Harbour porpoise occurrence in relation to the Prinses Amaliawindpark

Tamara van Polanen Petel, Steve Geelhoed & Erik Meesters

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Summary

From the 1st of September 2009 until the 2nd September 2010 the acoustic activity of harbour porpoises (*Phocoena phocoena*) was studied by means of two Continuous POrpoise Detectors (CPODs) in the Princess Amalia Wind Farm (in Dutch: Prinses Amaliawindpark, abbreviated PAWP) and two CPODs in a reference area at 5.5 km north of the wind farm. The study area lies 23 km offshore, west of the province of North Holland. The study was conducted in the second year of operation of the wind farm. CPODs are passive acoustic monitoring devices that can record echolocation signals of harbour porpoises continuously. This acoustic activity can be used as a proxy for the occurrence of harbour porpoises. The four CPODs detected harbour porpoises on 89.8% of the days they recorded data. To analyze the data a basic unit was used: the so-called Porpoise Positive Minute (PPM), a minute in which harbour porpoise clicks were detected. Daily click frequency (%PPM per day) varied from on average 0.65 to 0.94 PPM/day. The daily click intensity varied from 0.26 to 0.46 clicks/PPM. Both click frequency and click intensity showed a distinct temporal pattern with higher activity in March and December, and the least activity in April-May.
A GAMM-model was used to compare the data from CPODs within the wind farm to those in the reference area. This analysis showed no difference between the two areas, indicating no effect of the wind farm on the occurrence of harbour porpoises.

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We would like to thank the crew of the Rijkswaterstaat vessel “Terschelling”for all the long hours they have spent helping us deploy and recover the CPODs, for their professional work under sometimes difficult conditions and the hospitality on board the ship. Geert Aarts commented on the statistical analysis. Elze Dijkman made the map. Kathrin Krügel and Anne Hermann of the German Oceanographic Museum calibrated the CPODs. Nick Tregenza (Chelonia Ltd) and Klaus Lucke helped with interpreting the calibration results.

1 Introduction

The Dutch government is currently investing into sustainable energy in The Netherlands and as such has made it possible to construct two offshore wind farms within the Dutch part of the North Sea; Offshore Wind Farm Egmond aan Zee (OWEZ) in 2007 and Prinses Amaliawindpark in 2008. Construction of a number of additional wind farms is planned for the forthcoming years. Wind energy is one of the most important forms of sustainable energy that can be used on a large scale. Consequently, wind energy can make a substantial contribution to the provision of sustainable energy.

1.1 Wind farms and marine life

The potential effects of the construction and operation of wind farms at sea on marine life is a pertinent question in today's world. Although for this report we focus on harbour porpoises (*Phocoena phocoena*), wind farms have the potential to affect all marine life, including marine mammals, fish, birds, and benthic species. Indeed research has shown that effects of the construction and or operation of wind farms on marine life occur; for example on seals (e.g. Edrén *et al.*, 2004), harbour porpoises (e.g. Gilles *et al.*, 2009), birds (e.g. Leopold *et al.*, under review) fish (e.g. Hvidt *et al.*, 2005), and benthic organisms (e.g. Zettler & Pollehne, 2006). However, not all effects are negative, with research showing positive effects on for example, the benthic macro-fauna (Zettler & Pollehne 2006). These authors found a general increase in diversity, abundance and biomass of benthic macro-fauna on the new hard substrate of wind turbines.

The construction and operation of wind farms at sea has the potential to affect harbour porpoises in and around the area. The most important factor associated with construction can be considered to be underwater noise. The construction phase often includes profiling, shipping, driving of heavy steel piles into the seabed, trenching and dredging (Nedwell & Howell, 2004). All of these activities generate noise of varying intensity, duration and frequency, with pile-driving producing powerful shock waves. In general, pile-driving during construction is considered the activity most likely to affect marine mammals (Koschinski *et al.*, 2003; Madsen *et al.*, 2006; Thomsen *et al.*, 2006). Noise can induce hearing impairment at close range, and cause disturbance at ranges of many kilometers. Modeled ranges indicate that pile driving sounds should be audible to marine mammals at very long ranges of more than 100 km (Madsen *et al.* 2006). Operating wind turbines commonly generate low sound levels, unlikely to impair hearing in marine mammals. However, associated activities, such as shipping and maintenance still have the potential to affect the animals. Furthermore, the physical presence of the turbines can cause animals to partly or completely avoid the area. Alternatively, the presence of the turbines can result in the creation of an artificial reef. The foundations acting as substrate on which animals and plants can grow, thereby attracting fish (commercial fishing is forbidden in wind farms in the Netherlands). Such changes to the fish fauna and productivity are likely to be neutral or even positive to opportunistic feeders like porpoises.

1.2 Status of harbour porpoise in the Netherlands

The harbour porpoise is the most common cetacean in the North Sea with numbers estimated at 230,000 individuals in the entire North Sea in 2005 (SCANS II, 2008). Estimates for Dutch waters are around 86,000 individuals in March 2011, when peak numbers are (expected to be) present (Geelhoed *et al.*, 2011). However, this has not always been the case as porpoises were a rare visitor to the Dutch coast in the 1970s-1980s (van Deinse, 1952; Reijnders, 1992; Smeenk, 1987). In the early 1990s, live sightings as well as dead strandings, started to increase and have continued to do so until 2006 (Arts, 2010; Camphuysen, 1994; Reijnders *et al.*, 1996; Witte *et al.*, 1998). Prior to the 1950s however, porpoises were not an uncommon species to observe in Dutch waters, including some rivers. The causes for the changes in abundance are not known, but most likely caused by a change in the distribution of prey of porpoises (Camphuysen, 2004).

2 Assignment

The porpoise research in the Q7 wind park as described in this report aims at:

1. investigating the local occurrence of harbour porpoises throughout one year in the wind farm
2. compare the seasonal patterns of occurrence with known seasonal patterns based on coastal observations
3. compare observed habitat use between the Prinses Amaliawindpark and the reference area
4. put the obtained results into a larger context by comparing it to existing datasets on harbour porpoise distribution and abundance on a larger scale

The general aim of this study is to determine harbour porpoise occurrence in relation to Prinses Amaliawindpark during operation. No data were collected before and during construction.

3 Materials and Methods

3.1 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 Prinses Amaliawindpark was constructed. Construction began in October 2006 with all the turbines standing by November 2007. The wind farm was fully operational in June 2008. The wind farm is located 23 km offshore and is the worlds first wind farm outside the 12 miles zone. The approximately area of the wind farm is 14 km^2 with an additional 500 m exclusion zone around the wind farm. The complete total area is declared as a restricted area in which no shipping or fishing vessels may enter. The water depth ranges from 19-24 m. There are 60 V80 wind turbines, separated by 550 m, with a hub height of 59 meters above median sea level (MSL) and a rotor diameter of 80 m. Each has a nominal capacity of 2 MW, with a annual production of 435 GWh.

Figure 1. Location of the CPODs in relation to the Prinses Amaliawindpark and OWEZ wind farm.

3.2 Acoustic monitoring – CPODs

For the purpose of this study, four CPODs were used, two within the wind farm and two to the north of the wind farm (reference area). Two CPODs were used in each area to account for individual CPOD variation. And to identify how consistent porpoises use the two areas. This measurement allows natural variation within an area to be determined.

CPODs PAW 3 and PAW 4 were positioned within the wind farm and were 1.4 km apart. CPODs PAW 1 and PAW 2 were positioned north of the wind farm and were separated by 2.1 km (Figure 1, Table 1). The positions were chosen for logistical reasons to avoid conflict with areas of shipping traffic, and electrical cables and turbines. The smaller separation distance between CPODs within the wind farm, compared to the reference area, was a result of these conflicts. The distances between CPODs ensured that no two CPODS recorded the same porpoise.

The reference area was approximately 5.5 km from the most northerly placed turbine. This distance should ensure that the reference area has the same biotic and abiotic conditions as in the wind farm, but is outside the potential disturbance range of the wind farm. Studies in Denmark and Sweden indicate that the impact zones of underwater noise from wind turbines are several tens of meters at the maximum for harbour porpoises (Tougaard & Damsgaard Henriksen, 2009).

Table 1. Position of CPODs within and to the north of the wind farm.

