# Gemini T-0: passive acoustic monitoring and aerial surveys of harbour porpoises

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## Summary

In accordance with the monitoring and evaluation plan (MEP) for the 'Gemini Offshore Wind Farm' the ecological monitoring of harbour porpoises was carried out by IMARES and IBL Umweltplanung, concerning the distribution and numbers of harbour porpoises in and around the wind farm prior to construction (T-0). For this purpose aerial surveys as well as passive acoustic monitoring were performed.

In total, seven of eight planned survey flights were conducted at a height of 183 m (600 ft) between August 2013 and June 2014, covering a survey area of nearly 7,800 km². A survey scheduled for December 2013 had to be postponed to December 2014 due to adverse weather conditions, but could not be conducted in 2014 as well due to unfavorable weather conditions.
For the passive acoustic monitoring, 15 CPODs were deployed in a design spreading 40 km to the west and 15 km to the south of the intended wind farm site. Between September 2011 and July 2014, 6,881 days of CPOD recordings were obtained during two distinct one-year sampling periods.

Overall 691 harbour porpoises, and 54 harbour and grey seals were recorded during the aerial surveys. This yields harbour porpoise densities between 0.3 and 1.5 individuals/km² (on average 1.0 /km²). The maximum was observed in April 2014, following lowest numbers in February and early March. Densities of harbour porpoise tended to be higher in the central part of the survey area where the intended Gemini offshore wind farm is located. In June and August 19 calves were seen during the flight surveys.

By passive acoustic monitoring harbour porpoises were detected on 93.2% of days sampled. Harbour porpoise acoustic activity showed a strong seasonal pattern. There was a peak in detections in March and lowest acoustic activity occurred in May-June and December-January. Detection peaks were also associated with high-tide cycles and morning periods.

Although the results of aerial surveys and passive acoustic monitoring do not show exactly the same pattern for the flight dates, they reveal a quite similar porpoise phenology over the year and show that the Gemini offshore wind farm is very frequently used by harbour porpoises, especially in spring.

# 1. Introduction

## 1.1 Background

Project Gemini is a 600MW offshore windpark, and is to comprise 150 turbines. Gemini windpark is located 55 km north of the island of Schiermonnikoog in the southern North Sea, in water depths that range between 28 and 36m. Project Gemini consists of two sites both 34 km2, Buitengaats and ZeeEnergie (Figure 1). The nearest large port to the Gemini area is Eemshaven and a submarine power-cable is to connect the windpark with this port. Towers for the turbines are to be pile-driven into the seabed to a depth of approximately 18-24 m, from July onwards in 2015 and 2016. The Wind Turbine Generators (WTG's) for Gemini windpark will be installed on monopile foundations and connected to two offshore transformer platforms, from which two sets of 100 km offshore cables will export the power to an onshore public grid owned by TenneT. Energy production is anticipated to commence in 2016/2017.

*Figure 1. Location of Gemini offshore windparks (indicated by arrows), and surrounding windparks planned (yellow), in construction (orange) and operational (green). Details from "Karte Offshore-Windkraftanlagen in der Deutschen Bucht" by Maximilian Dörrbecker (Chumwa).*

During the last decade, the Dutch government has formulated a strategy to develop a capacity of 4450 MW of energy from offshore windparks (Social Economic Council agreement, August 2013). Construction, operation and decommissioning of offshore windparks has the potential to negatively affect marine ecosystems (Prins et al. 2008). Therefore, offshore windpark developments in the Dutch Exclusive Economic Zone (EEZ) require a 'Waterwet' permit (Water Act, Wtw-permit, until August 2013 also including the Natura2000 legal framework, formerly 'Wet Beheer Rijkswaterstaatwerken', Wbr-permit). Rijkswaterstaat, the management organisation of the Dutch Ministry of Infrastructure and Environment, is the 'Competent Authority' that issues Wtw-permits. In August 2013, the Ministry of Economic Affairs became the Competent Authority with respect to the Natura2000 legal framework (Nb Wet [Nature Management Act], FF Wet [Flora and Fauna Act]).

As part of the application to Rijkswaterstaat for a Wtw-permit for Gemini (WV/2009-1138 and 1139), an 'Environmental Impact Assessment' and an 'Appropriate Assessment' were conducted on each of the two sites (Schuchardt et al. 2009a, b). Based on the Assessments, the Wtw-permit included the obligation to prepare a 'Monitoring and Evaluation Plan' (MEP). The MEP, approved in 2012, contained nine topics, including

1. Monitoring of harbour porpoises in relation to the offshore wind farm
2. Monitoring of seals in relation to the offshore wind farm (in draft, Brasseur et al. 2014)
3. Monitoring of seabirds in relation to the offshore wind farm (see Van Bemmelen et al. 2014)

This study describes program 1, concerning the distribution and numbers of harbour porpoises in and around the Gemini offshore wind farm, prior to construction (time zero, or T-0).

## 1.2 Assignment

This report describes T-0 surveys in and around the Gemini offshore wind farms. The results of acoustic monitoring studies and aerial surveys are combined in one report. The aim of this report is to:

> describe the harbour porpoise temporal and spatial distribution patterns in the vicinity of the Gemini offshore wind farms, to provide a baseline of data and as a basis for advice to monitoring of potential impacts on harbour porpoises during the construction and post-construction phases.

The principal research question for the T-0 surveys is: 'How are harbour porpoises distributed in the general area, in the absence of construction at the Gemini wind farms?' The research assignment was to map year-round harbour porpoise presence, numbers, and distribution, and where possible to record other cetacean species and pinnipeds (harbour and grey seals) in the vicinity.

## 1.3 Harbour porpoise

The harbour porpoise (*Phocoena phocoena*) is a small cetacean that is the most abundant marine mammal species in the North Sea. The Greater North Sea population is estimated at 386,000 animals (Hammond et al., 2002, 2013). In recent years, the harbour porpoise population has undergone a redistribution across its range (Hammond et al., 2002, 2013), resulting in an increase in harbour porpoise abundance in Dutch waters (Camphuysen, 2004). The maximum numbers in Dutch waters were estimated at ca 86,000 animals in March 2011 (Geelhoed et al., 2013).

The harbour porpoise is a protected species in Dutch waters. In European legislation (i.e. the EU Habitat Directive) the harbour porpoise has a higher conservation status than other marine mammals. The Netherlands has signed international (ASCOBANS) and national agreements on the protection of the harbour porpoise in the national Bruinvisbeschermingsplan (Camphuysen & Siemensma, 2012).

Harbour porpoises spend their entire life in the water. They are mammals and have to come to the surface to breathe. Tagged porpoises (n = 35) showed that the time spent at the surface varies between 3.4 and 6% of the time, whereas time spent in the upper layer, 0-2 m below the sea surface, varies between 42.5 and 61.5% of the time (Teilmann et al., 2013). This behaviour makes aerial surveys a feasible method, since porpoises can be typically seen till about 2 m below the surface.

Harbour porpoises use echolocation as an active sensory system for information about their environment, and to a lesser extent as a means of communication. For echolocation harbour porpoises use clicks that

are extremely directional (Villadsgaard et al., 2007) and emitted in a narrow beam in both the horizontal and vertical plane. These echolocation signals are distinctive in lasting about 50-150 microseconds, and containing virtually no energy below 100 kHz (Figure 2). The main part of the energy is around 132 kHz in a narrow band between 120-150 kHz (Au et al., 1999). These characteristics make acoustic detection of porpoises relatively easy.

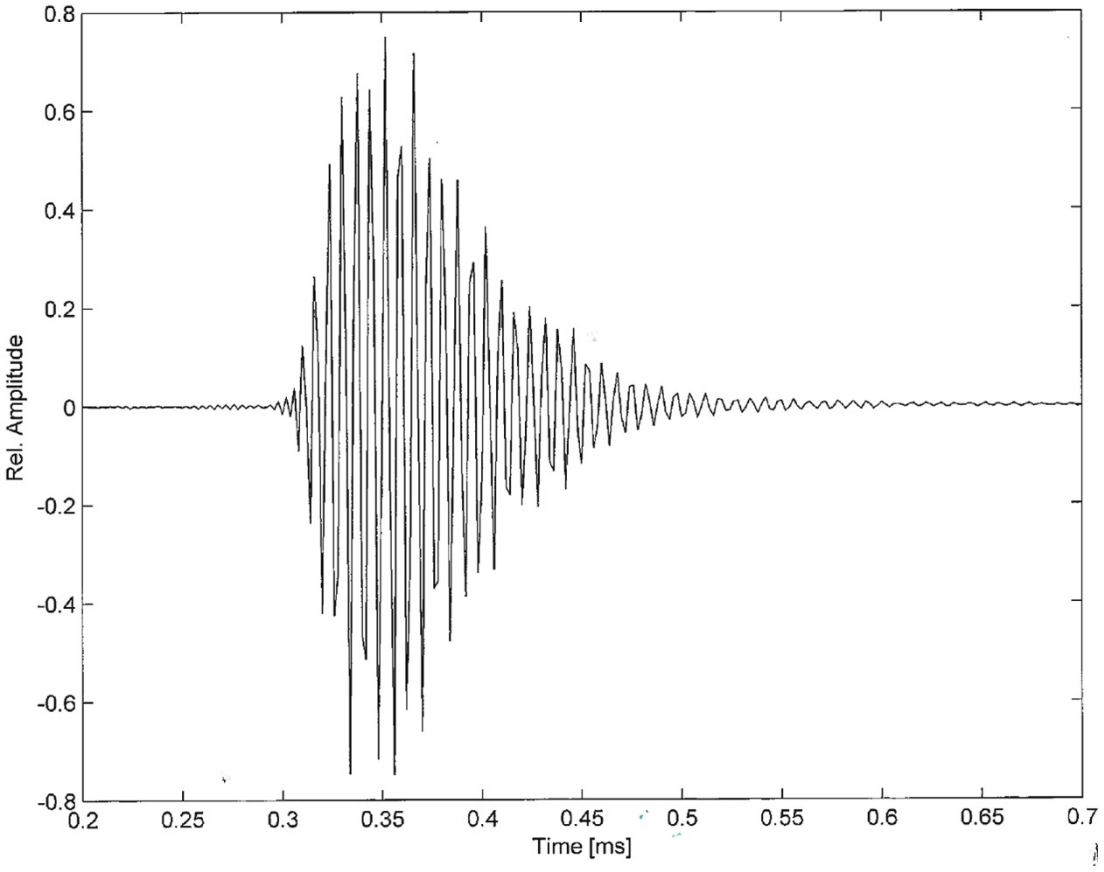


*Figure 2. Harbour porpoise click.*

Porpoises have extremely sensitive hearing making them vulnerable to noise-induced effects from anthropogenic activities at sea (Kastelein et al., 2010; 2012a-b; 2013a-d; 2014a-b; Lucke et al., 2009). Construction of offshore wind farms is known to displace harbour porpoises (Brandt et al., 2011, Dähne et al., 2013, Tougaard et al., 2009). The most important aspect for the effect range on harbour porpoises of the construction of offshore wind farms is sound production and underwater propagation. Sound is the main mediator for behavioural reactions in harbour porpoises. The pile-driving impulse sound is audible to harbour porpoises over wide ranges and in open waters it propagates more or less evenly in all directions. Based on results from comparable studies at wind farms in German and Danish waters, it is evident that pile-driving can result in avoidance over a range of 20 km or more (Brandt et al., 2011, Dähne et al., 2013, Tougaard et al., 2009). An effect on behaviour can (theoretically) occur over a wider range. Kastelein et al. (2013d) exposed a single harbour porpoise in a pool (under very quiet conditions) to playbacks of pile driving sounds and recorded the animal's behaviour. They found a threshold of $SEL_1$ = 136 dB re 1 µPa$^2$s (SPL = 145 dB re 1 µPa) which corresponds to an avoidance distance of ca 30 km for this animal in the North Sea under quiet conditions (no masking). This is the maximum distance; the actual distance will vary depending on the source level, propagation conditions, and background noise. Investigations of the maximum range for impact (i.c. a change in behaviour) include a study in Scotland (Thompson et al., 2010), in which no reduction in the acoustic activity of

harbour porpoises were observed at 40 km, their farthest location, indicating that the extent of the impact zone was less than 40 km. Thus the impact zone of pile driving probably extends to 20 km at a minimum and between 30 and 40 km at maximum.

## 2. Materials and Methods

Harbour porpoises were surveyed using two methods: passive acoustic monitoring (PAM) and aerial surveys. Aerial surveys allow covering a large area, including the entire potential impact area, in a short period of time. The acoustic monitoring, on the other hand, continuously records the acoustic activity of harbour porpoises within a small radius (<300 m) around the PAM. A combination of both methods provides quantitative data, comprising good spatial coverage (aerials) and high local resolution (PAM).

### 2.1 Survey area

The location for Gemini offshore wind farms is approximately 55 km north of the island Schiermonnikoog, in the Dutch EEZ, at the Dutch-German border (Figure 3). Substantial anthropogenic sound already comes from a number of sources in the area. Immediately to the north of Gemini are intensively used shipping routes, that require designated traffic separation lanes. To the east, in German waters, and within 50 km of Gemini, there are three operational wind farms and another eight under construction.

