OERA Research on Tidal Marine Energy

Assessing marine mammal presence in and near the FORCE Lease Area during winter and early spring – addressing base-line data gaps and sensor performance

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Project Summary:

Current tidal power proposals and developments to harness tidal energy from high flow sites in the Bay of Fundy require examination of the potential effects of tidal turbines on the environment, including impacts on marine mammals. Studies conducted to date, at and near the Fundy Ocean Research Centre for Energy (FORCE) in-stream tidal turbine test site in Minas Passage, have included passive acoustic monitoring (PAM) of harbour porpoises during late spring, summer and fall months (Wood et al., 2013). A lack of winter and early spring (Dec-May) baseline data on harbour porpoise presence in Minas Passage was one of the issues identified in a DFO review of the environmental monitoring program at FORCE (DFO, 2012).

To address both the seasonal data gap and performance of different hydrophone technologies in a high flow site, we conducted a winter/spring survey of marine mammals at multiple locations in and near the FORCE site during Dec 2013 – June 2014. This involved the use of C-POD porpoise detectors (Chelonia Ltd) and the icListenHF smart hydrophone (Ocean Sonics Ltd). Both technologies are non-invasive and continuously monitor harbour porpoise click trains within their operational detection range. The main objectives of this study were to close the seasonal (winter/spring) gap in data on harbour porpoise activity in the Minas Passage and to determine detection range (distance from hydrophone) and performance in relation to varying tidal conditions for each of the hydrophone technologies.

Winter-spring data collected from SUB buoy moored C-PODS at four of the PAM sites showed low presence during winter with activity increasing in March and peaking in June when Atlantic herring and other fishes are known to be regionally present in high abundance. The new data were pooled with all prior C-POD data from the Minas Passage (2010-2012 dataset) and a statistical analysis was conducted. A new GAM/GEE model was prepared with plots of covariates showing porpoise detection results in relation to Julian Day (seasonal trends), noise (as indicated by C-POD performance metrics - % Time Lost), day vs night, location, tidal height and current speed. The full dataset (2010-2014) and revised statistical model provide year-round baseline conditions that will be needed for studies of tidal turbine installation/operation impact on harbour porpoises.

In-field testing of hydrophone performance involved assessing the detection range of each device type (C-POD and icListenHF) while housed in a bottom moored instrument platform in the FORCE test site. Using a surface drifting speaker (icTalk, 120-140 kHz), C-PODs detected transmissions up to 300 m from the sound source, however, detection efficiency was greatest within 100 m and detections were uncommon at depth-averaged current speeds of >1m/s. In contrast, a shrouded (20 ppi, ½ inch acoustic foam) icListenHF hydrophone detected icTalk transmissions at distances up to 300 m (>30% efficiency), with 100% detection efficiency at distances up to 150m, and no apparent reduction in detection performance as current speed increased.

Harbour porpoise detections by C-PODs housed on the bottom moored instrument platform (platform) were considerably greater than shown for a co-located C-POD in a SUB buoy 2-3 m off the seafloor. Factors that may affect performance of SUB buoy mounted C-PODs include excessive tilt of the unit during high flow periods. Detection of non-target noise that results in % Time Lost was also greater for the SUB mounted C-POD. These tests of hydrophone performance are currently being used to inform both the Environmental Effects Monitoring Program and sensor platform research at FORCE.

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1.0 Introduction

Tidal power developments globally are focused on the testing of various large-scale commercial Tidal In-Stream Energy Conversion (TISEC) devices. There have been few installations to date and concerns remain regarding how TISEC device installation and operation will impact on marine life, especially marine mammals and fish (Langhamer et al., 2010). As the number of installed TISEC devices grows, the potential for negative impacts on marine animals (e.g. blade strikes) increases. It is unknown if the noise produced during operation of the turbines will negatively affect marine mammals, but it is likely that each species will respond differently (Stewart et al., 2002). At this early stage of testing TISEC devices, it is necessary to determine how marine mammals use any tidal energy test site (via baseline data) so that any effects can be monitored.

The Fundy Ocean Research Centre for Energy (FORCE) is a TISEC test facility in Minas Passage, Bay of Fundy, where tidal energy developers can lease a designated berth (200 m diameter) to test and monitor their prototype devices and arrays. One of the main objectives of FORCE is to investigate environmental effects of TISEC operation, including effects of, and on, the environment (FORCE, 2012). This requires the collection of baseline data on the energy resource, the geophysical conditions and various biological components, including the use of the site by marine mammals. As the most commonly occurring marine mammal at the FORCE test site is the harbour porpoise (*Phocoena phocoena*) (OEER, 2008) they are the primary mammal species of concern.

Harbour porpoises are easily monitored with passive acoustic monitoring (PAM) devices because they are highly vocal and use echolocation (in the form of click trains) to gain perception of objects and landmarks for navigating and prey detection. The frequency of echolocation click trains that harbour porpoises emit is between 100-160 kHz, with 75-150 μs duration and a narrow angle of the echolocation beam (15°) (Villadsgaard *et al*., 2006). Audiograms of harbour porpoises yield a maximum hearing sensitivity between 100 and 140 kHz (Kastelein, *et al*., 2002).

PAM devices are underwater microphones (hydrophones) that record sound (pressure differences) continuously over time. They are non-invasive, unaffected by weather, and monitor a specific area rather than an individual animal (Villadsgaard, 2006). Hydrophones monitor within limited distances from their moored locations and can record a large spectrum of sounds or can be specialized to detect specific sounds (e.g. porpoise click trains) based on preset characteristics. Two hydrophone technologies (Figure 1.1) have been used to monitor harbour porpoises in the Minas Passage: C-PODs (Chelonia Ltd.), which are porpoise detectors that detect click trains between 20-160 kHz, and the icListenHF hydrophone (Ocean Sonics Ltd.), which records sound from 0.01-204.8 kHz (Porskamp, 2013, Wood et al., 2013).

Figure 1.1 Hydrophone images. Top: C-POD (Chelonia Ltd). Bottom: icListenHF (Ocean Sonics Ltd).

During 2010-2012, multiple C-PODs were deployed at and near the FORCE turbine test site to examine harbour porpoise presence for baseline purposes (Wood et al., 2013). These PAM studies were limited to late spring, summer and fall months. The winter gap allowed time for equipment maintenance and repairs during a period when little marine mammal activity was expected in Minas Passage. The current study tests that assumption and the new data will be used to update the prior statistical analyses (GAM/GEE) of the C-POD datasets and models that predict peak porpoise presence in late winter/early spring (Wood et al., 2013). Filling the seasonal data gap will better inform current understanding of the seasonal trends and will allow post turbine installation changes in porpoise activity (if any) to be assessed.

1.1 Objectives

The main objective of this study was to close the winter/spring (Dec-May) baseline data gap via deployments of multiple C-PODs housed in SUB buoys (as in the prior multi-year study) at four selected monitoring locations and to reanalyze the year-round C-POD dataset for determination of trends in porpoise presence.

A secondary objective was the determination of the detection range and efficiency of two hydrophone types, the icListenHF (Ocean Sonics) and C-PODs (Chelonia Ltd.), over different current speeds during the tidal cycle at FORCE. Both instrument types have been successfully used in the Minas Passage (Tollit et al. 2011; Porskamp, 2013; Wood et al., 2013) but are known to be less efficient as flow noise increases. Quantifying this aspect of sensor performance has not been previously addressed.

Lastly, we will test an alternate mooring method (bottom instrument platform) for deploying autonomous C-POD and icListenHF hydrophones to assess and compare hydrophone detection performance under a range of flow and noise conditions, and to compare the detection performance of C-PODs housed in a tethered SUB buoy and a bottom moored instrument platform.

2.0 Filling Winter / Early Spring C-POD Data Gaps

2.1 Methods

To fill the seasonal data gap in prior harbour porpoise monitoring (Wood et al., 2013), C-PODs were deployed at selected monitoring sites (E1, W1, W2 and S1) in and near the FORCE test site (Figure 2.1), from December 2013 to June 2014. This timeframe overlapped by one month (June) with previous monitoring studies (2010-2012).

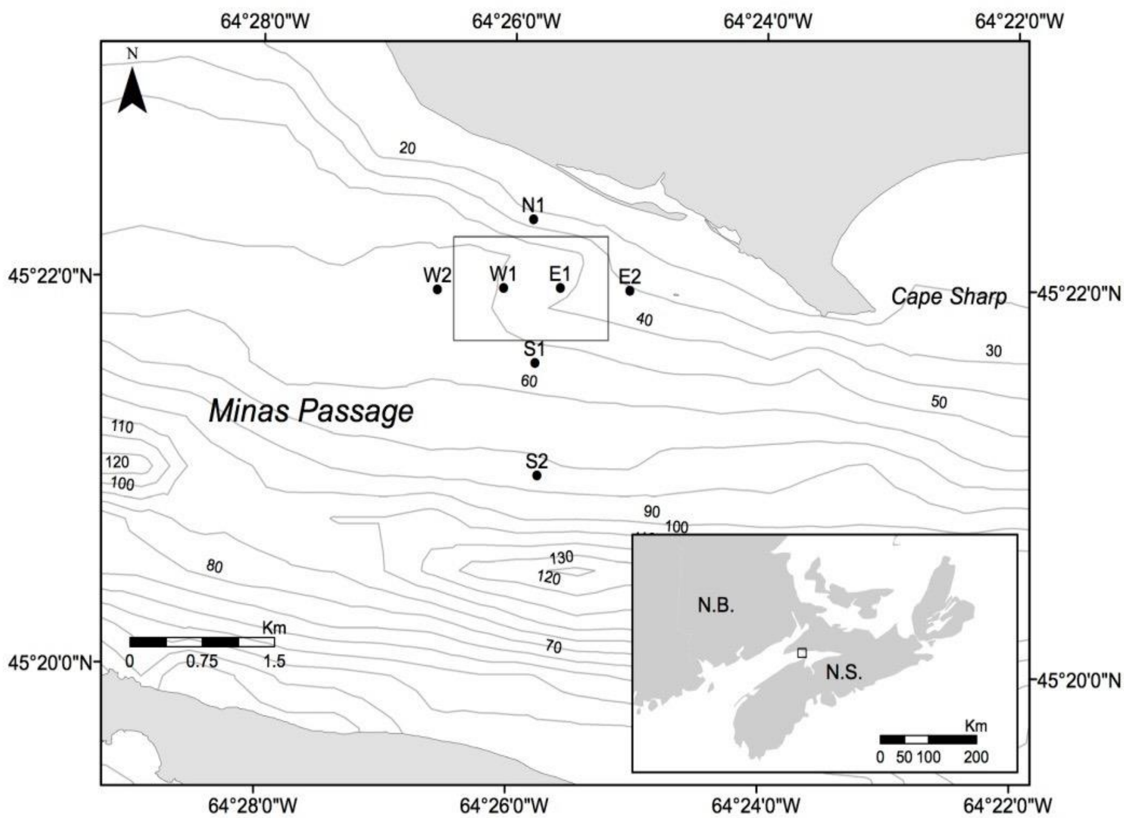


Figure 2.1. Bathymetric map of study location in Minas Passage and multi-year (2010-2014) hydrophone stations at and near the FORCE test site. FORCE dimensions (rectangle) are 1.0 km x 1.6 km. Stations E2, S2 and N1 not included in the current study.

C-PODS were deployed at 4 stations (E1, W1, W2, and S1) from December 2013 to July 2014. In preparation for deployment in the Minas Passage, each C-POD was attached to the strongback of a Teledyne Benthos 875-T acoustic release and housed in a SUB buoy modified to fit the coupled sensors. The acoustic release of each unit was attached to a 2-3 m long, galvanized steel riser chain (1.27 cm di-am.) and anchored with approximately 200 kg of large anchor chain links. Units were deployed from a chartered commercial lobster fishing vessel. The methodology of deployment and recovery is described in greater detail in Tollit *et al*. (2011).

On December 5th 2013 one C-POD was deployed at each of 4 monitoring sites; W1, W2, S1 and E1, with a duplicate C-POD deployed at W1. Battery and memory card replacements were conducted for recovered C-PODs on April 2nd 2014. All units were recovered successfully except C-POD 639 (duplicate at W1). This unit was found on the shore near Parrsboro in May 2014 and returned to Acadia. After reviewing the tilt logs it was clear that the unit had released from its mooring the day after we attempted recovery. Due to unknown reasons (possibly battery clip issues) C-POD 1616 recorded for only 5 days. After battery and memory card replacements, all recovered units were redeployed at the same station and a spare C-POD (643) was deployed at W1 to replace C-POD 639. Recovery of these units took place on 2 July 2014.

