Southern North Sea Harbour Porpoise Population Modelling Validation – Acoustic Processing Report

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Acronyms & Abbreviations

ADD	Acoustic Deterrent Device
AIC	Akaike Information Criterion
C-POD	Continuous Porpoise Detector
DC	Direct Current
EA1	East Anglia ONE
EC	European Commission
FBW	Full bandwidth
FCS	Favourable Conservation Status
GAM	Generalised Additive Model
HP	Harbour porpoise
iPCoD	Interim Population Consequences of Disturbance
IAMMWG	Inter-Agency Marine Mammal Working Group
ITT	Invitation to tender
JNCC	Joint Nature Conservation Committee
kJ	Kilojoule
kHz	Kilohertz
kU	Kilo-units
MU	Mega-units
ms	Milliseconds
NBHF	Narrow-band high-frequency
NOAA	National Oceanic and Atmospheric Administration
N_{PPM}	Number of Porpoise Positive Minutes
N_{PP10M}	Number of Porpoise Positive 10-Minute periods
N_{PPH}	Number of Porpoise Positive Hours
OSC	Ocean Science Consulting Ltd.
OWF	Offshore Wind Farm
PPH^{-d}	Porpoise Positive Hours per day
PPMs	Porpoise Positive Minutes
PPM^{-h}	Porpoise Positive Minutes per hour
PTS	Permanent threshold shift
QC	Quality Control
s	Seconds
SAC	Special Area of Conservation
SAMS	Scottish Association of Marine Science
SEL	Sound Exposure Level
SPL	Sound Pressure Level
SPR	ScottishPower Renewables
TTS	Temporary threshold shift
UTC	Coordinated Universal Time
UXO	Unexploded ordnance
WP-A	Work Package A
WP-B	Work Package B
WTG	Wind Turbine Generator

1 INTRODUCTION

1.1 Project Background

The harbour porpoise (*Phocoena phocoena*) is the smallest and most commonly observed cetacean species found in UK waters. The species is protected under UK and international regulations but is susceptible to overlapping anthropogenic pressures across its range, such as bycatch in fisheries, chemical contamination and noise pollution. Current regulations require that the Favourable Conservation Status (FCS) of the species be maintained or restored through appropriate conservation measures. As the harbour porpoise is listed under Annex II of the EC Habitats Directive (incorporated into UK legislation), there is an additional need to establish a network of Special Areas of Conservation (SACs) for the species. The Southern North Sea SAC is one such designated site (JNCC, 2019), and the ScottishPower Renewables' (SPR) East Anglia ONE Offshore Wind Farm (OWF), the focus of the current project, sits inside this SAC's boundary. For clarity, harbour porpoises in this area are considered part of the North Sea Management Unit as originally reported by ICES (2014) and described in more detail by IAMMWG (2015).

Cetaceans such as harbour porpoises are known to be sensitive to anthropogenic noise pollution, such as that produced by offshore construction activities involving pile-driving (e.g. Brandt et al., 2016; Carstensen et al., 2006; Teilmann and Carstensen, 2012). Considerable amounts of pile-driving related to the continued expansion of the offshore wind sector are either ongoing or forecast to occur over the next decade throughout the North Sea. There are concerns about auditory injury, acoustic masking and disturbance imposed upon animals from this activity, particularly when considering the cumulative impacts of different overlapping construction projects and noise from other industries such as shipping, and oil and gas exploration. This, in turn, has driven calls for more detailed assessments of how localised disturbances might impact the porpoise population across larger spatial and temporal scales, as well as the need to consider and mitigate potential cumulative effects.

One potential way to address these needs is through the use of predictive models. The interim Population Consequences of Disturbance (iPCoD; Harwood et al., 2014; King et al., 2015) and DEPONS (Nabe-Nielsen et al., 2018 & 2021) models have been specifically developed to predict potential population-level effects of construction and operation of offshore renewable energy devices on harbour porpoises. These models offer an approach for assessing and quantifying the potential for long-term, aggregate/cumulative effects of marine industrial activities, to improve strategic spatio-temporal planning, with a view to minimise impacts on harbour porpoise populations and not affect their FCS, as required under the EC Habitats Directive and derived national legislation.

1.2 Project Objectives

The current project seeks to clarify the consequences of the construction of the East Anglia ONE offshore wind farm (henceforth referred to as EA1) on the wider North Sea harbour porpoise Management Unit (hereafter referred to as 'the North Sea harbour porpoise population'). SAMS Enterprise (previously SAMS Research Services Ltd.; SRSL) aims to apply the two currently available population consequence modelling approaches developed for the North Sea (iPCoD and DEPONS) to EA1, underpinned by observations of harbour porpoise acoustic presence using autonomous porpoise click detectors (C-PODs) and full bandwidth acoustic recorders, collected during various stages of the construction process. SAMS Enterprise will assess applicability of the iPCoD and DEPONS models to EA1 data and evaluate these models' limitations and sensitivities to changes in crucial parameters, so that uncertainty in results, can be fully considered.

The project aims to:

- Determine how harbour porpoises respond to pile-driving activities at a local scale in and around EA1, on the basis of data collected through Work Package-A (ITT-752262);
- Assess the use of collected acoustic data as a proxy for behavioural responses of porpoises towards OWF construction, which could improve input parameters for future model applications;
- Run available model frameworks using project-specific input data, including those obtained from analyses of the acoustic data, to assess potential larger-scale or cumulative impacts; and,
- Evaluate and compare the suitability and sensitivity of iPCoD and DEPONS model approaches to assess population consequences to disturbance from pile-driving.

1.3 Document Purpose

The present Acoustic Processing Report (Document Reference 02564_0008) is part of a series of documents produced for SPR as part of the delivery of the Southern North Sea harbour porpoise population modelling project. This document should be read in conjunction with the Data Quality Control Report (van Geel et al., 2023a). The Method Statement should be referred to for additional information on the purpose and background of the project, whilst the Data Quality Control Report describes the quality control process undertaken on the raw acoustic full bandwidth and C-POD data after having received these data from Ocean Science Consulting Ltd. (OSC) via SPR.

This Acoustic Processing Report describes the acoustic processing undertaken to derive the various parameters required to apply the iPCoD and DEPONS modelling frameworks in a project-specific context. Specifically, the EA1 acoustic data were combined with sound propagation modelling and analysed using a Generalised Additive Modelling (GAM) approach. This was done to quantify the values for the Piling Impact Zone, the permanent threshold shift zone (PTS Zone), the number of Residual Disturbance days, the Response Threshold, the Absorption Coefficient, and the Spreading Loss Factor.

The application of population impact modelling frameworks will be detailed in the 'Population Impact Modelling' project output report (van Geel et al., 2023b).

2 METHODOLOGY

2.1 Site Description

SPR's EA1 wind farm is located in the southern North Sea, 43 km off the coast of southeast England. The site (300 km^2, average water depth 45 m) features 102 Siemens Gamesa turbines with a combined capacity of 714 MW[1]. Each turbine sits atop a three-legged jacket foundation, each leg of which required pin-piling operations for installation (2.5 m diameter piles); pin-piling was also required for the construction of the offshore substation. Collectively, this resulted in 310 individual pin-piling events. Other noise sources associated with EA1 construction included vessel noise, detonations of unexploded ordnance (UXO), and the use of Lofitech Acoustic Deterrent Devices (ADD) to exclude marine mammals from the construction and UXO detonation sites. Wind farm construction started in 2018, with pin-piling occurring non-continuously from 25th April 2018 until 30th January 2019, and the farm started operating in July 2020 (Figure 1).

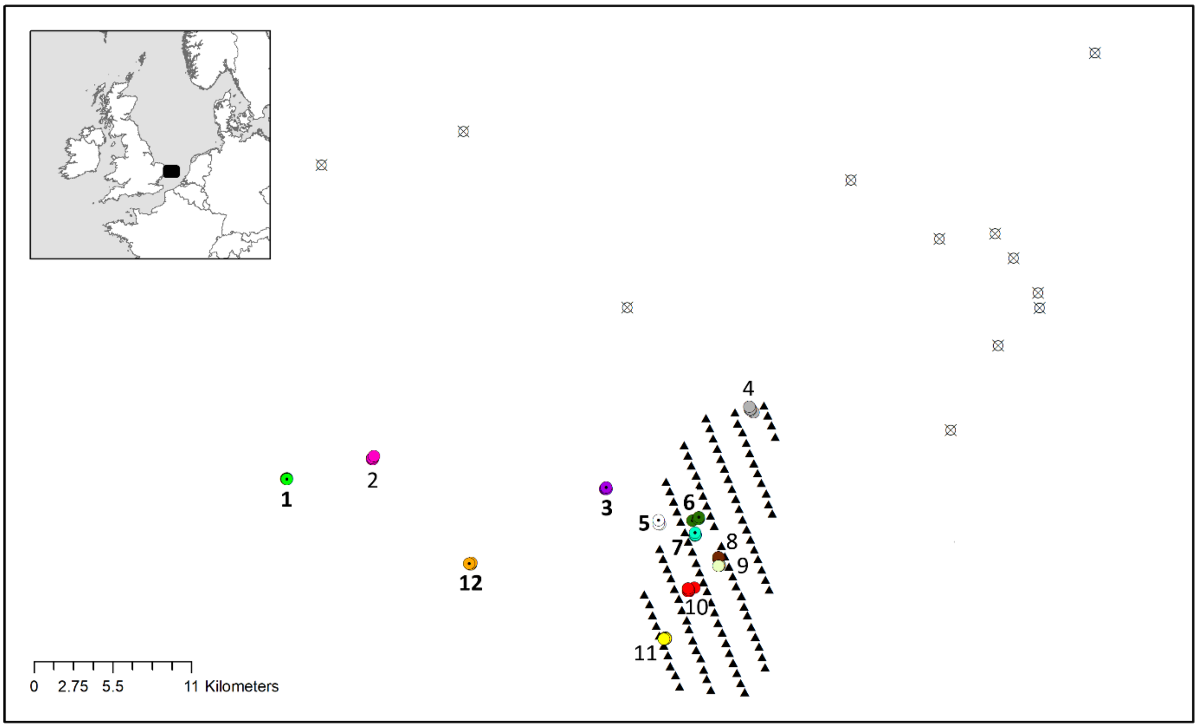


Figure 1. *Location of the SPR EA1 wind farm, with positions of individual turbines (black triangles) and acoustic monitoring locations (circles). Monitoring locations where both full bandwidth data and C-POD data were collected are indicated by a dot in the circle, and mooring location numbers are presented in bold type. Blank, crossed circles indicate the original, incorrect Leg 1 mooring deployment locations (see Section 2.3.1 for details). European country data from European Commission, Eurostat, GISCO @EuroGeographics and UN-FAO.*

[1] https://www.scottishpowerrenewables.com/pages/east_anglia_one.aspx.

2.2 Acoustic Data Availability

To investigate the consequences of the construction of the EA1 OWF on the wider North Sea harbour porpoise population, SPR has commissioned two work packages, as outlined in the tenders ITT 752262 (hereafter WP-A) and ITT 752263 (hereafter WP-B). Collectively, these two scopes of work sought to address the overarching question of whether EA1 might have an impact on the North Sea harbour porpoise population, and assess applicability of currently available population consequence models developed for the North Sea to wind farm project-scale questions.

WP-A involved the collection of harbour porpoise presence data (using C-POD bespoke porpoise click detectors; Chelonia Ltd.), and full bandwidth acoustic data (using RTSYS EA-SDA14 recorders) for the calibration of the transmission loss model, as well as to quantify ambient sound levels. This work was carried out by OSC from February 2018 until June 2019. These data were subsequently transferred to SAMS Enterprise for Quality Control (QC) checking and analysis as part of WP-B (van Geel et al., 2023a; current report). Data collection locations relative to the finalised wind farm are presented in Figure 1, with C-POD data collected at 12 sites, and full bandwidth (FBW) data simultaneously collected at six of these sites (Locations 01, 03, 05, 06, 07 and 12).

Terminology originally used by OSC to describe work undertaken under WP-A has been adopted throughout this report, with 'Leg' describing the deployment number; specific deployments are indicated by the combination of their Leg and OSC mooring location (e.g. 05_04 describing the deployment during Leg 05 at Location 04).

Controlled UXO clearing operations by high-order detonation occurred at various points during the construction process; in-depth analysis of the effects of absolute sound levels generated during these events is explicitly excluded from the scope of this project.

An overview of the overall monitoring effort is provided in Table 1. Figures 2 & 3 present a visualisation of the collected C-POD and full bandwidth data respectively, independent of suitability for further analysis. These data represent the starting point for the analyses described in the current Acoustic Processing Report.

Table 1. *Summary overview of WP-A monitoring effort as provided by OSC. Whilst the monitoring period covers deployment date to recovery date, some equipment was recovered by third parties before or after the general equipment recovery/change-over date. Additionally, the full bandwidth data collection typically ceased recording prior to retrieval when they ran out of battery power.*

Leg	*Monitoring period*	*Notes*
1	17/02/2018 – 11/03/2018	Incorrect deployment locations
2	11/03/2018 – 06/05/2018	No deployment at mooring Locations 07 & 08
3	05/05/2018 – 03/06/2018	Mooring Location 03 not recovered
4	03/06/2018 – 06/07/2018	
5	06/07/2018 – 13/09/2018	Mooring Location 02 not recovered
6	13/09/2018 – 16/02/2019	Mooring Locations 06 & 11 not recovered
7	16/02/2019 – 22/03/2019	
8	21/03/2019 – 22/05/2019	Mooring Location 01 not recovered
9	22/05/2019 – 21/06/2019	

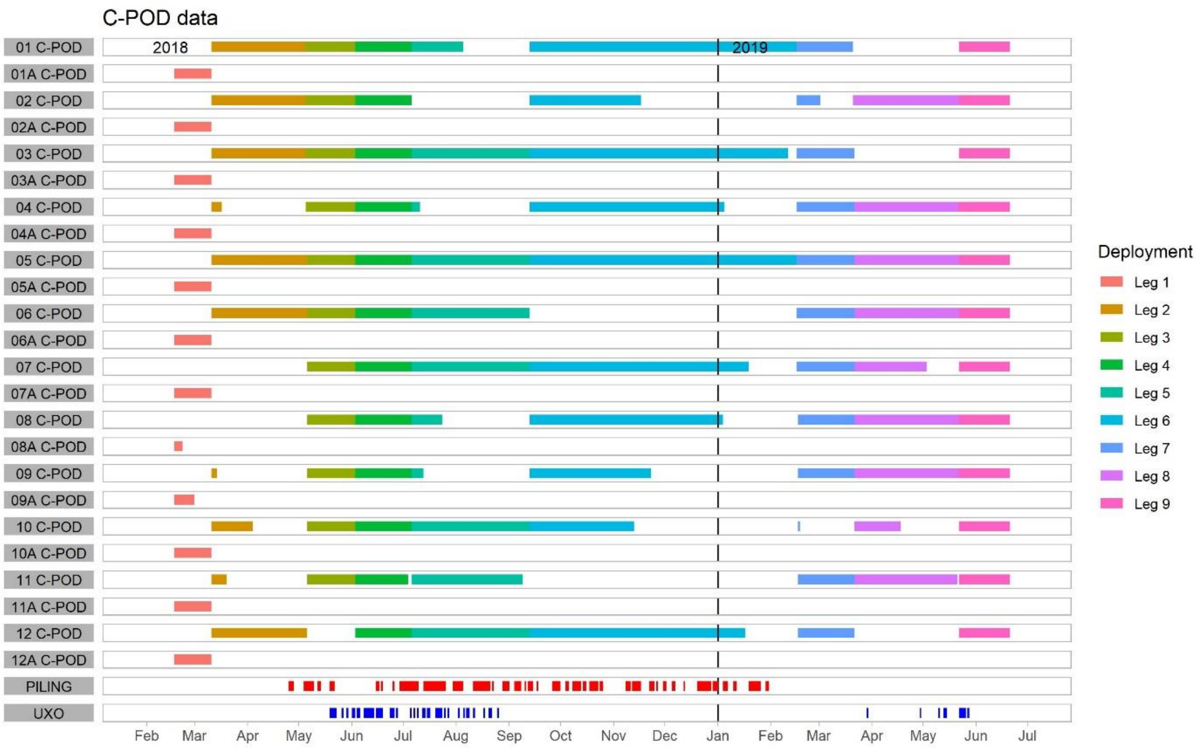


Figure 2. *Summary of C-POD data availability in relation to realised EA1 piling (bottom rows, in red) and unexploded ordnance (UXO) detonation activity (bottom rows, in blue). Data presented cover the period from C-POD deployment to retrieval, unless OSC reported that units had broken free before retrieval occurred. Leg 1 data are offset as they were accidentally deployed in incorrect locations; these data have not been used in subsequent analyses.*

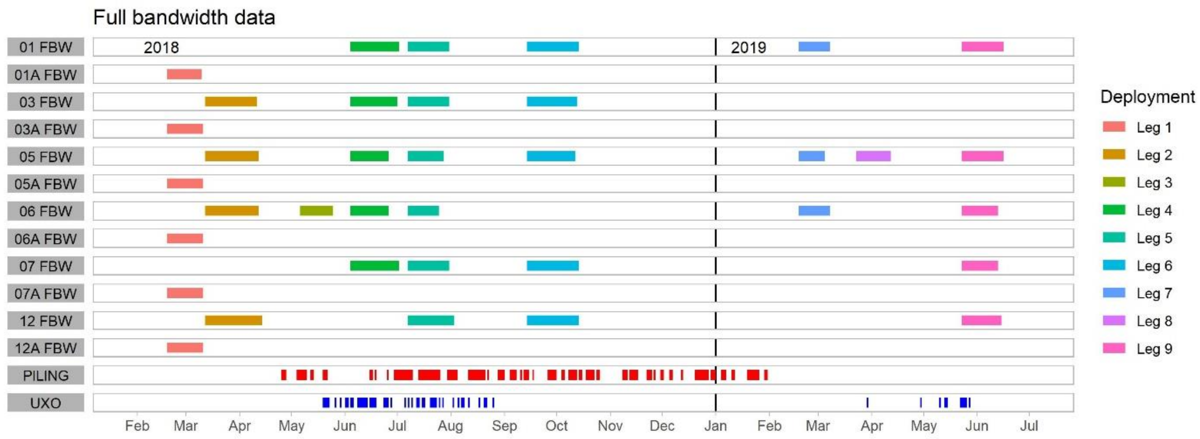


Figure 3. *Summary of full bandwidth data available in relation to realised EA1 piling (in red) and UXO detonation activity (in blue). Data presented cover the time period of acoustic FBW data present, independent of any issues encountered. Leg 1 data are offset as they were deployed in incorrect locations; these data have not been used in subsequent analyses.*

For the purpose of the current project, acoustic data were processed and analysed to derive project-specific input parameters required for the subsequent iPCoD and DEPONS population impact modelling. Specifically, the following input parameters (Nabe-Nielsen et al., 2021; Sinclair et al., 2019) were based on project-specific acoustic data:

- The overall project **Piling Impact Zone**, here defined as the area where harbour porpoise presence was negatively affected by piling activity throughout the duration of the construction phase; to be multiplied with harbour porpoise density information to obtain an estimate of the number of individual porpoises disturbed on a typical piling day (for iPCoD);
- The overall project **PTS Zone**, defined here as the modelled area in which harbour porpoises might be exposed to permanent threshold shift (PTS) if remaining within that area for a 24-hour period; to be multiplied with porpoise density information to obtain an estimate of the number of individuals experiencing PTS during each piling day (for iPCoD);
- The period of **Residual Disturbance** in addition to the actual piling day, here approximated by the Waiting Time and complemented by Recovery Time exploration (for iPCoD);
- The **Response Threshold**, defined as the received sound level above which porpoises are deterred (for DEPONS);
- The **Absorption Coefficient**; a frequency-dependent and site-specific parameter influencing sound transmission loss (for DEPONS); and,
- The **Spreading Loss Factor**; a constant influencing sound transmission loss (for DEPONS).

The conceptual framework of the process by which these parameters were obtained from the collected acoustic data, and their respective use in the subsequent population impact modelling, is illustrated in Figure 4.

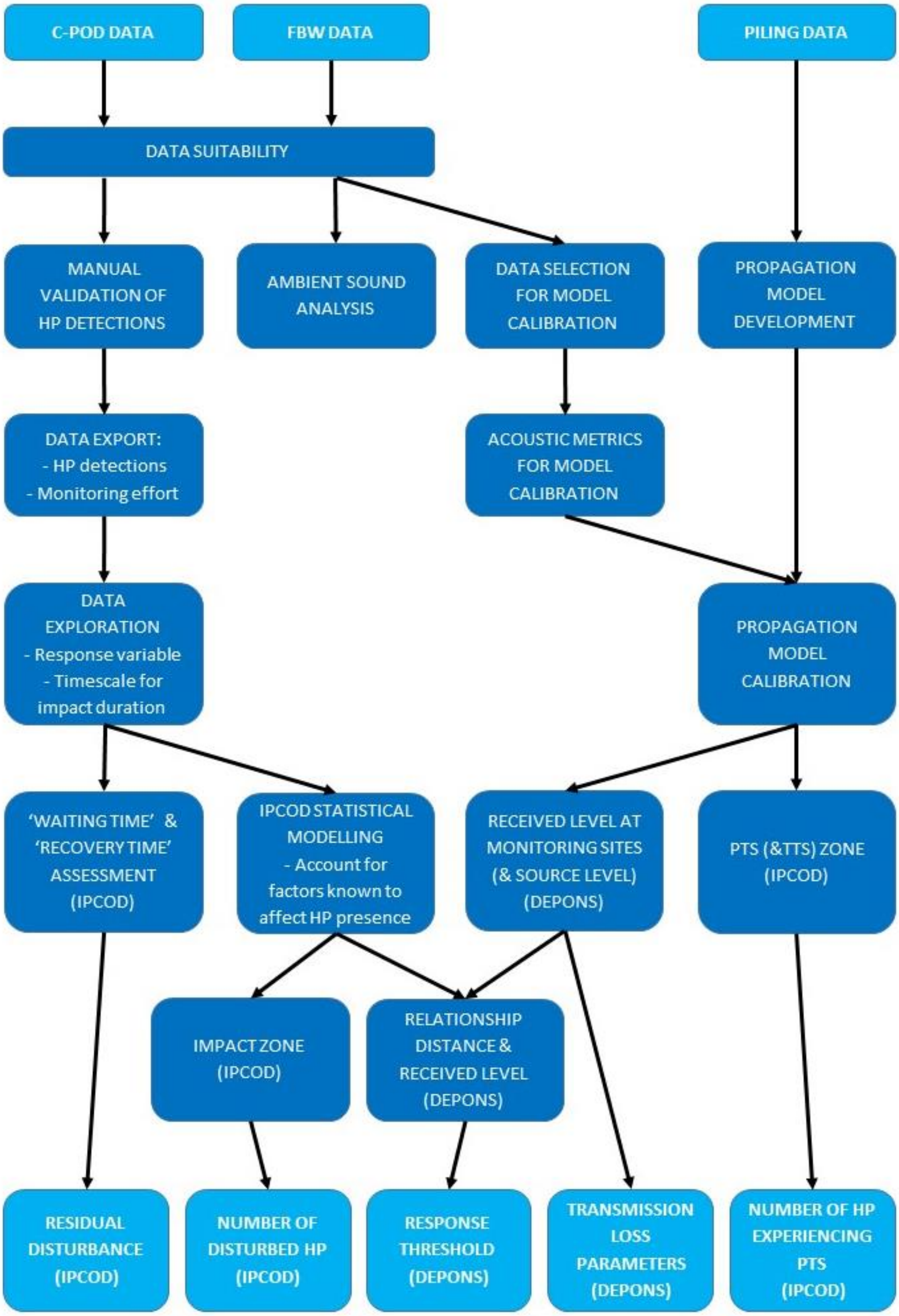


Figure 4. *Schematic data processing framework used in this project. FBW = full bandwidth data; HP = harbour porpoise. Note: The temporal threshold shift (TTS) Zone, is not a requirement for the population impact modelling. Nevertheless, the estimated overall TTS range is presented in this report.*

2.3 Harbour Porpoise Presence Data Analysis

2.3.1 Data suitability

All C-POD data were processed using the proprietary analytical software CPOD.exe (Version 2.044; Chelonia Ltd), applying the KERNO NBHF (Narrow-Band High Frequency) species classifier and the 'Hi' (high) and 'Mod' (moderate) train filter detection quality settings, as per guidance from the manufacturer (Chelonia Ltd., 2013). All data from Leg 1 were excluded from further analysis because recorders had been placed in incorrect locations, thereby invalidating their inclusion in the site-specific time series. Analysis of these Leg 1 data was outside the scope of the current project, although they could provide additional information on harbour porpoise presence in the wider EA1 area. Additionally, the QC process highlighted the need for a careful assessment of the data from those deployments where C-PODs were lost but subsequently recovered. A careful assessment of C-POD data (overall noise profiles, and data from their built-in inclinometer and temperature sensors) was undertaken to investigate which portions of data from these deployments were still usable.

2.3.2 Manual verification of harbour porpoise detections

The CPOD.exe software applies algorithms to identify harbour porpoise (NBHF) echolocation click trains and performs a quality assessment indicating the relative certainty of correct classification. As part of standard QC procedures, a subset of these detections requires manual verification to obtain information about the scale of false positive detections (i.e. sounds that have been incorrectly identified by the software as harbour porpoise click trains). If not accounted for, the presence of false positive detections may result in an overestimation of harbour porpoise occurrence; the extent of this problem depends on the number of false porpoise detections relative to the number of true porpoise detections, as well as on the temporal resolution used. This potential error can be site/noise-specific, and hence needs to be checked to assess whether adjustments to the data are necessary.

Data from Legs 4 and 9 were selected for initial manual verification because C-POD data were available from all 12 monitoring locations for these deployments. Following the manufacturer's guidance (Chelonia Ltd., 2013), the percentages of potential false positive porpoise detections (at a temporal resolution of individual minutes) relative to the total amount of Porpoise Positive Minutes (minutes containing at least one identified porpoise echolocation click train; hereafter PPMs) were calculated by checking at least 10% of PPMs spread throughout the monitoring period. Since not all individual C-PODs used in this project were deployed during either Leg 4 or Leg 9, seven additional deployment datasets were selected and manually verified to ensure that at least one dataset was reviewed for each individual C-POD used at any point during the entire data collection period.

In several cases, overall PPM detection rates were very low (i.e. <150 PPMs per deployment); in these situations, higher percentages of PPMs were manually verified (up to 100%). Based on guidance from the manufacturer (Chelonia Ltd., 2013), a decision was made to set the acceptable false positive rate at 10% of all PPMs within a given C-POD file. Should the observed false positive rate exceed this level, more in-depth evaluation of each individual click train (i.e. 100% of PPMs) in that file would be undertaken to determine whether the file should be carried forward into the next stage of analysis.

2.3.3 Harbour porpoise presence

To maximise options for analysis, harbour porpoise detection data were exported from CPOD.exe in various formats, including counts of Porpoise Positive Minutes (N_{PPM}), counts of Porpoise Positive 10-Minute periods (N_{PP10M}) and counts of Porpoise Positive Hours (N_{PPH}). These were subsequently converted to detection rates across different timescales (e.g. N_{PPM}/hour, N_{PPM}/day, N_{PP10M}/day, N_{PPH}/day). These outputs served as a basis for further data exploration and subsequent statistical modelling efforts (see Section 2.2.4). It is important to note that these represent conservative metrics of porpoise presence only, as porpoises may have been present but not detected because a) they were not vocalising, b) because their echolocation clicks are projected in a narrow beam that, for whatever reason, did not strike the C-POD receiver, and/or c) because they remained out with the C-PODs' detection range (typically limited to a few hundred meters, but variable depending on environmental conditions and vocalisation behaviour). It is also worth noting that individual porpoises cannot be identified using C-POD data, meaning that acoustic detections from such static recorders are, without substantial additional work (see Kyhn et al., 2012; Marques et al., 2012; Thomas & Burt, 2016; Jacobson et al., 2017), generally not suitable for absolute abundance estimation.

C-PODs were programmed to log a maximum of 4,096 click-like sounds of any origin during any given minute of data collection. Under particularly noisy conditions, such as when tidal currents cause sediment movement and acoustic self-noise, or in areas with high levels of vessel traffic, this limit may be reached prior to completing a full minute of monitoring. The C-POD then temporarily stops recording until the onset of the next minute, resulting in a temporary loss of recording capability, and thus reduced monitoring effort, during minutes where this 'buffering' occurs.

The QC process revealed that the 12 deployment locations were influenced by tides and exposed to other noisy activities to varying degrees, resulting in varying amounts of buffering throughout deployment legs. This resulted in variation in total C-POD monitoring effort among different monitoring locations as well as at the same location over time, complicating direct comparisons between monitoring locations and across the monitoring period. In order to be able to take this into consideration during the processing stage, the fraction of each minute not monitored was also exported (at a temporal resolution of individual minutes). This was subsequently visualised in combination with the detected porpoise presence data for each site to assess how actual monitoring efforts (with C-PODs activated for 60 minutes per hour, but with potential buffering occurring within each of these 60 minutes) may have affected porpoise detectability. Based on the observed site-specific relationships between porpoise detection and effective monitoring effort, it was decided that only hours monitored >90% of the time would be included in further analysis (except to obtain the Waiting Time – see Section 2.3.3.2).

2.3.3.1 Hourly porpoise presence

Following the broad-scale data exploration described above, data on hourly porpoise presence, assessed as Porpoise Positive Minutes per hour (PPM^{-h}), were collated for each of the monitoring locations. These were subsequently averaged on a daily basis and visualised to assess detected porpoise presence throughout the different stages of the EA1 project (i.e. pre-, during, and post-construction).

2.3.3.2 Waiting Time and Recovery Time

To assess for how long porpoises were displaced (or vocally inactive[2]) as a result of pile-driving, Waiting Times were calculated, defined here as the time interval (in minutes) between the end of piling and the first porpoise echolocation detection recorded thereafter. Waiting Times were calculated for each break in the piling schedule (the 'piling break') that exceeded three hours. Instances where the Waiting Time was longer than the piling break duration were excluded from this analysis. Likewise, those occasions where UXO detonations took place within the 24-hour period prior to the end of piling or during the piling break were omitted, unless porpoises were detected in the break before the UXO detonation occurred.

The Recovery Time was also assessed for the limited occasions where post-piling porpoise presence could be compared to a pre-piling baseline. Initial data selection was based on a non-piling period of >96 hours prior to individual turbine construction, and a post-piling break of >24 hours. Only turbine locations where piling was completed within a 24-hour period were included (thereby excluding e.g. situations where gaps of several hours occurred during the piling of any one particular turbine). As only four out of 102 turbines matched these criteria, the pre-piling gap requirement was reduced to >72 hours to increase sample size, resulting in an additional three turbines that could be used for the calculation of Recovery Time.

Following Graham et al. (2019), the reference baseline was defined as the 24-hour period starting 48 hours prior to piling (which was thus preceded by a 'quiet' period of minimal 24 hours). This approach also allowed for potential changes in porpoise presence in the 24-hour period prior to piling that could occur in response to increases in other construction-related activities (Brandt et al., 2016).

For each available C-POD dataset, comparisons were made between pre- and post-piling porpoise presence, quantified as both the proportion of PPH within a 24-hour period as well as the average hourly PPM within a 24-hour period. For cases where post-piling presence revealed a >0.1 reduction in proportional PPH, or >0.1 proportional decrease in average hourly PPM, the post-piling 24-hour period was shifted by 1 hour at a time until porpoise presence had recovered to within a difference of 0.1 compared to the reference period (Figure 5; Box 1).

The data exclusion process described in Section 2.3.3 reduced the number of hours within the assessed pre- and post-piling 24-hour periods available for analysis. For this reason, all data with ≤6 hours remaining in the pre- and/or post-piling 24-hour period were excluded, and Recovery Time results (in hours) were presented with a distinction between those based on 7-12 hours and ≥12 hours available for the assessment.

[2] Passive acoustic monitoring only provides information on the acoustic presence of animals. An absence of acoustic detections may indicate an absence of animals, or animals present but not vocalising or otherwise not detected.

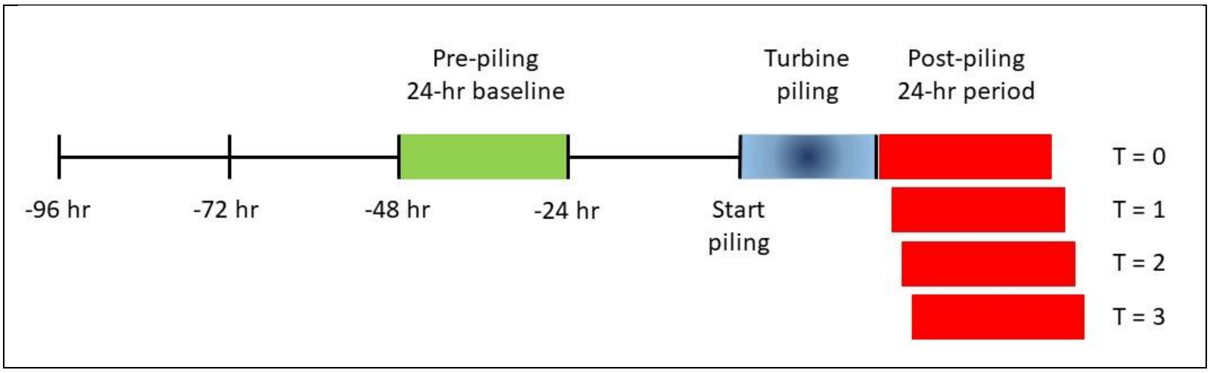


Figure 5. *Overview of pre-piling baseline and post-piling 24-hour periods used to assess changes in porpoise presence. Post-piling 24-hour assessment periods were shifted by 1-hour steps (T = 0 - 3 etc.) to identify the Recovery Time where post-piling presence returned to within a 0.1 decrease of baseline presence.*

Box 1. *Example of Recovery Time assessment for both approaches used to quantify porpoise presence.*

PPH:

Pre-piling baseline period:

12 Porpoise Positive Hours (PPH) within a 24-hour period results in a proportional presence of 12 / 24 = 0.5.

Post-piling period:

6 PPH within a 24-hour period with 18 hours of remaining effort (after exclusion of insufficiently monitored hours) results in a proportional presence of 6 / 18 = 0.33.

Difference in proportions:

0.5 - 0.33 = 0.17 reduction in proportional presence when compared to pre-piling baseline.