		Latitude Degrees.min.sec	Longitude Degrees.min.sec	Waterdepth (m -NAP)
Reference	PAW 1	52°39.268'N	4°16.280'E	25
Area	PAW 2	52°39.268'N	4°14.430'E	25
Inside	PAW 3	52°34.989'N	4°12.944'E	25
wind farm	PAW 4	52°35.568'N	4°13.727'E	22

3.2.1 Technical description of CPODs

The CPOD Continuous POrpoise Detector (CPOD version 1, Chelonia Ltd) is a new generation of passive acoustic monitoring devices. The principle is the same as the T-POD which has formerly been used in passive acoustic monitoring studies (Blew *et al.*, 2006; Scheidat *et al.*, 2009; Tougaard *et al.*, 2006 a & b), however, CPODs have an increased endurance and a higher capability to store memory. The CPOD consists of a polypropylene casing with hydrophone housing at one end and a removable lid at the other end. There is a metal retaining ring around the centre of the CPOD that holds the mooring line. Two lines, one of which is housed in a anti-chaffing tube to prevent chaffing, are attached to the anchor. Inside the housing is an amplifier, a digital waveform analyser, a data-logger that logs echolocation click-activity and 10 D-cell batteries; the CPOD has a positive buoyancy of approximately 0.7 kg. The data are stored on a Secure Digital (SD) flash card and later analysed with a PC to identify the presence of cetaceans by detecting the trains of ultrasonic echo-location clicks they produce. To minimise data storage requirements a summary of the click features is logged, comprising time, duration, dominant frequency, bandwidth and amplitude.

The CPOD relies on the highly stereotypical nature of porpoise echolocation signals. These are distinctive in lasting about 50-150 microseconds, and containing virtually no energy below 100 kHz. The main part of the energy is around 132 kHz in a narrow band between 120-150 kHz, which makes the signals ideal for automatic detection. Most other sounds in the sea, with the exception of some boat sonars, are generally more broadband or have energy at lower frequencies. Although many non-porpoise clicks are also recorded, these, as well as boat sonars and echosounders, are filtered out during post-processing, by analysing intervals between successive clicks. Porpoise click trains are recognisable by a gradual change of click intervals and amplitudes throughout a click sequence, whereas boat sonars and echosounders have highly consistent inter-click intervals. Clicks of other origins tend to occur at random with highly irregular intervals, so a probability model of a train is used as the basis of the train filter.
For this study, the A-filter frequency was set at 100 kHz and the B-filter frequency was set to 80 kHz. The train quality filter was set to record Hi(gh) and Mod(erate) quality click trains from porpoise like and dolphin clicks. The maximum detection range of the CPOD is ca 300 m.

Although CPOD records 'porpoise like' and dolphin clicks, there is no commonly occurring cetacean found in the North Sea that 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).

3.2.2 Calibration and servicing

With the help of the RWS-vessel Terschelling the four CPODs were deployed 1 September 2009, and recovered 2 September 2010. The PODs were serviced 15 December 2009, 9 March 2010 and 26 May 2010 (see Appendices A-E). This included cleaning, changing the batteries, and exchanging the memory card for each CPOD, and when necessary replacing lost or broken CPODs. The sensitivity of the CPODs was standardized by the manufacturer (Chelonia Ltd) before shipping to IMARES. The CPOD is rotated in a sound field and adjusted to give a radially averaged, temperature corrected, sound pressure reading within 5% of the standard at 130KHz (±0.5dB). The standard has been measured by the National Physical Laboratory in the United Kingdom. Only PODs that have a radial variation < ±3 dB relative to the mean sensitivity are shipped.
The CPODs were calibrated in the accredited German Meeresmuseum in Stralsund, on 7 March 2012 (POD 715), 12 April 2012 (POD 716) and 11 May 2012 (POD 717 & 719), see Appendices F and G. Details of the calibration can be found in Verfuß *et al.* (2010).

3.2.3 Mooring technique

The mooring used for the CPODs in the Dutch coastal waters was designed using robust material, i.e. buoys, chain and concrete anchors. The CPODs within the wind farm were secured with a mooring consisting of one buoy while the CPODS in the reference area were secured with a mooring of two buoys, of which the larger was equipped with a yellow warning lantern (Figure 2). The second buoy served as an extra security measure to avoid the risk of collision with trawlers in the area. The CPOD floats approximately 1 m above the concrete anchoring and thus approximately 1 m above the sea bed.

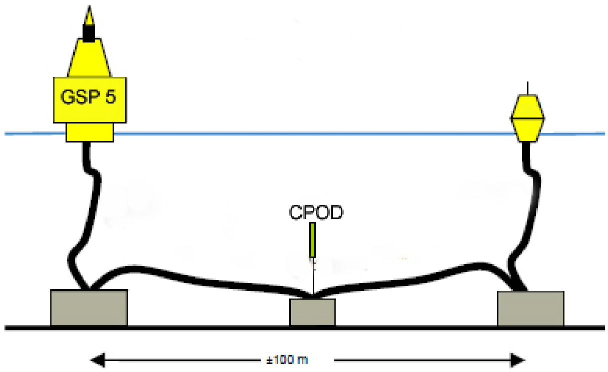

Figure 2. Schematic view of the CPOD anchoring method used outside the wind farm.

3.3 Analysis of CPOD data

Following recovery of the CPODs, data is downloaded on to a PC *in situ*. Harbour porpoise echolocation clicks are 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. Version 1.037 of the software "CPOD.exe" was used to analyse the data. Data were exported and further analysed using Excell and R-software (R Development Core Team, 2009).

3.3.1 Echolocation activity indicators

In line with previous studies (Carstensen *et al.*, 2006, Tougaard *et al.*, 2006a & b; Teilmann *et al.*, 2009), two indicators were extracted from the exported CPOD data, which had the fundamental unit of clicks per minute. This signal, denoted xt, 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:

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

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

The click frequency is expressed as a percentage PPM and thus indicates the fraction of the day (out of 1440 minutes for a full day of recordings) wherein one or more porpoise click trains could be detected. The click intensity is expressed as clicks per PPM, and indicates the daily average number of clicks in minutes where clicks were detected.

3.3.2 Statistical analysis

Since we expect non-linear patterns in the data so-called smooth functions were incorparated in the statistical model construction (Wood, 2006). To study the possible impact of the wind farm on harbour porpoises Generalized Additive Mixed Models (GAMM) were used comparing porpoise activity inside the wind farm with the registered activity in the reference area. This group of models takes different sources of variation (CPODs, season, data gaps, temporal correlation) into account and finally compares porpoise activity inside and outside the wind farm. For the best model the observed counts were fourth root transformed to homogenize the variation and the model included, apart from a variable for the two areas (inside and outside the windfarm) a cyclic smoother for the day of the year. This means that the smooth function is restricted in such a way, that the first value of the smoother needs to connect to the last value. This to ensure that day 1 attaches to day 365, which is necessary if a seasonal pattern in the data is expected. Furthermore, the CPODs are modeled as a random effect, as each CPOD may have a small amount of extra variation (e.g. resulting from device specific bias or a difference caused by deployment depth) though the average effect is supposed to by zero. Finally, remaining temporal correlation was removed by including a temporal correlation structure on the data. This is necessary as p-values are influenced by the amount of data and the calculation of p-values assumes independence of the data. However, if there is temporal (or spatial) correlation within the data, they are not independent and corrections thus must be made to obtain correct p-values.

4 Results

4.1 Monitoring Effort

Between the 1st of September 2009 and the 2d of September 2010 CPODs were deployed 366 days, of which a proportion yielded data (see Table 2 and Figure 3). PAW 3 and PAW 4 inside the wind farm recorded almost continuously (93.2 and 94.5% of all deployment days), whereas PAW 1 and PAW 2 in the reference area outside the farm collected data on acoustic signals for a shorter time period (84.2 and 75.1%). Though PAW 1 and PAW 2 did not record in November 2009 and January-February 2010 respectively, the overall coverage is high.

Table 2. Summary of the total effort expressed as number of deployment days and daily indicators of porpoise activity, click frequency and click intensity.

	Effort	PPM	Click frequency				Click intensity			
	(days (/%))	(days(%))	Min	Mean	Median	Max	Min	Mean	Median	Max
PAW 1	308 (84.2)	283 (91.9)	0	0.94	0.56	11.39	0	0.42	0.21	6.14
PAW 2	282 (75.1)	260 (92.2)	0	0.91	0.49	17.37	0	0.46	0.17	11.24
PAW 3	341 (93.2)	291 (85.3)	0	0.65	0.42	7.99	0	0.26	0.12	3.84
PAW 4	346 (94.5)	307 (88.7)	0	0.84	0.49	8.13	0	0.40	0.20	4.80

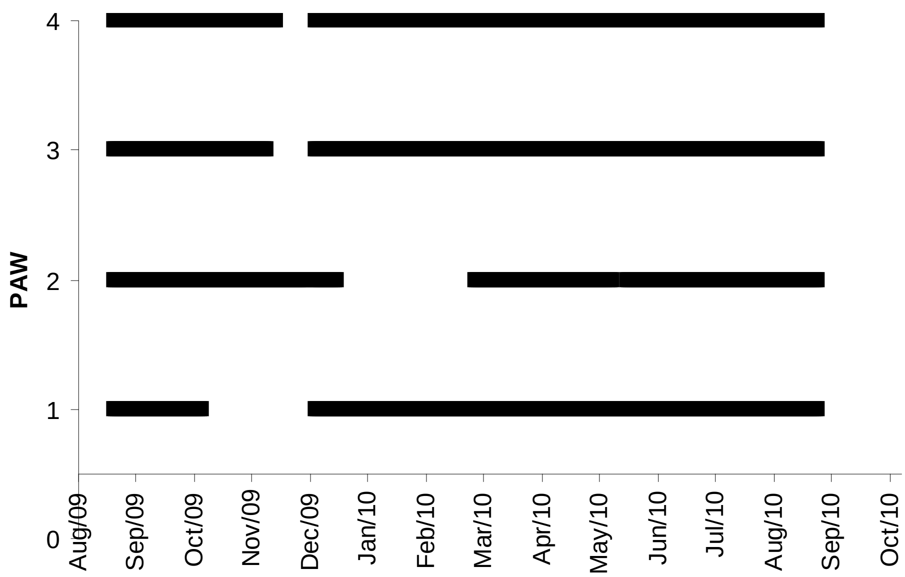

Figure 3. Daily recording effort of CPODs. The lines represent recording effort.

