Assessment of the Effects of the Offshore Wind Farm Egmond aan Zee (OWEZ) for Harbour Porpoise (comparison T_0 and T_1)

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Note: Photo on front cover taken by Erwin Winter.

Executive summary

The aim of this study was to investigate whether the Offshore Wind farm Egmond aan Zee (OWEZ) has influenced the occurrence of harbour porpoises.
In order to evaluate the environmental impacts of OWEZ, porpoise acoustic activity in the area was monitored;

1) during a baseline (T_0) study 2003/2004 (Brasseur at al. 2004)
2) after the construction of the wind farm (T_1) from 2007 to 2009.

The comparison between the T_0 and the T_1 was conducted to determine if and how harbour porpoise occurrence is affected by the presence of the wind farm. This report describes the results and analyses of this comparison.

Harbour porpoise activity and presence was measured by acoustic monitoring of echolocation sounds at eight stations equipped with stationary acoustic porpoise detectors (T-PODs) which were permanently deployed and were operating on a 24 hour basis. Bi-monthly visual surveys were also carried out to investigate harbour porpoise occurrence. The results of the visual surveys showed that detection rates were highly weather dependent, in general very low and variable between surveys. The results from the T_0 study and a power analyses indicated that the most adequate method to determine an effect of the wind farm was through acoustic monitoring with T-PODs.

During both the T_0 and T_1study the T-PODs functioned very well and provided a wealth of data. Four indicators of click activity (porpoise positive minutes, clicks per porpoise positive minutes, encounter duration and waiting time between encounters) were chosen for the analyses. These indicators can be related directly to porpoise occurrence and habitat use in the study area. To investigate a potential effect of the wind farm a statistical Before-After Control-Impact (BACI) design was used. Here conditions in the wind farm (impact area, T_1) were compared to both the baseline conditions (T_0) and to conditions in the nearby reference area.

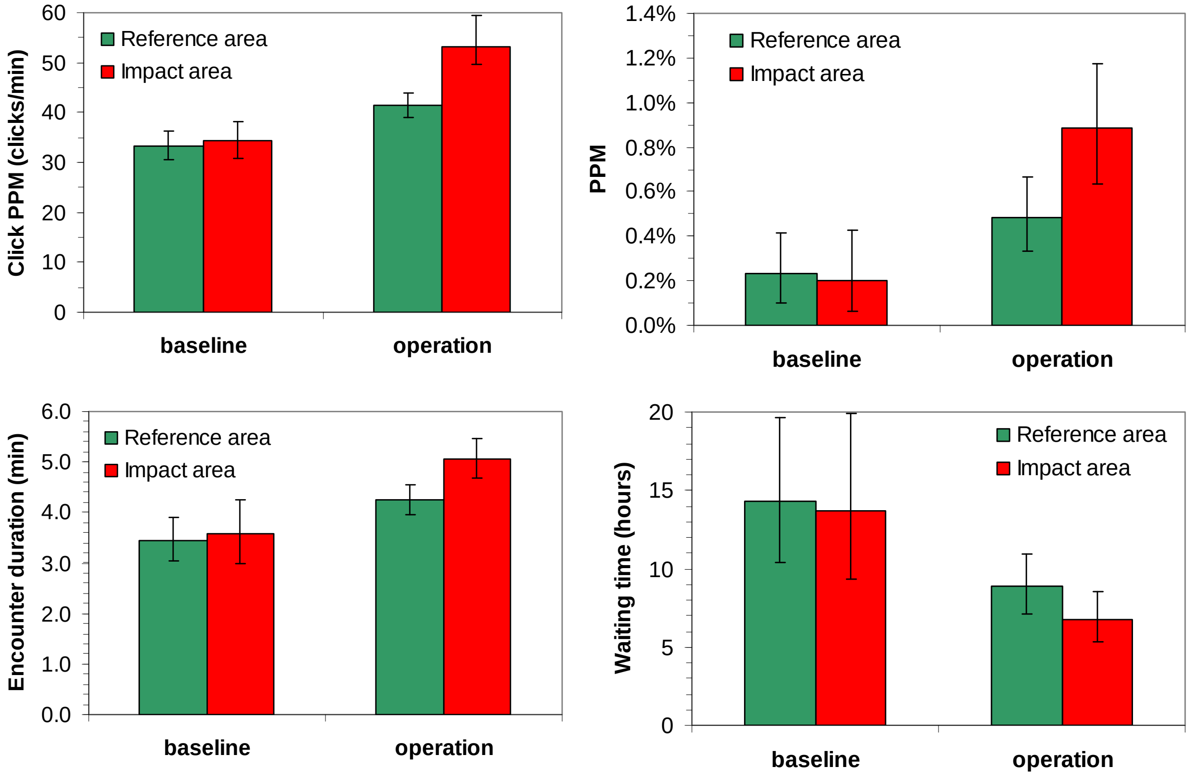
The acoustic results show a strong seasonal variation in harbour porpoise occurrence, with more recordings of animals in the autumn/winter/spring seasons compared to the summer months. This pattern was similar in both the T_0 and in the T_1 study.

There was a general increase in harbour porpoise occurrence from T_0 to T_1 for all T-POD stations, which was confirmed by an increase in porpoise sightings in the Dutch coastal area. During T_0, the spatial distribution of porpoises did not differ significantly between the impact area (wind farm) and the two reference areas north and south of the wind farm.

The results of the BACI design showed that during the T_1 porpoises showed a significant change in distribution between the reference areas and the impact area. A higher porpoise acoustic activity was recorded inside the wind farm relative to outside, which is most likely linked to an increase in local porpoise occurrence.

Because of the introduction of new T-PODs to the study and the specific differences between individual T-PODs , the variation between these devices might have caused a higher variation in the resulting data. Thus, when interpreting the effects, one should take into account that the confidence interval of the results might be larger and that the true effect might be stronger or lower than the one reported here. However, this does not influence the overall conclusions.

The cause behind the increase of porpoises in the farm could not be determined, but may be linked to increased food availability due to the reef effect of the turbine foundations and the exclusion of fishery from the wind farm. The increase of harbour porpoise acoustic activity inside the wind farm is in contrast to results from other offshore wind farms. This shows that results from one wind farm are not necessarily transferable or valid for other wind farms located in different areas.



Mean values for combinations of area and period back-transformed to the original scale for combinations of the two areas and the two periods. Error bars indicate 95% confidence limits for the mean values. Variations caused by differences in sub-areas (Control N and S) and months have been accounted for by calculating marginal means.

Acknowledgement

The Offshore Wind farm Egmond aan Zee has a subsidy of the Ministry of Economic Affairs under the CO_2 Reduction Scheme of the Netherlands.

We would like to thank the crew of the Rijkswaterstaat owned vessel "Terschelling" for all the long hours they have spent on the deployment and recovery of the T-PODs, for their professional work under sometimes difficult conditions and the hospitality onboard the boat.

1 Introduction

1.1 Background of this study

Dutch government policy aims at realising sustainable energy production in The Netherlands. One possibility explored is offshore wind power. The government permitted the construction of Offshore Wind farm Egmond aan Zee (OWEZ) as a demonstration project, used for assessing both technological and environmental challenges in relation to operation. In order to evaluate environmental impacts from an offshore wind farm it is necessary to conduct a baseline or T_0 study, which provides a thorough description of the ecological reference situation, as well as, an impact study T_1, where the actual impact of the wind farm is assessed by comparison with the T_0 study.

Previous studies have shown a reduction in harbour porpoise occurrence during the construction of other offshore wind farms (Carstensen et al. 2006, Tougaard et al. 2006b). In particular the installation of steel monopole foundations by means of percussive pile driving represents a substantial impact in an area covering several hundred km^2 around the construction site (Tougaard et al. 2009, Brandt et al. 2009). Operation of offshore wind farms probably presents a smaller impact, but throughout an extended period of time. Most significant negative impacts from an operating wind farm on harbour porpoises are likely to be underwater noise from the turbines and ship traffic related to service and maintenance (Madsen et al. 2006). Noise levels from operating turbines are expected to be low by any standard and effects, if any, are expected to be local, i.e. inside the wind farm and in the immediate vicinity of the wind farm (Tougaard et al. 2009). Potential positive effects have also been discussed and include a potential increase in potential prey (fish) in the wind farm due to a reduction of fishing activities as well as the introduction of artificial hard substrate habitat.

Harbour porpoise activity and presence was measured by acoustic monitoring of echolocation sounds with eight acoustic porpoise detectors (T-PODs), permanently deployed and operating on a 24 hour basis. The comparison of the two study periods was done with a statistical BACI design, where conditions in the wind farm (impact area) is compared both to baseline conditions (T_0) and to conditions in nearby reference areas not affected by the wind farm.

1.2 Status of harbour porpoise in the Netherlands

The harbour porpoise (*Phocoena phocoena*) used to be a common animal in Dutch coastal waters. Until the 1950s it was not uncommon to encounter porpoises from the beach, in harbours, and even up rivers. Numbers observed started to decline in the second half of the century to such an extent that the porpoise became a rare visitor to the Dutch coast in the 1970s/1980s (van Deinse 1952, Reijnders 1992, Smeenk 1987). However, in the early 1990s, live sightings as well as dead strandings, started to increase and have continued to do so until present day (Camphuysen 1994, Reijnders et al. 1996, Witte et al. 1998).

2 Methods

2.1 Choice of methods

Different methods are available for monitoring the occurrence and habitat use of harbour porpoises.

When using visual surveys, e.g. using vessels or aircraft, only a proportion of the animals present can be recorded. Harbour porpoises spend most of the time under the water's surface, and are thus only visible to an observer for part of the time. Additionally sighting rates are dependent on a large number of parameters, such as weather conditions and observer expertise. Unless the general density is very high or the study area and the effort are very large, sighting rates will most likely be too low to have sufficient power to detect change. Also, the survey provides a snapshot of the distribution during a short time period (e.g. days, or even hours). As porpoises are highly mobile this can be problematic when surveying a small area. As the changes in distribution, even if small, will result in changes of sighting rates.

During the T_0 and T_1 study bird ship surveys were conducted that also collected information on marine mammals. In addition, during several surveys a towed hydrophone array was used to investigate if this method could provide sufficient data for the analyses of impacts.
The results from T_0 showed that both the towed hydrophone as well as the visual surveys where not appropriate to study impacts of the OWEZ of porpoise presence. The detection and sighting rates respectively were generally too low to give sufficient statistical power of the analysis to detect even large changes in occurrence of porpoises.

T-PODs, stationary acoustic porpoise detectors, continuously register the presence of porpoises within the targeted areas (i.e. the wind farm site and two control sites). This method proved very powerful during T_0 and has also proven successful in studies to monitor the effects of wind farms on harbour porpoise in Denmark (Tougaard et al. 2003, Carstensen et al. 2006). This method was therefore chosen as the primary method in the study presented here.

2.2 Site description

The study site is located in the North Sea, west of the province of North Holland (The Netherlands), where the offshore wind farm Egmond aan Zee (OWEZ) was constructed (*Figure 1*). OWEZ is located 8-18 km offshore with an approximate area of 40 km^2. There are 36 wind turbines with a hub height of 70 meters above median sea level (MSL), each with a nominal capacity of 3 MW. Construction began in April 2006 with all the turbines standing by August 2006 (pile driving period). The wind farm was commissioned on 1 January 2007.

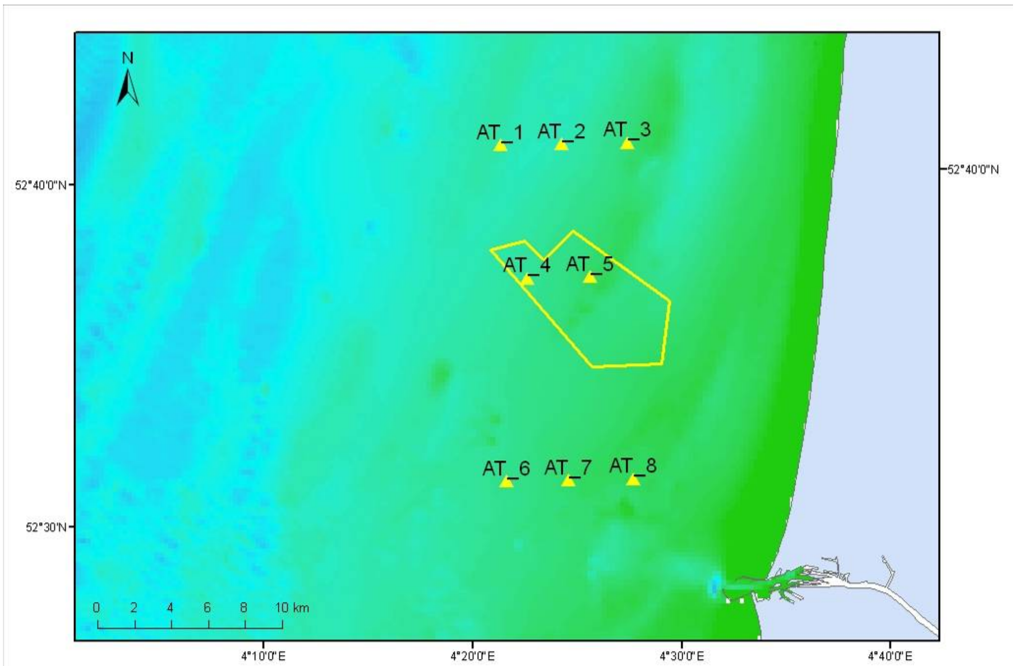


Figure 1. Positions of the eight monitoring stations (AT1 –AT8), northwest of the harbour of IJmuiden (NL). The yellow line shows the outline of the OWEZ wind farm area.

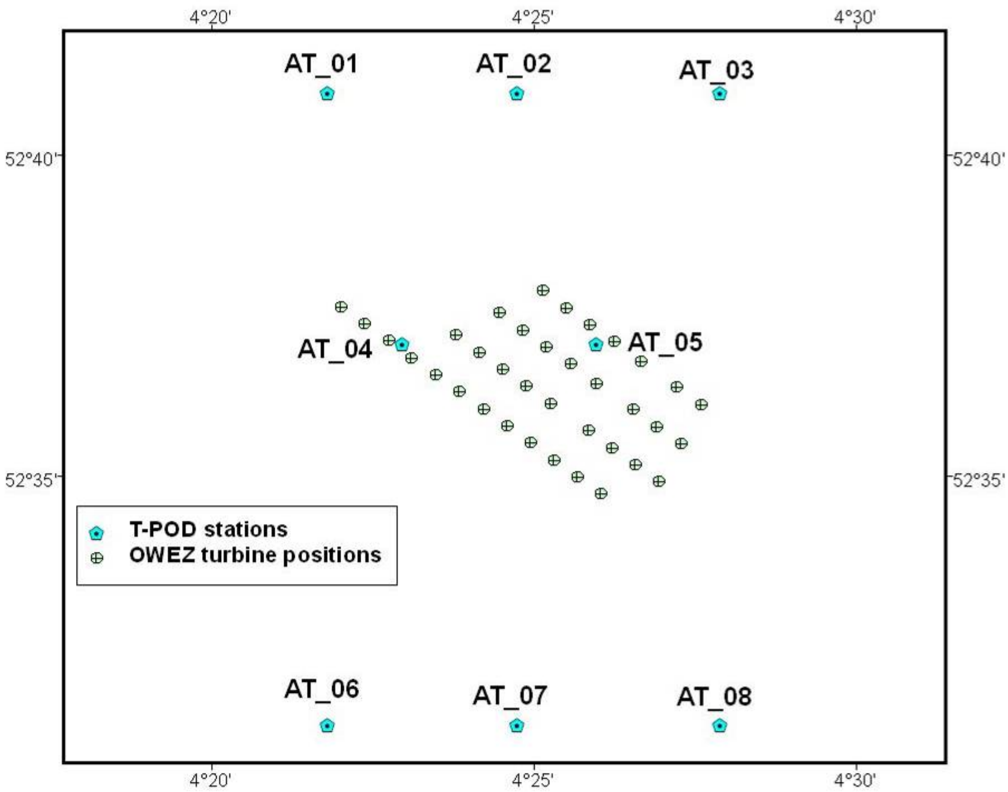


Figure 2: Positions of wind turbines of OWEZ as well as the eight monitoring stations.

2.3 Acoustic monitoring (T-PODs)

The effect of Egmond aan Zee wind farm on harbour porpoises was studied by static acoustic monitoring. Static acoustic loggers (T-PODs, see below) were deployed in a period prior to construction, denoted "baseline" or T_0 (June 2003 – May 2004) and a post-construction period, denoted "operation" or T_1 (June 2007 – April 2009). A total of 8 fixed stations were used for acoustic monitoring of harbour porpoises; three control stations north of the wind farm area, three control stations south of the wind farm and two stations within the wind farm area (Fig 1). The locations of the acoustic monitoring stations were chosen prior to the T_0 study at which time the final positions of the wind turbines were not known. This explains why the positions AT_04 and AT_05 are close to the edge of the wind farm and not in the central part as originally planned.

