point on the Y-axis. This analysis indicates that Percent Time Lost had little effect on data quality between an ebb current speed of <2.4 m/s (95% of 10-minute periods) and a flood current speed of <2 m/s (71% of 10-minute periods). A similar picture is observed using a plot of the proportion of data that has no Percent (%) Time Lost at all (Figure B) and reinforces the need to include a Percent (%) Time Lost variable in any effect assessment. Finally, a Loess regression approach was used to describe the overall relationship between Percent Time Lost and current speed (Figure C). At ebb current speeds up to 2.9 m/s (99% of 10-minute periods) and flood current speeds up to 3.5 m/s (95.5% of 10-minute periods), Percent Time Lost does not exceed 65%. Despite that the effects of these covariates were controlled for within the GEE modelling frame, C-POD monitoring performance above these current speeds is clearly less reliable, noting that these speeds only occur a very small fraction of the tidal cycle.

Figure A. Heat map of Percent (%) Time Lost proportions within each current speed bin (cut off at 0.05). Dark blue signifies that >90% of all data samples are at that Y axis level of Percent Time Lost, as seen at 0 Percent (%) Time Lost at low current speeds. Ebb currents are negative and flood positive.

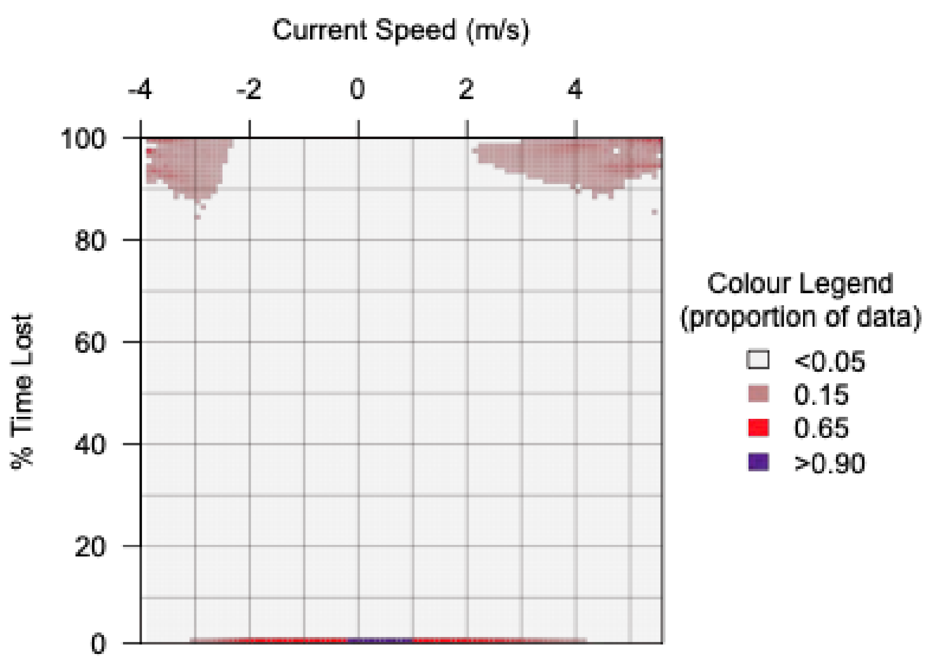

Figure B. Proportion of data with no Percent (%) Time Lost by current speed (m/s) bin. Ebb currents are negative and flood currents positive.

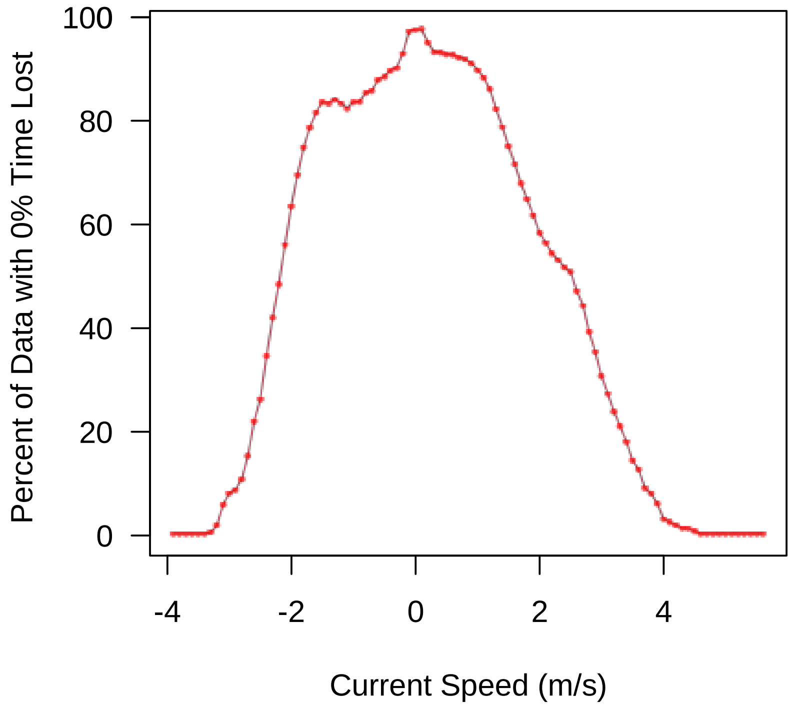

Figure C. Loess Regression of % Time Loss on Current Speed. At ebb current speeds <2.9 m/s or flood current speeds <3.5 m/s we expect 65% Time Lost or greater. Based on the Loess regression, we expect 38% Time Lost at ebb current speeds of 2.4 m/s, and 24% Time Lost at flood current speeds of 2.0 m/s. Ebb currents are negative and flood currents positive.