4.2 Porpoise acoustic activity

Based on the number of clicks the indicators PPM (Porpoise Positive Minutes) and clicks per PPM were calculated on a daily basis. Harbour porpoises were detected on 1141 of the 1270 recording days. In other words porpoises were not detected on 10.2% of the recording days. PAW 1 and PAW 2 recorded porpoise activity on 91.9 and 92.2% of all days, PAW 3 and PAW 4 on 85.3 and 88.7% of all days (Table 2). Due to differences in recording effort a direct comparison of these numbers is not possible, but it is obvious that harbour porpoises occur frequently in the study area.

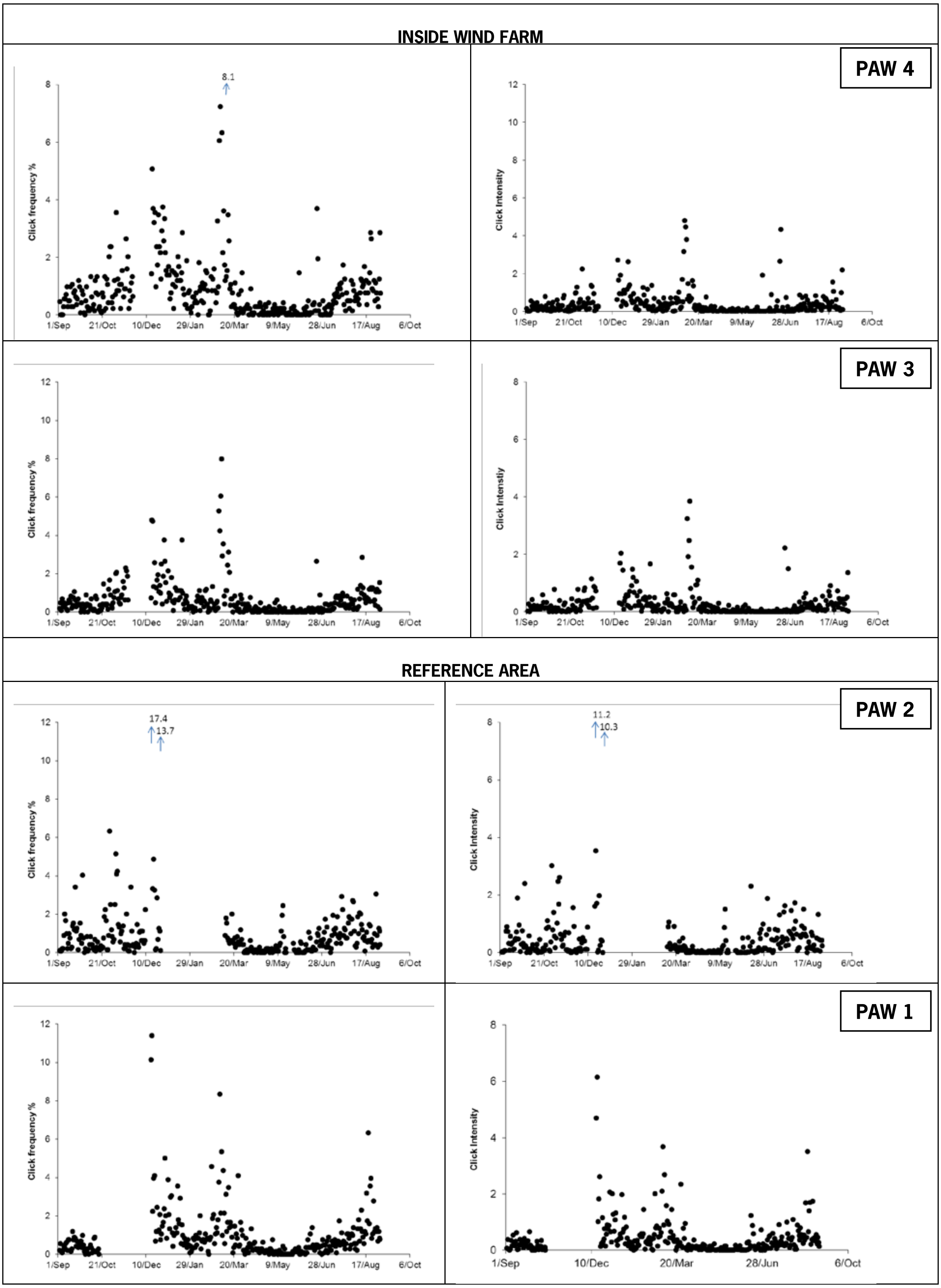

Figure 4. Daily click frequency (left) and click intensity (right) extracted from the four CPODs. Top rows PAW 4 and PAW 3 inside the wind farm, and bottom rows PAW 2 and PAW 1 outside the wind farm.

From these indicators the click frequency and click intensity were derived. Daily click frequency varied from on average 0.65 PPM/day at PAW 3 to 0.94 PPM/day at PAW 1, the median click frequencies ranged from 0.42 to 0.56 PPM/day (Table 2). The click frequency showed a distinct temporal pattern with higher activity in March and December, and the least activity in April-May (Figure 4).

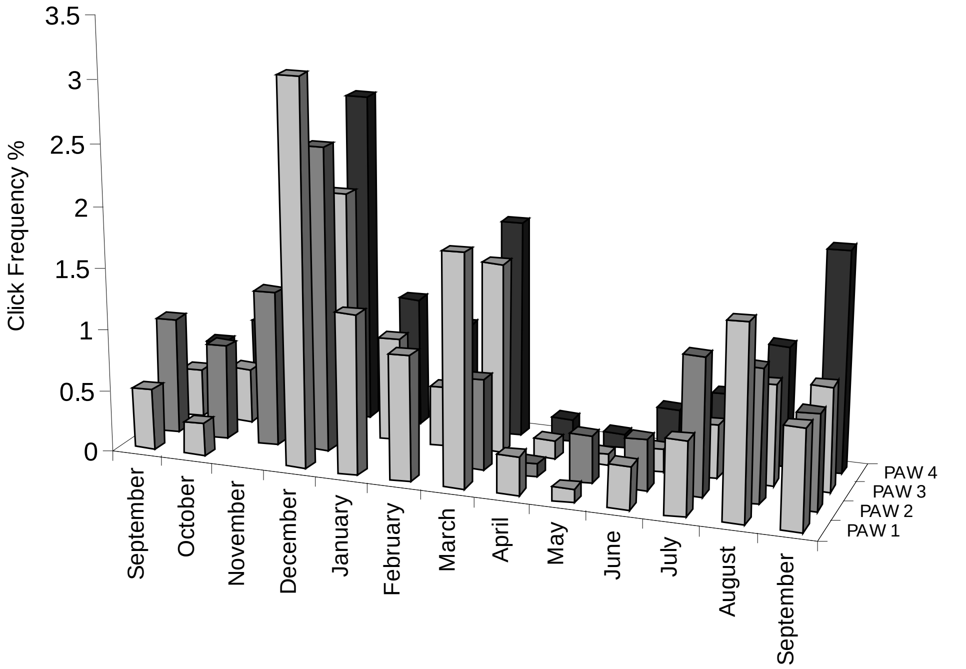

Figure 5. Average monthly click frequency for each CPOD, 1 September 2009 until 2 September 2010.