The positions of the T-POD stations were chosen on the following grounds:

- In the wind farm (OWEZ): T-PODs have to be placed at least 1 nautical mile or more apart from one another, to assure that T-POD can be considered independent and to avoid the situation of a porpoise being detected simultaneously by 2 neighbouring T-PODs. Maximum detection distance of T-PODs is around 500 m (Tougaard 2008). The two T-PODs positioned in the wind farm were AT4 and AT5.
- Outside the wind farm, based on experience obtained during wind farm studies in Denmark (Teilmann et al. 2002, Carstensen et al. 2006, Tougaard et al. 2006b, Teilmann et al. 2009) the T-PODs in the two reference areas were placed approximately 5-6 nautical miles from the wind farm. This distance should ensure that the reference area has the same biotic and abiotic factors as in the wind farm, but is outside the potential disturbance range of the wind farm. The distance between the T-PODs in the reference areas was the same as for T-PODs inside the wind farm.
- The choice for 3 T-PODs in two reference areas north and south of the wind farm (respectively AT1 - AT3 and AT6 - AT8) and 2 in the farm is based on the considerations that:

a) only two T-PODs (with the required separation) would fit inside the wind farm
b) Higher losses of equipment was anticipated outside of the wind farm
c) a potential geographical gradient in abundance from north to south of the wind farm could be investigated.

2.3.1 Technical description of T-PODS

The T-POD or POrpoise Detector is a small self-contained data-logger that logs echolocation clicks from harbour porpoises and other cetaceans. It is developed by Nick Tregenza (Chelonia, UK). It is programmable and can be set to specifically detect and record the echolocation signals from harbour porpoises. The T-POD consists of a hydrophone, an amplifier, a number of band-pass filters and a data-logger that logs echolocation click-activity. It processes the recorded signals in real-time and only logs time and duration sounds fulfilling a number of acoustic criteria set by the user. These criteria relate to click-length (duration), frequency distribution and intensity, and are set to match the specific characteristics of echolocation-clicks. The T-POD operates with six individually programmable set of settings.

To maximise the chance to detect harbour porpoises during this study, identical settings were used for all six sets, based on the recommendations provided by the manufacturer and experience from studies in Danish wind farms (Table 1).

Table 1. T-POD filter settings used during deployments. Settings were used based on the recommendations provided by the manufacturer and the experience from studies in Danish wind farms.

	Version 3	Version 5
A filter: frequency (kHz)	130	130
B filter: frequency (kHz)	90	92
Ratio: A/B	5	n.a.
A filter: Q (kHz) / integration time	short	n.a.
B filter: Q (kHz) / integration time	long	n.a.
Bandwidth	n.a.	5
Automatic gain control	n.a.	+
Sensitivity:	6	10
Max number of clicks / scan:	160	160
Minimum click duration: (µs)	30	30

Each of the six set of settings (also referred to as scans) were employed sequentially for 9 seconds, with 6 seconds per minute assigned for change between settings. This gives an overall duty cycle of 90% (54 seconds per minute), 15% for individual scans (9 seconds per minute). In order to minimise data storage requirements only the onset time of clicks and their duration are logged. This is done with a resolution of 10 µs. The absolute accuracy of the timing (time since deployment) is considerably less than this, due to drift in the T-PODs clock during deployment (up to a few minutes per month). This drift however, is only of concern when comparing records from two T-PODs deployed simultaneously. Clicks shorter than 30 µs and sounds longer than 2550 µs were discarded.

The T-POD relies on the highly stereotypical nature of porpoise sonar signals. These are unique in being very short (50-150 microseconds) and containing virtually no energy below 100 kHz. The main part of the energy is in a narrow band between 120-150 kHz, which makes the signals ideal for automatic detection. Most other sounds in the sea, with the important exception of echosounders and boat sonars, are characterised by being either more broadband (energy distributed over a wider frequency range), longer in duration, with peak energy at lower frequencies or combinations of the three.

The actual detection of porpoise signals is performed by comparing signal energy in a narrow filter centred at 130 kHz with another narrow filter centred at 90 kHz. Any signal, which has substantially more energy in the high filter relative to the low filter and is below 200 microseconds in duration is highly likely to be either a porpoise or a man-made sound (echosounder or boat sonar). Some spurious clicks of undetermined origin (such as background noise and cavitation sounds from high-speed propellers) may also be recorded. These, as well as boat sonars and echosounders are filtered out off-line in software, by analysing intervals between subsequent clicks. Porpoise click trains are recognisable by a gradual change of click intervals throughout a click sequence, whereas boat sonars and echosounders have highly regular repetition rates (almost constant click intervals). Clicks of other origins tend to occur at random, thus with highly irregular intervals.

No other cetacean regularly found in the North Sea uses sonar signals that can be confused with porpoise signals. Dolphins (with the exception of the genus *Cephalorhynchus*, which does not occur in the North Sea) use broadband sonar clicks, i.e. energy distributed over a wide frequency range, from below 20 kHz to above 200 kHz in some cases (Rasmussen et al. 2002). It is thus unlikely that dolphins would have triggered the T-POD when porpoise settings were used.

Figure 3: Standard T-POD (taken from www.chelonia.co.uk); the hydrophone is located at the top, the batteries are stored in the bottom part of the T-POD.

Comparison of T-POD recordings with simultaneous visual tracking of porpoises with theodolite show that the effective detection distance is between 100 and 200 meters (with a maximum detection of around 500m). Of 37 animals observed closer than 100 m from the T-POD, 81% were registered by the T-POD. Of 34 animals that came within 100-200 meters, of the T-POD, 31% were recorded by the T-POD (Tougaard 2008).

2.3.2 Field calibration of T-PODs

Two versions of T-PODs were used in this study: version 3 (V3) and version 5 (V5). The V3's were equipped with 32 MB RAM and the v5's with 128MB RAM and powered by 12 or 15 alkaline D-cells, respectively. This gives a maximum logging period of about 120 days.

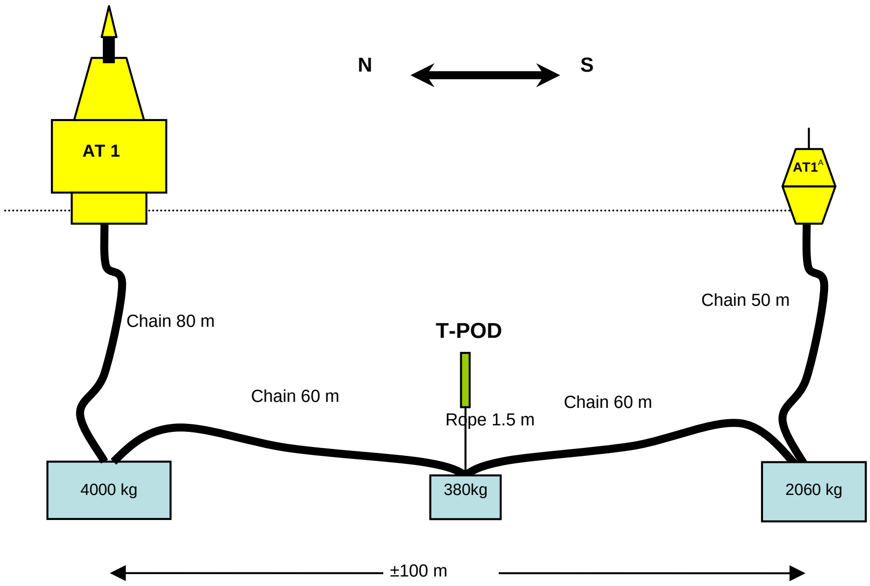
To make sure that the eight T-PODs were working and provided similar results they were deployed simultaneously in a porpoise rich area in Denmark prior to the study in the OWEZ wind farm area. Results of this can be found in Brasseur et al. 2004.

Field calibrations were done at the beginning of the T_0 study (Brasseur et al. 2004). Hydrographic data was collected in T_0 (Brasseur et al. 2004), but was found not to correlate with the recording and thus salinity was not logged T_1. During the T_1 study new versions of T-PODs (V5) were used, as v3 T-PODs became unavailable from the manufacturer. To allow data analyses between the T_0 version (V3) and the T_1 version (V5) during the T_1 phase on a number of positions two different T-PODs were placed together on one position. T-PODs were taped to each other using duct tape in a way that the hydrophones at the top (mid point to mid point) were approximately 14 cm apart. This was done to calibrate the two different T-POD versions (v3 in the T_0 and v5 in the T_1). Deploying them together allowed a comparison of the data at a later stage, and thus allowed the two versions to be used interchangeably.

2.3.3 Mooring technique

The mooring used for the T-PODs in the Dutch coastal waters was designed using robust material. Where in other areas T-PODs are usually attached to small anchor blocks and small buoys, this study used very heavy equipment for anchoring the T-PODs due to the risk of collision with trawlers in the area. Approximately 15 tonnes of buoys, chain, and concrete is used for anchoring a single T-POD securely (Figure 4).

Figure 4. Schematic setup of the T-POD mooring. The large buoy is lighted at night.



Each T-POD was deployed between two large buoys, of which the larger was equipped with a yellow warning lantern. Furthermore, the experimental setup was proclaimed on VHF-radio regularly by the local authorities.

Figure 5. Set-up of the anchoring. View above water (photo Saskia Mulder, RIKZ)

2.3.4 Servicing of T-PODs

The acoustic monitoring stations were regularly visited to service the deployed T-PODs. This included cleaning, downloading the data and changing the batteries and, when necessary replacing lost or broken T-PODs. Servicing periods were set in a way to ensure that batteries were changed before drained (about every 100 days) however, for several reasons of technical nature (see section 3.1.2) the actual time of recording was in several cases less than that.

Figure 6. Complete anchoring system on board the "Terschelling" (photo Saskia Mulder, RIKZ)

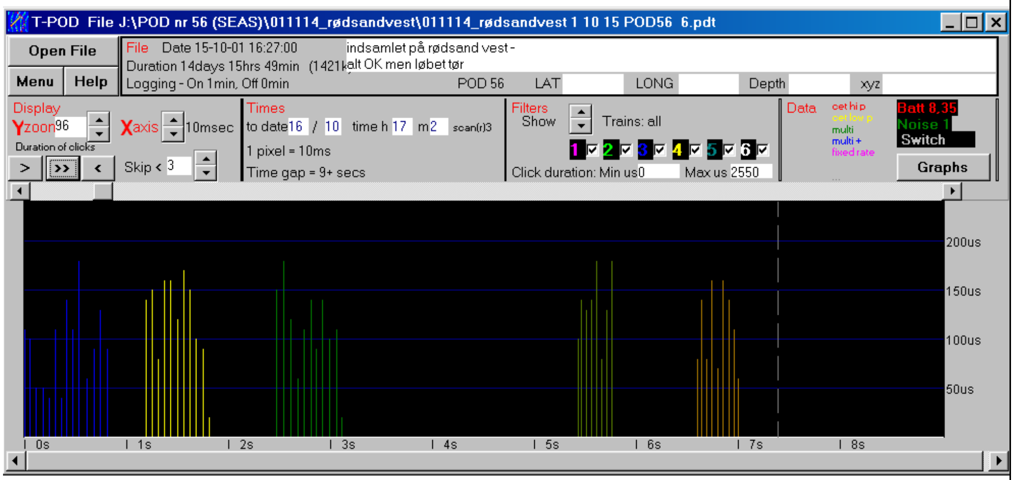
Figure 7: T-POD being attached to the anchoring system. The Kevlar line is reinforced with rubber tubing and a PVC foam float is attached at the top of the T-POD to increase the buoyancy (see appendix 3 for sketch).

Figure 8: T-POD about to be deployed at position AT_5 in the OWEZ

2.3.5 Analysis of T-POD data

Following recovery of the T-PODs, data logged were downloaded to a PC while still on board. Figure 8 shows an example of downloaded data. Harbour porpoise echolocation clicks were extracted from the background noise using a filtering algorithm that filters out non-porpoise clicks such as cavitation noise from boat propellers, echo sounder signals and similar high frequency noise. This filter has several classes of confidence of which the second highest class ("cetaceans all") was used. Version 8.17 of the software "tpod.exe" was used to analyse all data collected from both T_0 and T_1. See (Kyhn et al. 2008) for details on the filtering. Data were exported in ASCII format for statistical analysis after filtering.

Figure 9. Screen snapshot from the T-POD.exe program. Five series of porpoise clicks can be seen as vertical bars. Time in seconds is shown on the X-axis, and the duration of each click is shown on the Y-axis.



2.3.5.1 Echolocation activity indicators

In line with previous studies (Carstensen et al. 2006, Tougaard et al. 2006a, Tougaard et al. 2006b, Teilmann et al. 2009), four indicators were extracted from the exported T-POD data, which had the fundamental unit of clicks per minute. This signal, denoted x_t, describes the recorded number of clicks per minute and consisted of many zero observations (minutes without clicks). The click activity was aggregated into daily values of:

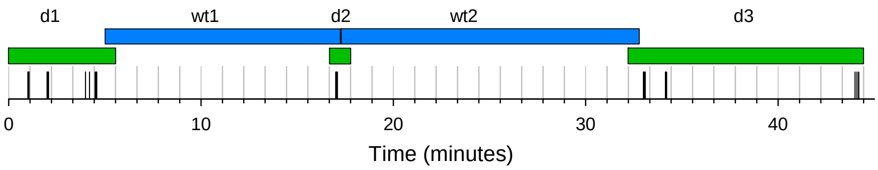
$$\text{PPM} = \text{Porpoise Positive Minutes} = \frac{\text{Number of minutes with clicks}}{\text{Total number of minutes}} = \frac{N\{x_t > 0\}}{N_{total}}$$

$$\text{clicks per PPM} = \frac{1}{N\{x_t > 0\}} \sum_{x_t > 0} x_t$$

PPM is expressed as a percentage and thus indicates the fraction of the day (out of 1440 minutes for a full day of recordings) wherein one porpoise click train or more could be detected. *Clicks per PPM* on the other hand indicates the daily average number of clicks *in minutes where clicks were detected.*

Another approach in analysis is to consider the recorded click as a point process, i.e. separate events occurring within the monitored time span. Therefore x_t was considered a sequence of porpoise encounters within the T-POD range of detection separated by silent periods without any clicks recorded. Porpoise clicks were often recorded in short-term sequences consisting of both minute observations with and without clicks. Such short-term sequences were considered to belong to the same encounter although there were also silent periods (minutes without clicks) within the sequence. In line with previous studies a silent period of 10 minutes was used to define two encounters as being separate from each other. Thus, two click recordings separated by a 9 minute silent period would still be part of the same encounter, whereas 10 silent minutes would yield the minimum waiting time of 11 minutes, i.e. the time between the midpoints of the two porpoise positive minutes defining the end and start of the encounters before and after the waiting time, respectively. A schematic example is shown in Figure 10.

Figure 10. Schematic illustration of encounter durations (green) and waiting times (blue) for a sequence of click trains.



Converting the constant frequency time series into a point process resulted in two new indicators for porpoise echolocation activity.

Encounter duration = Number of minutes between two silent periods

Waiting time = Number of minutes in a silent period >10 minutes

The definition of waiting time implies that it has a natural lower bound of 11 minutes, and that encounters potentially include minutes without clicks. Encounter duration and waiting times were computed from data from each T-POD deployment, individually identifying the first and last encounters and the waiting times in-between. Consequently, each deployment resulted in one more observation of encounter duration, since the silent periods at beginning and end of deployment were truncated (interrupted) observations of waiting times. Encounter duration and waiting time observations were temporally associated with the time of the midpoint observation, i.e. a silent period starting 30th September at 12:14 and ending 1st October at 1:43 was associated with the mean time of 30th September 18:59 and categorised as a September observation.

2.3.5.2 Statistical design and model

First, differences between the two T-POD types (v3 and v5) were investigated in a paired analysis of the two daily indicators (clicks per PPM and PPM) using only deployments days, where both types had been in operation for an entire day at the same position. As the T-PODs in some cases were started at different times and in all cases ended logging at different times of the day, only indicators from days with a complete dataset (24 hours) were used in the comparison.

The indicators, derived from different types of T-PODs at the same station and date, were related by means of least squares regression to investigate if the two types of T-PODs recorded comparable echolocation activity. A few observations, 1 for clicks per PPM and 3 for PPM, were identified as outliers and excluded from the regression analysis. A similar comparative analysis could not be carried out for encounter duration and waiting time, because observations of these indicators can not be paired over time in the same manner as clicks per PPM and PPM, i.e. between the two T-POD types encounters and waiting times do not always match across time.

Second, the indicators were analysed according to a modified Before-After Control-Impact (BACI)-design (Green 1979) that included station-specific and seasonal variation as well. Variation in all four indicators reflecting different features of the same porpoise echolocation activity were assumed to be potentially affected by the following factors (5 fixed and 3 random) and combinations thereof:

- *Area* (fixed factor with 2 levels: *impact* and *control*) describes the spatial variation between control areas and impact area (wind farm).
- *Subarea(area)* (fixed factor with 3 levels: *control N, control S* and *impact*) describes the spatial variation between the three areas. As this factor is nested within *area*, it describes differences between the two control areas *control N* and *control S*.
- *Station (area subarea)* (random factor with 8 levels: *AT1-AT8*) describes the station-specific variation (variation among stations) within each of the three areas.
- *Period* (fixed factor having 2 levels: T_0 and T_1) describes the difference between baseline and operation period.
- *Year(period)* (random factor with 5 levels: *2003, 2004, 2007, 2008, 2009*) describes the variation between years within the two periods T_0 and T_1.
- *Month* (fixed factor with 12 levels: *Jan-Dec*) describes the seasonal variation by means of monthly values.
- *Podtype* (fixed factor with 2 levels: v3 and v5) describes the difference between v3 and v5 T-PODs.
- *Podid* (random factor with 20 levels: serial number of T-POD) describes the random variation between different T-PODs for v3 and v5 separately.