After SD cards were downloaded the data was run through click detection software from Chelonia Ltd. (Software Version 2.043) to filter the data in order to distinguish between click-trains and other broadband sounds recorded by the C-POD. Each click-train was assessed and categorized by quality as questionable, low, moderate, or high probability that it was indeed part of a click-train. Moderate or high quality click trains that are recorded within a minute are deemed a detection positive minute (DPM). The second stage determines the type of click-train (Delphinidae, Phocoenidae, other click-train source, boat sonar or unclassified) by assessing inter-click interval (ICI), frequency, and the length/amplitude of the click-train. The automated process is not perfect and therefore the post-processed data is assessed along with the original data to determine false positives and false negatives. Each click train was examined for how intensity varied over the click train (the envelope). After quality control is complete DPM can be visualized (Figure 2.2).

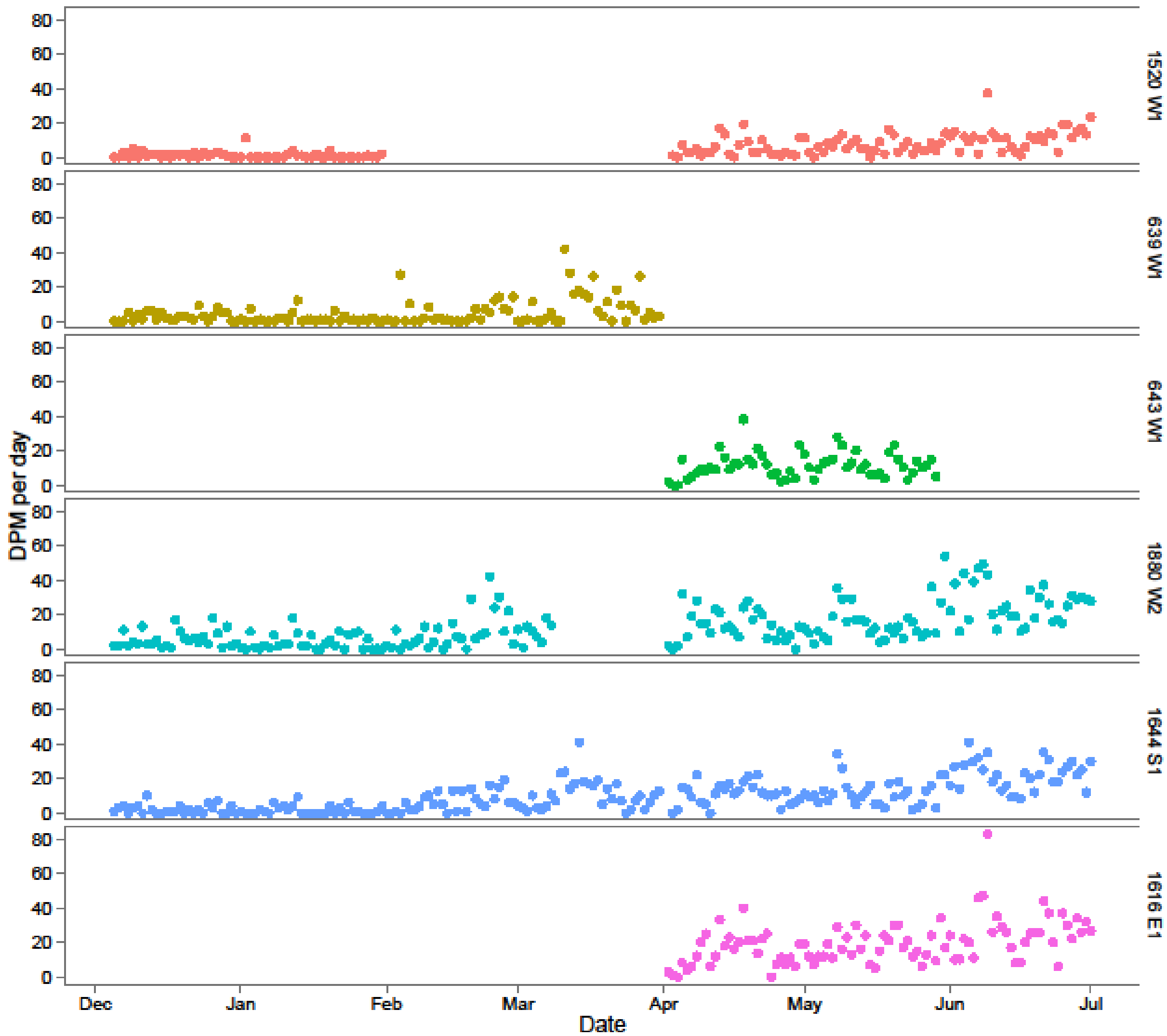


Figure 2.2. C-POD DPM per day for the 2013-2014 winter and spring deployments at sites W1, W2, S1 and E1. Note that C-POD batteries and SD cards were exchanged on 2 April 2014. C-POD 1520 provided duplicate coverage at W1 for most of the study period.

2.2 Model Selection

The 2013-2104 data (winter / spring) was combined with datasets from previous monitoring years for a reassessment of harbour porpoise activity trends, using methods similar to those outlined in Wood et al. (2013). All statistical analyses were conducted using the computer package 'R' (R Core Team, 2014). The following packages were used in model creation: mgcv (Wood, 2014); geepack (Hojsgaard, *et al.*, 2006); splines (R Core Team, 2012); car (Fox and Weisberg, 2011); mvtnorm (Genz *et al.*, 2012); MRSea (Scott-Hayward *et al.*, 2014).

In order to interpret the full dataset, a GAM (General Additive Model) was built. A binary unit, DPMp10M (detection positive minutes per 10 minute period), was used as the response. The response was modelled with a wide range of covariates inside GAM with logit link and binomial error. One assumption of a GAM is that the model errors are independent. Since the C-POD observations were collected close together in time the errors are not independent. The autocorrelation must be accounted for in the modelling approach. Since the raw data is zero inflated, it is likely that there will be a very low mean-variance relationship resulting in underestimation of the uncertainty around model estimates.

To account for autocorrelation the GAM created was run within a Generalized Estimating Equations (GEE) construct. GEEs can be used to account for temporal and spatial autocorrelation within a dataset. In order to facilitate the GEE the data within the model were grouped into panels. This allows for the model errors to be correlated and panel size to be independent. The panel size was chosen using autocorrelation function plots. Autocorrelation results suggested that a panel size of 120 minutes would remove any autocorrelation present. This model structure provides identical coefficients to those of a standard GAM model, but the standard errors will differ under the GEE structure.

To determine if sensitivity varied between C-POD units, **C-POD ID** was included as a covariate in the models. **Location** at which C-PODs were deployed was included to determine spatial differences within the study area. **Area** was included to determine if detections in and out of the FORCE test site differed. **Click max** was included to determine if the setting had an impact on detection. Click max settings (4096 or 65536 depending on deployment) refer to the maximum number of "clicks" the C-POD can record over a one minute period. If the number of clicks exceeds the set amount, the unit will stop recording for the rest of the minute. Click max ensures the memory card does not fill before the normal deployment period is over. To control for sediment noise and pseudonoise, we included **% Time Lost** (% of logging time lost due to minutes maxing out; this function is built in so that in times of high noise the C-POD's memory card does not prematurely fill). **Julian Day** was included to determine if harbour porpoises detections exhibited seasonal patterns. **Temperature** was also included to determine if it had an effect on harbour porpoise patterns. To determine if porpoises within the Minas Passage exhibit diurnal patterns a **Day Night Index (DNI)** was included in the model. The DNI was a continuous index between 0 and 2. Values between 0 and 1 indicate daylight, values between 1 and 2 indicate night. **Tidal Velocity** and **Tidal Height** were also included in the model to determine if the porpoise patterns were related to velocity or tidal stage. Julian Day and DNI used circular splines since they are continuous variables which rollover: 365 to 1 for Julian Day, and 2 to 0 for DNI.

The number of knots and knot placement was determined using a spatially adaptive smoothing algorithm (SALSA). MRSea contains this algorithm and can apply SALSA in an automated process. The fitness measure chosen to compare models was Akaike Information Criterion (AIC). The maximum iterations was set to 10 for each covariate. To ensure that all knots did not congregate around the same Julian Day a gap of 15 days was chosen.

The initial GAM model failed to converge due to singularities. Singularities are caused by only one level of a covariate being present in a single level of another covariate (e.g. a single C-POD ID only being present in one location). Due to singularities both C-POD ID and Area were dropped. To avoid collinearity, the use of 'variance inflation factors' (VIF) was implemented using the vif function in the 'car package' in R. Large VIF values indicate collinearity. A common practice is to use a VIF threshold of 10 which was used in our model selection. Temperature was collinear with Julian Day and was dropped from the model.

Of the seven covariates remaining, all seven were kept in the final model due to significant (i.e. <0.05) GEE-based p-values. The relationship between each predictor variable and the response from the GAM/GEE model was plotted (Figure 2.3). The horizontal x-axis is the variable of interest in determining change in porpoise detections. The vertical y-axis explains how porpoise detection rates change as the variable of interest (x-axis) changes. The model plot **does not** depict actual DPM10M. The grey lines around splines and error bars depict 95% confidence intervals for the predicted relationships.

To determine the relative importance of each covariate in the model the Concordance Correlation (CC) coefficients were calculated. Each time the model was run a covariate was removed and then the CC was compared to the CC of the whole model to determine which one had the largest impact (Table 2.1).

Table 2.1. Concordance correlation coefficients (CC) for the significant DPM10M covariates in the GAM/GEE model for all data collected (2011-2014). Based on CC values each covariate was ranked. See plots in Figure 2.3.

Covariate	**Full CC**	**Covariate CC**	**Difference in CC**	**Rank**
Julian Day	0.0812	0.0451	0.0360	1
% Time Lost	0.0812	0.0614	0.0197	2
DNI	0.0812	0.0722	0.0089	3
Location	0.0812	0.0735	0.0077	4
Tidal Height	0.0812	0.0747	0.0064	5
Tidal Velocity	0.0812	0.0788	0.0024	6
Click Max	0.0812	0.0811	0.0001	7

2.3 Model Results

The new GAM/GEE plots for the full dataset (2010-2014) show the largest peak in porpoise activity in late spring/early summer (June) followed by a smaller peak in the fall (late October) (Figure 2.3). Low porpoise detections are associated with mid-late summer and winter periods. The new model includes winter and early spring data which improves the original model predictions shown in Appendix Figure 1A. However both the original and new models show Julian day to be the most important covariate.

% Time Lost is the second most important predictor. As it increases, porpoise detections decrease markedly. This covariate can be considered a proxy for current speed given that current-induced noise (e.g. bedload transport) causes the time lost effect.

Diel trends (Day Night Index or DNI) in porpoise detections were as expected. As in the original model, the lowest porpoise detection rates are associated with midday – early afternoon (DNI ~0.65); the highest detection rates (i.e. feeding activity) are in the middle of the night (DNI of ~ 1.50) (Figure 2.3).

Porpoise detection rates vary across station locations with higher detection rates in deeper waters (S1, 84 m) and lower detection rates at shallow depths (N1, 27 m) (Figure 2.3). All others stations are located at depths ranging from 40-60 m. Location results are similar to the original model.

The model predicts low porpoise detection at extreme low and high tide heights (relative to mean height) which is not surprising given that these events are less common than moderate tidal heights.

As expected, the GAM/GEE model predicts highest porpoise detection at low tidal velocities – at or near slack water (high and low tides) (Figure 2.3). At these times, ambient noise is low and thus % time lost is also low. Detections drop markedly at depth averaged velocities >2 m/s. Tidal velocity ranks 6th (out of 7) in importance compared to the original model where this covariate was ranked 2nd.

The click max setting of 4096 resulted in greater predicted porpoise detections compared to using a click max setting of 65536 (Figure 2.2). After it was determined that the 65536 click max setting filled the memory cards too soon, and thus limited porpoise click train detections, this setting was no longer used. The higher click max setting is represented only by 6% of the full dataset.