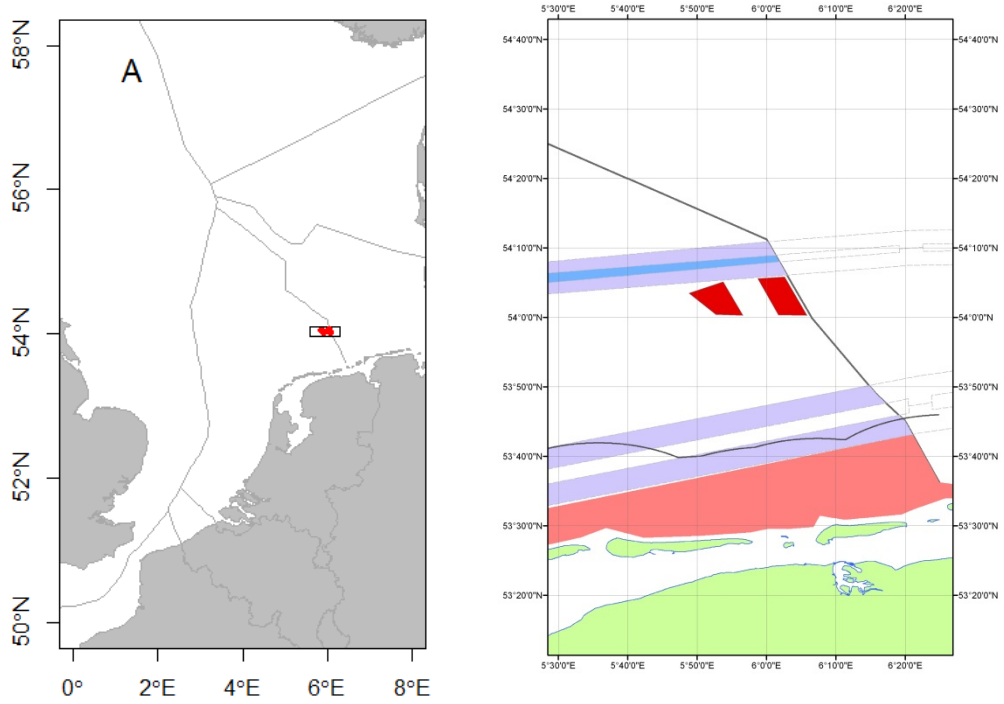


*Figure 3. Location of study area in the North Sea. Left panel: Right panel: detail of the Gemini wind farm area (red); shipping lanes in purple, land in green.*

In order to study and assess the potential impact of Gemini wind farm construction and operation on harbour porpoises, an aerial survey was designed to collect baseline data from an area with a range of ca. 40 km to the North, ca. 55 km to the South and ca. 30 km to the East and West (Figure 4 & Figure 5). Passive acoustic monitoring of harbour porpoises was planned using CPODs (Continuous Porpoise Detectors, from Chelonia Limited, UK). These were deployed in a smaller area that extended ca. 15 km to the SSE from Buitengaats and ca. 40 km to WSW from ZeeEnergie.

Due to the close proximity of Buitengaats and ZeeEnergie, i.e. 5 km apart, baseline data on harbour porpoise distribution/abundance were monitored for both sites simultaneously. The analysis of the

results, however, can take into account the different ranges of potential impact that the construction of each wind farm might have. The study area covers also the Borkum Riffgrund area which is a special protected area (SPA) in German waters.

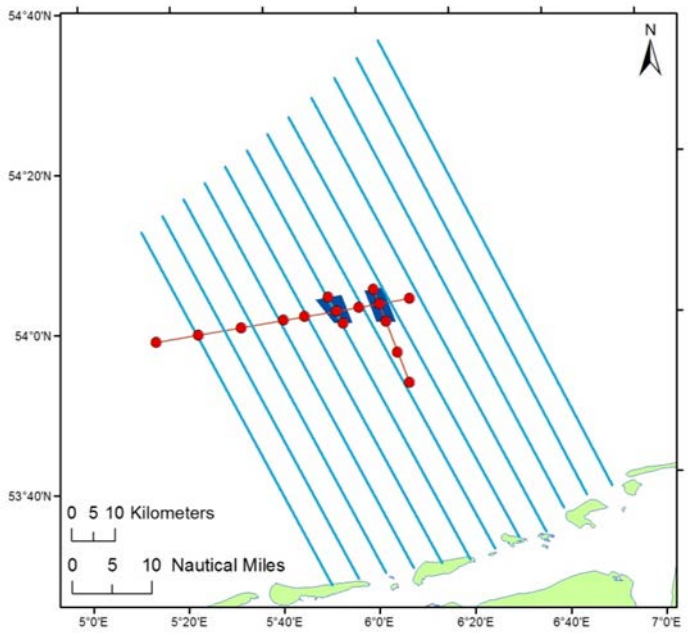


*Figure 4. Configuration of transect lines (NWN-SES) blue lines and the CPODs (red dots) in relation to the future wind farms (blue polygons).*

## 2.2 Aerial surveys

For the aerial surveys, the T-0 design comprises 12 transect lines (Figure 5) each between 93 and 116 km long, with a total length of ca. 1,275 km. The transect lines are spaced 6.1 km apart. The survey area covers approximately 7,777 km². The transect lines extend out from the coastline of the western Wadden Sea Islands in a NNW direction and run perpendicular to depth contours.

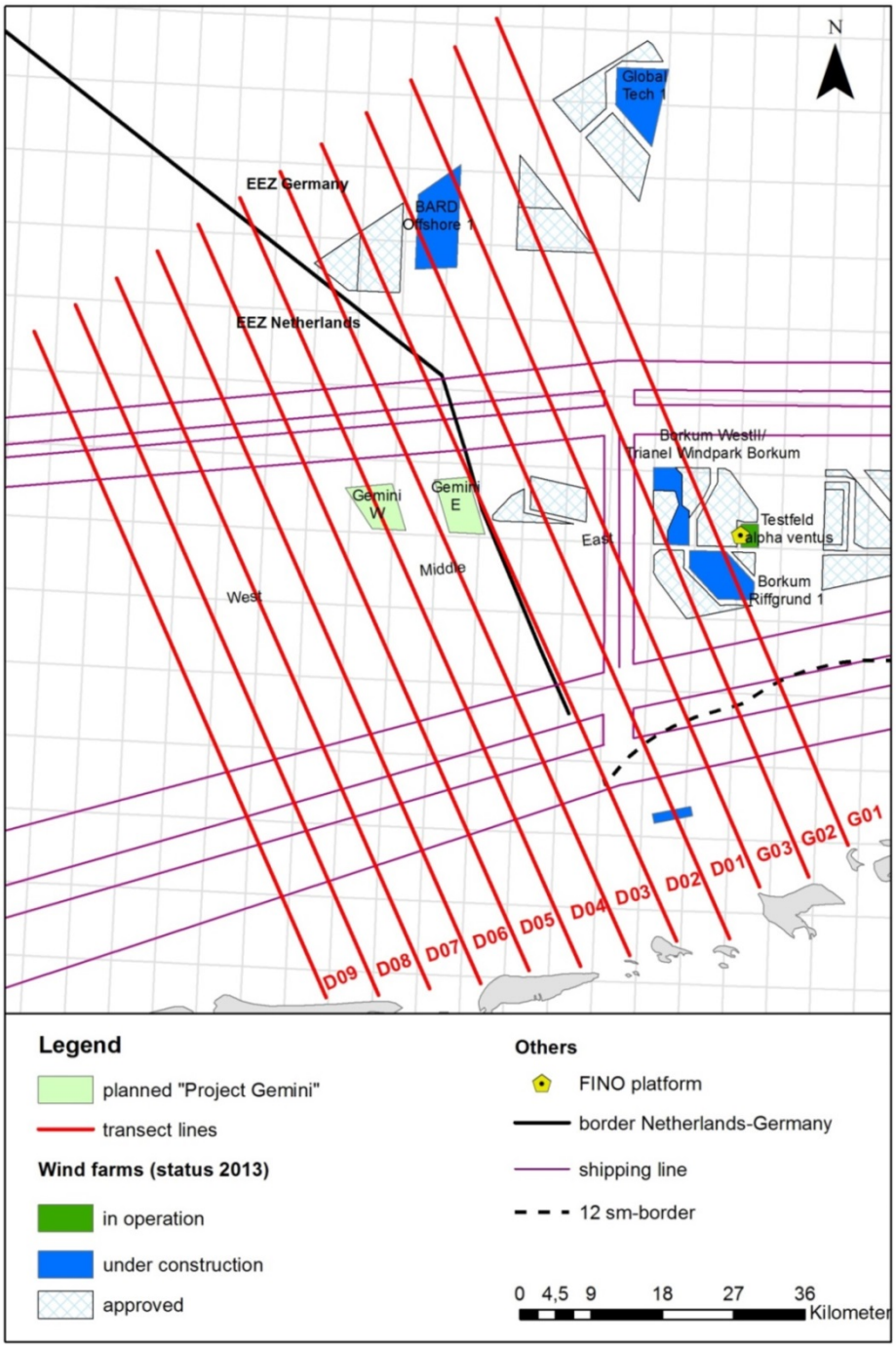


*Figure 5. Survey design for the aerial surveys.*

Timing of surveys was influenced by an expected peak in abundance of the harbour porpoises earlier in the calendar year. Greater resolution of the data could be obtained by focussing flights around the peak. Accordingly, flights were conducted monthly in the period February to June (5 flights in the first half of the year), and (planned) bi-monthly later in the year (another 3 flights).

The study area could be surveyed within one day using two airplanes/teams simultaneously. The transect lines were divided into three parts (West, Middle, East). One team surveyed the longer 'East' transects, which included transects in German waters, which required flights around or above some established

wind farms (due to regulations), while the other team surveyed the remaining 'Middle' and 'West' sets of transects. The second team stopped for refuelling between transect sets at the German island Borkum. Surveys were conducted in weather conditions safe for flying operations (no fog or rain, no chance of freezing rain, visibility > 3km) and suitable for porpoise surveys (Beaufort sea state ≤ 3).

## 2.3 Data collection aerial surveys

Aerial surveys were conducted with two Britten-Norman BN-2 Islanders, a high-winged twin-engine airplane equipped with bubble windows, flying at an altitude of ca. 183 m (600 feet) with a speed of ca. 186 km/hr (ca. 100 knots). Every four seconds, the time and the aircraft's position were recorded automatically onto a laptop computer connected to a GPS. Surveys were conducted by a team of three people. Sighting information and details on environmental conditions were entered by one person (the navigator) at the beginning of each transect and whenever conditions changed. Observations were made by two dedicated observers located at bubble windows on each side of the aircraft. For each observation of a cetacean or seal, the observer acquired the following data: species, declination angle - measured with an inclinometer from the aircraft abeam to the group, group size, presence of calves, behaviour (see Table 1), swimming direction, cue, and reaction to the survey plane. The perpendicular distances from the transect to the sighting were later calculated from aircraft altitude and declination angle. Environmental data included sea-state (Beaufort scale), turbidity (4 classes, assessed by visibility of objects below the sea surface), cloud cover (in octaves), glare and subjective sighting conditions (Table 2). These sighting conditions represent each observer's subjective view of the likelihood that the observer would see a harbour porpoise within the primary search area (<300 m from the track line) should one be present, and could differ between left and right sides of the airplane.

*Table 1. Behavioural codes and description for marine mammals.*

| Code | Behaviour |
|---|---|
| Swim | Directional swimming |
| Slswim | Slow directional swimming |
| Fasw | Fast directional swimming or porpoising |
| Mill | Milling, non-directional swimming |
| Rest | Resting/logging: not moving at the surface |
| Feed | Feeding |
| Headup | Spy-hop of seals vertically in the water column |
| Other | Other behaviour, noted down in comments |

*Table 2. Description of subjective sighting conditions.*

| Sighting condition | Description |
|---|---|
| Good (G) | Observer's assessment that the likelihood of seeing a porpoise, should one occur within the search strip, is good. Normally, good subjective conditions will require a sea state of two or less and a turbidity of less than two. |
| Moderate (M) | Observer's assessment that the likelihood of seeing a porpoise, should one occur within the searching area, is moderate. |
| Poor (P) | Observer's assessment that it is unlikely to see a porpoise, should one occur within the search strip. |
| Off effort (X) | Observer off effort due to adverse circumstances (e.g. rain or fog) |

## 2.4 Analysis aerial surveys

All collected data was checked, e.g. for consistency of codes, and subsequently stored in the Dutch database. During line-transect distance sampling, the perpendicular distance of a sighting (a single animal or the centre of a group of animals) to the track line is measured. To measure the distance, the plane flies at a constant height (600 ft = 183 m) and the vertical or 'declination' angle to the animal is measured when it comes (or is estimated to come) abeam. These distances are used in the later analyses to estimate the effective strip-width (ESW) covered by the observers. The ESW is essential to calculate the density of animals along the track line. The ESW is calculated using the distance sampling software DISTANCE 6.0 (Thomas et al. 2010). It is determined by the detection function that describes the distribution of the sightings. The latter typically shows a non-linear decline with increasing perpendicular distance from the transect line (Buckland et al. 2001).
For analysis only transects flown at "good" or "moderate" sighting conditions and at sea-states equal or less than Beaufort 3 are used. The DISTANCE software adjusts a detection function using variations of key parameters (cosine, hazard rate) and adjustment terms if necessary (uniform, half-normal). The best fitted function was chosen by the smallest AIC (Akaike Information Criterion) value. Based on the data recorded so far the effective strip width (ESW) for good and moderate sighting conditions is 226 m in good and 215 m in moderate sighting conditions (Table 3). The 95 % confidence intervals are also calculated as a measure of possible variation in densities of animals.