Four of the fixed factors (main factors *area*, *period*, *month* as well as nested factor *subarea(area)*), and their 7 interactions, describe the spatial-temporal variation in the echolocation activity, whereas *podtype* describes a potential monitoring bias from replacing v3 with v5 T-PODs. The use of different T-POD versions was assumed not to interact with the spatial-temporal variation, and consequently interactions between *podtype* and all the spatial-temporal components (first 6 factors in the list above) were disregarded in order to limit the model. Thus, variations in the echolocation indicators, after appropriate transformation, were assumed to be normal-distributed with a mean value described by the equation:

$$\begin{aligned}\mu_{ijklm} &= area_i + subarea(area)_{j(i)} + period_k + area_i \times period_k + subarea(area)_{j(i)} \times period_k \\ &+ month_l + area_i \times month_l + subarea(area)_{j(i)} \times month_l + period_k \times month_l \\ &+ area_i \times period_k \times month_l + subarea(area)_{j(i)} \times period_k \times month_l + podtype_m\end{aligned} \quad (1)$$

where subscripts *i, j, k, l* and *m* indicates the various levels of *area, subarea, period, month* and *podtype,* respectively.

Random effects of the model included *station(area subarea)* and *year(period)* and their interactions with the fixed factors in (1) as well as *podid(podtype)* that has a version-specific variance, i.e. captures a difference in magnitude of variation between T-PODs for v3 and v5.

The temporal variation in the indicators was assumed to follow an overall fixed seasonal pattern described by monthly means, but fluctuations in the harbour porpoise density in the region on a shorter time scale may potentially give rise to serial correlations in the observations. For example, the waiting time following a short waiting time is likely to be short as well. Similar arguments can be proposed for the other indicators. In order to account for any autocorrelation in the residuals we formulated a covariance structure for the random variation by means of an ARMA(1,1)-process (Chatfield 1984) subject to observations within separate deployments, i.e. complete independence was assumed across gaps in the time series.

Transformations, distributions and back-transformations were selected separately for the different indicators by investigating the statistical properties of data. The data comprised an unbalanced design, i.e. uneven number for the different combinations of factors in the model, and arithmetic means by averaging over groups within a given factor may therefore not reflect the "typical" response of that factor because they do not take other effects into account. Typical responses of the different factors were calculated by marginal means (Searle et al. 1980) where the variation in other factors was taken into account.

Table 2: List of transformation, distributions and back-transformation employed on the four indicators for harbour porpoise echolocation activity.

Indicator	Transformation	Distribution	Back-transformation
Clicks per PPM	Logarithmic – log(y)	Normal	$\exp(\mu + \sigma^2/2)$ [1]
PPM	Angular – $\sin^{-1}(\sqrt{y})$	Normal	Table 6 (Rohlf & Sokal 1981)
Encounter duration	Logarithmic – log(y)	Normal	$\exp(\mu + \sigma^2/2)$ [1]
Waiting time	Logarithmic – log(y-10)	Normal	$\exp(\mu + \sigma^2/2)+10$ [1]

[1]The back-transformation of the logarithmic transformation can be found in e.g. (McCullagh & Nelder 1989), p. 285.

Waiting times had a natural bound of 11 minutes imposed by the encounter definition, and we therefore subtracted 10 minutes from these observations before taking the logarithm in order to derive a more typical lognormal distribution. Applying the log-transformation had the implication that additive factors as described in Eq. (1) were multiplicative on the original scale. This meant that e.g. the seasonal variation was described by monthly scaling means rather than by additive means. Variations in the four indicators were investigated within the framework of generalised linear mixed models (McCullagh & Nelder 1989), and the significance of the different factors in Eq. (1) was tested using F-test (type III SS) for the normal distribution (SAS Institute 2003).

The factor $area_i \times period_k$, also referred to as the BACI effect, describes a step-wise change (from T_0 to T_1) in the wind farm different from that in the control areas. A significant BACI effect implies that changes in activity in the wind farm area from T_0 to T_1 differ from changes in the control area. In other words a significant BACI effect implies that changes in the wind farm area cannot be explained alone by general changes from T_0 to T_1 in the complete study area but must be ascribed to the impact (i.e. the presence of the wind farm).

The switch from v3 to v5 T-PODs during T_1 could potentially introduce a bias into the BACI design. It was possible to test for a general change in sensitivity from v3 to v5 (*podtype*), but since sensitivity is specific to the T-POD deviations from a general pattern could be expected. It was not possible to include a factor describing specific differences in sensitivity for each replacement of v3 with v5, particularly if the expected difference was scale-dependent and not strictly additive. Differences in sensitivity were expected to yield different, however proportional, responses that for indicators with a log-transformation (Table 2) would correspond to an additive term, but for PPM a multiplicative factor was expected. Moreover, there were simultaneous deployments of v3 and v5 at 5 stations only, suggesting that a general intercalibration pattern should be identified to assess the overall effect for all stations. Therefore, periods with simultaneous deployments of v3 and v5 were selected for an intercalibration analysis. The two indicators with a daily resolution, PPM and Click per PPM, were paired by date and compared through regression analyses. For the two other indicators such pairing could not be carried out, and therefore the distributions of encounter duration and waiting time were analysed in relation to factors *podtype* and *station* as well as their interaction *podtype*×*station*. Based on the results from these analyses a new data set with the four indicators for T-POD v5 recalculated into T-POD v3 indicator values was computed. The BACI analysis was carried out for both the non-intercalibrated and the intercalibrated data sets.

The statistical analyses were carried out within the framework of mixed linear models (Littell et al. 1996) by means of PROC MIXED in the SAS system. Statistical testing for fixed effects (F-test with Satterthwaite approximation for denominator degrees of freedom) and random effects (Wald Z) were carried out at a 5% significance level (Littell et al. 1996). The F-test for fixed effects was partial, i.e. taking all other factors of the model into account, and non-significant factors were removed by backward elimination and the model re-estimated. Only the final models, after eliminating all non-significant factors, are presented in the results.

2.4 Ship based surveys

A detailed description of the visual surveys for birds can be found in Leopold et al. 2004 and 2009. An overview of all conducted surveys is given in table 3. All porpoise sightings were recorded. Ship groundspeed was kept at approximately 10 knots and this was constantly monitored by a portable GPS. The ships positions were logged every 5 minutes and mid-positions of individual 5 minutes calculated. Porpoises were counted in two (left and right, conditions permitting) or one (left or right) strips adjacent to the ship, following Tasker et al. (1984) and Camphuysen & Garthe (2001).

Table 3: Overview over all visual surveys conducted during T_0 and T1

Phase	**Survey work**	Phase	**Survey work**
T_0	September 23-27, 2002	T_1	April 9-11, 2007
T_0	October 21, 22, 24, 2002	T_1	June 27-29, 2007
T_0	April 07-11, 2003	T_1	August 19-22, 2007
T_0	May 19-23, 2003	T_1	September 24-27, 2007
T_0	June 23-27, 2003	T_1	November 20-24, 2007
T_0	August 11-15, 2003	T_1	January 14, 16-18, 2008
T_0	November 04-07, 2003	T_1	April 7-10, 2008
T_0	February 16-19, 2004	T_1	June 23-26, 2008
		T_1	August 11-14, 2008
		T_1	January 19-22, 2009
		T_1	April 6-9, 2009

2.5 Comparison of data derived from T-PODS and visual observations

Monitoring programs using T-PODs and survey programs are in some sense orthogonal investigations that supplement each other well and with almost no redundancy. Surveys thus have high spatial resolution, but poor temporal resolution, whereas the situation is exactly the opposite for T-PODs (low spatial and very high temporal resolution).

Because of the reasons described earlier (section 2.1) we did not perform direct quantitative comparisons of the results of the T-POD data with the survey data. We will describe some of the results from the ship surveys and compare the data qualitatively with the T-POD results, looking for similar trends during seasons.

3 Results

3.1 Effort

3.1.1 Monitoring effort

Monitoring effort in T_0 started in June 2003 and ended in May 2004. In T_1 first deployments were made in April 2007 and the last T-PODs were recovered in April 2009. Figure 11 gives an overview of the data collected at the different stations. An overview of all dates of T-POD exchange is given in Appendix 1.

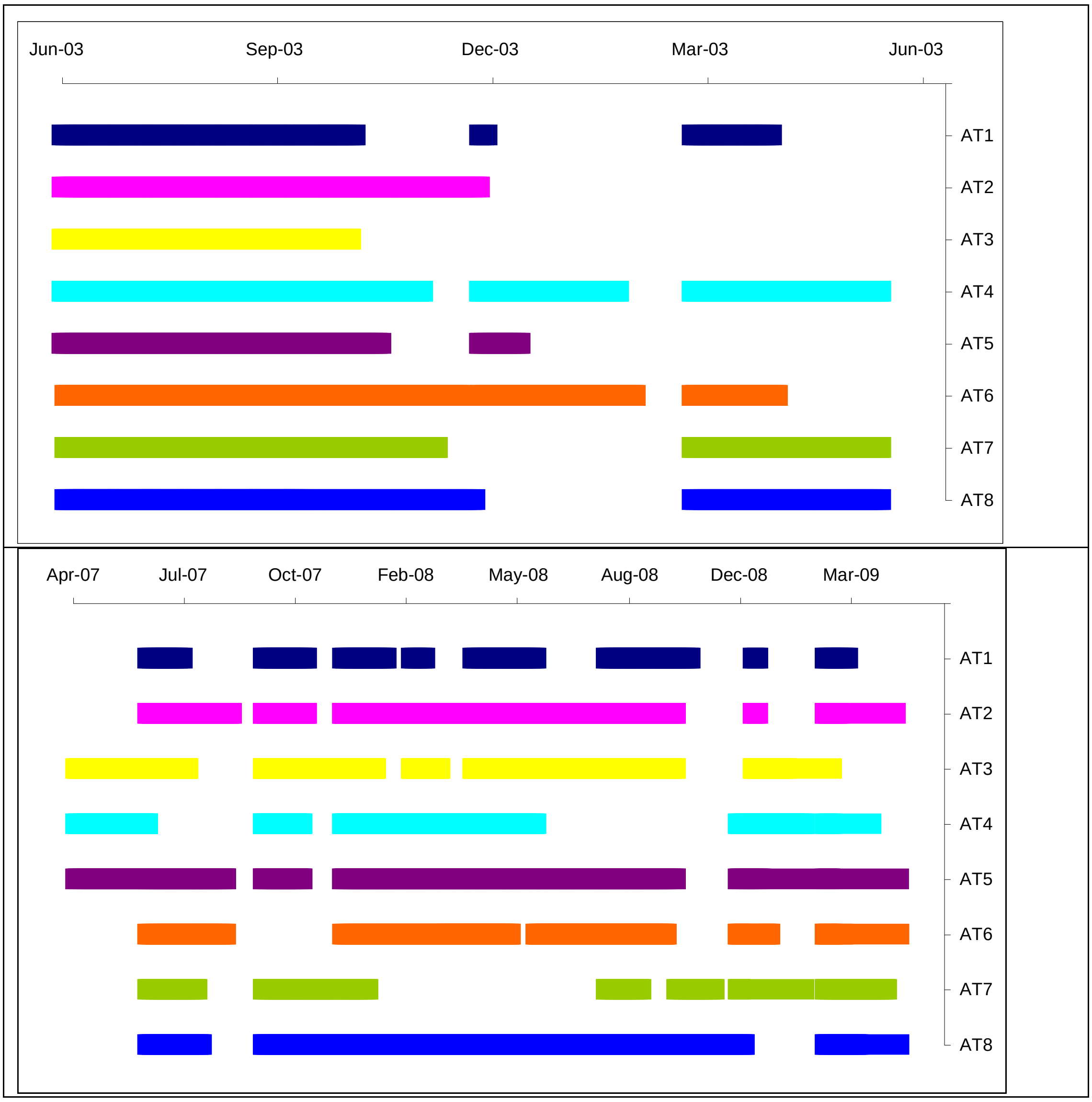


Figure 11. Monitoring effort at the stations AT1-AT8 during T_0 (A) and T_1 (B). During parts of T_1 two T-PODs of different versions were deployed simultaneously on some stations. Details can be found in appendix 1.

3.1.2 Logistical problems

Periods without data (Figure 11) were due to various logistical issues and included loss of T-PODs, T-POD failure and full memory of T-PODs. In the beginning of the study a number of T-PODs were lost from their anchoring system.

Some of the losses could be ascribed to T-PODs being pushed down near the bottom for several days by strong currents in bad weather situations. While pushed horizontally onto the sea floor, the line connecting the T-POD to the weight was wearing through. To solve this problem the rope was changed to a Kevlar rope with a rubber tubing around it. Additionally a PVC foam float was added to the top of the T-POD. The upper edge of the float was attached 9 cm below the top of the T-POD in a way to avoid interference with the hydrophone (see figure 7 and 8 & appendix for detailed sketch). Although the air filled float probably generated additional echoes which could potentially interfere with detection, the fact that the housing itself is air-filled and thus generates strong echoes in any case makes it less likely that the sensitivity of T-PODs were changed significantly by the floats. The adaptation of this design allowed the T-POD to hang vertically in the water column and reduced the losses of equipment substantially. The new design was first implemented in December 2007 and subsequently all used T-PODs were equipped with the new design when deployed.

Additionally, in at least two cases fishing operations were interacting directly with the anchoring system, partly damaging the buoys and/or ripping off the T-PODs from their anchor stone. Whenever losses of T-PODs occurred the T-POD itself was generally found within the next months and retrieved by IMARES. In many cases usable data could be retrieved from the salvaged units.

A different source of data loss was battery loss. This was either occurring because batteries were drained faster than expected (e.g. colder weather), or because rough weather caused connections within the T-POD to loosen and stop the energy supply. Additionally, particularly during longer periods of storms, more acoustic signals were recorded by the T-PODs because of an increase in underwater noise. This caused the memory to fill up earlier than expected. To respond to this we increased the servicing trips during the winter months when weather permitting.

Even with some loss of recording time, the amount of data collected by the T-PODs was sufficient to detect changes in the occurrence of harbour porpoises in the study area with the desired statistical power (see Brasseur et al. 2004).

3.2 Stationary T-POD data

There was a total of 5624 active station days with T-POD monitoring data. One active station day is one day of data from one station. The maximal data that could have been collected was thus 8 x 365 station-days per year or about 8700 potential station days for the entire period. In reality, data for 65% of the potential station days were collected, with more than twice as many active station days during T_1 (n=3903) than during T_0 (n=1721). The area Control S had the highest number of active station days (n=2221), followed by Control N (n=1797). The wind farm area with its two stations had the least number of active station days (n=1606). The data was relatively evenly distributed across the 8 positions ranging from 458 station days at AT1 to 862 station days at AT8. A total of 2565 station days were recorded with v3 T-PODs (46%) and 3059 station days were recorded with v5 T-PODs (54%), and of these 124 station days had simultaneous recordings on the two types at the same position.