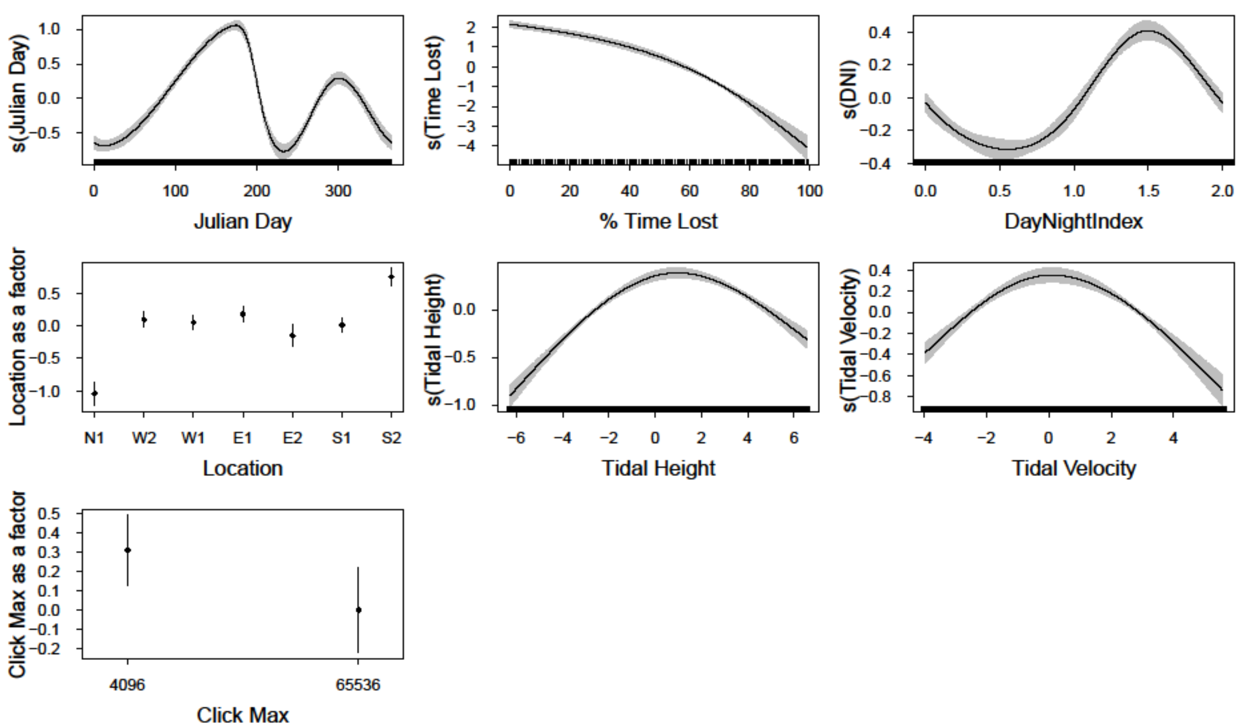


Figure 2.3. GAM/GEE plots of significant covariates and their relationship to porpoise DPM10M, in order of importance (see Table 2.1). Shaded areas and error bars represent 95% confidence intervals. Data includes all data collected during 2010-2014. For the Day Night Index, values between 0 (sunrise) and 1 (sunset) indicate daylight, values between 1 and 2 (sunrise) indicate night.

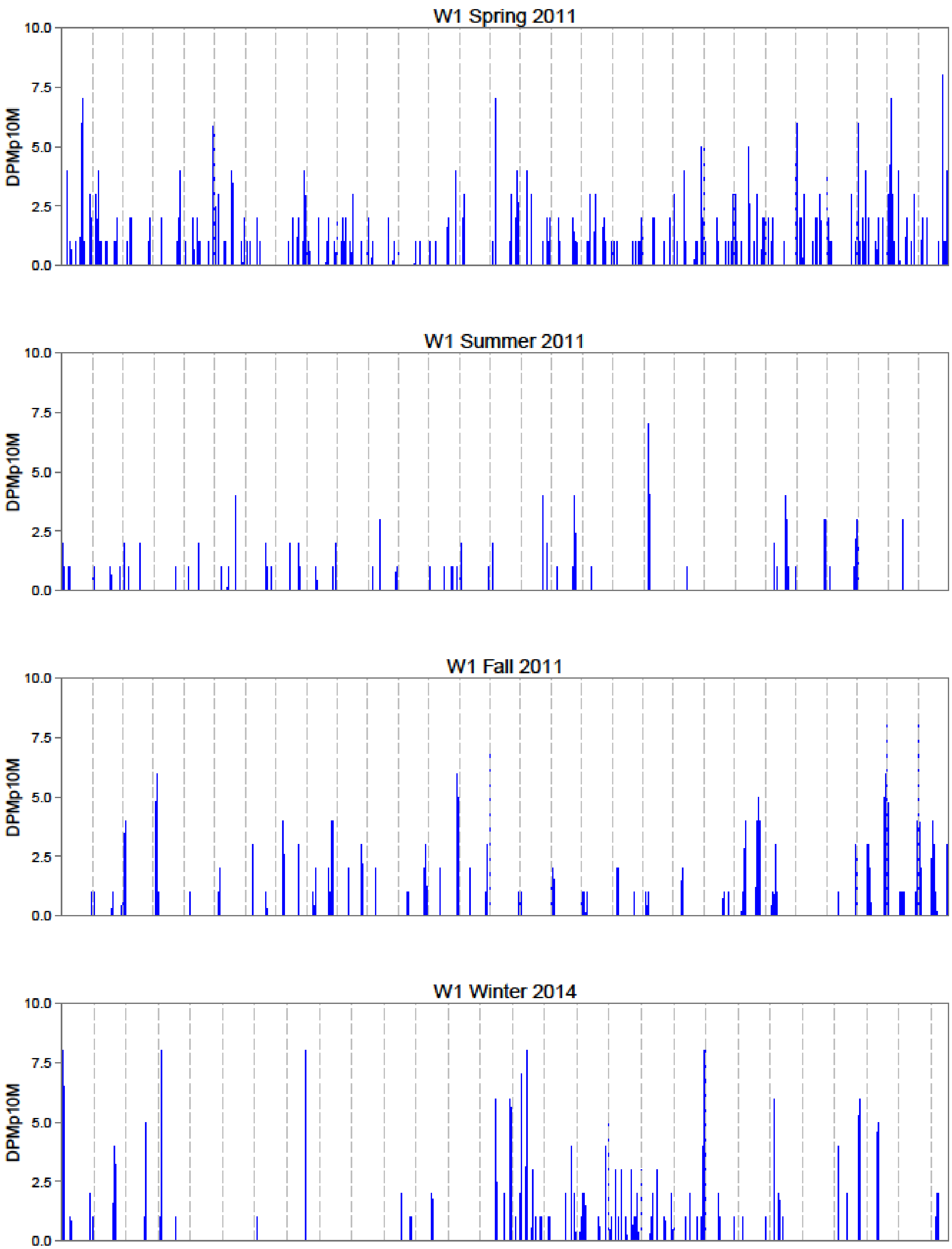


Figure 2.4. DPMp10M at location W1 highlighting detection trends across and within months. Vertical dashed lines indicate the start of a new day (i.e. midnight). Spring, summer and fall plots are from Wood et al. (2013). See Table 2.3 for Julian Day periods.

2.4 Descriptive Statistics

Because Location W1 has the most data and is the longest continuous monitoring location through all years of monitoring, it was chosen to highlight seasonal trends in porpoise detections. Figure 2.4 and Table 2.3 shows 30 day period trends in DPMp10M during spring, summer, fall and winter. The results concur with the GAM/GEE model which predicts spring to have the most DPMp10M and summer to have the lowest. Summer and winter detections are irregular on a temporal scale and are most likely driven by how porpoises are using the Minas Passage during those seasons. Detections typically occur in the hours just before and after midnight (vertical dashed lines).

The following sections describe the statistics for each covariate but should be interpreted with care. This is because the data is zero inflated (many zeros throughout the dataset) and the standard deviation is large. Median and mode cannot be used because in most cases they would be 0. The raw statistics are still important because they can be compared to the model to determine how accurately the model reflects the collected data.

Julian Day

The spring peak is almost double the fall peak, with winter and fall being approximately the same (Table 2.3). Note the winter sample size (2014 data) is smaller because there is only one year of data and not two or more like all other seasons. The GAM/GEE model and descriptive statistics show similar trends.

Table 2.3. Descriptive statistics for periods of 30 Julian Days corresponding to spring, summer, fall and winter periods as shown in Figure 2.4. The % of 10MP with DPM is the percentage of 10 minute periods with at least one porpoise detection.

Julian Day Range (season)	Dates	Mean DPMp10M	SD	% of 10 MP with DPM	No. of 10MP
30-60 (winter)	30 Jan – 1 March	0.05	0.40	2.2	12563
130-160 (spring)	10 May – 9 June	0.13	0.59	6.7	42497
220-250 (summer)	8 Aug – 7 Sept	0.03	0.28	1.8	34735
280-310 (fall)	7 Oct – 6 Nov	0.09	0.55	4.1	41670

Tidal Velocity

Descriptive statistics suggest that the highest porpoise presence is associated with low current velocities on the ebb tide (-2 to 0 m/s) (Table 2.4). Trends here are not taking into account % time lost, which occurs at high flow velocities, especially on the flood tide. The sample size for fast flood currents (depth average speed >2 m/s) is 2x larger than fast ebb currents because flood tidal currents exceed 2 m/s for longer periods.

Table 2.4. Descriptive statistics for four Tidal Velocity classes (depth-averaged velocity). The % of 10MP with DPM is the percentage of 10 minute periods with at least one porpoise detection.

Velocity (m/s) (tidal stage)	Mean DPMp10M	SD	% of 10 MP with DPM	No. of 10MP
-4 to -2 (fast ebb)	0.05	0.37	2.9	33921
-2 to 0 (low ebb)	0.12	0.60	5.5	94885
0 to 2 (low flood)	0.06	0.41	3.6	78132
2 to 4 (fast flood)	0.07	0.46	3.3	68329

Tidal Height

The GAM/GEE model suggests that the porpoise detections are highest at moderate tide heights (relative to mean tide height) and lowest at low tide when water volume in Minas Passage is at its lowest. The descriptive statistics show an increase in porpoise presence as tidal height increases (Table 2.5), contrary to the model.

Table 2.5. Descriptive statistics for five tidal height classes. A tidal height of zero is the mean tidal height in Minas Passage. The % of 10MP with DPM is the percentage of 10 minute periods with at least one porpoise detection.

Tidal Height (m) Relative to Mean Tidal Height	Mean DPMp10M	SD	% of 10 MP with DPM	No. of 10MP
-6 to -4	0.05	0.37	2.5	40718
-4 to -2	0.06	0.40	3.3	63425
-2 to 2	0.09	0.55	4.4	82115
2 to 4	0.09	0.53	4.6	53307
4 to 6	0.11	0.54	5.5	41321

Location

The descriptive statistics for station location (Table 2.6) are generally in line with the GAM/GEE model which predicts low porpoise presence in the shallow near shore (N1, 27 m) and highest detections at the deepest site (S2, 84 m). The other locations are between 40 and 60 m in depth and have similar detection rates except for E2 (41 m) which is located near Black Rock and has extremely high levels of ambient noise (i.e. high % lost time).

Table 2.6. Descriptive statistics for the seven locations used in this study. % of 10MP with DPM is the percentage of 10 minute periods with at least one porpoise detection. Sites in the FORCE lease area are in bold. Depths are provided in brackets after each location. See Figure 2.1 for map locations.

Location (depth:m)	Mean DPMp10M	SD	% of 10 MP with DPM	No. of 10MP
N1 (27)	0.03	0.26	1.3	26212
W2 (59)	0.09	0.49	4.7	30275
W1 (56)	0.09	0.54	4.3	77165
E1 (52)	0.11	0.56	5.3	67021
E2 (41)	0.04	0.36	1.7	24213
S1 (59)	0.07	0.43	3.6	49790
S2 (84)	0.11	0.52	6.4	13774

Day Night Index (DNI)

DPMp10M results indicate that periods with daylight have lower porpoise detection rates than nighttime periods (Table 2.7). The GAM/GEE model showed a similar pattern.

Table 2.7. Descriptive statistics for four Day Night Index classes. The % of 10MP with DPM is the percentage of 10 minute periods with at least one porpoise detection. Note that DNI values of 0 and 2 represent sunrise and an index value of 1 is sunset.

Day Night Index	Mean DPMp10M	SD	% of 10 MP with DPM	No. of 10MP
0.0 to 0.5	0.07	0.43	3.7	73016
0.5 to 1.0	0.06	0.42	3.5	73147
1.0 to 1.5	0.10	0.55	4.5	66367
1.5 to 2.0	0.10	0.55	4.8	67444

Percent Time Lost

When the minute memory limit fills prior to 60 sec, the remaining detection time within that minute is lost. This effect occurred during 36% of the 10 MPs in the full dataset. Not surprisingly, lost time has an effect on porpoise detection rates with detections decreasing as % lost time increased (Table 2.8). The GAM/GEE model (Figure 2.3) shows a similar pattern.

