Underwater sound measurements

During the installation of the Borssele OWF

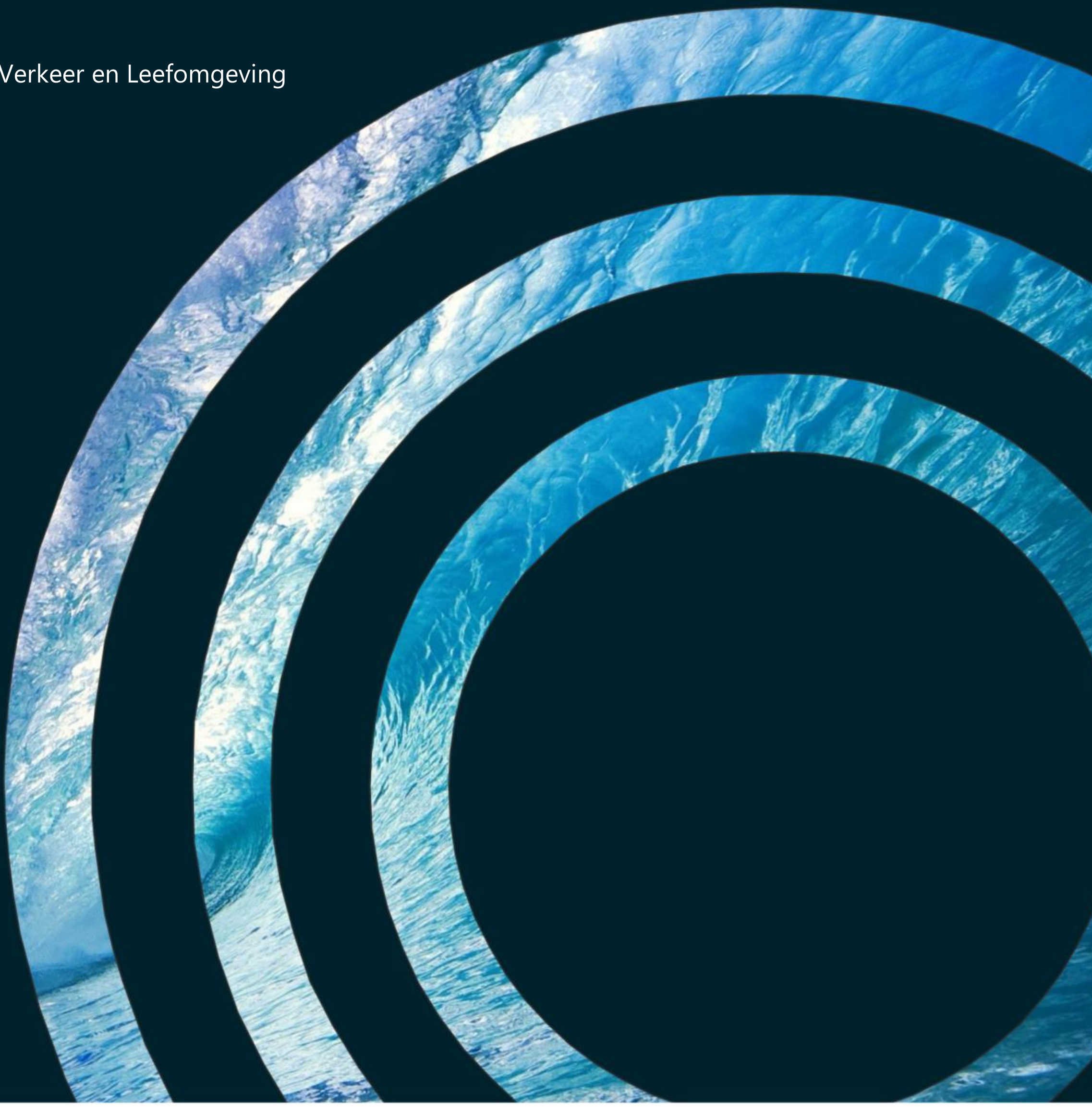
Client:
Rijkswaterstaat Water, Verkeer en Leefomgeving

Date:
08/02/2021

Clients Reference:
31151099

Our Reference:
WP2019_1173_R9r1

Version:
Final



WATER PROOF Marine Consultancy & Services BV.

WAGENINGEN UNIVERSITY & RESEARCH

Title

Underwater noise measurements – During the installation of Borssele OWF

Client

Rijkswaterstaat Water, Verkeer en Leefomgeving

Reference

31151099

Keywords

Underwater sound, piling noise, acoustic measurements, Borssele OWF, harbour porpoise

Version	Date	Author	Review & Approval
R9r0	26-11-2020	J.A. Brinkkemper S.C.V Geelhoed B.J.P. Berges C.A. Noort D.N. Nieuwendijk J.P. Verdaat	R.C. Snoek M. Scheidat
R9r1	08-02-2021	J.A. Brinkkemper S.C.V Geelhoed B.J.P. Berges C.A. Noort D.N. Nieuwendijk J.P. Verdaat	R.C. Snoek M. Scheidat

TABLE OF CONTENTS

1 GENERAL

1.1 INTRODUCTION

The Dutch government has set ambitious targets for the development of offshore wind energy, with 3.5GW being developed in the period up to 2023. The development of these various offshore wind farms has an impact on the marine ecosystem, which is being closely monitored by the Dutch government.

In 2016, the Ministry of Economic Affairs and Climate (EZK) commissioned Rijkswaterstaat to setup an integrated research program to reduce the knowledge gaps regarding the effects of offshore wind farms on the North Sea ecosystem. This *Wind op Zee Ecologisch Programma* (WoZEP) runs from 2016 to 2023 and the results of the studies carried out are used in the Ecology and Cumulation Framework (KEC) in which cumulative effects of current and planned wind farms on protected species are determined.

The WoZEP project aims to:

- Reduce uncertainties of assumptions and knowledge gaps in the KEC, environmental impact reports (EIA) and appropriate assessments (AA);
- Reduce uncertainties of assumptions and knowledge gaps regarding long-term effects due to scaling up of wind energy at sea;
- Gain insight in the effectiveness of mitigation measures to reduce adverse effects.

Pile driving impulses are audible over ranges of tens of km's and propagate more or less evenly in all directions in areas without differences in depth. Bottom topography in the Borssele area is more differentiated, with roughly deeper water west of the future wind farms and shallows east of them. Geelhoed et al. (2018) concluded that the avoidance distance of harbour porpoise during construction of the Gemini wind farms were between 10 and 20 km. It should be noted that no mitigation measures were taken during the construction of these wind farms. Studies on Danish and German wind farms, however, show avoidance distances between 17-21 km with mitigation measures to reduce sound emission (Brandt et al. 2011, 2016; Tougaard et al. 2009).

One of the current knowledge gaps in determining the effects of underwater noise on harbour porpoises is whether frequency weighting needs to be applied to noise thresholds for avoidance of the pile driving location. Factors that influence the frequency spectrum of the underwater sound at a distance from the piling location are (among other things) the water depth and the sound mitigation measures used.

In 2019/2020, the Borssele wind farm was constructed. The Borssele wind farm consists of lots I + II and III + IV and is located offshore of the southwestern coast of the Netherlands (Figure 1.1). In both lots monopiles are used as foundations for the windmills. Monopiles are installed by means of pile driving, a method that results in high levels of emitted underwater noise. To reduce the impact on marine life, the Dutch government set a season-dependent noise threshold level that is not to be exceeded. To remain below the noise thresholds, noise mitigation measures are required to reduce emitted sound levels. Blauwwind built the wind mills in lots III + IV and installed between October 2019 and April 2020. Blauwwind used as mitigation measures an AdBM Noise Abatement System and/or a (single or double) Big Bubble Curtain. Ørsted constructed the wind farms of lots I + II between January 2020 and May 2020. The mitigating measures that Ørsted used are an Hydro Sound Dampener (HSD) and/or a (single or double) Big Bubble Screen.

The different lots of the Borssele wind park have a different depth and different noise mitigating measures were used during the installation, this made the construction of this wind park an ideal moment to collect data to address the before mentioned knowledge gaps. With the knowledge this gains, the models that calculate the effects of sound on the harbour porpoise population in the North Sea can be improved.

This report describes the acoustic measurements that were collected from October 2019 up to September 2020 during the construction of the Borssele OWF and addresses questions related to the data availability and quality that are relevant for the analysis of the collected data.

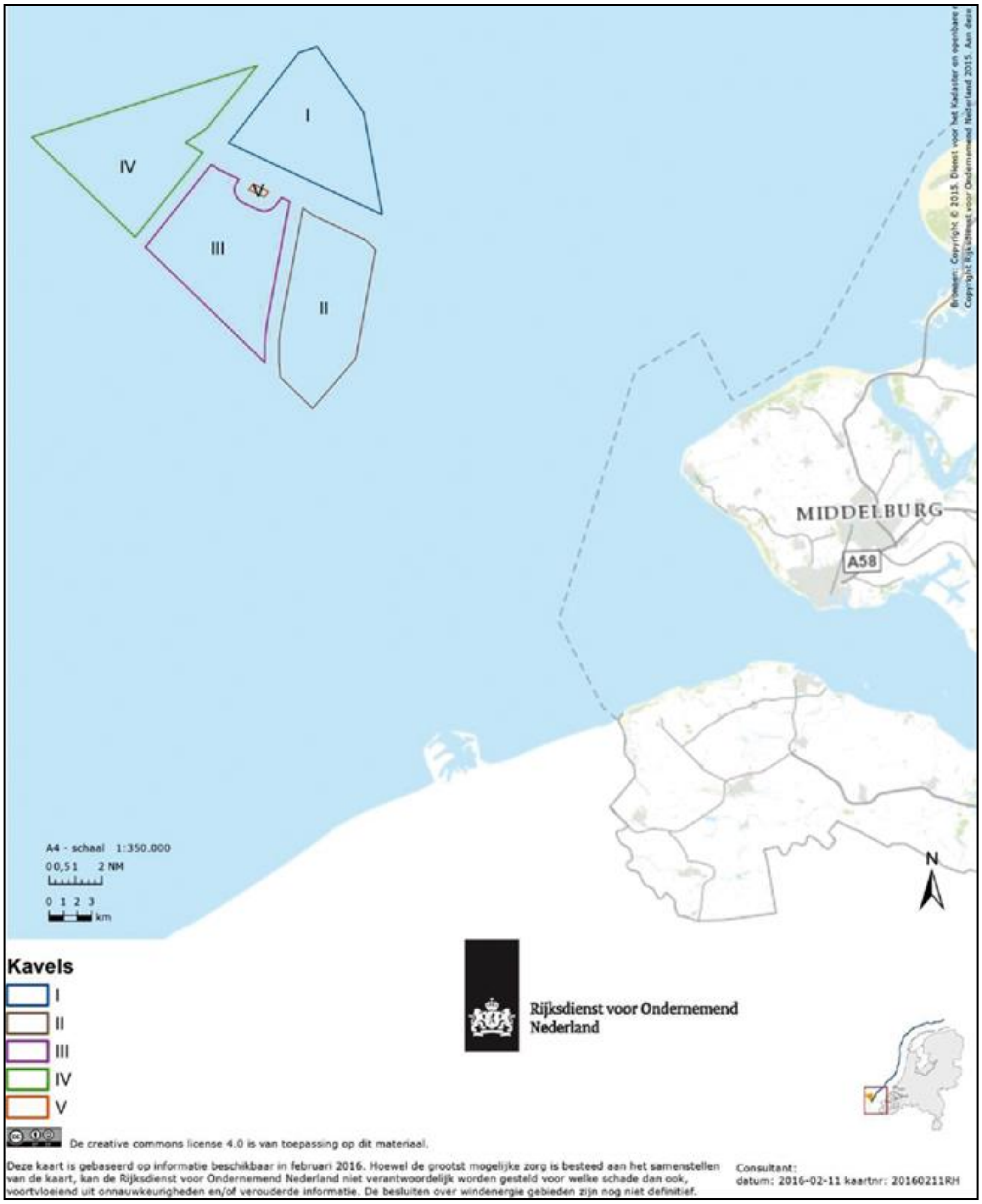


Figure 1.1 OWF Borssele, with lots I+II and lots III+IV as installed by Ørsted en Blauwwind respectively (source: RVO.nl).