→ Recovery Time assessment: obtain the number of hours needed for the difference between pre- and post-piling presence to be <0.1 (i.e. the post-piling value recovers to >0.4 (0.5 - 0.1).

Average PPM^{-h}:

Pre-piling baseline period:

Hourly average of 5.62 PPM^{-h} for the 24-hour baseline.

Post-piling period:

Hourly average of 2.36 PPM^{-h} for the 24-hour period, calculated over the 18 hours of remaining effort.

Proportional difference:

2.36 / 5.62 = 0.42

→ Recovery Time assessment: obtain the number of hours needed for the post-piling value to be within a proportional reduction of <0.1 (i.e. post-piling value recovers to >5.06 (0.9 * 5.62).

2.3.4 Harbour porpoise presence modelling

The aim of the statistical porpoise presence modelling work was to obtain project-specific values for the parameters required for population impact modelling using iPCoD and DEPONS. Statistical modelling was undertaken to infer the Piling Impact Zone, to be multiplied with local porpoise density information to quantify the estimated disturbed part of the population, as required for the iPCoD modelling framework. Here, the predicted porpoise presence across different distances from the piling activity was compared to their distribution over distance in the absence of piling. Separate piling and non-piling baseline iPCoD modelling datasets were created to achieve this. The piling dataset contained all hours during which pin-piling activity took place. The non-piling dataset consisted of all non-piling days, except for the exclusion of the two calendar days prior to or following a piling day.

Numerous studies have provided evidence that harbour porpoise spatio-temporal distribution is related to environmental factors varying in space and time (e.g. Benjamins et al., 2017; Booth et al., 2013; Embling et al., 2010; Marubini et al., 2009; Skov and Thomsen, 2008; Williamson et al., 2017). Harbour porpoise presence in the EA1 area, as in the wider southern North Sea, is thought to vary seasonally and annually (Gilles et al., 2016; Heinänen and Skov, 2015; Paxton et al., 2016). As such, several cyclical covariate parameters, including diel, ebb-flood tidal and lunar cycles (driving spring/neap tides) were considered in the modelling; an overview of all explanatory variables considered for analysis is presented in Table 2. In addition to environmental and temporal variables, piling-related covariates were considered in the piling dataset only; these were excluded from the baseline model.

Sunset and sunrise times were obtained using the sun-methods function of the R '*maptools*' package (Bivand and Lewin-Koh, 2020) for Location 08 centred in the EA1 OWF. Tidal information was extracted from POLTIPS (Version 3.9.0/16; National Oceanography Centre). Distances of monitoring equipment to piling activity were calculated in QGIS. For each monitoring location, the distances for the non-piling dataset were randomly sub-sampled from the distribution of WTG-recorder distance combinations in the piling dataset.

To assess differences in the likelihood of harbour porpoise detection relative to distance from piling compared to their baseline distribution during non-piling periods, statistical modelling was conducted in R (Version 4.0.2; R Core Team, 2020) and implemented in the R package '*mgcv*' (Wood, 2017a) by means of a binomial GAM (i.e. modelling porpoise presence/absence) with a logit link function. The models were fitted via restricted maximum likelihood (REML), and model selection was based on Akaike Information Criterion (AIC) values. The model datasets were analysed at an hourly resolution; as specified above, only those hours effectively monitored >90% of the time were retained. During the statistical modelling process, the covariate "Distance" was always retained as this was required for the overarching project objectives.

Table 2. *Overview of candidate parameters considered in the statistical modelling. * Values across the piling and non-piling, as well as iPCoD and DEPONS datasets combined prior to data exclusions.*

Parameter	***Description***	***Values ****	***Modelled***
Response variable			
HP Presence	Hourly presence/absence of porpoise detections of 'Hi' or 'Mod' quality	0 = Absent 1 = Present	Response
Covariates of main interest			
Distance	Linear distance (in m) between each piling event and each C-POD deployment site	1,179 – 35,912	Linear; Smooth
Received Level	Measured frequency-weighted received sound level (in dB re 1 µPa^{2}s SEL; calculated over the 40 Hz – 16 kHz 1/3-octave band frequency range) at C-POD location	94.1 – 194.5	Linear; Smooth
Other covariates			
Leg	Identifier of successive deployments	2 – 9	Random effect
Location	Identifier of the deployment location	1 – 12	Random effect
Julian Day	Julian day	4 – 365	Cyclic smooth
Month	Calendar month	1 – 12	Cyclic smooth
Year	Calendar year	2018; 2019	As factor
Hour	Hour of the day (in UTC)	0 – 23	Cyclic smooth
Diel Cycle	Temporal position in the diel cycle; related to changes in daylight levels	0 – <1 0=1 = Sunrise 0.5 = Sunset	Cyclic smooth
Tidal Cycle	Temporal position in the tidal cycle; related to changes in the tidal cycle (water level & tidal flow speed)	0 – <1 0=1 = High tide 0.5 = Low tide	Cyclic smooth
Lunar Cycle	Temporal position in the tidal cycle; related to changes in changes in Spring-Neap tidal cycle (water level & tidal flow speed)	0 – <1 0=1 = Spring tide 0.5 = Neap tide	Cyclic smooth
Project Day	Numbered sequence of days from the beginning of the project	1 – 468	Linear; Smooth
Cumulative Piling Day	Numbered sequence of piling days throughout the project	1 – 136	Linear; Smooth
Consecutive Piling Day	Numbered sequence of consecutive piling days without a break (i.e. calendar day without piling)	1 – 13	Linear; Smooth
Hammer Energy	Maximum hammer energy (in kJ)	475 – 1,169	Linear; Smooth
Source Level	Modelled frequency-weighted piling source level (in dB re 1 µPa^{2}s SEL at 1 m)	178.3 – 182.2	Linear; Smooth
UXO Day	Presence/absence of UXO detonation (or attempt) that day	0 = Absent 1 = Present	As factor
UXO Hour	Presence/absence of UXO detonation (or attempt) that hour	0 = Absent 1 = Present	As factor
C-POD Number	Individual C-POD ID number	825 – 3,199	Random effect
Angle	Angle (in °) describing C-POD deviation from vertical	0 – 84.5	Linear; Smooth
Number of Clicks	Average number of unfiltered clicks recorded per minute within an hour; index of noise levels	0 – 4,095	Linear; Smooth

Data exploration included testing for concurvity[3], with selected covariates excluded from further modelling when high (>0.8) worst-case concurvity estimates were present between pairs of covariates. The model fitting approach broadly followed Pirotta *et al.* (2011). First, several covariates were tested for their inclusion in linear form, or incorporation as a smooth term (see Table 2). Secondly, a full model, including all remaining potential covariates, was identified and stepwise backward model selection was applied to identify the best subset of covariates. Next, the selected covariates were included in the model in order of declining importance (i.e. the first covariate would lead to the biggest increase in AIC if excluded from the model). The significance of each covariate was tested using the Wald's test; using a significance threshold of $\alpha = 0.05$, non-significant covariates were excluded from the model. Finally, the parameter k-values (related to the degrees of freedom allocated to a smooth) were optimised, at each step excluding those covariates that had become non-significant as a result of alteration of the k-value.

Following final model selection for the piling and non-piling datasets, posterior simulation was undertaken (Wood, 2017b; Section 7.2.7). Posterior simulation allows for the quantification of the trend in the probability of porpoise presence as a function of Distance (or Received Level; see below), whereby the values of other model covariates, and their uncertainties, are taken into account. Additionally, this approach allows predictions to be made over covariate value combinations not present in the original dataset.

The prediction matrix was generated over a prediction grid representing ~740,000 (piling) and 1.5 million (non-piling) possible combinations of values for the covariates that were included in the fitted model. This matrix maps the model parameters to the predictions of the linear predictor for any supplied values of the covariates. Next, 500 replicate parameter vectors were randomly sampled from the posterior distribution of the parameters by taking 500 multivariate normal samples from the posterior distribution of the model coefficients. These parameter vectors, containing the coefficients for the model intercept and each model term, were multiplied with the prediction matrix, and the inverse link function was applied to generate the predictor values on the response scale (i.e. probability of acoustic porpoise presence) for the given set of covariate values specified in the prediction grid. The median predicted smooth and associated 95% confidence intervals for the relationship between Distance and the probability of porpoise presence were visualised for the piling and non-piling datasets using the R package '*ggplot2*' (Wickham, 2016).

The Response Threshold, for incorporation in the DEPONS modelling framework, was subsequently derived by using the relationship between Distance and the estimated frequency-weighted Received Level at the C-POD deployment sites (in dB re 1 $\mu Pa^2 s$ Sound Exposure Level as obtained from the propagation modelling; see Section 2.3.3). Here, the Response Threshold is the frequency-weighted Received Level corresponding to the impact range obtained from the statistical modelling described previously.

[3] Concurvity occurs when a model smooth term could be approximated by one or more of the other smooth terms in the model. Such non-linear dependencies among predictor variables may lead to instability of the estimated coefficients in GAMs (Amodio et al., 2014).

Given the significant amount of full bandwidth (FBW) data collected (see Section 2.3), a second approach to quantify the Response Threshold considered the measured frequency-weighted Received Level from the FBW data. These measured levels also included sound from non-piling sources; in contrast, the aforementioned estimated levels derived from the propagation modelling were solely based on modelled piling noise. For this alternative approach, the non-piling baseline dataset consisted of all acoustic files for each location collected on non-piling days, with the additional exclusion of the two calendar days prior to or following a piling day. The piling dataset included all acoustic files for each hour in which piling took place, independent of whether piling was actually recorded in each individual sound file. Median hourly frequency-weighted Received Levels were calculated for the piling and non-piling datasets over the 40 Hz – 16 kHz 1/3-octave bands (i.e. 35.481 Hz – 17.783 kHz; coinciding with the frequency range over which the piling signal was distinguishable from background noise; see Appendix E). These were incorporated into separate statistical models with the relevant additional environmental, temporal and piling-related variables (summarised in Table 2). In total, the original piling dataset consisted of 444 hours of data, whilst the original non-piling dataset contained 2,356 hours of data. Following limited amounts of data exclusion during the statistical modelling process, this resulted in 421 and 2,168 hours, respectively, included in the modelling for each of these datasets. The same analytical approach was followed as for the iPCoD data described above (i.e. GAM modelling to solve for the Distance parameter), although these DEPONS model datasets included the measured frequency-weighted Received Level (instead of Distance) as the main covariate of interest. The prediction grids for the DEPONS piling and non-piling datasets contained >300,000 and one million possible combinations of values for the covariates, respectively (reflecting a smaller number of covariates, and a smaller range of values for the model covariates, for the fitted piling model). The final fitted non-piling model included Received Level as the 6th term, and it only explained a limited amount of the variation present in the data. As such, comparison with the probability of porpoise presence under piling conditions (where Received Level was the most important explanatory variable), was impeded and the applied approach did not work. The results of this analysis will thus not be presented or discussed further in this report; the primary reason for its inclusion here is to record that this effort took place.

2.4 Full Bandwidth Data Analysis

2.4.1 Data suitability

Various potential issues pertaining to the full bandwidth acoustic data were identified during the QC process (van Geel et al., 2023). In particular, the gain settings applied during Leg 1 and Leg 2 were too high, resulting in substantial clipping of the waveform throughout, rendering the data unusable for sound level analysis. These data were therefore omitted from further processing.

Additionally, during Leg 6, there were various indications that the equipment deployed at Location 07 had started moving away from its intended monitoring location soon after deployment. These indications included the lack of piling noise in the FBW recordings, absence of concurrent piling activity in the C-POD acoustic data, atypical C-POD tilt and noise data compared to other data collected at this site, and recordings by OSC of an unsuccessful retrieval attempt during equipment change-over and eventual return of the equipment from abroad. Consequently, FBW data from this particular deployment were also excluded from further analysis.

The QC check revealed that the signal response for deployment 04_05 was low. Noise levels obtained were compared to those simultaneously received at other locations, and to those from other deployments at Location 05, in order to assess whether the data from 04_05 could be retained or needed to be excluded from further analyses. This assessment indicated these data should be excluded.

Whilst the data exclusions mentioned above involve entire deployments, previous inspection of sample sound files (a minimum of four per deployment day) during the QC process using Raven Lite software (Version 2.0.0; Cornell Lab of Ornithology) also highlighted some issues with individual files. In several cases, waveform and spectrogram visualisation revealed the presence of problems such as corrupted files, files with sections during which no data were collected, as well as files with DC offset jumps (described in more detail in van Geel et al., 2023). In these situations, all other sound files recorded during these deployments were manually assessed and excluded if necessary. Since these issues might have been related to an undiagnosed technical issue within specific FBW devices, the data from other deployments collected by the same device received increased scrutiny, with up to 100% of all recorded files examined if it was considered necessary.

2.4.2 Data for propagation model calibration

Once all FBS-associated data (acoustic recordings, piling schedule and Acoustic Deterrent Device (ADD) activation schedule) were correctly aligned to UTC, these datasets were evaluated with a view to identify suitable subsets of data for calibrating the transmission loss model (see next Section). The selection of FBW data for this calibration was based on the following criteria:

- Recordings of piling activity (approximately 10 minutes in continuous duration) should be available from all six FBW monitoring locations;
- The piling signal should not be clipped in the sound files from any of the recorders;
- The piling signal should be clearly distinguishable in the signal waveform;
- Recordings should be clean without other noises present such as those caused by strumming moorings or nearby vessels. To this end, they should also not coincide with the three–hour period before or after a UXO detonation;
- Recordings should start at least 30 minutes after the start of piling, to avoid inclusion of data collected under ‘soft start’ procedures (which were reported to last 20 minutes); and,
- The recording should include a break within or cessation of piling to allow synchronisation of acoustic signals recorded at different sensors to account for different arrival times.

For the selected data, peak sound pressure level (peak SPL; $L_{p,\mathrm{pk}}$; in dB re 1 µPa) was computed for 35 1/3-octave bands with a nominal central frequency ranging from 25 Hz to 63 kHz over a 1-second window using a customised MATLAB script. The resulting measurements were provided to Xi Engineering Consultants for incorporation in the propagation model calibration procedure.

2.4.3 Propagation modelling

A site-specific transmission loss model was developed by Xi Engineering Consultants. The model integrated two techniques for modelling the propagation of underwater noise, each of which was appropriate for specific frequency ranges. For each of these techniques, the model incorporated data on local bathymetry, sediment type, sound attenuation in seawater, piling location, piling schedule and hammer energetics, and was calibrated using acoustic measurements of the selected FBW field data provided by SAMS Enterprise. Following the protocols set out by Southall et al. (2019) and NMFS (2018), the model was applied to calculate the porpoise frequency-weighted Source Level of piling at each WTG location as sound exposure level (SEL; $L_{E,p}$; in dB re 1 µPa^{2}s at 1 m; based on maximum hammer energy), and to derive frequency-weighted Received Levels (as SEL in dB re 1 µPa^{2}s) at the C-POD deployment locations during construction of each WTG. The harbour porpoise weighting functions (i.e. high-frequency and very high-frequency functional marine mammal hearing groups in NMFS (2018) and Southall et al. (2019) respectively) are computationally identical between these sets of guidelines, as are the associated PTS and TTS threshold values (24-hour SEL thresholds of 173 and 153 dB re 1 µPa^{2}s, respectively). Additionally, frequency-weighted PTS and TTS radii were computed per 24 hours, assuming stationary animals. From this, the extent of the PTS Zones could be inferred for each modelled scenario.

Whilst calculations of frequency-weighted Source Level and Received Level were solely based on pin-piling noise, sound generated by the Lofitech ADD (used to explicitly deter marine mammals away from the immediate area surrounding the construction site; Brandt et al., 2013) was also incorporated in the computation of the PTS and TTS radii.

For a more detailed methodological description, please refer to Appendix E, which contains the Propagation Modelling Report produced by Xi Engineering Consultants.

In DEPONS Versions 2.1 and 2.2, incorporation of the transmission loss equation within the agent-based modelling framework allows adjustment of the Spreading Loss Factor ($\hat{\beta}$) and Absorption Coefficient ($\hat{\alpha}$), which collectively determine the sound transmission loss, and thus the received level (R) animals are exposed to at various distances from the piling (dist(p,k); in meters) (Equation 1) (Nabe-Nielsen et al., 2021).

$$R = SL - \hat{\beta}\log_{10}\big(\text{dist}(p,k)\big) - \hat{\alpha}\,(\text{dist}(p,k)) \qquad \text{[Eqn. 1]}$$

The values of these parameters should be adjusted to best approximate the relationship between the modelled Source Level and the at-distance modelled Received Level, upon which the GAM modelling of the Response Threshold is based so that impact ranges in DEPONS align with those of the underlying modelling data.

The Absorption Coefficient is frequency-dependent, and can be calculated over a wide range of frequencies (f, in kHz) using Equation 2 (Malme et al., 1995):

$$\hat{\alpha} = 0.036\, f^{1.5} \text{ (dB / km)} \qquad \text{[Eqn. 2]}$$

As piling noise has a broadband character, the Absorption Coefficient was calculated for the dominant frequency (1/3-octave band) identified by reviewing the frequency-weighted piling Source Level spectra derived from measurements of the FBW data selected for calibration of the developed noise transmission loss model (see also Appendix E).

To obtain the Spreading Loss Factor, the modelled frequency-weighted Received Levels and Source Levels for each constructed WTG pin-pile A (as identified in the piling schedule) were plotted in R against the distance from piling for each available pin-pile – C-POD combination. The best-fitted $\hat{\beta}$ value was extracted using the mean Source Level associated with these pin-piles.

2.4.4 Ambient sound analysis

FBW data were analysed using a modified version of PAMGuide (Merchant et al., 2015). Sound pressure levels for the entire dataset was processed at 1-second resolution, using a Hann window, and 0% window overlap for the 1/3-octave bands centred on 25 Hz – 63 kHz. Median 1/3-octave SPL (in dB re 1 µPa), and various additional percentile statistics (5, 10, 25, 75, 90 & 95th percentiles) were computed to present the spatio-temporal variability in ambient sound levels across the EA1 monitoring locations. Processing outputs were then aggregated to present ambient sound conditions coinciding with piling activity, as well as when no piling activity was taking place. A maximum non-piling period of 5 s was accepted at the start or the end of an acoustic file. All acoustic files with more than 5 s non-piling were excluded from the piling dataset.

3 RESULTS

3.1 C-POD data

3.1.1 Data suitability

The detailed assessment described in Section 2.2 identified data from 86 out of 112 independent deployments as being suitable for further analysis in this project. Whilst the data from the first deployment (Leg 1) were excluded entirely, specific sections of data from additional deployments were also excluded, in addition to recording periods already excluded by OSC (Table 3).

Table 3. *Overview of C-POD data excluded from further analysis over and above the recording periods already excluded by OSC during WP-A[4]. * The C-POD continued to collect data until 31/01/2019, but the deployment change-over date was recorded as 13/09/2018.*

Deployment (Leg_Location)	Data collection period	Data excluded by SAMS Enterprise following detailed assessment
01_01	17/02/2018 – 11/03/2018	Entire deployment
01_02	17/02/2018 – 11/03/2018	Entire deployment
01_03	17/02/2018 – 11/03/2018	Entire deployment
01_04	17/02/2018 – 11/03/2018	Entire deployment
01_05	17/02/2018 – 11/03/2018	Entire deployment
01_06	17/02/2018 – 11/03/2018	Entire deployment
01_07	17/02/2018 – 11/03/2018	Entire deployment
01_08	17/02/2018 – 22/02/2018	Entire deployment
01_09	17/02/2018 – 01/03/2018	Entire deployment
01_10	17/02/2018 – 11/03/2018	Entire deployment
01_11	17/02/2018 – 11/03/2018	Entire deployment
01_12	17/02/2018 – 11/03/2018	Entire deployment
05_03	06/07/2018 – 13/09/2018 *	28/08/2018 – 13/09/2018
06_03	13/09/2018 – 11/02/2019	17/01/2019 – 11/02/2019
06_07	13/09/2018 – 19/01/2019	16/09/2018 – 19/01/2019
06_12	13/09/2018 – 17/01/2019	18/10/2018 – 17/01/2019
07_02	16/02/2019 – 02/03/2019	28/02/2019 – 02/03/2019

Most of the additionally excluded data, as well as the data exclusion periods already identified by OSC, related to Leg 6 when C-PODs were deployed in September 2018, but equipment change-over did not occur until February 2019. This prolonged deployment period, in combination with severe winter weather, caused more C-PODs to break from their moorings compared to other Legs, resulting in an increased amount of data having to be excluded post-recovery.

An overview of the final remaining C-POD dataset available for subsequent analysis is presented in Figure 6. Suitable C-POD effort differed between monitoring locations and through time. Location 05 is unique among the datasets in that C-POD data were collected without interruption throughout the

[4] See Excel document OSC_2019_SPR_EA1_PODSettingsDeployment_SAMS_5.0 received via SPR 04/09/2019.

survey period. Overall, data were available across most of the intended monitoring period, although the amount of pre-piling data available was limited following the exclusion of Leg 1 data, and fewer data were available for the 2018/2019 winter period, mainly due to C-POD and/or mooring failure during Leg 6.

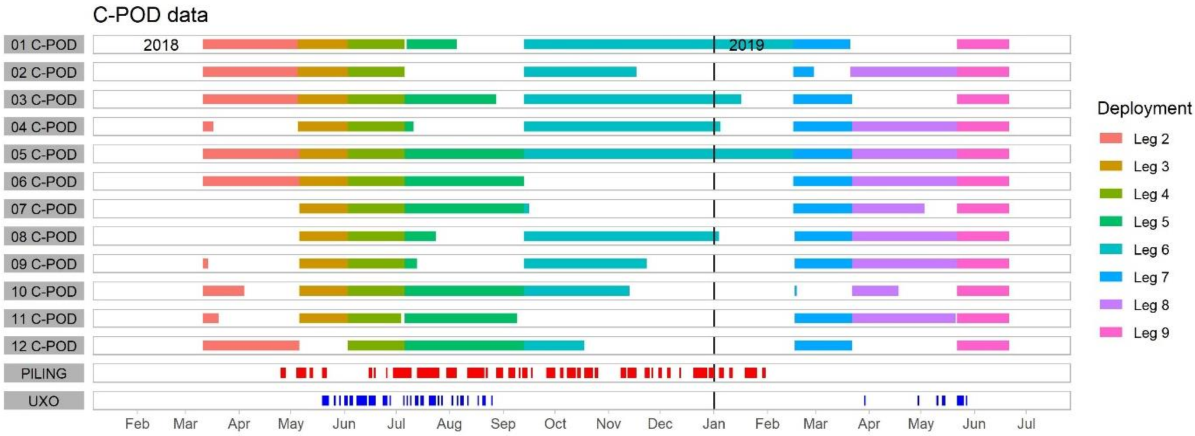


Figure 6. *Summary of C-POD data suitable for subsequent analysis, in relation to realised EA1 piling (at bottom, in red) and Unexploded Ordnance (UXO) detonation activity (at bottom, in blue).*

3.1.2 Manual verification of harbour porpoise detections

Manual verification was undertaken for 31 of 86 independent C-POD deployments. Based on a conservative assessment, the percentage of potential false positive harbour porpoise detections in the manually verified data ranged between 0 – 8.3%. For 25 deployments, the percentage of potential false positive detections was <5% (Table 4). As the pre-set critical false positive rate of 10% of the PPMs previously identified by the software was not exceeded in any of the reviewed C-POD files, the decision was made to continue with the analysis using all available C-POD data.

Table 4. *Overview of manually verified individual deployments and associated percentages of false positive harbour porpoise detections ('Hi' & 'Mod' quality), based on the validation of at least 10% of detection-positive minutes. * Due to the limited number of porpoise detections identified by the software during these deployments, either >30% or 100% of potential detections were manually validated.*

Deployment (Leg_Location)	$N_{Minutes}$ (entire deployment)	N_{PPM} (entire deployment)	N_{PPM} independently checked	% of total N_{PPM} independently checked	Percentage false positive PPM (%)
02_10	33,814	1,904	190	10.0	1.1
03_02	41,933	1,447	145	10.0	4.1
04_01	47,287	929	96	10.3	1.0
04_02	47,282	370	39	10.5	2.6
04_03	47,287	928	93	10.0	1.1
04_04	47,274	1,206	121	10.0	3.3
04_05	47,264	432	44	10.2	4.5
04_06	47,275	653	66	10.1	0.0
04_07	47,278	510	64	12.5	3.1
04_08	47,292	695	72	10.4	8.3
04_09	47,295	520	53	10.2	5.7
04_10	47,293	430	44	10.2	4.5
04_11	44,007	168	17	10.1	5.9
04_12	47,341	1,387	140	10.1	2.1
05_10	99,432	953	97	10.2	3.1
06_02	48,567	657	66	10.0	4.5
08_06	87,861	1,231	124	10.1	1.6
08_09	87,860	744	75	10.1	8.0
08_10	39,329	1,390	139	10.0	4.3
09_01	43,263	1,688	169	10.0	1.2
09_02	43,246	751	76	10.1	3.9
09_03	43,226	140	15	10.7	0.0
09_04	43,209	166	17	10.2	0.0
09_05	43,195	36	36	100.0	5.6 *
09_06	43,187	52	52	100.0	3.8 *
09_07	43,169	68	23	33.8	4.3 *
09_08	43,163	102	11	10.8	0.0
09_09	43,157	140	16	11.4	0.0
09_10	43,163	85	29	34.1	3.4 *
09_11	43,157	145	48	33.1	6.3 *
09_12	43,152	715	72	10.1	1.4

3.1.3 Harbour porpoise presence

3.1.3.1 Broad-scale porpoise presence and monitoring effort

Across the entire project duration (11,203 hours between 11th March 2018 and 21st June 2019), site-specific C-POD monitoring effort ranged between 5,739 – 11,195 hours, with harbour porpoises acoustically detected during 17.5 – 62.3% of realised effort[5] (Table 5).

Table 5. *Summary of hourly harbour porpoise presence at each of the 12 EA1 C-POD locations in relation to realised and effective monitoring efforts in the period between 11/03/2018 – 21/06/2019.*

Location	Realised effort (complete hours)	Porpoise Positive Hours in realised effort	Percentage porpoise presence in realised effort	Effective effort (complete hours)	Percentage data excluded	Porpoise Positive Hours in effective effort	Percentage porpoise presence in effective effort
01	8,749	5,451	62.3	8,426	3.7	5,324	63.2
02	6,855	2,522	36.8	4,203	38.7	2,232	53.1
03	8,634	2,595	30.1	6,165	28.6	2,346	38.1
04	7,488	2,498	33.4	6,269	16.3	2,368	37.8
05	11,195	2,640	23.6	9,668	13.6	2,503	25.9
06	7,446	1,554	20.9	6,146	17.5	1,453	23.6
07	5,739	1,019	17.8	3,638	36.6	885	24.3
08	7,588	1,416	18.7	5,342	29.6	1,324	24.8
09	6,351	1,114	17.5	4,924	22.5	1,057	21.5
10	6,534	1,156	17.7	5,892	9.8	1,134	19.2
11	6,082	1,310	21.5	4,842	20.4	1,265	26.1
12	6,125	2,575	42.0	4,009	34.5	2,250	56.1

Considerable intra- and inter-Leg variation was apparent in terms of number of porpoise detections and amounts of noise, expressed through the $N_{TimeLost}$ metric (Number of minutes where recording time was lost due to 'buffering' under noisy conditions; see Tables B1 – B9 in Appendix B at the resolution of individual Legs).

A more detailed assessment of hourly porpoise presence in relation to effective monitoring effort is presented in Figure 7. The degree to which different monitoring locations were affected by noise varied considerably both within and between Legs (bottom panels). For example, in Location 01 (furthest from the wind farm), the number of click-like sounds observed within a minute rarely exceeded the pre-set limit of 4,096 clicks (see Section 2.2.3), and hourly monitoring effort was therefore not significantly reduced. In contrast, a far greater percentage of unmonitored time resulting from the pre-set limit being exceeded was found for Location 02.

[5] 'Realised effort' is defined here as the number of hours monitored independent of the effort within each hour. This is in contrast to 'effective effort', which considers the monitoring effort within an hour.

These visualisations reveal that monitoring was affected by the tidal cycle, with some degree of tidal periodicity visible at all sites (illustrated by the diagonal patterns). The direct and indirect effects of tides, as observed across individual monitoring stations, were driven by the spring-neap tidal cycles and the deployment Leg (as the exact deployment locations differed slightly between successive Legs).

As illustrated by the daily recurrence of long periods of unmonitored time (bottom panels), effective monitoring at various locations was substantially influenced by the tide, showing significant reductions in actual monitored time under high tidal flow conditions. Throughout the monitoring period, effective monitoring efforts in these locations became limited to periods of slack water and reduced tidal flow, which for some sites is reflected in the mirrored porpoise presence patterns (top panels) (e.g. Locations 02, 03 and 12).

Various locations also experienced longer-term (i.e. continuously up to several days) periods of reduced monitoring efforts (vertical lines in bottom panels of Figure 7), primarily caused by noise produced by nearby vessels.

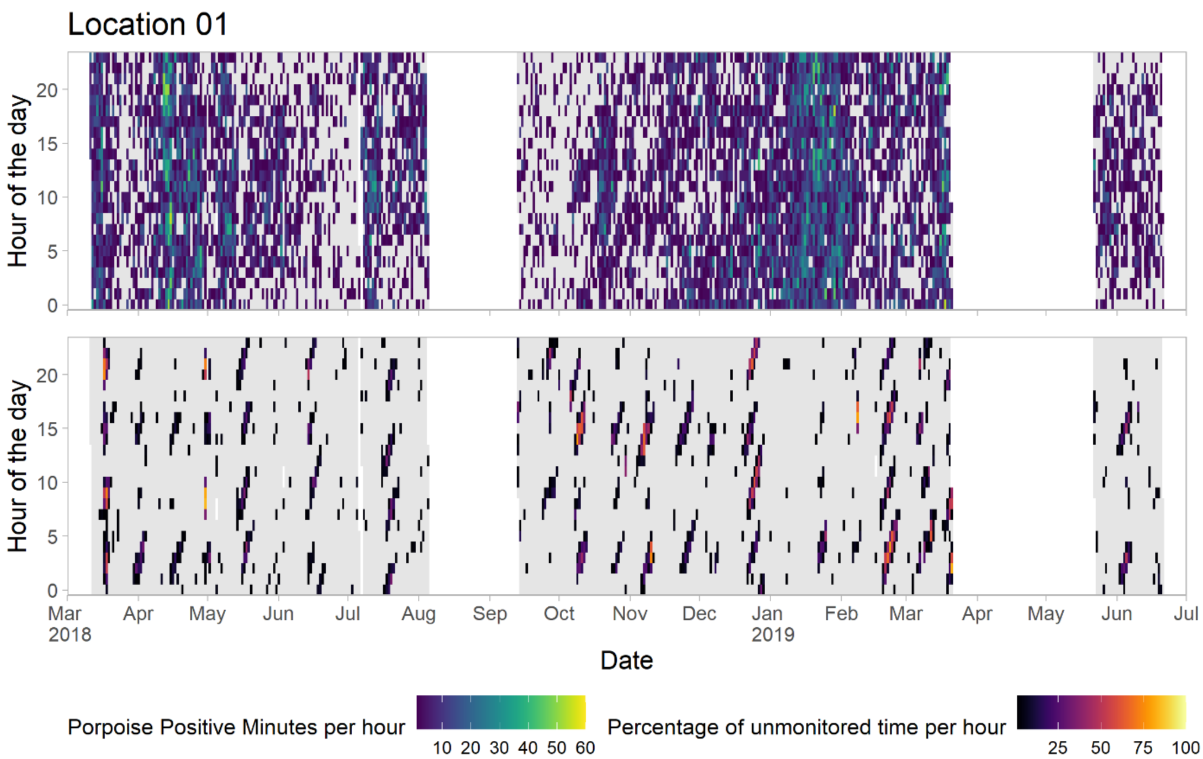
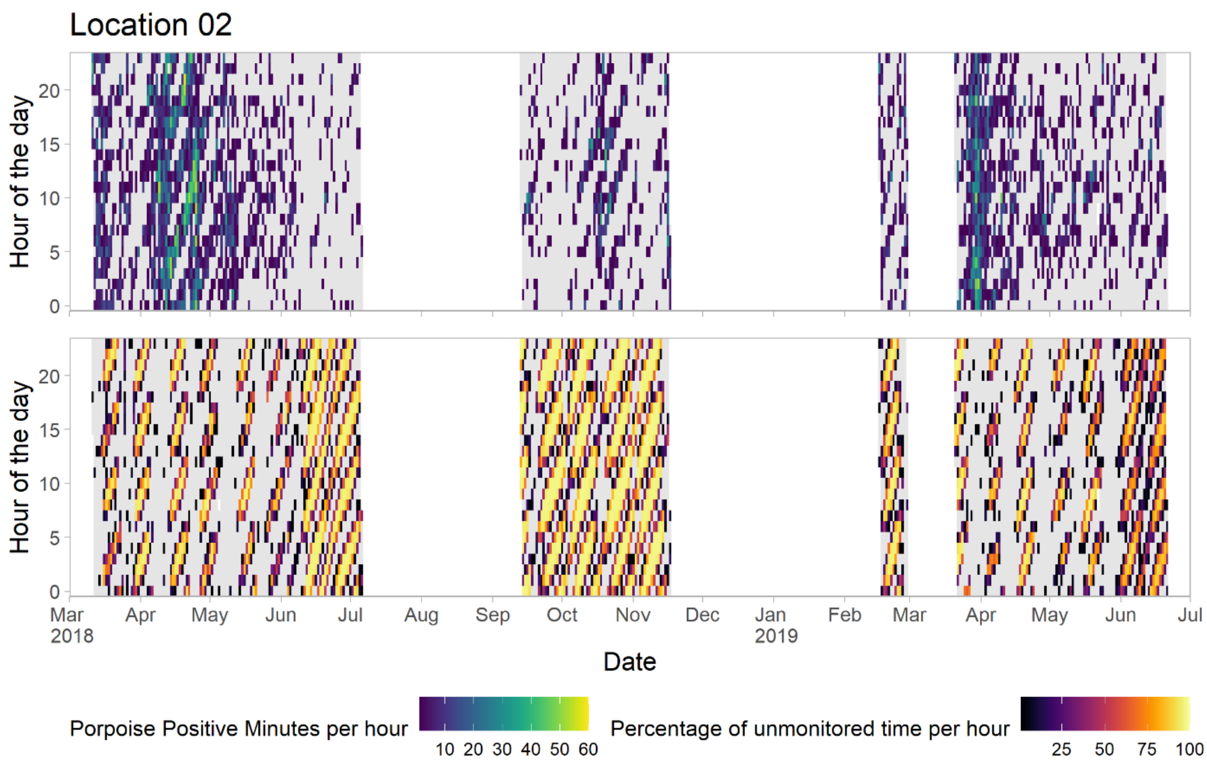