*Table 3. Effective strip width (ESW) for good and moderate sighting conditions. Lower 95% confidence interval (LCI) and higher 95% confidence interval (HCI) are given.*

| Subjective sighting conditions | Good | Moderate |
|---|---|---|
| ESW (m) | 226 | 215 |
| ESW LCI (m) | 204 | 193 |
| ESW HCI (m) | 250 | 239 |
| Model, key function | hazard-rate | hazard-rate |

One of the assumptions of line-transect distance sampling is that all animals are detected on the track line, which would mean that the chance to see all animals at a distance of 0 m from the track line is 1 (100%). For cetaceans this assumption is not true. A correction factor, called g(0), needs to be obtained to correct for the proportion of animals missed on the track line, in order to calculate actual density estimates from the observations. In practice there are two reasons why animals are not recorded: 1. the animals are not "available" to be seen, (e.g. because they are submerged) or 2. they are missed by the observers ("observer bias"). So, the proportion of present animals that is detected by the observer team must be known. Of these, the observer bias is a potential problem when using two (identical) airplanes as the different teams might have different values for observer bias. We deal with this problem by randomizing observers over observer teams, so that we end up with a single g(0) for the entire team.

To calculate g(0), we use the 'racetrack' method (Hiby & Lovell 1998, Hiby 1999), where the plane circles back over a section of the transect line and re-samples it. This allows an estimate to be made of the resightability of an animal which is known to be present (and detection of animals that were not available to the observer on the first pass). In general 50-100 racetracks are needed to determine a reliable g(0) for a particular area. During the first seven aerial surveys 18 racetracks were flown. The number of racetracks is still too low to calculate a g(0) at this stage. The porpoise monitoring for Gemini is expected to be done, using the same method, during T-0, T-construction and during five years in the operational phase. This gives us another five years to estimate Gemini-specific g(0)'s. Spreading the racetrack flights over the entire duration of the project is also preferred from a statistical point of view, assuming the survey team does not change considerably. For the time being, the g(0) values used by

IMARES in Dutch waters and by ITAW in German waters are alternatively used (Scheidat et al., 2008): g(0) of 0.37 for good sighting conditions and 0.14 for moderate conditions.
The data analysis (analysis of changes between years) necessary to quantify potential effects of the Gemini offshore wind farm can also be carried out without 'Gemini-specific' g(0)'s. Having these, however, would result in absolute density estimates and would allow comparison of observations with other density estimates, and would hence strongly improve the degree to which the data from this project can be put into a broader perspective. From a scientific standpoint, such a wider perspective is needed, as survey observations (even repeated observations) are still isolated snapshots in time.

In distance analyses, detection probability of clusters of individuals is modelled. This means that the resulting density represents the density of clusters of individuals. To achieve a density of individuals, the density of clusters needs to be multiplied by the average group size.

## 2.5 Passive acoustic monitoring

For the passive acoustic monitoring during T-0, the design comprised of 15 CPODs (Figure 6, Table 4). The positions of the CPODs were restricted by the shipping lane in the north, and the German border, as well as planned and operational wind farms in Germany, in the east. Six CPODs were positioned in the centre and on the northern and southern edge of the future ZeeEnergie and Buitengaats wind farm areas. The line of CPODs in Buitengaats was extended with two more CPODs, thus perpendicular to depth gradients (locations 12 and 13). Another series of CPODs was positioned along a gradient parallel to the ship traffic route. A final CPOD (14) was positioned in German waters (under a specific permit), east of Gemini.

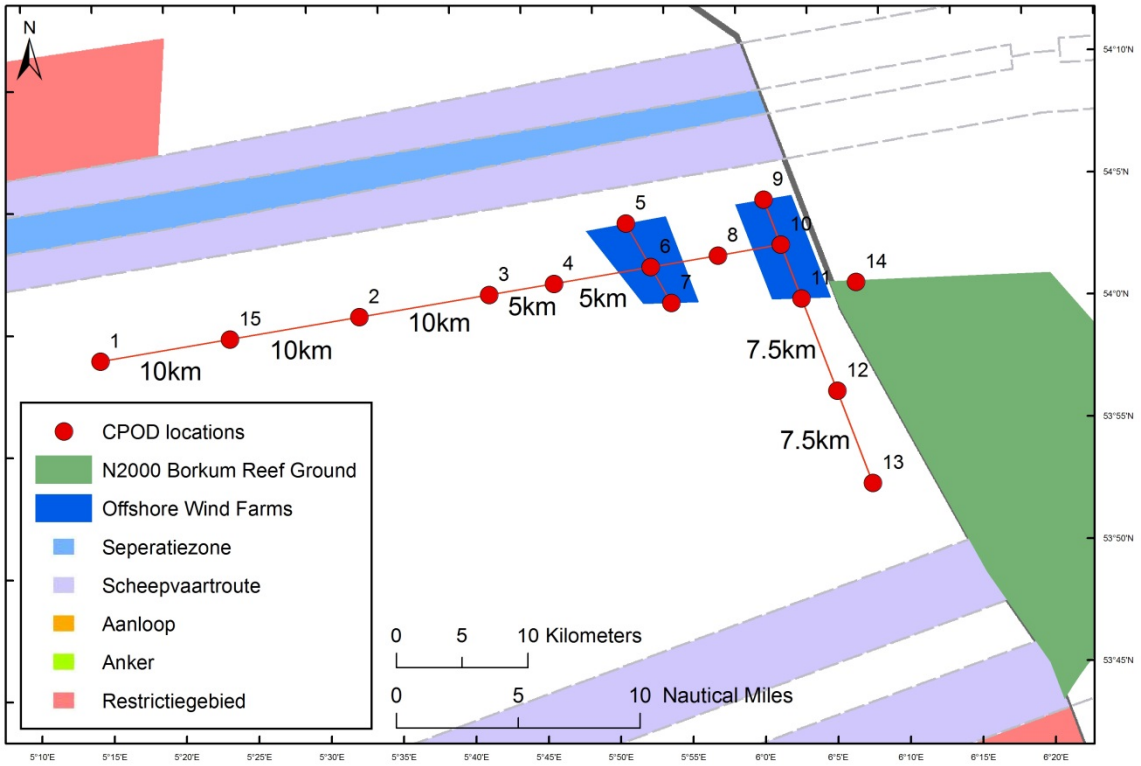


*Figure 6. Location of the CPODs.*

*Table 4. Location of CPODs in the Gemini-study area. Coordinates in UTM 31N ETRS89 are presented in Appendix 1.*

| CPOD location | Description | Latitude (N) | Longitude (E) |
|---|---|---|---|
| GEM 01 | 40 km west of Gemini | 53.980790 | 5.247168 |
| GEM 02 | 20 km west of Gemini | 54.005150 | 5.549318 |
| GEM 03 | 10 km west of Gemini | 54.017050 | 5.700516 |
| GEM 04 | 5 km west of Gemini | 54.022930 | 5.776145 |
| GEM 05 | ZeeEnergie North | 54.062010 | 5.862341 |
| GEM 06 | ZeeEnergie centre | 54.031630 | 5.889241 |
| GEM 07 | ZeeEnergie South | 54.006590 | 5.911363 |
| GEM 08 | between ZeeEnergie and Buitengaats | 54.037610 | 5.967867 |
| GEM 09 | Buitengaats North | 54.074430 | 6.023167 |
| GEM 10 | Buitengaats centre | 54.043420 | 6.040990 |
| GEM 11 | Buitengaats South | 54.005890 | 6.062597 |
| GEM 12 | 7.5 km south of Buitengaats | 53.941920 | 6.099270 |
| GEM 13 | 15 km south of Buitengaats | 53.877940 | 6.135835 |
| GEM 14 | in German waters | 54.015620 | 6.126370 |
| GEM 15 | 30 km west of ZeeEnergie | 53.992970 | 5.398243 |

## 2.6 Data collection passive acoustic monitoring

For the purpose of this study, a pool of 30 CPODs (v1, Version 1) was required, to have 15 in the water at a time, and replace those periodically. Retrieved CPODs had their data cards removed and downloaded and were cleaned and equipped with new batteries for following deployments.

A CPOD relies on the 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 in a narrow band between 120-150 kHz, peaking at around 132 kHz, which makes the signals ideal for automatic detection. Detection of harbour porpoise clicks is basically done by a comparison of the energy of the acoustic signal in a small band around a high and a low frequency, the so-called A- and B-filter. Acoustic signals that have substantially more energy in the A-filter is probably a harbour porpoise. Most other sounds in the sea, with the exception of some boat sonars, are more broadband or have more energy at lower frequencies. Although many non-porpoise clicks are also recorded, these, as well as boat sonars and echo-sounders, are filtered out during post-processing, by analysing the time intervals between successive clicks. Porpoise click trains are recognisable by a gradual change of click intervals and amplitudes throughout a click sequence. In comparison boat sonars and echo-sounders 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 clicks and dolphin clicks. This setting filters out click trains of low quality and thus reduces the number of false detections.

The sensitivity of the CPODs was standardized by the manufacturer (Chelonia Ltd) before shipping to IMARES. To check the calibration of each CPOD, it is rotated in a sound field and adjusted to give a radially averaged, temperature corrected, sound pressure reading within 5% of the standard at 130 kHz (±0.5 dB). Calibration was undertaken by the National Physical Laboratory in the United Kingdom. Only CPODs that have a radial variation < ±3 dB relative to the mean sensitivity are used. On top of the

manufacturer's standardization, the calibration of all CPODs was rechecked twice in the accredited German Meeresmuseum in Stralsund, 17-22 July 2013 and 28 January-4 February 2014. The CPODs were tested in a test tank to estimate the variation in sensitivity, using calibrated hydrophones as receiver and transmitter. The transmitter sent out acoustic signals at different frequencies that were measured by a calibrated hydrophone. This hydrophone was then replaced by a CPOD for sound exposure to the same calibration signals. The same procedure was repeated on four different positions along the PODs horizontal axis in order to measure directional variation. The sensitivity of a CPOD is compared to the received levels and mean peak-to-peak pressures (Ppp) of the calibrated hydrophones. Detection thresholds and the relationship between receiving level and the corresponding Ppp-values for each CPOD were calculated with two methods: 50 % detection thresholds and linear regression models. Details of these calculations and the calibration method can be found in Verfuß et al. (2010). Only CPODs that showed differences 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), were used for the study. CPODs that did not function within the AMPOD-limits were replaced by other CPODs.

With the help of the RWS-vessel Terschelling the first deployments at the fifteen CPOD locations were made in Autumn 2011 (29 Sep, 3 & 27 Oct). The CPOD locations were serviced four times (CPODs at each location were replaced with new CPODs) and all equipment was recovered in July 2014. When necessary, lost or broken CPODs were replaced.

The mooring used for the CPODs was similar to the moorings used previously (Figure 5 and Figure 6), for example for the Prinses Amalia Wind Park in the Dutch coastal zone (Van Polanen Petel et al., 2012). This included using robust material, i.e. buoys, chain and concrete anchors. The CPODs were secured with a mooring of two buoys, of which the larger was equipped with a yellow warning lantern. 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.

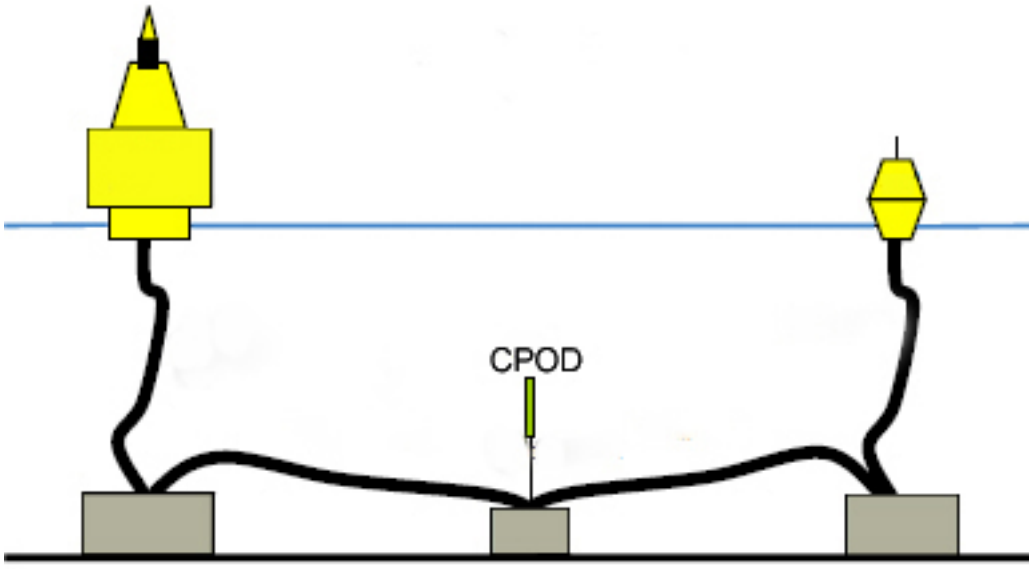


*Figure 7. Schematic view of the CPOD anchoring method.*

*Figure 8. Mooring-buoy system for two CPODs on the back-deck of the Terschelling, demonstrating the size of the buoys and concrete blocks (Photo by Hans Verdaat).*

## 2.7 Analysis passive acoustic monitoring

Following recovery of the CPODs, the memory card is taken out and the data downloaded. Harbour porpoise echolocation clicks are extracted from the background noise using an algorithm that filters out non-porpoise clicks, such as cavitation noise from boat propellers, echo sounder signals and similar high frequency noise. Version 2.024 of the software "CPOD.exe" was used to download and analyse the data. Data were exported and further analysed using Excel and R-software (R Development Core Team, 2009).