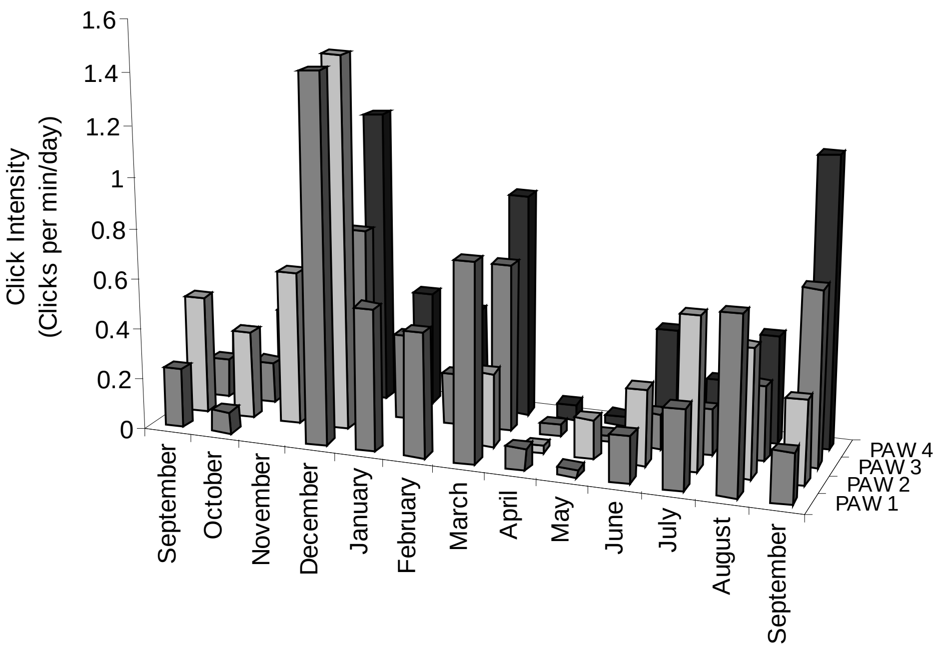

Figure 6. Average monthly click intensity for each CPOD, 1 September 2009 until 2 September 2010.

The daily click intensity (clicks/PPM) showed less variation than the click frequency, with on average a minimum of 0.26 (PAW 3) and a maximum of 0.46 (PAW 2) clicks/PPM. The median values ranged from 0.12 (PAW 3) to 0.21 (PAW 1) clicks/PPM (Table 2). Though the click intensity does not have a linear correlation with the click frequency, both parameters show roughly the same temporal pattern (Figure 4). To summarize these patterns, the data are pooled per month (Figures 5 & 6).

4.3 Comparison of the wind farm and the reference area

Results of the GAMM model are presented in table 3. The best model included a single smoother ($p=7.33 \times 10^{-9}$) for all CPODs (Table 3, Figure 7). The output of the model should be viewed as follows: the model generates a value which is the transformed value, thus to get the click frequency it has to be back-transformed. The fitted value consists of an intercept and a value that is added to the output if it is within a windfarm (In Windpark); furthermore a value from the smooth function is added. Next to the temporal trend in the data, it remained necessary to impose a temporal correlation structure on the data. It basically means that the correlation between points that are close in time is taken into account which deflates the p-values to correct for the dependency in the data. The statistical output indicates that a clear yearly pattern in harbour porpoise recorded minutes per day exists that is highly significant and that there is no significant effect of the wind farm (In1, p=0.175).

From November onwards click frequency increases till a peak is observed at the end of December after which the click frequency decreases again to a minimum in early April.
Since the data showed no differences between the CPODs, daily and tidal patterns in the acoustic activity were not analyzed,

Table 3. Statistical output of the GAMM model.

	Estimate	Std. Error	t –value	Pr(>|t|)
Intercept	0.8357	0.0434	19.278	<2e-16
In Windpark	-0.081	0.0595	-1.355	0.175
Approximate significance of smooth terms:				
	edf	Ref.df	F	p-value
s(Julian_day)	3	3	13.8	7.33E-09

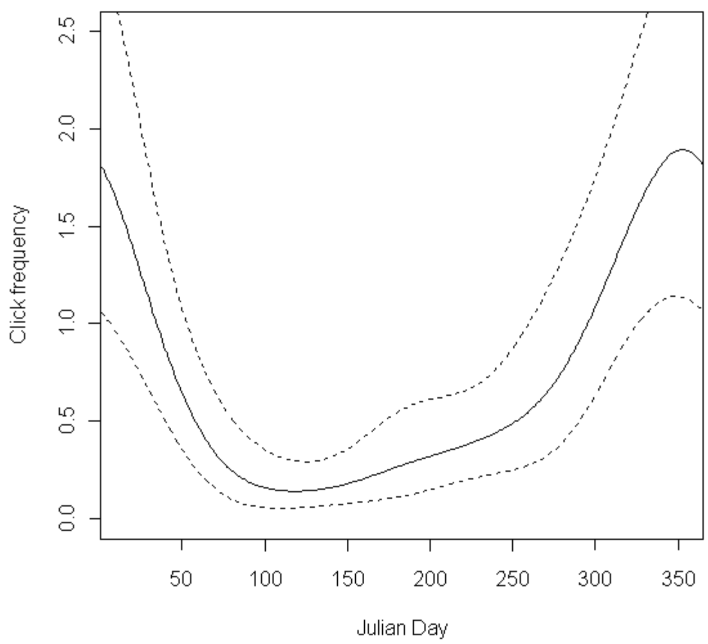

Figure 7. Estimated click frequency (solid line) for each day with 95% confidence limits (dashed line). Julian Day 1 = 1st of January.

5 Discussion

5.1 Methodology

From the 1st of September 2009 until the 2nd of September 2010, four CPODs collected data on the presence of harbour porpoises within Prinses Amaliawindpark and a reference area to the north of the wind farm during 89.8% of all (deployment) days. Technical failures were the most likely cause for the lack of recording data. During the last deployment period (May-Sep) growth on the CPODs does not appear to have had an effect on the data; the recorded porpoise clicks do not decrease in time, as you would expect when growth limits the sensitivity of a CPOD.

The results of the calibration (Appendix F & G) show neglible differences in the mean peak-to-peak pressure (Ppp) of the CPODs 716, 717 and 719 at the measured emitted frequencies 100, 110, 120, 130 and 140 kHz. Apparently CPOD 715 differs from the other PODs. Since the main part of the energy of a porpoise click is around 132 kHZ the differences at 130 kHz are the most applicable for comparison. At 130 kHz CPOD 715 shows a mean peak-to-peak pressure that is 15 bar-m lower than the other PODs (110 vs 125 bar-m, Appendix G). This difference in peak-to-peak pressure corresponds to a difference in received sound level less than 3 dB. This level is well below the maximum accepted variation recommended by the international AMPOD-project aimed at standardizing the use of passive acoustic monitoring devices (Verfuß *et al.*, 2010). Therefore, we draw the conclusion that the received sound levels of all the CPODs are within the accepted standards for variations and, consequently, make a comparison of porpoise activity inside and outside the wind farm feasible.

It has to be stressed that the collected data are an approximation of the occurrence of harbour porpoises. These animals use echolocation as an active sensory system for information about their environment, and to a lesser extent as a means of communication. Two different studies concluded that porpoises virtually use echolocation continuously. Verfuß *et al.* (2005) demonstrated the continuous use of echolocation on the basis of porpoises in the wild. Differences in the environment or changes in behaviour were reflected in differences in click intensity and did not result in interruptions of echolocation. In Danish waters a wild porpoise was equipped with an acoustic data logger to record the animal's echolocation activity (Teilmann *et al.*, 2005). This study also showed an almost continuous use of echolocation. Therefore it is reasonable to conclude that CPODs can give a reliable picture of the occurrence of harbour porpoises, but the collected data cannot be used to assess the number of porpoises as research has found no linear correlation between acoustic activity and the density of porpoises (Kyhn *et al.*, 2008; Kyhn & Tougaard, 2009).

5.2 Porpoise occurrence on a broader temporal and spatial scale

The CPODs have shown the regular presence of porpoises in the study area, with the lowest acoustic activity in April-May and peak activity in winter and early spring. During ship based surveys to study the effects of offshore wind farms no porpoises were detected in the study area (Leopold, unpublished data). The pattern revealed by CPODs fits the situation along the Dutch coast as seen during systematic land based observations of seabird migration by members of the Working Group Club van Zeetrekwaarnemers from the Dutch Seabird Group (CvZ/NZG). These observations show that porpoises are present in coastal waters throughout the year, with the highest numbers in winter and early spring (Dec-Mar). Observations in June and July are relatively scarce, but a summer peak is evident in August (e.g. Camphuysen, 2004). The observed numbers along the Dutch coast strongly fluctuate on a temporal and spatial scale.