Figure 7. *Summary of hourly Porpoise Positive Minutes (PPM^{-h}) in relation to effective hourly monitoring effort throughout the monitoring period at each of the 12 C-POD locations. Top panels show the number of PPM^{-h}, with grey areas representing an absence of detections. Bottom panels show the percentage of unmonitored time, with grey areas representing fully monitored hours. White areas represent an absence of data for both panels.*



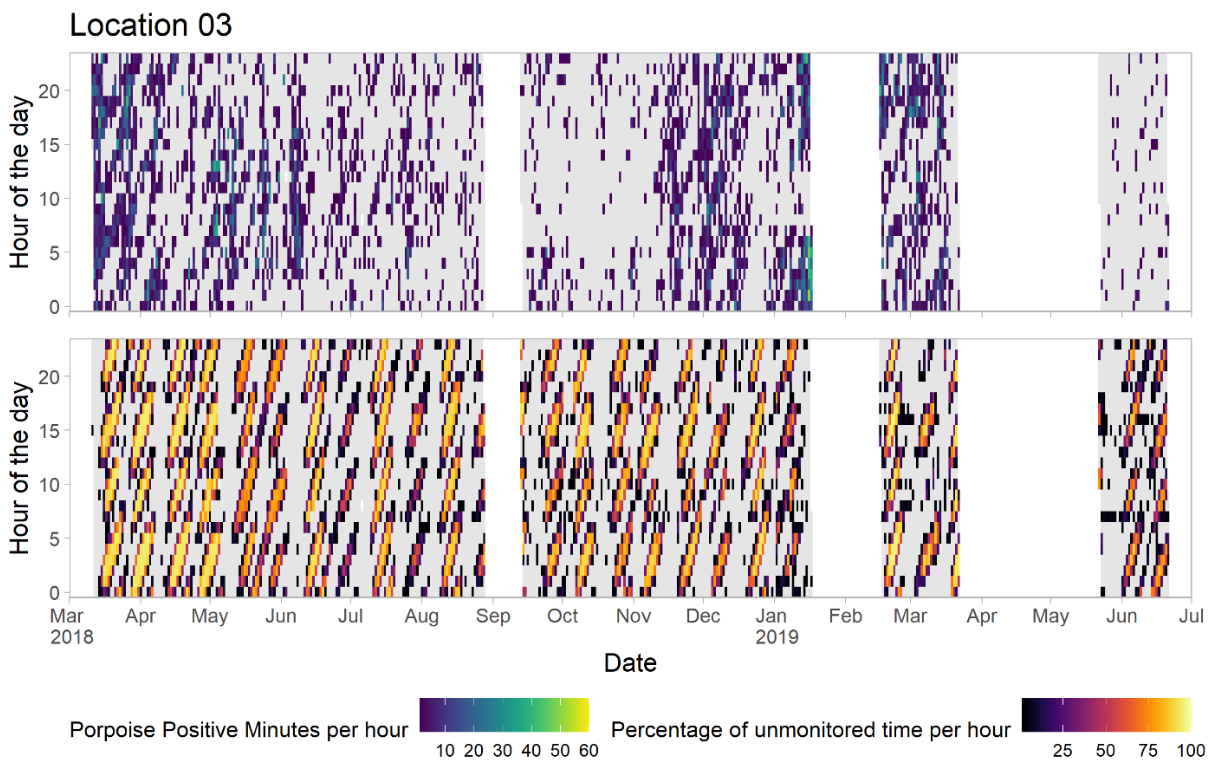
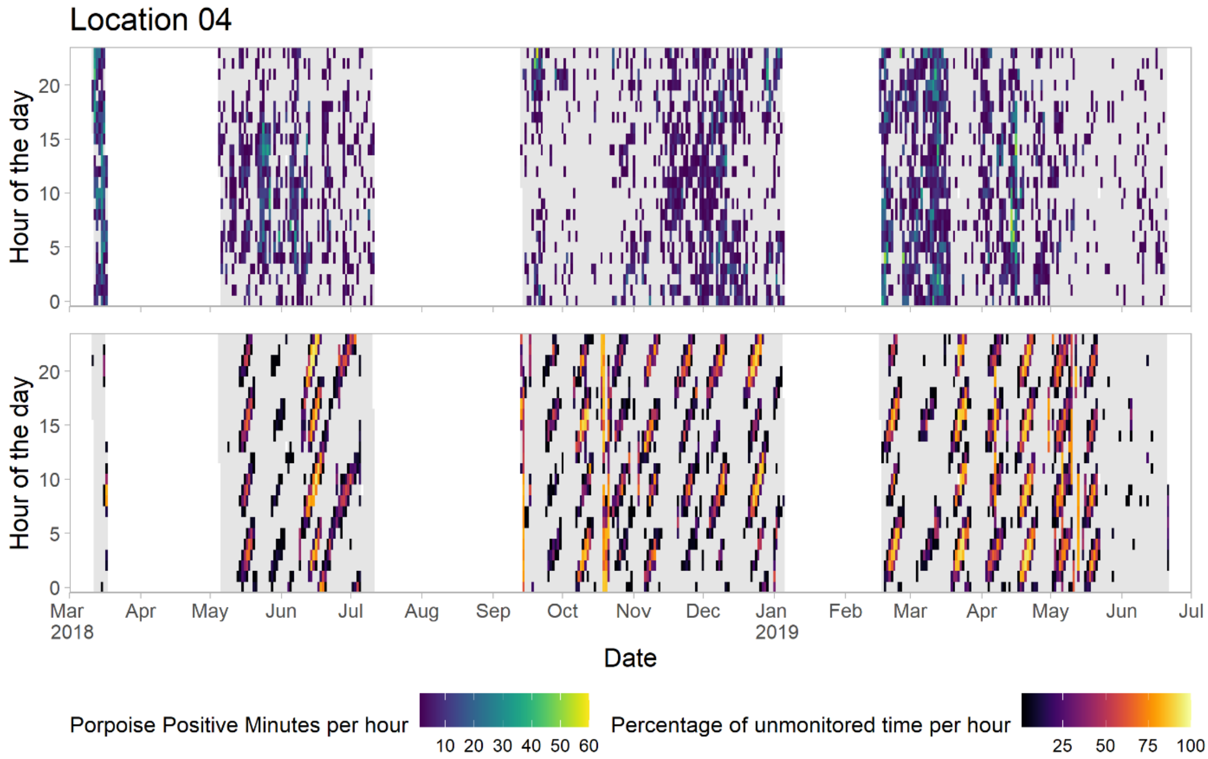


Figure 7 (continued). *Summary of hourly Porpoise Positive Minutes (PPM^{-h}) in relation to effective hourly monitoring effort throughout the monitoring period at each of the 12 C-POD locations. Top panels show the number of PPM^{-h}, with grey areas representing an absence of detections. Bottom panels show the percentage of unmonitored time, with grey areas representing fully monitored hours. White areas represent an absence of data for both panels.*



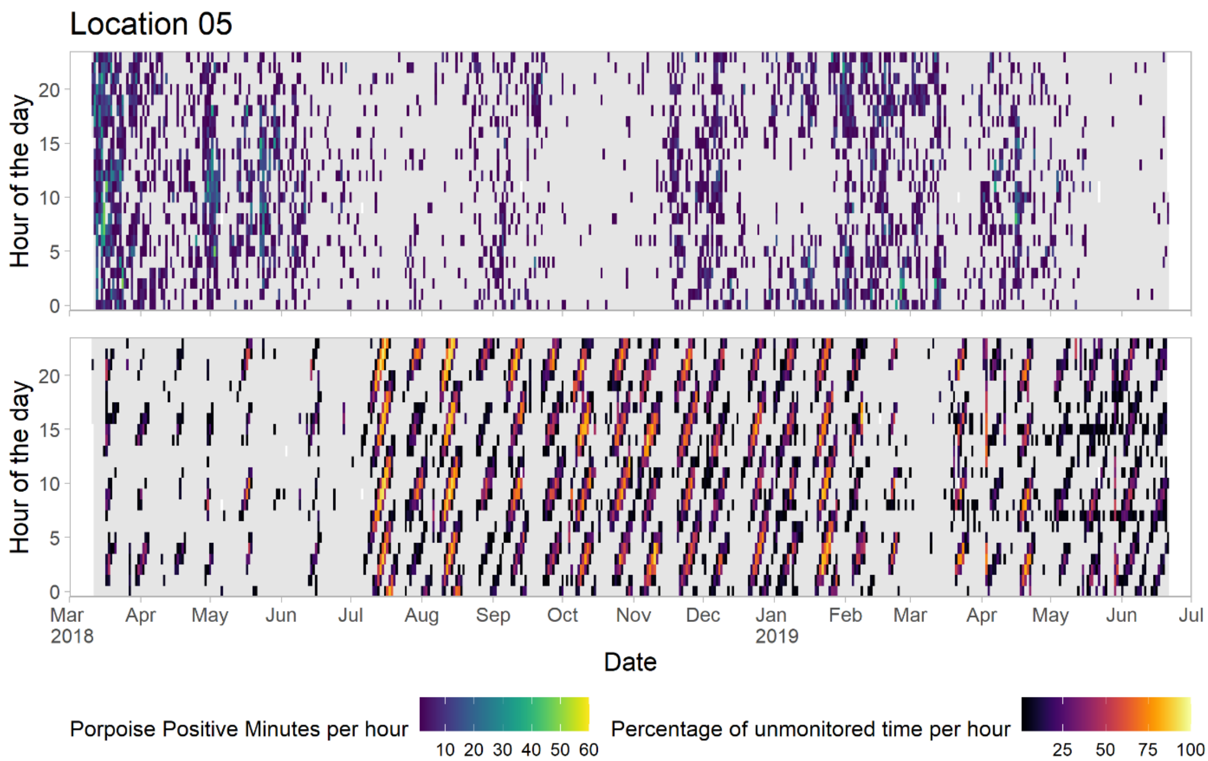


Figure 7 (continued). *Summary of hourly Porpoise Positive Minutes (PPM^{-h}) in relation to effective hourly monitoring effort throughout the monitoring period at each of the 12 C-POD locations. Top panels show the number of PPM^{-h}, with grey areas representing an absence of detections. Bottom panels show the percentage of unmonitored time, with grey areas representing fully monitored hours. White areas represent an absence of data for both panels.*

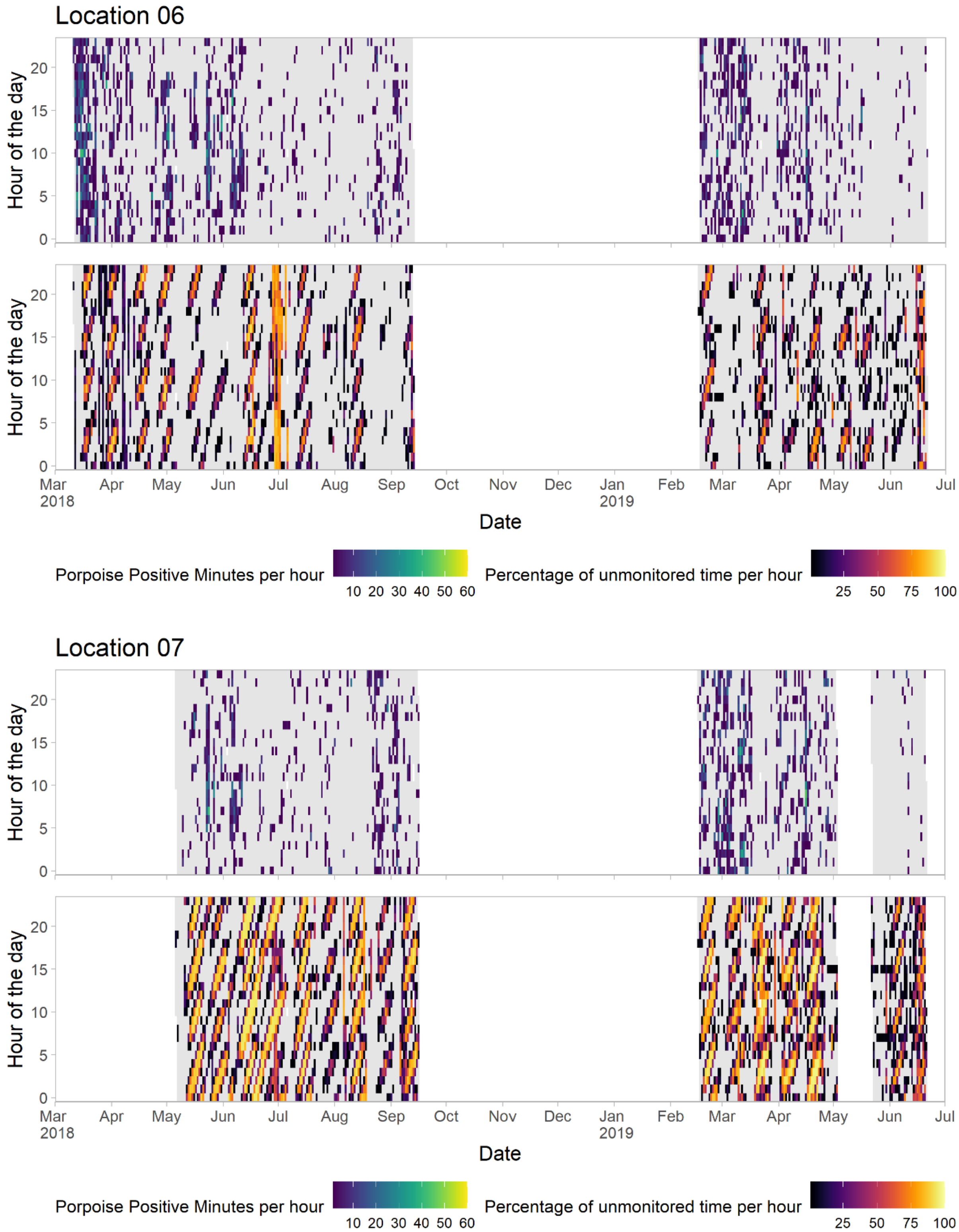
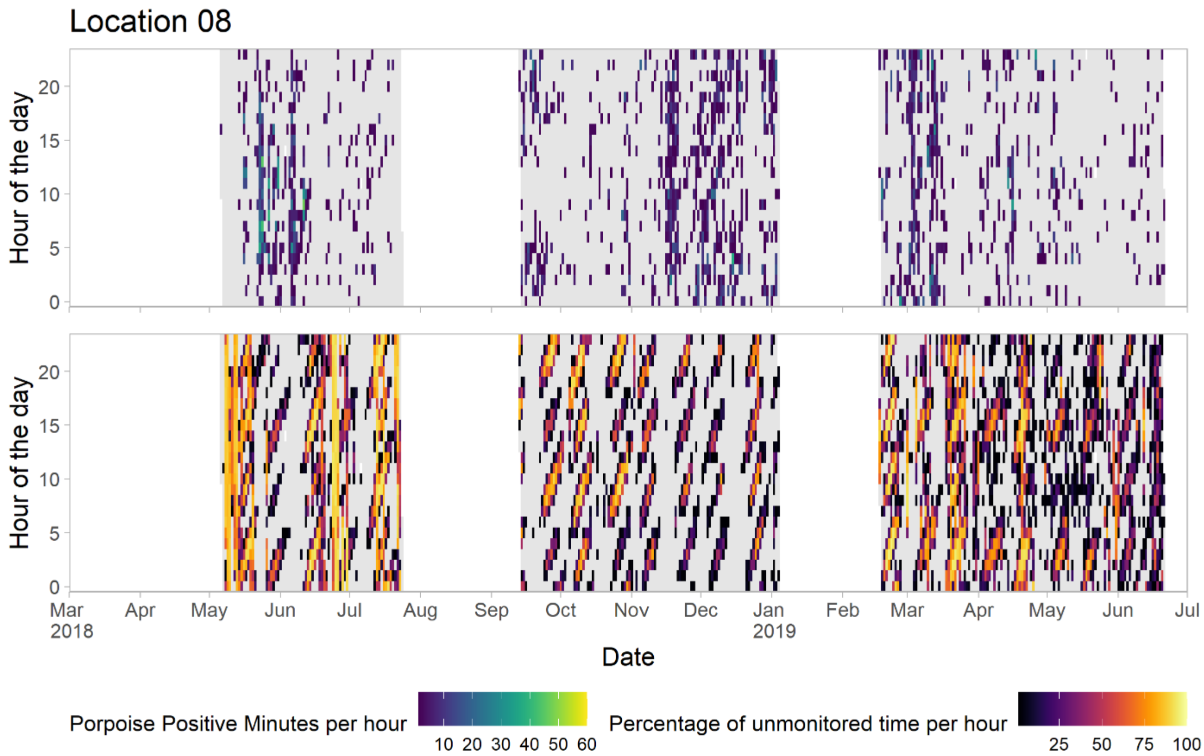


Figure 7 (continued). *Summary of hourly Porpoise Positive Minutes (PPM^{-h}) in relation to effective hourly monitoring effort throughout the monitoring period at each of the 12 C-POD locations. Top panels show the number of PPM^{-h}, with grey areas representing an absence of detections. Bottom panels show the percentage of unmonitored time, with grey areas representing fully monitored hours. White areas represent an absence of data for both panels.*



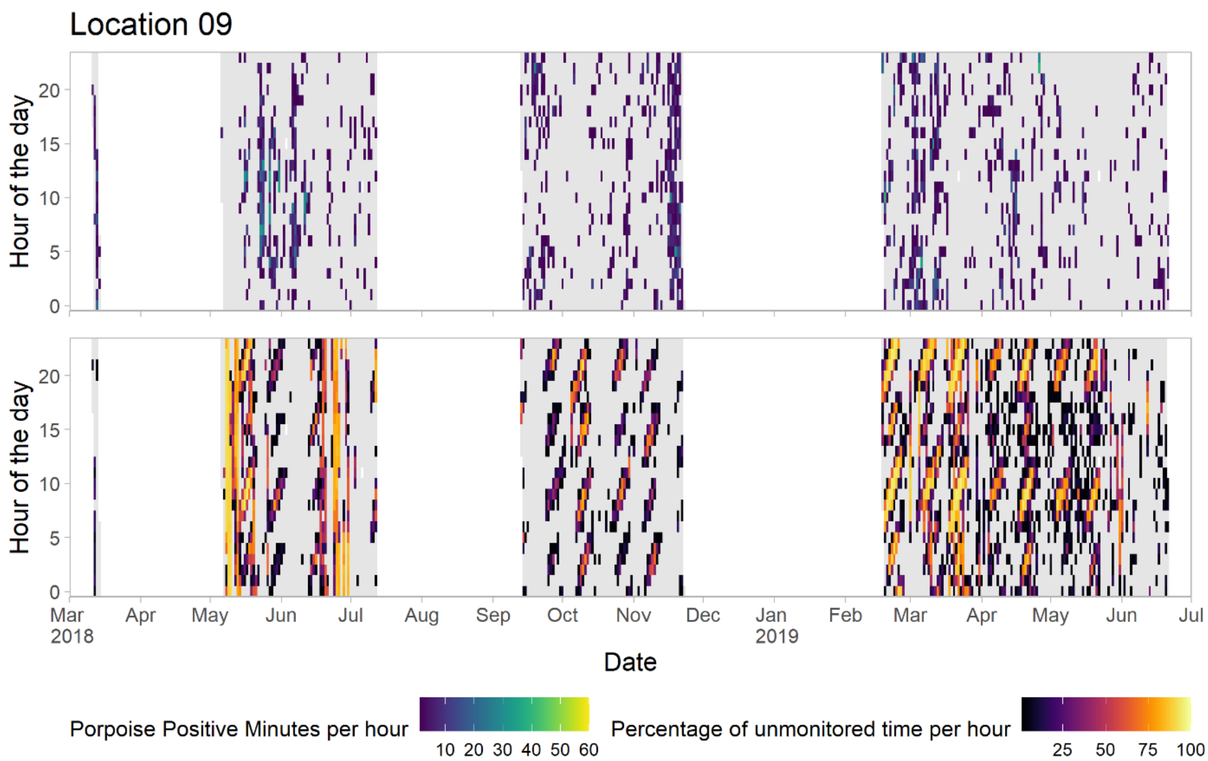
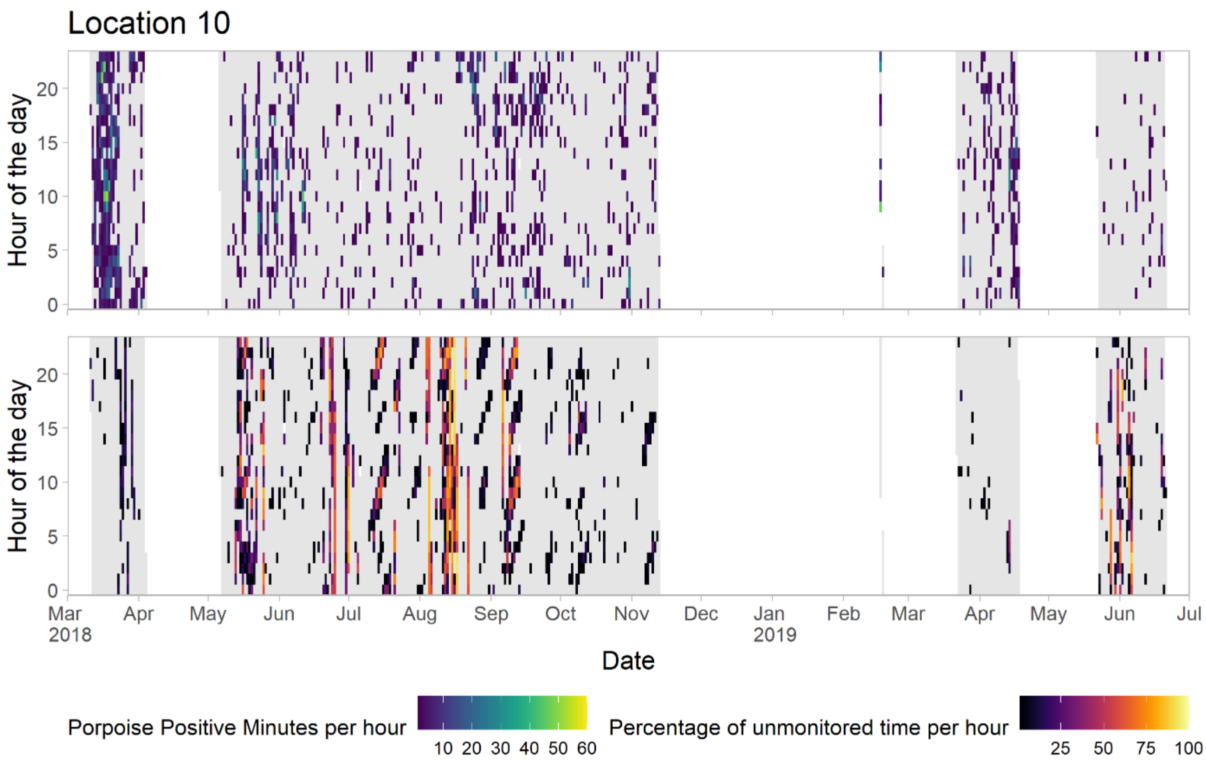


Figure 7 (continued). *Summary of hourly Porpoise Positive Minutes (PPM^{-h}) in relation to effective hourly monitoring effort throughout the monitoring period at each of the 12 C-POD locations. Top panels show the number of PPM^{-h}, with grey areas representing an absence of detections. Bottom panels show the percentage of unmonitored time, with grey areas representing fully monitored hours. White areas represent an absence of data for both panels.*



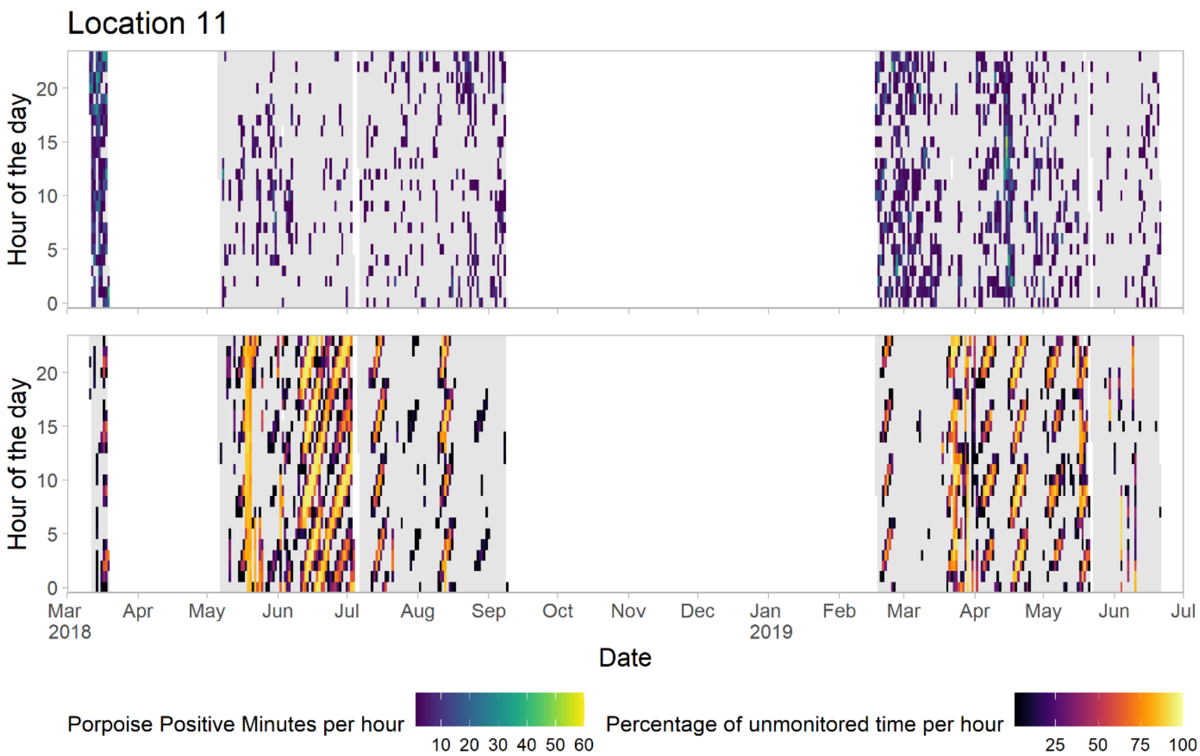


***Figure 7 (continued).** Summary of hourly Porpoise Positive Minutes (PPM^{-h}) in relation to effective hourly monitoring effort throughout the monitoring period at each of the 12 C-POD locations. Top panels show the number of PPM^{-h}, with grey areas representing an absence of detections. Bottom panels show the percentage of unmonitored time, with grey areas representing fully monitored hours. White areas represent an absence of data for both panels.*

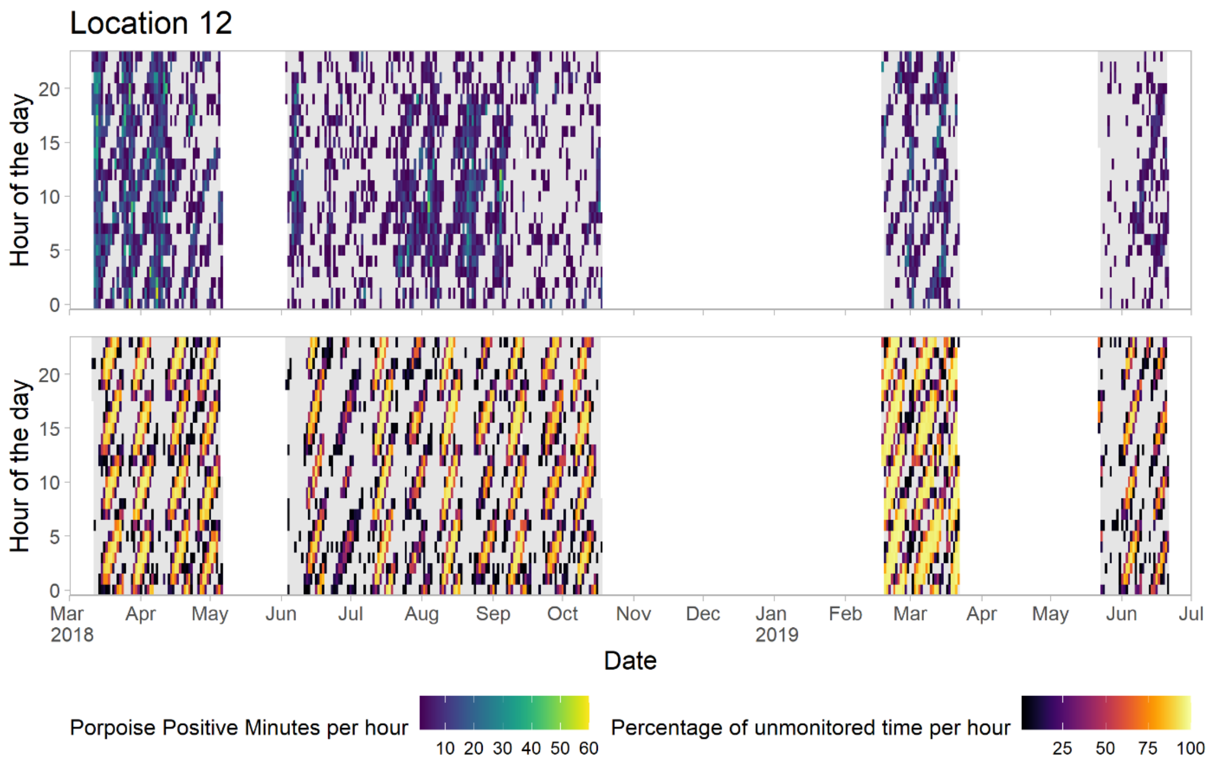


Figure 7 (continued). *Summary of hourly Porpoise Positive Minutes (PPM^{-h}) in relation to effective hourly monitoring effort throughout the monitoring period at each of the 12 C-POD locations. Top panels show the number of PPM^{-h}, with grey areas representing an absence of detections. Bottom panels show the percentage of unmonitored time, with grey areas representing fully monitored hours. White areas represent an absence of data for both panels.*

The most important point illustrated by the various graphs in Figure 7 is the observation that effective passive acoustic monitoring for porpoises varied considerably over time, predominantly because of tide-related influences. As a result, the presence of porpoises could not be assessed consistently across the tidal cycle due to impeded detection capability at higher flow speeds, meaning that the actual presence of porpoises during these periods may be underestimated. Based on these results, the decision was made to exclude hours considered insufficiently monitored (≤90% of each hour) from further analysis, representing 3.7 – 38.7% of the originally available data (Table 5). It is important to note that the data included in subsequent assessment of hourly porpoise presence and the statistical modelling (i.e. hours >90% effectively monitored) therefore represent only those periods coinciding with reduced tidal influence.

Following data exclusions, the remaining total amounts of site-specific effective monitoring effort ranged between 3,638 – 9,668 hours (Table 5). Porpoise detections, described as the fraction of monitored hours containing porpoise click trains, were substantially higher at Locations 01, 02 and 12, which are the ones furthest away from the wind farm. Porpoises were present at these locations at least 50% of the time. In contrast, the lowest percentages were obtained from those locations sited within the wind farm (i.e. Locations 06 – 10), with intermediate presence at locations nearer the edge of the wind farm (Table 5).

3.1.3.2 Hourly porpoise presence

Pre-construction porpoise detection rates were relatively high but declined significantly during the period of piling activity. Especially for locations within the wind farm, detections remained low post-piling (Figure 8). Whilst the number of sites with reasonable monitoring coverage across both summer and winter was limited, porpoise detections appeared to increase during winter compared to the summer, which may reflect a local seasonal distribution shift. However, it is important to consider monitoring effort when assessing harbour porpoise presence across space and over time. As such, Figure 8 below, presenting PPM^{-h} for each monitoring site for the duration of the project, should be interpreted with care, as the monitoring effort within each day was not consistent across the C-POD array and over the duration of the project. Similar plots for all available data (i.e. prior to the exclusion of hours monitored ≤90%) are presented in Appendix C.