1.2 Objectives

The monitoring plan was designed to collect measurement data of pile driving noise and harbour porpoise presence to answer the following research question:

Is frequency weighing necessary for the determination of avoidance threshold levels for harbour porpoise with respect to underwater pile driving noise during the installation of offshore wind farms in the North Sea?

More specifically, to answer the following research questions:

1) What is the distance harbour porpoises are displaced from the area of pile driving?
2) How does this distance depend on water depth and the different noise mitigation systems applied during construction?

The following conditions are provided by Rijkswaterstaat:

- The measurements should provide insight in the (1) influence of water depth and (2) the different noise mitigation systems on noise propagation;
- The data collected should be suitable to compare with data collected during the construction of the Gemini wind farm.

2 METHODOLOGY

2.1 ACOUSTIC MONITORING LOCATIONS AND DEPLOYMENTS

Taking into account previous studies (see Section 1.1), it was prudent to monitor an area up to distances of 25 km from pile driving locations. Avoidance becomes more difficult to prove at greater distances since the number of displaced individuals are spread out over a bigger area; to have an equal chance of detecting these, the number of monitoring instruments should theoretically be increased exponentially as well. Due to the logistical constraints this would post, it was more effective to focus data collection in a close to mid-range and limit the number of measurement locations further away.

In coordination with TNO, 16 locations (Figure 2.1, Table 2.1) were selected at which recorders were installed which detect harbor porpoise presence, at 7 of these locations these recorders were collocated with acoustic recorders to record pile-driving noise levels over the frequency range 20 Hz – 20 kHz.

Harbour porpoise presence was measured inside the windfarm in a grid consisting of recorders with distances of roughly 6 km between one another. Additional data on harbour porpoise acoustic activity outside the windfarm area and at greater distances were collected on two lines with measurement locations further apart. The locations with the acoustic recorders were chosen to represent as much variety in the environmental conditions (mainly water depth and topography on sound propagation path) as possible to provide calibration and validation data for the modeling study that follows on this measurement campaign. The exact locations were determined in coordination with Rijksrederij, Coastguard, Ørsted and Blauwwind.

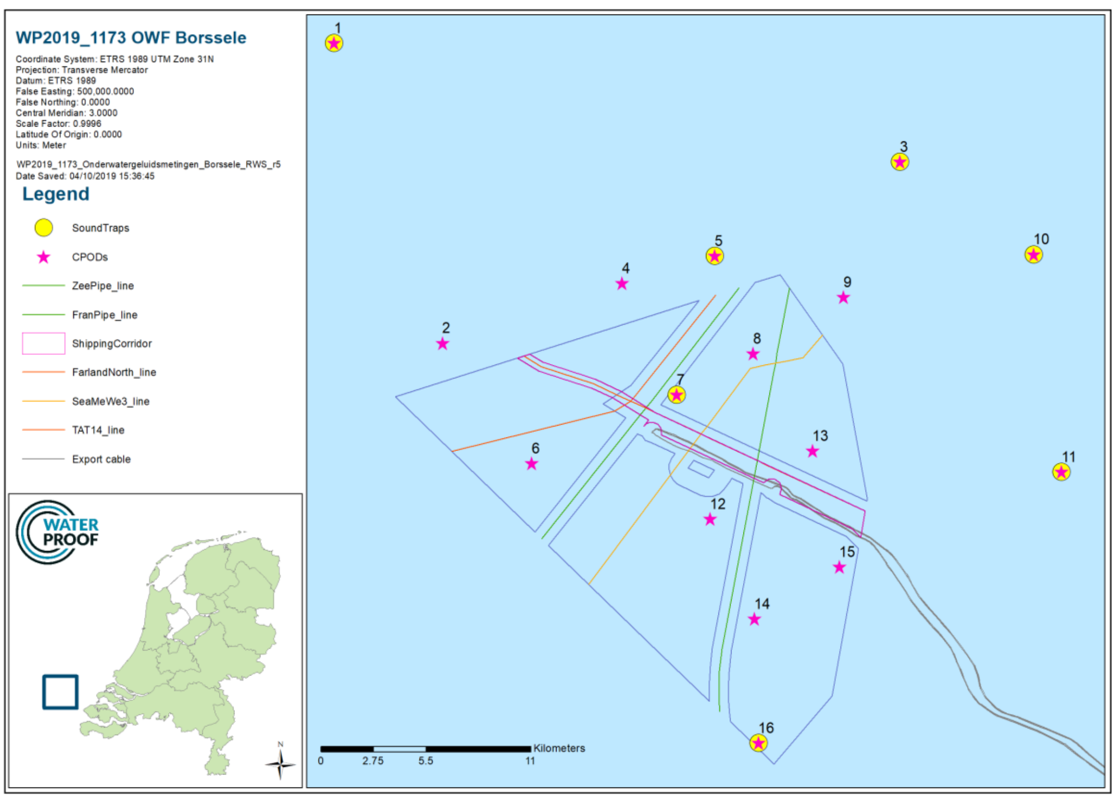


Figure 2.1 Monitoring locations with broadband acoustic recorders (SoundTraps, yellow circles), and detectors for acoustic activity of harbor porpoises (CPODs, pink stars).

Table 2.1: Coordinates of monitoring locations

Station ID	SoundTrap/ CPOD	Inside / outside OWF area	X	Y	Lat	Long	Cardinal mark (existing)
BOR01	ST + CPOD	OUT	480958,48	5751006,04	51,909475	2,7231889	EURO-W
BOR02	CPOD	OUT	486659,16	5735289,78	51,768333	2,8066667	WF-BO 1
BOR03	ST + CPOD	OUT	510664,01	5744774,14	51,853667	3,1548333	MW 3
BOR04	CPOD	OUT	496092,20	5738424,81	51,796667	2,9433334	WF-BO 2
BOR05	ST + CPOD	OUT	500932,19	5739846,17	51,809459	3,0135214	
BOR06	CPOD	IN	491340,02	5728986,73	51,711753	2,8746575	
BOR07	ST + CPOD	IN	498953,26	5732576,89	51,744099	2,9848389	
BOR08	CPOD	IN	502955,88	5734735,89	51,763504	3,0428316	
BOR09	CPOD	OUT	507701,80	5737687,73	51,790000	3,1116666	WF-BO 3
BOR10	ST + CPOD	OUT	517671,81	5739937,28	51,810000	3,2563333	SNE
BOR11	ST + CPOD	OUT	519140,25	5728544,82	51,707519	3,2770055	SBZ
BOR12	CPOD	IN	500716,87	5726071,94	51,685611	3,0103698	
BOR13	CPOD	IN	506076,28	5729653,34	51,717780	3,0879583	
BOR14	CPOD	IN	503041,16	5720848,35	51,638635	3,0439462	
BOR15	CPOD	IN	507493,69	5723570,83	51,663073	3,1083455	
BOR16	ST + CPOD	IN	503251,84	5714329,97	51,580024	3,0469301	

Instrument deployments and retrievals were primarily conducted from the Rijksrederij vessel the Frans Naerebout (see Figure 2.2). This vessel is equipped with Dynamic Positioning (DP) and was therefore capable of accurate deployment of the stations on the planned monitoring locations. In case the Frans Naerebout was not available, one of the sister vessels from Rijksrederij was used (MS Rotterdam). The dates on which instruments were deployed, retrieved and serviced are indicated in Table 2.2.

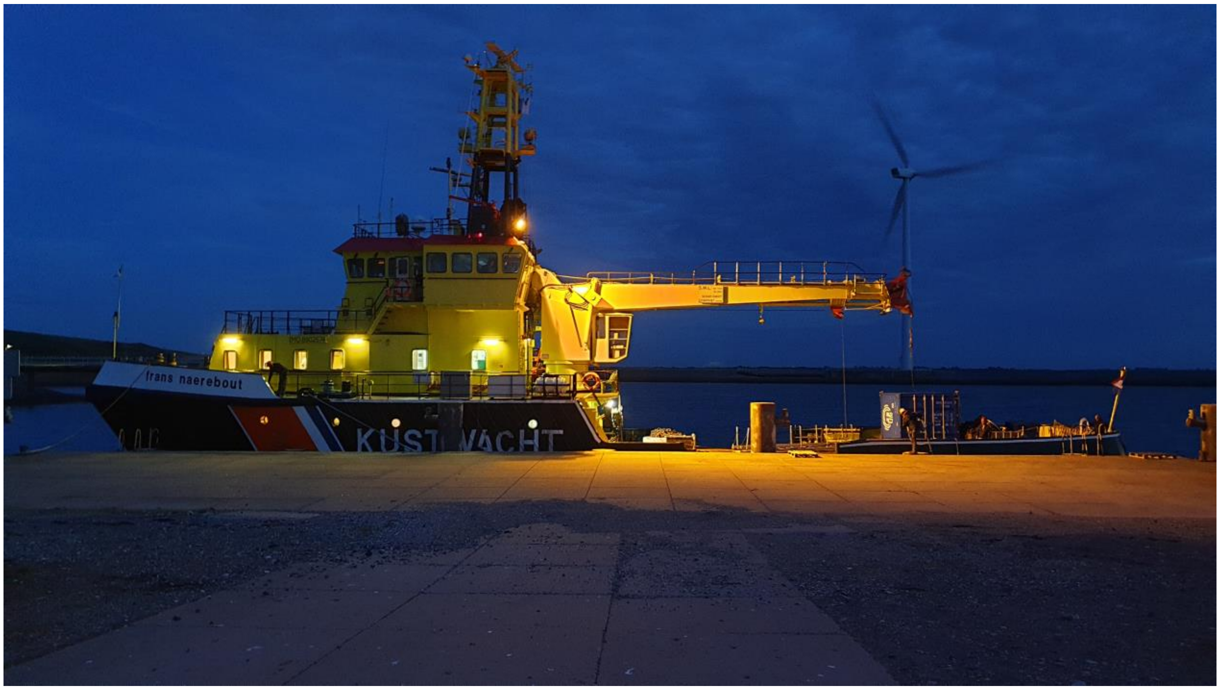


Figure 2.2 Vessel Frans Naerebout from Rijkswaterstaat (foto: Hans Verdaat).