3.2.1 Porpoise acoustic activity

Based on the number of clicks per minute the indicators PPM (porpoise positive minutes) and clicks per PPM were calculated (*Figure 12*, *Table 4*), as was the indicators encounter duration and inter-encounter waiting time (*Figure 13*,

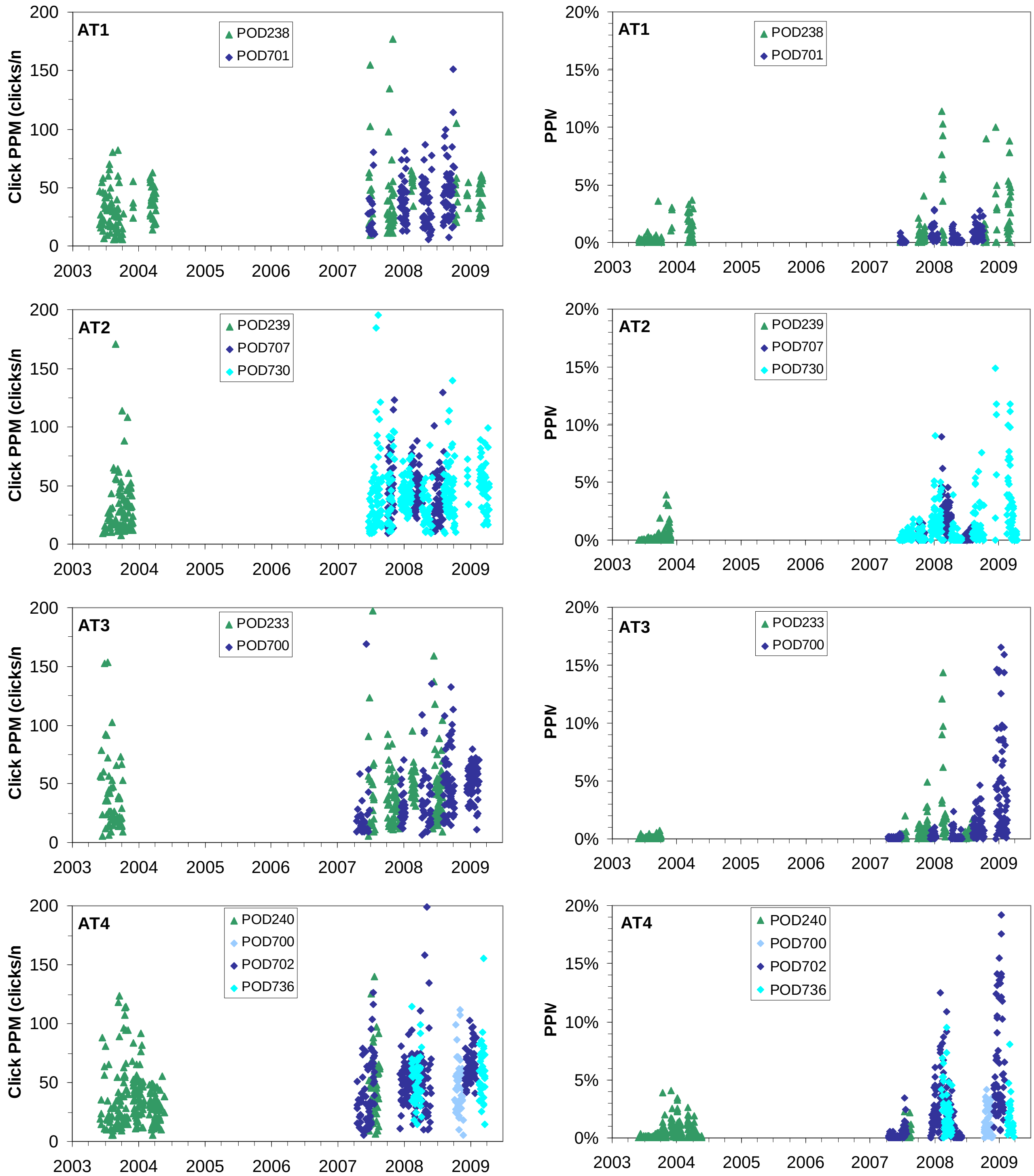
Table 5: Statistics of encounters and waiting times monitored in the baseline and operation periods at Offshore Wind farm Egmond aan Zee.

). Clicks per PPM could be calculated for 4179 station-days daily values of e.g. number of days with click recordings. 26% of the deployment days were silent, most of these occurred between May and August. Temporal variations and variation between positions and PODs were relatively smaller for clicks per PPM compared to PPM (*Table 4*). For the two periods and the 8 positions the coefficients of variation varied between 43% and 119% for clicks per PPM and between 141% and 268% for PPM.

Encounter duration (n=26519) and waiting time between encounters (n=26423) were calculated from the POD data (*Figure 13*,

Table 5: Statistics of encounters and waiting times monitored in the baseline and operation periods at Offshore Wind farm Egmond aan Zee.

). The two control areas (Control N and S) each had about 7000-8000 encounters and waiting times, whereas the impact area had almost 11000. The numbers of encounters and waiting times across the 8 positions ranged from ~1900 at AT1 to ~5800 at AT5 (Table 4). There were about six times as many encounters and waiting times during operation compared to baseline, i.e. higher activity than could be accounted for simply by the larger number of stations days during operation (*Table 4*). For the 2 periods and 8 positions the relative variation in encounter duration (CV=123-259%) and waiting time (138-351%) was larger than for the clicks per PPM but similar to PPM, however, there was also more than four times as many observations. Both duration and waiting time distributions were strongly skewed to the right with observations exceeding 1 hour for encounter duration and 5 days for waiting time (*Figure 13*).


Click PPM (clicks/n
PPM
AT1
POD238
POD701
AT2
POD239
POD707
POD730
AT3
POD233
POD700
AT4
POD240
POD700
POD702
POD736
0
50
100
150
200
0%
5%
10%
15%
20%
2003
2004
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2006
2007
2008
2009

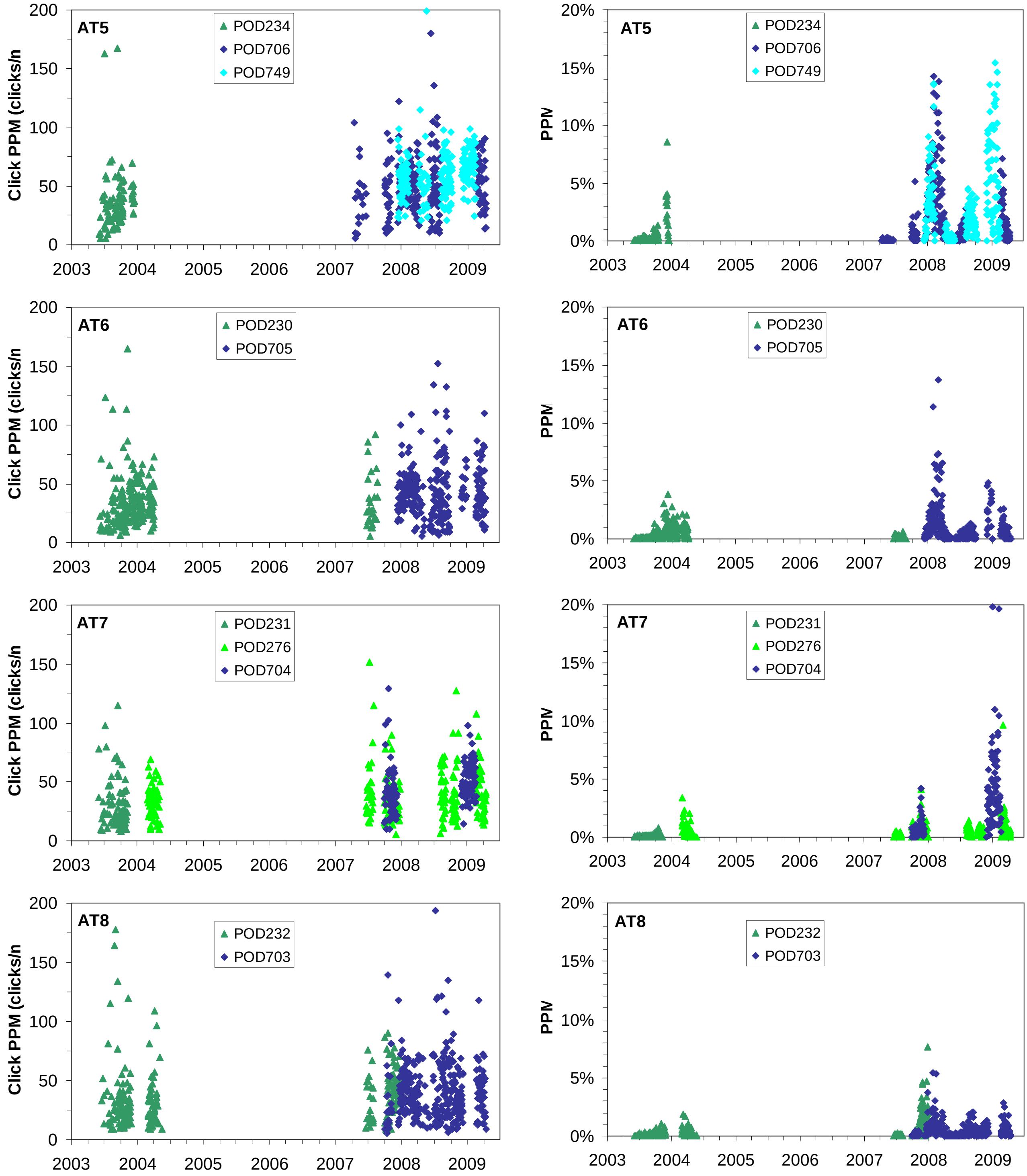


Figure 12: Clicks per PPM (left panel) and PPM (right panel) extracted from T-POD data collected at Offshore Wind farm Egmond aan Zee during baseline (June 2003 – May 2004) and operation (June 2007 – March 2009). Different symbols and colours mark observations derived from different T-PODs (green triangles = v3, blue diamonds = v5). A few clicks per PPM estimates (11 observations) and PPM estimates (4 observations) exceeded the plotting range (not shown).

Table 4: Statistics of the two daily indicators monitored in the baseline and operation periods at Offshore Wind farm Egmond aan Zee. Number of days with PPM is equal to the number of deployment days, whereas number of days with clicks per PPM can be less due to days without any click recordings (missing value of clicks per PPM).

Period	Area	Posi-tion	clicks per PPM (clicks/minute)					PPM (%)				
			N	Min	Median	Mean	Max	N	Min	Median	Mean	Max
Baseline	Control N	AT1	105	5.6	31.7	32.6	82	151	0	0.14	0.48	3.7
		AT2	95	7.8	26.7	36.3	261	183	0	0.07	0.20	3.9
	Impact	AT3	67	5.6	26.7	45.4	370	127	0	0.07	0.09	0.8
		AT4	197	5.6	31.1	35.9	123	304	0	0.07	0.35	4.0
		AT5	87	5.6	33.9	37.5	168	159	0	0.07	0.37	8.5
	Control S	AT6	195	6.1	31.9	35.1	165	287	0	0.14	0.43	3.8
		AT7	138	7.8	29.7	32.0	115	247	0	0.07	0.21	3.4
		AT8	139	8.9	26.7	35.2	278	263	0	0.07	0.17	1.9
Operation	Control N	AT1	259	5.6	39.1	41.7	177	307	0	0.28	0.91	11.4
		AT2	452	8.9	41.6	44.5	196	543	0	0.42	1.12	14.9
	Impact	AT3	384	5.6	40.1	43.6	253	486	0	0.21	1.16	15.5
		AT4	464	5.6	52.4	53.0	499	539	0	0.90	1.95	24.5
		AT5	512	5.6	54.7	55.6	228	604	0	1.11	2.39	25.1
	Control S	AT6	305	5.6	40.3	43.8	262	417	0	0.21	0.85	20.5
		AT7	343	5.6	39.8	44.0	320	408	0	0.49	1.28	8.1
		AT8	437	5.6	37.7	40.7	193	599	0	0.21	0.48	7.6

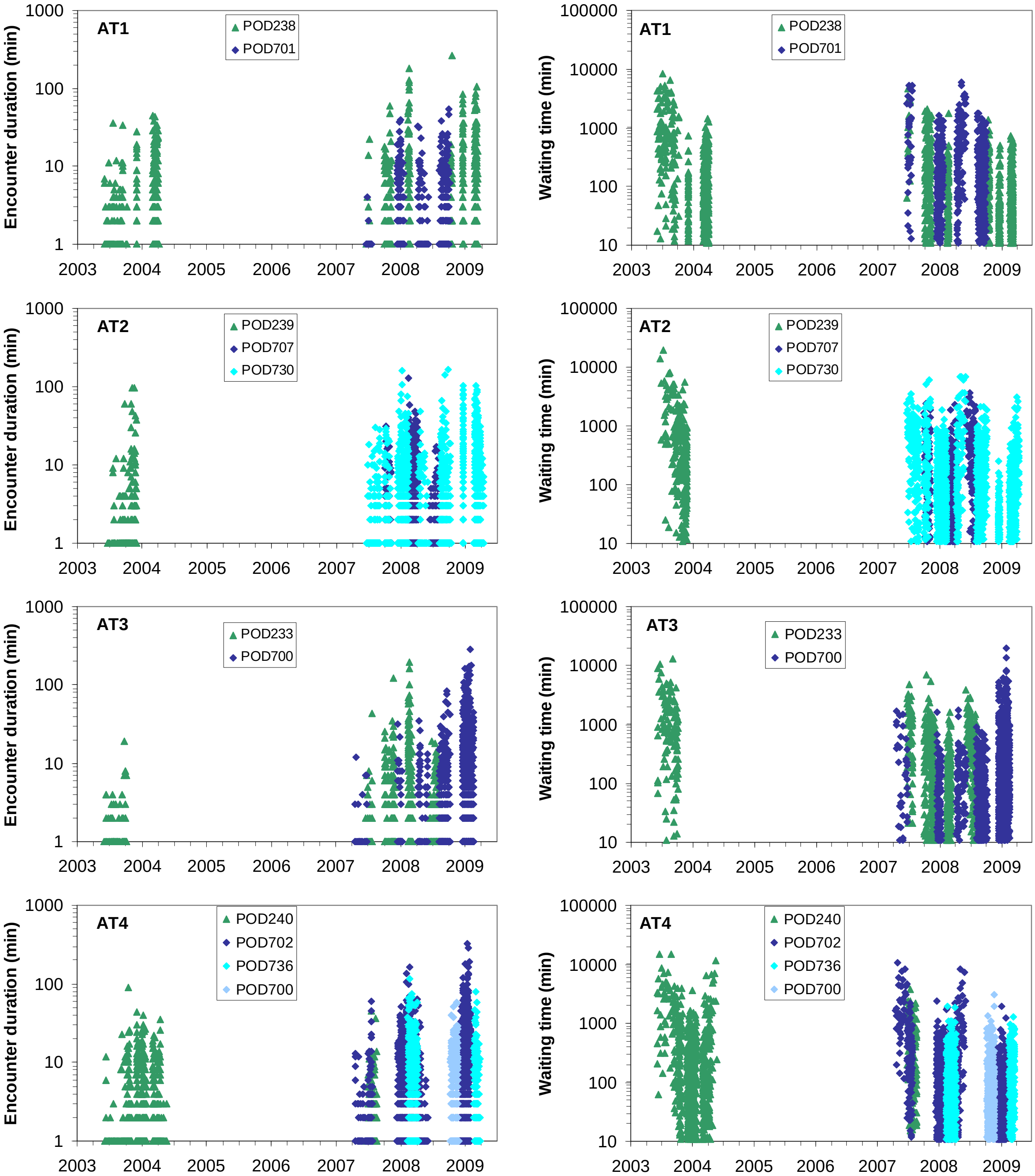
Encounters were on average 81% longer during operation than during the baseline period, whereas waiting times in the operation period were only 35% of those observed during the baseline. This observed increase in T-POD acoustic indicators can be due to an overall change in presence and behaviour between T_1 and T_0, the shift from v3 to v5 T-PODs and changes in the months of monitoring between the two periods. Spatial differences were also apparent from the observations (*Figure 13*,

Table 5: Statistics of encounters and waiting times monitored in the baseline and operation periods at Offshore Wind farm Egmond aan Zee.

), but due to seasonal variation combined with differences in the months covered by the monitoring and the employment of two different T-POD versions during the operation period the statistics given in

Table 5: Statistics of encounters and waiting times monitored in the baseline and operation periods at Offshore Wind farm Egmond aan Zee.

cannot be compared without resolving all the different sources of variation. These different sources of variation are partitioned out in the statistical analysis of the encounter statistics.


AT1
POD238
POD701
Encounter duration (min)
Waiting time (min)
AT2
POD239
POD707
POD730
AT3
POD233
POD700
AT4
POD240
POD702
POD736
POD700
1
10
100
1000
10000
100000
2003
2004
2005
2006
2007
2008
2009

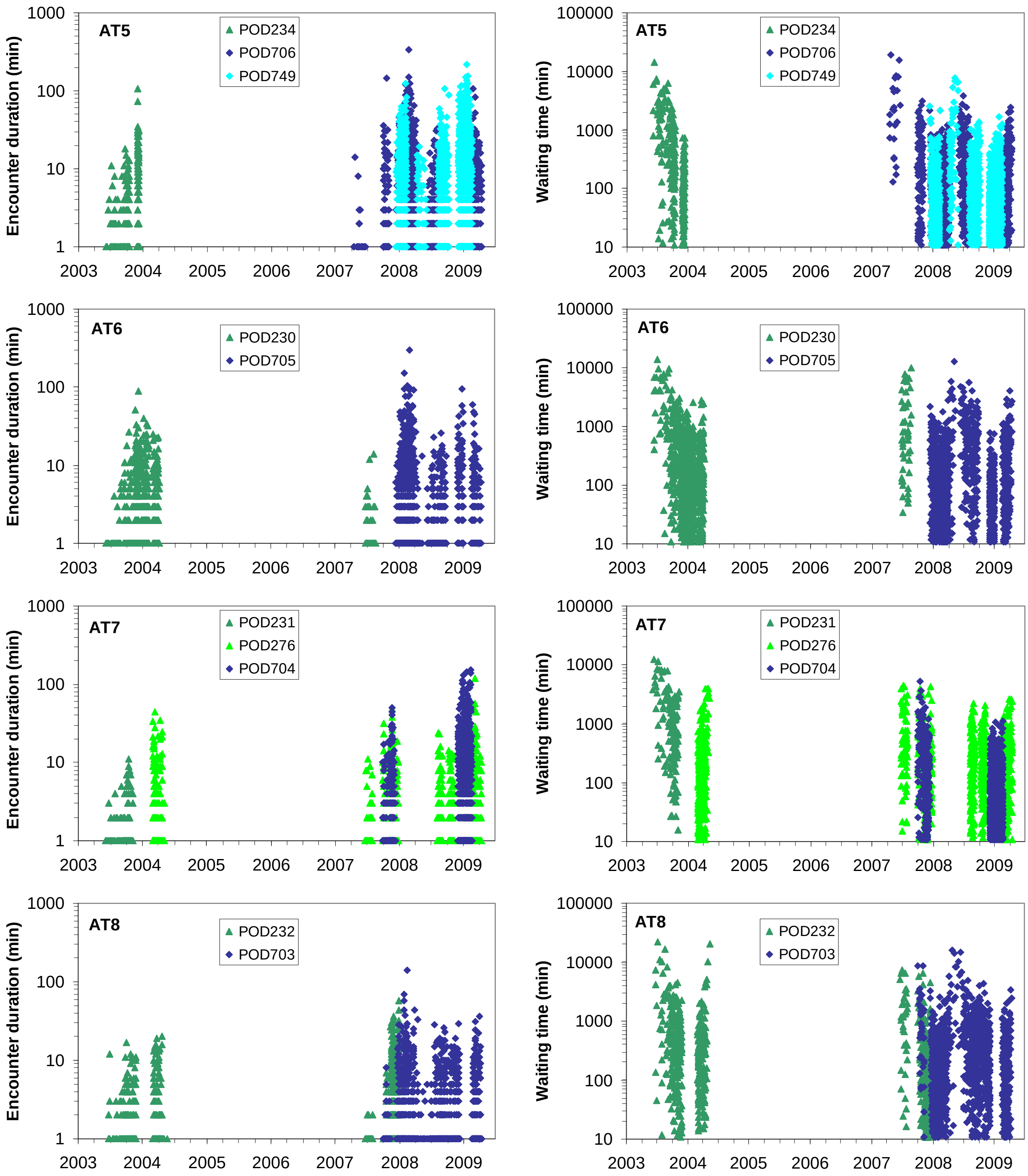


Figure 13: Encounter duration (left panel) and waiting time (right panel) extracted from T-POD data collected at Offshore Wind farm Egmond aan Zee during baseline (June 2003 – May 2004) and operation (June 2007 – March 2009). Different symbols mark observations derived from different T-PODs (green triangles = v3, blue diamonds = v5). Note the log-scale on the y-axis.