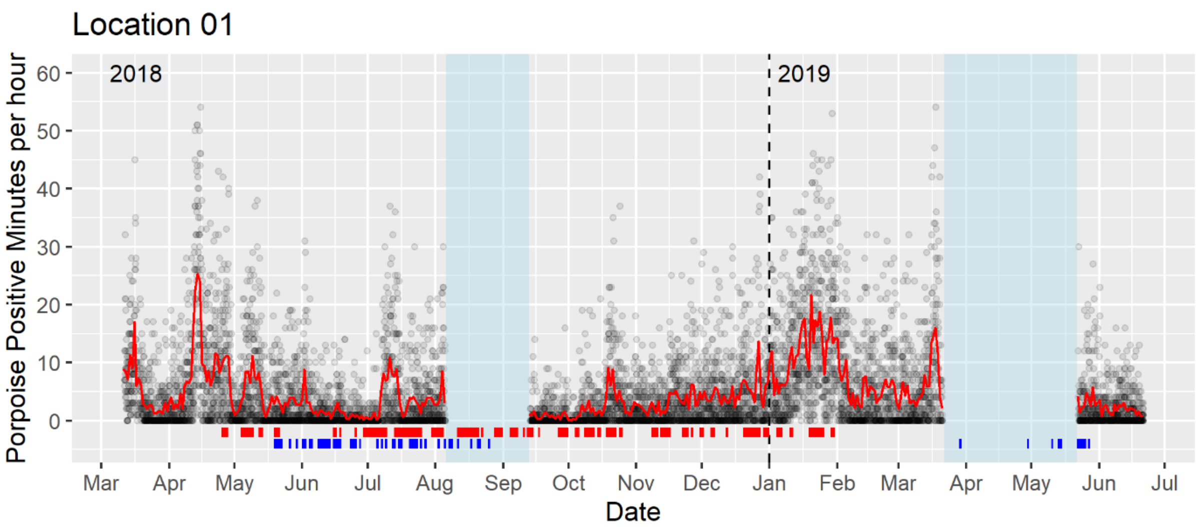


Figure 8. *Overview of hourly (circles) and daily averaged (red line) Porpoise Positive Minutes throughout the monitoring period at each of the 12 C-POD locations. Light blue areas represent an absence of data; days with piling and UXO detonation activities are indicated with red and blue markers, respectively.*

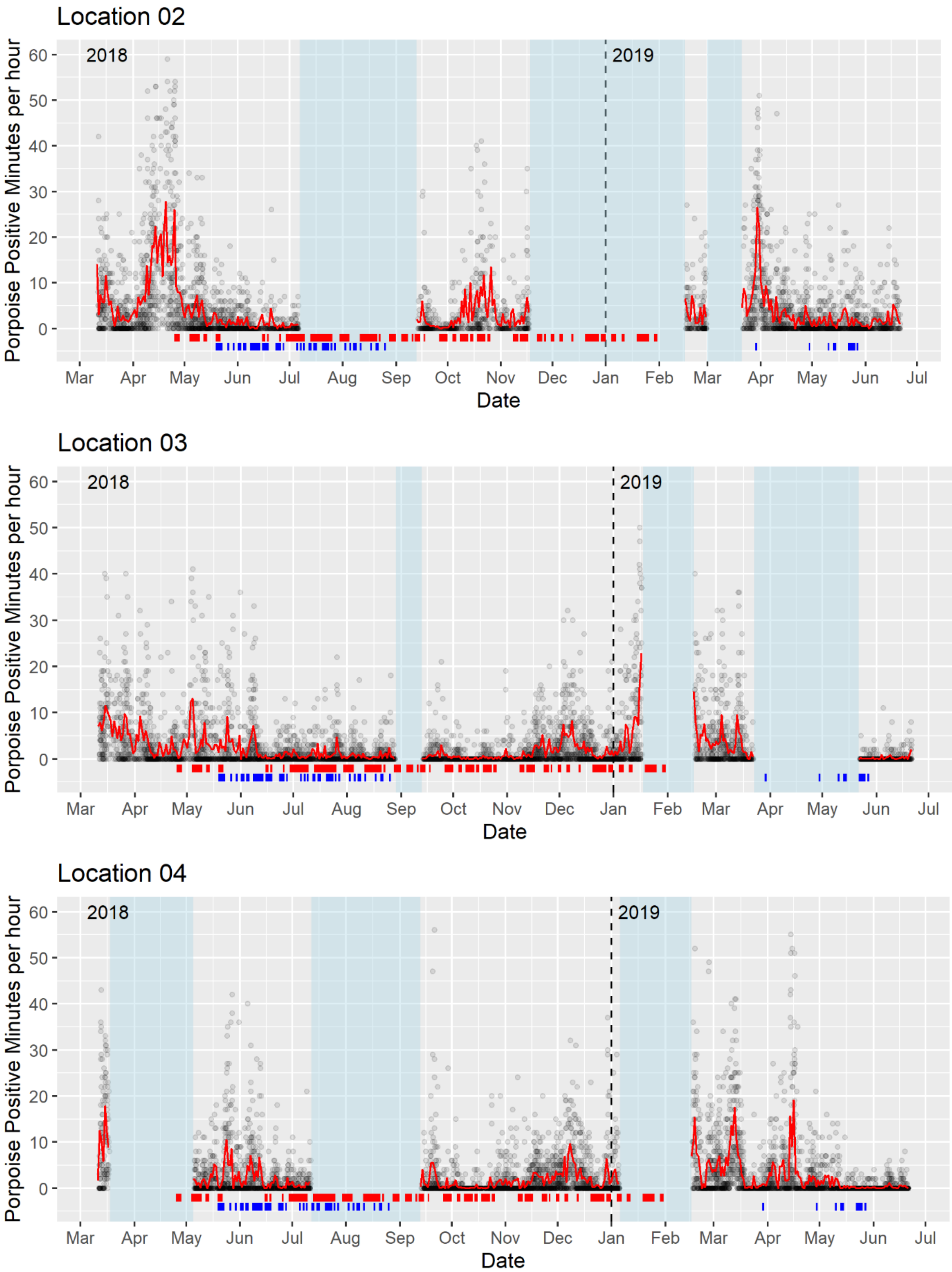


Figure 8 (continued)*. Overview of hourly (circles) and daily averaged (red line) Porpoise Positive Minutes throughout the monitoring period at each of the 12 C-POD locations. Light blue areas represent an absence of data; days with piling and UXO detonation activities are indicated with red and blue markers, respectively.*

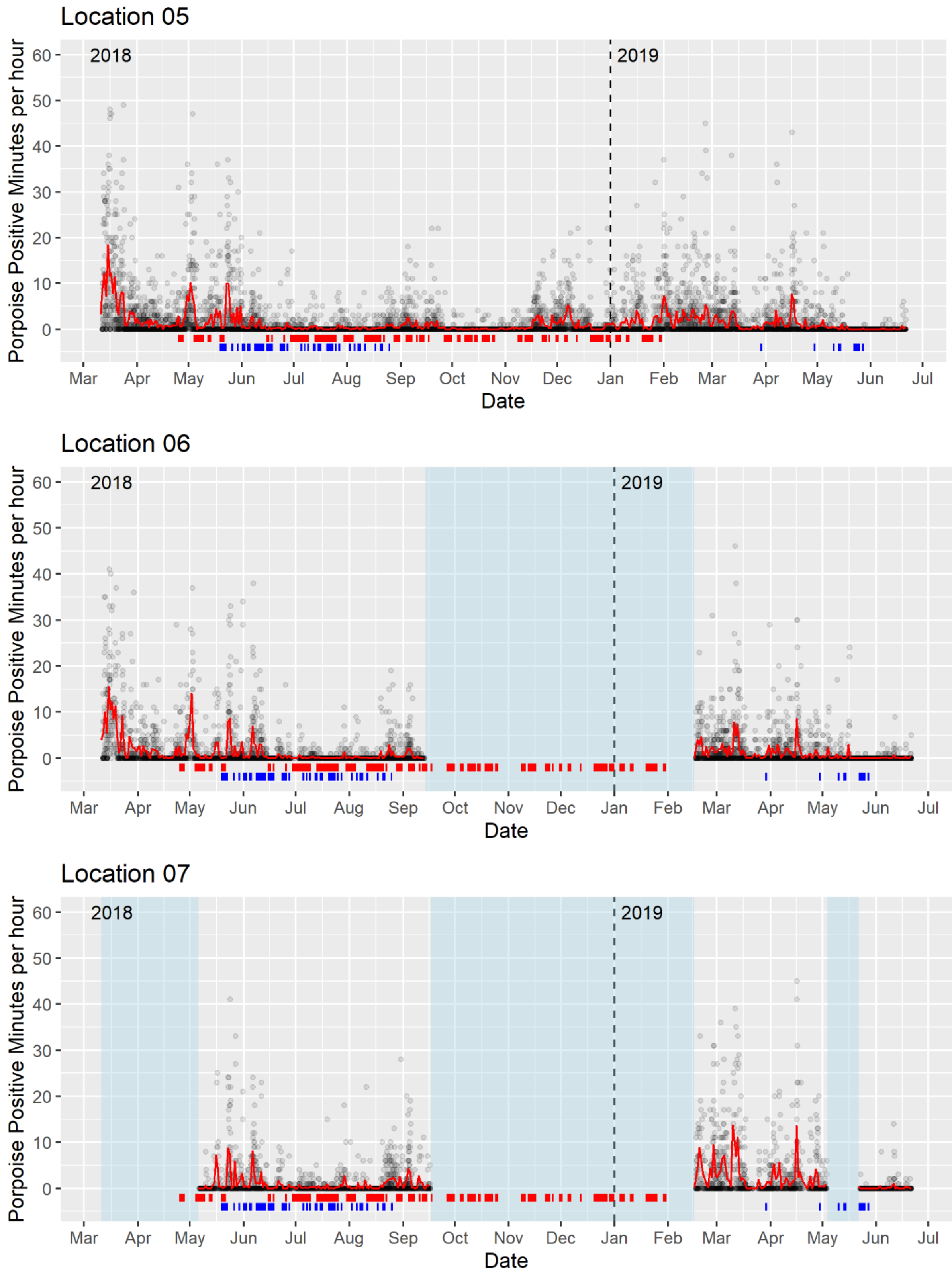


Figure 8 (continued)*. Overview of hourly (circles) and daily averaged (red line) Porpoise Positive Minutes throughout the monitoring period at each of the 12 C-POD locations. Light blue areas represent an absence of data; days with piling and UXO detonation activities are indicated with red and blue markers, respectively.*

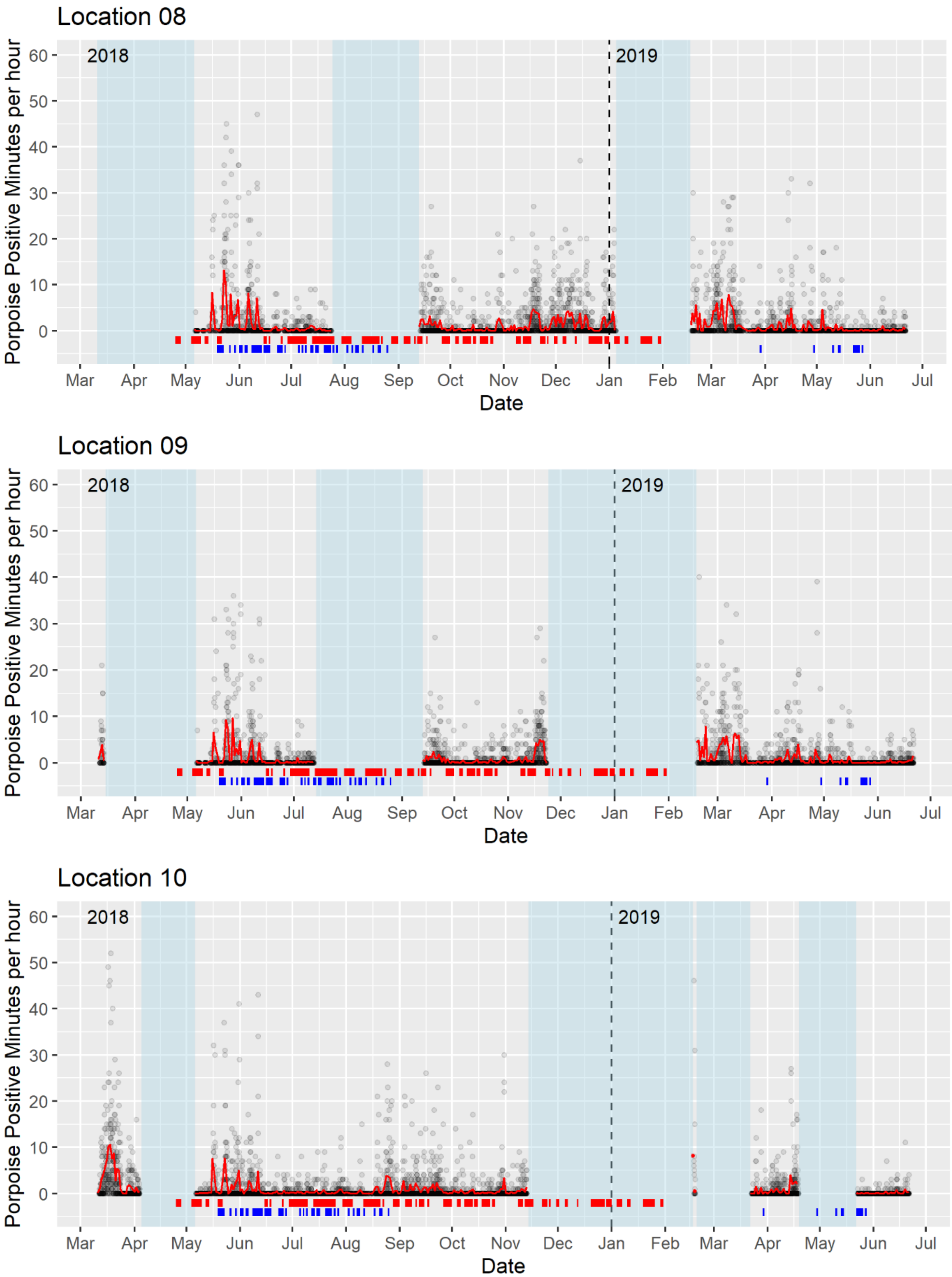
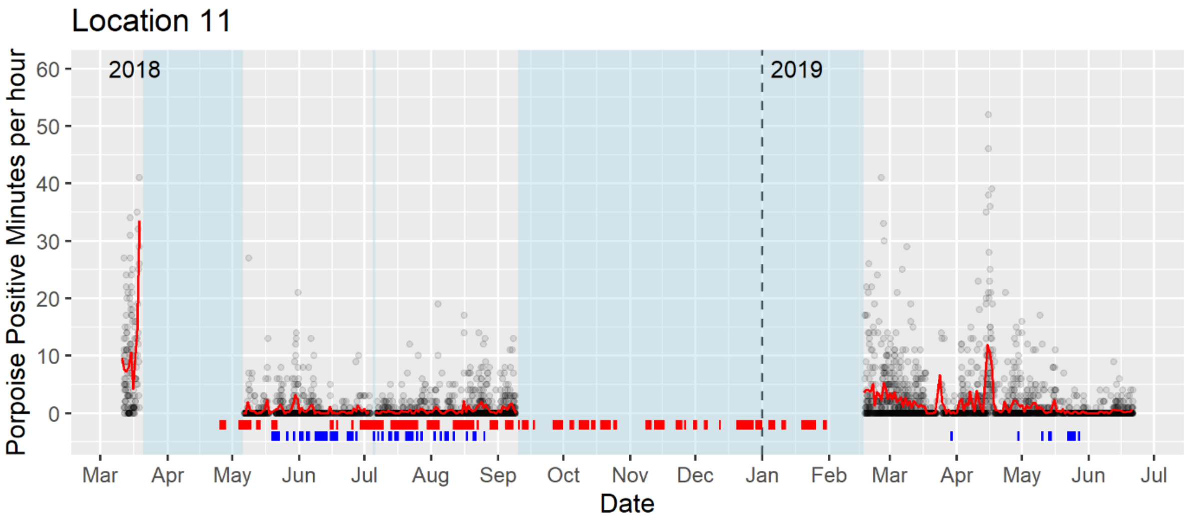


***Figure 8 (continued)**. Overview of hourly (circles) and daily averaged (red line) Porpoise Positive Minutes throughout the monitoring period at each of the 12 C-POD locations. Light blue areas represent an absence of data; days with piling and UXO detonation activities are indicated with red and blue markers, respectively.*



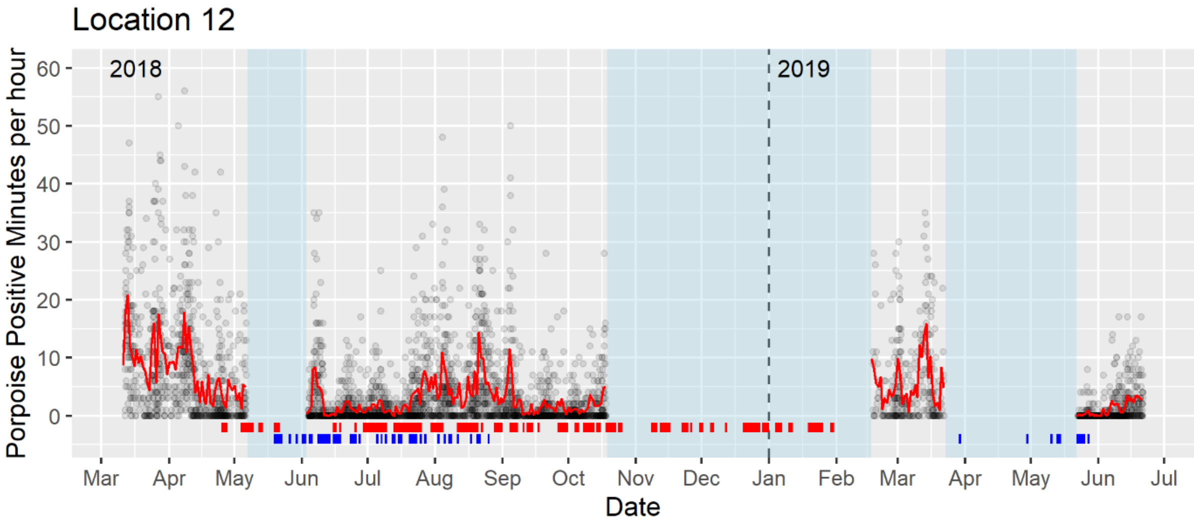


Figure 8 (continued)*. Overview of hourly (circles) and daily averaged (red line) Porpoise Positive Minutes throughout the monitoring period at each of the 12 C-POD locations. Light blue areas represent an absence of data; days with piling and UXO detonation activities are indicated with red and blue markers, respectively.*

An overview of harbour porpoise detections between hours of piling and non-piling hours at each of the 12 monitoring locations is presented in Table 6. Within both the piling and non-piling datasets, hourly porpoise acoustic presence was substantially lower among locations inside the farm compared to those further away. Overall, porpoises were detected more often during non-piling hours compared to hours during which piling activity took place. These differences were less pronounced at Locations 02 and 12 further away from the wind farm, and the percentage of monitored hours during which porpoises were present even increased for Location 01.

Table 6. *Summary of hourly harbour porpoise acoustic presence at the 12 EA1 C-POD locations in relation to effective monitoring during non-piling and piling hours (at least 1 minute of piling activity within an hour).*

Location	Non-piling hours			Piling hours		
	Effective effort	*Porpoise Presence*	*% porpoise presence*	*Effective effort*	*Porpoise presence*	*% porpoise presence*
01	7,561	4,774	59.2	865	550	63.6
02	3,980	2,119	53.2	223	113	50.7
03	5,504	2,230	40.5	661	116	17.5
04	5,784	2,296	39.7	485	72	14.8
05	8,792	2,437	27.7	876	66	7.5
06	5,718	1,434	25.1	428	19	4.4
07	3,305	862	26.1	333	23	6.9
08	4,886	1,304	26.7	456	20	4.4
09	4,578	1,044	22.8	346	13	3.8
10	5,219	1,094	21.0	673	40	5.9
11	4,480	1,233	27.5	362	32	8.8
12	,3573	2,029	56.8	434	219	50.5

3.1.3.3 Waiting Time and Recovery Time

A total of 977 piling breaks ≥3 hours were identified in the piling schedule; 236 of these were excluded because the first post-piling porpoise detection only occurred after piling had commenced again. A further 151 piling breaks were excluded because UXO detonation took place within 24-hour prior to the end of piling, or occurred during the piling break before any echolocation was detected, resulting in 590 piling breaks suitable for analysis.

Results for the remaining piling breaks showed an overall decrease in Waiting Time with increasing distance from the piling activity, despite a reasonable spread in Waiting Time (Figure 9). During the construction phase, there was no indication of a substantial change in Waiting Time duration (Figure 10). This Figure also confirmed the general pattern of shorter Waiting Times at greater distances from the piling activity, which was observed consistently throughout the construction phase.

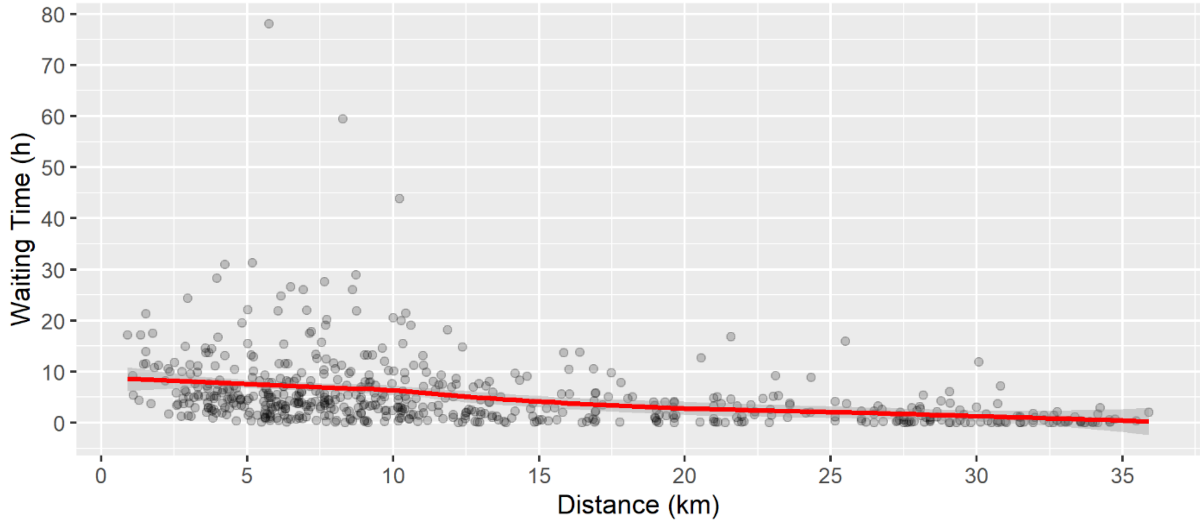


Figure 9. *Waiting Time in relation to distance from pile-driving activity during EA1 construction.*

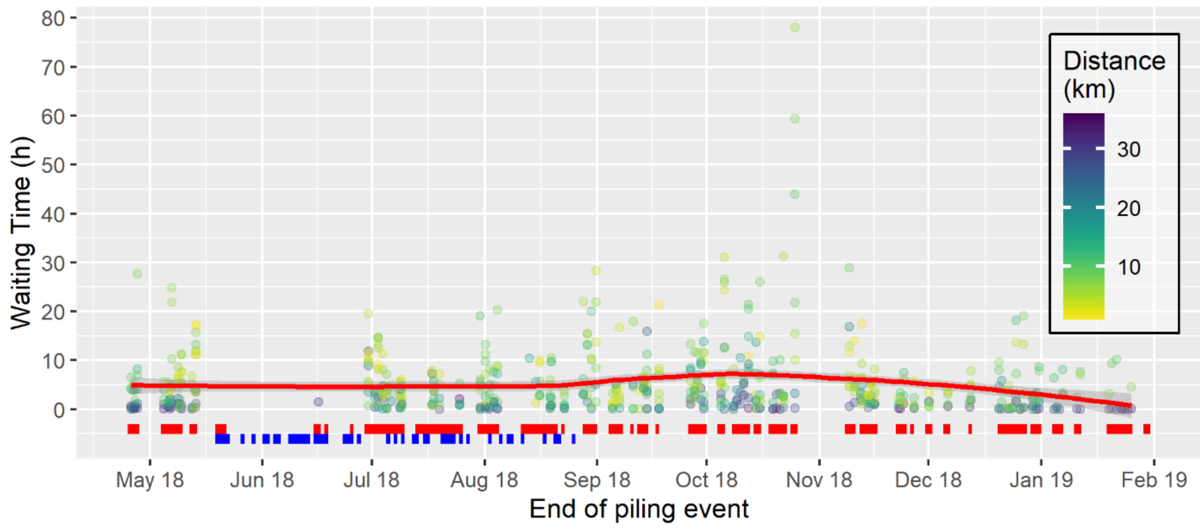


Figure 10. *Waiting Time across distances throughout the EA1 construction period and aligned to realised piling activity (red bars) and UXO detonation (blue bars). Points are colour coded according to the distance of detections from piling activity.*

The construction events linked to seven individual turbines, with their associated pre- and post-piling breaks, met the criteria for inclusion in the Recovery Time assessment; four events with a pre-piling break of >96 hours, and an additional three events that were preceded by a >72-hour pre-piling break (Table 7). A geographic representation of these turbines in reference to the C-POD monitoring locations is provided in Figure 11.

Table 7. *Summary of piling information associated with the turbines included in the Recovery Time assessment.*

WTG	***Sequen-tial WTG number***	***Start piling***	***End piling***	***Piling period (hh:mm)***	***Actual piling duration (hh:mm)***	***Pre-piling break duration (hh:mm)***	***Post-piling break duration (hh:mm)***
D05	5	19/05/2018 09:27	20/05/2018 03:07	17:39	6:47	137:11	26:52
D14	9	25/06/2018 03:21	25/06/2018 22:46	19:24	9:43	152:24	82:16
D17	10	29/06/2018 09:02	30/06/2018 03:09	18:07	5:41	82:16	41:04
F26	46	10/09/2018 10:30	10/09/2018 18:46	8:16	4:56	79:10	32:20
E15	78	30/11/2018 18:01	01/12/2018 01:54	8:53	5:22	89:47	111:43
E16	79	05/12/2018 21:37	06/12/2018 06:09	8:32	5:18	111:43	145:56
F19	102	29/01/2019 17:21	30:01/2019 02:28	9:08	5:17	97:05	NA (piling completed)

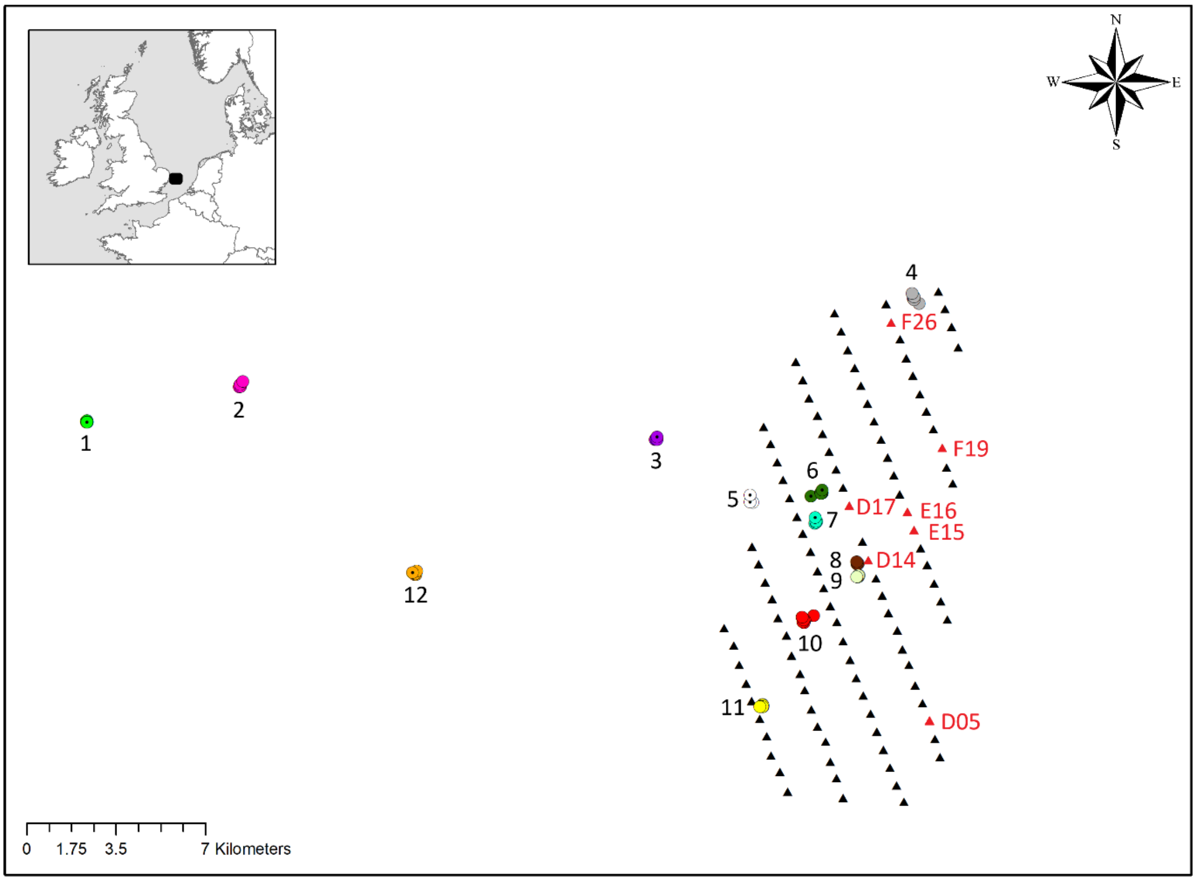


Figure 11. *Overview of the turbine construction activity incorporated in the Recovery Time assessment in relation to the C-POD monitoring locations.*

Results revealed both increases and decreases in post-piling porpoise presence compared to the baseline, independent of presence quantified as proportional PPH or in hourly averaged PPM, and there was no clear relationship between the occurrences of increases/decreases and distance from piling (Figures 12A, 13A).

For those occurrences that revealed a post-piling decrease >0.1 in proportional PPH in the 24-hour following the cessation of piling compared to the proportional PPH in the 24-hour pre-piling baseline period (Figure 12A), or a >0.1 proportional decrease in average hourly PPM in the post-piling 24-hour period compared to the pre-piling baseline (Figure 13A), the Recovery Time ranged between 1-21 hours (Figures 12B, 13B). On various occasions, the post-piling break lasted insufficiently long to identify the Recovery Time, with porpoise presence not recovered before construction of the next turbine started. For example, piling re-started approximately 32 hours after completion of turbine F26, only allowing for eight 1-hour shifts of the 24-hour post-piling period.

Overall, insufficient data were available to allow any kind of comprehensive deterrence assessment, such as an analysis of spatial differences to determine deterrence distances associated with individual piling events, or a temporal analysis to better understand porpoise detection recovery at various distances from piling, and changes in these throughout the entire piling period of EA1.

Nevertheless, the results from the Waiting Time assessment described above, in combination with the limited post-piling recovery of porpoise detections, indicate that porpoises were typically present near the monitoring locations within hours following cessation of piling activity, independent of either distance from piling events or the particular phase of construction ongoing at the time.

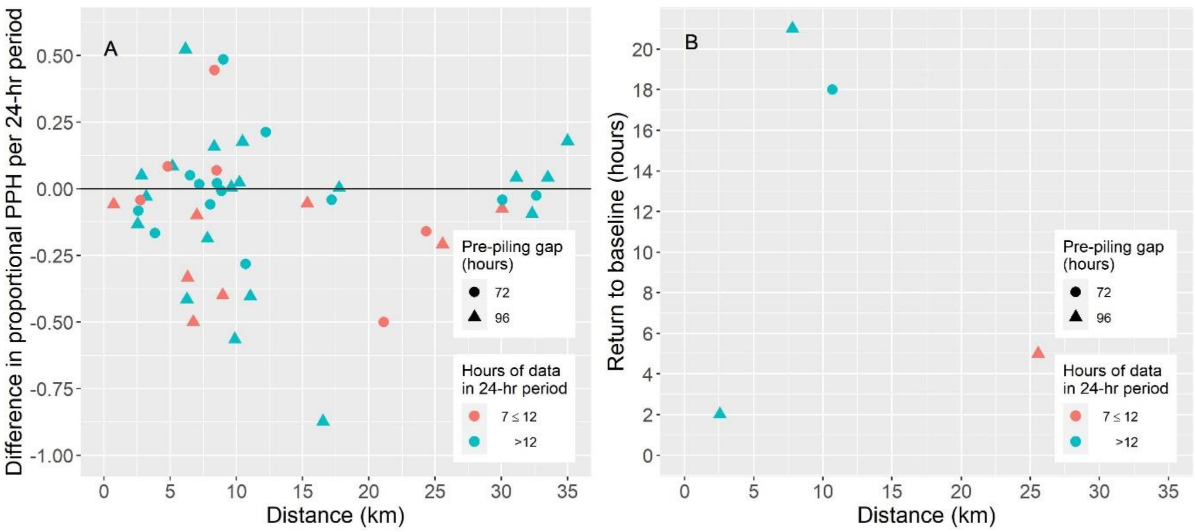


Figure 12. *Difference in pre- (baseline) and post-piling porpoise presence quantified as proportional Porpoise Positive Hours (PPH) per 24-hour period (A) and demonstrated Recovery Time (B). Recovery Time was defined as the number of hours after which porpoise presence recovered to within a 0.1 reduction of baseline presence.*

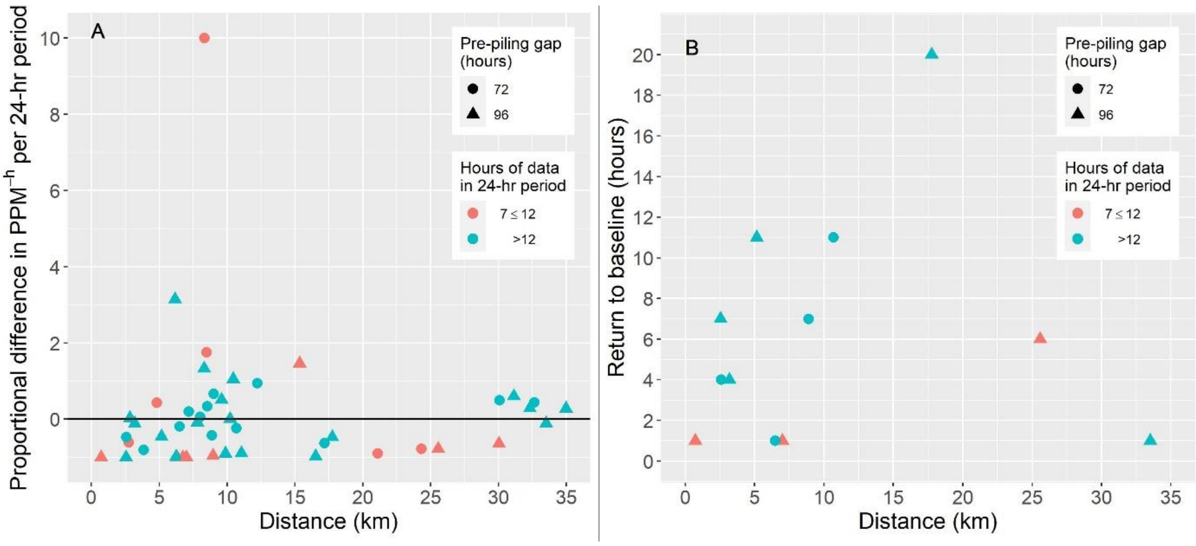


Figure 13. *Proportional difference in pre- (baseline) and post-piling porpoise presence quantified as average Porpoise Positive Minutes per hour (PPM^{-h}) per 24-hour period (A) and demonstrated Recovery Time (B). Recovery Time was defined as the number of hours after which porpoise presence recovered to within a 0.1 proportional decrease of the baseline.*

3.1.4 Harbour porpoise presence modelling

Two separate GAM models were developed: a piling model, and a non-piling model. Distance was included as the main covariate of interest in both models. Whilst a total of 8,208 hours of C-POD data coincided with piling activity, the exclusion of hours that were ≤90% monitored resulted in a total of 6,143 hours available for the statistical modelling of harbour porpoise presence. The non-piling dataset originally contained a total of 47,297 hours of data, of which 37,680 hours remained after excluding hours considered to be insufficiently monitored. Following further exclusion of data where the Number of Clicks exceeded 2,700 and 3,500 for the piling and non-piling datasets, respectively, the final models were based on 6,102 and 37,607 hours of data, respectively, to underpin subsequent iPCoD modelling efforts.