Table 2.8 Descriptive statistics for four classes of % Time Lost. The % of 10MP with DPM is the percentage of 10 minute periods with at least one porpoise detection.

% Time Lost	Mean DPMp10M	SD	% of 10 MP with DPM	No. of 10MP
0-25	0.10	0.56	5.4	207996
25-50	0.03	0.28	1.8	8403
50-75	0.01	0.13	0.6	12969
75-99	0.00	0.07	0.1	54164

Click Max

As the model predicts porpoise detection rates were higher with a click max of 4096 than with a click max of 65536 (Table 2.9). As click max settings represent different deployment periods, results should be interpreted with care.

Table 4.9. Descriptive statistics for the two Click Max settings used in this study. % of 10MP with DPM is the percentage of 10 minute periods with at least one porpoise detection.

Click Max	Mean DPMp10M	SD	% of 10 MP with DPM	No. of 10MP
4096	0.08	0.50	4.2	271500 (94%)
65536	0.04	0.32	2.4	16950 (6%)

3.0 icListenHF Hydrophone Performance With & Without Shrouding: Tank Tests

During the spring of 2014, tests were conducted to compare the porpoise detection performance of C-PODs and icListenHF hydrophones in Minas Passage. Prior to the field tests, two icListenHF hydrophones were calibrated. Various acoustic shroud materials were then tested for effectiveness in reducing flow noise at the sensor tip (pseudonoise).

3.1 Hydrophone Calibration

All icListenHF hydrophone calibrations were conducted at the OceanSonics Ltd facility in Great Village, Nova Scotia. Calibration results are shown in Figure 3.1 for hydrophones 1211 and 1239, both with HDPE guards (Figure 3.1). Hydrophone 1211 was slightly more sensitive in the range of porpoise echolocation frequency (130 kHz) compared to hydrophone 1239. However, hydrophone 1211 was less sensitive at higher and lower frequencies compared to hydrophone 1239.

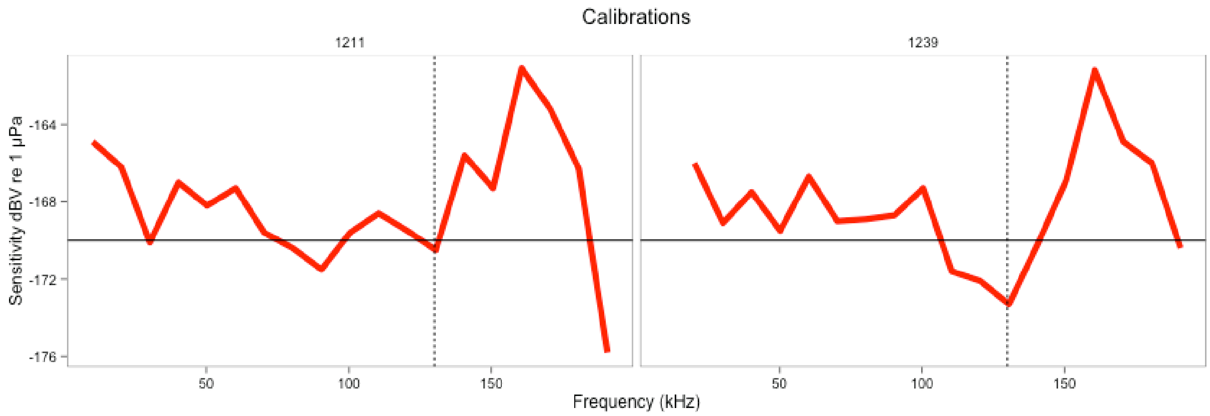


Figure 3.1. Calibration results for icListenHF 1211 and 1239 fitted with HDPE guards. Horizontal bar is a reference at -170 dBV re 1uPa. Vertical dashed line (130 kHz) is within the frequency that harbour porpoises use for echolocation.

3.2 Acoustic Foam Shroud Testing

The effect on performance of the icListenHF hydrophone when it is shrouded with acoustic foam was tested using foam densities of 20 ppi (pores per inch), 30 ppi and 40 ppi, and with three different thicknesses: ½ inch, 1 inch and 1.5 inch. All shroud plus guard setups were calibrated except for the 40 ppi foam because this foam type attenuated all sound.

icListenHF 1211 was selected as the control unit because the initial calibration showed it was more sensitive at 130 kHz when compared to icListenHF 1239 (Figure 3.1). Calibration results for various shroud setups with hydrophone 1239 are shown in Figure 3.3. The shroud setup using 20 ppi attenuated low frequency sounds and was the best performing acoustic foam type for preserving higher frequency sounds. As thickness of the 20ppi foam increased, the amount of attenuation increased. The shroud setup using 30 ppi attenuated high frequencies while preserving the lower frequencies.

Figure 3.2. IcListenHF hydrophone tip with custom made HDPE guard (left) and with a ½ inch 20 ppi foam cover secured over the guard (right).

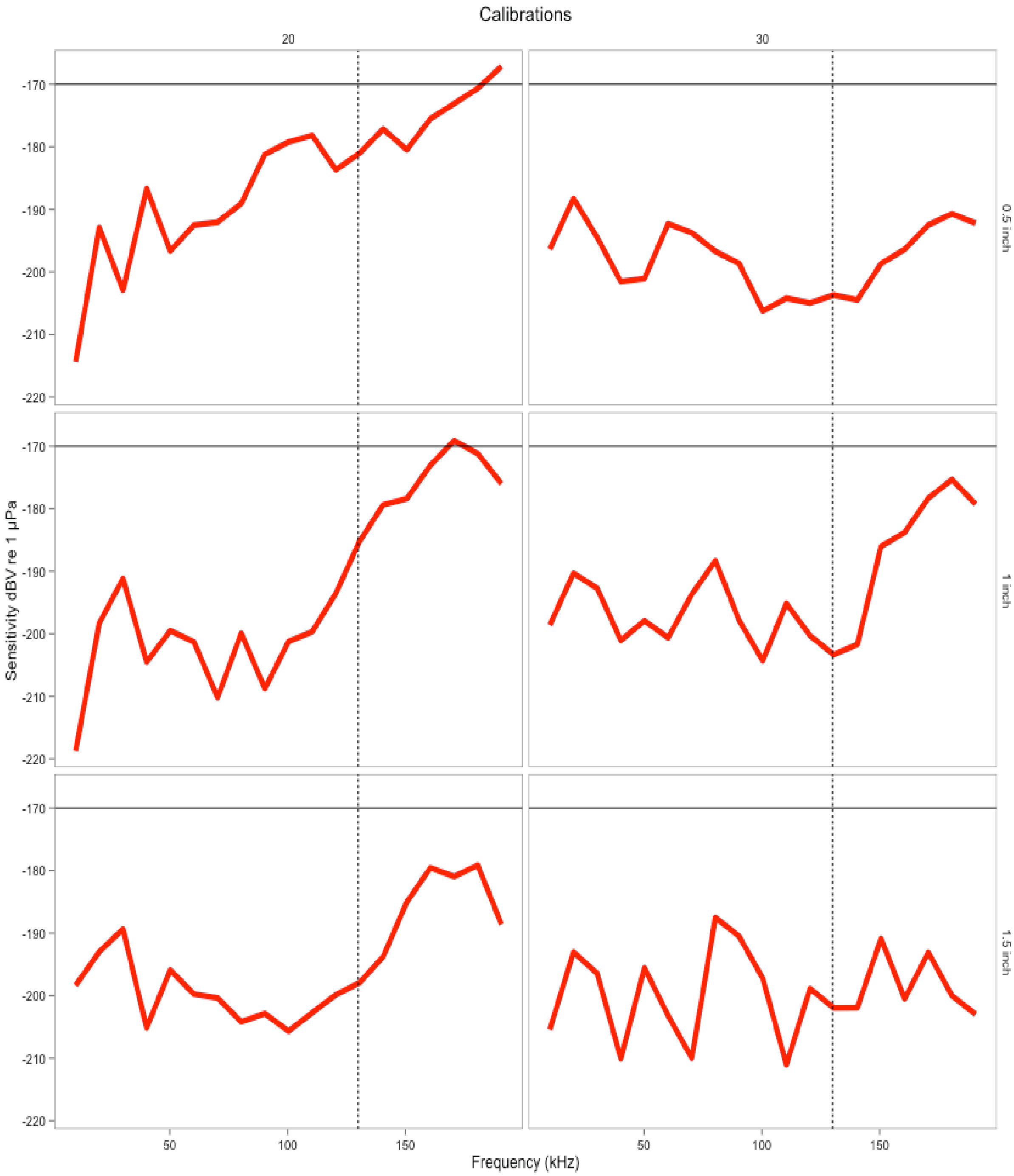


Figure 3.3. Calibration results for icListenHF 1239 for various shroud setups. Horizontal bar is a reference at -170 dBV re 1uPa. Vertical dashed line (130 kHz) is within the frequency that porpoises use for echolocation. Rows represent various acoustic foam thicknesses tested and columns represented pore density (20 ppi and 30 ppi).

Following the shrouded hydrophone calibration tests, 20 ppi foam at both ½ inch and 1 inch thicknesses were selected for flow testing (at 1 m/s) because the calibrations showed these two setups attenuated sound at low frequencies while maintaining sensitivity at higher frequencies (e.g. porpoises click trains).

3.3 In-tank Flow Tests

Each of the three hydrophone setups were tested for performance at a flow speed of 1 m/s for 30s periods. The hydrophone setups were: guard only, guard plus ½ inch 20 ppi foam, and guard + 1 inch 20 ppi foam. Five trials were conducted for each setup.

An icTalk speaker (Ocean Sonics Ltd) was used during the tank flow tests to produce a sound sweep from 120 kHz to 140 kHz at 120 dB re 1μPa. The sweep duration was 0.1 s with a 0.9 s rest.

Flow noise can be seen during the trials at all frequencies although primarily occurring between 0 – 80 kHz (Figure 3.4). Noise above 100 kHz may be due to a phenomenon known as "thermal noise" which is caused by water particles striking the hydrophone tip. Hydrophone spectrograms of the flow tests reflect the calibration results; as the foam thickness increased, attenuation increased at all frequencies (Figures 3.4 & 3.5).

Compared to the control hydrophone the ½ inch 20 ppi foam reduced the reverb of the icTalk clicks, reduced click intensity by 10 dB ± 2 dB, and reduced flow noise by 30 dB ± 4 dB. The 1 inch foam completely removed the reverb of the icTalk, reduced click intensity by 20 dB ± 3 dB, and reduced flow noise by 30 dB ± 5 dB. Because the ½ inch foam had the least impact on click intensity, this foam thickness was selected for the field deployments in Minas Passage.