Table 5: Statistics of encounters and waiting times monitored in the baseline and operation periods at Offshore Wind farm Egmond aan Zee.

Period	Area	Posi-tion	Encounter duration (minutes)					Waiting time (minutes)				
			N	Min	Median	Mean	Max	N	Min	Median	Mean	Max
Baseline	Control N	AT1	496	1	1	4.1	45	492	11	101	420	8510
		AT2	242	1	1	4.5	97	241	11	354	972	19290
	Impact	AT3	116	1	1	1.7	19	115	11	794	1534	13212
		AT4	750	1	1	3.8	91	746	11	146	557	14968
		AT5	312	1	1	5.2	108	310	11	156	678	14635
	Control S	AT6	879	1	1	3.9	88	876	11	152	446	14132
		AT7	408	1	1	3.2	44	406	11	238	793	12258
		AT8	403	1	1	2.6	20	401	11	299	853	22068
Operation	Control N	AT1	1416	1	1	6.0	264	1404	11	100	285	6057
		AT2	3089	1	2	6.1	166	3077	11	75	230	6946
	Impact	AT3	2301	1	1	7.6	287	2290	11	70	282	16105
		AT4	4270	1	3	7.4	329	4260	11	56	169	10597
		AT5	5501	1	3	8.1	332	5491	11	49	145	19148
	Control S	AT6	1775	1	1	6.1	299	1767	11	80	303	13058
		AT7	2538	1	2	6.3	152	2529	11	71	209	5281
		AT8	2023	1	1	3.7	142	2018	11	135	408	15812

3.2.1.1 Seasonal variation

There was a distinctive seasonal pattern for PPM in both the baseline period and operation period, but there appeared to be no seasonal pattern for clicks per PPM (*Figure 14*). Clicks per PPM was on average 28% higher during operation than during the baseline period, whereas PPM was almost 4 times higher during operation. This increase could be due to the same reasons as mention in the previous section. Spatial differences were also apparent from the observations (*Figure 12*, *Table 4*), but due to seasonal variation combined with differences in the months covered by the monitoring and the employment of two different T-POD version during the operation period the statistics, given in *Table 4*, cannot be compared without resolving all the different sources of variation. These different sources of variation will be partitioned out in the statistical analysis of the daily indicator observations.

The baseline and operation periods had similar and distinctive seasonal patterns for encounter duration and waiting times (*Figure 15*). Encounters were shorter and waiting times longer in the summer months, whereas in winter, encounters were longer and waiting times shorter. This seasonal pattern corresponds to the observed pattern for PPM (*Figure 14*).

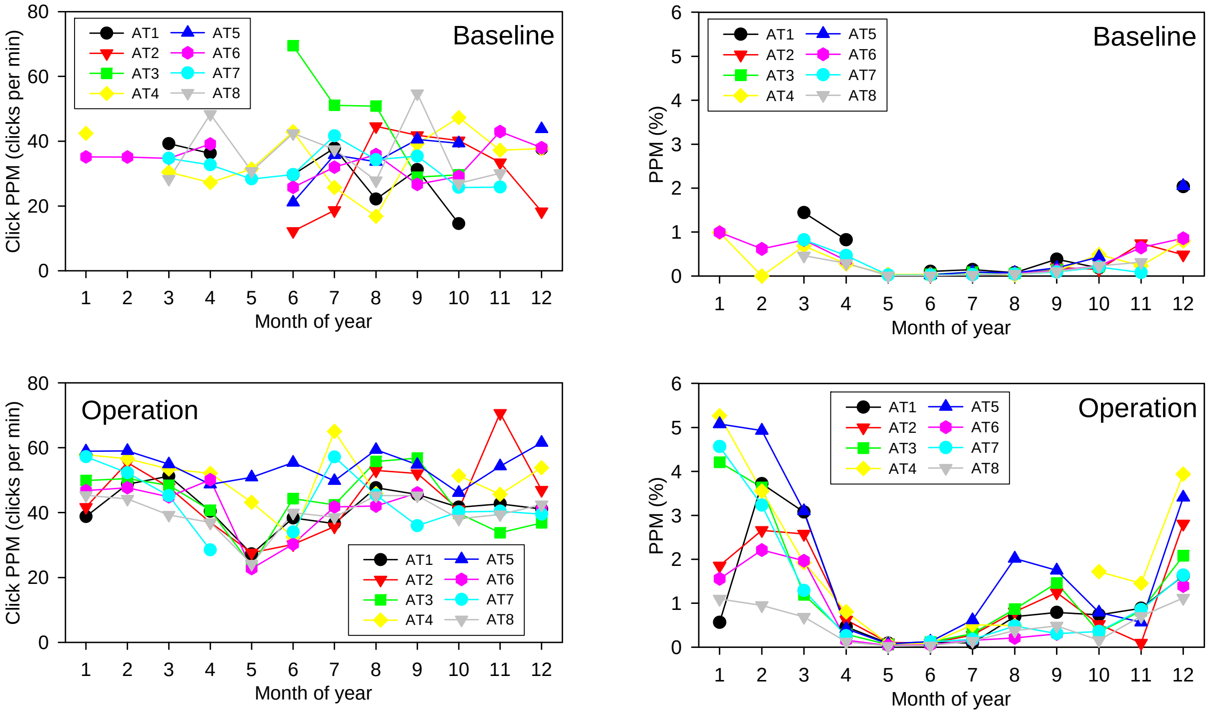


Figure 14: Monthly averages of clicks per PPM (left panel) and PPM (right panel) for the 8 stations during baseline and operation periods. The two stations in the impact area (AT4 and AT5) are red coloured, whereas area Control N and Control S are dark and light green, respectively.

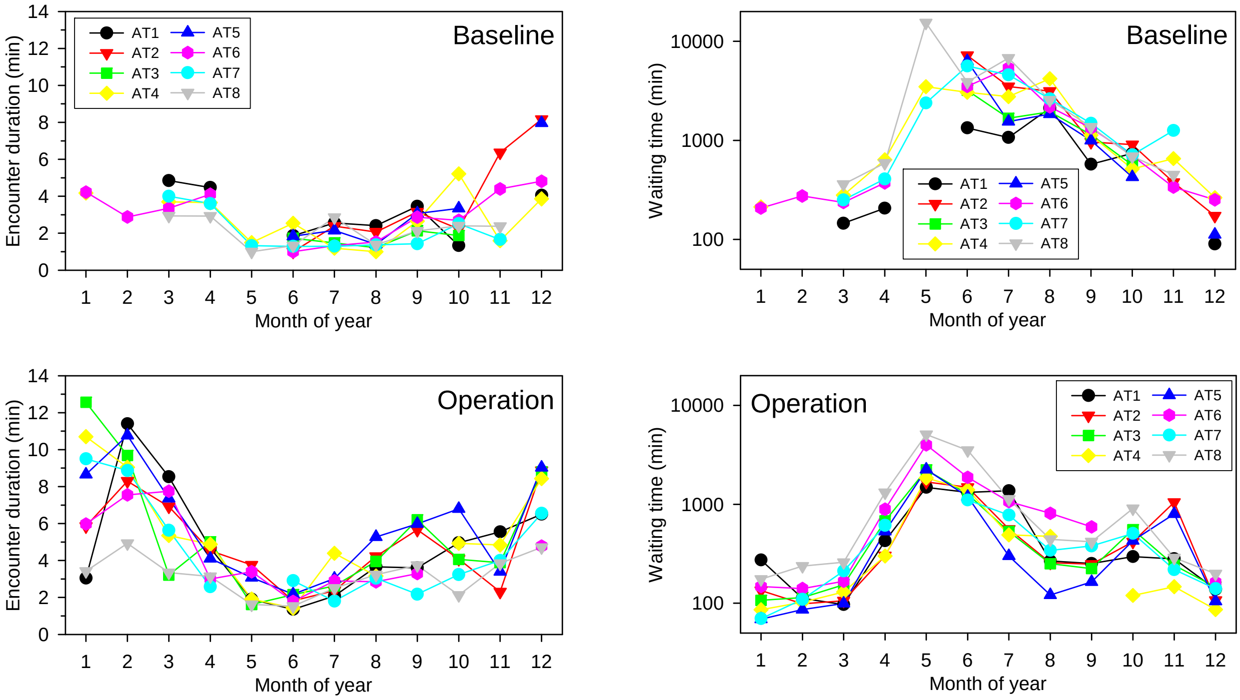


Figure 15: Monthly averages of encounter duration (left panel) and waiting time (right panel) for the 8 stations during baseline and operation periods. The two stations in the impact area (AT4 and AT5) are red coloured, whereas area Control N and Control S are dark and light green, respectively.

3.2.2 Differences across stations

Figure 16 shows the station-specific means for the four variables, separated into T_0 and T_1. Common to all stations is an increase in acoustic activity from T_0 to T_1, seen as an increase in mean PPM, clicks per PPM and encounter duration and a decrease in waiting time between encounters. Two other general effects are obvious. First, the increase in acoustic activity in the wind farm area (AT4 and AT5) appears greater than that in the control areas (AT1-AT3 and AT6-AT8). Secondly, the apparent east-west gradient in activity during T_0, with most activity at the off-shore stations (AT1 and AT6), is absent during the T_1.

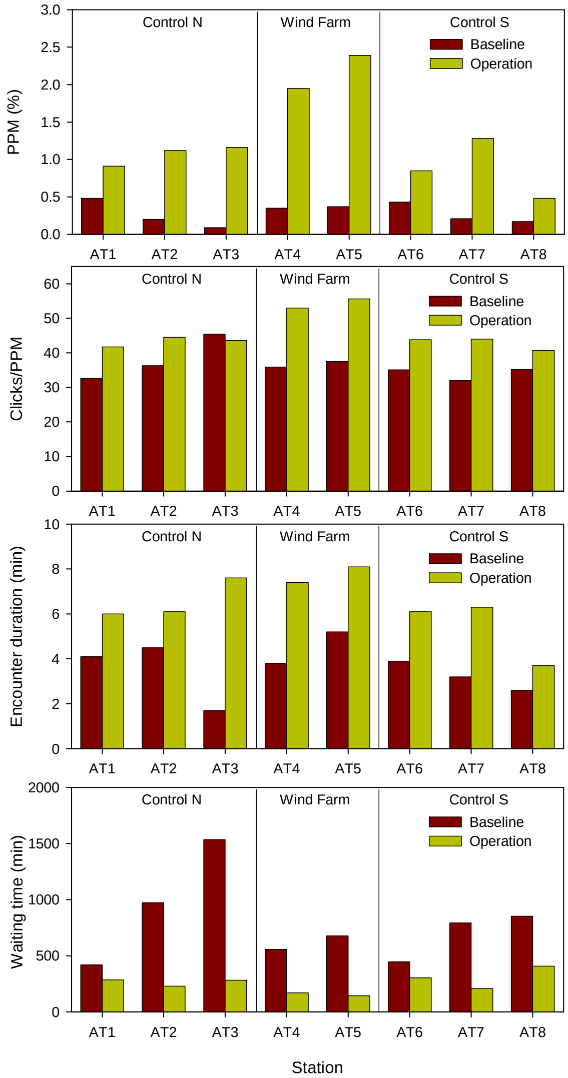


Figure 16. Station-specific averages of the four indicators. Stations within each area are ranked from west to east. PPM – Porpoise positive minutes per day; Click PPM – Click per porpoise positive minute per day

3.2.3 Intercalibration v3 vs. v5

On five positions (AT1, AT3, AT4, AT7 and AT8) two T-PODs of different types were deployed simultaneously for periods during T_1. The two different types of T-PODs (v3 and v5) could thus be intercalibrated by comparing their daily indicators. Two clicks per PPM observations at AT1 and AT4 obtained on the exact same day (July 1st 2007) gave very high v3 recording in a single minute (154 and 499 clicks per minute, cf. *Figure 12*) and much higher than what was obtained with the concurrent v5 T-POD (15.6 and 20.6 clicks per minute). Similarly, during 3 days within a week (December 2007 at AT8) high PPM was recorded with the v3 T-POD (>2.5%) and more moderate PPM (~0.5%), similar to the overall level for the period as a whole, were recorded with the v5 T-POD. These observations were considered outliers and excluded from the regression analysis.

Combining the clicks per PPM and PPM indicators by their days of monitoring for the 5 positions with two T-PODs deployed resulted in 116 indicator values for clicks per PPM and PPM. There were significant correlations between the indicator values obtained with the two types of T-PODs, and overall the slopes of the intercalibration curves were not significantly different from 1 when differences between pair of deployed T-PODs were not considered (Figure 17).

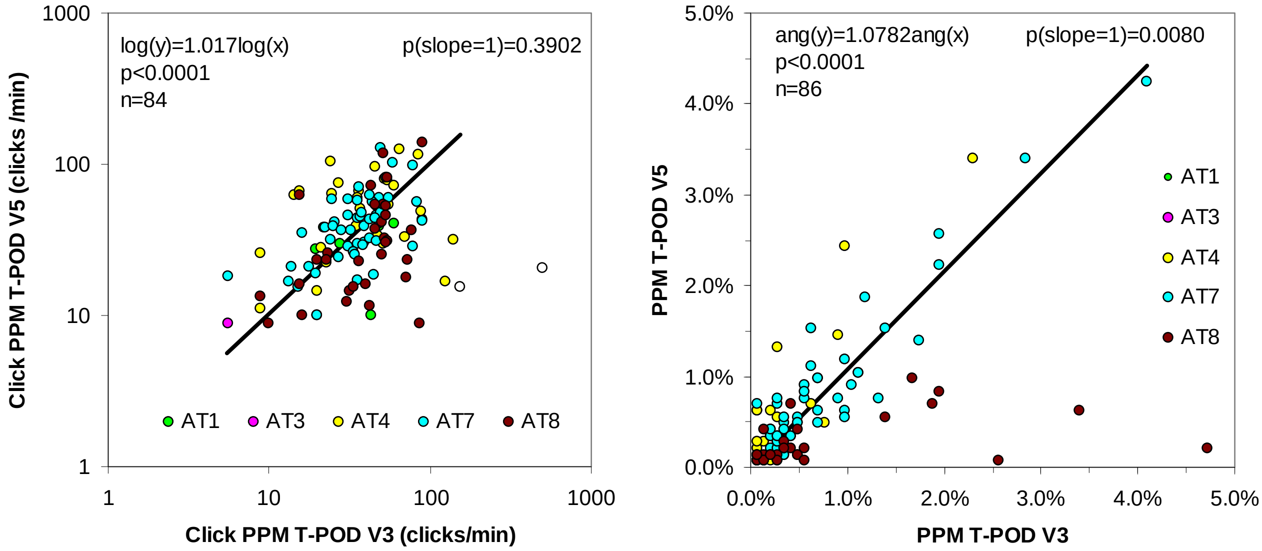


Figure 17: Intercalibration of v3 and v5 T-PODs by means of the daily indicators, clicks per PPM and PPM. Regressions were carried out on transformed variables (logarithmic transformation for Click PPM (clicks per PPM) and angular transformation for PPM) but are shown using the back-transformations. Observations from AT8 as well as two observations of clicks per PPM were excluded from the regressions as outliers (shown by open symbols).

However, since the T-POD sensitivity is specific to T-POD unit rather than the T-POD version, differences between v3 and v5 across stations was investigated. For clicks per PPM an additive difference was expected on the log-scale, and differences between v3 and v5 was analysed by means of a paired t-test for each station individually. There were no differences between the two T-POD versions at all stations except AT8 where v5 recorded 26% less clicks per PPM (t_{29}=2.24; P=0.0329).