In previous studies (Carstensen et al., 2006, Van Polanen Petel et al., 2012; Teilmann et al., 2009; Tougaard et al., 2006a & b), two indicators of harbour porpoise presence, click frequency and click intensity, have been extracted from the exported CPOD data. Both indicators are based on the fundamental unit of clicks-per-minute. This consists of many zero observations (minutes without click trains), as well as porpoise positive minutes. The click activity was aggregated into daily values of:

Proportion of porpoise Positive Minutes (PPM) per day

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

In this study, we have not investigated click intensity, which examines the number of clicks per minute. That would require more detailed analysis and adds little to the quantitative determination of harbour porpoise usage of the area, as numbers of individuals cannot be interpreted.

To describe the spatial and temporal distribution of harbour porpoises in the area, Generalized Additive Mixed Models (GAMM) were used. This procedure takes different sources of variation, including CPOD

number, season, data gaps, temporal correlation (day of the year), longitude, and environmental covariates such as time to high tide, wind speed etc. into account in describing harbour porpoise acoustic activity in the area. For some of these variables (e.g. longitude) a non-linear effect is expected, in which case a smooth function was incorporated in the model. Time of the day and time to high tide are cyclic variables, for which cyclic smoothers were used. 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.

To determine which covariate has the largest effect on the number of porpoise positive minutes, a (stepwise) forward selection procedure, based on the Akaike Information Criterion (AIC), is applied. The model with the best fit and the least number of covariates has the lowest AIC and is selected as best model. The covariate that produced that best model is then taken out and the step-wise procedure continues with the remaining covariates. If adding a variable leads to a lower AIC, it means that the inclusion of that variable significantly describes the variability in porpoise detections. Based on the final model, a prediction is made of the daily mean PPM/h as a function of individual covariates and the result is graphically presented.

## 2.8 Comparison with noise logger data

Noise is generally seen as an important anthropogenic driver for harbour porpoise behaviour and distribution. To describe the soundscape in the Gemini-area two AMAR noise loggers were deployed: one at CPOD location GEM 01 ca. 40 km west of ZeeEnergie and one at CPOD location GEM 08 between ZeeEnergie and Buitengaats. A summary of the underwater noise measurements, focussed on the summer of 2013, is provided by Lucke (2014). A brief comparison of the noise logger data with the CPOD data is provided in this report.

# 3. Results

## 3.1 Aerial surveys

### *3.1.1 Effort*

Between August 2013 and June 2014, seven of eight planned aerial surveys were carried out by a team of seven observers and three navigators from IMARES and IBL Umweltplanung (Table 5). All surveys were completed in single days of flying. The observer team was kept as constant as possible to minimize observer variation. Using two planes simultaneously each survey was conducted in one day.
A survey scheduled for December 2013 could not be carried out due to long-lasting adverse weather conditions. The survey was postponed to December 2014 but could not be conducted due to unfavorable weather conditions. The survey on 19 February 2014 had to be stopped after completing two thirds of the transect lines due to poor sighting conditions in the eastern part of the survey area.

*Table 5. Planes and observers per aerial survey.*

| Flight date | Planes* | Observer | Observer | Navigator |
|---|---|---|---|---|
| 22 Aug 2013 | D-ILFD | Helmut Wendeln | Michael Joost | Undine von Elsberg |
| | D-ILFC | Marco Schilz | Andreas Michaelik | Hans Schlage |
| 16 Oct 2013 | D-ILFC | Hans Verdaat** | Helmut Wendeln | Nicole Stöber |
| | D-IEST | Andreas Michalik | Alexander Braasch | Undine von Elsberg |
| Dec 2013 | Survey couldn't be realized due to long-lasting adverse weather conditions. | | | |
| 19 Feb 2014 | D-IEST | Helmut Wendeln | Brigitte Hielen | Hans Schlage |
| | D-ILFC | Alexander Braasch | Marco Schilz | Undine von Elsberg |
| 4 Mar 2014 | D-IEST | Andreas Michalik | Helmut Wendeln | Hans Schlage |
| | D-ILFC | Alexander Braasch | Marco Schilz | Undine von Elsberg |
| 16 Apr 2014 | D-ILFC | Helmut Wendeln | Marco Schilz | Nicole Stöber |
| | D-ILFH | Michael Joost | Alexander Braasch | Undine von Elsberg |
| 5 May 2014 | D-ILFH | Marco Schilz | Brigitte Hielen | Undine von Elsberg |
| | D-ILFC | Andreas Michalik | Alexander Braasch | Hans Schlage |
| 3 Jun 2014 | D-ILFC | Hans Verdaat** | Helmut Wendeln | Nicole Stöber |
| | D-ILFH | Alexander Braasch | Brigitte Hielen | Hans Schlage |
| Dec 2014 | Survey couldn't be realized due to long-lasting adverse weather conditions. | | | |

* = Britten Normans Islanders BN2; the used planes are identical in construction and are without difference concerning observing conditions; ** = IMARES; all other observers from IBL Umweltplanung

Over seven surveys, a total of 7,960 km was flown (Table 6, racetracks excluded). For each survey the total effort was calculated as kilometer covered on each side, e.g. a 10 km track line covered by both observers results in 20 km survey effort. On most survey flights some sections had to be excluded from evaluation due to unsuitable sighting conditions (sea-state >3, sighting conditions P or X). The residual total effort is listed for each flight in Table 6, summing up to a total of 14,704 km.

*Table 6. Effort per survey. Valid survey effort is the sum of the surveyed distance on both sides under good and moderate sighting conditions.*

| Flight Date | Distance covered (km) | Surveyed distance (km) per sea-state (both sides) | | | | Surveyed distance (km) per sighting condition (both sides) | | | Total survey effort (km) |
|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | g | m | p, x | |
| 22 Aug 2013 | 1213 | 1213 | 1212 | 0 | 0 | 870 | 1541 | 15 | 2410 |
| 16 Oct 2013 | 1197 | 0 | 1920 | 475 | 0 | 41 | 2353 | 0 | 2394 |
| 19 Feb 2014 | 762 | 8 | 379 | 1041 | 97 | 0 | 1368 | 157 | 1366 |
| 4 Mar 2014 | 1202 | 141 | 1315 | 947 | 0 | 673 | 1675 | 54 | 2349 |
| 16 Apr 2014 | 1202 | 873 | 1530 | 2 | 0 | 1158 | 1033 | 215 | 2190 |
| 5 May 2014 | 1195 | 291 | 1757 | 342 | 0 | 652 | 1471 | 267 | 2123 |
| 3 Jun 2014 | 1188 | 1410 | 450 | 360 | 157 | 562 | 1465 | 348 | 1871 |
| Total | 7960 | 3936 | 8562 | 3168 | 254 | 3956 | 10907 | 1056 | 14704 |

**Sightings**

Overall, 691 harbour porpoises, 24 harbour seals, 6 grey seals and 24 unidentified seals were observed during the seven surveys between August 2013 and June 2014. Unidentified seals very likely belong to one of the two indigenous seal species. Most seals were observed in October and April. The actually flown transect lines and all recorded marine mammals are shown in Appendix 2 for each flight in detail.

*Table 7. List of recorded marine mammals. Total number of individuals observed per survey.*

| Flight Date | Harbour Porpoise (calves) | Harbour Seal | Grey Seal | Unidentified seal |
|---|---|---|---|---|
| 22 Aug 2013 | 105 (11) | 2 | - | 5 |
| 16 Oct 2013 | 78 (1) | 8 | 1 | 4 |
| 19 Feb 2014 | 17 | - | 1 | - |
| 4 Mar 2014 | 57 (1) | 2 | - | - |
| 16 Apr 2014 | 213 | 8 | 2 | 13 |
| 5 May 2014 | 113 | - | - | 1 |
| 3 Jun 2014 | 108 (8) | 4 | 2 | 1 |
| Total | 691 (21) | 24 | 6 | 24 |

**Seasonal and spatial pattern occurrence of harbour porpoise in the study area**

In total 580 groups of harbour porpoises totalling 691 animals were sighted during the seven survey flights (Table 8). The mean group size for all surveys was 1.19 porpoises per sighting (Table 8). Most groups were observed in June and August. During these surveys 19 mother–calf pairs were seen in the area. The calf rate was 7.5 % and 10.5 % during these two months. Two older 'calves' or immature animals were observed, one in in October and the other in March.

The determined densities ranged between 0.3 porpoises/km² (19 February 2014) and 1.5 porpoises/km² (16 April 2014). The average density in the Gemini study area was about 1.0 porpoises/km² during the eleven month period. Above-average densities were found in April and May. The lowest density was found in February (Table 8).

*Table 8. Density of harbour porpoises for each of the seven surveys (lower 95% confidence interval (LCI) and higher 95% confidence interval (HCI) are given).*

| Flight Date | Survey area* (km²) | Number of porpoises | Porpoise sightings | Mean group size | Mean density | Density HCI** | Density LCI** |
|---|---|---|---|---|---|---|---|
| 22 Aug 2013 | 119.1 | 105 | 82 | 1.28 | **0.88** | 0.80 | 0.98 |
| 16 Oct 2013 | 74.3 | 77 | 65 | 1.18 | **1.04** | 0.93 | 1.15 |
| 19 Feb 2014 | 41.1 | 14 | 13 | 1.08 | **0.34** | 0.31 | 0.38 |
| 4 Mar 2014 | 106.7 | 57 | 48 | 1.19 | **0.53** | 0.48 | 0.59 |
| 16 Apr 2014 | 127.9 | 192 | 167 | 1.15 | **1.50** | 1.36 | 1.67 |
| 5 May 2014 | 98.8 | 112 | 98 | 1.14 | **1.13** | 1.02 | 1.26 |
| 3 Jun 2014 | 86.4 | 90 | 70 | 1.29 | **1.04** | 0.94 | 1.16 |
| Total | 654.3 | 647 | 543 | 1.19 | 0.99 | 0.89 | 1.10 |

* = under good and moderate sighting conditions, including g(0) = 0.37 (Scheidat et al. 2008) and ESW = 226 m for good sighting conditions and g(0) = 0.14 (Scheidat et al. 2008) and ESW = 215 m for moderate sighting conditions; ** = based on $ESW_{HCI}$ and $ESW_{LCI}$ for good and moderate sighting conditions, see Table 3.

The seasonal phenology of harbour porpoises in the wider Gemini area during the survey period shows lowest densities in February and March 2014 at 0.5 porpoises/km² or below (Figure 9). After that the maximum value was reached in April at 1.5 porpoises/km². Subsequently, the abundance slightly decreased to an average level, roughly around 1.0 porpoises/km², in May and June. More or less the same level was detected in August and October 2013. Overall, the abundance seems quite constant from spring to autumn.