For both piling and non-piling models, Distance was revealed to be either the most or second-most important explanatory variable in predicting harbour porpoise presence. The fitted piling model contained fewer model covariates but explained a higher percentage of deviance in the dataset (38.4% versus 25.1%; Table 8). The posterior simulation indicates that, despite large 95% confidence intervals (CI) when uncertainty around all model coefficients were incorporated, the median probability of harbour porpoises across the 500 simulations was lower during piling than in the non-piling period out until a distance of 14.0 km from the piling activity (Figure 14).

Table 8. *Harbour porpoise statistical modelling results[6]. The notation s() represents a smooth term.*

Dataset	*Fitted model*	*Deviance explained*
Non-piling	HP Presence ~ s(Julian Day) + s(Distance) + as.factor(Year) + s(Number of Clicks) + s(Tidal Cycle) + s(Diel Cycle) + s(Lunar Cycle) + s(Angle)	25.1%
Piling	HP Presence ~ s(Distance) + s(Julian Day) + s(Number of Clicks) + s(Angle) + s(Lunar Cycle)	38.4%

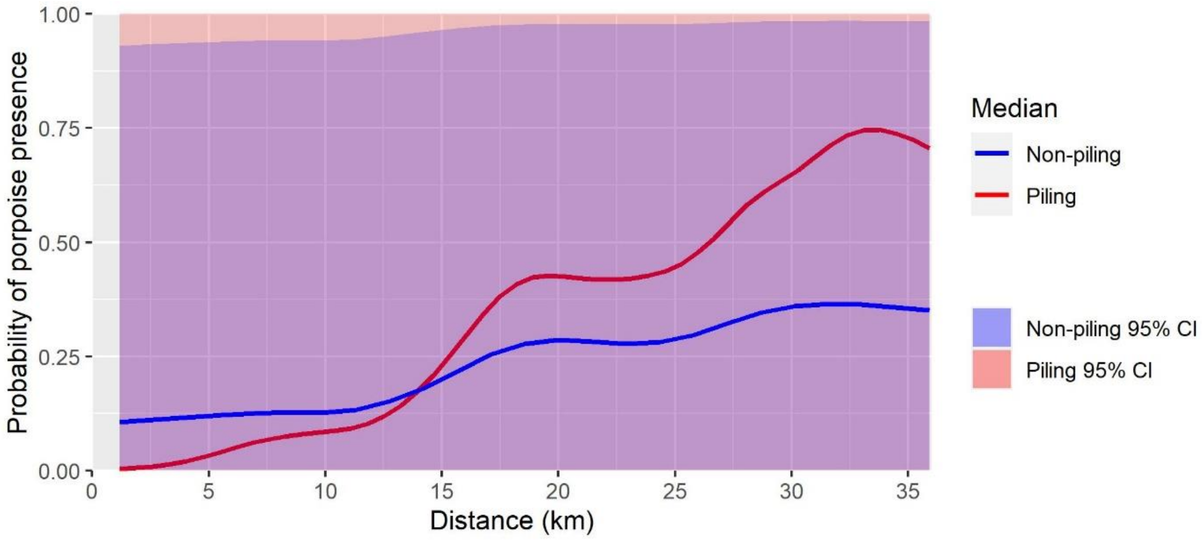


Figure 14. *The effect of Distance on harbour porpoise presence at the EA1 site during non-piling baseline periods as well as during piling activity. The probability of porpoise presence during piling remains below the probability estimated in the absence of piling at distances out to 14.0 km from the piling activity.*

Making use of the relationship between Distance and modelled frequency-weighted Received Level (Figure 15), the DEPONS Response Threshold, specified as the Received Level associated with a distance of 14.0 km, is 103.0 dB re 1 μPa^{2}s SEL.

[6] The amount of insufficiently monitored data excluded differed between monitoring locations. The remaining data represented those periods with reduced tidal influences. Assessment of the relationship of acoustic porpoise presence with tides may therefore be hampered by the monitoring capability of C-PODs.

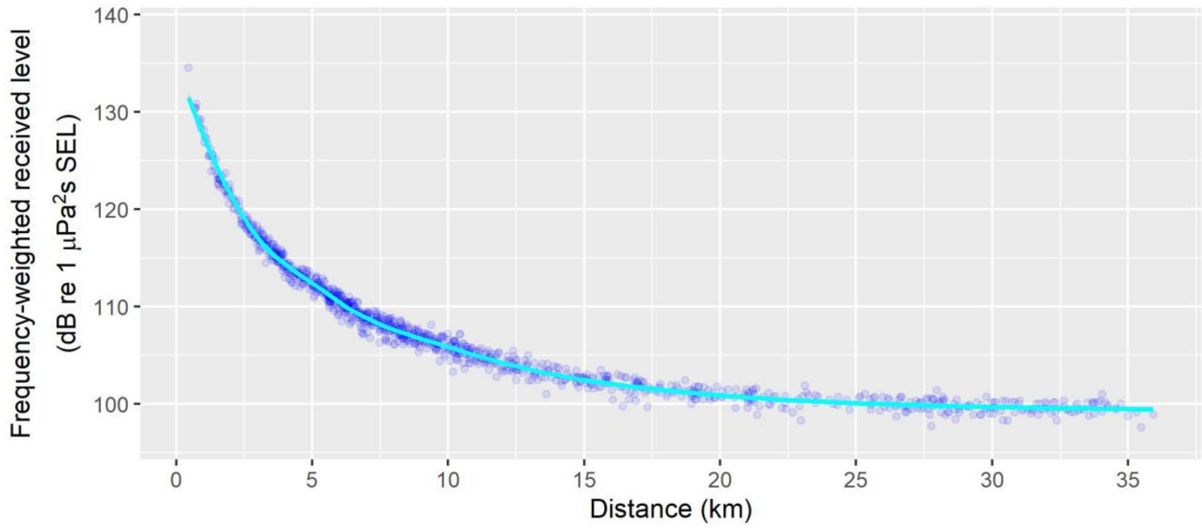


Figure 15. *Relationship between the two main covariates of interest, Distance (iPCoD) and Received Level for the 40 Hz – 16 kHz 1/3-octave band frequency range (DEPONS).*

From the statistical modelling, it can be concluded that the project-specific Response Threshold, required in the DEPONS model, can be set at **103.0** dB re 1 μPa^{2}s SEL. Using the piling impact radius of 14.0 km, the resulting Piling Impact Zone was **615.75** km^2. When multiplied with the animal density, this will provide an estimate of the number of animals disturbed by piling for incorporation in the iPCoD model[7]. By linking the 14.0 km impact distance to the Waiting Time (Figure 9), an overall Residual Disturbance period of **6:50:29** hours was derived (averaged over 384 events within 14.0 km from piling). Subsequent iPCoD population impact modelling will incorporate uncertainty relating to these parameters.

3.2 Full Bandwidth Data Analysis

3.2.1 Data suitability

As described in more detail in Section 2.3.1, prior QC assessment revealed issues with gain settings for Leg 1 and Leg 2, and equipment migration for the recorder deployed at Location 07 during Leg 6; consequently, it was decided to exclude these data. The noise levels for deployment 04_05 were substantially lower than anticipated, and checked against those recorded simultaneously at other locations, as well as against other deployments at this specific location, confirming a 20 – 30 dB difference. As such, deployment 04_05 was subsequently excluded from further analyses. The final days monitored during deployments 04_01 and 06_05 before the batteries ran out resulted in sound files that were unsuitable for further processing; these were therefore also excluded. In addition, a

[7] Assessment of local porpoise density and subsequent estimation of the number of disturbed individuals is part of the Population Impact Modelling Report.

technical fault with the RTSYS recorder during deployment 06_12 resulted in the exclusion of all data collected on 5 – 14 October 2018. Finally, a limited number of individual files across other deployments had to be excluded for a variety of reasons (e.g. corrupted files).

An overview of the remaining suitable FBW deployment dataset is presented in Figure 16, illustrating the spatial and temporal spread of 24 deployments, each lasting up to a month. Suitable data were available from between one (Leg 3 and Leg 8) and six locations (Leg 5). Data from Locations 03, 07 and 12 were collected on three Legs, whilst Locations 01 and 05 had data collected from five Legs. No pre-piling FBW data were available, and only limited data were available for the 2018/2019 winter period, similar to the C-POD monitoring. In contrast to the C-POD data, FBW coverage of the post-construction period was also limited.

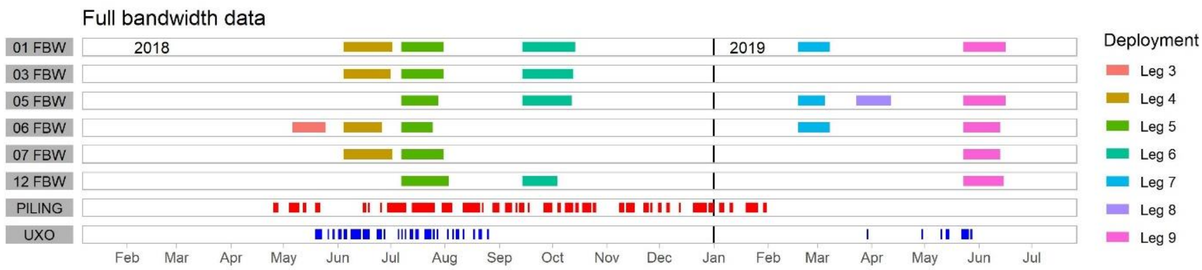


Figure 16. *Summary of FBW data suitable (on deployment level) for subsequent analysis, in relation to realised EA1 piling (at bottom, in red) and Unexploded Ordnance (UXO) detonation activity (at bottom, in blue).*

3.2.2 Data for propagation model calibration

Based on the criteria outlined in Section 2.4.2, three datasets were selected for the calibration of the transmission loss model (Figure 17; see Appendix D for further details and visualised examples of the selected data):

- Dataset 1 was collected from 21:14 – 21:25 UTC on 24/07/2018, while piling WTG D03;
- Dataset 2 was collected from 23:27 – 23:37 UTC on 13/07/2018, while piling WTG C03;
- Dataset 3 was collected from 09:43 – 09:55 UTC on 22/07/2018, while piling WTG E25.

All three datasets were considered during the model calibration stage (see below).

Selection of appropriate data for calibration of the transmission loss model was limited by four main factors, namely:

- Data availability. Concurrent data from all six monitoring locations were only available during Leg 5, during which piling was conducted on 15 days when all six recorders were active;

- The 6-hourly on/off duty cycle, originally applied to extend the effective deployment duration of the RTSYS recorders. This reduced the potential extent of piling activity to be assessed to those periods of the day for which acoustic FBW data were collected concurrently;
- The proximity of monitoring locations to piling activity. Piling signals were regularly clipped (making accurate amplitude measurements impossible) in recordings collected by the device(s) closest to the piling location, such that suitable data were restricted to recordings of piling activity collected at greater distances; and,
- The tidal influence experienced at Location 01, furthest from the piling locations. Like the other sites, this location was influenced by semi-diurnal reversing tidal currents. However, tidally-driven system self-noise (such as strumming signals generated by the mooring) was more prominent here than the relatively weak piling signals. Therefore, clean piling signals from this location could only be selected during low-flow periods ('slack water') around low and high tide.

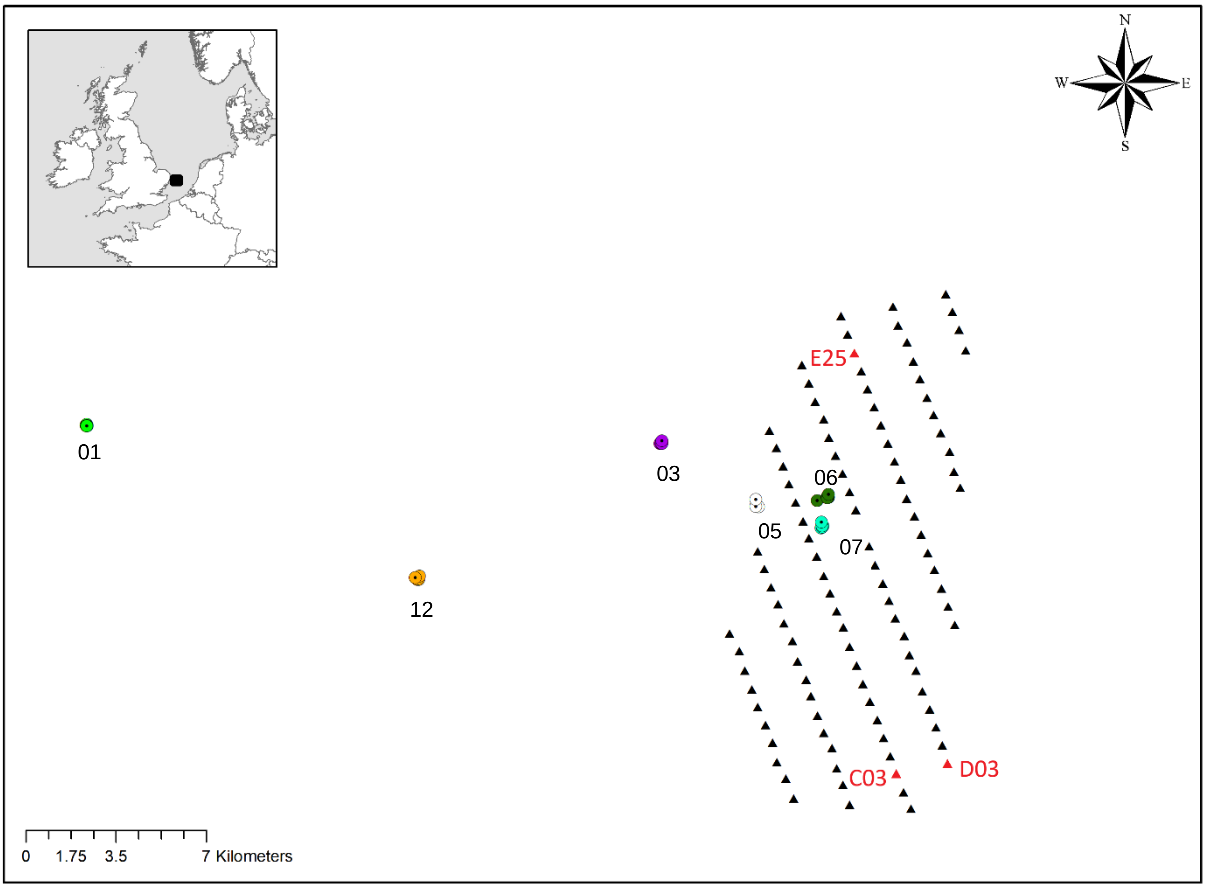


Figure 17. *EA1 FBW monitoring locations (circles) in relation to the positions of the constructed wind turbines (triangles). Data selected for propagation model calibration were collected during the construction of turbines C03, D03, and E25 (red triangles).*

3.2.3 Propagation modelling

3.2.3.1 Source Level

Using the calibrated transmission loss model, species-specific frequency-weighted Source Levels were computed for each of the 2,551 piling entries present in the piling schedule provided by SPR. These Source Levels represented levels based on maximum hammer energy (in kJ) provided for each event and ranged between 178.3 and 182.2 dB re 1 µPa^{2}s SEL at 1 m (Figure 18). The un-weighted Source Levels ranged between 211.9 and 215.2 dB re 1 µPa^{2}s SEL at 1 m.

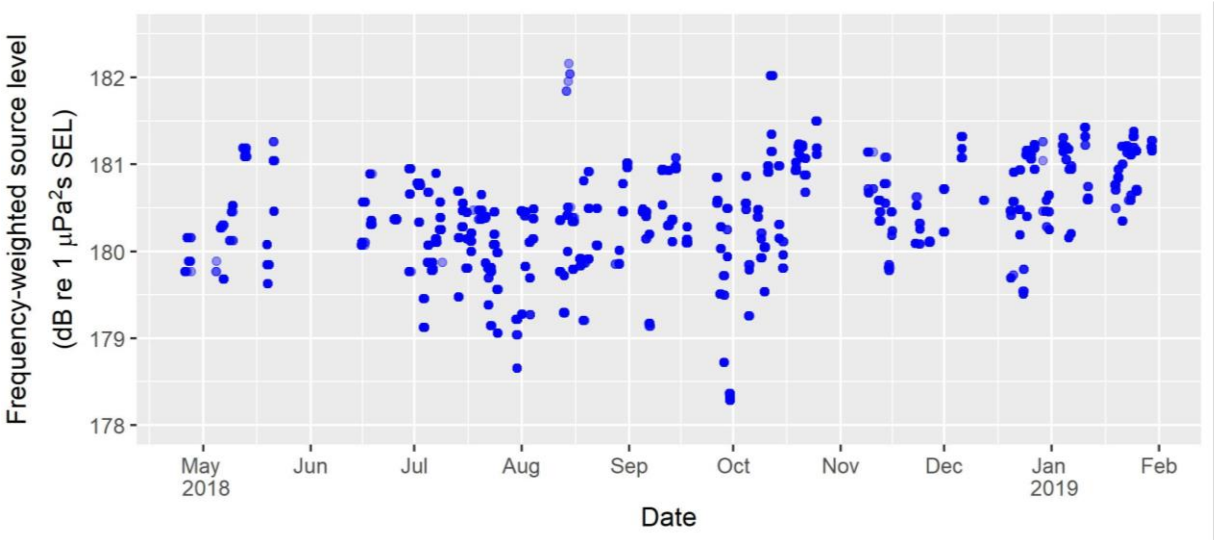


Figure 18. *Modelled frequency-weighted Source Levels for each WTG and Offshore sub-station piling event at EA1. Source Level calculated for the 40 Hz – 16 kHz 1/3-octave band frequency range.*

3.2.3.2 PTS and TTS ranges

Information regarding the modelled source level, the temporal and spatial piling schedule, acoustic ADD outputs, and ADD activation schedule were incorporated into the developed propagation model to obtain cumulative 24-hour noise levels across the frequency range (from the 40 Hz to the 16 kHz 1/3-octave bands), for each calendar day where piling took place.

Subsequent application of the auditory weighting function for harbour porpoises, and comparison with TTS and PTS thresholds specified by NMFS (2018) and Southall et al. (2019), resulted in estimated TTS distances ranging between 740 – 8,580 m, and estimated PTS distances ranging between 100 – 880 m from the piling locations (Figure 19). TTS ranges were almost an order of magnitude larger than the PTS ranges. Variation in estimated TTS and PTS ranges were predominantly determined by the daily piling duration (Figure 20). Throughout the construction phase, the mean PTS range was 551.2 m (median = 600.0 m), resulting in a PTS Zone of **0.95** km^2 which, when integrated with porpoise density information, will provide estimates of the number of harbour porpoises that experienced PTS for inclusion in the iPCoD model[8].

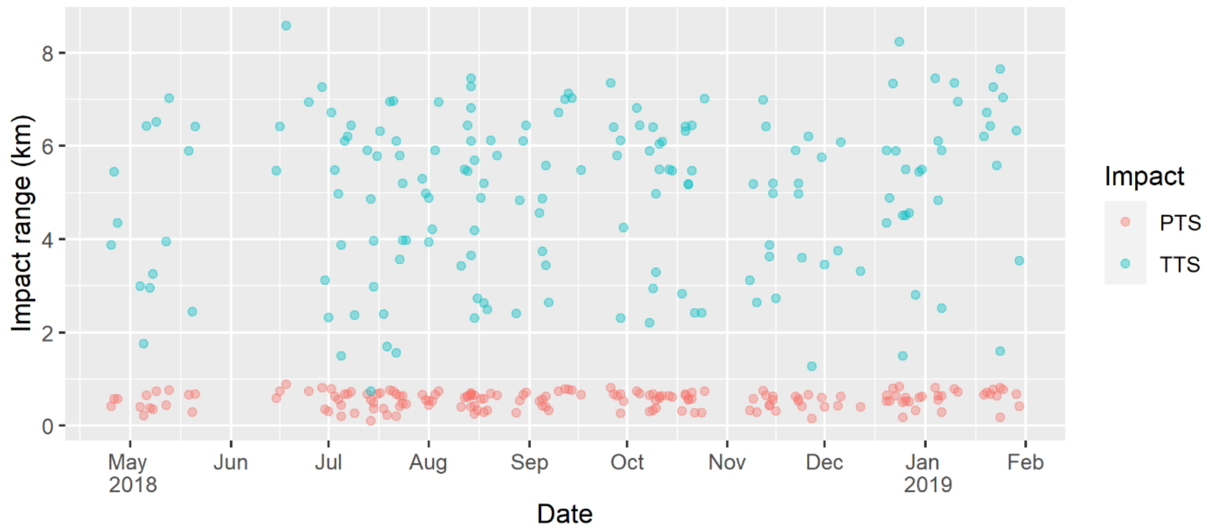


Figure 19. *PTS and TTS distances, incorporating both piling noise and ADD transmissions, throughout the construction phase of EA1.*

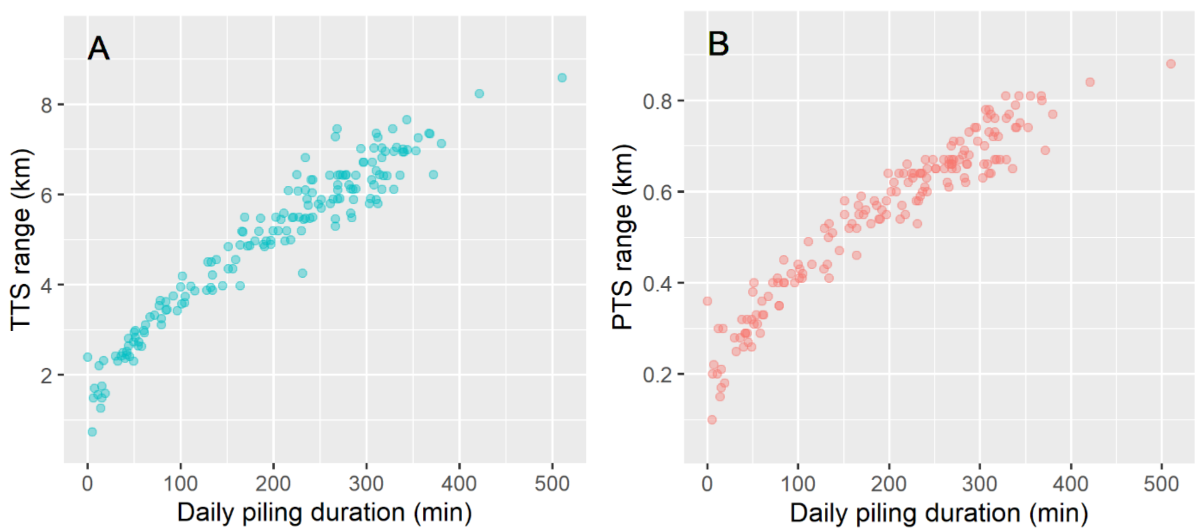


Figure 20. *Relationship between daily piling duration (min) and (A) TTS range (km); (B) PTS range (km).*

[8] Assessment of local porpoise density and subsequent estimation of the number of individuals that may experience PTS, is part of the Population Impact Modelling Report.

3.2.3.3 Absorption Coefficient ($\hat{\alpha}$) and Spreading Loss Factor ($\hat{\boldsymbol{\beta}}$)

Frequency-weighted Source Levels measured for the calibration data collected during the construction of WTGs C03, D03 and E25, revealed a dominant frequency of 6.3 kHz (Figures 5 – 7 in Appendix E), resulting in $\hat{\alpha}$ = 0.56926348205 dB / km (i.e. 0. 0005693 dB / m), following Equation 2.

Applying this Absorption Coefficient and a mean frequency-weighted Source Level of 180.45 dB re 1 µPa^{2}s SEL at 1 m, the fit of curves with various $\hat{\beta}$ values were explored (Figure 21). Statistically, the best-fitted value revealed a $\hat{\beta}$ = 18.26 (Figure 21, black dashed line). The curve associated with this value fits the first part of the relationship between sound level and Distance well. It, however, under-estimates received levels at distances over ~20 km, which is where most of the porpoises in the DEPONS model will be located.

Therefore, more precautionary values of $\hat{\beta}$ were used to generate Received Levels exceeding the numerically modelled values out to a distance of 25-30 km from the piling location. Porpoises were considered unlikely to react behaviourally beyond such distances. Additionally, inspection of the FBW sound files for Location 01 (located ~26-35 km away from piling, depending on the individual turbine location where piling occurred) revealed that piling noise regularly dropped below ambient sound levels, or that the piling signal became indistinguishable from tidal influences at these distances. A Spreading Loss Factor value of 17.75 best approximated this situation (Figure 21, yellow line).

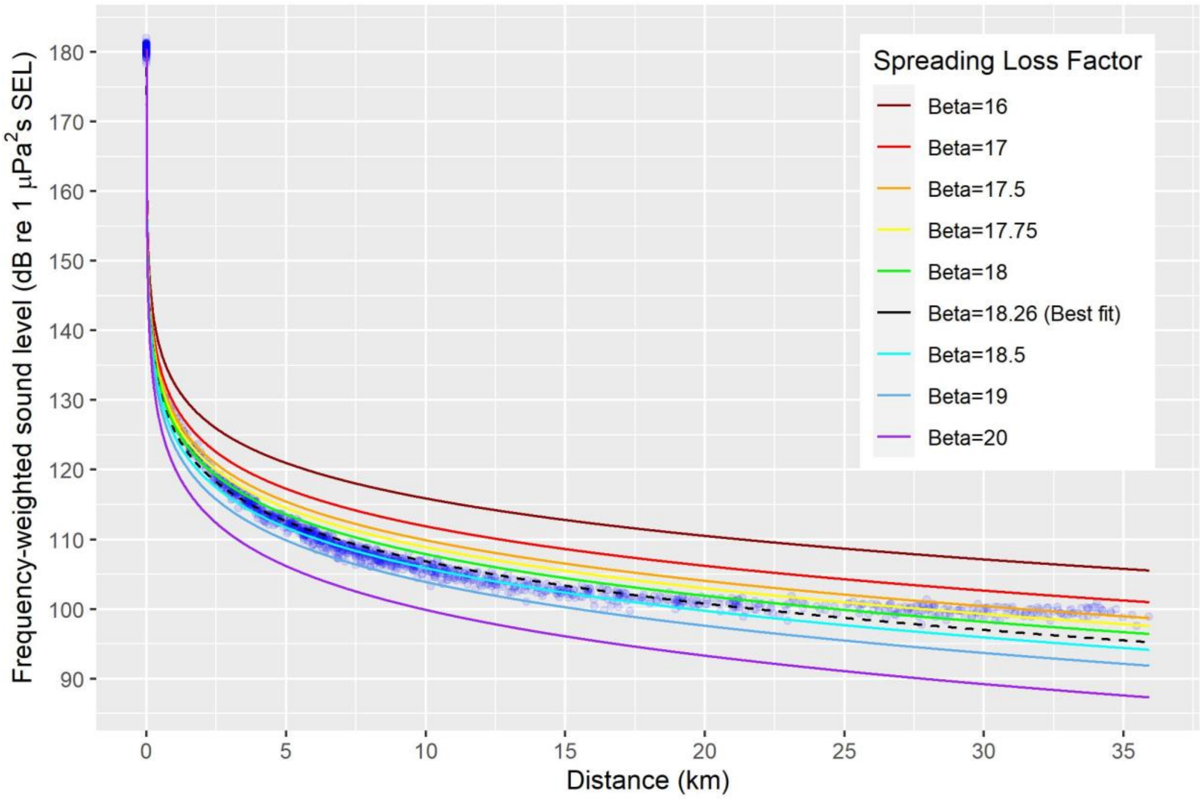


Figure 21. *Visualisation of the relationship between distance and frequency-weighted sound level (modelled Source and Received Levels) approximated using different Spreading Loss Factor values.*

3.2.4 Ambient sound analysis

Across all locations, a total of 321,013 suitable FBW acoustics recordings were analysed, of which 21,960 were collected while piling activity was ongoing. Of these, 18,528 acoustic files were included in the piling dataset, and the remaining 3,432 were excluded from both the piling and non-piling datasets. Visualisations of the variation (5 – 95% percentiles) in ambient sound levels, measured at each of the six FBW monitoring sites throughout the monitoring period, are provided in Figures 22 – 27. In each Figure, data are presented for the 1/3-octave bands centred from 25 Hz to 63 kHz, with acoustic recording files split between those where no piling occurred (top panel) and those where piling activity took place (bottom panel). These graphs show that overall ambient sound levels were higher during piling activity than during periods when no piling occurred, particularly for TOLs up to ~10 kHz. This pattern was not present at Location 01, and much reduced at Location 12, as these were substantially further removed from any piling activity. Direct inter-location comparisons, however, are complicated by the considerable differences in the time periods during which data were collected at each monitoring station (see Figure 16), as well as site-specific tidal influences that also affect noise measurements of FBW data (van Geel et al., 2020).

Nevertheless, substantial variation in ambient sound was present across frequency bands, both during piling and in the absence of piling, at all locations. Whilst alignment with the piling schedule facilitated the exclusion of piling activity from the non-piling data, these ambient sound levels also included sounds from other sources, such as shipping (whether or not associated with construction work), tidally-driven acoustic self-noise including flow noise (typically in the <200 Hz frequency bands) and mooring platform self-noise (e.g. strumming of mooring lines, lines knocking against the recording equipment), and the occasional UXO detonation. Additionally, the noise values for the highest 1/3 octave band appeared to be limited by the noise floor of the equipment. Recorder sensitivity at these high frequencies was not sensitive enough to detect signals with lower amplitude, as indicated by the very low spread in the data. As a result, the noise level for this 1/3-octave band may be a slight over-estimation of actual values.

Clipping is a distortion resulting from excessively loud signals that are beyond the recording equipment's measurement capability, commonly referred to as the dynamic range. In cases of clipping, the waveform is not fully captured resulting in erroneous sound level measurements. For example, clipping may occur where the peaks of the signal are missing from the data, and peaks are being truncated at the full-scale value of the system (see van Geel et al. (2023) for examples). Additionally, a very loud (high-amplitude) signal can cause the amplifier electronics to become saturated, and it may take some time for the system to recover from this effect (Robinson et al., 2014). As such, it is important to note that the measured noise levels shown in the bottom panels of Figures 22 – 27 represent an approximation of actual ambient sound levels in an environment impacted by piling, due to regular clipping of piling signals in the data collected by the acoustic recorders closest to piling activity, and the incorporation of brief non-piling periods in the 73-second recording files (up to 5 s at the start or end of each file, as well as short piling breaks and non-piling periods in-between hammer strikes). Clipping also occurred in the non-piling data. For example, clipping was regularly present in the deployment 04_06 data for the 4th, 5th, 8th and 9th June, indicating that the actual noise levels for these days may be under-recorded.