There were no station-specific differences in the intercalibration slope ($F_{3,80}$=0.79; P=0.5015) for clicks per PPM, when data from AT8 were not included, and none of the individual slopes or common slope (Figure 17) were significantly different from 1 suggesting that the difference for clicks per PPM between v3 and v5 was generally small and that one of the T-PODs deployed at AT8 could have been malfunctioning.

For PPM there were significant differences among the station-specific slopes ($F_{4,108}$=11.61; P<0.0001), but this significant difference was entirely due to the observations from AT8. There were no significant differences among the station-specific slopes when excluding observations from AT8 ($F_{3,82}$=1.74; P=0.1654). PPM was significantly higher (~8%) for v5 than v3 when observations from AT8 were not included in the intercalibration regression (Figure 17).

For the days with simultaneous deployments of v3 and v5 T-PODs 1008 encounters and 1001 waiting times were recorded at the 5 positions. Differences between T-POD versions, positions and their interaction were investigated on the log-transform of encounters and waiting times by means of analysis of variance. Again, AT8 behaved completely different from the other positions and if observations from this position were excluded the interaction between position and T-POD version was not significant for neither encounters ($F_{3,772}$=0.60; P=0.6119) nor waiting time ($F_{3,766}$=0.90; P=0.4393). Without AT8 observations there was no difference in encounter duration between v3 and v5 ($F_{1,775}$=0.07; P=0.7980), whereas waiting times were longer for v3 (22%) although not significant at a 95% confidence level ($F_{1,769}$=2.76; P=0.0970). Thus, there is potentially a general bias towards v5 T-PODs being more sensitive that v3 T-PODs, except for AT8, where the opposite was the case.

3.2.4 BACI analyses (effect of wind farm)

The model for spatial-temporal variation as well as T-POD specific variation (Eq. 1) and an ARMA(1,1) correlation structure was computed for the 4 indicators. Only 6 out of the 12 fixed effects in Eq. (1) could significantly explain variation in the echolocation indicators (Table 6). For none of the four indicators the T-POD specific variation was found significant, neither as a systematic bias between v3 and v5 nor as a difference in the variation between T-PODs for the two versions. Although v5 yielded slightly higher echolocation activity than v3 in the models, the bias was not significant relative to the large overall residual variation, when the T-PODs were deployed in a natural environment. These results correspond to the general results (without station-specific intercalibration) obtained from the intercalibration of the two T-POD types on a reduced data set (Section 3.2.3). However, in the intercalibration analysis it was also realised that the T-PODs at position AT8 behaved significantly different from any other pair of T-PODs deployed simultaneously, and that T-POD recordings from this position may impair the overall conclusion that the change from v3 to v5 T-PODs did not affect conclusions (see also further discussion below). This deviating pattern with a decrease in click monitoring from v3 to v5 could be due to an extraordinary sensitive transducer in POD323 (v3) or an equally insensitive transducer in POD702 (v5).

The BACI analyses were consequently carried out on two data sets: 1) assuming no effect of switching from v3 to v5 T-PODs and 2) using the results from the intercalibration analysis to recalculate indicators from v5 to v3. In the intercalibration data set data from the v5 T-pod at AT8 were discarded, because the v3 (POD323) was deployed at AT8 in both T_0 and T_1 and thus even if this T-POD had a deviating sensitivity this difference would be the same for both T_0 and T_1 and thus not affect the BACI results. Moreover, PPM values calculated from v5 data was divided by the estimated intercalibration factor of 1.078 and waiting times calculated from v5 data was multiplied by the estimated intercalibration factor of 1.22. These two data sets will be referred to as the non-calibrated and intercalibrated data sets, respectively. The models obtained with both data sets, after eliminating non-significant effects, were similar in structure and allowed for a direct comparison of the intercalibration exercise.

Two random factors were consistently significant for all four indicators: *month×year(period)* which describes changes in the seasonal pattern between years for the two periods and *station×month×year(area subarea period)* describes that this random season pattern varies significantly also at the station level. In addition, the random factor *station×year(area subarea period)*, describing random shifts across stations from year to year in the two periods, was significant for PPM only. Finally, for all indicators the correlation structure of the residuals (cf. ARMA(1,1) dependency) was significant, although for clicks per PPM and PPM the correlation structure of the residuals could be reduced to an AR(1) process. The significant autocorrelation suggests that porpoise echolocation activity follows smaller scale temporal variations (order of days) in addition to the overall seasonal pattern, i.e. consecutive days have similar echolocation activity.

Table 6: Significance testing of fixed effects in Eq. (1) for the four indicators (non-calibrated data set) after removing non-significant fixed and random effects. Results for non-significant tests not included.

Fixed effects	Clicks per PPM			PPM		
	DFs	F	P	DFs	F	P
area	1, 149	22.12	<0.0001			n.s.[1)]
subarea(area)			n.s	1, 21.9	13.43	0.0014
period	1, 23.5	38.31	<0.0001	1, 31.2	13.55	0.0009
area×period	1, 150	13.93	0.0002	1, 22.3	8.75	0.0072
month	11, 18.6	4.52	<0.0001	11, 21.8	7.96	<0.0001
area×month			n.s.	11, 119	2.61	0.0051
Fixed effects	**Encounter duration**			**Waiting time**		
	DFs	F	P	DFs	F	P
area	1, 125	4.68	0.0325	1, 185	6.20	0.0136
subarea(area)	1, 108	7.68	0.0066	1, 149	30.57	<0.0001
period	1, 108	15.54	0.0001	1, 22.1	13.43	0.0013
area×period	1, 125	3.15	0.0782	1, 186	4.79	0.0229
month	11, 40.4	8.05	<0.0001	11, 20.3	11.26	<0.0001
area×month			n.s.			n.s.

Table 7: Significance testing of fixed effects in Eq. (1) for the four indicators (intercalibrated data set) after removing non-significant fixed and random effects. Results for non-significant tests not included.

Fixed effects	Clicks per PPM			PPM		
	DFs	F	P	DFs	F	P
area	1, 149	19.86	<0.0001			n.s.[1)]
subarea(area)			n.s	1, 13.0	7.62	0.0162
period	1, 24.2	40.20	<0.0001	1, 29.5	11.86	0.0017
area×period	1, 150	12.01	0.0005	1, 12.1	6.39	0.0253
month	11, 19.9	4.57	<0.0001	11, 21.7	7.79	<0.0001
area×month			n.s.	11, 109	2.30	0.0141
Fixed effects	**Encounter duration**			**Waiting time**		
	DFs	F	P	DFs	F	P
area	1, 109	3.76	0.0549	1, 151	3.36	0.0686
subarea(area)			n.s.	1, 123	11.80	0.0008
period	1, 101	17.79	<0.0001	1, 23.1	9.45	0.0053
area×period	1, 110	1.60	0.2088	1, 153	1.69	0.1951
month	11, 40.5	7.98	<0.0001	1, 20.5	11.09	<0.0001
area×month			n.s.			n.s.

Differences between the BACI analyses carried out on non-calibrated data (Table 6) vs. intercalibrated data (

Table 7) were generally small. The significance of the different factors was generally reduced with the intercalibrated data set, and the variation between Control N and Control S (*subarea(area)*) turned insignificant and was removed. The most important difference between the two analyses was that the BACI factor (*area*×*period*) became non-significant for waiting time with the intercalibrated data set. This change was mainly caused by excluding data from POD702 (v5) that increased the mean waiting time in the control area during T_1. Due to the suspect data from this T-POD and the expected improved sensitivity switching from v3 to v5, the analysis based on the intercalibrated data set is believed to more correct than the analysis based on non-calibrated data, and in the following results from the BACI analysis using the intercalibrated data set will be shown only.

For clicks per PPM there was a significant difference between the reference area (37.1 clicks/min) and the impact area (42.7 clicks/min), but there was no difference between the reference areas Control N and Control S. For PPM the difference between reference area (0.35%) and impact area (0.48%) was not significant, but so was the difference between Control N (0.44%) and Control S (0.26%). The mean encounter duration for the reference area (3.8 min) was lower than in the impact area (4.2 min), although not significant at a 5% significance level, whereas there was no difference in encounter duration between Control N and Control S. The mean waiting time in the reference area (11.2 h) was higher than in the impact area (9.6 h), although not significant, but there was a significant difference between Control N (9.8 h) and Control S (13.1 h). Overall, all four indicators showed that the impact area had the highest echolocation activity together with Control N (at almost the same level), whereas Control S had the lowest activity level.

All four indicators also showed a significant increase in echolocation activity from T_0 to T_1: clicks per PPM increased from 33.9 clicks/min to 47.2 clicks/min, PPM more than tripled from 0.22% to 0.67%, encounter duration increased from 3.5 minutes to 4.6 minutes, and waiting times decreased from 14.0 hours to 7.7 hours.

However, the significance of *area×period* for clicks per PPM and PPM as well as a tendency for relatively longer encounters and shorter waiting times in the impact area during T_1 suggested that echolocation activity in the impact area increased more than in the reference area (Figure 18). Echolocation activity was similar in the two areas during the baseline, but increased significantly more during the operation period in the impact area. The increase in the impact area relative to the reference areas was 24% for clicks per PPM, 109% for PPM, 15% for encounter duration and a 20% decrease in waiting times.

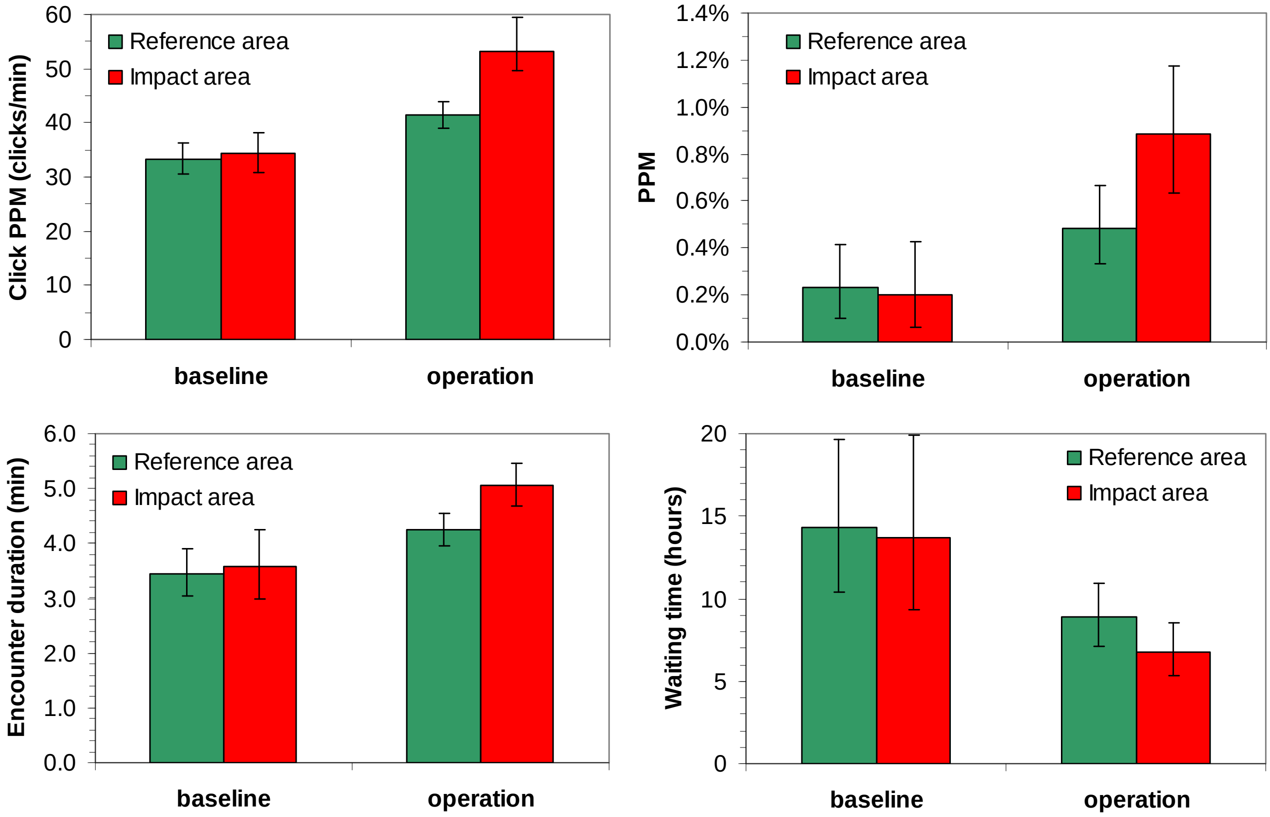


Figure 18: Mean values for combinations of T-POD data within reference and impact areas and period (from intercalibrated data set) back-transformed to the original scale for comparisons of the two areas and the two periods. Error bars indicate 95% confidence limits for the mean values. Variations caused by differences in sub-areas (Control N and S) and months have been accounted for by calculating marginal means.

All four indicators were characterized by a significant seasonal variation that was common to both the reference and impact area, except for PPM (*Table 6*). Echolocation activity was generally high during the winter months and low during the summer months (*Figure 19*). Mean clicks per PPM varied from 28 clicks/min in May to 51 clicks/min in February. The seasonal pattern for PPM was not common to the reference and impact area. Most of the year PPM was highest in the impact area, but in the low echolocation activity months (April, May and June) as well as March more clicks were recording in the reference area relative to the impact area. Overall, for the two areas combined PPM varied from 0.01% in June to 1.8% in January. Encounter duration displayed a pattern quite similar to clicks per PPM ranging from 2.8 minutes in May to 5.9 minutes in January. Waiting times had the reverse pattern with the shortest waiting times in January (3.2 h) and the longest waiting times in May (54.2 h), i.e. more than two days between encounters.

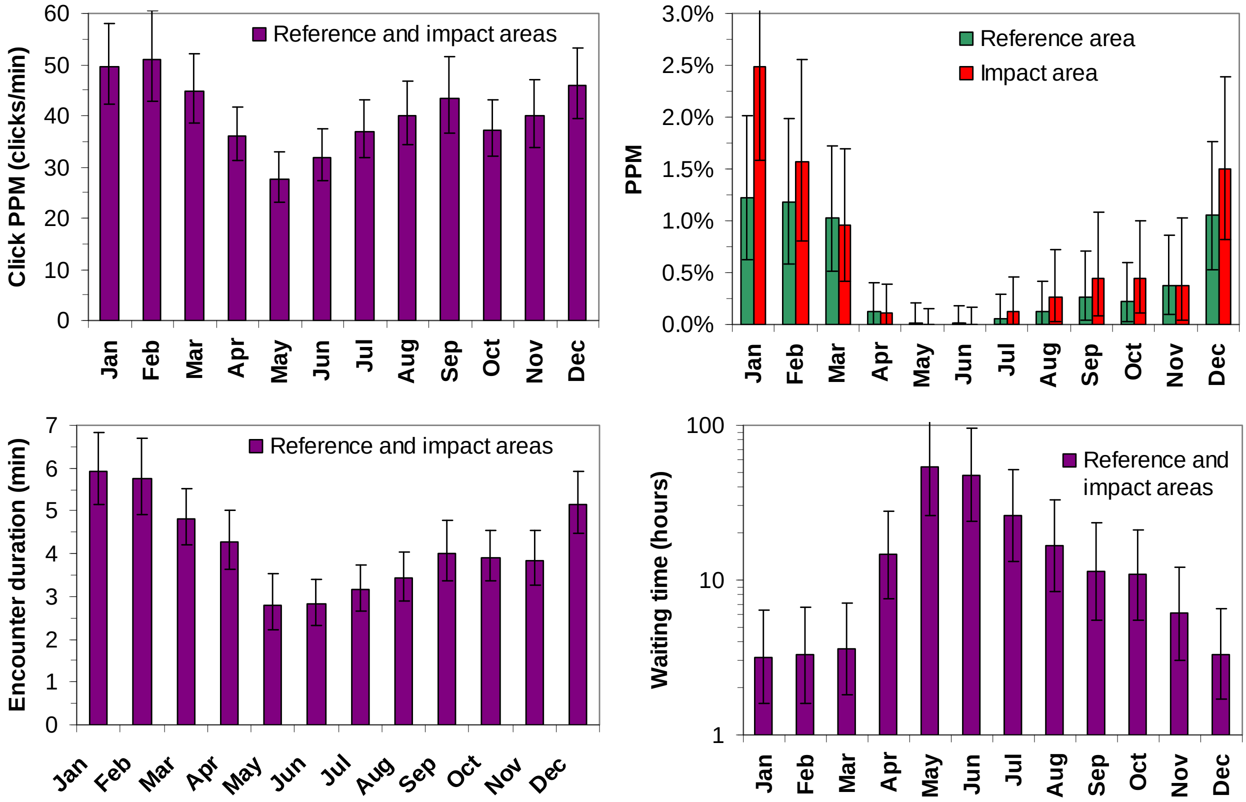


Figure 19: Monthly means for the four indicators after back-transformation. Error bars show 95% confidence limits of the mean values. Variations caused by differences in area, sub-area and period have been accounted for by calculating marginal means. Only PPM showed significantly different seasonal variation in the two areas and are thus plotted separately.