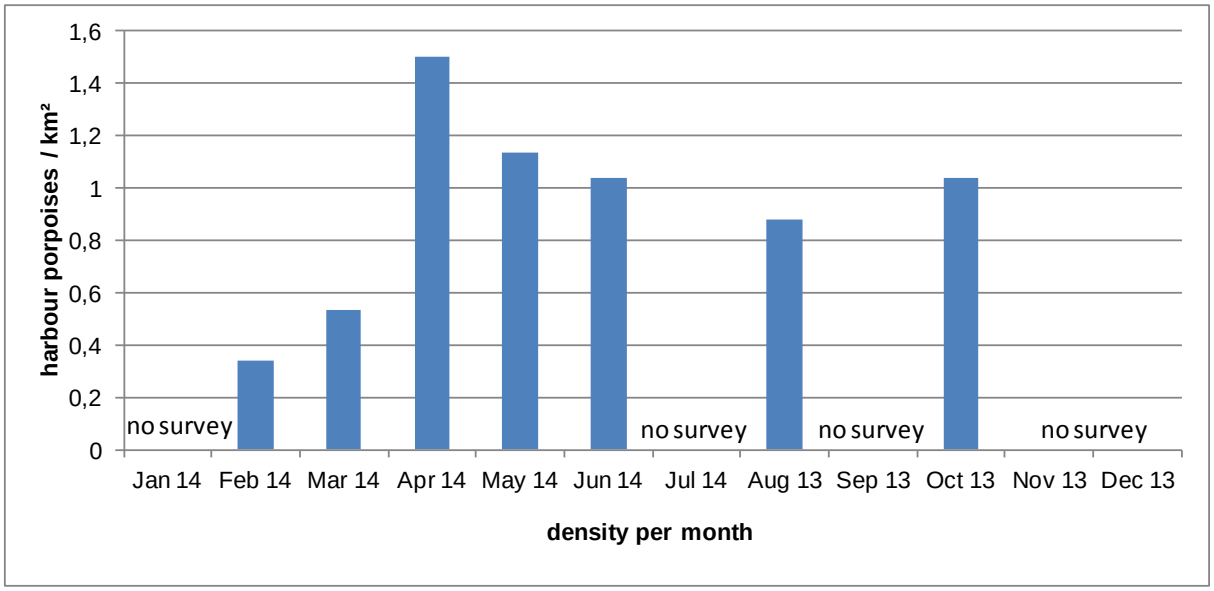


*Figure 9. Densities of harbour porpoises per survey month.*

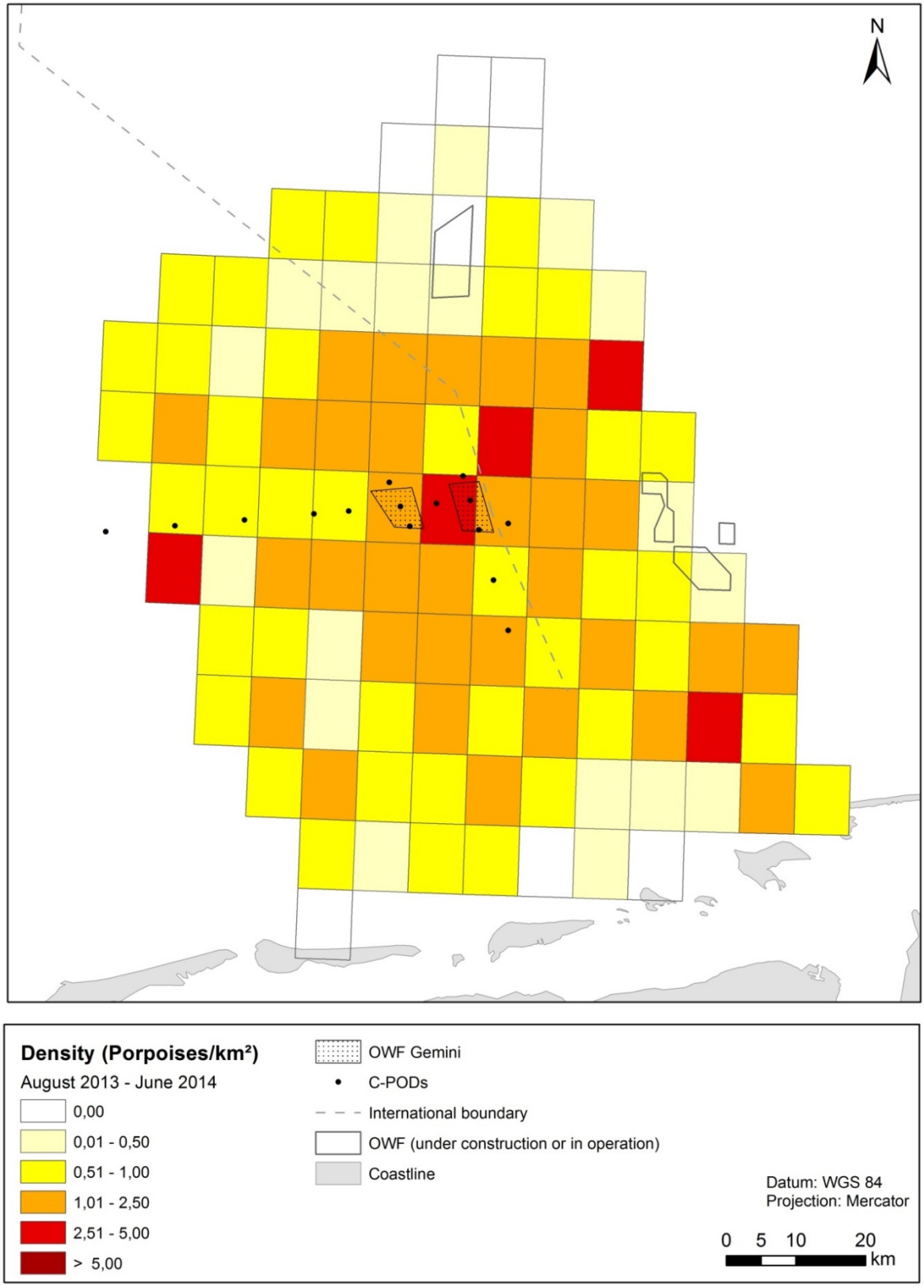


*Figure 10. Density of harbour porpoises (n/km²) based on seven survey flights from August 2013 to June 2014 (8 x 10 km rectangular grid).*

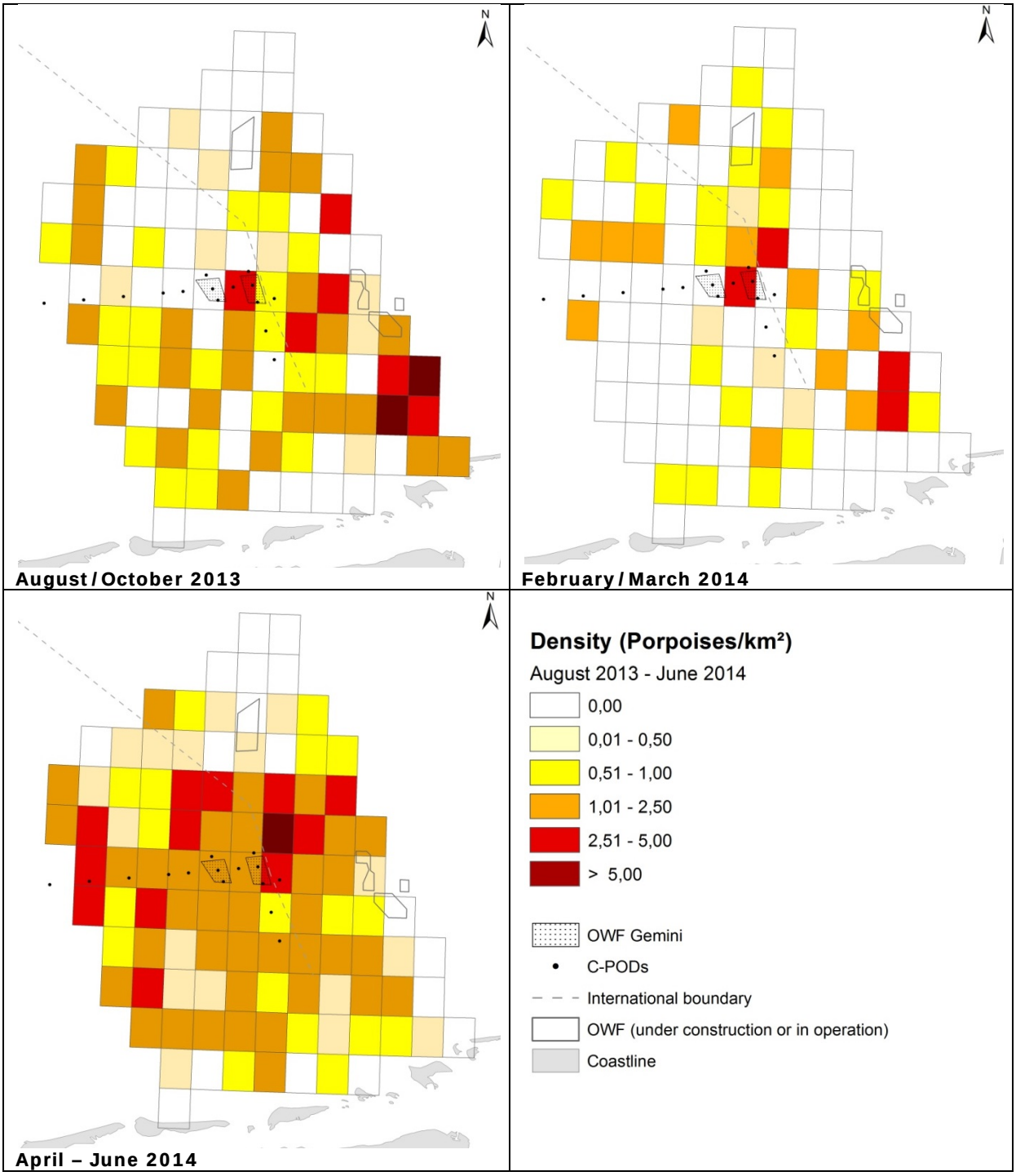


*Figure 11. Density of harbour porpoises (n/km²) during the periods August/October 2013 (2 surveys), February/March 2014 (2 surveys) and April-June (3 surveys; 8 x 10 km rectangular grid).*

The distribution map combining all seven surveys shows a relatively similar porpoise presence for the largest part of the study area (Figure 10). However, a tendency towards higher densities in the central part of the area (Borkum Reef) is obvious. The two intended Gemini wind farm sites are situated within this preferred area. In contrast, densities in the most northern and most southern parts are low (Figure 10). These areas are the coastal zone and the area north of the BARD Offshore 1 wind farm in German waters.

Figure 11 shows the summarized distribution for three specific periods. The combined survey results for the periods August/October 2013, February/March 2014 and April to June 2014 confirm the overall lower density in February/March but do not reveal any obvious seasonal variation of the porpoise distribution in the area. Harbour porpoises were present in the vicinity of the intended wind farm sites during all seasons. The sites generally belong to the preferred central part of the investigation area (see above).

## 3.2 Passive acoustic monitoring

### *3.2.1 Effort*

Between 29 September 2011 and 31 July 2014, 6,881 days of CPOD recordings were obtained. These came from two distinct sampling periods: September 2011 to August 2012 and July 2013 to July 2014 (Figure 12). Not all CPOD locations were included in the initial sampling.
At individual CPOD locations, the amount of data collected was influenced by individual qualities of the PODs, such as battery life, memory capacity, amount of ambient noise filling the memory, technical problems like memory cards being dislodged from slots, and occasional loss of the CPODS. The exact causes of losses could not be determined, but they were attributed to failure of mooring lines due to exceptionally rough weather, or interactions with vessels (such as trawler-fishing equipment). The data collected from individual locations ranged from 189 days at GEM 15 (ca 30 km west of ZeeEnergie) to 610 days at GEM 05 (in ZeeEnergie).

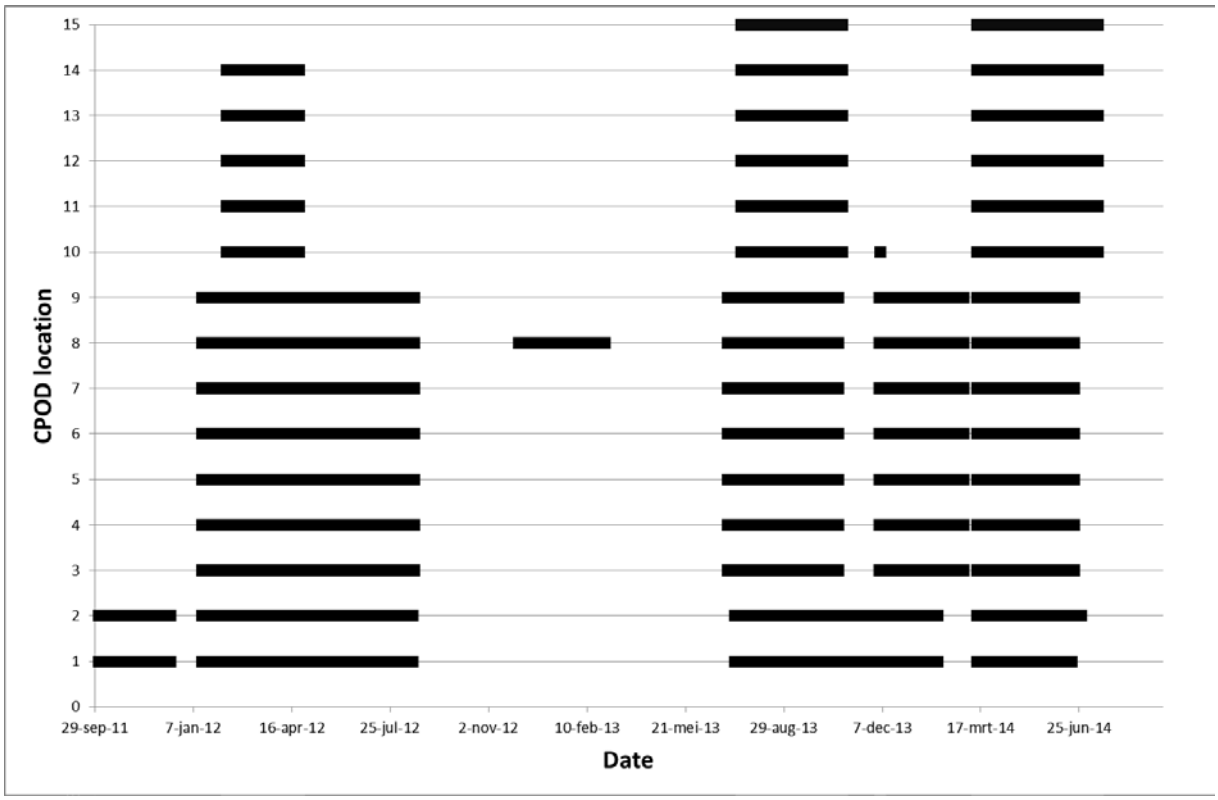


*Figure 12. Daily recording effort per CPOD location. The lines represent recording effort.*

*Table 9. Total effort expressed as number of days that CPODs were deployed and data were retrieved and the percentage of those days in which harbour porpoise clicks were detected.*

| CPOD location | Days with data | % days HP detected |
|---|---|---|
| GEM 01 | 586 | 93.3 |
| GEM 02 | 296 | 99.3 |
| GEM 03 | 519 | 95.2 |
| GEM 04 | 597 | 92.1 |
| GEM 05 | 610 | 98.7 |
| GEM 06 | 593 | 94.4 |
| GEM 07 | 453 | 96.2 |
| GEM 08 | 495 | 70.7 |
| GEM 09 | 378 | 94.7 |
| GEM 10 | 304 | 96.4 |
| GEM 11 | 459 | 98.5 |
| GEM 12 | 686 | 96.9 |
| GEM 13 | 421 | 90.7 |
| GEM 14 | 295 | 85.4 |
| GEM 15 | 189 | 92.6 |
| Total | 6,881 | 93.2 |

### 3.3 Spatial and seasonal pattern in the study area

Harbour porpoises were detected on 93.2% (min 70.7%, max 99.3%) of days sampled (Table 9). This high rate indicates that harbour porpoises were continuously present in the study area. It should be noted that a direct comparison of the CPODs is not possible, due to differences in recording effort (Figure 12), especially in combination with underlying patterns in acoustic activity. Harbour porpoise acoustic activity showed strong daily variation. Seasonal patterns per CPOD expressed as daily click frequency are shown in Appendix 3. The GAMM-analysis to explore underlying patterns in acoustic activity of harbour porpoises indicated that the acoustic activity, expressed as PPM/hr, was best explained by five variables, which in order of influence on data variability were: 1. Day of the year; 2. Hour of the day; 3. Wind force; 4. Latitude; and 5. Time to high tide (Table 10). Adding the Longitude to the model leads to a small decrease in AIC (< 2). This means that the effect of longitude on the acoustic activity is neglible.