Table 2.2 Dates when deployment, retrieval and servicing of the equipment was conducted. sound-velocity profiles (by means of measuring conductivity, temperature and depth (CTD) profiles) were measured on several locations during four trips (see Section 2.2.3).

Dates	Actions sound measurements	Additional actions
17 - 28 October 2019	Deployment all stations	CTD profiles measured
19 - 23 November 2019	Service & data download all stations	
20 – 23 January 2020	Service & data download all stations	
16 - 19 March 2020	Service & data download all stations	CTD profiles measured
15 - 17 June 2020	Service & data download all stations	CTD profiles measured
13 – 15 July 2020	Service & data download all stations	
14 – 16 September 2020	Retrieval all stations	CTD profiles measured

2.2 Measurement equipment

2.2.1 Noise monitoring

The noise monitoring was conducted with the Ocean Instrument SoundTrap ST300HF (SoundTrap hereafter, Figure 2.3) with an external battery pack for longer recording duration. These SoundTraps are equipped with a broadband hydrophone with a sensitivity around 185 dB re 1 V/µPa and sound can be recorded with a measurement frequency up to 576 kS/s. The distinguishing feature of this recorder is that it can store broadband sound measurements with a low sampling frequency (e.g. 48 kHz) and simultaneously use a threshold exceedance algorithm to detect high-frequency echolocation clicks of cetaceans. When a suspected click is detected, a short snippet with a max. duration of 1.5 ms and the highest sampling frequency is recorded. This allows for long deployment times in comparison with sound recorders that need a continuous high sampling frequency to allow for the detection of high-frequency cetaceans, which are limited by the amount of data storage. Moreover, the short snippet that is recorded for each detected click does allow for more detailed data analyses in comparison with instruments that only detect echolocation clicks and basic properties of these clicks (like CPODs). These detected clicked and recorded snippets can be used to compare with the CPOD collected clicks to compare the two instruments, CPODs are used as the main instrument for harbour porpoise detection in this project to be able to compare the collected data to previous projects.

The used SoundTrap ST300HF with extra battery pack has sufficient storage and battery capacity to measure continuously, with a sampling frequency of 48 kS/s, over a period of 64 days. This ensured sufficient flexibility to schedule the service interval and data retrieval during calm weather periods. The instrument is small and lightweight and is thus easy to deploy and retrieve. The measured analog signal is digitized with a 16-bit SAR ADC. The service-cycle for data back-up and battery replacement was aimed to be 4-8 weeks for each SoundTrap. During servicing the internal clock of the instruments was also synchronized to UTC using the field laptop.

Figure 2.3 SoundTrap ST300HF

All instruments were calibrated prior to the project. The frequency response of the instruments was determined for the frequency range between 20 Hz and 150 kHz in the anechoic basin of TNO (shown up to 50 kHz in Figure 2.4). Instrument calibration is conducted using a sound source at 1 m distance from the hydrophone, the hydrophone output is compared with a B&K 8106 reference hydrophone to determine the frequency dependent sensitivity.

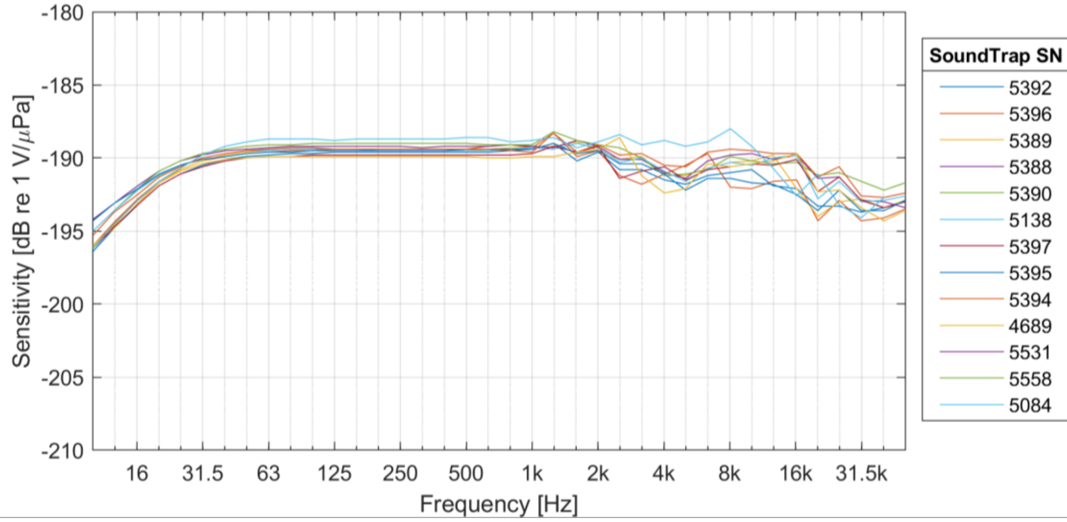


Figure 2.4 Frequency response of the SoundTraps used during the measurement campaign, measured in the anechoic basin of TNO.

2.2.2 Harbour porpoise presence

The CPOD Continuous POrpoise Detector (CPOD version 1, Chelonia Ltd., U.K., shown in Figure 2.5) is a passive acoustic monitoring device. A CPOD consists of a polypropylene casing with the hydrophone housing at one end and a removable lid at the other end. There is a metal retaining ring around the center of the CPOD that holds the mooring line. Two lines, one of which is housed in a anti-chaffing tube to prevent chaffing, are attached to the anchor. Inside the housing is an amplifier, a digital waveform analyzer, a data-logger that logs echolocation click-activity and 10 D-cell batteries; the CPOD has a positive buoyancy of approximately 0.7 kg. The data are stored on a Secure Digital (SD) flash card and later analyzed with a PC to identify the presence of harbour porpoises by detecting the trains of ultrasonic echo-location clicks they produce. To minimize data storage requirements a summary of the click features is logged, comprising time, duration, dominant frequency, bandwidth and amplitude.

Figure 2.5 CPOD setup (photo: Hans Verdaat).

All CPODs were calibrated twice by the German Oceanographic Museum (Meeresmuseum, Stralsund,). The first calibration took place in August 2019 (Appendix I), before the start of the measuring campaign. The second calibration took place November 2020 (Appendix II), after all CPODs were retrieved from the study area.

This calibration ensures that all devices are performing as expected and that the results are comparable between the different locations and over time. The German Oceanographic Museum has developed a standard calibration for the CPODs according to guidelines from the international AMPOD-project (Verfuß et al., 2010). Each device is calibrated before its deployment, and after the measuring campaign has ended.

Each individual CPOD was tested in a tank at the museum to quantify it's sensitivity, using calibrated hydrophones as receiver and transmitter. The transmitter sent out acoustic signals at different frequencies that are measured by a calibrated hydrophone. This hydrophone was replaced by a CPOD that was exposed to the same calibration signals from the transmitter. The same procedure was repeated for different positions along the CPODs horizontal axis in order to measure directional variation. The sensitivity of a CPOD was compared to the received levels and mean peak-to-peak pressures (Ppp) of the calibrated hydrophones. Detection thresholds and the relationship between receiving level and the corresponding Ppp-values for each CPOD were calculated with two methods: 50%-detection thresholds and linear regression models. Details of these calculations and the calibration method can be found in Verfuß et al. (2010).

For the calibrations, the received levels of mean peak-to-peak pressures emitted frequencies of 100, 110, 120, 130 and 140 kHz were measured for each individual CPOD. Since the main part of the energy of a porpoise click is around 132 kHz the differences at 130 kHz are the most applicable for comparison. The highest variation in peak-to-peak pressure at 130 kHz lies between 110 and 120 dB re µ1Pa for most PODs. This difference in peak-to-peak pressure corresponds to a difference in received sound level of less than 3 dB. Only CPODs that operate within the maximum accepted variation recommended by the international AMPOD-project (Verfuß et al., 2010) were used.

As a result of the calibration in August (Appendix I) some CPODs were not used for this project, since they did not work correctly (CPOD 390) or showed some inaccuracies (CPODs 1519 and 1760). The calibration after all CPODs were retrieved form the Borssele area are shown in appendix II.

2.2.3 Sound velocity profiles

During four servicing trips (Table 2.2), CTD (Conductivity, Temperature, Depth) profiles were measured, at several location in the windfarm. These profiles were used to calculate the underwater sound velocity over the depth, using the UNESCO algorithm (Fofonoff and Millard, 1983) as updated by Wong and Zhu (1995), to be used as an input to or to validate underwater sound models. The CTD profiles were measured with a calibrated RBRconcerto CTD. During the first deployment trip (17-28 October 2019) CTD profiles were measured using a Van Essen CTD-Diver.

2.3 Mooring setup

2.3.1 Outside Borssele OWF area

The mooring set-up for the locations outside the Borssele OWF area was combined with existing cardinal buoys. Two additional anchors were added, the first anchor was connected to the cardinal buoy anchor with a 100 m long chain and contained the acoustic instruments elevated from the bed using a subsurface float, the second anchor was connected to the first anchor with a 50 m long chain and to a subsurface float for retrieval of the acoustic instruments (Figure 2.6). The SoundTrap was placed at an elevation of 4 m above the bed, the CPOD at a height of 8 m.

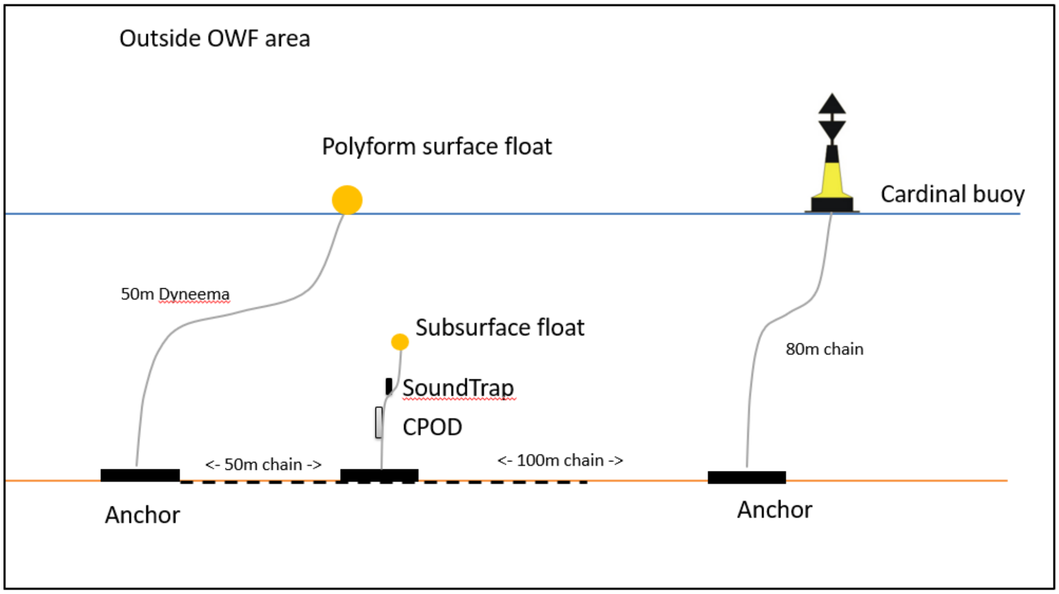


Figure 2.6 Mooring & equipment setup outside OWF area

2.3.2 Inside Borssele OWF area

The mooring set-up inside the OWF area consisted of two anchors which were interconnected with a 100 m chain (Figure 2.7). The first anchor was attached to a spar surface buoy, the second anchor was attached to the acoustic instruments and a subsurface float to elevate the instruments from the seabed. The elevation of the SoundTrap and CPOD above the bed was here also 4 and 8 m, respectively.