3.3 Ship based surveys

In total eight surveys were conducted during the T_0 phase and 12 during the T_1 phase. Table 6 gives an overview of all dates on which surveys were conducted. The average density of porpoises (animals per km², not corrected for animals missed on or away from the trackline) was calculated for each survey and plotted in figure 20 for the survey month. Both the period 2002 to 2004 and 2007 to 2009 show a seasonal pattern of porpoise density in the study area with highest densities in the winter months. Sighting rate within the perimeter of OWEZ were too rare to make a useful impact-control comparison.

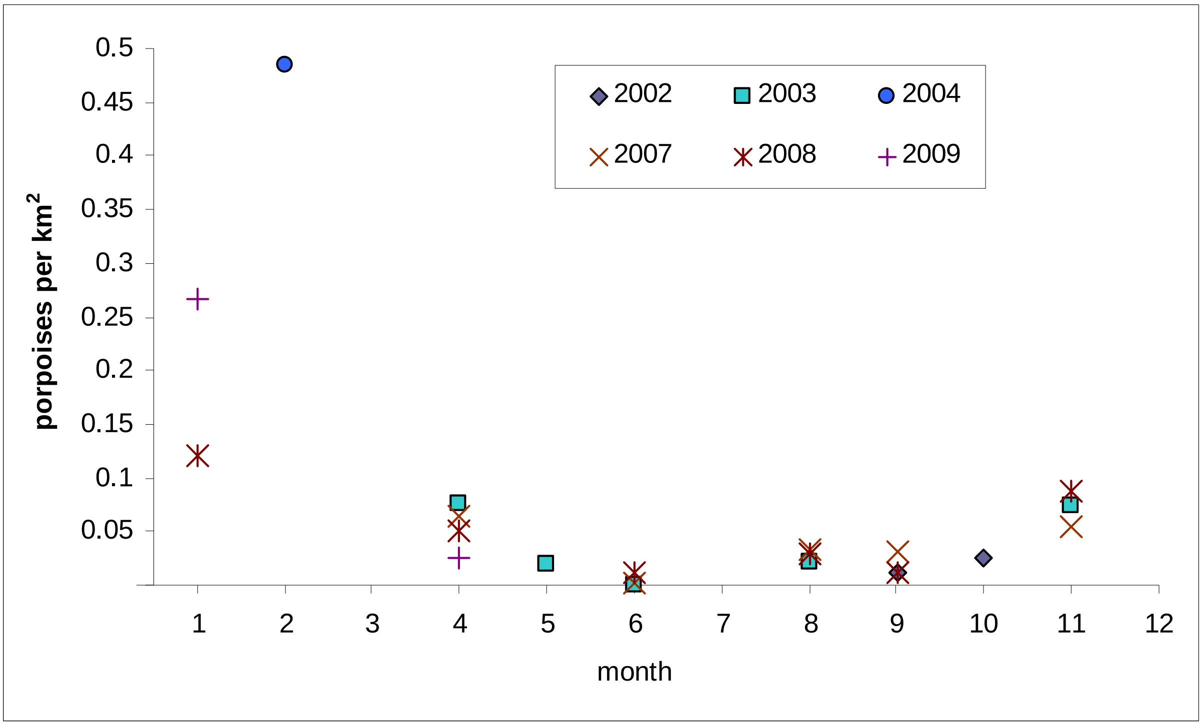


Figure 20. Mean harbour porpoise density (animals per km², not corrected for animals missed by the observers) estimated from the visual boat surveys. Densities are averaged for a week's survey effort per symbol, combining all sightings in a survey area of approximately 900 km², around and including the OWEZ site (Leopold et al. 2004).

4 Discussion

The data collected before and after construction of the Offshore Wind Park Egmond aan Zee constitutes a large and well balanced dataset for evaluation of the effects of the wind farm on harbour porpoises. The statistical analysis of the results included 8 explanatory variables and a number of interactions among these variables. Conclusions based on the results are divided into those relating to 1) methodological considerations, 2) changes in occurrence between years and months as well as 3) the effects of the wind farm.

4.1 Methodological considerations

The OWEZ site is located 8 – 18 km off the coast. Because of the expected exposure to strong currents and conflict with potential fishing operations the anchoring system of the T-PODs was carefully considered. Unfortunately, even with heavy weights and large buoys some T-PODs were lost and as a consequence data loss occurred. Even so large amounts of continuous data over long time periods were collected and 65% of the total monitoring time at the eight stations were covered.

The introduction of v5 T-PODs into the study during T_1 was unfortunate but necessary. Detailed analysis of intercalibration data showed that on average the v5 T-PODs were slightly more sensitive than the v3 T-PODs, with a pronounced exception at station AT8, where the v5 T-POD was considerably less sensitive than the v3 T-POD at that position. However, even if these factors are taken into account in the analysis (increased sensitivity of v5 and exclusion of station AT8 v5 data) the overall results of the BACI analysis remains unaltered.
Similarly the statistical modelling showed that differences between individual T-PODs (POD-ID) was not significant (with the noted exception of AT8).

Conducting long-term studies in an offshore environment are logistically challenging. As mentioned above, the loss of equipment meant that T-PODs had to be replaced, which led to an increased number of different recording devices used throughout the study period. In the future this problem could be addressed by improving deployment methods and assuring that the recording devices used are comparable (e.g. the same version) over the entire study time. Because of the introduction of new T-PODs to the study and the specific differences between individual T-PODs, the variation between these devices might have caused a higher variation in the resulting data. Thus, when interpreting the effects, one should take into account that the confidence interval of the results might be larger and that the true effect might be stronger or lower than the one reported here. It is evident from the results that even with an increased variance there is no indication of a negative effect of the wind farm area on porpoise click activity and on the occurrence of porpoises.

4.2 False negatives and false positives

No detector is perfect. There is thus always the possibility that true signals will be missed (false negatives) and that spurious signals will be classified as true signals (false positives).
Two types of false negatives can exist: 1. Porpoises in the vicinity of the T-POD but signals not picked up by the T-POD, either because the porpoise is not vocalizing or because it is pointing its acoustic beam away from the T-POD, and 2. porpoise signals are received by the T-POD but not recognized as made by porpoises (removed by the off-line filtering algorithm). For this study false negatives are of a lesser concern, as we do not assume in the analysis that all porpoises in the vicinity of a T-POD are detected. The acoustic activity of porpoises is used as an index of porpoise occurrence, not of absolute abundance. However, it is an important assumption of any study relying on indices rather than absolute counts that the number of false negatives does not change, spatially or temporally (Anderson, 2001). This assumption is technically difficult to test, but we have no indications or reasons to believe that it should not be fulfilled. The challenges faced in this study in this respect are not fundamentally different from any other method relying on indices. Even methods that attempt to quantify the absolute number of cetaceans in the wild (e.g. distance sampling with visual or acoustic surveys) need to correct for missed animals. Currently work is under way to adopt point distance sampling techniques to passive acoustic monitoring (see Tougaard 2008), but currently the method is immature and as the aim of the current study was not to obtain absolute abundance estimates of porpoises, but to investigate the relative changes in porpoise habitat use over time, the use of relative indices is fully appropriate.

The second potential problem is the detection of false positives by the T-POD. This means that an acoustic signal is recorded and classified as a porpoise, although it is not. Several signals are known to be capable of being incorrectly detected, most notably some echosounders, but also cavitation from high-speed propellers. Determining the proportion of false positives in the wild is a difficult task and no studies have dealt with this problem under realistic deployment conditions. Thomsen et al. (2005) however, undertook experiments with six captive harbour porpoises at the Dolfinarium Harderwijk. Their results showed that the classification of clicks was more biased towards the increase of false negatives (e.g. signals were not classified as porpoises, when they were indeed porpoises). There were no recordings of false positives, which is not surprising in a controlled environment (the only additional sound source was a water pump). Akamatsu et al. (2001 and 2008) investigated finless porpoises using underwater sound monitoring with hydrophones concurrent with visual observations. The acoustic system they used could detect the presence of the finless porpoise 82% of the time. A false alarm in the system occurred with a frequency of 0.9%. The sound signal of a finless porpoise is similar to a harbour porpoise, nevertheless the river environment and the different acoustic recording device make it difficult to directly apply the 1% false positive rate to our study. In a similar set up, Wang et al. (2005) used acoustic data loggers on finless porpoises in combination with an array of hydrophones and visual observations. In contrast to Akamatsu et al. (2001) they had a lower correct detection rate (77.6%) and a higher false alarm rate (5.8%).
In contrast to false negatives, false positives pose problems even if the rate is constant (but unknown). The more abundant animals are, the less important the false positives becomes, as they constitute a smaller and smaller proportion of all detections. In the current study, the false positive rate must have been very low, as long periods (days) without detections are recorded during summer.

As the bulk of the data is collected in the winter months where animal abundance is high, the false positive fraction of all detections must be very small and unlikely to affect conclusions. However, the generally poorer weather and higher currents in the winter months could be suspected to lead to more general noise recorded on the T-POD and hence more false positives and could be speculated in the worst case be responsible for the peak of detections seen in winter. This is unlikely for two reasons. First of all, the strong seasonality seen in acoustic detections closely matches the seasonal pattern seen in visual observations from land (Camphuysen et al. 2004) and from sea (Brasseur et al 2004). Secondly, the strong peak in acoustic detections during winter months is completely absent in data from T-POD studies in the Baltic Sea (Verfuß et al. 2007) and the Danish North Sea (Tougaard et al. 2006b, Carstensen et al. 2006).

A single potential source of false positives deserves mentioning. During the T_1 project a parallel study to investigate the movement of fish (sole and cod) in the wind farm area was conducted. Animals were equipped with implantable transmitters (V7) which transmitted a signal that could be detected by receivers in the wind farm. It would be highly unfortunate if these signals were erroneously picked up by the T-PODs as being porpoises. However, the fish transmitters operate at 69 kHz and were programmed to transmit at a rate of one pulse per 30-120 seconds. The frequency of the signals as well as the very low repetition rate as compared to porpoises (50-500 pulses/s) makes it completely unlikely that these signals could have interfered with the T-POD detection of porpoises.

4.3 Porpoise occurrence

The results of T-POD monitoring demonstrated a substantial general increase in acoustic activity from T_0 to T_1 (significant factor *period*). The higher occurrence in the study area is in line with conclusions from a number of other studies that indicate a general increase in harbour porpoise abundance in Dutch waters over the last two decades (Hammond et al. 2002, SCANS II 2008). For Dutch waters, some quantitative information on coastal abundance is provided by the systematic "seawatching" counts carried out by the Dutch Seabird Group. Although initiated for birds, data on presence of marine mammals has also been collected since its establishment in 1972. It is clear from the data that the number of harbour porpoises observed has increased dramatically since the mid 1990s. During T_0 (June 2003-May 2004) the total amount of harbour porpoises sighted in the Dutch coastal zone was 497. During the T_1, in the period June 2007-May 2008, 602 harbour porpoises were sighted and in the period June 2008-March 2009 1146. This observed increase is a clear indication that the increased T-POD data depict reality and are not just an artefact caused by using different types of T-PODs. The reasons for the increase remain unclear. Possible explanations include changes in prey availability in the southern North Sea (Camphuysen 2004).

4.4 Seasonality

The T-POD results show a strong and significant seasonal pattern in porpoise echolocation activity for all four indicators. Most acoustic detections are recorded in the winter months (December to March) and very few during early summer (almost no detections in May and June). A similar pattern was observed throughout the boat survey by Leopold et al. (2004, 2009). Camphuysen (2004) described a seasonal pattern of harbour porpoise occurrence along the Dutch coast with most animals observed between February and April.

The seasonal trend is in general the same between the baseline and impact study period. This pattern differs from areas further north such as the German Bight and at Horns Reef, where the highest densities are observed in the summer months (Siebert et al. 2006, Tougaard et al. 2006b).

4.5 Effect of construction

Monitoring was not undertaken during construction of the wind farm and it is thus not possible to comment on the effects on porpoises during this period. However, from other studies of offshore wind farms, in particular the construction of Horns Rev 1 and Horns Rev 2 (Horns Reef) it is evident that construction activities can have a negative effect on the presence of porpoises. In particular the installation of steel monopile foundations by means of percussive piling has been shown to affect porpoise behaviour at distances of at least 20-30 km from the piling site and for durations of up to 24 hours after the installation of each monopile (Tougaard et al. 2009, Brandt et al. 2009). As monopile size and installation procedure used in OWEZ is comparable to the wind farms at Horns Reef it would be expected that harbour porpoises would be affected in a similar way during monopile installations in OWEZ. The present data (T_1) show that the effect *year(period)* was not significant and no difference could be seen between the three monitoring years (2007 to 2009). This implies that either there was little construction effect on harbour porpoise distribution (which is unlikely considering the data from Horns Rev), or that recovery after construction took place fairly quickly thereafter.

Of interest is the construction of Prinses Amalia Wind farm. That wind farm consists of 60 wind turbines on monopile foundations, just like in OWEZ. The construction of the wind farm occurred between October 2006 and April 2008. Given the close vicinity of the wind farm to OWEZ (approx. 9 km), it is likely that harbour porpoises recorded in OWEZ during that time frame were negatively affected by the construction of the wind farm. A more detailed analysis of this possible effect was beyond the scope of this study.

4.6 Effect of operation on presence of harbour porpoises

The BACI analysis demonstrated a positive effect of the wind farm on porpoise acoustic activity (factor *area×period*), or expressed more clearly: there was more acoustic activity in the wind farm area after the establishment of the wind farm, even when taking into account that there was a significant general increase in acoustic activity at all stations from the baseline period to the operational period (see below). Thus, if higher acoustic activity is interpreted as higher abundance of porpoises, then relatively more porpoises are found in the wind farm area compared to the two reference areas. This relative increase was significant in both the analysis on the complete dataset and the dataset modified to remove possible bias related to the introduction of v5 T-PODs during T_1.

The fact that no significant differential changes were found between the northern and the southern reference areas, or in seasonality patterns between areas (factors *subarea(area)×period* and *area×period×month*, respectively) suggests that the effect is genuinely linked to the presence of the wind farm, as it cannot be explained by either a general north-south change in distribution of porpoises or a local change in seasonality pattern within the wind farm area.

As discussed above under methodological considerations the acoustic activity recorded by the T-PODs is only an index for porpoise abundance. A close correlation between abundance and acoustic activity, as monitored by static acoustic monitoring, remains to be established. However, studies where acoustic activity of free-swimming porpoises in the wild were equipped with acoustic dataloggers demonstrates that porpoises are vocalising almost constantly (Akamatsu et al. 2005, 2007). These data showed that porpoises rarely remained silent for more than one minute at a time, meaning that even though animals may be more vocal during certain behaviours (such as foraging) than others, these differences are expected to have little influence on the statistics porpoise positive minutes (PPM), encounter duration and inter-encounter waiting time. There are thus good reasons to believe that the increase in acoustic activity inside the wind farm is in fact a reflection of a higher abundance of porpoises. In theory it is a possibility that the increase in acoustic activity reflects an altered use of echolocation by the porpoises inside the wind farm, but this seems less likely. One reason for a change in echolocation behaviour would be that the area is more complex due to the presence of the foundations. However, the foundations are relatively widely dispersed and it is thus not likely that the foundations will add much clutter to the acoustic environment except when the porpoises are very close to the foundations and it is thus not likely that this would be reflected in elevated activity recorded at T-PODs placed further away from the turbines. An even less likely explanation could be an increased sound production due to masking of sonar signals by noise from the turbines, but as the turbine noise has no energy above 500-1000 Hz (Tougaard et al, 2009b), it is physically not possible to mask the sonar clicks located 10 octaves above in frequency.
As the two T-POD stations were located close to the eastern and western edges of the wind farm, respectively, one could raise concern that the increase observed is not due to more animals *inside* the wind farm, but rather caused by animals outside the wind farm. Such edge-effects have been discussed example migrating birds (e.g. Bruderer and Liechti 1998, van Dobben 1953, Meyer et al. 2000). The higher acoustic activity recorded by the T-PODs inside the wind farm would then be due to recordings of higher than normal concentrations of porpoises moving up and down along the outer edges of the wind farm and thus be indicative of an *avoidance* of the turbines. However, this scenario is unlikely, given that the T-PODs have maximal detection ranges of 3-500 m and drastically reduced detection probabilities beyond 100-150 m (Tougaard, 2008). As the T-PODs are locate more than 150 m inside the wind farm, the absence of detections near the T-POD (where detection probability is high) should be counterbalanced by an increased occurrence of porpoises at the very edge of the detection range of the T-POD, and only along a fraction of the perimeter of the area of detection (the part that reaches outside the wind farm). This would require unrealistically high numbers of porpoises to be present immediately outside the wind farm. Thus, because of the low spatial resolution of the T-PODs, it is very unlikely that the increased acoustic activity recorded inside the wind farm can be explained by even a very steep gradient in porpoise occurrence perpendicular to the edge of the wind farm.

The local change in habitat use with an increase in porpoises in the wind farm relative to adjacent areas indicates that there is a reason for animals to change their distribution locally. Conceivable reasons for the observed increase in porpoise occurrence could be an avoidance of disturbance that is occurring outside the wind farm (e.g. increased shipping) or an attraction to the characteristics of the park (such as more fish or different kinds of fish due to the reef effect of the foundations). The most likely reason for an increased occurrence of porpoises is that the wind farm provides an increase in prey occurrence.