*Table 10. Variables selected by the step-wise forward selection GAMM analysis as best explaining variation in the harbour porpoise acoustic detection frequency data. Lower AICs mean the variable explains less variation in acoustic activity.*

| Variable | AIC |
|---|---|
| Day of year | 713844.8 |
| Hour | 709014.7 |
| Wind force (FG) | 706217.0 |
| Latitide (lat) | 705807.8 |
| Time_to_high_tide | 705425.3 |

The relationships between each variable and the acoustic activity of harbour porpoises are presented in Figure 13 to Figure 17. With respect to Day of the year (Figure 13), a strong seasonal pattern was evident. There was a peak in harbour porpoise detections in March. Low acoustic activity occurred in

May-June and December-January. During the early Spring peak, there was 5-times the number of harbour porpoise detections. There was also a peak in harbour porpoise detections associated with morning periods (Figure 14) and with high-tide cycles (Schiermonnikoog which has the same cycle as Gemini-area Figure 17). The relative large decrease in the AIC after adding the effect of hour of the data to the model, suggest this covariate significantly influences the variability in porpoise detections. The decrease in AIC after adding the covariate time to high tide is relatively small, indicating that influence of the tide is relatively low. The location of the CPOD was also important. The relationship along a north-south axis was interesting as this involved a relatively small spatial scale. Detections were higher at the more northerly locations (Figure 16). Of the weather variables, only wind force explained the variation in detected porpoise clicks significantly (Figure 15). Up to wind speeds of 5 m/s (Beaufort 3) the number of detected clicks remained more or less constant. With increasing wind speed the number drops initially and then increased, with an increased variation associated with the increase (possibly due to low sample sizes at these high levels).

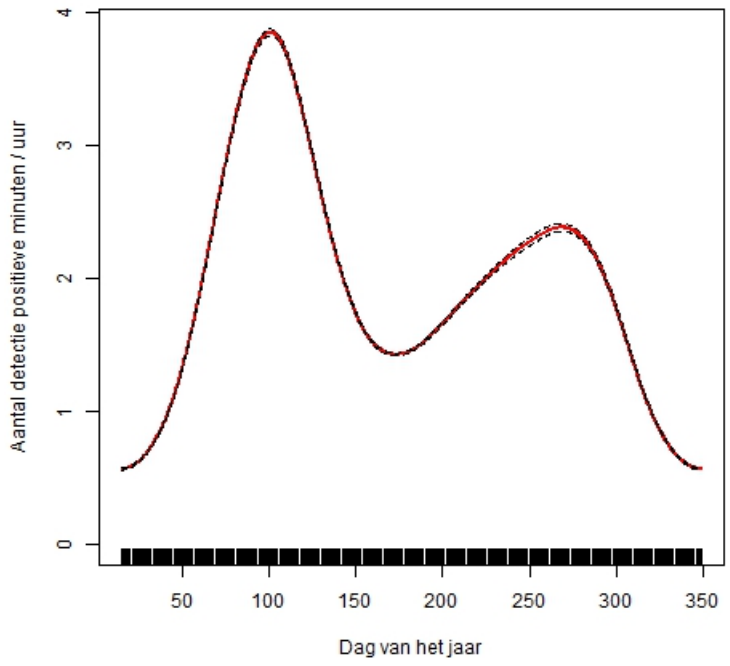


*Figure 13. Seasonal pattern of harbour porpoise acoustic activity in the Gemini-area (solid red line) for each day with 95% confidence limits (dashed line). Data points are indicated by inside tick marks.*

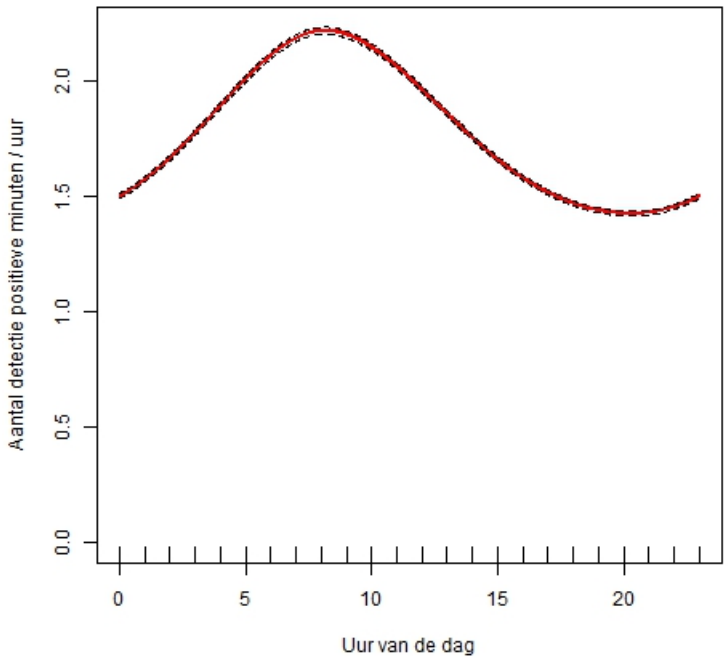


*Figure 14. Harbour porpoise acoustic activity in the Gemini-area in relation to hour of the day. See Figure 13 for explanation*

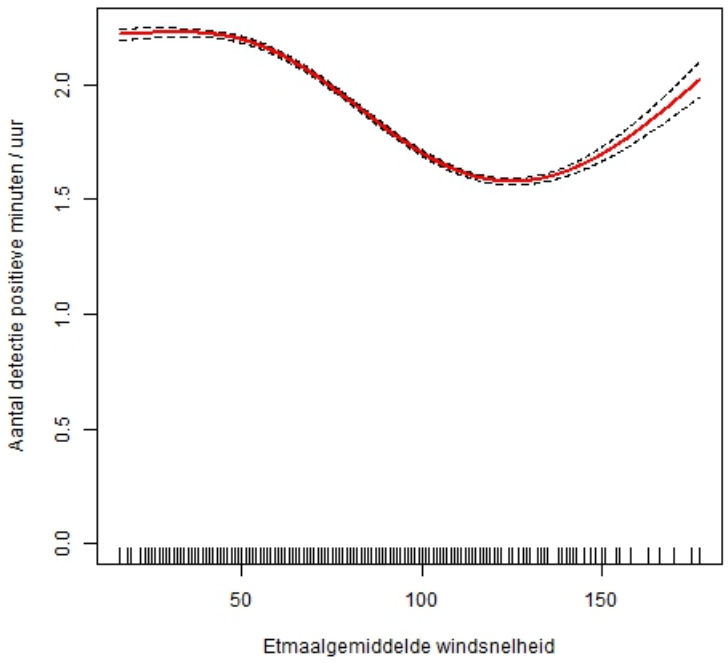


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*Figure 15. Harbour porpoise acoustic activity in the Gemini-area in relation to wind force (0.1 m/s) at Vlieland. See Figure 13 for explanation.*

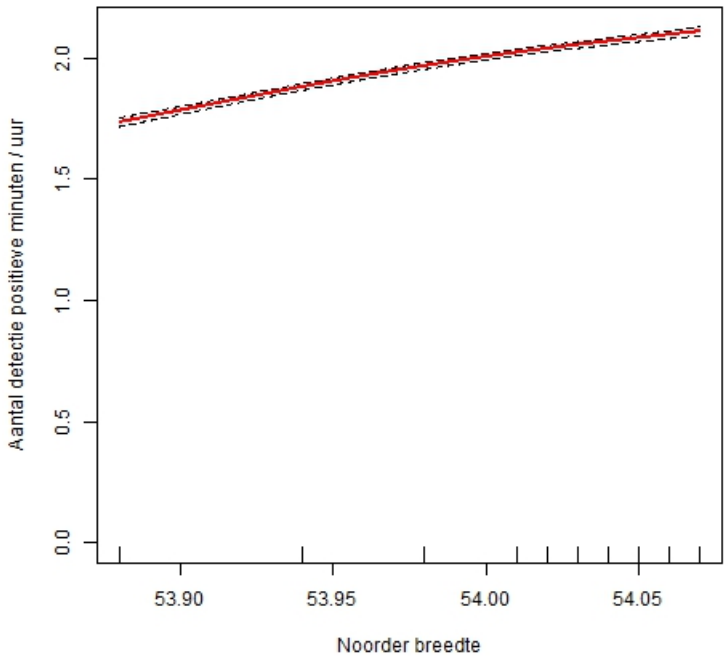



*Figure 16. Harbour porpoise acoustic activity in the Gemini-area in relation to latitude. See Figure 13 for explanation.*

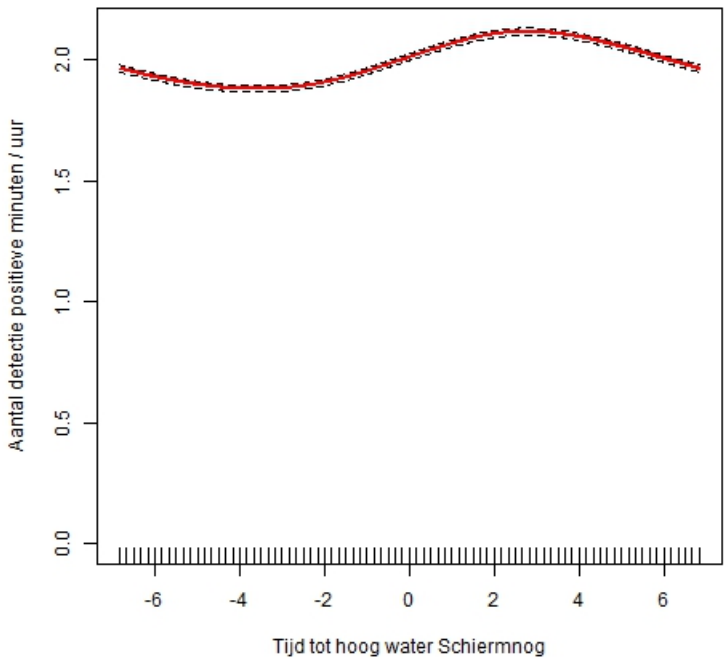



*Figure 17. Harbour porpoise acoustic activity in the Gemini-area in relation to high tide on Schiermonnikoog (hours in relation to high tide). See Figure 13 for explanation.*

### 3.4 Comparison with noise logger data

Shipping noise and pile driving noise were the most dominant measured sounds. Pile driving impulse sounds were detected on 18 days between 18 July 2013 and 7 September 2013 over a total of 62 hours. Due to their transient nature, lasting less than half a second at a repetition rate of two seconds on average, the pile driving impulses were acoustically present over approximately 15.5 hours. In this period pile driving took place on 13 days for the construction of the Windpark Global Tech I (Maria Boethling, Bundesamt für Seeschifffahrt und Hydrographie, in litt). This wind park is located at ca 60 and 90 km from the noise loggers. The noise loggers also recorded underwater explosions (*Table 11*). Four explosions were clearly identified in the recordings and two more acoustic events could potentially also be attributed to such explosions.