The situation further offshore differs from the situation in the coastal zone. Bi-monhtly aerial surveys (Arts, 2010), primarily aimed at monitoring seabird numbers, show the occurrence of harbour porpoises on the Dutch Continental Shelf throughout the year, with peak densities in April-May and a dip in numbers between August and January, followed by increasing densities in February-March. The bi-monthly distribution seems to indicate an inshore and southward movement in February-March, whereas peak numbers in April-May occur in the NW of the DCS, North of the Wadden Isles and in the Central North Sea. The southern North Sea is virtually devoid of porpoises in June-July (Arts, 2010). Aerial surveys aimed at assessing the abundance and distribution of harbour porpoises on the Dutch Continental Shelf showed a slightly different pattern, with peak numbers in March and lower numbers in July and October/November when more than 25,000 animals are present (Geelhoed *et al.*, 2011).

To summarize, the seasonal pattern in the Prinses Amaliawindpark fits in with the broader picture of seasonal changes in harbour porpoise distribution on the Dutch Continental Shelf. The high numbers in April-May seem to contradict this, but they occur largely north of Prinses Amaliawindpark.

5.3 Comparison with other offshore wind farms

A comparison of this study with the results of acoustic studies already carried out during the operation phase in other offshore wind farms, in particular Horns Rev 1 and Nysted in Denmark and OWEZ in the Netherlands, cannot directly be made, since these studies used different passive acoustic monitoring devices. This study used the more advanced CPOD, while the previous studies used different versions of the T-POD, the predecessor of the CPOD. Neither the detection thresholds of the used monitoring devices for harbour porpoise acoustic signals, nor the relationship between measured acoustic activity and number of harbour porpoises is known. Consequently, a comparison between the conducted studies can only be done qualitatively.

Horns Rev I is the first studied offshore wind farm in European waters. It is located along a shallow reef in Danish North Sea waters just north of Germany. The study was aimed at determining possible differences in the abundance of harbour porpoise before, during and after construction by means of monitoring acoustic activity in the wind farm with T-PODs. (Tougaard *et al.*, 2006b). After a decline during the construction in 2002 a full recovery of porpoise acoustic activity to baseline levels was reached in the first year of operation. A study in the subsequent operation year confirmed these results (Blew *et al.*, 2006).

Nysted in the Danish Baltic Sea, where harbour porpoise density is relatively low, was constructed in 2002-2003. Possible effects were studied with T-PODs in a so-called BACI design: before, during and after construction, in the wind farm and at a reference area 10 km away. In the second year of operation, the acoustic activity of harbour porpoises within the wind farm was still below baseline levels, whereas this activity reached baseline levels in the reference area (Tougaard *et al.*, 2006a). On a smaller scale of several hundred meters Blew *et al.* (2006) found no differences in acoustic activity along a gradient across the edge of the wind farm. These studies indicate that effects are probably restricted to the vicinity of this wind farm.
Overall, the Danish studies showed no or a negative effect of operational wind farms on the occurrence of harbour porpoises. The situation in the first Dutch offshore wind farm (OWEZ) northeast of the Prinses Amaliawindpark is different.

Table 4. Characteristics of the two Dutch offshore wind farms, where impact studies on harbour porpoises have been conducted during the operational phase.

	Distance from coast (km)	Water depth (m)	Area (km2)	Number of turbines	Nominal capacity per turbine (MW)	Study Period
PAWP	23	19-24	14	60	2	Sep 2009-Sep 2010
OWEZ	13-18	18-20	40	36	3	Jun 2007-Apr 2009

OWEZ is located in the North Sea, 8-18 km west of Egmond aan Zee (see Table 4). Construction of this wind farm began in April 2006 with all the turbines installed by August of the same year. The wind farm was commissioned on the 1st of January 2007. In the two years following construction a study on the effects using a BACI design was conducted. This study showed a significant change in the distribution of harbour porpoises between the reference areas outside the wind farm and the impact area inside the wind farm. Acoustic activity levels –as an approximation of harbour porpouise occurrence- increased above the baseline levels both inside and outside the windfarm. The increase in porpoise acoustic activity was higher inside the wind farm relative to the two reference areas outside the wind farm. The cause of the increase was not determined, but a likely possibility was an increased food available for porpoises due to the reef effect of the turbine foundations and the exclusion of fishery and shipping inside the wind farm (Scheidat *et al.*, 2009 & 2011).

Even though the same underlying mechanisms could be expected in the present study, no increase in harbour porpoise activity was found. A potential effect –positive or negative- of Prinses Amaliawindpark could have occurred initially, before the present study was undertaken. harbour porpoises might habituate to a wind farm. Possible explanations for the difference between wind farms are speculative, since we do not have data on for instance (changes in) food availability in Prinses Amaliawindpark, but the system might be stabilizing after an initial increase in fish abundance. Furthermore, the higher density of turbines in Prinses Amaliawindpark could theoretically emit more sound than the turbines in the OWEZ-farm, counter balancing possible positive effects of increased fish abundance.

6 Conclusions

In this study no difference was found between the acoustic activity of harbour porpoises within the wind farm and in the reference area during the second year of operation of the wind farm.
It is not evident whether the different effects (negative in Nysted, no effect at Horns Rev I and Prinses Amaliawindpark, and positive effect in OWEZ) can be attributed to differences in the farms per se (e.g. differences in density of turbines, turbine types or foundation) or whether general ecological differences between the areas cause harbour porpoises to respond different.

7 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 C177/10
Project Number: 430 61142 01

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

Approved: Meike Scheidat
Senior researcher

Signature:

Date: 30 May 2012

Approved: Jakob Asjes
Head of department IMARES Ecosystems

Signature:

Date:

Number of copies:	NA
Number of pages	34
Number of tables:	4
Number of figures:	7
Number of appendix attachments:	7

Appendix A: Cruise Report 1

On the 1st of September 2009 CPODs 715, 716, 717 and 719 were successfully deployed with the vessel Terschelling.

CPOD 715 was deployed at PAW 1, 52°39.2678 N and 004°16.2800 E, which is to the north of the wind farm. The CPOD was deployed ca -25 m NAP (Normaal Amsterdams Peil).

CPOD 716 was deployed at PAW 2, 52°39.2678 N and 004°14.4300 E, which is to the north of the wind farm. The CPOD was deployed ca -25 m NAP.

CPOD 717 was deployed at PAW 3, 52°34.9891 N and 004°12.9440 E, which is in the wind farm. The CPOD was deployed ca -25 m NAP.

CPOD 719 was deployed at PAW 4, 52°35.5683 N and 004°13.7269 E, which is in the wind farm. The CPOD was deployed ca -22 m NAP.

The distance between PAW 1 and PAW 2 is 2.1 km, while the distance between PAW 3 and PAW 4 is 1.39 km. The distance between PAW 2 and Paw 4 (closest CPODS from north to south (inside and out of the wind farm)) is 6.81 km.

Appendix B: Cruise Report 2

On the 15th of December 2009 CPODs 715, 716, 717 and 719 were recovered.

CPOD 715
Recorded data between 2/9/2009 and 17/10/2009. The CPOD recorded for 44% of the time. Reasons for the failure to record are unknown, but did not included battery deficiency.

CPOD 716
Recorded data between 2/9/2009 and 09/11/2009. The CPOD recorded for 95% of the time. Memory card read 99% full.

CPOD 717
Recorded data between 2/9/2009 and 19/11/2009. The CPOD recorded for 76% of the time. Reasons for the failure to record after the 19th are unknown, but did not include battery deficiency.

CPOD 719
Recorded data between 2/9/2009 and 24/11/2009. The CPOD recorded for 81% of the time. Reasons for the failure to record after the 24th are unknown, but did not include battery deficiency.

The same CPODs were redeployed on the 15th of December 2009.

Appendix C: Cruise Report 3

On the 9th of March 2010 CPODs 715, 716, 717 and 719 were recovered and CPODs 715, 716 & 717 were redeployed. CPOD 719 was not redeployed as there were issues with the power source. CPOD 714 was deployed in it's place.

<u>CPOD 715</u>
Recorded data between 15/12/2009 and 09/03/2010. The CPOD recorded for 100% of the time.

<u>CPOD 716</u>
Recorded data between 15/12/2009 and 26/12/2009. The CPOD recorded for 14% of the time. Reasons for the failure to record after the 26th are unknown, but did not include battery deficiency.

<u>CPOD 717</u>
Recorded data between 15/12/2009 and 09/03/2010. The CPOD recorded for 100% of the time.

<u>CPOD 719</u>
Recorded data between 15/12/2009 and 09/03/2010. The CPOD recorded for 100% of the time.

Appendix D: Cruise Report 4

On the 26th of May 2010 CPODs 714, 715, 716 and 717 were recovered and then redeployed.

CPOD 714
Recorded data between 09/03/2010 and 26/05/2010 and. The CPOD recorded for 100% of the time.

CPOD 715
Recorded data between 09/03/2010 and 18/05/2010. The CPOD recorded for 90% of the time. Reasons for the failure to record after the 18th are unknown, but did not include battery deficiency.

CPOD 716
Recorded data between 09/03/2010 and 26/05/2010. The CPOD recorded for 100% of the time.