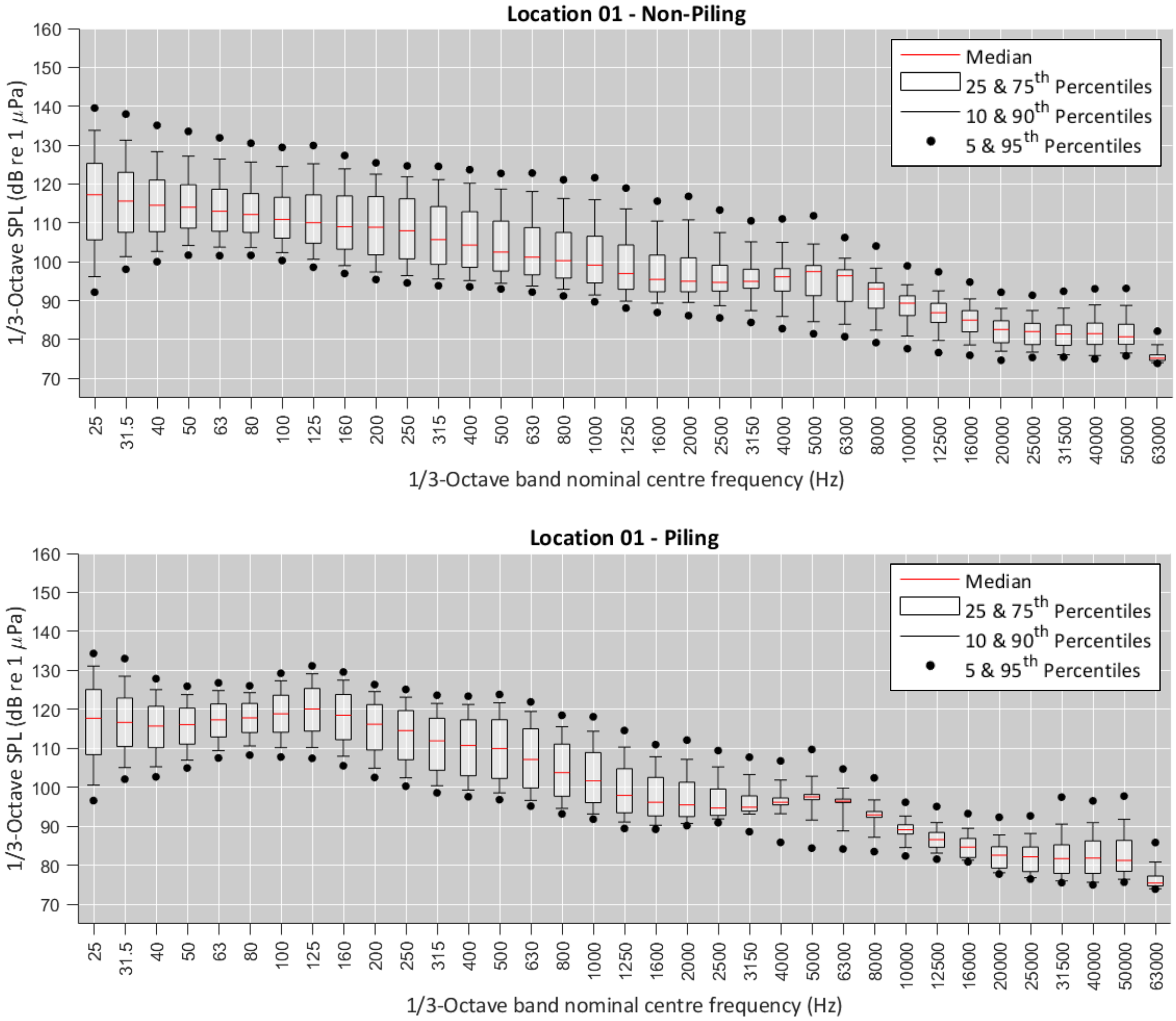


Figure 22. *Ambient sound levels across 1/3-octave bands for non-piling recordings (top; 68,284 files), and for recordings coinciding with piling activity (bottom; 4,044 files) at monitoring Location 01.*

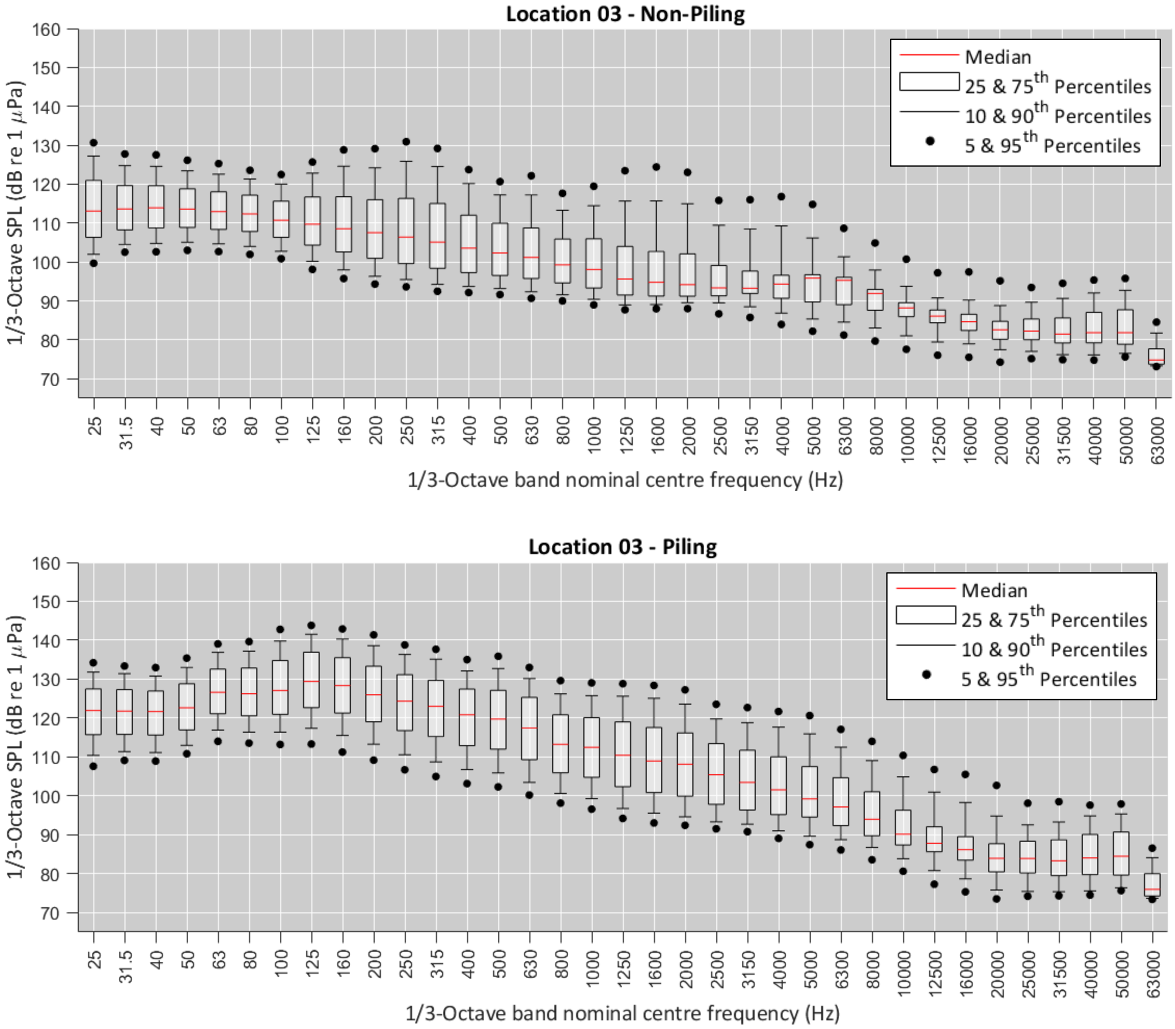
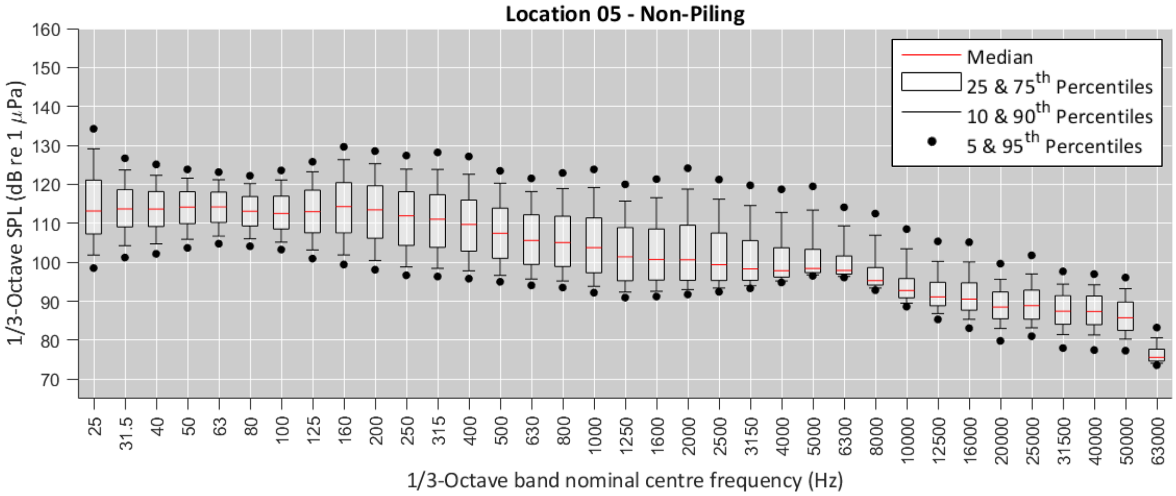


Figure 23. *Ambient sound levels across 1/3-octave bands for non-piling recordings (top; 42,378 files), and for recordings coinciding with piling activity (bottom; 4,007 files) at monitoring Location 03.*



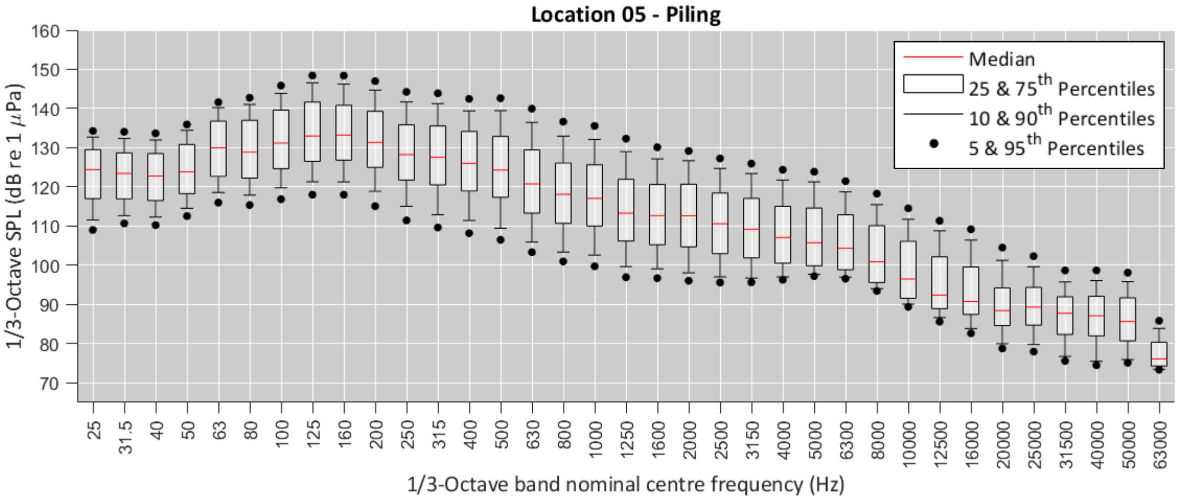


Figure 24. *Ambient sound levels across 1/3-octave bands for non-piling recordings (top; 58,628 files), and for recordings coinciding with piling activity (bottom; 33,029 files) at monitoring Location 05.*

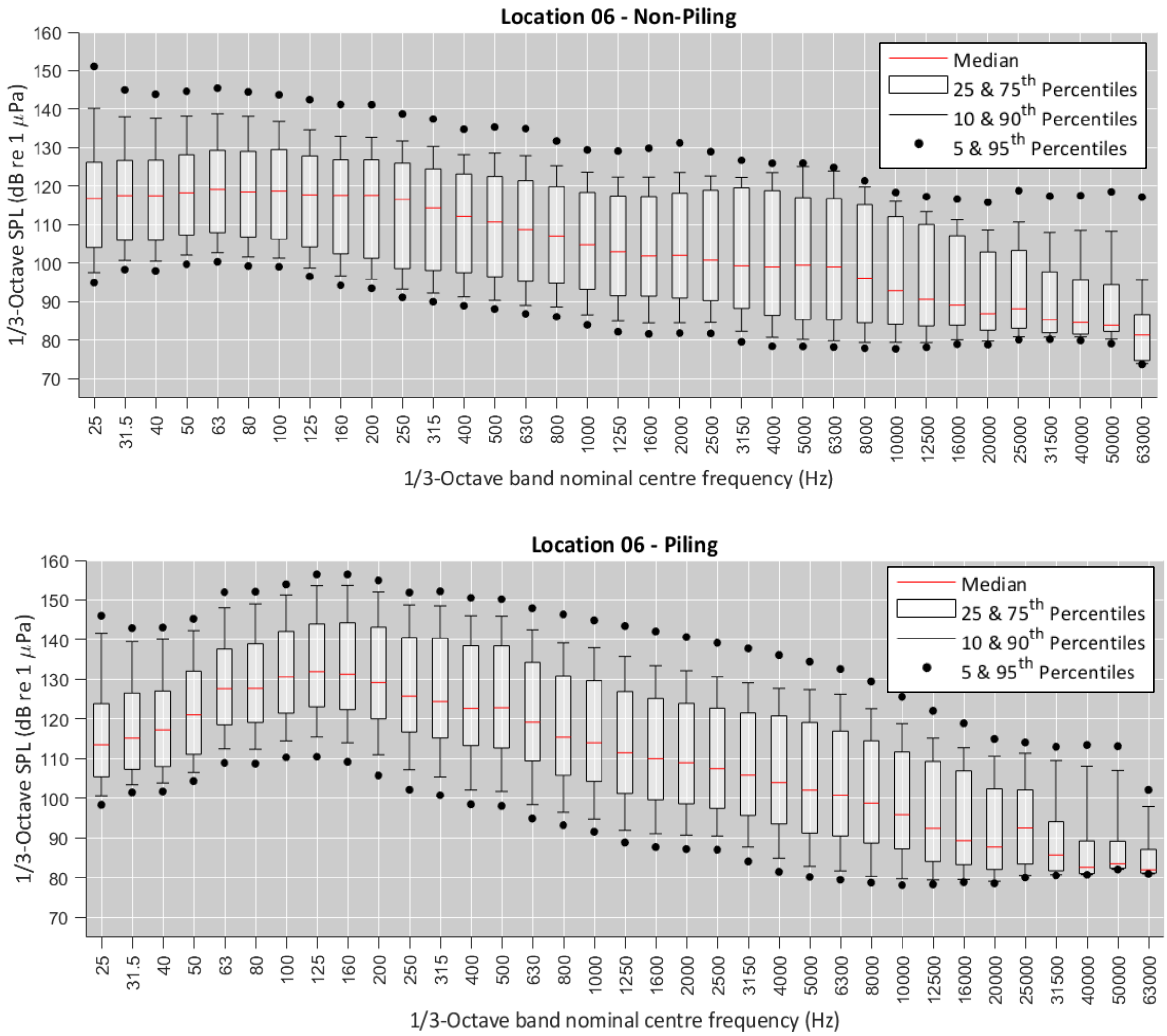
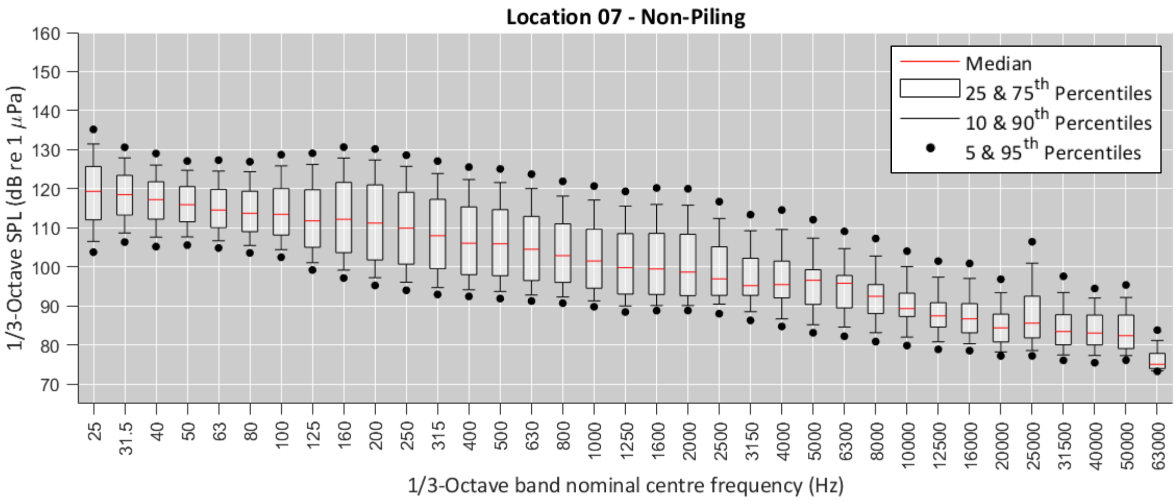


Figure 25. *Ambient sound levels across 1/3-octave bands for non-piling recordings (top; 54,440 files), and for recordings coinciding with piling activity (bottom; 2,617 files) at monitoring Location 06.*



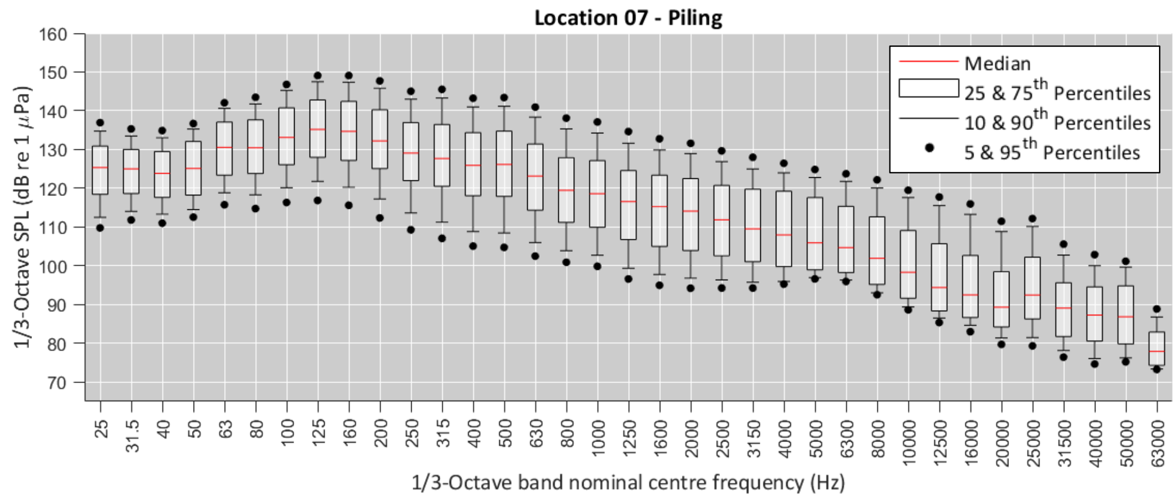
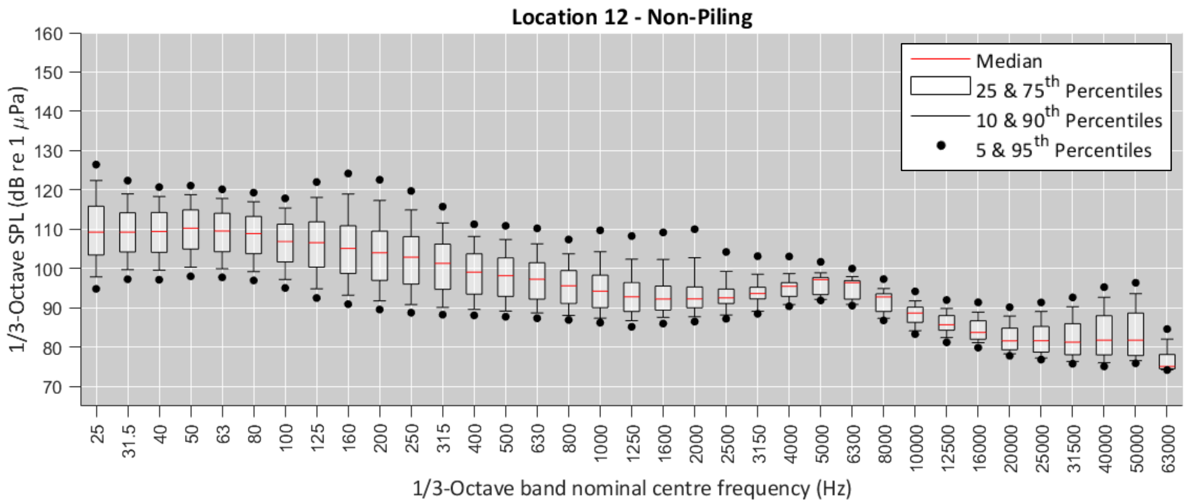


Figure 26. *Ambient sound levels across 1/3-octave bands for non-piling recordings (top; 39,701 files), and for recordings coinciding with piling activity (bottom; 2,281 files) at monitoring Location 07.*



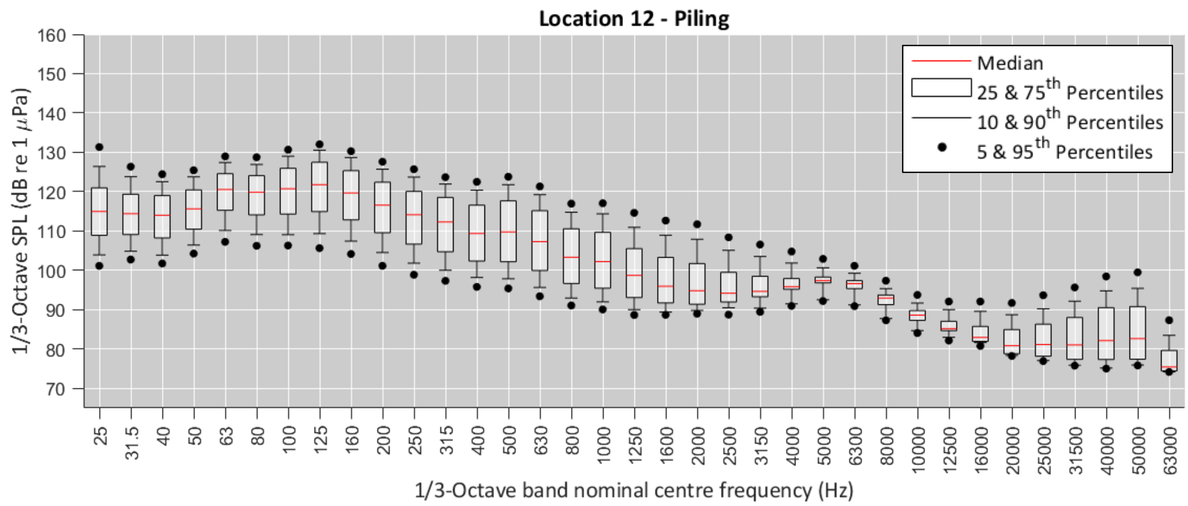


Figure 27. *Ambient sound levels across 1/3-octave bands for non-piling recordings (top; 37,322 files), and for recordings coinciding with piling activity (bottom; 2,550 files) at monitoring Location 12.*

4 CONCLUSION

The objective of this work was to obtain project-specific parameters from acoustic monitoring data collected at the EA1 wind farm for use in the iPCoD and DEPONS modelling frameworks. The work was carried out to assess the suitability of these two population impact models to quantify the impact of the construction of the EA1 wind farm on the wider North Sea harbour porpoise population.

Through a combination of processing of acoustic data, propagation modelling and statistical modelling, the following parameters, which are specific to the location and construction of EA1 as monitored in this project, were quantified:

- Piling Impact Zone (iPCoD): **615.75** km^2;
- PTS Zone (iPCoD): **0.95** km^2;
- Period of Residual Disturbance (iPCoD): **6:50** hours;
- Response Threshold (DEPONS): **103.0** dB re 1 $\mu Pa^2 s$ SEL;
- Absorption Coefficient (DEPONS): **0.0005693** dB / m; and,
- Spreading Loss Factor (DEPONS): **17.75**.

5 REFERENCES

Amodio, S., Aria, M., and D'Ambrosio, A. (2014). On concurvity in nonlinear and nonparametric regression models. *Statistica* 74(1), 85–98. doi: 10.6092/issn.1973-2201/4599.

Benjamins, S., van Geel, N., Hastie, G., Elliott, J. and Wilson, B. (2017). Harbour porpoise distribution can vary at small spatiotemporal scales in energetic habitats. *Deep-Sea Research Part II: Topical Studies in Oceanography* 141, 191–202. doi: 10.1016/j.dsr2.2016.07.002.

Bivand, R. and Lewin-Koh, N. (2020). Maptools: Tools for handling spatial objects. R package version 1.0-1. Available at: https://CRAN.R-project.org/package=maptools [Accessed July 28, 2023].

Booth, C.G., Embling, C., Gordon, J., Calderan, S.V., and Hammond, P.S. (2013). Habitat preferences and distribution of the harbour porpoise *Phocoena phocoena* west of Scotland. *Marine Ecology Progress Series* 478, 273–285. doi: 10.3354/meps10239.

Brandt, M.J., Höschle, C., Diederichs, A., Betke, K., Matuschek, R., and Nehls, G. (2013). Seal scarers as a tool to deter harbour porpoises from offshore construction sites. *Marine Ecology Progress Series* 475, 291–302. doi: 10.3354/meps10100.

Brandt, M.J., Dragon, A.-C., Diederichs, A., Schubert, A., Kosarev, V., Nehls, G., Wahl, V., Michalik, A., Brasch, A., Hinz, C., Ketzer, C., Todeskino, D., Gauger, M., Laczny, M., and Piper, W. (2016). Effects of offshore pile driving on harbour porpoise abundance in the German Bight. Assessment of noise effects. Final report prepared for Offshore Forum Windenergy: 246 pp. Available at: https://tethys.pnnl.gov/sites/default/files/publications/Brandt-et-al-2016.pdf [Accessed July 28, 2023].

Carstensen, J., Henriksen, O., and Teilmann, J. (2006). Impacts of offshore wind farm construction on harbour porpoises: Acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). *Marine Ecology Progress Series* 321, 295–308. doi: 10.3354/meps321295.

Embling, C.B., Gillibrand, P.A., Gordon, J., Shrimpton, J., Stevick, P.T., and Hammond, P.S. (2010). Using habitat models to identify suitable sites for marine protected areas for harbour porpoises (*Phocoena phocoena*). *Biological Conservation* 143(2), 267–279. doi: 10.1016j.biocon.2009.09.005.

Gilles, A., Viquerat, S., Becker, E.A., Forney, K.A., Geelhoed, S.C.V., Healters, J., Nabe-Nielsen, J., Scheidat, M., Siebert, U., Sveegaard, S., van Beest, F.M., van Bemmelen, R., and Aarts, G. (2016). Seasonal habitat-based density models for a marine top predator, the harbor porpoise, in a dynamic environment. *Ecosphere* 7(6), e01367 (22 pp). doi: 10.1002/ecs2.1367.

Graham, I.M., Merchant, N.D., Farcas, A., Barton, T.R., Cheney, B., Bono, S., and Thompson, P.M. (2019). Harbour porpoise responses to pile-driving diminish over time. *Royal Society Open Science* 6, 190335 (13 pp). doi: 10.1098/rsos.190335.

Harwood, J., King, S.L., Schick, R., Donovan, C., and Booth, C. (2014). A protocol for implementing the Interim Population Consequences of Disturbance (PCoD) approach: Quantifying and assessing the effects of UK offshore renewable energy developments on marine mammal populations. Report SMRUL-TCE-2013-014. Scottish Marine and Freshwater Science 5(2): 90 pp. Available at: http://www.gov.scot/Resource/0044/00443360.pdf [Accessed July 28, 2023].

Heinänen, S. and Skov, H. (2015). The identification of discrete and persistent areas of relatively high harbour porpoise density in the wider UK marine area. Joint Nature Conservation Committee, JNCC Report No. 544: 108 pp. Available at: https://hub.jncc.gov.uk/assets/f7450390-9a89-4986-8389-9bff5ea1978a [Accessed July 28, 2023].

IAMMWG (Inter-Agency Marine Mammal Working Group) (2015) Management Units for cetaceans in UK waters (January 2015). JNCC Report No. 547, JNCC Peterborough: 37 pp. Available at: https://hub.jncc.gov.uk/assets/f07fe770-e9a3-418d-af2c-44002a3f2872 [Accessed July 28, 2023].

ICES (International Council for the Exploration of the Sea) (2014). OSPAR request on implementation on MSFD for marine mammals. Special Request. Available at: https://ices-library.figshare.com/articles/report/OSPAR_request_on_implementation_of_MSFD_for_marine_mammals/18687344 [Accessed July 28, 2023].

Jacobson, E.K., Forney, K.A., and Barlow, J. (2017). Using paired visual and passive acoustic surveys to estimate passive acoustic detection parameters for harbour porpoise abundance estimates. *Journal of the Acoustical Society of America* 141(1), 219–230. doi: 10.1121/1.4973415.

JNCC (Joint Nature Conservation Committee) (2019). 1351 Harbour porpoise *Phocoena phocoena*. Available at: https://sac.jncc.gov.uk/species/S1351/ [Accessed July 28, 2023].

King, S.L., Schick, R.S., Donovan, C., Booth, C.G., Burgman, M., Thomas, L., and Harwood, J. (2015). An interim framework for assessing the population consequences of disturbance. *Methods in Ecology and Evolution* 6(10), 1150-1158. doi: 10.1111/2041-210X.12411.

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

Malme, C.I., Beranek, B., and Newman Inc. (1995). Chapter 4 – Sound propagation: 59–86. In: Richardson, W.J., Greene Jr., C.R., Malme, C.I., and Thomson, D.H. (eds). Marine mammals and noise. Academic Press, San Diego.

Marques, T.A, Thomas, L., Martin, S.W., Mellinger, D.K., Ward, J.A., Moretti, D.J., Harris, D., and Tyack, P.L. (2012) Estimating animal population density using passive acoustics. *Biological Reviews* 88(2), 287–309. doi: 10.1111/brv.12001.

Marubini, F., Gimona, A., Evans, P.G.H., Wright, P.J., and Pierce, G.J. (2009). Habitat preferences and interannual variability in occurrence of the harbour porpoise *Phocoena phocoena* off northwest Scotland. *Marine Ecology Progress Series* 381, 297–310. doi: 10.3354/meps07893.

Merchant, N.D., Fristrup, K.M., Johnson, M.P., Tyack, P.L., Witt, M.J., Blondel, P., and Parks, S.E. (2015). Measuring acoustic habitats. *Methods in Ecology and Evolution* 6, 257–265. doi: 10.1111/2041-210X.12330.

Nabe-Nielsen, J., van Beest, F.M., Grimm, V., Sibly, R.M., Teilmann, J., and Thompson, P.M. (2018). Predicting the impacts of anthropogenic disturbances on marine populations. *Conservation. Letters* 11, e12563 (8 pp). doi: 10.1111/conl.12563.

Nabe-Nielsen, J., van Beest, F.M., Grimm, V., Sibly, R.M., Teilmann, J., and Thompson, P.M. (2021). TRACE document DEPONS 2.2: Individual-based model for simulating impact of wind farm construction noise on the North Sea harbour porpoise population: 62 pp. Available at: https://github.com/jacobnabe/DEPONS/blob/master/DEPONS%202.2%20%E2%80%93%20TRACE%202021-08-31.pdf [Accessed July 28, 2023].

NMFS (National Marine Fisheries Service) (2018). Revisions to: Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (Version 2.0): Underwater thresholds for onset of permanent and temporary threshold shifts. U.S. Dept. of Commer., NOAA. NOAA Technical Memorandum NMFS-OPR-59: 167 pp. Available at: https://www.fisheries.noaa.gov/resource/document/technical-guidance-assessing-effects-anthropogenic-sound-marine-mammal-hearing [Accessed July 28, 2023].

Paxton, C.G.M., Scott-Hayward, L., Mackenzie, M., Rexstad, E., and Tomas, L. (2016). Revised Phase III Data Analysis of Joint Cetacean Protocol Data Resources. Joint Nature Conservation Committee, JNCC Report & Advisory Note No. 517: 197 pp. Available at: https://hub.jncc.gov.uk/assets/01adfabd-e75f-48ba-9643-2d594983201e [Accessed July 28, 2023].

Pirotta, E., Matthiopoulos, J., MacKenzie, M., Scott-Hayward, L. and Rendell, L. (2011). Modelling sperm whale habitat preference: a novel approach combining transect and follow data. *Marine Ecology Progress Series* 436: 257-272. doi: 10.3354/meps09236.

R Core Team (2020) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: https:www.R-project.org/ [Accessed July 28, 2023].

Robinson, S.P., Lepper, P.A., and Hazelwood, R.A. (2014). Good practice guide for underwater noise measurement. National Measurement Office, Marine Scotland, The Crown Estate: 95 pp. NPL Good Practic Guide No. 133. Available at: https://www.npl.co.uk/special-pages/guides/gpg133underwater [Accessed July 28, 2023].

Sinclair, R., Booth, C., Harwood, J. and Sparling, C. (2019). Helpfile for the interim PCoD v5 model: 63

pp. Available at: https://www.smruconsulting.com/population-consequences-of-disturbance-pcod [Accessed July 28, 2023].

Skov, H., and Thomsen, F. (2008). Resolving fine-scale spatio-temporal dynamics in the harbour porpoise *Phocoena phocoena*. *Marine Ecology Progress Series* 373, 173–186. doi: 10.3354/meps07666.

Southall, B.L., Finneran, J.J., Reichmuth, C., Nachtigall, P.E., Ketten, D.R., Bowles, A E., Ellison, W.T., Nowacek, D.P., and Tyack, P.L. (2019). Marine mammal noise exposure criteria: Updated scientific recommendations for residual hearing effects. *Aquatic Mammals* 45, 125–232. doi: 10.1578/AM.45.2.2019.125.

Teilmann, J., and Carstensen, J. (2012). Negative long term effects on harbour porpoises from a large scale offshore wind farm in the Baltic - Evidence of slow recovery. *Environmental Research Letters* 7, 045101. doi: 10.1088/1748-9326/7/4/045101.

Thomas, L., and Burt, M.L. (2016). Statistical analysis of SAMBAH survey and associated data. CREEM Technical Report 2016-1, University of St Andrews: 130 pp. Available at: https://research-repository.st-andrews.ac.uk/handle/10023/17328 [Accessed July 28, 2023].

van Geel, N.C.F., Merchant, N.D., Culloch, R.M., Edwards, E.J.W., Davies, I.M., O'Hara Murray, R.B. and Brookes, K.L. (2020). Exclusion of tidal influence on ambient sound measurements. *Journal of the Acoustical Society of America* 148, 701–712. doi: 10.1121/10.0001704.

van Geel, N.C.F., Wittich, A. and Benjamins S. (2023a). Southern North Sea harbour porpoise population modelling validation – Data Quality Control Report. A report by SAMS Enterprise for ScottishPower Renewables: 28 pp.

van Geel, N.C.F., Benjamins S., Risch, D., Wittich, A., and Wilson, B. (2023b). Southern North Sea harbour porpoise population modelling validation – Population Impact Modelling Report. A report by SAMS Enterprise for ScottishPower Renewables: 104 pp.

Wickham, H. (2016). ggplot2: Elegant graphics for data analysists. Springer-Verlag, New York.

Williamson, L.D., Brookes, K.L., Scott, B.E., Graham, I.M., and Thompson, P.M. (2017). Diurnal variation in harbour porpoise detection potential implications for management. *Marine Ecology Progress Series* 570, 223–232. doi: 10.3354/meps12118.

Wood, S.N. (2017a). mgcv: Mixed GAM Computation Vehicle with GCV/AIC/REML smoothness estimation and GAMMs by REML/PQL. R package version 1.8-31. Available at: https://CRAN.R-project.org/package=mgcv [Accessed July 28, 2023].

Wood, S.N. (2017b). Generalized Additive Models: An Introduction with R (2nd Edition). Boca Raton, Chapman and Hall/CRC. doi: 10.1201/9781315370279.