It can be hypothesized that exclusion of fishery from the wind farm area and the introduction of hard substrate to the otherwise homogeneous sand bottom will increase both biodiversity and biomass. It is well known that such hard substrates will attract sessile organisms that in turn attract fish and invertebrate species otherwise not commonly found on sandy bottoms (Petersen & Malm 2006, Leonhard & Pedersen 2006), some of which may provide a beneficial addition to the food resources available to porpoises.

The finding that harbour porpoises may be attracted to the wind farm is in contrast to findings from other wind farm studies of comparable size (both regarding turbine numbers and size). In the Danish offshore wind farm Nysted, located in the Western Baltic close to the Darss-sill usually defining the border to the Baltic Proper, a strong negative effect of construction was observed on acoustic activity of harbour porpoises in the wind farm area and adjacent reference area (Carstensen et al. 2006). This negative effect extended into the operation period, where porpoise activity was still reduced 2 years after construction within the wind farm, whilst it had returned to baseline levels in the reference area (Tougaard et al. 2006a). The cause behind the reduction has not been identified and it is currently unknown whether porpoise activity has re-established to baseline levels. However, it is important to note that there are many differences between the general ecology of the two locations where Nysted wind farm and OWEZ are located. OWEZ is located in the open North Sea in an area dominated by hydrographical frontal systems created by the efflux from large rivers, most notably the Rhine, whereas Nysted is located in near-brackish waters with lower biodiversity and lower overall density of harbour porpoises. There is also a difference in the wind farm construction itself with Nysted wind turbines consisting of concrete caisson foundations and Horns Rev and OWEZ of monopole foundations. It is thus not immediately evident whether the different effect of the two wind farms on harbour porpoises can be attributed to differences in the parks *per se* (e.g. differences in turbine types or foundation) or whether general ecological differences between the two areas causes harbour porpoises to respond differently to the presence of a wind farm.

At the second Danish offshore wind farm "Horns Rev 1", located on Horns Reef at the northern border of the German Bight, also a pronounced effect of construction was seen but with complete recovery to baseline levels during the first year after the wind farm was put into regular operation (Tougaard et al. 2006b). The Horns Reef area is more similar to the OWEZ, than to the Nysted area, with sandy bottom, in the open North Sea and is dominated by riverine frontal systems. However, Horns Reef is hydrographically much more complex than OWEZ due to the presence of the long shallow reef which acts as a strong damping barrier to the tidal current. Thus, as with the Nysted Offshore Wind Farm, it is not immediately evident whether the different effects of the wind farms (no effect at Horns Rev, positive effect at Egmond aan Zee) are due to differences between the areas or the wind farms. This conclusion is of great importance in planning future wind farms as it stresses the point that results from one wind farm are not necessarily transferable or valid for another wind farms located in a different area.

Based on the experiences of this study, future research could benefit from improved calibrations of T-PODs (or similar recording devices) and an improved sample design to go beyond the scope of only investigating the general habitat use in and outside of the wind farm area by porpoises. New analyses approaches could be used to not only investigate click activity, but also to look at the occurrence of different behaviour types (e.g. feeding). The comparison of this type of data from inside and outside the wind farm area could be helpful to obtain more specific information on the underlying ecological reasons for observed changes in porpoise occurrence.

5 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 57846-2009-AQ-NLD-RvA). This certificate is valid until 15 December 2012. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Justification

Rapport: OWEZ_R_253_T1_20120202
IMARES C012.12

Project Number: 439.61018.08

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Drs. F.C. Groenendijk
Head of department

Signature:

Date: 2-2-2012

Approved: Prof. dr. H.J. Lindeboom
Board of directors - Science

Signature:

Date: 2-2-2012

Appendix 1

Overview of deployment of T-PODs

Position	Depth (m)	3-4/06/03	26/08/03	02/12/03		04/03/04		25-26/05/04
		Dep	Serviced	Rec?	Dep	Rec?	Dep	Final Rec
AT1 (CTD 488)	20	238	238	238			238	238
AT2	21	239	239	239			@	NA
AT3	17	233	233	^	233	233		233
AT4	18	240	240	240		240		240
AT5 (CTD 489)	18	234	234	234		234		234
AT6	20	230	230	230		230		230
AT7	19	231	231	*			276	276
AT8	18	232	232	#			232	232

^ TPOD found on Dutch coast on 11/10/03.
* TPOD found at Hondsboschse zeeweering on 20/11/03.
# missing, but TPOD found on 10/12/03.
@ TPOD found on Texel on 08/01/04.

Position	17/04/07	21/06/07		02/10/07		13/12/07		13/02/08		09/04/08	
	Dep	Rec	Dep	Rec	Dep	Rec	Dep	Rec	Dep	Rec	Dep
AT1	701	701	701+238	701+238	238	238	701	701	238	238	701
AT2	707*	707	707+730	#	707+730	#	730	730	707	707	730
AT3	700	700	700+233	700+233	233	233	700	700	233	233	700
AT4	702	702	702+240	702+240	240	#	702	702	702+736	702+736	702
AT5	706	706	234	#	706	706	706+749	706+749	706	706	749
AT6	705	705	705+230	705+230	230	230	705+230	705+230	705	705	705
AT7	704	704	276	276	704+276	704+276	276	276	704	704	276
AT8	703	703	232	232	232+703	#	703	703	703	703	703

* TPOD not functioning on 17/4/07 therefore deployed in May
# found to be missing

Position	05/06/08		07/08/08		09/10/08		03/12/08		16/12/08		19/02/09		14/04/09	15/04/09	16/04/09
	Rec	Dep	Rec	Dep	Rec	Dep	Rec	Dep	Rec	Dep	Rec	Dep	Final Rec	Final Rec	Final Rec
AT1	701	238	238	701	701	238	238	^	NA	238	238	238	238	-	-
AT2	730	707	707	730	730	707	^	^	#	730	730	730	730	-	-
AT3	700	233	233	700	700	233	^	^	233	70	700	233	233	-	-
AT4	702	736	736	702	702	700	#	702	NA	NA	702	736	-	736	-
AT5	749	706	706	749	749	706	#	749	NA	NA	749	706	-	706	-
AT6	705	705	705	705	705	705	705	705	NA	NA	705	705	-	-	705
AT7	276	704	704	276	276	276	276	704	NA	NA	704	276	-	-	276
AT8	703	703	703	703	703	703	703	703	NA	NA	703	703	-	-	703

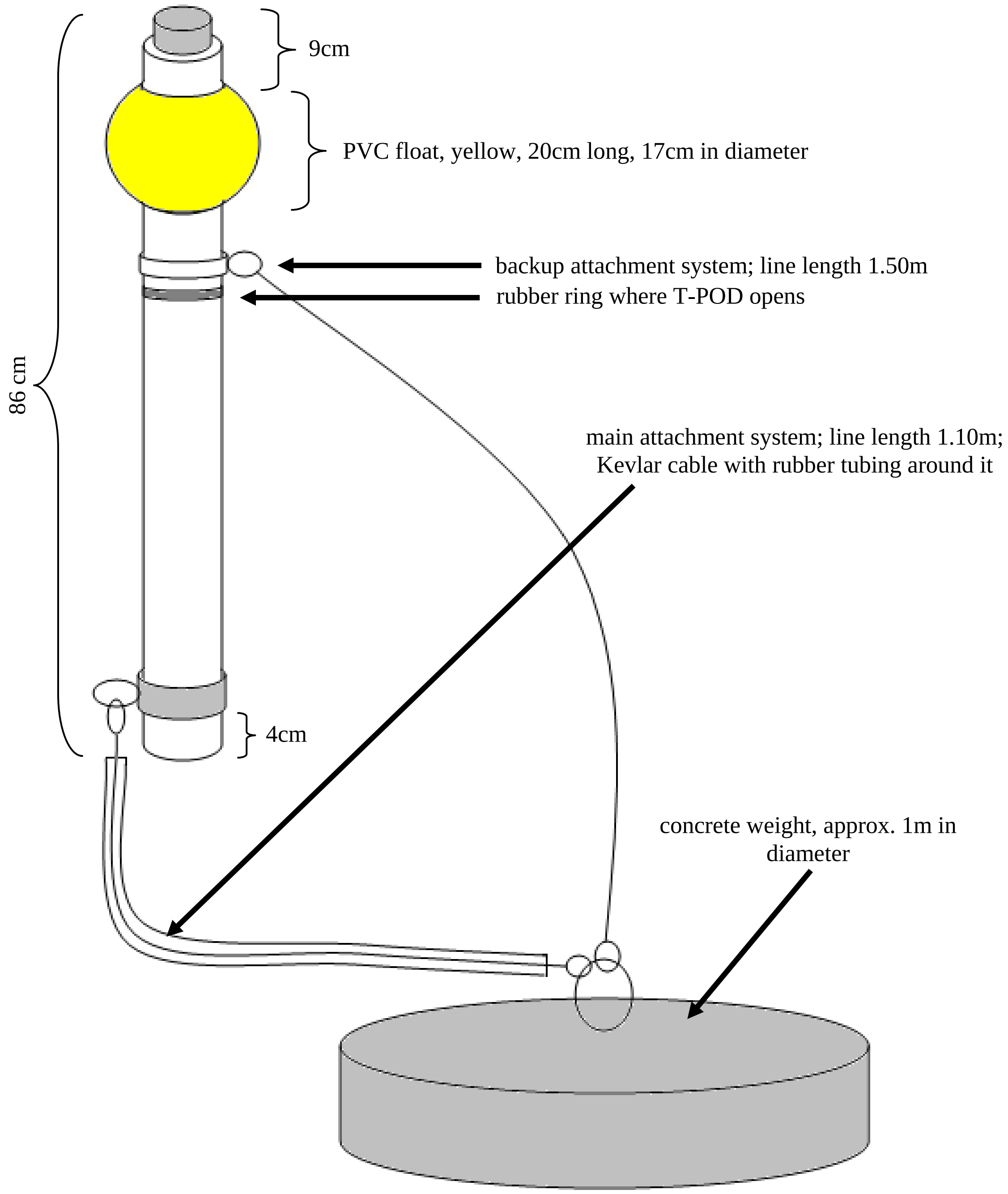
found to be missing
^ not deployed/recovered due to weather conditions
NA not applicable due to already having been recovered and deployed on the 3/12/08
- final recovery took three days (14th-16th of April 09)

Appendix 2

TPOD	History
238	lost after 10/12/03, found 08/01/04
239	lost after 02/12/03
233	found on Dutch coast 11/10/03 sent for repairs
240	lost after 2/10/07
234	lost after 21/06/07
230	no longer used after 13/02/08 due to crack on the outside (water and mud found inside - memory chip okay, but TPOD could not be repaired)
231	found on Hodsboschse zeeweering, damaged and sent for repair. Not used here after
276	all good
232	lost after 26/08/03, found on texel stripped but working, Sent for repair, deployed at next opportunity. Lost after 2/10/07
701	communication error after 9/10/08 therefore no longer used
707	lost after 21/6/07 and recovered before 2/10/07, missing after 9/10/08
700	all good
730	lost after 21/6/07 and recovered before 2/10/07, lost after 2/10/07 and recovered before 13/12/07
702	all good
706	lost after 9/10/06 and recovered in November in Scheveningen
70	all good
704	all good
703	lost after 2/10/07 and recovered before 13/12/07
749	all good

Appendix 3 Adapted design of T-POD

Sketch (here shown a version 5) is not true to scale. The added float gives additional buoyancy to make sure that the T-POD hangs vertically in the water column. The adaptation of this design reduced losses of T-PODs.



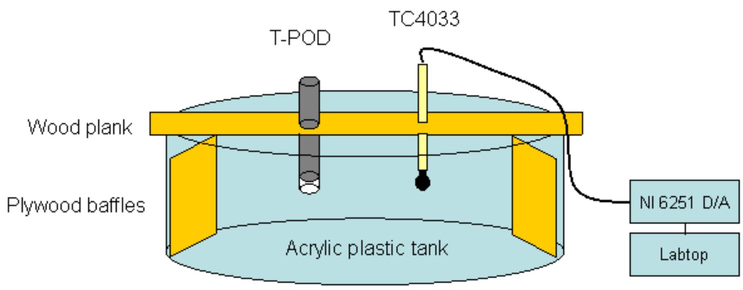
Appendix 4 Calibration of T-PODs during the OWEZ T_1 study[1]

Method:

The T-POD does not record waveforms or even absolute sound pressures, instead it records time and duration of signals detected according to the hard-ware filter and detection circuit. Sensitivity is thus expressed as the sound pressure at which 50% of a porpoise-like click is detected by the T-POD.

Setup and stimulus

Calibration was performed in a circular tank made of acrylic plastic, approx. 1.5 m diameter and 0.9 m water depth. The T-POD is placed hydrophone down in a special holder, with the hydrophone approx.40 cm below the surface. 50 cm from the T-POD in the same depth as the hydrophone of the T-POD is the transmitter, a Reson TC4033, placed. Prior to measurements on T-PODs the setup is calibrated by placing a RESON TC4034 at the place of the T-POD hydrophone (T-POD removed) and thus verifying playback sound pressure. T-POD and transmitter are placed in the middle of the pool and by means of wood baffles the amount of reflections are reduced so that 1) the directly transmitted pulse is well separated in time from the first arriving echo and 2) amplitudes of echoes are all well below the amplitude of the directly transmitted pulse. Although a lot of echoes are recorded at higher intensities, the procedure guarantees that the threshold relates to the directly transmitted signal only.



[1]*Details on the field calibration done for T-PODs v3 (version 3) can be found in: Brasseur et al. 2004. Baseline data on the harbour porpoise, Phocoena phocoena, in relation to the intended wind farm site NSW, in the Netherlands. Alterra-rapport 1043).*

Signals were 13 cycles of a 130 kHz sine wave, shaped with a raised cosine envelope and generated by a National Instruments 6251 D/A converter at 500 ksamples/s. The stimulus sequence consisted of 31 consecutive blocks of each 10 pulses, with amplitude decreasing from block to block in 1 dB steps.

Analysis

Recordings of the stimulus sequence (presented multiple times) were made at 4 different angles of incidence in the horizontal plane, to assess directionality of the T-POD hydrophone.

Recordings were analysed and thresholds expressed as mean sound pressure levels of the 130 kHz pulse (across 4 angles of incidence), corresponding to 50% detection.

Results:

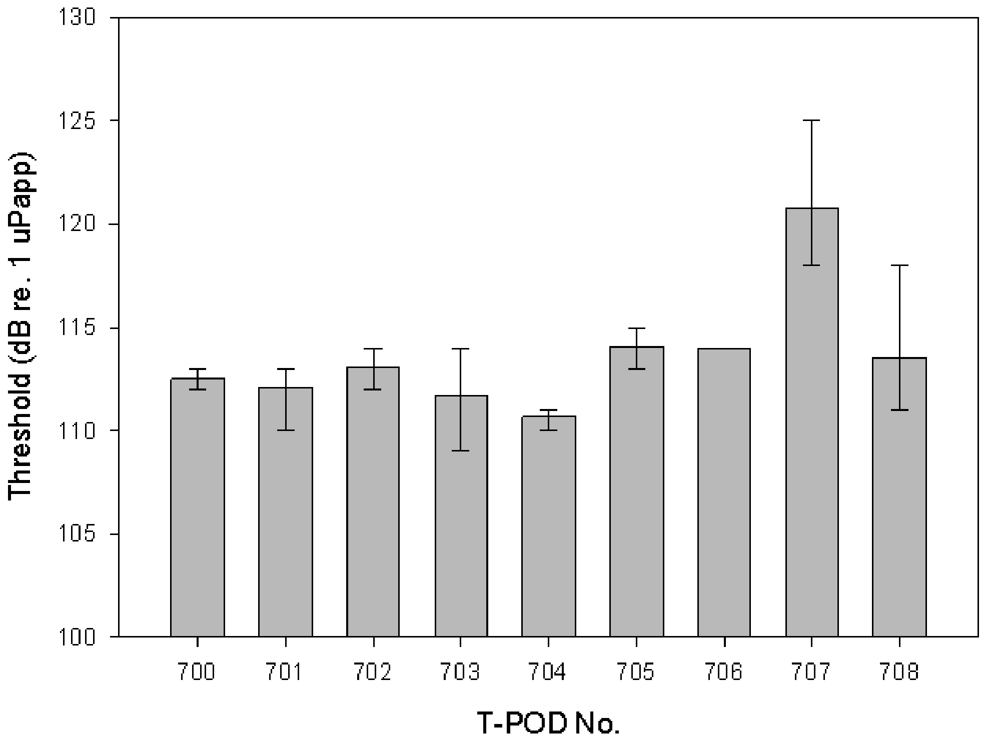


Figure 1: Results of the tank calibration of the T-PODs (v5) used during the T_1 study

Sensitivity between the individual T-PODs was very similar (Figure 1), with the exception of T-POD 707. Therefore T-POD 707 was returned to the manufacturer. It was found that the T-POD had a battery problem and its transducer cable was trapped in the transducer housing joint. Both issues were resolved before the T-POD was used.