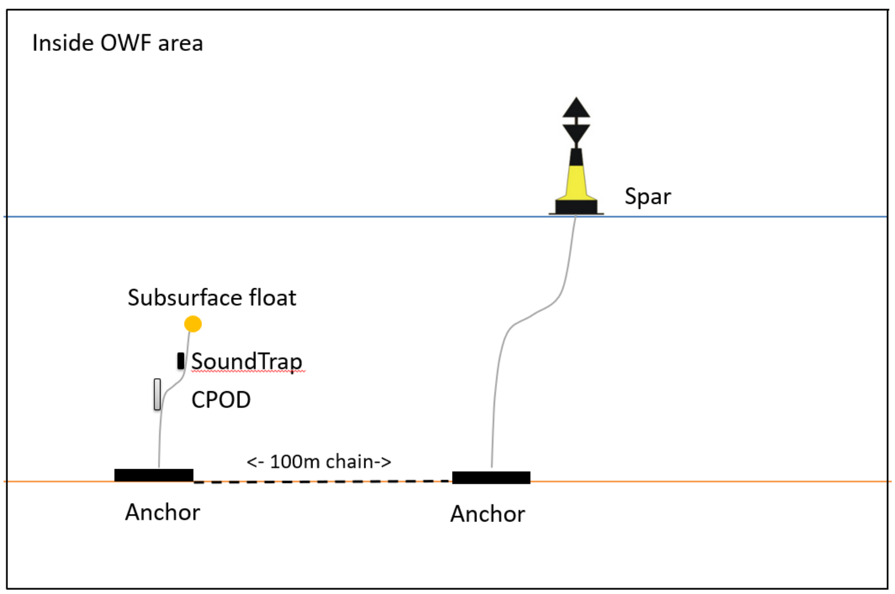


Figure 2.7 Mooring & equipment setup inside OWF area.

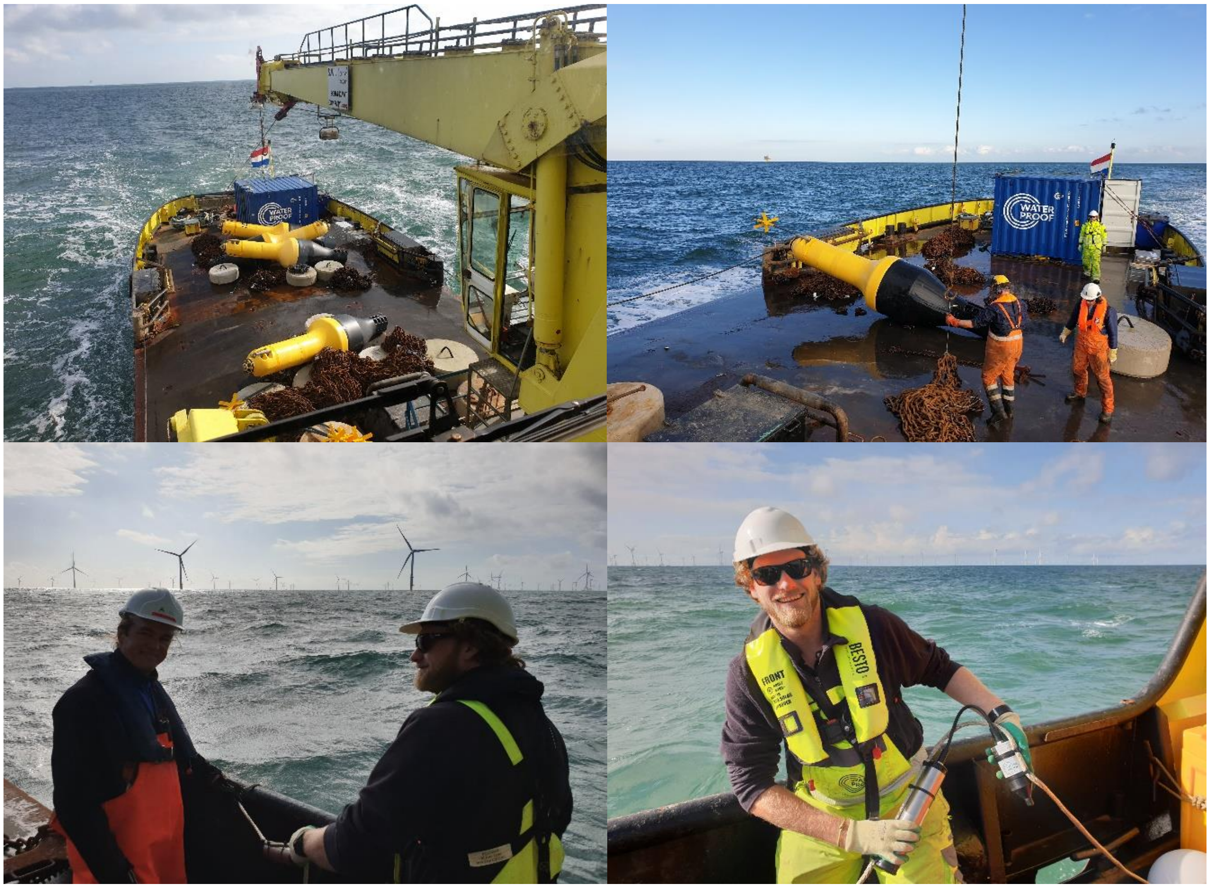


Figure 2.8 Photo-impression of deployments and retrievals with vessel Frans Naerebout (photo's: Roelant Snoek).

2.4 DATA AVAILABILITY

Data was collected from 17 October 2019 till 16 September 2020. During servicing trips, acoustic recorders that were retrieved needed time to charge and download data, and thus fresh recorders were deployed at each location. The serial numbers of the recorders that were deployed at each location are given in Table 2.3.

Table 2.3 Serial numbers of SoundTraps that were deployed at the different monitoring stations.

	Oct-Nov 2019	Nov-Jan 2019-2020	Jan-Mar 2020	Mar-Jun 2020	Jun-Jul 2020	Jul-Sep 2020
BOR01	ST5390	ST5392	ST5396	ST4689	ST5389	ST5392
BOR03	ST5138	ST5390	ST5392	ST5388	ST5394	ST5389
BOR05	ST5389	ST5388	ST5389	ST5392	ST5395	ST5531
BOR07	ST5396	ST5394	ST5388	ST5394	ST5397	ST5388
BOR10	ST5397	ST5389	ST4689	ST5397	ST5531	ST5397
BOR11	ST5388	ST4689	ST5397	ST5531	ST5558	ST5138
BOR16	ST5392	ST5395	ST5394	ST5395	ST4689	ST5558

The data availability is given in Figure 2.9, which shows the good quality data in green. Periods with lacking data for BOR05 (at the end), BOR07 (in November and January), BOR10 (February and March) and BOR16 (January) are due to a failure of the external battery pack to deliver power to the recorder. At BOR01 in February and part of March, the data was corrupt as the hydrophone appeared to be damaged by impact during a deployment/retrieval procedure. For the period at the end of May and beginning of June no acoustic data is available. This was because the recorders could not be serviced in time to provide fresh batteries, as no vessels were available due to restrictions related to the COVID-19 pandemic.

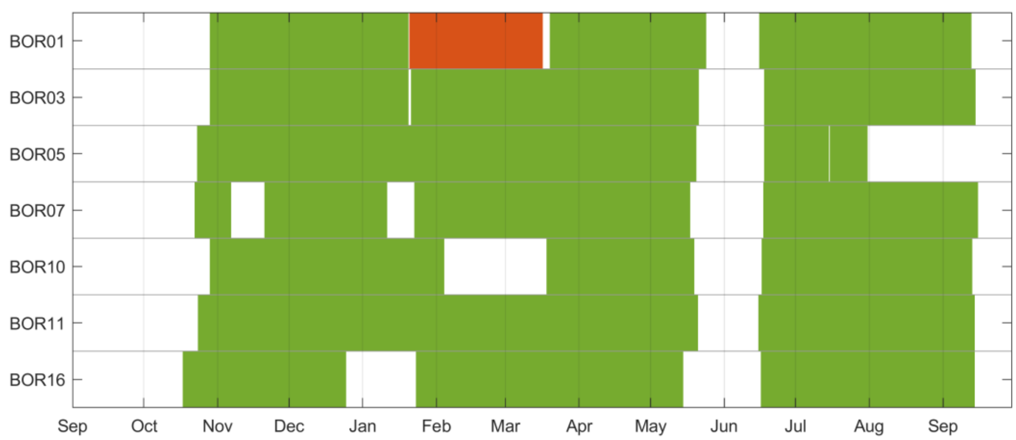


Figure 2.9 Available broadband acoustic data for the 7 SoundTrap stations, with (white) no data, (red) corrupt data, and (green) good quality data.

In the same period, 16 CPODs were deployed and serviced regularly (Table 2.4). During servicing of the CPODs the SD-card was removed, checked for a summary file, and replaced by another SD card. Five CPODs were replaced during servicing. CPODs 1519 and 1760 were replaced after the first deployment, since the calibration results showed some inaccuracies that were, however, within the maximum accepted AMPOD variation. Three other CPODs were replaced for various reasons. On location BOR07 CPOD 376 had to be replaced by CPOD 3175 after the first deployment, since it did not start again. During the subsequent servicing visit CPOD 3175 was found back severely damaged and was replaced. Finally, CPOD

372 was replaced, since it did not start again after retrieval. All five CPODs recorded data, that showed no apparent errors.

All CPODs recorded acoustic activity almost continuous, with on average 328.5 deployment days (320-335 days), which was restricted by the initial deployment and recovery date of the CPOD.