CPOD 717
Recorded data between 09/03/2010 and 26/05/2010. The CPOD recorded for 100% of the time.

Appendix E: Cruise Report 5

On the 2nd of September 2010 CPODs 714, 715, 716 and 717 were recovered. All had substantial algal and seaweed growth.

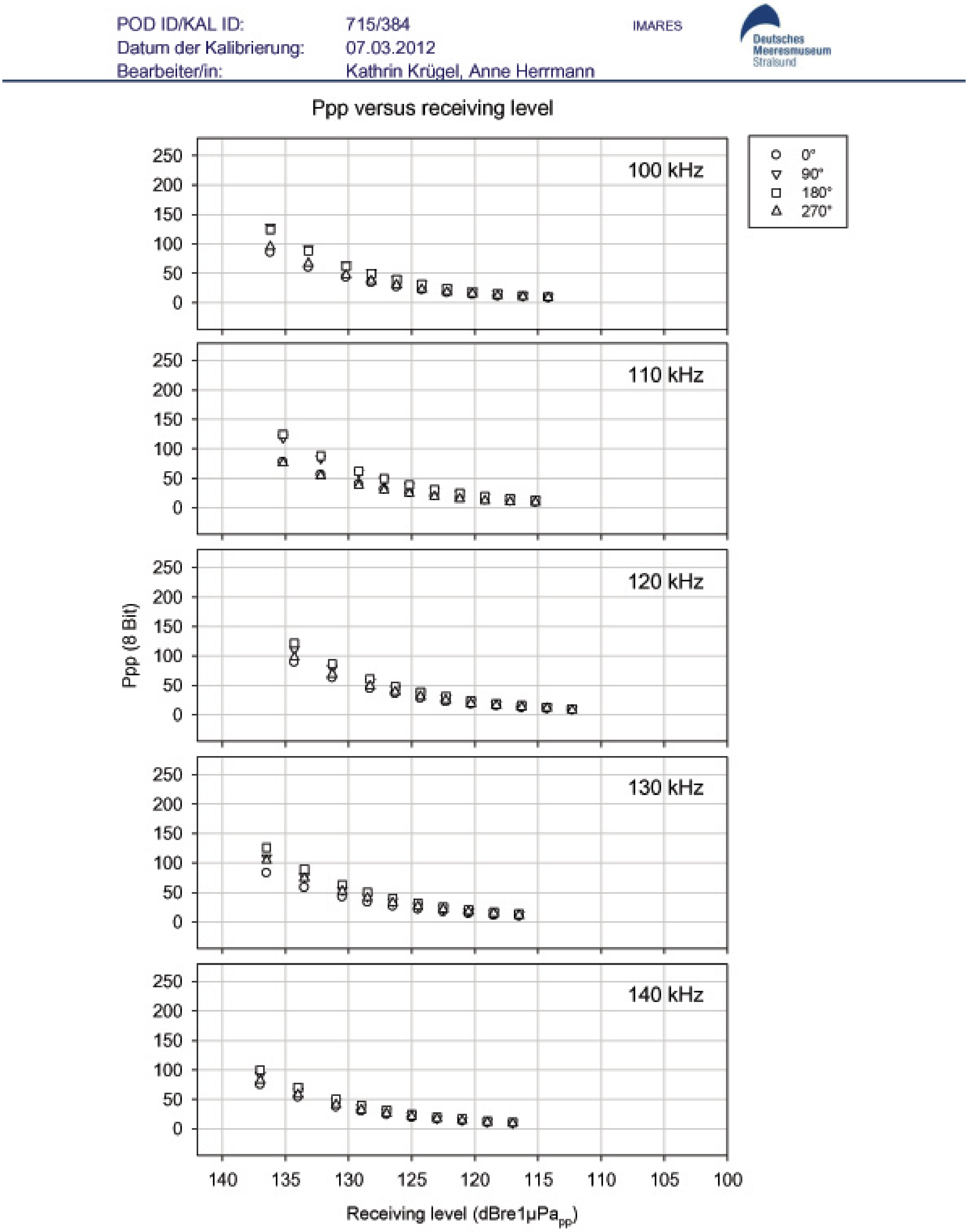
CPOD 714
Recorded data between 26/05/2010 and 02/09/2010. The CPOD recorded for 100% of the time.

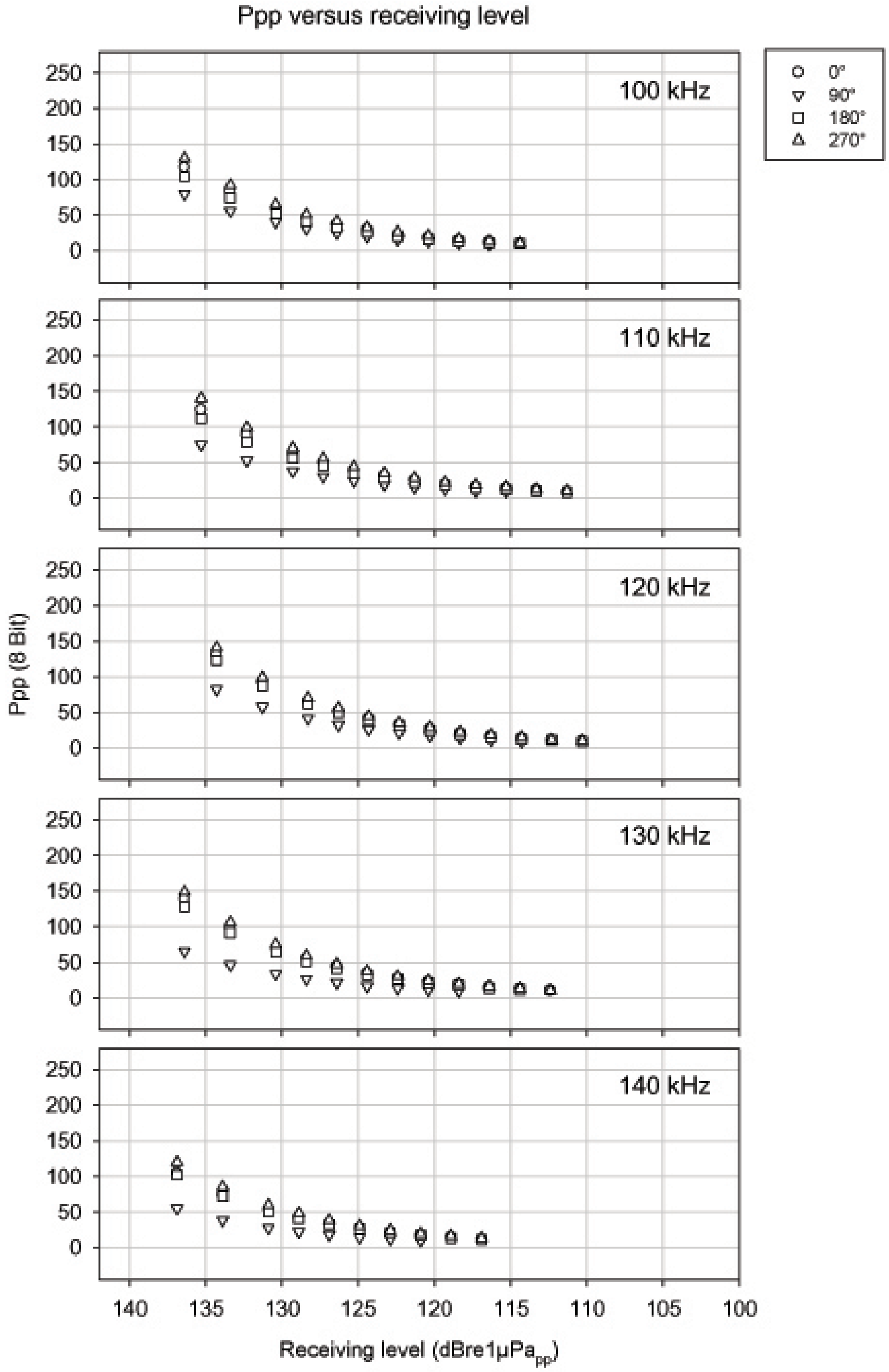
CPOD 715
Recorded data between 26/05/2010 and 02/09/2010. The CPOD recorded for 100% of the time.