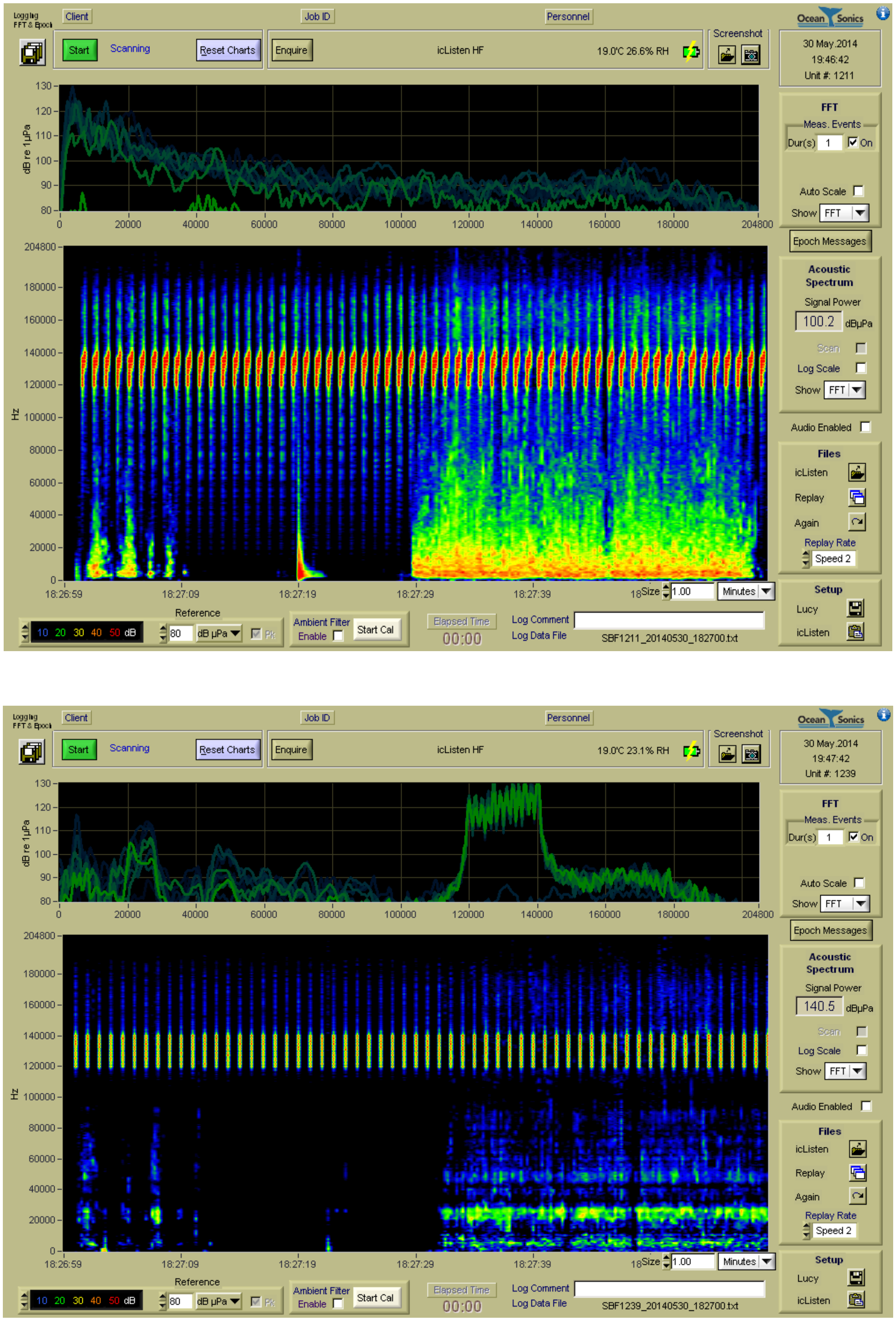


*Figure 3.4 IcListen spectrograms from tank test trials. **Top:** without acoustic foam. **Bottom:** ½ inch thick, 20 ppi acoustic foam. The tank test trial commenced half way through the minute.*

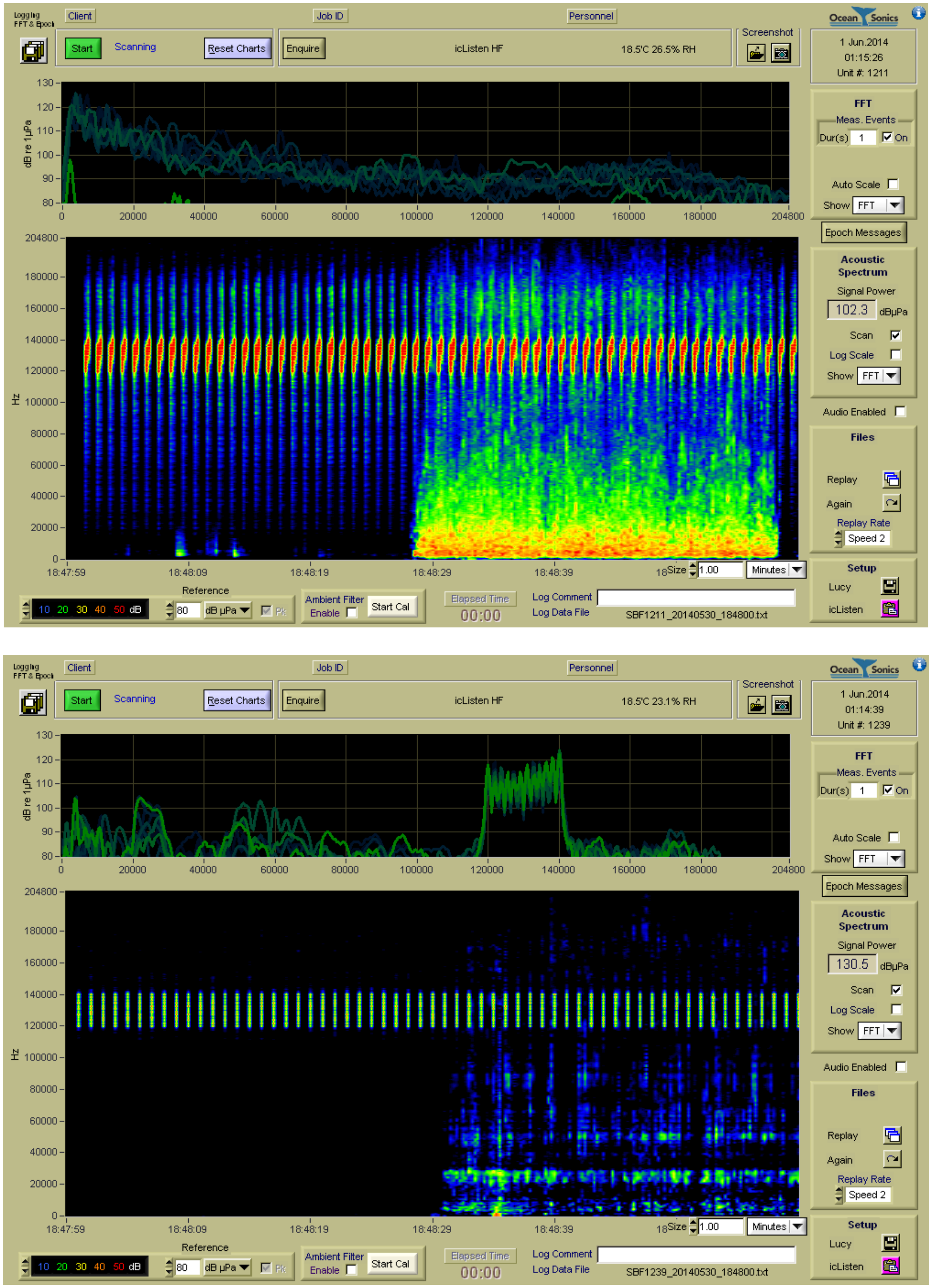


Figure 3.5. IcListen spectrograms from tank test trials. ***Top:*** *without acoustic foam.* ***Bottom:*** *1 inch thick, 20 ppi acoustic foam. The tank test trial commenced half way through the minute.*

4.0 C-POD and icListen Hydrophone Performance: Field Tests

4.1 Introduction

Since 2009, all PAM studies of harbour porpoise in the Minas Passage have employed SUB buoys (Open Seas Instrumentation Inc.) (Tollit et al., 2011; Wood et al., 2013). SUB buoys have a streamlined casing (about 2 m long) with internal floats that swivel with current direction (Figure 4.1), tethered about 2-3 m above the seafloor. Roughly 200 kg of large chain links are used as an anchor to prevent moored units from moving off site during high flow periods. A hydrophone and a Teledyne Benthos 875-T acoustic release for recovery are housed within the mid-section of the SUB buoy. The use of acoustic releases eliminates the need for a surface buoy, and thus reduces drag and risk of mooring movement. This configuration has been previously used to house both C-PODs and an icListenHF. The battery pack for the icListenHF, however, caused significant tilt under high flow conditions (Porskamp, 2013), which may have resulted in increased noise and reduced detection of harbour porpoises.

In an attempt to reduce tilt effects and non-target noise, this project tests the performance of C-PODs and icListenHF hydrophones (with and without an acoustic foam shroud), housed in a bottom standing instrument platform (lander) (Figure 4.1).

4.2 Sensor Platform, Deployment and Recovery

An instrument platform (also referred to as a lander) was fitted with an acoustic release (ORE Sport Release), temperature logger, pressure logger, tilt logger, two VEMCO VR2Ws, two icListenHFs two C-PODs, and approximately 400 kg of anchor weight (Figures 4.1 and 4.2). The sensors were located about 1 m off the seafloor, within the boundary layer where current speeds are reduced (<1 m/s). A spool of high tensile strength rope and two viny ball floats were attached to the platform. Triggering of the acoustic release uncoils the rope enabling the floats to rise to the surface to allow platform recovery. To ensure a successful recovery a low drag surface buoy was attached via rope to a safety anchor (200 kg of large anchor chain), connected to the platform via a 100 m stainless steel cable. A VEMCO acoustic transmitter was attached to the riser chain 3 m above the safety anchor and provided transmissions (69 kHz) at 8 min intervals for detection by all hydrophones.

The instrument platform was deployed at station W1 (Figure 2.1) on 5 June 2014 and recovered from the Minas Passage on 2 July 2014. During deployment an Teledyne Benthos 866 acoustic release used to lower the platform failed to release. As a result, a second charter (12 June) was required to pull the platform up and manually remove the acoustic release. At this time, all sensors were inspected and it was noted that the icListenHF 1211 guard arm was cracked but still attached at the base. The platform was successfully redeployed using a ¾ inch rope running through a shackle attached to the platform. The damage was most likely caused by the failed acoustic release making contact with the sensors at high flow speeds during the 1st week of deployment. The temperature, pressure and tilt loggers performed as expected.

Upon recovery of the platform on 2 July, it was noted that one of the 2 co-located C-PODs (1615) was missing (reason unknown). It was later found on the shore near Parrsboro, NS and returned to Acadia in December 2014. The dataset indicated that it became detached from the platform on 12 June, most likely during the redeployment of the platform. Both icListenHF hydrophones were inspected by Ocean Sonics Ltd. for damage and recalibrated. Results from the re-calibrations determined that the entire dataset collected by icListenHF 1239 throughout the deployment period was valid. The tip of icListenHF 1211 was damaged; the stored data was inspected by looking at the floor changes in all spectrograms. It was concluded that, after 7 days of successfully recording data, the hydrophone sustained damage and all further data were considered not valid. Analyses of the data collected by unit 1211 included only the first 7 days of the deployment period.

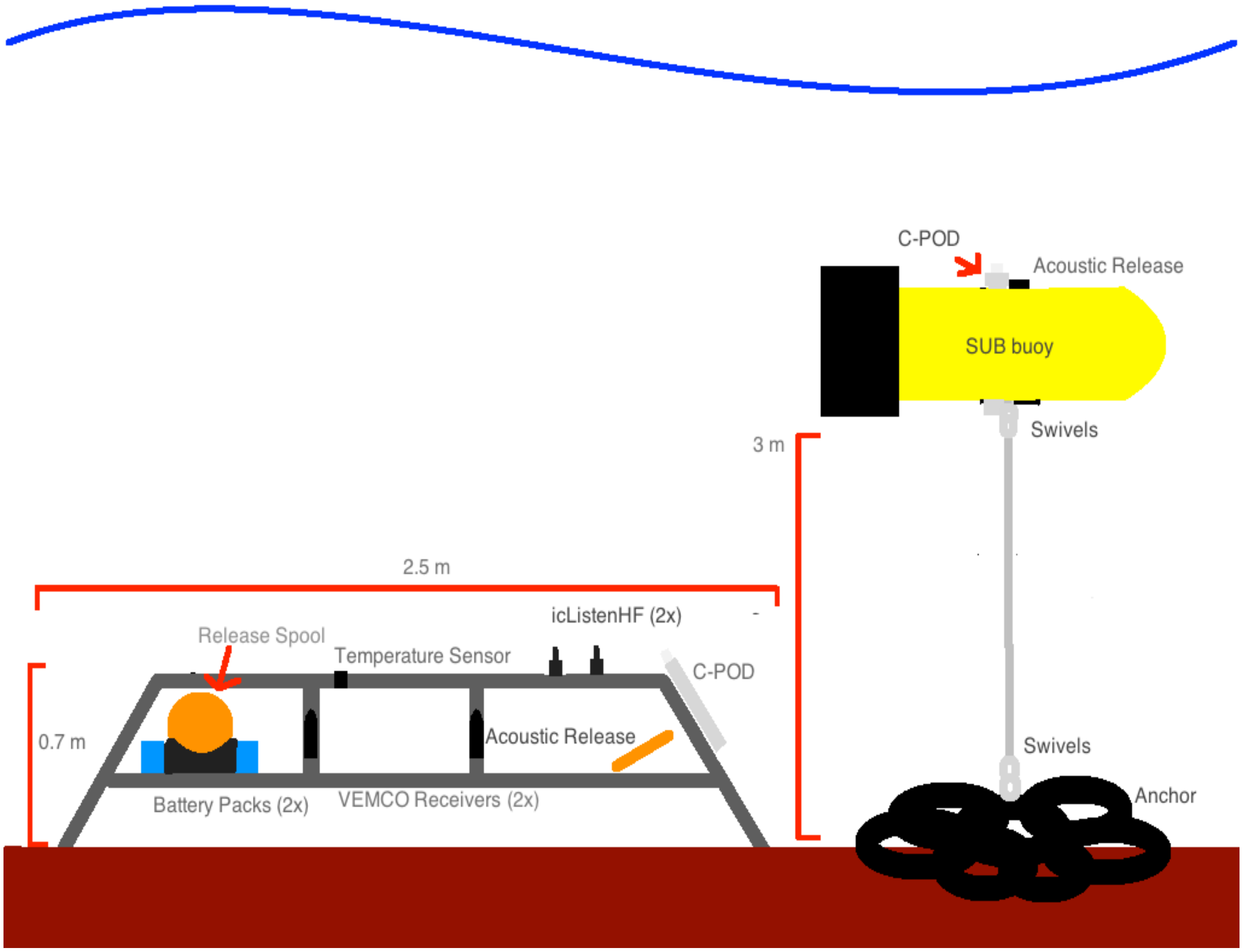


Figure 4.1. Mooring designs. ***Left:*** *Instrument platform housing two icListenHF hydrophones with battery packs, a C-POD, and an acoustic release, plus other sensors (temperature, VEMCO receivers).* ***Right****: SUB buoy housing an acoustic release and a C-POD, and attached to anchor weight (about 200 kg) with a 3 m long riser chain.*

Figure 4.2. Image of instrument platform ready for deployment. Note the 2 C-PODs in the far corners and the shrouded and non-shrouded icListenHF hydrophones (black sensors) located above their battery packs. The instrument hanging vertically above the frame is the Teledyne Benthos 866-a acoustic release.