*Table 11. List of underwater explosions detected in recordings at CPOD locations GEM 01 and GEM 08 between July and September 2013.*

| Date | Time | Explosion | Comment |
|---|---|---|---|
| 30 Jul 2013 | 10:58 | near, >120 dB | Confirmed |
| 30 Jul 2013 | 17:19 | Distant | Uncertain |
| 31 Jul 2013 | 16:10 | Distant | Uncertain |
| 31 Jul 2013 | 20:04 | Distant | Confirmed |
| 2 Aug 2013 | 17:22 | Distant | Confirmed |
| 2 Aug 2013 | 18: 07 | near, >120 dB | Confirmed |

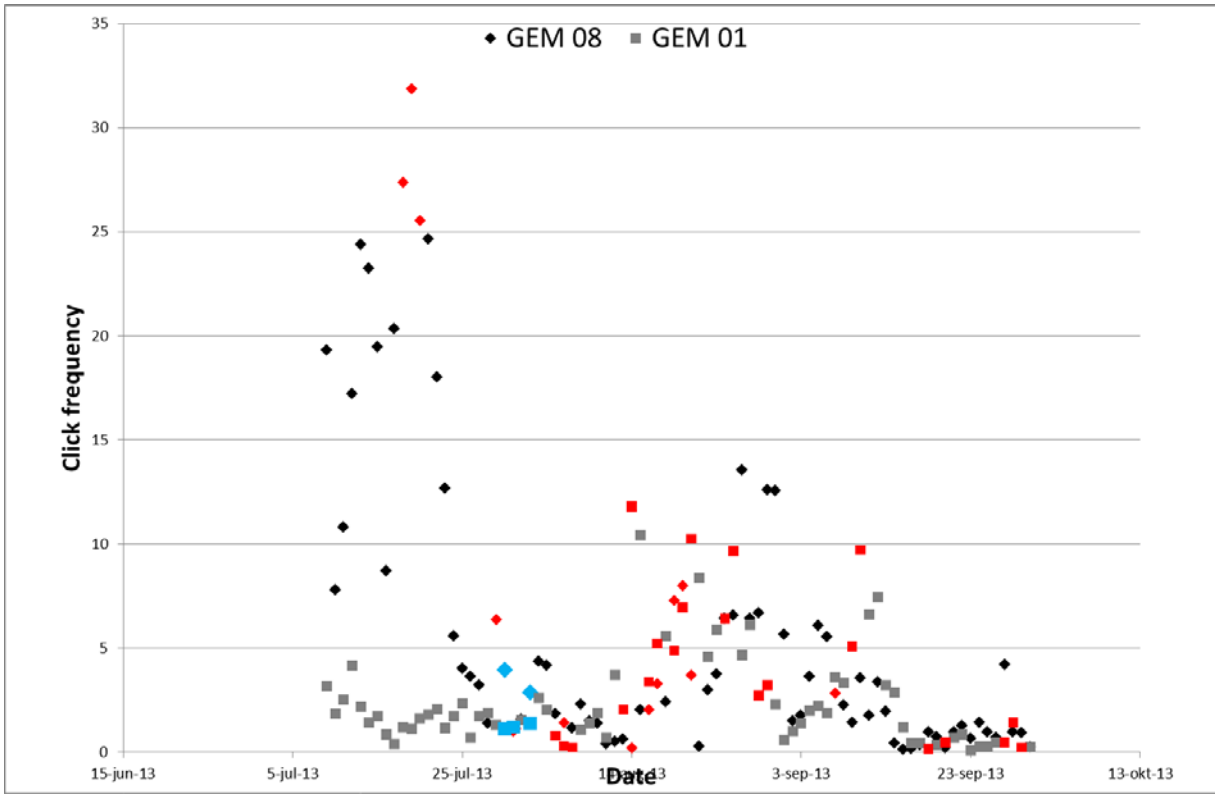



*Figure 18. Daily click frequency at CPOD locations GEM 01 and GEM 08 during a period the noise loggers collected data. Red symbols indicate days with piling events. Blue symbols indicate days with explosions recorded at the CPOD location.*

Since the described period with sound events does only comprise a small part of the period covered by CPODs a first rough exploration of possible effects of the recorded impulse sounds on harbour porpoise acoustic activity is done. The daily click frequencies from the CPOD locations GEM 01 and GEM 08, where the noise loggers were deployed, 18 July 2013 and 7 September 2013 are shown in Figure 18. Days with recorded explosions and piling events are marked for each CPOD individually. The picture is not straightforward. Piling events coincided with different levels of acoustic activity at both CPOD locations. The explosions coincide with low click frequencies at both CPOD locations where noise loggers were deployed. The piling events show no clear pattern. A more detailed GAMM analysis including impulsive sound events and other anthropogenic activities besides the variables described in Table 10 should provide insight in the effects of these on harbour porpoise acoustic activity in the study area. This analysis should preferably be done with all CPODs, on a more detailed level and for a longer period to take seasonal variations in other variables into account.

# 4. Discussion / synthesis

## 4.1 Methodology

Aerial surveys were conducted between August 2013 and June 2014. Applying distance sampling methods to the data, these surveys resulted in estimates of harbour porpoise densities. An underlying assumption of distance sampling is that all animals on the track-line are detected. For marine mammals this assumption is not valid. Thus a correction factor g(0) is needed to calculate absolute densities. This g(0) depends on the availability of the animals and on so-called observer bias. Ideally this g(0) is determined for each observer team under different sighting conditions. This can be achieved by performing 50-100 so-called racetracks (Hiby, 1998; Hiby & Lovell, 1996). This number should be achieved during the complete Gemini-monitoring period. For the time being the g(0)s from the German ITAW and Dutch IMARES aerial observer teams is used (Scheidat et al., 2008). It should be noted that the resulting densities could differ from the true densities, but using these g(0)s allows a general comparison of the Gemini surveys with other areas.

From September/October 2011 until July 2014, CPODs collected data on the presence of harbour porpoises on fifteen locations within the Gemini wind farm area and surroundings during 44.2% of all potential (deployment) days. Dislocation of CPODs and to a lesser extent technical failures were the main causes for the discontinuous series of recorded data.

To ensure that each CPOD's sensitivity is up to the desired standards, the CPODs were calibrated twice. The results of the calibrations showed the CPODs were operating correctly (presented in Appendix 4 and 5). For the calibrations, the received levels of mean peak-to-peak pressures (Ppp) emitted frequencies of 100, 110, 120, 130 and 140 kHz are examined for each individual CPOD. Since the main part of the energy of a porpoise click is around 132 kHz the differences at 130 kHz are the most applicable for comparison. CPOD 716, 1519, 1744 and 1817 show the highest variation in Ppp, but at 130 kHz even these CPODs show a mean peak-to-peak pressure between 110 and 120 dB re µ1Pa. This difference in peak-to-peak pressure corresponds to a difference in received sound level of less than 3 dB. This level is well below the maximum accepted variation recommended by the international AMPOD-project. Aim of the AMPOD-project was 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, a direct comparison of the recorded acoustic signals between the CPODs is feasible. As pointed out in the previous chapter a direct comparison between individual CPOD locations is not possible, since the amount of data differed per location due to various reasons.

An important question about CPOD data is what is actually detected. Does PAM measure densities of harbour porpoises? Do the patterns found reflect patterns in harbour porpoise (acoustic) behaviour or in their use of the area?
The collected acoustic data, however, are an approximation of the occurrence of harbour porpoises derived from their acoustic activity. Comparable temporal patterns (seasonal, time of day, time to high tide) are found in other studies as well (eg. Brasseur et al., 2010; Van Polanen Petel et al., 2012 in the Netherlands; Evans et al. 1993, Pierpoint 2008 in the UK).
Two different studies concluded that porpoises use echolocation virtually 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. Recent studies in Danish waters, however, where six

acoustic and behavioural logging units were deployed on harbour porpoises between May 2010 and August 2011 for 53 to 72 hrs per porpoise showed potential sleeping periods (Wright et al., 2013). One of the characteristics of these periods is a reduced acoustic activity. All in all it seems reasonable to conclude that acoustic monitoring with CPODs can give a reliable picture of the occurrence of harbour porpoises. At this point in time the collected data, however, cannot be used to assess the numbers and densities of porpoises. Several studies are underway to develop methods that will allow the use of acoustic activity to derive density estimates (e.g. Kyhn et al., 2008).

## 4.2 Comparison aerial survey and passive acoustic monitoring

Aerial and acoustic surveys are not directly comparable because the spatial and temporal scale monitored by the two techniques is different. The CPODs are permanently monitoring porpoises within a limited radius around the POD (< 300 m). The aerial surveys are covering a large area, nearly 7,800 km², but are only taking snapshots in time. One important observation, however, is that the aerial surveys show higher densities in the central part of the study area, which corresponds with the area where the Gemini wind farms will be located and where the CPODs were deployed.

A direct comparison of aerial survey data and CPOD data recorded on the same dates does not provide a direct correlation (Figure 19). For example, the highest porpoise detection rate by the CPODs on 22 August corresponded with the lowest density on that day. The data from April-June and October show a tendency that higher acoustic detection rates coincide with higher densities. Daily variation in porpoise presence and activity can explain the absence of a direct correlation.

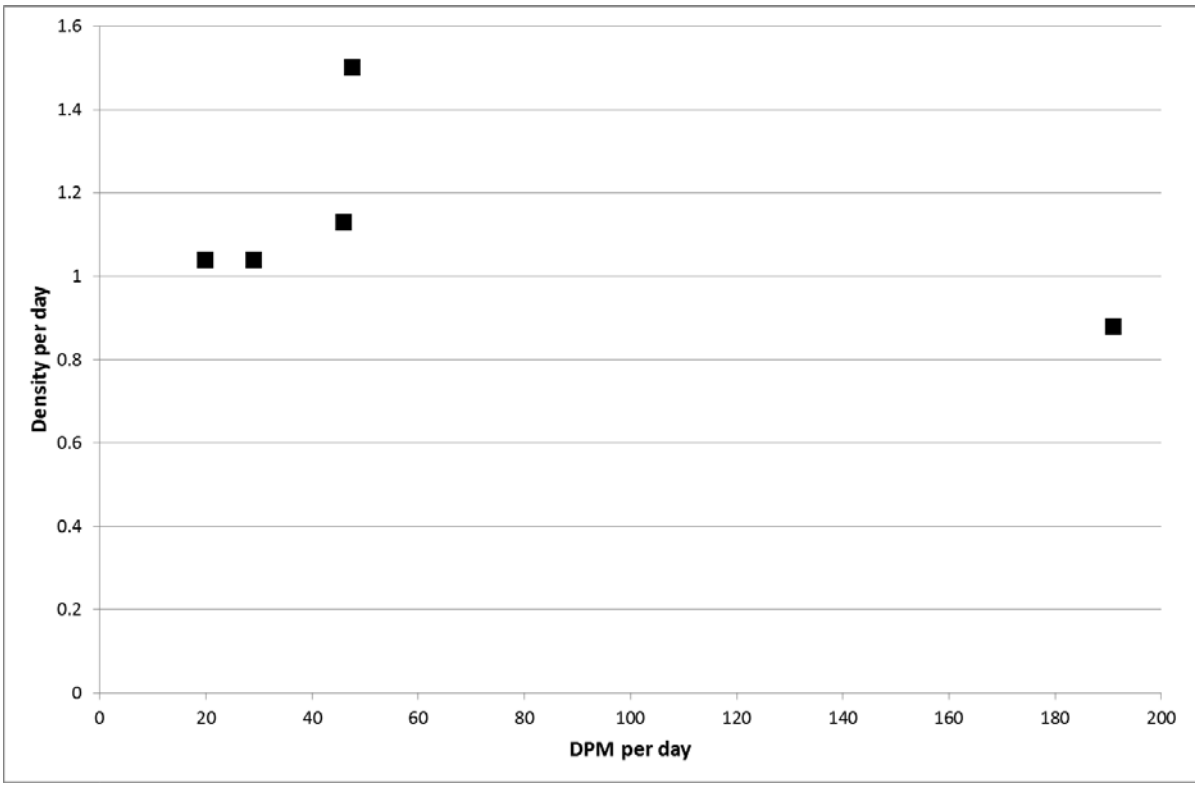



*Figure 19. Comparison of PAM results (sum of DPM) with results of aerial surveys in August, October 2013 and April, May and June 2014 (density).*

However, when looking at the data as a whole, the aerial and acoustic data reveal a similar temporal distribution (see Figure 9 and Figure 13 for comparison). After lowest values in Winter the maximum presence is reached in Spring, subsequently decreasing to average levels during summer and autumn. Based on the CPOD data the maximum porpoise presence in springtime (esp. March) seems to occur one month earlier than indicated by the flight data. This might be due to the fact that in March the flight took place early in March (on the 5th) whereas the CPOD data covers the whole month.

### 4.3 Spatial and seasonal pattern of harbor porpoise in the North Sea

The results of both the aerial surveys and the acoustic monitoring show a distinct seasonal pattern in abundance and acoustic activity of harbour porpoises; a peak is recorded in late Winter to early Spring whilst activity is lowest in Summer and early Winter. This pattern fits the general seasonal occurrence as shown by previous passive acoustic monitoring and visual observations in the North Sea (see references below).

In the Dutch North Sea passive acoustic monitoring studies have been conducted in and around the Offshore Wind farm Egmond aan Zee (OWEZ) and Prinses Amalia Wind Park (PAWP) wind farm sites off the mainland coast. In the OWEZ, Scheidat et al. (2011) found most acoustic detections in the Winter months (Dec-Mar) and virtually no detections in May and June. In the PAWP, the click frequency showed a distinct temporal pattern with higher activity in March and December, and the least activity in April-May (Van Polanen Petel et al., 2012). A slightly different pattern has been shown along the Dutch-German border, where a row of CPODs was deployed from the island of Borkum into the Eems-Dollard estuary. These CPODs recorded the lowest click frequency in April-July and a higher click frequency between August and December (Brasseur et al., 2010).