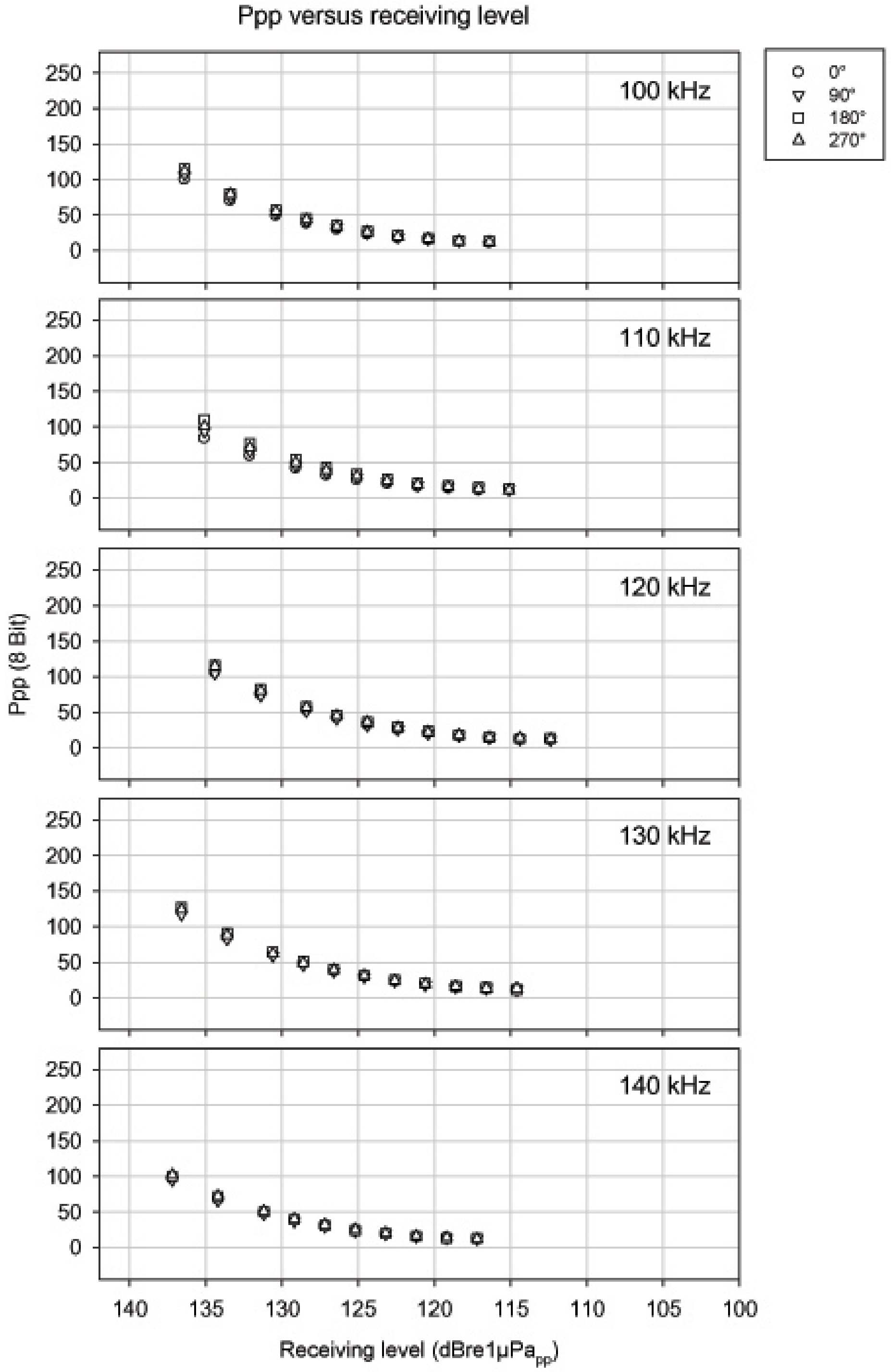
CPOD 716
Recorded data between 26/05/2010 and 02/09/2010. The CPOD recorded for 100% of the time.

CPOD 717
Recorded data between 26/05/2010 and 02/09/2010. The CPOD recorded for 100% of the time.

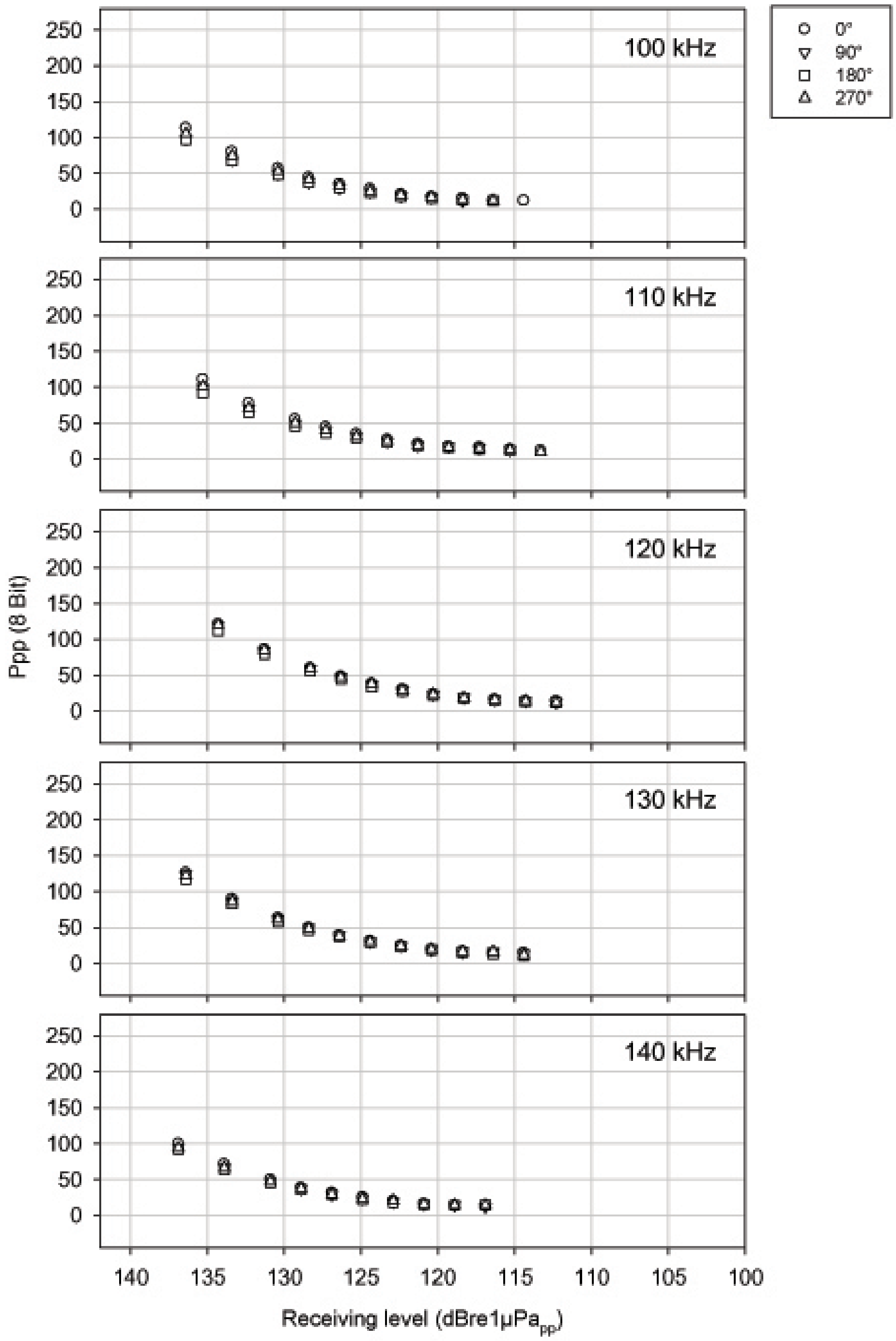
Appendix F: calibration results - Ppp vs receiving level



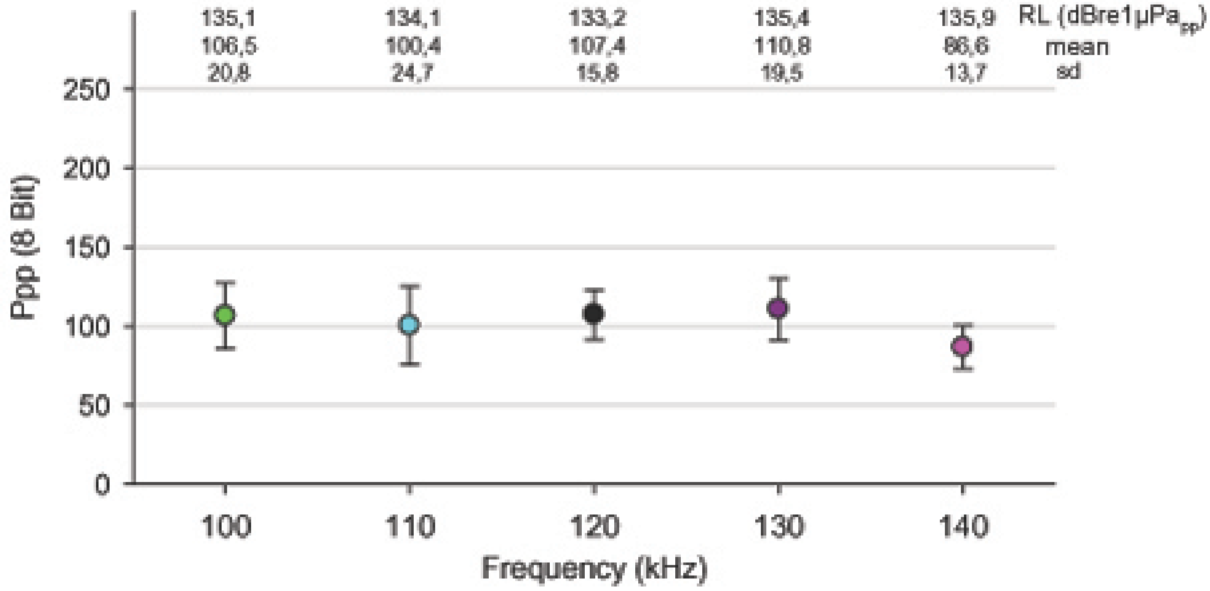

Ppp versus receiving level
0°
90°
180°
270°
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
250
200
150
100
50
0
Ppp (8 Bit)
140
135
130
125
120
115
110
105
100
Receiving level (dBre1µPa$_{pp}$)


Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
250
200
150
100
50
0
140
135
130
125
120
115
110
105
100
Receiving level (dBre1μPa$_{pp}$)

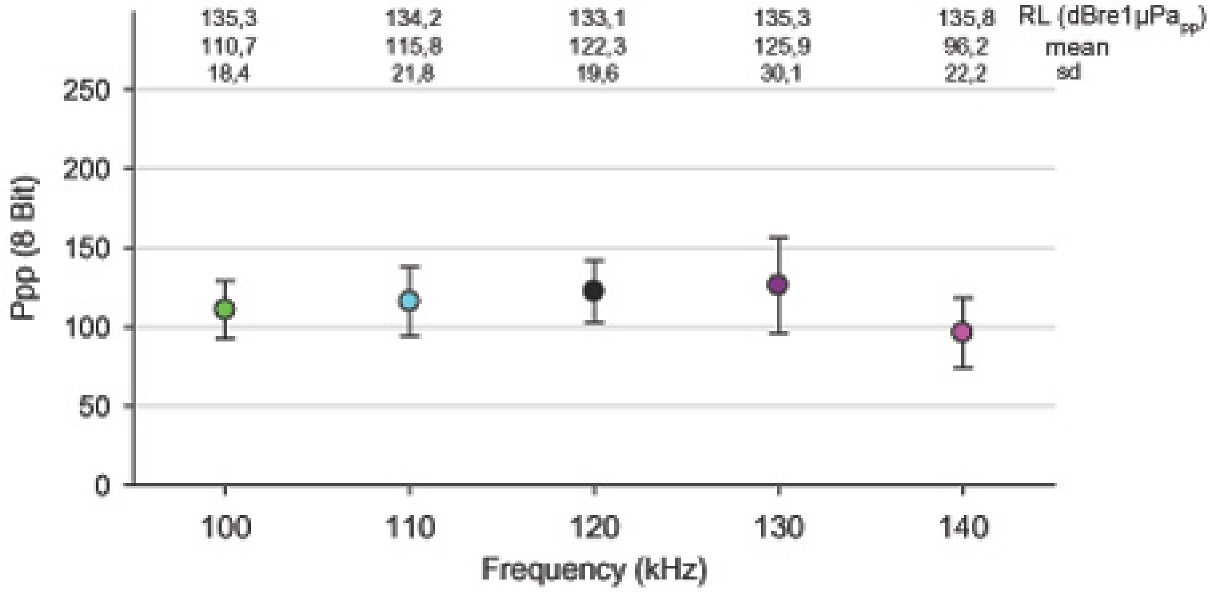
Ppp versus receiving level



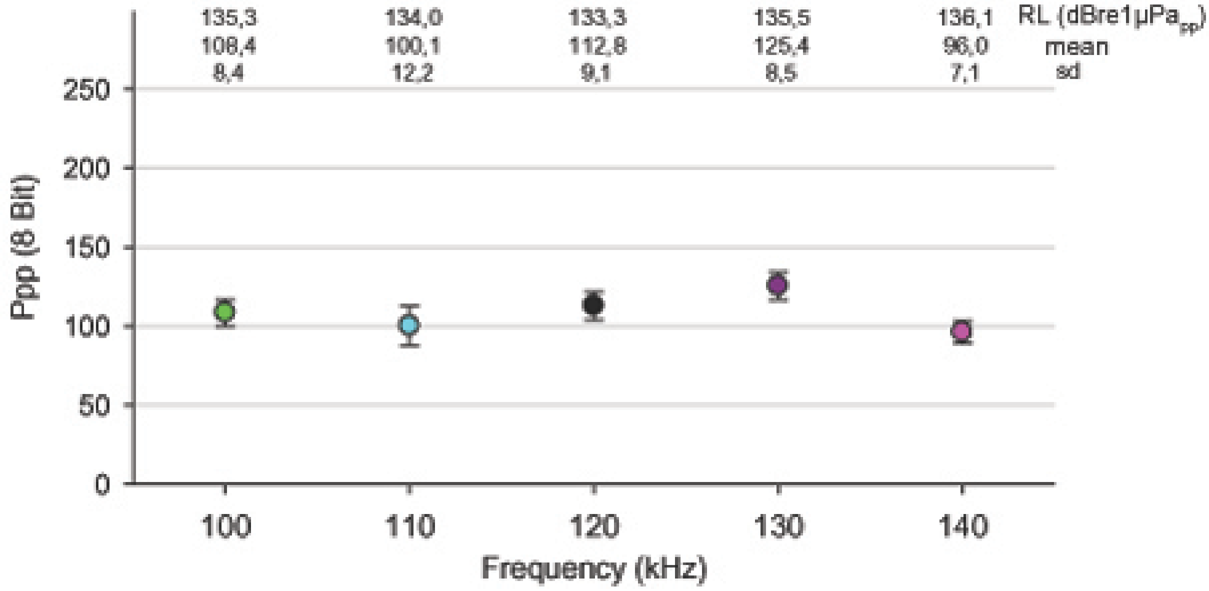
Appendix G: calibration results – Ppp vs frequency



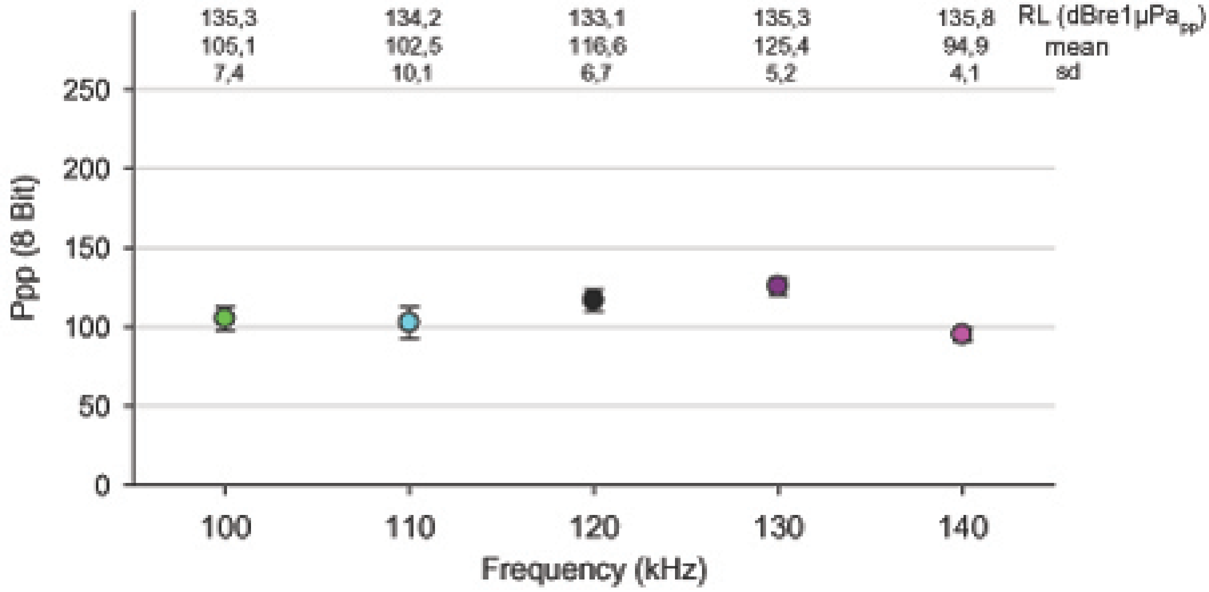
CPOD 715



CPOD 716



CPOD 717



CPOD 719