4.2 Results

C-POD Detections – SUBS vs Platform

Harbour porpoise DPM/day were calculated for the platform mounted C-PODs and the SUB buoy mounted C-PODs co-located at location W1 (Table 4.1). The platform mounted C-PODs detected greater numbers of click-trains and greater detection positive minutes (DPM/day) compared to the co-located SUB buoys (Figure 4.3). Platform mounted C-PODs 639 and 1615 showed similar detection peaks in early June after which C-POD 1615 became detached from the platform.

Table 4.1. C-POD detection results from co-located units at station location W1. Two units were moored in SUB units (2 April – 2 July 2014) and 2 were housed on the platform in June 2014.

C-POD	Deployment Method	Detection Start / End Dates	Detection Duration	DPMs recorded (ave/day)
643	SUBS	2 April / 1 June	58d 19h 58m	659 (11.2)
1520	SUBS	2 April / 2 July	86d 22h 02m	504 (5.8)
639	platform	5 June / 2 July	29d 22h 53m	378 (12.6)
1615	platform	5 June / 13 June	8d 13h 26m	85 (10.4)

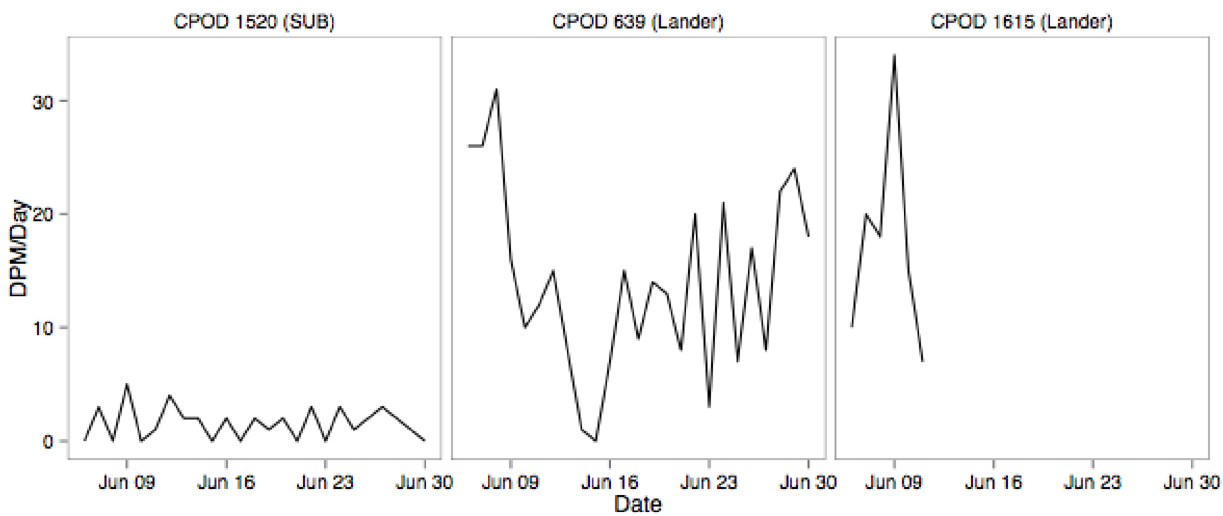


Figure 4.3. DPM/Day of SUB buoy mounted C-POD 1520 and platform (lander) mounted C-PODs 639 and 1615 (detached on June 12th). No data is available for SUB buoy mounted C-POD 643 for this period because this unit stopped functioning on 1 June 2014.

Lost Time Analysis – SUB vs Platform

% Lost Time was similar for the SUB buoy C-POD (1520) and platform mounted C-PODs (1615 and 639) during flood tides (Figure 4.4). But during the ebb tide, the platform shows less lost detection time. A Wilcoxon signed rank test (α = 0.05) with continuity correction was run to compare the two datasets and returned a p-value of 2.2e-16 indicating that the SUB buoy C-POD lost significantly more time than the platform unit.

Previous studies (SUB buoy only) involving C-PODs 1520 and 639 located at the same site showed comparable % time lost results.

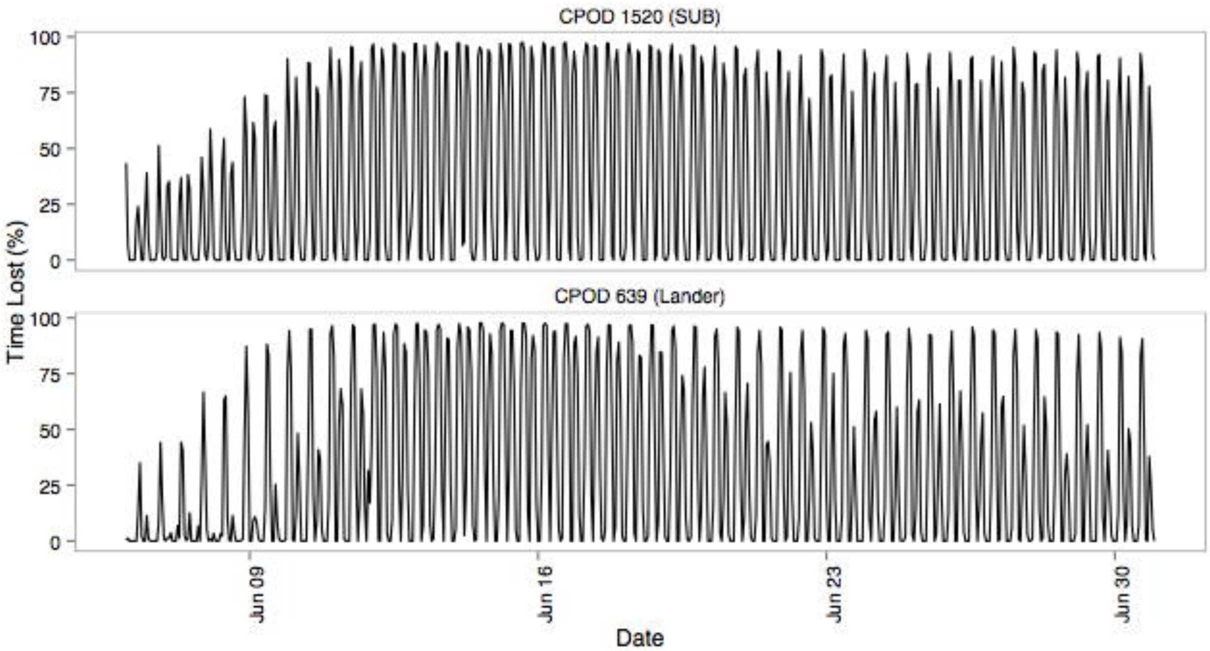


Figure 4.4. C-POD percent lost time plots. ***Top:*** *SUB Buoy mounted C-POD 1520;* ***Bottom****: platform mounted C-POD 639. The series of peaks represent the sequence of flood and ebb tides during June 2014 with flood tides showing greater % lost time compared to ebb tides. A spring-neap pattern is also evident; a full moon occurred on 13 June 2014.*

Mooring Unit Tilt Analysis – SUB vs Platform

Data was successfully retrieved from tilt sensors housed on both the platform and a co-located SUB buoy. The mean tilt for the deployment period for each axis was calculated and was set as a reference. Then each point was compared to the reference tilt value. For ease of viewing the absolute values are plotted in Figure 4.5.

During the deployment period (June 2014), the platform tilt sensor exhibited very low movement in both the pitch (z.tilt) and roll (y.tilt). In contrast, the SUB buoy showed up to 60 degrees on the pitch during the flood tide and 25 degrees on the roll, with tilt greater at depth-averaged flow speeds exceeding 1 m/s (Figure 4.5).

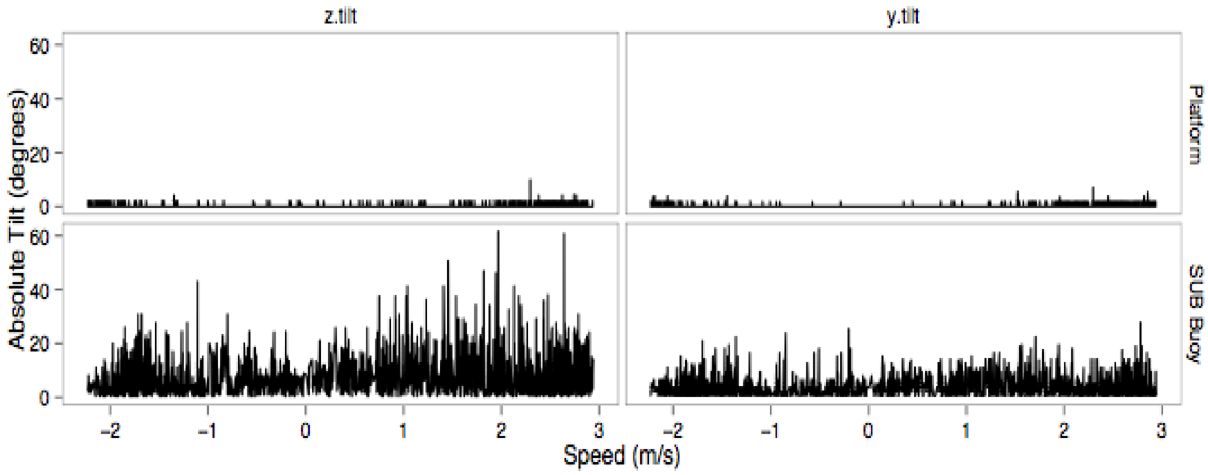


Figure 4.5. Tilt plots comparing pitch (z.tilt) and roll (y.tilt) with depth-averaged current speed (m/s) on the ebb (-) and flood (+) tides for the instrument platform and a SUB buoy located at station location W1.

C-POD and icListenHF Range Tests – Platform

The instrument platform provided a stable platform for the testing of detection ranges for co-located C-PODs and icListenHF hydrophones. An Ocean Sonics speaker, the icTalk, was drifted multiple times over the instrument platform following platform deployments on 2 June 2014 and 12 June 2014 (Figure 4.6). The drift unit consisted of a spar buoy (floatation), rubber tubing (isolates surface movement of floatation from the hydrophone), GPS (accurate tracking storing one point every 5 seconds), and chimney sweeps to ensure the unit was vertical throughout the water column (Figure 4.7). A metal plate was added to the spar buoy to allow radar to locate the drift buoy. The icTalk was setup to produce a sound sweep from 120 to 140 kHz, over 0.1s followed by 1s of rest at 140 dB re 1μPa, and repeated for all drifts. The drifts spanned a 1 km radius from the platform station. A V13 acoustic tag, a secondary transmitter, was attached to the drifter just above the icTalk speaker.