APPENDIX A – SUITABLE EA1 C-POD DATA

Table A1. *Summary of suitable EA1 C-POD data. Deployment = Leg_Location.*

Deployment	Start	End	Deployment	Start	End
02_01	11/03/2018 13:35	05/05/2018 07:51	06_01	13/09/2018 08:16	16/02/2019 11:58
02_02	11/03/2018 14:01	05/05/2018 08:44	06_02	13/09/2018 08:52	17/11/2018 08:43
02_03	11/03/2018 14:58	05/05/2018 10:00	06_03	13/09/2018 09:44	17/01/2019 07:59
02_04	11/03/2018 15:27	17/03/2018 14:41	06_04	13/09/2018 10:38	05/01/2019 18:01
02_05	11/03/2018 15:53	06/05/2018 08:12	06_05	13/09/2018 11:09	16/02/2019 16:29
02_06	11/03/2018 16:09	06/05/2018 08:37	06_07	13/09/2018 12:08	16/09/2018 21:16
02_09	11/03/2018 16:28	14/03/2018 07:16	06_08	13/09/2018 12:29	04/01/2019 21:29
02_10	11/03/2018 16:41	04/04/2018 04:15	06_09	13/09/2018 12:50	23/11/2018 01:54
02_11	11/03/2018 17:09	20/03/2018 04:25	06_10	13/09/2018 13:13	13/11/2018 07:43
02_12	11/03/2018 17:46	06/05/2018 11:45	06_12	13/09/2018 14:14	18/10/2018 09:09
03_01	05/05/2018 08:10	03/06/2018 10:58	07_01	16/02/2019 12:08	21/03/2019 10:54
03_02	05/05/2018 08:52	03/06/2018 11:46	07_02	16/02/2019 12:39	28/02/2019 17:10
03_03	05/05/2018 10:05	03/06/2018 12:32	07_03	16/02/2019 14:04	22/03/2019 09:02
03_04	05/05/2018 11:31	03/06/2018 13:08	07_04	16/02/2019 15:25	22/03/2019 09:56
03_05	06/05/2018 08:19	03/06/2018 13:51	07_05	16/02/2019 16:35	22/03/2019 10:34
03_06	06/05/2018 08:46	03/06/2018 14:17	07_06	16/02/2019 17:07	22/03/2019 10:59
03_07	06/05/2018 09:03	03/06/2018 14:33	07_07	16/02/2019 17:34	22/03/2019 11:23
03_08	06/05/2018 09:16	03/06/2018 14:50	07_08	17/02/2019 07:36	22/03/2019 11:42
03_09	06/05/2018 09:34	03/06/2018 15:03	07_09	17/02/2019 07:50	22/03/2019 12:04
03_10	06/05/2018 10:06	03/06/2018 15:31	07_10	17/02/2019 08:12	18/02/2019 06:40
03_11	06/05/2018 11:04	03/06/2018 16:21	07_11	17/02/2019 08:55	22/03/2019 12:56
04_01	03/06/2018 11:19	06/07/2018 07:26	07_12	17/02/2019 11:11	22/03/2019 13:43
04_02	03/06/2018 11:59	06/07/2018 08:01	08_02	21/03/2019 11:45	22/05/2019 08:48
04_03	03/06/2018 12:38	06/07/2018 08:45	08_04	22/03/2019 10:06	22/05/2019 10:30
04_04	03/06/2018 13:17	06/07/2018 09:11	08_05	22/03/2019 10:14	22/05/2019 10:44
04_05	03/06/2018 13:54	06/07/2018 09:38	08_06	22/03/2019 11:14	22/05/2019 11:32
04_06	03/06/2018 14:23	06/07/2018 10:18	08_07	22/03/2019 11:35	03/05/2019 17:50
04_07	03/06/2018 14:37	06/07/2018 10:35	08_08	22/03/2019 11:56	22/05/2019 12:19
04_08	03/06/2018 14:56	06/07/2018 11:08	08_09	22/03/2019 12:15	22/05/2019 12:33
04_09	03/06/2018 15:11	06/07/2018 11:27	08_10	22/03/2019 12:46	18/04/2019 20:10
04_10	03/06/2018 15:35	06/07/2018 11:48	08_11	22/03/2019 13:06	21/05/2019 09:05
04_11	03/06/2018 16:29	04/07/2018 05:56	09_01	22/05/2019 08:26	21/06/2019 09:29
04_12	03/06/2018 18:05	06/07/2018 15:06	09_02	22/05/2019 09:03	21/06/2019 09:49
05_01	07/07/2018 11:57	05/08/2018 14:43	09_03	22/05/2019 09:57	21/06/2019 10:23
05_03	06/07/2018 08:48	28/08/2018 18:25	09_04	22/05/2019 10:41	21/06/2019 10:50
05_04	06/07/2018 09:14	11/07/2018 17:43	09_05	22/05/2019 11:18	21/06/2019 11:13
05_05	06/07/2018 09:52	13/09/2018 11:02	09_06	22/05/2019 11:41	21/06/2019 11:28
05_06	06/07/2018 10:22	13/09/2018 11:25	09_07	22/05/2019 12:04	21/06/2019 11:33
05_07	06/07/2018 10:51	13/09/2018 11:53	09_08	22/05/2019 12:25	21/06/2019 11:48
05_08	06/07/2018 11:16	24/07/2018 07:32	09_09	22/05/2019 12:39	21/06/2019 11:56
05_09	06/07/2018 11:32	13/07/2018 00:08	09_10	22/05/2019 13:05	21/06/2019 12:28
05_10	06/07/2018 11:53	13/09/2018 13:05	09_11	22/05/2019 13:25	21/06/2019 12:42
05_11	06/07/2018 12:36	09/09/2018 01:04	09_12	22/05/2019 14:06	21/06/2019 13:18
05_12	06/07/2018 14:10	13/09/2018 14:08			

APPENDIX B – HARBOUR PORPOISE DETECTION RATES IN EA1 C-POD DATA (ALL DATA)

The below tables summarise porpoise detection data for each Leg individually, as well as aggregating data from Legs 2 – 9 for Location 05 (the only site with continuous monitoring effort throughout the project). These summaries are based on all data, prior to the exclusion of hours monitored ≤90%.

Table B1. *Summary of C-POD data from Leg 2 (11/03/2018 – 06/05/2018). Porpoise detection data are aggregated by 1) total number of Porpoise Positive Minutes (N_{PPM}) over the entire deployment, 2-3) by average number of Porpoise Positive Minutes (N_{PPM}) per hour and per day, 4) by number of Porpoise Positive 10-Minutes (N_{PP10M}) per day, and 5) by number of Porpoise Positive Hours (N_{PPH}) per day. Total number of minutes during which time was lost due to excessive noise ($N_{TimeLost}$) is also provided. * Based on whole hours only. ^ Based on entire days only. No deployment occurred at Locations 07 and 08 during this Leg.*

Leg_Location	Deployment Duration (days / minutes)	Total N_{PPM} ($\%_{total}$)	Avg. N_{PPM}/Hour* (min-max)	Avg. N_{PPM}/Day^ (min-max)	Avg. N_{PP10M}/Day^ (min-max)	Avg. N_{PPH}/Day^ (min-max)	Total $N_{TimeLost}$ ($\%_{total}$)
2_01	54.8 / 78,856	8,798 (11.2%)	6.7 (0-24)	160.9 (22-609)	50.4 (9-123)	17.0 (4-24)	2,102 (2.7%)
2_02	54.8 / 78,883	8,432 (10.7%)	6.4 (0-59)	153.6 (8-625)	42.5 (4-110)	14.0 (3-24)	17,972 (22.8%)
2_03	54.8 / 78,902	3,986 (5.1%)	3.0 (0-41)	71.9 (3-235)	26.7 (2-76)	10.5 (2-22)	26,395 (33.5%)
2_04	6.0 / 8,594	1,488 (17.3%)	10.5 (0-43)	276.8 (141-427)	71.6 (44-102)	19.4 (16-24)	355 (4.1%)
2_05	55.7 / 80,179	4,832 (6.0%)	3.6 (0-49)	87.4 (1-441)	28.8 (1-103)	11.8 (1-24)	2,090 (2.6%)
2_06	55.7 / 80,188	3,406 (4.2%)	2.6 (0-41)	61.1 (0-373)	21.0 (0-101)	8.8 (0-24)	14,363 (17.9%)
2_09	2.6 / 3,768	133 (3.5%)	2.1 (0-21)	62.5 (32-93)	26.5 (16-37)	10.5 (7-14)	204 (5.4%)
2_10	23.5 / 33,814	1,904 (5.6%)	3.4 (0-52)	82.6 (0-256)	29.2 (0-75)	11.2 (0–23)	983 (2.9%)
2_11	8.5 / 12,196	1,486 (12.2%)	5.9 (0-47)	147.3 (0-254)	54.4 (40-82)	18.3 (13-22)	1,959 (16.1%)
2_12	55.7 / 80,279	7,769 (9.7%)	5.8 (0-56)	139.3 (16-500)	43.3 (9-116)	13.6 (5-24)	25,212 (31.4%)

Table B2. *Summary of C-POD data from Leg 3 (05/05/2018 – 03/06/2018). Porpoise detection data are aggregated by 1) total number of Porpoise Positive Minutes (N_{PPM}) over the entire deployment, 2-3) by average number of Porpoise Positive Minutes (N_{PPM}) per hour and per day, 4) by number of Porpoise Positive 10-Minutes (N_{PP10M}) per day, and 5) by number of Porpoise Positive Hours (N_{PPH}) per day. Total number of minutes during which time was lost due to excessive noise ($N_{TimeLost}$) is also provided. * Based on whole hours only. ^ Based on entire days only. The C-POD deployed at Location 12 during this Leg could not be retrieved.*

Leg_Location	Deployment Duration (days / minutes)	Total N_{PPM} ($\%_{total}$)	Avg. N_{PPM}/Hour* (min-max)	Avg. N_{PPM}/Day^ (min-max)	Avg. N_{PP10M}/Day^ (min-max)	Avg. N_{PPH}/Day^ (min-max)	Total $N_{TimeLost}$ ($\%_{total}$)
3_01	29.1 / 41,928	3,124 (7.5%)	4.5 (0-38)	104 (17-270)	38.1 (9-76)	15.5 (5-23)	772 (1.8%)
3_02	29.1 / 41,933	1,447 (3.5%)	2.1 (0-33)	48.9 (7-174)	20.6 (5-53)	9.9 (4-20)	6,106 (14.6%)
3_03	29.1 / 41,907	1,687 (4%)	2.4 (0-36)	55.8 (1-205)	20 (0-58)	7.8 (1-21)	10,725 (25.6%)
3_04	29.1 / 41,857	1,710 (4.1%)	2.5 (0-42)	59.8 (0-253)	22.1 (0-69)	9.4 (0-21)	2,626 (6.3%)
3_05	28.2 / 40,652	1,532 (3.8%)	2.3 (0-37)	56.6 (4-240)	18.7 (2-63)	8.3 (2-18)	976 (2.4%)
3_06	28.2 / 40,651	831 (2%)	1.2 (0-34)	30.6 (0-206)	11.8 (0-64)	5.1 (0-20)	3,658 (9%)
3_07	28.2 / 40,650	713 (1.8%)	1.1 (0-41)	26.3 (0-188)	9.7 (0-67)	4.2 (0-20)	11,435 (28.1%)
3_08	28.2 / 40,654	1,274 (3.1%)	1.9 (0-45)	46.7 (0-304)	13.7 (0-887)	5.1 (0-21)	15,786 (38.8%)
3_09	28.2 / 40,649	1,058 (2.6%)	1.6 (0-36)	38.8 (0-222)	12 (0-70)	4.5 (0-21)	13,959 (34.3%)
3_10	28.2 / 40,645	881 (2.2%)	1.3 (0-41)	32.6 (0-183)	11.1 (0-54)	5.1 (0-19)	5,018 (12.3%)
3_11	28.2 / 40,637	404 (1%)	0.6 (0-27)	14.7 (0-66)	6.6 (0-24)	3.7 (0-11)	9,204 (22.6%)

Table B3. *Summary of C-POD data from Leg 4 (03/06/2018 – 06/07/2018). Porpoise detection data are aggregated by 1) total number of Porpoise Positive Minutes (N_{PPM}) over the entire deployment, 2-3) by average number of Porpoise Positive Minutes (N_{PPM}) per hour and per day, 4) by number of Porpoise Positive 10-Minutes (N_{PP10M}) per day, and 5) by number of Porpoise Positive Hours (N_{PPH}) per day. Total number of minutes during which time was lost due to excessive noise ($N_{TimeLost}$) is also provided. * Based on whole hours only. ^ Based on entire days only.*

Leg_Location	Deployment Duration (days / minutes)	Total N_{PPM} (%total)	Avg. N_{PPM}/Hour* (min-max)	Avg. N_{PPM}/Day^ (min-max)	Avg. N_{PP10M}/Day^ (min-max)	Avg. N_{PPH}/Day^ (min-max)	Total $N_{TimeLost}$ (%total)
4_01	32.8 / 47,287	929 (2.0%)	1.2 (0-21)	27.7 (3-77)	14.2 (2-36)	8.3 (2-18)	520 (1.1%)
4_02	32.8 / 47,282	370 (0.8%)	0.5 (0-26)	11.3 (0-53)	5.6 (0-24)	3.4 (0-12)	20,638 (43.6%)
4_03	32.8 / 47,287	928 (2.0%)	1.2 (0-33)	28.8 (1-172)	13.3 (1-49)	7.1 (1-19)	8,269 (17.5%)
4_04	32.8 / 47,274	1,206 (2.6%)	1.5 (0-40)	36.9 (0-169)	15.5 (0-56)	7.7 (0-18)	6,213 (13.8%)
4_05	32.8 / 47,264	432 (0.9%)	0.5 (0-21)	13.4 (0-68)	6.8 (0-29)	4.3 (0-15)	965 (2.0%)
4_06	32.8 / 47,275	653 (1.4%)	0.8 (0-38)	20.1 (0-168)	8.1 (0-50)	4.2 (0-20)	12,023 (25.4%)
4_07	32.8 / 47,278	510 (1.1%)	0.6 (0-24)	15.8 (0-147)	6.5 (0-43)	3.4 (0-15)	17,910 (37.9%)
4_08	32.8 / 47,292	695 (1.5%)	0.9 (0-47)	21.7 (0-195)	8.1 (0-61)	4.1 (0-22)	14,503 (30.7%)
4_09	32.8 / 47,295	520 (1.1%)	0.7 (0-31)	16.3 (0-120)	6.5 (0-41)	3.4 (0-18)	10,340 (21.9%)
4_10	32.8 / 47,293	430 (0.9%)	0.5 (0-43)	13.2 (0-115)	5.7 (0-33)	3.3 (0-15)	5,771 (12.2%)
4_11	30.6 / 44,007	168 (0.4%)	0.2 (0-13)	5.6 (0-34)	3.0 (0-17)	2.0 (0-9)	18,353 (41.7%)
4_12	32.9 / 47,341	1,387 (2.9%)	1.8 (0-35)	42.1 (2-201)	17.1 (2-60)	8.4 (2-21)	6,793 (14.3%)

Table B4. *Summary of C-POD data from Leg 5 (06/07/2018 – 13/09/2018). Porpoise detection data are aggregated by 1) total number of Porpoise Positive Minutes (N_{PPM}) over the entire deployment, 2-3) by average number of Porpoise Positive Minutes (N_{PPM}) per hour and per day, 4) by number of Porpoise Positive 10-Minutes (N_{PP10M}) per day, and 5) by number of Porpoise Positive Hours (N_{PPH}) per day. Total number of minutes during which time was lost due to excessive noise ($N_{TimeLost}$) is also provided. * Based on whole hours only. ^ Based on entire days only. The C-POD deployed at Location 02 during this Leg could not be retrieved.*

Leg_Location	Deployment Duration (days / minutes)	Total N_{PPM} (%total)	Avg. N_{PPM}/Hour* (min-max)	Avg. N_{PPM}/Day^ (min-max)	Avg. N_{PP10M}/Day^ (min-max)	Avg. N_{PPH}/Day^ (min-max)	Total $N_{TimeLost}$ (%total)
5_01	29.1 / 41,926	3,124 (7.5%)	4.5 (0-37)	107.7 (17-263)	38.3 (9-71)	15.1 (4-22)	772 (1.8%)
5_03	53.4 / 76,899	849 (1.1%)	0.7 (0-22)	16.2 (0-97)	8.3 (0-33)	5.3 (0-13)	16,075 (20.9%)
5_04	5.4 / 7,709	93 (1.2%)	0.7 (0-21)	15.8 (3-30)	7.5 (3-10)	5.5 (2-8)	0 (0%)
5_05	69 / 99,430	635 (0.6%)	0.4 (0-18)	9.3 (0-64)	4.9 (0-28)	3.3 (0-8)	13,693 (13.8%)
5_06	69 / 99,423	555 (0.6%)	0.3 (0-19)	8.1 (0-71)	4.3 (0-28)	2.6 (0-13)	9,372 (9.4%)
5_07	69 / 99,422	902 (0.9%)	0.5 (0-28)	13.2 (0-100)	6 (0-43)	3.5 (0-17)	25,265 (25.4%)
5_08	17.8 / 25,696	84 (0.3%)	0.2 (0-9)	4.9 (0-15)	2.8 (0-7)	2.1 (0-7)	9,145 (35.6%)
5_09	6.5 / 9,396	31 (0.3%)	0.2 (0-2)	4.8 (1-10)	3.7 (1-6)	3.5 (1-6)	712 (7.6%)
5_10	69.1 / 99,432	953 (1%)	0.6 (0-28)	14 (0-92)	6 (0-31)	3.6 (0-15)	14,646 (14.7%)
5_11	64.5 / 92,908	803 (0.9%)	0.5 (0-19)	12.5 (0-48)	6.3 (0-21)	4.1 (0-13)	6,759 (7.3%)
5_12	69 / 99,358	5,271 (5.3%)	3.2 (0-50)	77.1 (0-345)	29.4 (0-89)	11.6 (0-23)	23,651 (23.8%)

Table B5. *Summary of C-POD data from Leg 6 (13/09/2018 – 16/02/2019). Porpoise detection data are aggregated by 1) total number of Porpoise Positive Minutes (N_{PPM}) over the entire deployment, 2-3) by average number of Porpoise Positive Minutes (N_{PPM}) per hour and per day, 4) by number of Porpoise Positive 10-Minutes (N_{PP10M}) per day, and 5) by number of Porpoise Positive Hours (N_{PPH}) per day. Total number of minutes during which time was lost due to excessive noise ($N_{TimeLost}$) is also provided. * Based on whole hours only. ^ Based on entire days only. The C-POD deployed at Locations 06 and 11 during this Leg could not be retrieved.*

Leg_Location	Deployment Duration (days / minutes)	Total N_{PPM} ($\%_{total}$)	Avg. N_{PPM}/Hour* (min-max)	Avg. N_{PPM}/Day^ (min-max)	Avg. N_{PP10M}/Day^ (min-max)	Avg. N_{PPH}/Day^ (min-max)	Total $N_{TimeLost}$ ($\%_{total}$)
6_01	156.2 / 224,862	19,029 (8.5%)	5.1 (0-53)	122.3 (1-521)	42.3 (1-114)	15.7 (1-24)	5,462 (2.4%)
6_02	65 / 93,591	2,136 (2.3%)	1.4 (0-41)	32.6 (0-160)	12.7 (0-52)	5.9 (0-18)	46,813 (50%)
6_03	125.9 / 181,335	3,743 (2.1%)	1.2 (0-36)	29.8 (0-168)	14.1 (0-74)	6.7 (0-20)	39,563 (21.8%)
6_04	114.3 / 164,603	4,282 (2.6%)	1.6 (0-56)	37.8 (0-155)	14.9 (0-50)	7.4 (0-22)	20,942 (12.7%)
6_05	156.2 / 224,960	3,594 (1.6%)	1 (0-37)	23 (0-175)	9.6 (0-52)	5.2 (0-19)	28,942 (12.9%)
6_07	3.4 / 4,868	25 (0.5%)	0.3 (0-7)	7 (0-14)	3 (0-6)	2.5 (0-5)	1,445 (29.7%)
6_08	113.4 / 163,260	2,932 (1.8%)	1.1 (0-37)	26.1 (0-112)	10.8 (0-48)	5.6 (0-19)	23,949 (14.7%)
6_09	70.5 / 101,584	1,297 (1.3%)	0.8 (0-29)	18.5 (0-119)	8.4 (0-49)	4.8 (0-19)	9,228 (9.1%)
6_10	60.8 / 87,510	783 (0.9%)	0.5 (0-30)	12.8 (0-80)	5.5 (0-22)	3.5 (0-13)	1,104 (1.3%)
6_12	34.8 / 50,095	942 (1.9%)	1.1 (0-28)	26.3 (3-116)	12.5 (2-43)	6.7 (2-15)	12,258 (24.5%)

Table B6. *Summary of C-POD data from Leg 7 (16/02/2019 – 22/03/2019). Porpoise detection data are aggregated by 1) total number of Porpoise Positive Minutes (N_{PPM}) over the entire deployment, 2-3) by average number of Porpoise Positive Minutes (N_{PPM}) per hour and per day, 4) by number of Porpoise Positive 10-Minutes (N_{PP10M}) per day, and 5) by number of Porpoise Positive Hours (N_{PPH}) per day. Total number of minutes during which time was lost due to excessive noise ($N_{TimeLost}$) is also provided. * Based on whole hours only. ^ Based on entire days only. † Based on less than one 24-hour day.*

Leg_Location	Deployment Duration (days / minutes)	Total N_{PPM} (%total)	Avg. N_{PPM}/Hour* (min-max)	Avg. N_{PPM}/Day^ (min-max)	Avg. N_{PP10M}/Day^ (min-max)	Avg. N_{PPH}/Day^ (min-max)	Total $N_{TimeLost}$ (%total)
7_01	32.9 / 47,446	4,486 (9.5%)	5.7 (0-54)	137.3 (50-385)	43.2 (21-86)	16.4 (10-23)	2,871 (6.1%)
7_02	12.2 / 17,551	597 (3.4%)	2 (0-27)	43 (13-126)	15.5 (0-44)	7.4 (0-16)	6,318 (36%)
7_03	33.8 / 48,658	2,432 (5%)	3 (0-40)	69.4 (0-203)	21.6 (0-62)	9 (0-19)	9,994 (20.5%)
7_04	33.8 / 48,629	4,269 (8.8%)	5.3 (0-52)	127.6 (0-377)	40.2 (0-96)	14.2 (0-24)	4,502 (9.3%)
7_05	33.7 / 48,599	1,523 (3.1%)	1.9 (0-45)	45.8 (0-127)	16.1 (0-40)	8.4 (0-21)	1,903 (3.9%)
7_06	33.7 / 48,595	1,507 (3.1%)	1.9 (0-46)	45.7 (1-178)	18.3 (1-55)	9.2 (1-18)	4,654 (9.6%)
7_07	33.7 / 48,592	2,106 (4.3%)	2.6 (0-39)	63.8 (0-226)	21.4 (0-63)	9 (0-20)	14,683 (30.2%)
7_08	33.2 / 47,766	1,480 (3.1%)	1.9 (0-33)	45.9 (0-141)	16.6 (0-58)	7.3 (0-20)	14,777 (30.9%)
7_09	33.2 / 47,775	1,325 (2.8%)	1.7 (0-40)	40 (0-127)	14.5 (0-42)	6.9 (0-19)	15,459 (32.4%)
7_10 †	0.9 / 1,353 †	138 (10.2%) †	6 (0-46) †	63 (3-123) †	16 (3-29) †	6 (2-10) †	6 (0.4%) †
7_11	33.2 / 47,761	1,695 (3.5%)	2.1 (0-41)	51.2 (0-127)	20 (0-47)	9.6 (0-18)	2,807 (5.9%)
7_12	33.1 / 47,672	2,366 (5%)	3 (0-35)	71.5 (6-229)	24.7 (4-68)	9.6 (2-21)	24,729 (51.9%)

Table B7. *Summary of C-POD data from Leg 8 (21/03/2019 – 22/05/2019). Porpoise detection data are aggregated by 1) total number of Porpoise Positive Minutes (N_{PPM}) over the entire deployment, 2-3) by average number of Porpoise Positive Minutes (N_{PPM}) per hour and per day, 4) by number of Porpoise Positive 10-Minutes (N_{PP10M}) per day, and 5) by number of Porpoise Positive Hours (N_{PPH}) per day. Total number of minutes during which time was lost due to excessive noise ($N_{TimeLost}$) is also provided. * Based on whole hours only. ^ Based on entire days only.*

Leg_Location	Deployment Duration (days / minutes)	Total N_{PPM} ($\%_{total}$)	Avg. N_{PPM}/Hour* (min-max)	Avg. N_{PPM}/Day^ (min-max)	Avg. N_{PP10M}/Day^ (min-max)	Avg. N_{PPH}/Day^ (min-max)	Total $N_{TimeLost}$ ($\%_{total}$)
8_02	61.9 / 89,103	5,060 (5.7%)	3.4 (0-51)	82.6 (1-636)	27.2 (1-123)	10.8 (0-24)	17,110 (19.2%)
8_04	61 / 87,864	2,752 (3.1%)	1.9 (0-55)	45.9 (0-459)	16.2 (0-97)	7.2 (0-22)	18,859 (21.5%)
8_05	61 / 87,870	1,344 (1.5%)	0.9 (0-43)	22.4 (0-185)	9.1 (0-56)	4.8 (0-18)	8,782 (10%)
8_06	61 / 87,858	1,231 (1.4%)	0.8 (0-30)	20.3 (0-206)	8.9 (0-67)	4.6 (0-20)	11,834 (13.5%)
8_07	42.3 / 60,854	1,205 (2%)	1.2 (0-45)	29.1 (0-268)	11.3 (0-67)	5.4 (0-21)	20,457 (33.6%)
8_08	61 / 87,861	818 (0.9%)	0.6 (0-33)	13.6 (0-113)	5.7 (0-40)	3.1 (0-12)	20,900 (23.8%)
8_09	61 / 87,858	744 (0.8%)	0.5 (0-39)	12.4 (0-92)	5.9 (0-30)	3.3 (0-14)	17,466 (19.9%)
8_10	27.3 / 39,324	523 (1.3%)	0.8 (0-27)	18.5 (0-81)	9.1 (0-37)	5 (0-18)	348 (0.9%)
8_11	59.8 / 86,159	1,930 (2.2%)	1.3 (0-52)	32.7 (0-286)	12.4 (0-84)	6 (0-23)	21,081 (24.5%)

Table B8. *Summary of C-POD data from Leg 9 (22/05/2019 – 21/06/2019). Porpoise detection data are aggregated by 1) total number of Porpoise Positive Minutes (N_{PPM}) over the entire deployment, 2-3) by average number of Porpoise Positive Minutes (N_{PPM}) per hour and per day, 4) by number of Porpoise Positive 10-Minutes (N_{PP10M}) per day, and 5) by number of Porpoise Positive Hours (N_{PPH}) per day. Total number of minutes during which time was lost due to excessive noise ($N_{TimeLost}$) is also provided. * Based on whole hours only. ^ Based on entire days only.*

Leg_Location	Deployment Duration (days / minutes)	Total N_{PPM} ($\%_{total}$)	Avg. N_{PPM}/Hour* (min-max)	Avg. N_{PPM}/Day^ (min-max)	Avg. N_{PP10M}/Day^ (min-max)	Avg. N_{PPH}/Day^ (min-max)	Total $N_{TimeLost}$ ($\%_{total}$)
9_1	30.0 / 43,263	1,688 (3.9%)	2.3 (0-30)	55.8 (17-140)	26.2 (9-47)	12.6 (7-18)	663 (1.5%)
9_2	30.0 / 43,246	751 (1.7%)	1.0 (0-22)	25.0 (0-57)	12.6 (0-30)	6.6 (0-12)	12,261 (28.4%)
9_3	30.0 / 43,226	140 (0.3%)	0.2 (0-11)	4.2 (0-15)	2.3 (0-8)	1.9 (0-5)	7,215 (16.7%)
9_4	30.0 / 43,209	166 (0.4%)	0.2 (0-8)	5.7 (0-27)	3.8 (0-18)	2.7 (0-11)	524 (1.2%)
9_5	30.0 / 43,195	36 (0.1%)	0.1 (0-6)	1.0 (0-16)	0.6 (0-6)	0.6 (0-5)	4,388 (10.2%)
9_6	30.0 / 43,187	52 (0.1%)	0.1 (0-9)	1.6 (0-18)	1.1 (0-10)	0.9 (0-6)	5,070 (11.7%)
9_7	30.0 / 43,169	68 (0.2%)	0.1 (0-14)	2.2 (0-24)	1.3 (0-15)	0.8 (0-7)	9,745 (22.6%)
9_8	30.0 / 43,163	102 (0.2%)	0.1 (0-7)	3.3 (0-17)	2.1 (0-9)	1.8 (0-7)	9,383 (21.7%)
9_9	30.0 / 43,157	140 (0.3%)	0.2 (0-7)	4.2 (0-21)	2.9 (0-12)	2.3 (0-8)	3,879 (9.0%)
9_10	30.0 / 43,163	85 (0.2%)	0.1 (0-11)	2.8 (0-18)	1.7 (0-10)	1.4 (0-9)	4,705 (10.9%)
9_11	30.0 / 43,157	145 (0.3%)	0.2 (0-9)	4.6 (0-15)	2.9 (0-10)	2.3 (0-8)	2,388 (5.5%)
9_12	30.0 / 43,152	715 (1.7%)	1.0 (0-24)	23.7 (0-82)	12.2 (0-41)	6.6 (0-15)	7,670 (17.8%)

***Table B9**. Summary of all C-POD data from Location 05 (across Legs 2 – 9). Porpoise detection data are aggregated by 1) total number of Porpoise Positive Minutes (N_{PPM}) over the entire deployment, 2-3) by average number of Porpoise Positive Minutes (N_{PPM}) per hour and per day, 4) by number of Porpoise Positive 10-Minutes (N_{PP10M}) per day, and 5) by number of Porpoise Positive Hours (N_{PPH}) per day. Total number of minutes during which time was lost due to excessive noise ($N_{TimeLost}$) is also provided. * Based on whole hours only. ^ Based on entire days only.*

Leg_Location	Deployment Duration (days / minutes)	Total N_{PPM} ($\%_{total}$)	Avg. N_{PPM}/Hour* (min-max)	Avg. N_{PPM}/Day^ (min-max)	Avg. N_{PP10M}/Day^ (min-max)	Avg. N_{PPH}/Day^ (min-max)	Total $N_{TimeLost}$ ($\%_{total}$)
2_05	55.7 / 80,179	4,832 (6.0%)	3.6 (0-49)	87.4 (1-441)	28.8 (1-103)	11.8 (1-24)	2,090 (2.6%)
3_05	28.2 / 40,652	1,532 (3.8%)	2.3 (0-37)	56.6 (4-240)	18.7 (2-63)	8.3 (2-18)	976 (2.4%)
4_05	32.8 / 47,264	432 (0.9%)	0.5 (0-21)	13.4 (0-68)	6.8 (0-29)	4.3 (0-15)	965 (2.0%)
5_05	69.0 / 99,430	635 (0.6%)	0.4 (0-18)	9.3 (0-64)	4.9 (0-28)	3.3 (0-12)	13,693 (13.8%)
6_05	156.2 / 224,960	3,594 (1.6%)	1.0 (0-37)	23.0 (0-175)	9.6 (0-52)	5.2 (0-19)	28,942 (12.9%)
7_05	33.7 / 48,599	1,523 (3.1%)	1.9 (0-45)	45.8 (0-127)	16.1 (0-40)	8.4 (0-21)	1,903 (3.9%)
8_05	61.0 / 87,870	1,344 (1.5%)	0.9 (0-43)	22.4 (0-185)	9.1 (0-56)	4.8 (0-18)	8,782 (10.0%)
9_05	30.0 / 43,195	36 (0.1%)	0.1 (0-6)	1.0 (0-16)	0.6 (0-6)	0.6 (0-5)	4,388 (10.2%)

APPENDIX C – HOURLY HARBOUR PORPOISE PRESENCE (ALL DATA)

Figure C1 below visualises harbour porpoise detection data per location. These overviews are based on all data, prior to the exclusion of hours monitored for ≤90%. Whilst the plots appear very similar to the results presented in Figure 8 (representing the results of effective monitoring, rather than the realised efforts), differences are most pronounced in the presence of a higher number of hours with zero or very low Porpoise Positive Minutes per hour and resulting lower daily averaged Porpoise Positive Minutes per hour in the plots presented here.

It is important to consider monitoring effort when assessing harbour porpoise presence across space and over time. The figures below, presenting PPM^{-h} for each monitoring site for the duration of the project, should be interpreted with care, as effective monitoring effort within each hour was not equal across the C-POD array and over the duration of the project.