Table 2.4. CPOD id's that were deployed at the different monitoring stations

	Oct-Nov 2019	Nov-Jan 2019-2020	Jan-Mar 2020	Mar-Jun 2020	Jun-Jul 2020	Jul-Sep 2020
BOR01	1747	1747	1747	1747	1747	1747
BOR02	1876	1876	1876	1876	1876	1876
BOR03	1760	3160	3160	3160	3160	3160
BOR04	3173	3173	3173	3173	3173	3173
BOR05	1873	1873	1873	1873	1873	1873
BOR06	1882	1882	1882	1882	1882	1882
BOR07	376[2]	3175[3]	3174	3174	3174	3174
BOR08	1752	1752	1752	1752	1752	1752
BOR09	1482	1482	1482	1482	1482	1482
BOR10	862	862	862	862	862	862
BOR11	392	392	392	392[4]	395	395
BOR12	3165	3165	3165	3165	3165	3165
BOR13	1519[5]	3177	3177	3177	3177	3177
BOR14	1844	1844	1844	1844	1844	1844
BOR15	1859	1859	1859	1859	1859	1859
BOR16	1878	1878	1878	1878	1878	1878

CPOD exchanged, because calibration showed inaccuracies; [2] CPOD replaced, because it did not start after retrieval'[3] CPOD replaced, because it was found severely damaged 70meter out of position; [4] CPOD replaced, because it did not start after retrieval; [5]CPOD replaced, because calibration showed inaccuracies

2.5 Data Processing

The current project aimed to collect data that is suitable to answer the stated research questions in Section 1.2. To ensure high-quality data was collected, the collected data was inspected during the course of the project in order to enhance measurements methods if needed. In-depth analyses of the data and the calculation of actual sound levels and harbour porpoise presence is the focus of a follow-up study.

2.5.1 Acoustic data

Data from the SoundTraps were downloaded and stored in raw data format on two separate external HDDs. A backup on two separate servers was made after retrieval each month at the WaterProof office.

The data processing included in this phase of the project focused on the assessment of the collected data throughout the measurement period. The purpose of this assessment was to ensure correct functioning of the equipment, determine the signal-to-noise ratio (SNR) of the measured piling noise in decidecade (one-third octave) frequency bands for samples of data, identify and eliminate disturbing factors based on the SNR in subsequent deployments within the duration of this project.

2.5.2 Harbour porpoise acoustic activity

Following recovery of the CPODs, data were downloaded and processed with the software "CPOD.exe" version 2.044, (Chelonia Ltd). Since CPODs cannot record real time, a date and a start time (i.c. the activation time of the CPOD) were assigned to the so-called CP1-files when downloading these files from the SD card. To validate the data the files were checked visually; a first cross-check was made to ensure the times that are noted during deployment and retrieval correspond with the times assigned to the data-file: CPOD activated, CPOD submerged, CPOD surfaced, and CPOD deactivated. Each file was truncated at the start and end to delete erroneous data, due to handling of the device. A sample of the data-files has been screened for errors by visually checking graphs that show parameters, like click frequency, CPOD angle, and temperature measured by the CPOD for unexpected transitions between data-files.

Data were further processed and checked for errors. First, classification of click trains was applied using the KERNO classifier from the "CPOD.exe" software, yielding *.CP3 files.

Data were further classified based on the method from Berges et al. (2019a, 2019b, Figure 2.10) to identify change in behaviour. The *.CP3 files were processed using custom code to extract Narrowband High Frequency clicks trains (NBHF), i.e. category associated with harbour porpoises. Every subsequent click train was separated into individual clicks and inter-click intervals (ICI) were calculated. The ICIs from all the recordings were used to form a log ICI distribution. A Gaussian mixture model was then fitted as in Pirotta et al. (2014) using four components to determine the following groupings of ICI:

- buzz ICI (prey capture or social communication)
- inter-train ICI (i.e. pauses between click trains)
- regular ICIs (regular clicking for navigation or prey searching)

Here, a four component distribution was used as there was a large proportion of regular ICIs compared to buzz ICIs. This is shown in Figure 2.11. The resulting components of the Gaussian distribution were then used to cluster the different ICIs into the different categories with buzz ICI defined as the lowest component, inter-train ICI as the highest component and regular ICIs with remaining clicks.

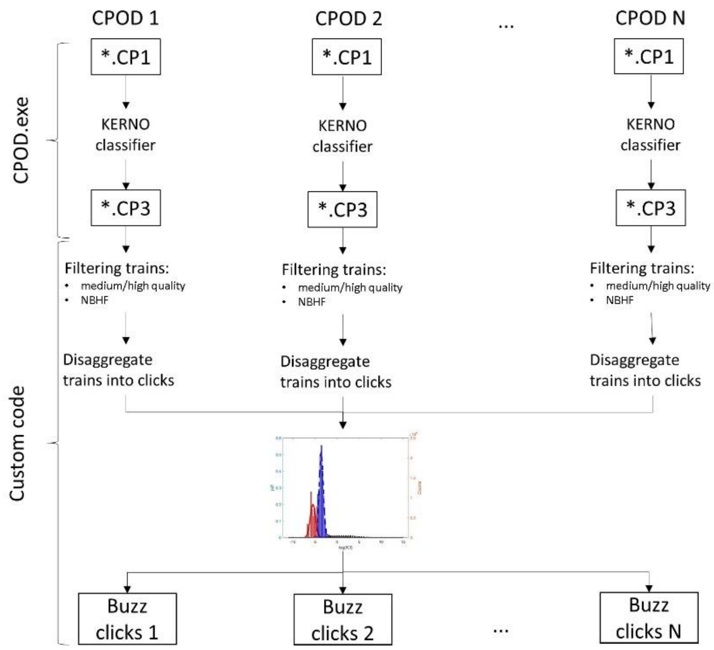


Figure 2.10: Flow diagram of the data processing for computing buzz clicks out of a data set of several CPOD stations. First, the raw CPOD data (.CP1 files) are processed using the "CPOD.exe software". This assigns the raw data into trains, stored in *.CP3. Using custom code, these trains are filtered to NBHF trains and trains presenting a medium or high quality. Then, clicks from all CPOD stations are aggregated and subsequent ICIs are clustered into 3 groups (buzz ICI, regular ICI, inter-train ICIs) using a 3 components Gaussian mixture model. Corresponding filtered clicks are then reassigned to their corresponding CPOD station. Extracted from* [2]

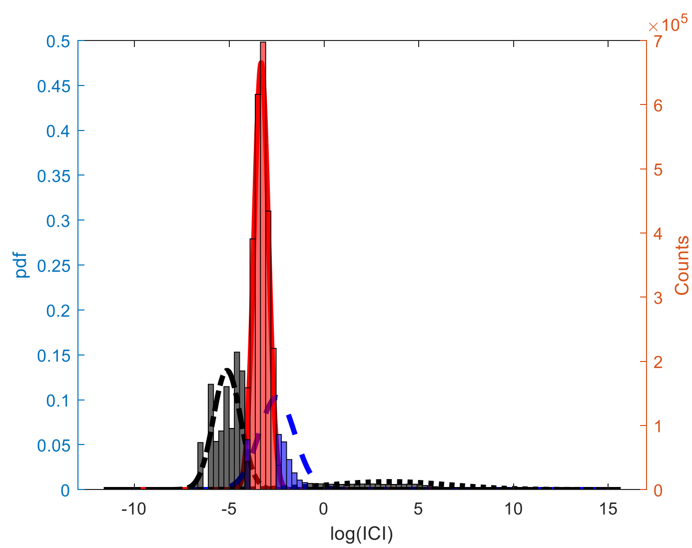


Figure 2.11: Gaussian mixture model fitted on ICIs from all CPOD stations. This is extracted from the supplementary material of [3]. *The Gaussian mixture model fitted here used four components because of the large proportion of regular ICIs. The dashed black line is the component associated with buzz ICIs, the solid red and dashed blue lines are the components associated with regular ICIs and the dotted black line is associated with inter-click ICIs..*

2.5.3 Data Deliverables

description	type of data	storage medium and location	file extension	metadata standard used	added to the Wozep repostitory.
Underwater noise 48 kHz	Raw data	HDD at office WaterProof with backup in second location	.wav	n.a.	no
CTD data	Raw data	HDD at office WaterProof with backup in second location	.csv	n.a.	no
CPOD data	Raw data	Wageningen University "Massive File storage DR "DR and versioning available	.CP	n.a.	no
Processed CPOD data	Processed data	Wageningen University "Massive File storage DR "DR and versioning available	.CP3& Matlab	n.a	no

The raw acoustic data is available upon request. The following metadata is available for each instrument deployment and is largely included in this report:

- Recorder ID;
- Date and time of measurements;
- Depth of hydrophone in water column;
- Coordinates of measurement location;
- Description of measurement equipment and used settings;
- Description of mooring setup;
- Hydrophone type and sensitivity;
- Calibration details per instrument;
- Water depth and tidal variation during measurement period (based on open available data);
- Windspeed and direction during measurements (based on open available data);
- Water temperature during measurements (based on open available data).

DATA OVERVIEW & QUALITY

2.6 ENVIRONMENTAL DATA

Hydrodynamic data is available from the RWS database, sea surface elevation, significant wave height, and the water temperature during the measurement period were retrieved for the Euro-platform (Figure 0.1). From February 2020, hydrodynamic data is also available for the Alpha-platform located in windfarm Borssele , providing more local conditions.

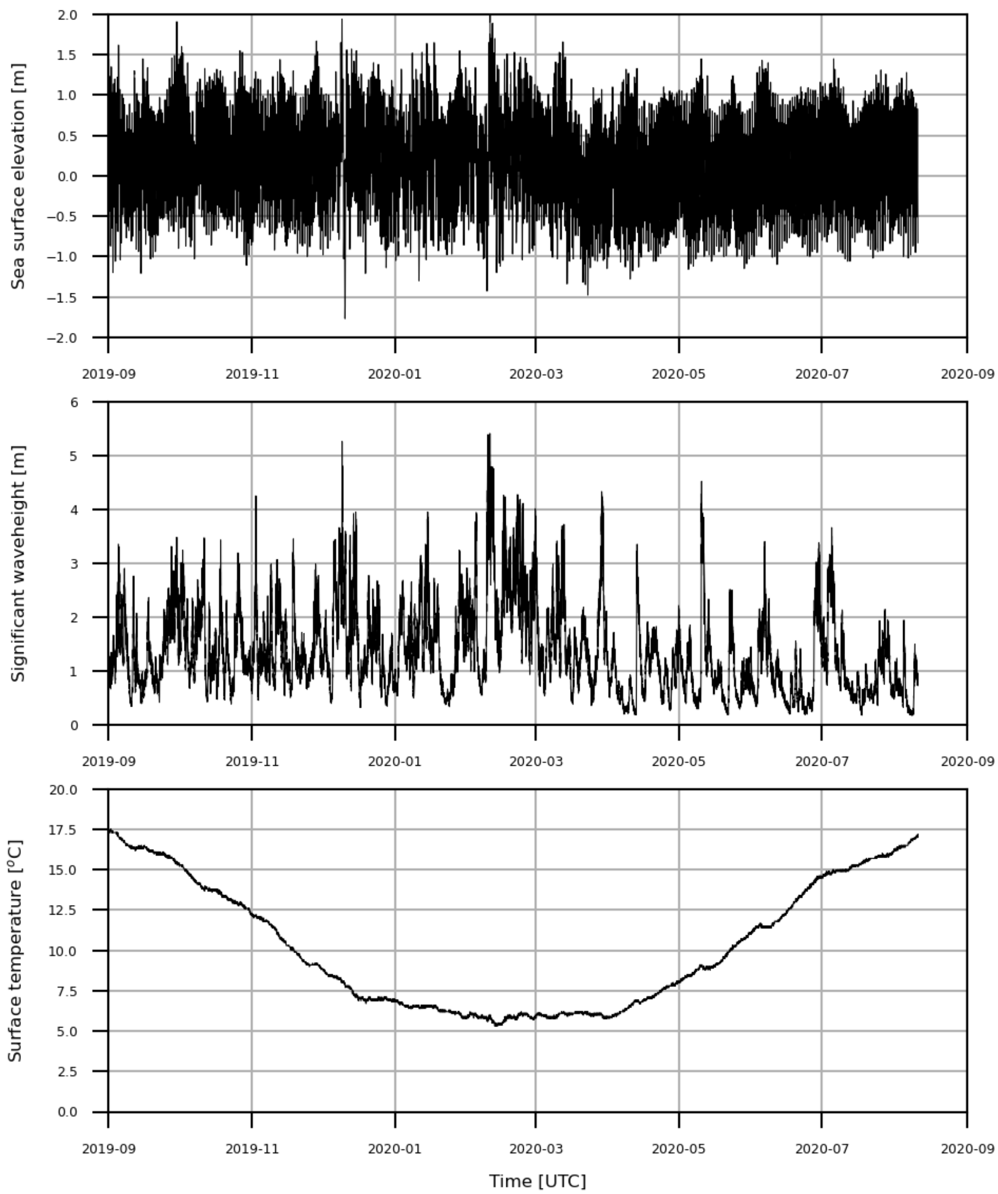


Figure 0.1 Hydrodynamic data collected at the Europlatform with (top) sea surface elevation, (middle) significant waveheight and (bottom) sea surface temperature.