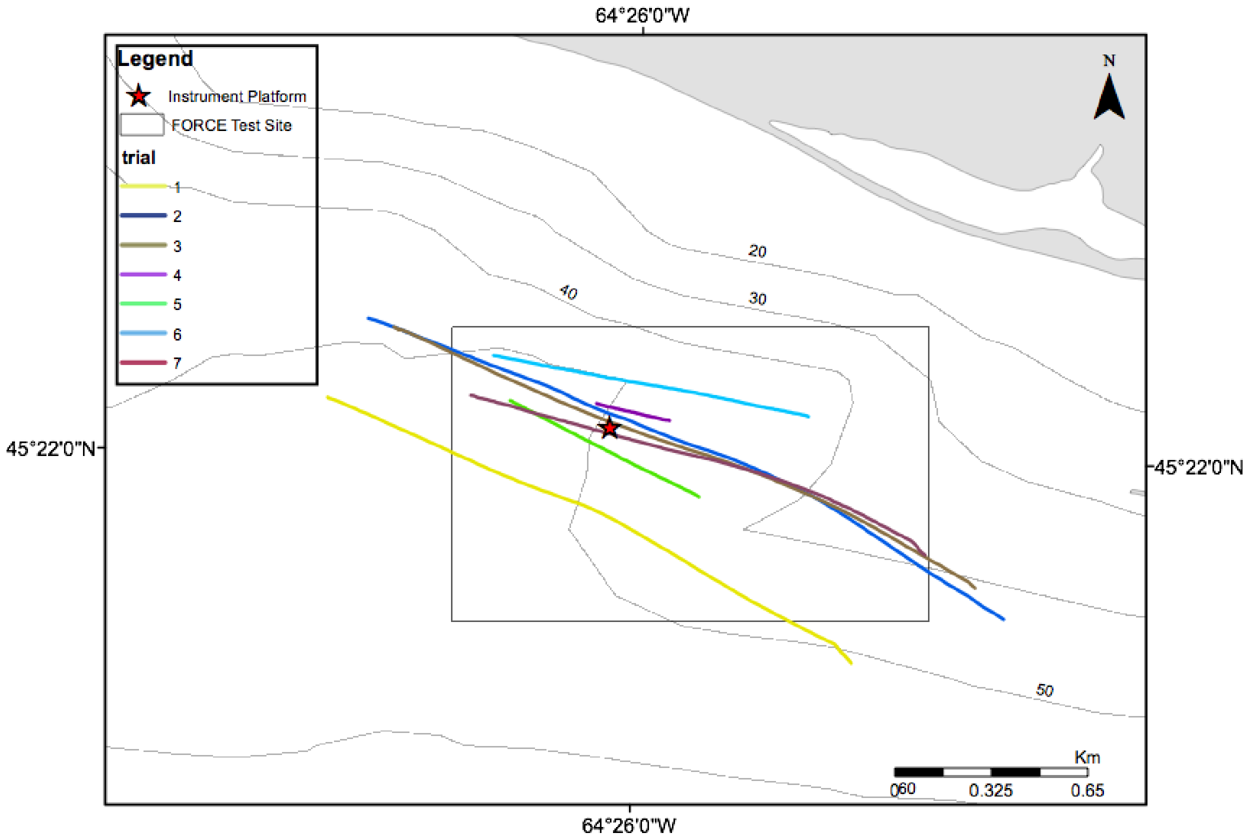


Figure 4.6. icTalk speaker tracks through the FORCE site and over the instrument platform (red star).

Figure 4.7. Spar buoy with GPS and radar deflector drifting over the instrument platform (lander). IcTalk speaker unit is drifting 2 m below surface.

The detection ranges (bins of 50 m) for the platform housed C-POD 1615 and iclistenHF 1239, in relation to depth-averaged current speed, are shown in Figure 4.8. The C-POD detected icTalk transmissions at all distances (up 300 m) but with greater detections at short range (<150 m) and low current speed (≤ 1 m/s). In contrast, the icListenHF hydrophone recorded a greater proportion of transmissions than the C-POD at all distances and current speeds (Figure 4.8).

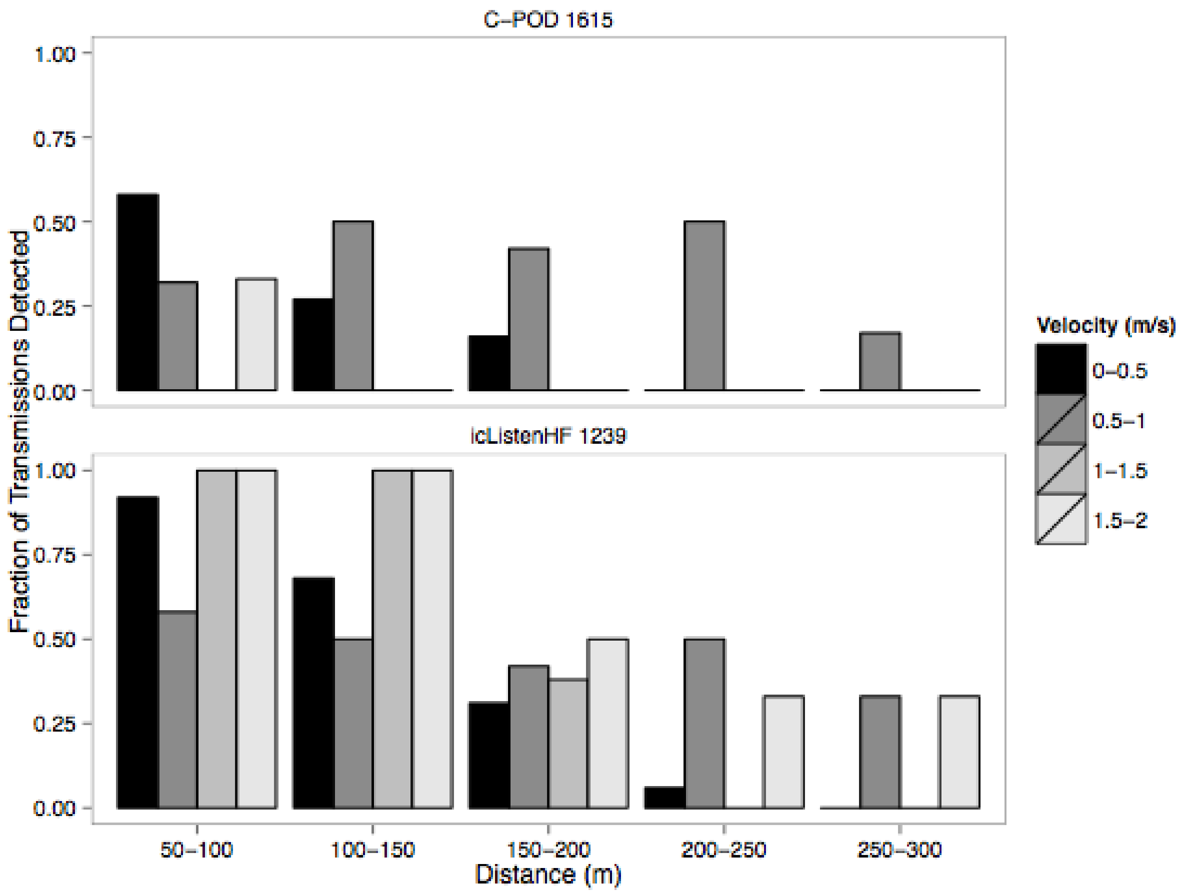


Figure 4.8. Fraction of icTalk transmissions detected by C-POD 1615 and icListenHF 1239 (shrouded) hydrophones. Detections are shown in relation to both distance from the icTalk speaker (drifting in surface waters about 50 m above the bottom) and depth-averaged current speed (m/s). Range test data were collected on 2 June and 12 June 2014.

An analysis of the soundscape and mean ambient noise measured (dB) by the icListenHF versus Frequency (kHz) shows that ambient noise increases with current speed and peaks for all speeds at about 13 kHz (Figure 4.9). The effect of current speed on ambient noise declines as frequency increases from 13 kHz to about 300 kHz. Interestingly, at icTalk sound sweep frequencies of 120-140 kHz, flood tide noise is greater than ebb tide noise only when depth-averaged current speed exceeds 2 m/s.

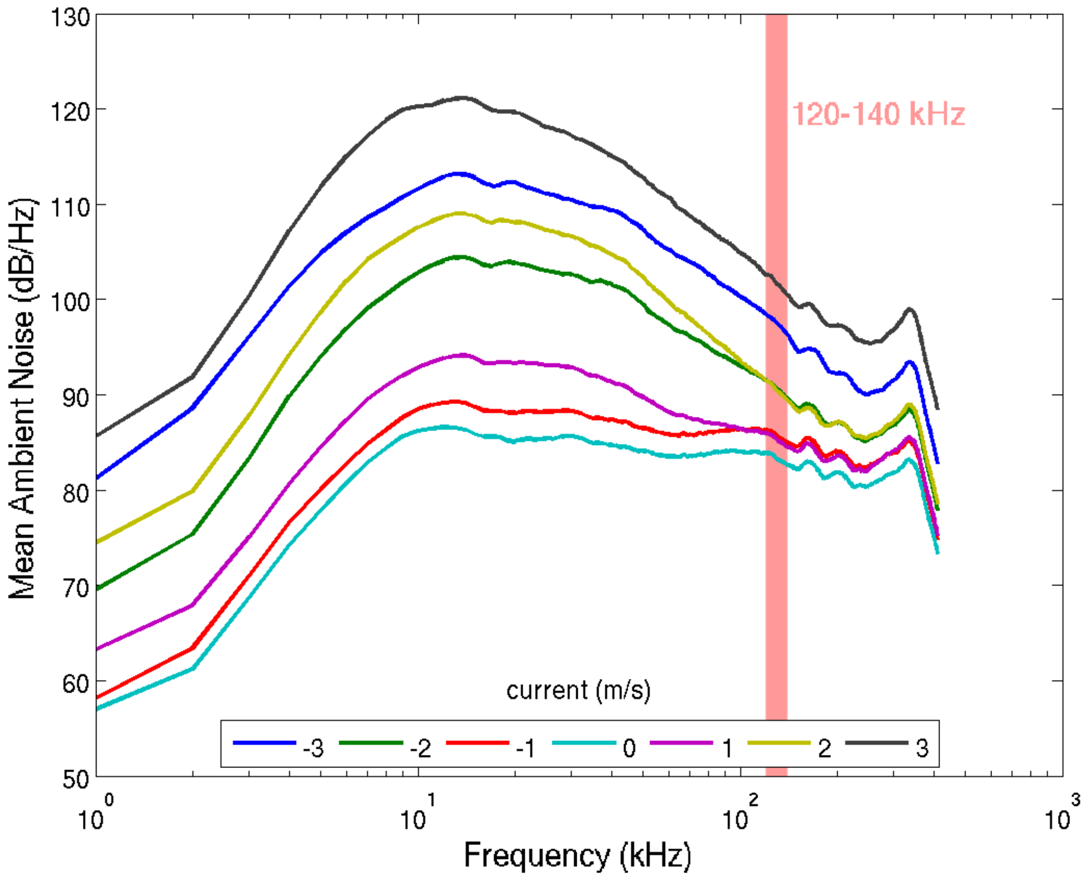
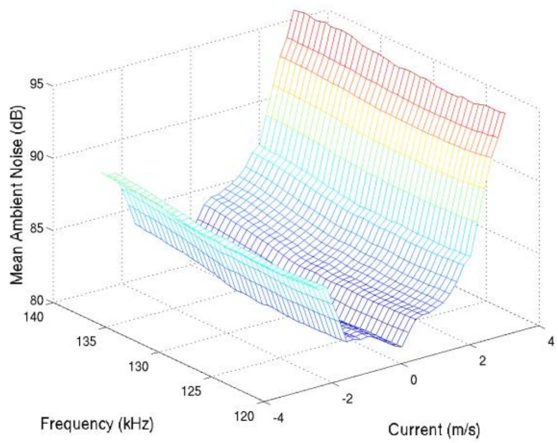


Figure 4.9. icListenHF 1239 hydrophone measures of ambient noise (dB/Hz)in Minas Passage, at FORCE monitoring location W1 during 6 June – 2 July 2014, as a function of frequency (kHz) for a range of current speeds (+/- 0.1 m/s) on the ebb (-) and flood (+) tides. The hydrophone was shrouded (20 ppi, ½ inch foam) and housed on the bottom moored instrument platform. Note that harbour porpoise echolocation click train frequencies are in the range of 120-140 kHz.