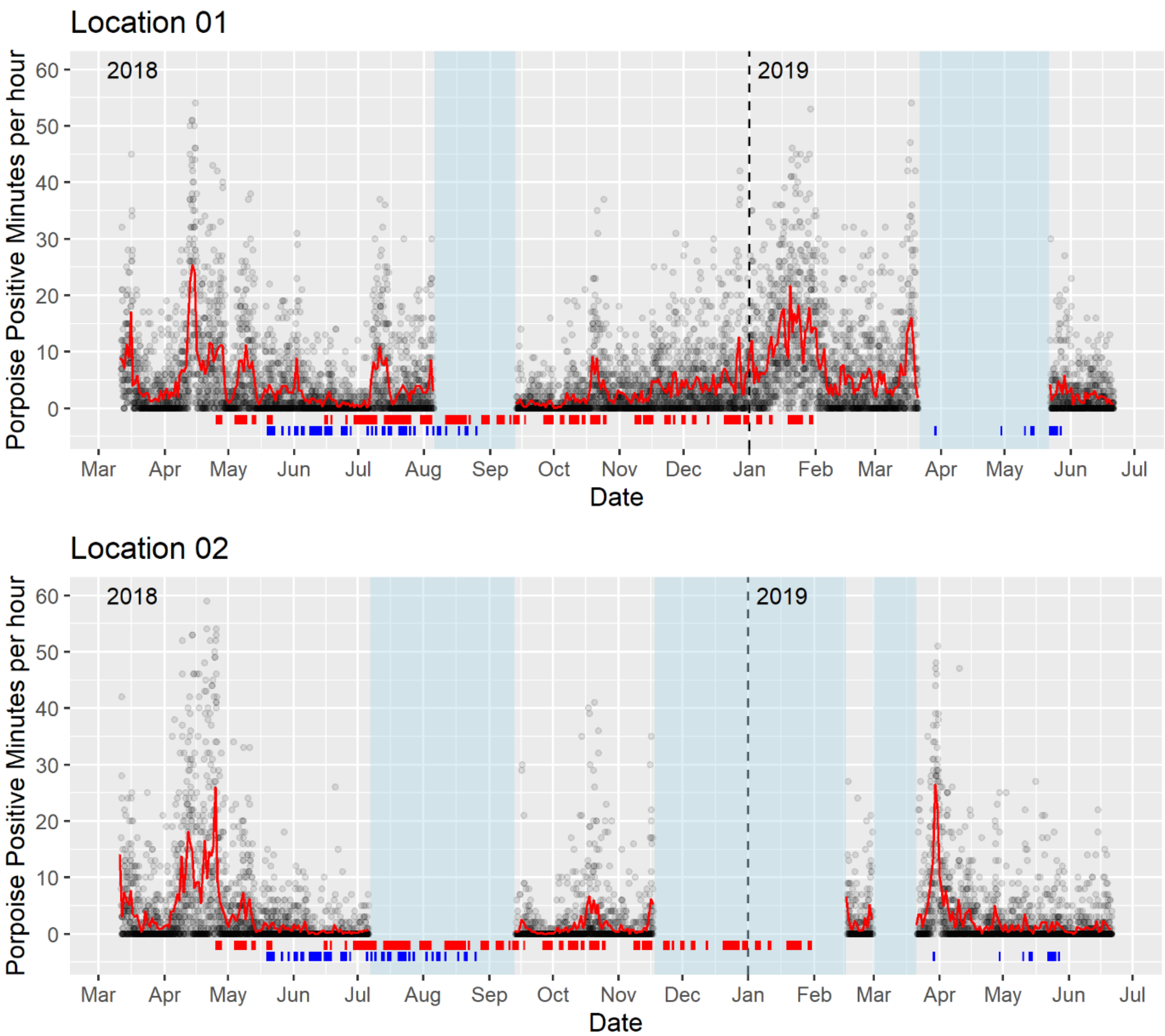
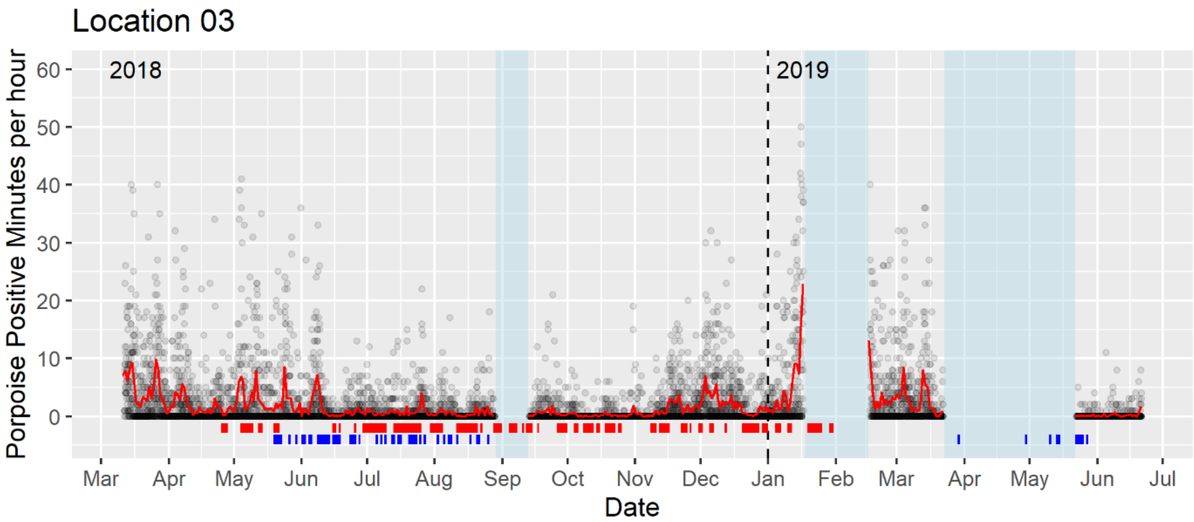
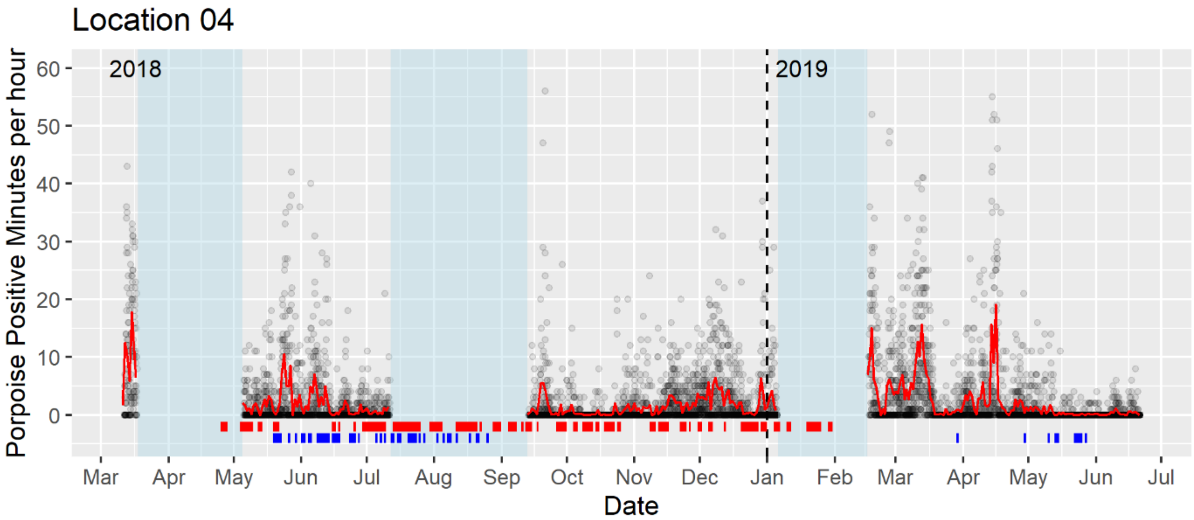


Figure C1. *Overview of hourly (circles) and daily averaged (red line) Porpoise Positive Minutes throughout the monitoring period at each of the 12 C-POD locations. Light blue areas represent an absence of data; days with piling and UXO detonation activities are indicated with red and blue markers, respectively.*





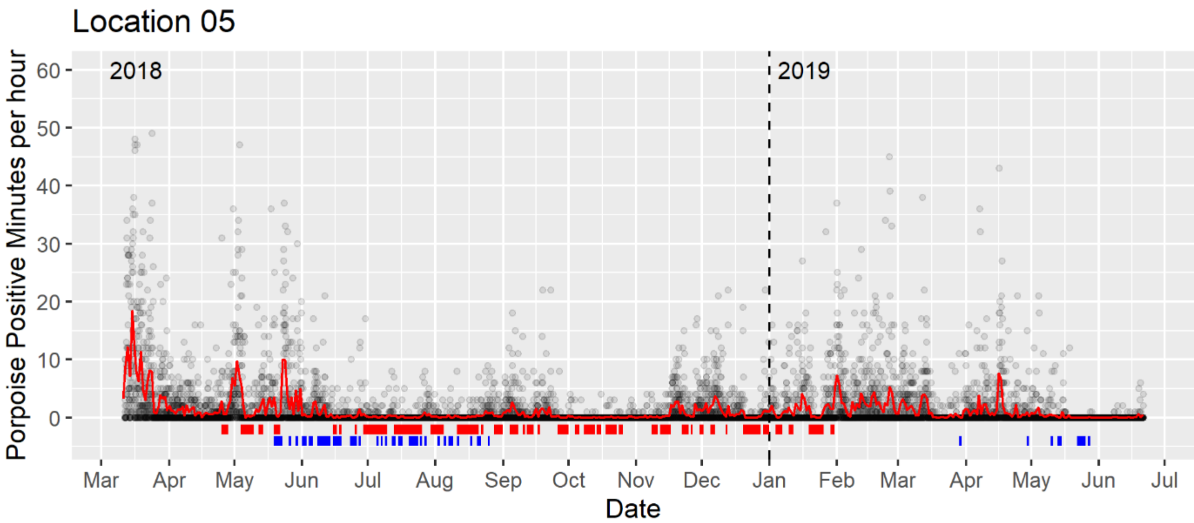


Figure C1 (continued). *Overview of hourly (circles) and daily averaged (red line) Porpoise Positive Minutes throughout the monitoring period at each of the 12 C-POD locations. Light blue areas represent an absence of data; days with piling and UXO detonation activities are indicated with red and blue markers, respectively.*

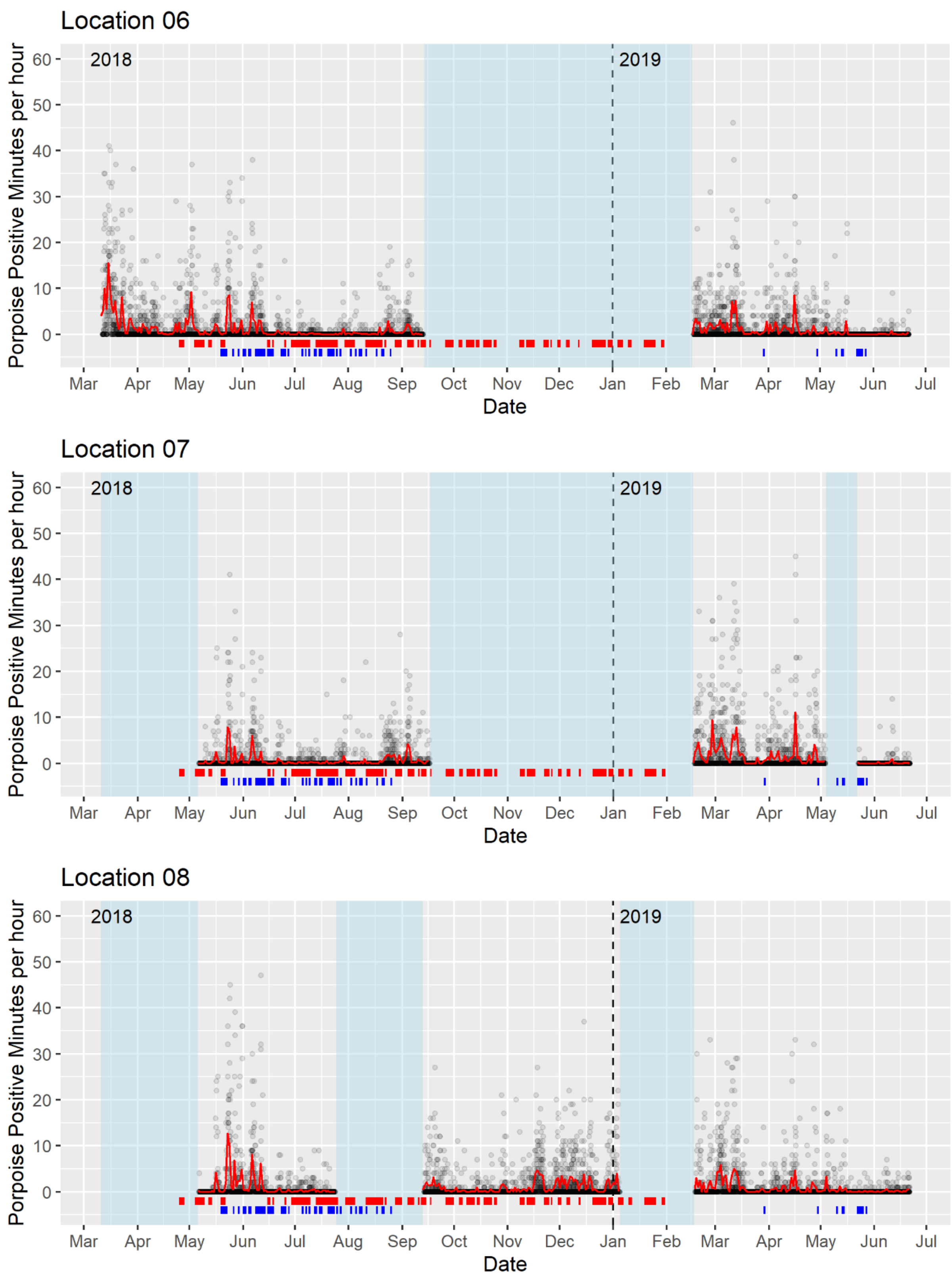


Figure C1 (continued). *Overview of hourly (circles) and daily averaged (red line) Porpoise Positive Minutes throughout the monitoring period at each of the 12 C-POD locations. Light blue areas represent an absence of data; days with piling and UXO detonation activities are indicated with red and blue markers, respectively.*

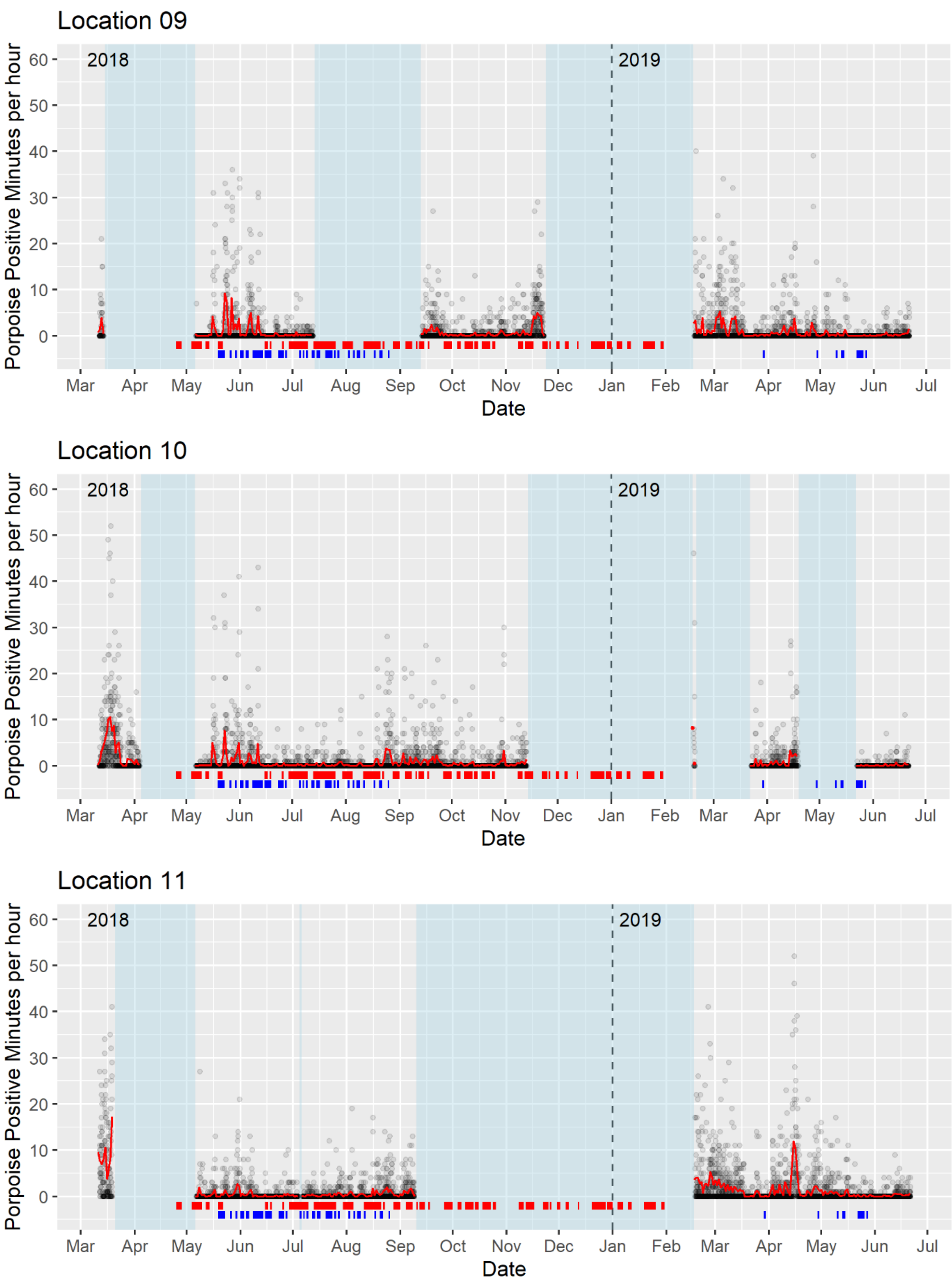


Figure C1 (continued). *Overview of hourly (circles) and daily averaged (red line) Porpoise Positive Minutes throughout the monitoring period at each of the 12 C-POD locations. Light blue areas represent an absence of data; days with piling and UXO detonation activities are indicated with red and blue markers, respectively.*

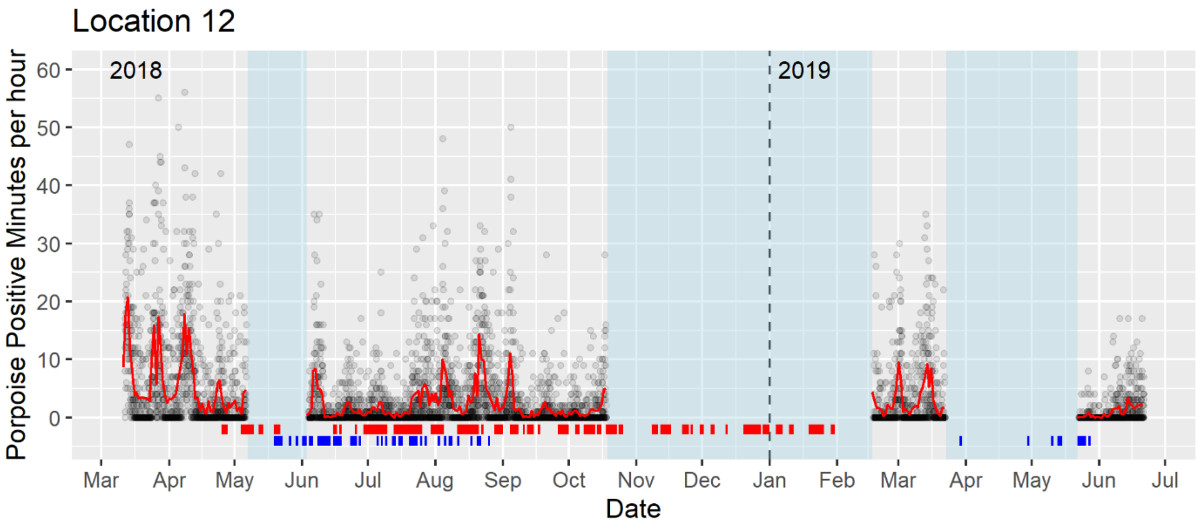


Figure C1 (continued). *Overview of hourly (circles) and daily averaged (red line) Porpoise Positive Minutes throughout the monitoring period at each of the 12 C-POD locations. Light blue areas represent an absence of data; days with piling and UXO detonation activities are indicated with red and blue markers, respectively.*

APPENDIX D – SELECTED DATA FOR PROPAGATION MODEL CALIBRATION

For each of the three possible datasets identified for propagation model calibration (see Section 3.2.2), the sections below present visualisations of the data collected by the acoustic recorder closest to the piling location (i.e. Monitoring Locations 06 and 07), and Location 01 furthest away from the piling. For each dataset, the first figure displays the waveform graph of the entire monitoring period selected (i.e. nine or ten sound files per location, totalling 11:12 or 12:25 minutes), whilst the second figure shows the spectrogram of one example sound file of 73 seconds (frequency scale for the latter have been standardised to show the 0 – 39 kHz range.

Acoustic signals are typically visualised as waveform graphs and spectrograms. In waveform graphs, the relative signal amplitude (i.e. signal strength; in kU or MU) is plotted on the vertical axis versus time (in ms, s or min) on the horizontal axis. The stronger the signal, the larger the positive and negative amplitude response. In spectrograms, the amplitude is displayed as a function of frequency over a certain period. Frequency (in kHz) is plotted on the y-axis and time on the x-axis. The relative amplitude or 'loudness' of the signal is presented on a greyscale for each time-frequency combination; the higher the relative amplitude measured for a certain frequency at a specific time, the darker the colour.

Because signal amplitude measurements made by the instruments depend on the overall system sensitivity (which is itself composed of unit-specific device sensitivity, hydrophone sensitivity and applied gain settings), these non-calibrated waveforms represent relative amplitude, as system sensitivity is not accounted for in these visualisations. As the devices deployed during WP-A had different system sensitivities, the relative amplitudes can therefore not be compared directly. Likewise, the amplitude colour saturation (i.e. the greyscale) of the spectrograms has been manually adjusted in order to highlight the signals, in turn impeding amplitude comparison between spectrograms.

Nevertheless, other noise characteristics can be obtained from these visualisations. It is particularly important to note 1) the time delay between the arrival of the piling signal sequences received by both recorders as it takes time for the sound to travel from the nearest recorder to the most distant one (compare waveforms), 2) the received frequency range associated with piling events, where the higher frequencies present at closer locations are not recorded at the largest distance (the disappearance of higher-frequency components is also visible for non-piling signals when comparing spectrograms), and 3) the approximate frequency of one piling strike every 1.5 s, resulting in a hammer rate of 0.66.

Finally, the inclusion of small sections of non-piling periods will aid in aligning individual strikes in the piling sequences.

D.1 Option 1

The first option includes data collected on 24/07/2018 from 21:14 – 21:25 UTC, whilst piling was taking place at WTG D03. Location 07 was geographically closest to the piling activity. For further details, see Figures D1 and D2.

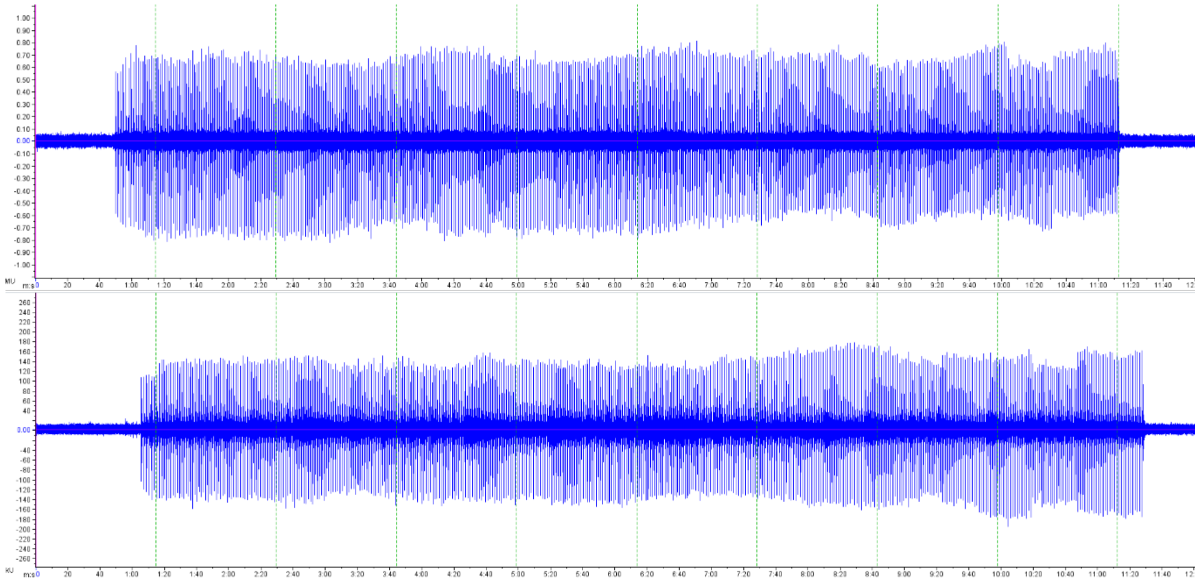


Figure D1. *Waveform of the data selected for propagation model calibration option 1, from monitoring Location 07 (top panel), and Location 01 (bottom panel).*

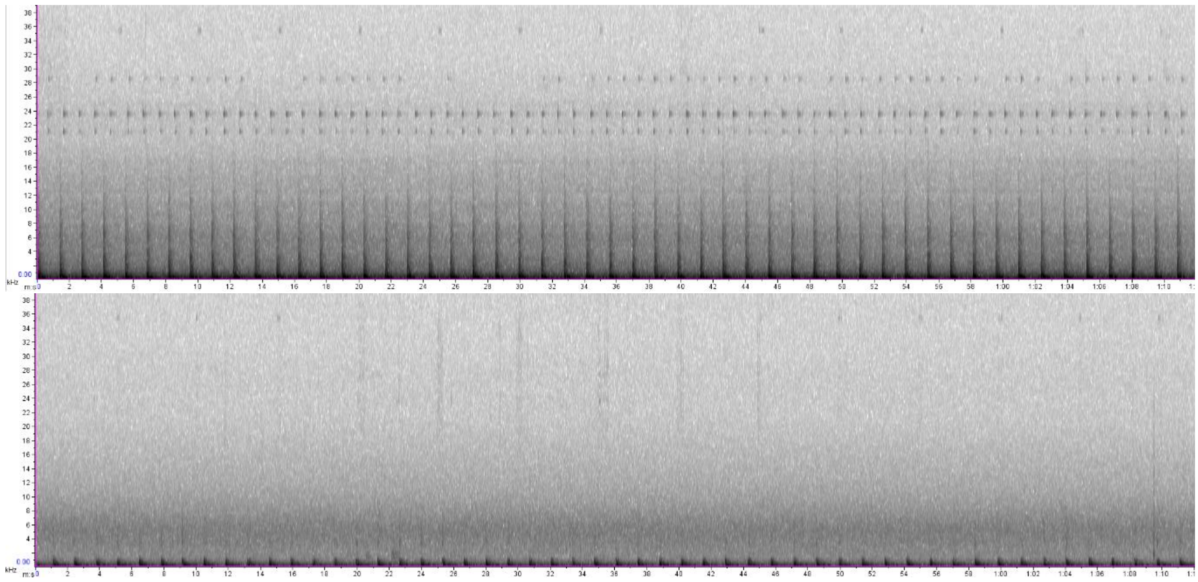


Figure D2. *Spectrogram for one example file selected for propagation model calibration Option 1, from monitoring Location 07 (top panel), and Location 01 (bottom panel).*

D.2 Option 2

The second option relates to data collected on 13/07/2018 from 23:27 – 23:37 UTC, whilst piling was being conducted at WTG C03. Location 07 was located closest to the piling activity. For further details, see Figures D3 and D4.

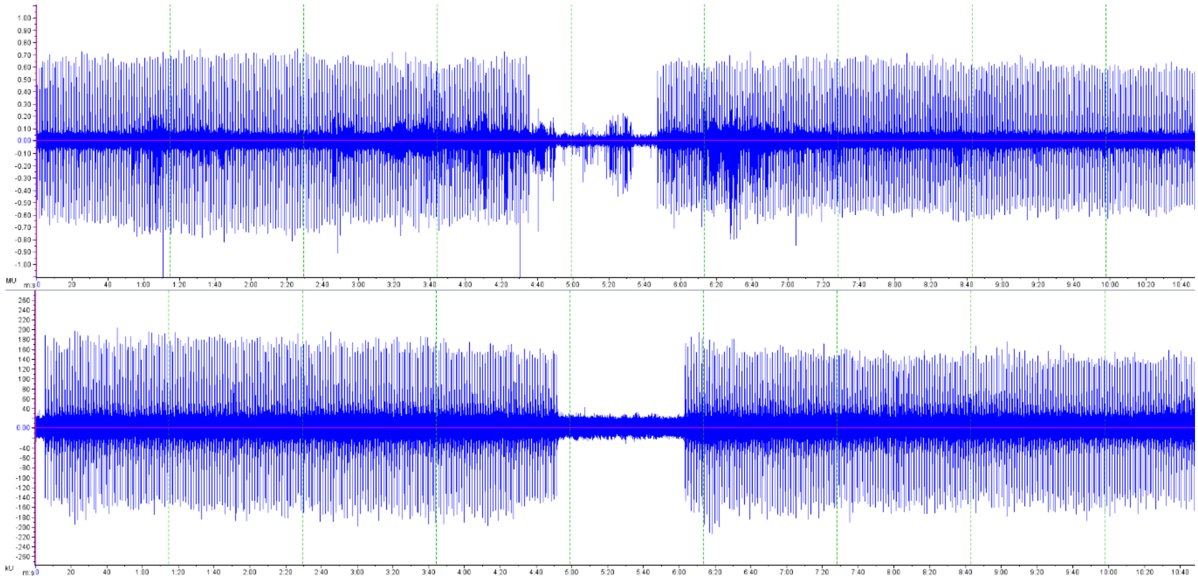


Figure D3. *Waveform of the data selected for propagation model calibration Option 2, from monitoring Location 07 (top panel), and Location 01 (bottom panel).*

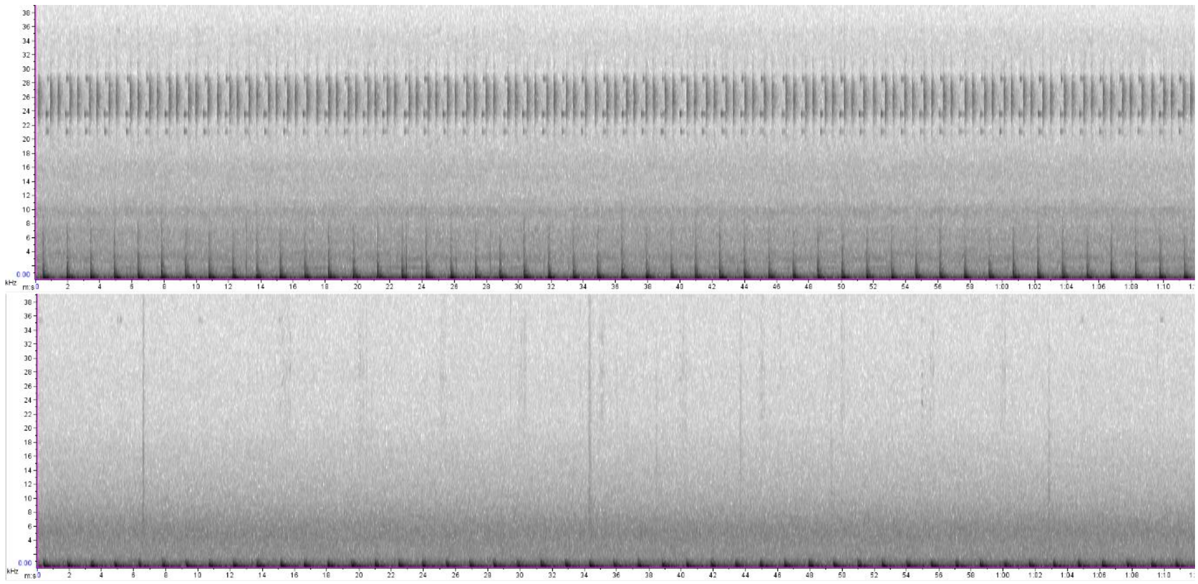


Figure D4. *Spectrogram for one example file selected for propagation model calibration Option 2, from monitoring Location 07 (top panel), and Location 01 (bottom panel).*

D.3 Option 3

The third option involves data collected on 22/07/2018 from 09:43 – 09:55 UTC, during the construction of WTG E25. The piling activity was closest to monitoring Location 06. For further details, see Figures D5 and D6.

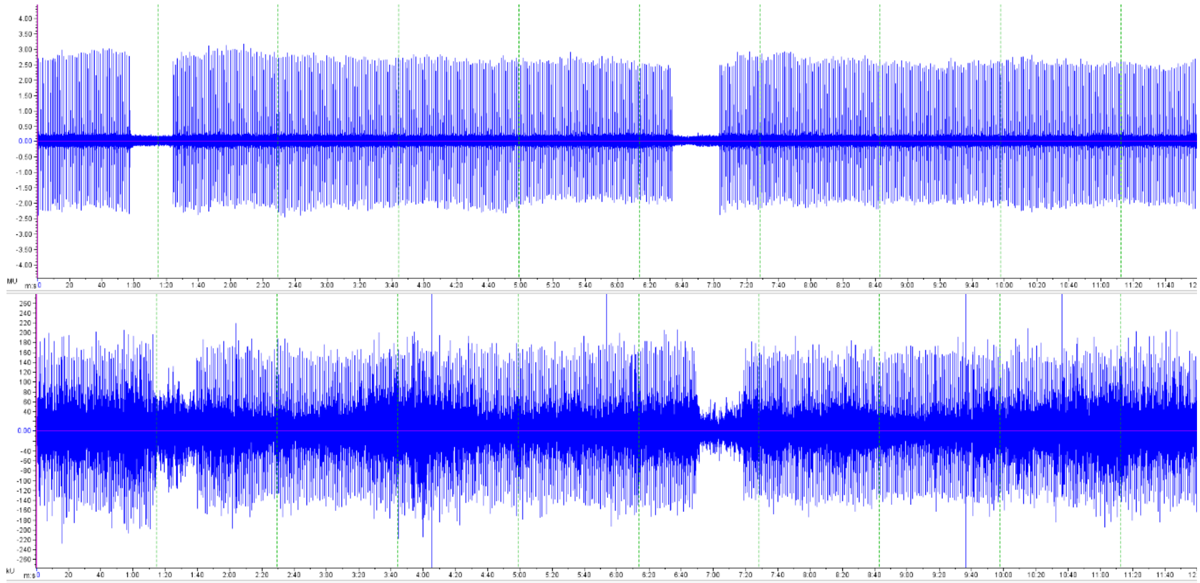


Figure D5. *Waveform of the data selected for propagation model calibration Option 3, from monitoring Location 06 (top panel), and Location 01 (bottom panel).*

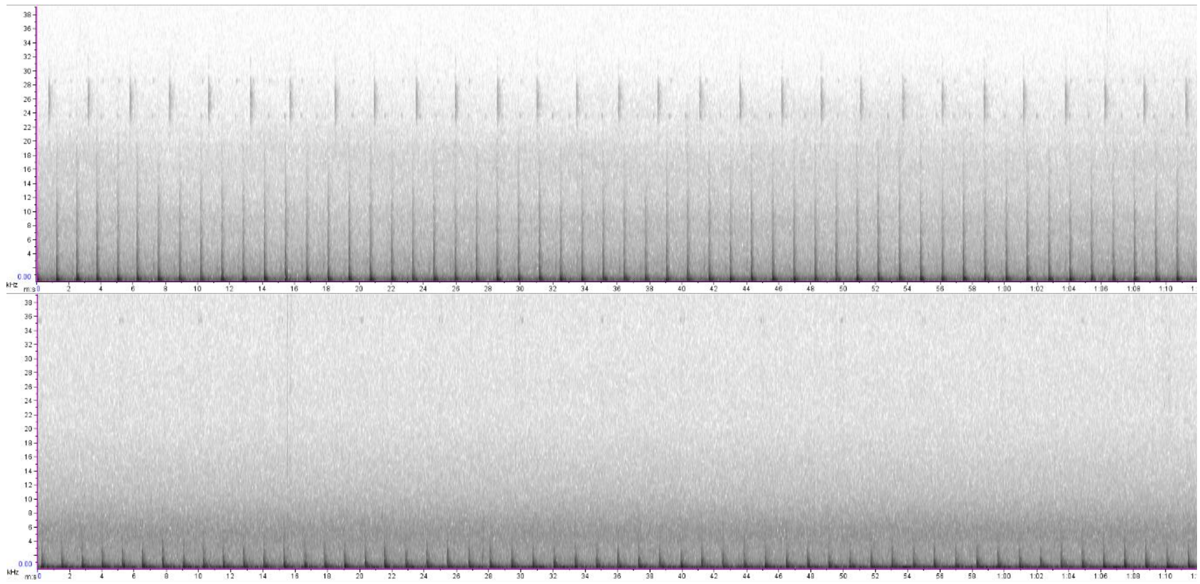


Figure D6. *Spectrogram for one example file selected for propagation model calibration Option 3, from monitoring Location 06 (top panel), and Location 01 (bottom panel).*

APPENDIX E – PROPAGATION MODELLING REPORT

The technical report produced by Xi Engineering Consultants that details the sound propagation modelling is embed with the link below.

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