The CTD profiles (Figure 0.2), that were taken during four offshore servicing trips (Table 2.2) on several acoustic measurement locations. Variability in the conductivity, temperature and thus sound velocity is dominantly seasonal and profiles are relatively homogeneous in the vertical. Occasionally a minor increase/decrease in temperature and conductivity was measured in the upper 5 meters of the water column. The derived sound speeds are between 1480 and 1520 m/s depending on the season.

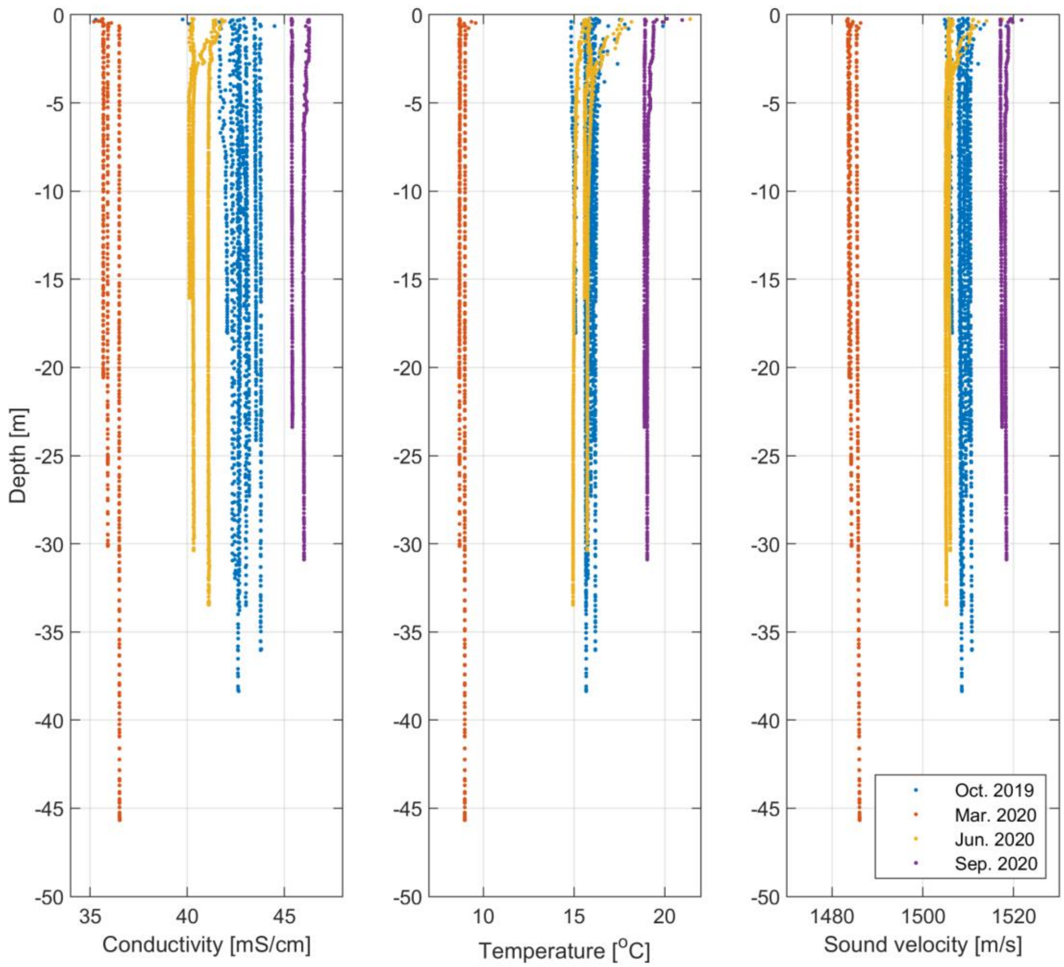


Figure 0.2 CTD profiles measured at different deployment locations during instrument service in (blue) October 2019, (red) March 2020, (yellow) June 2020, and (purple) September 2020. Sound velocity is calculated using the UNESCO algorithm.

2.7 BROADBAND ACOUSTIC DATA

The processing of the acoustic data during this project was conducted in between deployments and focused on the data-quality and the identification of causes for a possible reduced data quality. As this data quality assessment was conducted during the measurement phase, small adjustment to the deployment methods were incorporated, i.e. improvement in the way SoundTraps were suspended from the mooring set-up to reduce vibrations, as to maintain and if necessary improve data quality in the course of the measurement campaign. Two main reasons for a reduced signal-to-noise ratio (SNR) for the sound emitted during pile-driving were identified, (1) vessel noise, especially at larger distances from the windfarm as piling noise levels are low, and (2) tidal flow interfering with the mooring set-up. The first source of reduced SNR will limit the calculation of piling noise levels at large distances, but is part of the local soundscape and was thus not addressed in the assessment for the current project. Tidal flow introduces movement in the mooring set-up and can cause vibration in the mooring line, and shackles and chains to produce sound. Vibrations were reduced as much as possible by attaching the SoundTrap not directly to the mooring line. The required type of mooring set-up (for navigation safety), with the large cardinal buoys, did unfortunately not allow for a fully silent set-up and the lower frequencies are thus contaminated during high flow velocities. The quality of the collected data is as high as would be possible with the required mooring set-up and the high amount of monopiles installed will allow for only using high quality data without losing statistical significance of the findings.

Figure 0.4 shows three examples of the sound levels measured at different distances from a monopile installation. These decidecade values were calculated over 30 seconds of data during the installation of three monopiles on 23, 27 and 29 October 2019 (Figure 0.3). The different stations shown here were located at distances between 3.1 and 21.8 km from the piling location. For each location the sound levels are shown per frequency band for a period during pile driving (thick line) and for a period without pile driving (thin line). The SNR is the difference between the thick and the thin line in these figures. Station BOR07 for 23 October shows high SNR up to 500 Hz, while station BOR16 for the same monopile is dominated by vessel noise and shows a low SNR. During the installation of the first monopile, contamination by tidal flow is low and SNR values are thus also low for the low frequencies. This contamination is relatively high for the sound levels at the third example (29 October 2019), as can be seen by the high noise levels in the lower frequencies. Piling noise in this example only exceeds the background noise levels for a limited frequency range at BOR05 and BOR07 (14.8 and 8.0 km from the piling location respectively).

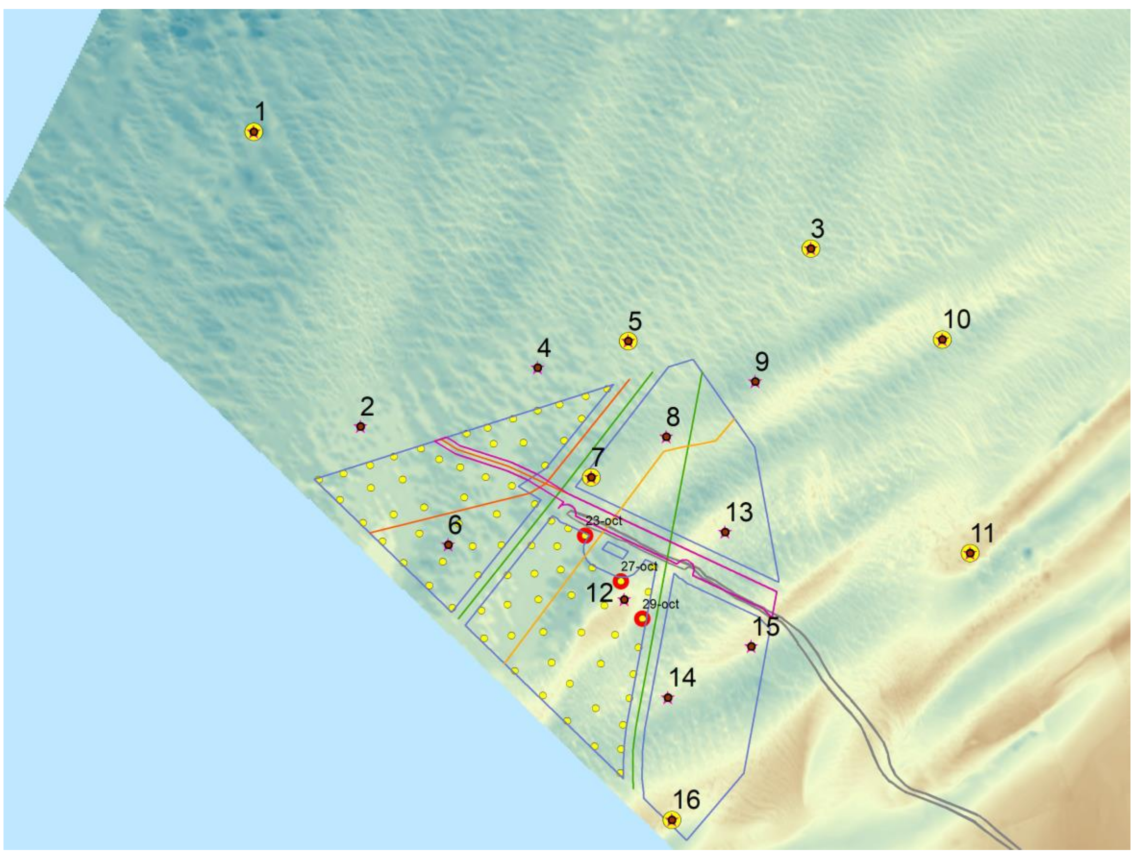


Figure 0.3 Location of the monitoring station and the monopiles installed on (north-to-south) October 23rd, October 27th and October 29th 2019.