Effect of Shrouding on icListenHF Performance – Platform

Two icListenHF hydrophones, one with and one without a shroud, recorded soundscape data at location W1 (platform mounted) in June 2014. Figure 4.10 shows the mean ambient noise measures (db) for 120-140 kHz during 6-11 June 2014. The shroud reduced the ambient noise by <3 dB and the highest reduction occurred during high flows on the flood tide (Figure 4.11). Overall, the effect of the shroud at these frequencies was minor.



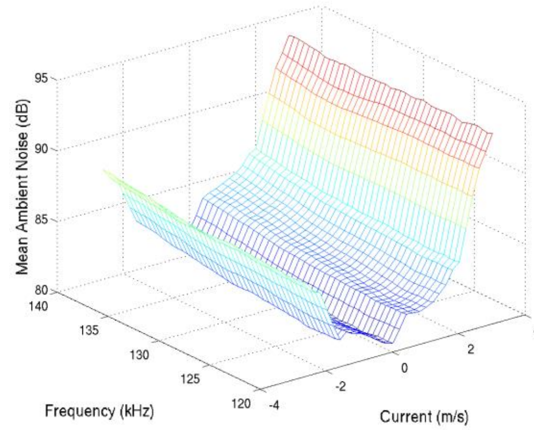


Figure 4.10. icListenHF hydrophone measures of mean ambient noise (dB) at 120-140 kHz, as a function of current speed (m/s), at location W1 during 6 June - 11 June 2014. ***Left****: hydrophone 1211 without a foam shroud;* ***Right****: hydrophone 1239 with ½ inch, 20 ppi acoustic foam shroud.*

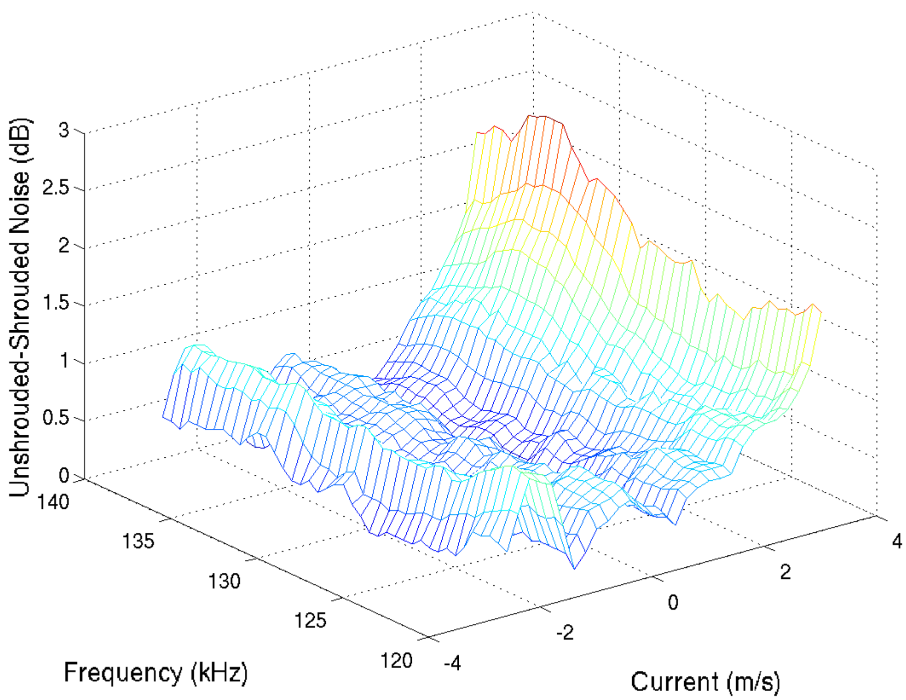


Figure 4.11. The difference in mean ambient noise (dB) between shrouded and unshrouded icListenHF hydrophones in Figure 4.10. Note that the difference is low overall (mostly <1 dB) and greatest at depth-averaged speeds >3 m/s on the flood tide.

5.0 General Discussion and Conclusions

C-POD data collected at several monitoring sites from 4 Dec 2014 to 2 July 2015 confirm year-round presence of harbour porpoise and was sufficient to close the winter / spring database gap (see Section 2). The updated GAM/GEE model uses the full dataset (2010-2014) to better predict porpoise presence in and around the FORCE test site (Figure 2.3) and identifies those covariates influencing C-POD detection of porpoises. As expected, the new model shows peaks in porpoise activity in late spring (June) and fall (October) with low presence in both summer and winter. The late spring peak in porpoise activity mirrors known movements of Atlantic herring (and other fishes) through the Minas Passage and their capture in intertidal weirs in Minas Basin. Greater porpoise click train detection at night shows that porpoises are using this time to feed; during much of the day they are at rest. As shown in Wood et al (2013), porpoises tend to avoid shallow water, preferring depths of 50 m or greater. This extended dataset and statistical model provides the baseline information needed for turbine installation/operation effects monitoring at FORCE.

Shrouding of the icListenHF hydrophone with acoustic foam (20 ppi, ½ inch) was shown to reduce flow noise in the tank tests. In the field, the shrouded hydrophone recorded a similar sound profile to the non-shrouded unit for the target frequency range 120-140 kHz (difference was < 3dB), with the difference being greatest at high current speeds on the flood tide (Figure 4.11).

An icTalk speaker was used as a sound source to mimic captive harbour porpoises for range testing purposes. Wild harbour porpoises can generate sounds 40 dB greater than captive porpoises (Villadsgaard *et al*., 2007) so the actual detection range for harbour porpoises in Minas Passage is likely to be a higher than that determined with the icTalk drift test. The icListenHF hydrophone greatly outperformed the C-POD in detections with both distance from the sound source (icTalk) and with current speed (Figure 4.8). The C-POD showed 20-55% detection efficiency at distances of 50-250 m, but did not detect any transmissions at distances greater than 100 m when depth-averaged current speeds exceeded 1 m/s (Figure 4.8). The shrouded icListenHF hydrophone detected 50-100% of icTalk transmissions at distances up to 150 m and >30% at distances of 250-300 m. Interestingly, an increase in current speed did not reduce the detection performance of the icListenHF hydrophone.

The two mooring types examined (tethered SUB buoy and bottom platform) presented different environmental conditions for hydrophone performance, and these are reflected in % time lost in C-POD recordings (Figure 4.4) and in tilt sensor data (Figure 4.5). Both % time lost and tilt were lower for C-PODs housed in the bottom-moored platform. The tethered SUB buoy (2-3 m above bottom) experiences extreme changes in tilt (up to 60 degrees) at high flow speeds compared to the platform, which remained in place throughout the deployment period. Noise that is generated by shackle and chain moment, vibrations, and strumming are likely to increase C-POD % lost time. C-POD comparisons at the same site (W1) showed that a platform mounted C-POD detected more harbour porpoise click trains than a C-POD housed in a SUB buoy unit (Figure 4.3).

Future monitoring efforts should consider use of a platform for deployment of an icListenHF hydrophone and C-PODs at a key site, with lower cost SUB units (with C-PODs) deployed at a range of sites for site comparisons and environmental effects monitoring.

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7.0 Acknowledgements

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8.0 Appendix

Table A1. Concordance correlation coefficients (CC) for the significant DPM10M covariates in the original GAM/GEE model with 2011-2013 data (Wood et al. 2013). Based on CC values each covariate was ranked. See related plot below (Figure A1).

Covariate	**Full CC**	**Covariate CC**	**Difference in CC**	**Rank**
Julian Day	0.1129	0.0820	0.0309	1
Tidal Velocity	0.1129	0.0906	0.0223	2
Tidal Height	0.1129	0.0927	0.0202	3
Location	0.1129	0.0969	0.0160	4
DNI	0.1129	0.0979	0.0150	5
% Time Lost	0.1129	0.0989	0.0140	6
Click Max	0.1129	0.1127	0.0002	7

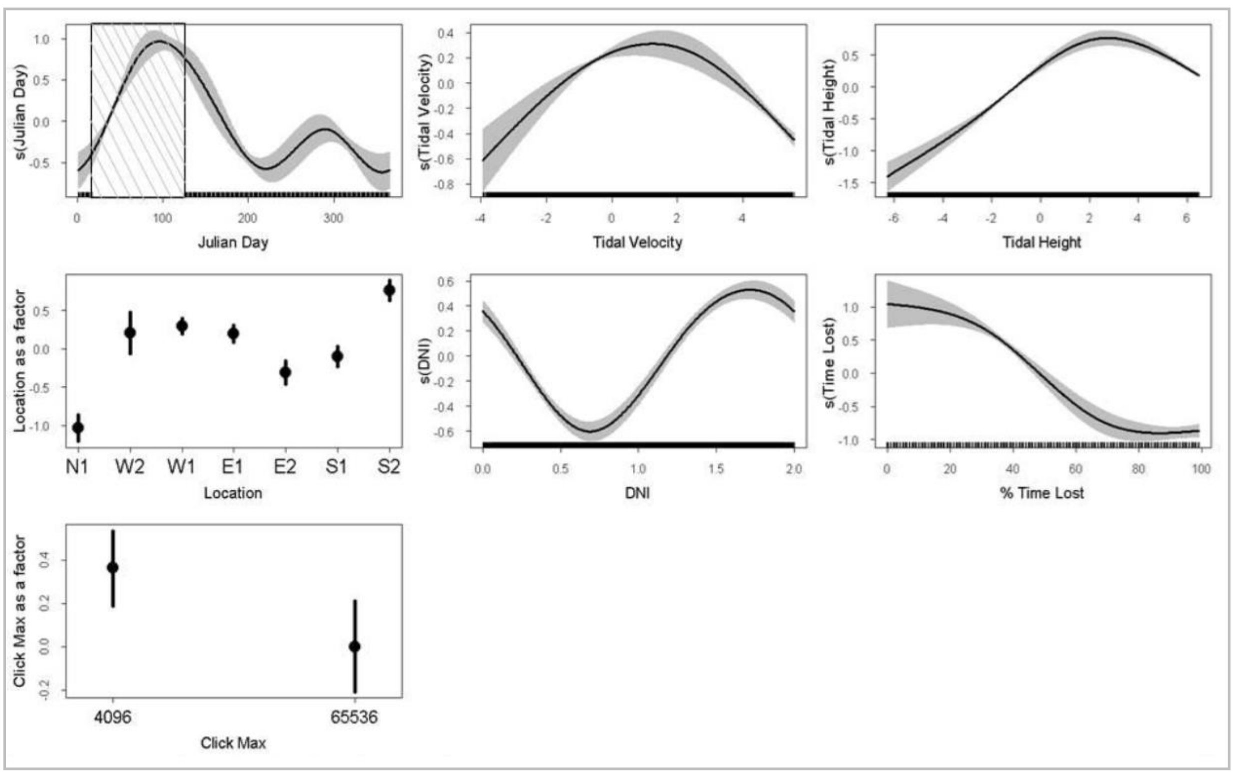

Figure A1. GAM/GEE plots of significant covariates and their relationship to porpoise DPM10M for spring- fall data during 2010-2013 (Wood et al., 2013). Shaded areas and error bars represent 95% confidence intervals. Covariates are shown in order of importance. Diagonal lines in the Julian Day plot indicate a period of no data.

Appendix B: Supplementary Information

Dissemination and Technology Transfer (since Oct 2013):

Presentations:

Peter Porskamp

- NS Energy R&D Forum, May 2014 (poster)
- ACCESS conference, Halifax, June 2014 Halifax (oral)
- MSc thesis in prep for completion in summer 2015

Anna Redden

- EIMR conference, Stornoway, Scotland, May 2014
- NS Energy R&D Forum, Halifax, May 2014
- OMAE conference, San Francisco, June 2014
- Coastal Zone Canada conference, Halifax, June 2014
- ICOE conference, Halifax, Nov 2014
- Various local public forums, 2014-2015

Journal article:

- in prep for submission to international journal: Estuaries and Coasts

Employment Summary:

Name	Position	Student (Yes/No)	PhD., MSc., Under-grad	Full or Part Time	Scientific contributions made to the research	Work-months associated with the Research Project
Jeremy Broome	Research Operations Manager & MSc student	Y	MSc	PT tech; PT student	Field technician, training of students, equipment prep and deployment, data management, report preparation	10 (part-time)
Peter Porskamp	MSc, Student	Y	MSc	FT, start 2013	Equipment prep, tank tests, field deployments and range testing, data downloads, data analysis, report preparation	16 (full-time)
Connor Sanderson	Assistant	Y	High School	PT	icListen spectrum viewing and data collection	0.5