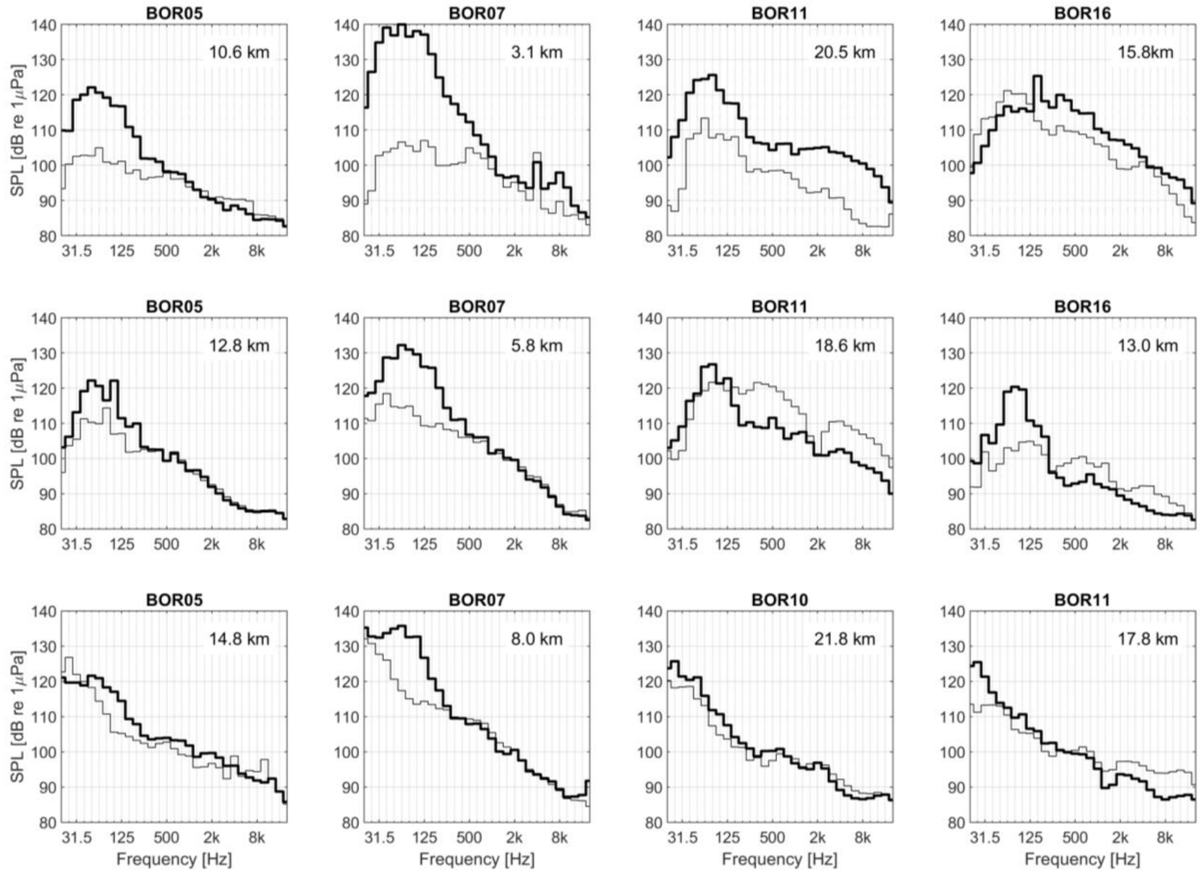


Figure 0.4 Examples of the sound pressure levels for the decidecade frequency bands between 20 Hz and 20 kHz at four locations for monopiles installed at (top) 23, (middle) 27 and (bottom) 29 October 2019. The thick line shows the SPL over 30 seconds during the highest sound levels of the monopile installation, the thin line shows the background level during the 30 seconds just before or after the piling sequence with the highest sound levels.

2.8 Harbour porpoise acoustic activity data

Acoustic activity of harbour porpoises was detected on all locations. A general overview of the number of clicks and the number of feeding buzzes per day per location is shown in Figure 0.5. Porpoise clicks were not only detected on all locations, but they were detected during the whole study period on each location as well. The number of clicks differed not only per location, but showed strong daily variation as well. Feeding buzzes were detected less frequent, but apparently showed similar patterns.

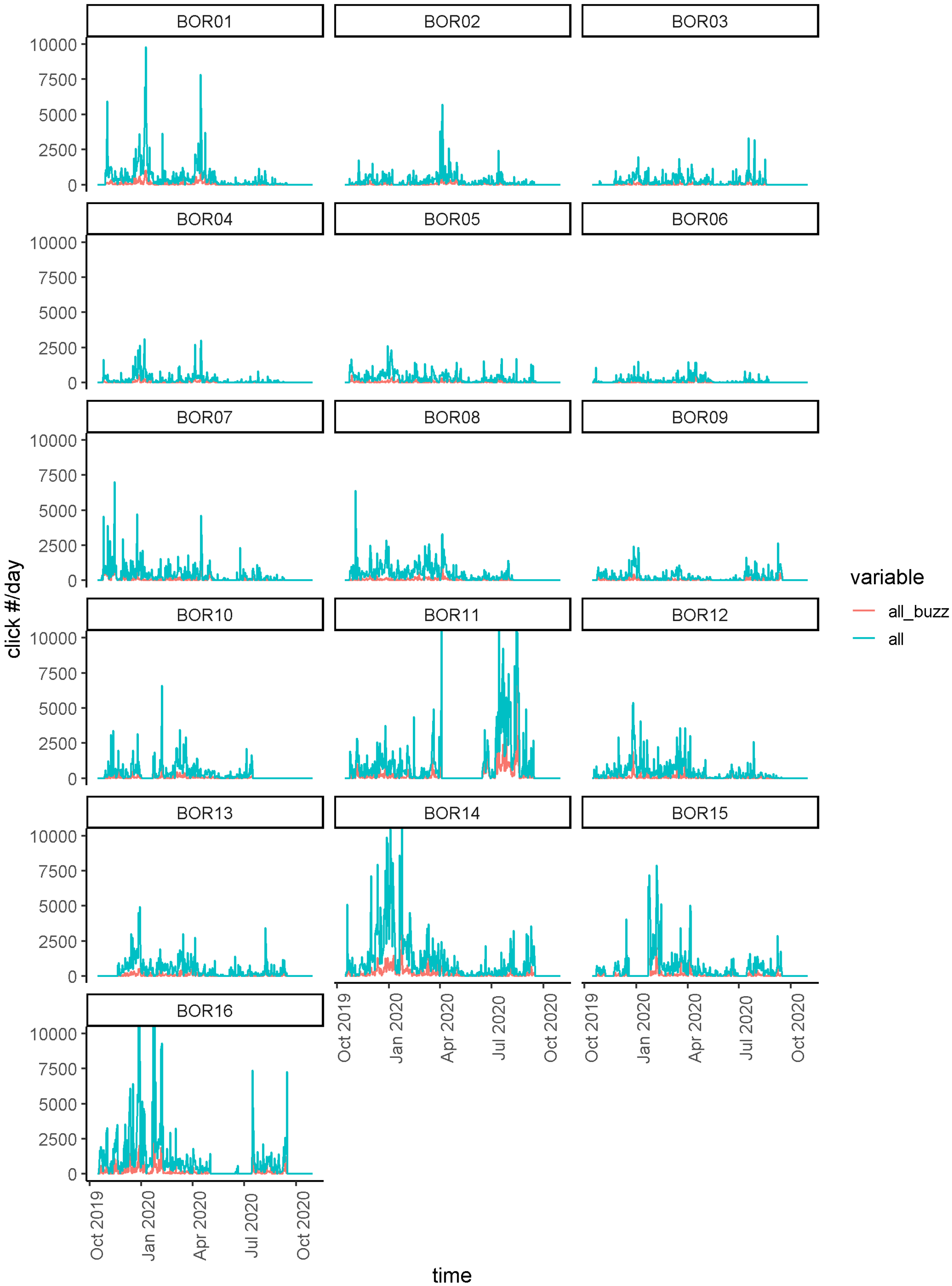

BOR01
BOR02
BOR03
BOR04
BOR05
BOR06
BOR07
BOR08
BOR09
BOR10
BOR11
BOR12
BOR13
BOR14
BOR15
BOR16
10000
7500
5000
2500
0
click #/day
time
Oct 2019
Jan 2020
Apr 2020
Jul 2020
Oct 2020
variable
all_buzz
all

Figure 0.5. . Harbour porpoise acoustic activity per location, expressed as daily number of clicks. all_buzz = feeding buzzes; all = all harbour porpoise clicks.

Based on the number of porpoise clicks the indicator PPM (Porpoise Positive Minutes) was calculated on an hourly basis, and visualized in Figure 0.6. Acoustic activity, expressed as PPM/hr, showed not only different seasonal patterns, but circadian patterns for each location as well. On BOR01 for example, most activity was recorded in January and July 2020, with most activity during darkness in January and during daylight in July.

To visualize seasonal patterns the indicator PPM was aggregated to monthly averages (Figure 0.7). Though each location had different patterns, the majority of the locations showed per month more acoustic activity of harbour porpoises in the first six months than in the last three months.

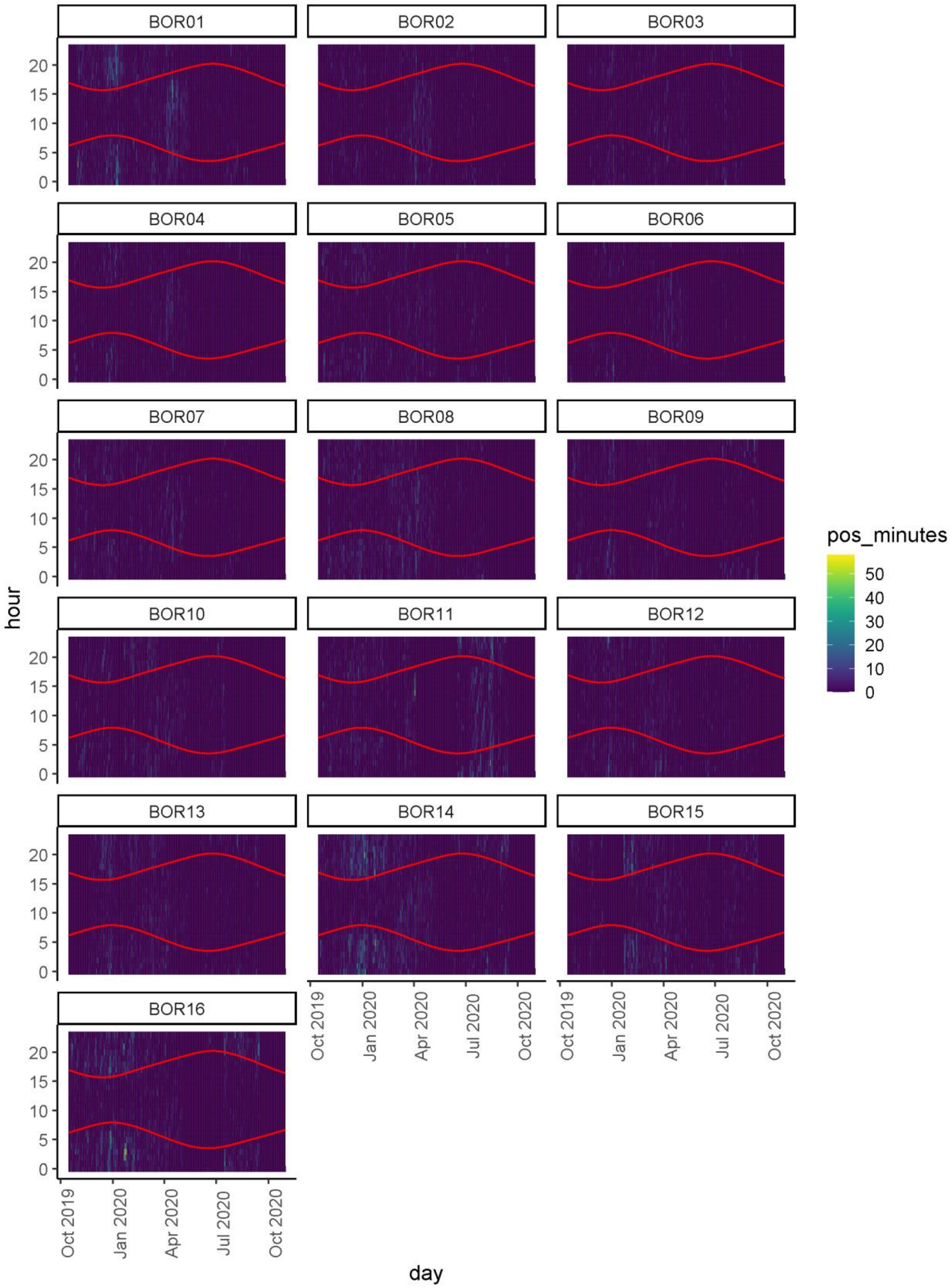


Figure 0.6. Harbour porpoise acoustic activity per location, expressed as porpoise positive minutes per hour. The red lines indicate sunset and sunrise.

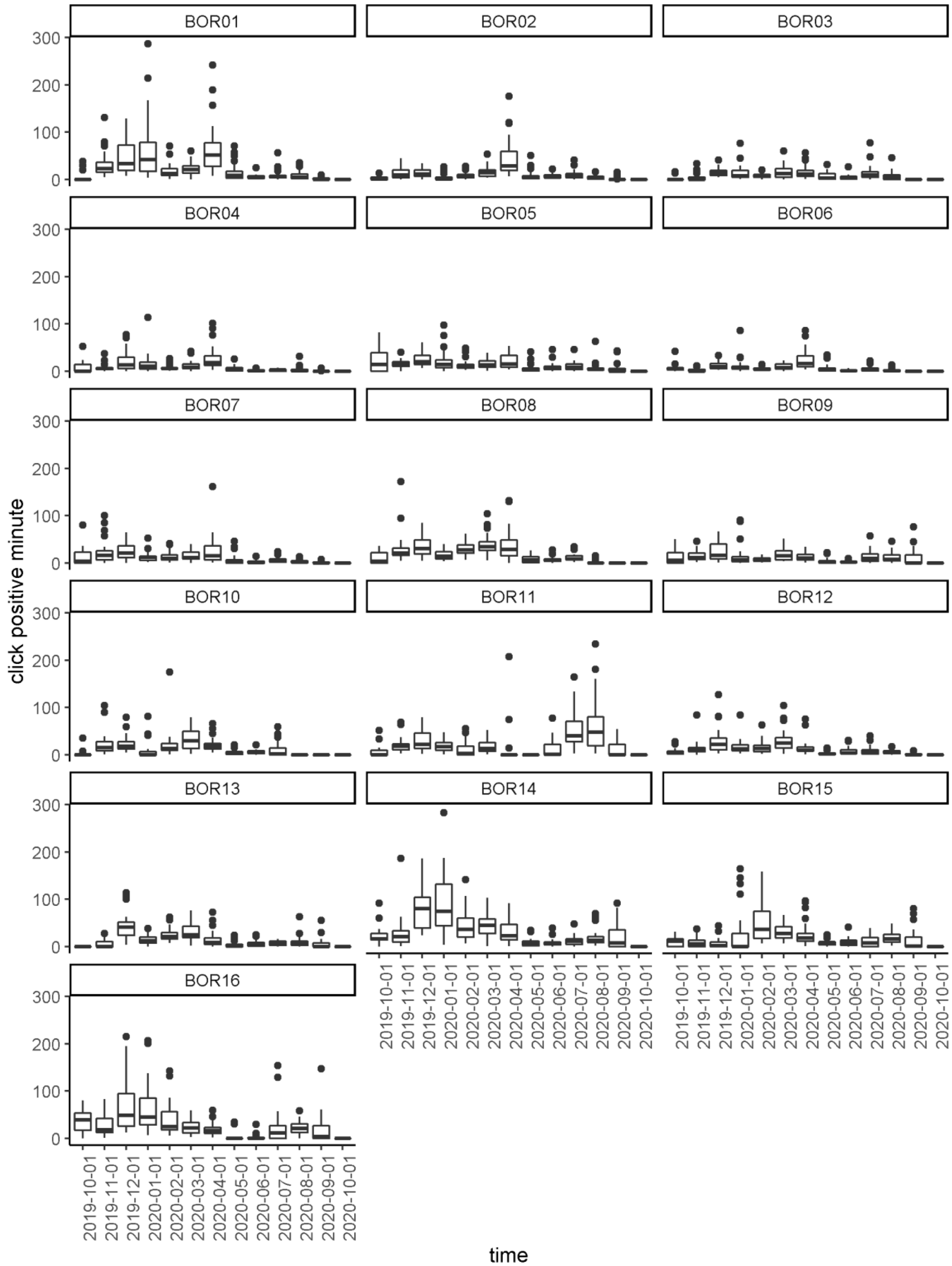


Figure 0.7. Harbour porpoise acoustic activity per location, expressed as average monthly number of porpoise positive minutes per day.

3 CONCLUSIONS AND OUTLOOK

During the installation of the monopile foundations at the offshore windfarm Borssele, between October 2019 and September 2020, acoustic measurements were collected at 16 locations. The acoustic instruments deployed consisted of 16 echolocation click detectors (CPODs) to record harbour porpoise presence, and 7 sound recorders (SoundTraps) to record broadband (up to 24 kHz) sound levels. These measurements were collected as an input to a follow-up project that addresses whether frequency weighing is necessary for the determination of avoidance threshold levels for harbour porpoise with respect to underwater pile driving noise. The current project included raw data inspection to assess data quality and availability, and included the calculation of positive click minutes (PPM) from the CPOD data.

Data availability for the broadband acoustic measurements combined is 80%, due to 9% data loss related to COVID-19 restrictions on vessel use and 11% due to technical issues with the acoustic recorders, CPODs have sampled 100% of the measurement period. Broadband acoustic measurements show a reduced data quality during periods with high tidal flow, as the mooring set-up was a compromise between the quality of recordings and the restrictions on anchor set-up imposed for visibility and vessel safety. This will slightly reduce the usability of the data during high tidal flow at large distances from the pile driving location, where piling noise does not exceed the platform-related deployment self-noise.

Harbour porpoise activity was detected throughout the measurement period at the 16 measurement locations and showed both a circadian as a well as a seasonal pattern in the amount of positive minutes per hour. Preliminary analyses shows more harbour porpoise activity during the first six months in comparison with the last three months of the measurement period. The CPOD data on harbour porpoise clicks can be used to feed into Generalized Additive Mixed Models (GAMM) to quantify the effect of pile driving on the acoustic activity of harbour porpoises, amongst others the avoidance distance of harbour porpoises in relation to the pile driving source.

4 ACKNOWLEDGEMENTS

We thank the captains and crew of the Rijksrederij vessels Frans Naerebout and Rotterdam that worked on this project for their safe and solid execution of the installation and retrieval of the measurement stations.

Also, we like to thank Birte Hansen of Ørsted and Arnold Reijnders of Blauwwind for coordinating the measurements with the installation activities of Borssele I + II and Borssele III + IV and for providing the necessary data on installation activities.

Furthermore, we like to thank Jaap van den Hoed of the Dutch Coastguard for coordination the locations of the measurement stations with respect to shipping and safety.

Finally, we thank Piet Wim van Leeuwen for providing support during the fieldwork for servicing the measurement stations.

5 REFERENCES

Berges, B. J. P., Geelhoed, S. C. V., Scheidat, M., and Tougaard, J., 2019a, "Quantifying harbour porpoise foraging behaviour in CPOD data: identification, automatic detection and potential application," *IJmuiden Wageningen Mar. Res. (Wageningen Mar. Res. Rep. C039/19)*, 2019.

Bergès, B. J. P., Geelhoed, S. C. V., Scheidat, M., and Tougaard, J., 2019b, "Quantifying harbour porpoise foraging behaviour in CPOD data," in *Proceedings of Meetings on Acoustics*, 2019, vol. 37, no. 070008.

Brandt, M.J., Diederichs, A., Betke, K. & Nehls, G., 2011. Responses of harbour porpoise to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. MEPS 421: 205-216.

Brandt, M.J., Dragon, A-C., Diederichs, A., Schubert, A., Kosarev, V., Nehls, G., Wahl, V., Michalik, A., Braasch, A., Hinz, C., Ketzer, C., Todeskino, D., Gauger, M., Laczny, M. & Piper, W,. 2016. Effects of offshore pile driving on harbour porpoise abundance in the German Bight- assessment of noise effects. Final report. IBL, IFAÖ & BioConsult.

Geelhoed, S.C.V., Friedrich, E., Joost, M., Machiels, M.A.M. & Stöber, N., 2018. Gemini T-c: aerial surveys and passive acoustic monitoring of harbour porpoises 2015. Wageningen, IMARES Wageningen UR (University & Research centre), IMARES report C020/17.

Fofonoff, N.P. & Millard Jr, R.C., 1983. Algorithms for computation of fundamental properties of seawater. UNESCO technical papers in marine science. No. 44, Division of Marine Sciences. UNESCO, Place de Fontenoy, 75700 Paris.

Pirotta, E., *et al.*, 2014. "Scale-dependent foraging ecology of a marine top predator modelled using passive acoustic data," *Funct. Ecol.*, 28(1): 206–217.

Tougaard, J., Carstensen, J., Teilmann, J., Skov, H. & Rasmussen, P., 2009. Pile driving zone of responsiveness extends beyond 20 km for harbour porpoises (*Phocoena phocoena*, (L.)). Journal of the Acoustical Society of America 126: 11–14.

Verfuß, U., Adler, S., Brandecker, A., Dähne, M., Diederichs, A., Gallus, A., Herrmann, A., Krügel, K., Lucke, K., Teilmann, J., Tougaard, J., Tregenza, N., Siebert, U. & Benke, H., 2010. AMPOD: Applications and analysis methods for the deployment of T-PODs in environmental impact studies for wind farms: Comparability and development of standard methods (FKZ 0327587). Final report to the Federal Ministry of the Environment. German Oceanographic Museum, Stralsund.

Wong, G.S.K. & Zhu, S., 1995. Speed of sound in seawater as a function of salinity, temperature and pressure. Journal of the Acoustical Society of America 97(3): 1732-1736.