Visual observations from systematic land-based observations of seabird migration (and marine mammals) by members of the Working Group 'Club van Zeetrekwaarnemers' from the Dutch Seabird Group (CvZ/NZG) and during aerial surveys by IMARES show that harbour porpoises are present in Dutch waters throughout the year. In the coastal waters, peak numbers are observed in Winter and early Spring (Dec-Mar), after this period the numbers drop. Observations in June are relatively scarce, but the numbers slightly increase from July onwards (e.g. Camphuysen 2004, 2011). Aerial surveys on the Dutch Continental Shelf show a peak in March and lower densities in Summer and Autumn (Geelhoed et al., 2013; Scheidat et al., 2012). In the German North Sea bordering Dutch waters, the highest densities occur in Spring. Whereas older aerial surveys indicated much lower porpoise densities during the rest of year (Gilles *et al.* 2009, 2011), more recent surveys revealed that density levels around Borkum Reef can still be high throughout the Summer (Gilles et al. 2012, Hansen et al. 2013, Höschle et al. 2011, Siebert et al. 2012, 2013). The area further north along the German coast is characterized by a peak in May and June (Gilles *et al.*, 2009). Along the Danish west coast aerial surveys show that densities are highest between April and August, with a peak in August, although data for June-July are lacking (Teilmann et al., 2008). In the western part of the North Sea, porpoise numbers peak in April along the south eastern coast of England; up north along the eastern coast numbers peak in August (Evans et al., 2003).

Although overall numbers of calf sightings are still too few to allow a solid interpretation of the results, the July flights suggest that harbour porpoises reproduce in Dutch waters. Sexually mature female porpoises can give birth to one calf each year (Gaskin *et al.*, 1974). This means that mating will take place shortly after parturition, indicating that areas with calves are important in the life cycle of porpoises.

In summary, the seasonal occurrence of harbour porpoises in the Gemini study area does not differ from what is known about the temporal distribution of these animals in the North Sea.

## 4.4 Noise logger results vs CPOD / aerial surveys

The noise logger data currently provides a full picture of the back-ground sounds that are detectable by harbour porpoises in the area of the Gemini wind parks, prior construction. Deployment of noise loggers during T-c and later years, would provide a means of determining if potential changes in harbour porpoise occurrence and distribution could relate to sounds produced during Gemini construction, or due to other, sound-producing, factors.

# 5. Conclusions

The results of the T-0 monitoring of harbour porpoises for the intended Gemini offshore wind farm show that harbour porpoises are permanently present in the area. Both the aerial surveys as the passive acoustic monitoring show the same seasonal pattern, with a peak in Winter and Spring and a dip in Summer.

The aerial survey data show that highest densities of harbour porpoises are found in the area where the intended wind farm site is located. The CPODs are deployed in this area.

The occurrence of calves in the study area indicates that it is used for reproduction. Sexually mature female porpoises can give birth to one calf each year (Gaskin *et al.*, 1974). This means that mating will take place shortly after parturition, indicating that areas with calves are important for reproduction.

Passive Acoustic Monitoring (PAM) shows the effect of underlying factors on the acoustic activity (and thus occurrence) of harbour porpoises in the area.

The T-0 survey results provide a good basis for an evaluation of potential wind farm related impacts during the coming phases, since it provides a detailed temporal and spatial picture of harbour porpoise occurrence in the area. Thus enabling a detailed description of harbour porpoise activity and occurrence in relation to underlying factors, including activities associated to the construction of the Gemini wind farms.

# 6. Recommendations for future monitoring

The combination of aerial surveys and passive acoustic monitoring provides a good overview of harbour porpoise temporal and spatial distribution in the area.
During the T0-monitoring the aerial surveys were carried out by human observers. This method has been proven in the detection of marine mammals and can be conducted even at higher densities of marine mammals. Disadvantages of this method are possibly a decreasing attention of the observers during long flights. For this reason, during long flights in the Gemini project breaks of at least one hour were taken. The advantages of this system are that the results of the flights are available shortly after landing and the costs are comparatively low.

Alternatively, aerial surveys could be carried out using suitable digital methods. Here, for example, the providers APEM (digital stills) or HiDef (digital video) established their recording systems. As digital flights are carried out at higher altitudes (about 500 to 600 m compared to 180 m), a wind farm, both operating or under construction, can be overflown in safe distance to the offshore installations. Furthermore, the potential influence of the observation platform on birds and marine mammals is reduced which results in higher sighting rates especially of species that are sensitive such as scoters. Another advantage is that the digital acquisition enables the quality control of sightings. A disadvantage of this method is, apart from the costs for the use of aircraft and the special cameras, the amount of time required to evaluate the photographic material. HiDef requires a minimum of 100 hours evaluation time for one flight hour in order to review the images and to identify the marine mammals.

Due to the fact that a digital flight in the project area Gemini would require up to 700 hours evaluation time, this method does not seem to be an alternative. Because the focus in this project is on marine mammals, especially during the construction phase, results could be obtained much faster and more cost-effectively by conventional aerial survey flights. *For a comparison of T0 and subsequent years it is necessary to use the same method or -when using different methods- to obtain absolute densities (see below).*

The flight schedule for the T-0 monitoring represented a balance between surveying in the months where the potential long-term effect of the Gemini offshore wind farm are largest (when densities are high) and months (August, October, December) where direct inter-annual comparison between T-0, T-construction and T-1 is possible (as pile driving in the Netherlands is restricted to post-June).

For the short-term effects of pile driving, additional measurements will be necessary during the construction phase, where flights take place just before, during and after pile driving sessions.

For a comparison with other areas absolute densities are necessary. Thus g(0) has to be calculated for the Gemini-study. The number of obtained racetracks so far is too low to calculate a g(0). Continuation of performing racetracks in subsequent surveys is expected to yield enough racetracks for a proper calculation of g(0), thus enabling absolute density and abundance estimates. To obtain absolute density estimates with digital methods specific g(0)'s have to be calculated as well.

To ensure a good comparison between T-0 and subsequent years the same set up for the Passive Acoustic Monitoring of harbour porpoises is advisable. Variation caused by changes in CPOD locations or CPOD numbers will be kept to a minimum. The covered area is designed to detect avoidance behaviour of harbour porpoises to piling. To keep the effect of individual CPODs to a minimum the PODs should be calibrated regularly to ensure their performance is within accepted ranges.

To study the possible impact of the wind farm on harbour porpoises, GAMMs are a valuable tool. This group of models is well suited to comparing porpoise activity in different situations taking the variation caused by additional parameters (e.g. stone laying, dredging, piling) into account. For instance a comparison of T-0 and T-1, or a comparison of harbour porpoise activity inside the operating wind farms with the registered activity outside the wind farms.

Deploying noise loggers during Tc and later years is advisable, in order to relate the sound produced during construction activities (pre- during and post)to harbour porpoise presence, density and behaviour (and potentially seal tracking data).

## Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

## References


Au WWL, Kastelein RA, Rippe T & Schooneman NM, 1999. Transmission beam pattern and echolocation signals of a harbor porpoise (*Phocoena phocoena*). Journal of the Acoustical Society of America 106(6): 3699-3705.

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

Brasseur SMJM, Van Polanen-Petel T, Geelhoed SCV, Aarts GM & Meesters HWG, 2010. Zeezoogdieren in de Eems 2009: overzicht van de verkregen data. Research Report IMARES Wageningen UR - Institute for Marine Resources & Ecosystem Studies, Report C023/10.

Camphuysen CJ, 2004. The return of the harbour porpoise (*Phocoena phocoena*) in Dutch coastal waters. Lutra 47(2): 113-122.

Camphuysen CJ, 2011. Recent trends and spatial patterns in nearshore sightings of harbour porpoises (*Phocoena phocoena*) in the Netherlands (Southern Bight, North Sea ), 1990-2010. Lutra 54: 39-47.

Camphuysen CJ & Siemensma ML, 2011. Conservation plan for the Harbour Porpoise *Phocoena phocoena* in The Netherlands: towards a favourable conservation status. NIOZ Report 2011-07, Royal Netherlands Institute for Sea Research, Texel).

Carstensen J, Henriksen OD & Teilmann J, 2006. Impacts on harbour porpoises from offshore wind farm construction: Acoustic monitoring of echolocation activity using porpoise detectors (T-PODs). Mar Ecol Prog Ser 321: 295-308.

Dähne M, Gilles A, Lucke K, Peschko V, Adler S, Kruegel K, Sundermeyer J & Siebert U, 2013. Effects of pile-driving on harbour porpoises (*Phocoena phocoena*) at the first offshore wind farm in Germany. Environmental Research Letters 8(2)

Evans PGH, Anderwald P & Baines M, 2003. UK cetacean status review. Sea Watch Foundation, Oxford, UK.

Evans PGH, Fisher P, Rees I, Wainwright J, Farrell J & Mayo W, 1993. Foraging ecology of harbour porpoises in Shetland. European Research on Cetaceans 7: 33–38.

Gaskin DE, Arnold PW & Blair BA, 1974. Phocoena phocoena. Mammalian Species 42:1-8.

Geelhoed S, Scheidat M, Aarts G, van Bemmelen R, Janinhoff N, Verdaat H & Witte, R, 2011. Shortlist Masterplan Wind – Aerial surveys of harbour porpoises on the Dutch Continental Shelf. Research Report IMARES Wageningen UR - Institute for Marine Resources & Ecosystem Studies, Report No. C103/11.

Geelhoed SCV, Scheidat M, van Bemmelen RSA & Aarts G, 2013. Abundance of harbour porpoises (*Phocoena phocoena*) on the Dutch Continental Shelf, aerial surveys in July 2010-March 2011. Lutra 56(1): 45-57.

Gilles A, Scheidat M & Siebert U, 2009. Seasonal distribution of harbour porpoises and possible interference of offshore wind farms in the German North Sea. Marine Ecology-Progress Series 383: 295-307.

Gilles A, Adler S, Kaschner K, Scheidat M & Siebert U, 2011. Modelling harbour porpoise seasonal density as a function of the German Bight environment: implications for management. Endangered Species Research 14: 157-169.

Gilles A, Peschko V & Siebert U, 2012. Monitoring von marinen Säugetieren 2012 in der deutschen Nord- und Ostsee. Visuelle Erfassung von Schweinswalen. Endbericht für das Bundesamt für Naturschutz, pp 11-51.

Hammond PS, Berggren P, Benke H, Borchers DL, Collet A, Heide Jorgensen MP, Heimlich S, Hiby AR, Leopold MF & Oien N, 2002. Abundance of harbour porpoise and other cetaceans in the North Sea and adjacent waters. Journal of Applied Ecology 39(2): 361-376.

Hammond P, Macleod K, Berggren P, Borchers D, Burt M, Cañadas A, Desportes G, Donovan G, Gilles A, Gillespie D, Gordon J, Hiby L, Kuklik I, Leaper R, Lehnert K, Leopold M, Lovell P, Øien N, Paxton

C, Ridoux V, Rogan E, Samarra F, Scheidat M, Sequeira M, Siebert U, Skov H, Swift R, Tasker M, Teilmann J, Van Canneyt O & Vázquez J, 2013. Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management. Biological Conservation 164:107–122.

Hansen S, Höschle C, Diederichs A, Nehls G, Laczny M & Piper W, 2013. Offshore-Testfeld Alpha ventus Fachgutachten Meeressäugetiere 2. Untersuchungsjahr der Betriebsphase (Januar - Dezember 2011). BioConsult SH & IfAÖ.

Hiby AR, 1998. The objective identification of duplicate sightings in aerial survey for porpoise. In: Marine Mammal Survey and Assessment Methods Rotterdam. Balkema.

Hiby AR & Lovell P, 1996. Using aircraft in tandem formation to estimate abundance of harbour porpoise. Biometrics 54: 1280-1289.

Höschle C, Diederichs A, Nehls G, Laczny M & Piper W, 2011. Statusbericht Meeressäugetiere im Bereich des Offshore-Testfeldes Alpha Ventus. Im Auftrag der Stiftung Offshore-Windenergie; Bioconsult SH & Biola.

Kastelein RA, Hoek L, Wensveen PJ, Terhune JM & de Jong CAF, 2010. The effect of signal duration on the underwater detection of a harbor porpoise (*Phocoena phocoena*) for single frequency-modulated tonal signals between 0.25 and 160 kHz. Journal of the Acoustical Society of America 128: 3211-3222.

Kastelein RA, Gransier R, Hoek L & de Jong CAF, 2012a. The hearing threshold of a harbor porpoise (*Phocoena phocoena*) for impulsive sounds (L). Journal of the Acoustical Society of America 132(2): 607-610.

Kastelein RA, Steen N, Gransier R, Wensveen PJ & de Jong CAF, 2012b. Threshold received sound pressure levels of single 1--2 kHz and 6--7 kHz up-sweeps and down-sweeps causing startle responses in a harbor porpoise (*Phocoena phocoena*). Journal of the Acoustical Society of America 3: 2325-2333.

Kastelein RA, Hoek L, Gransier R & de Jong CAF, 2013a. Hearing thresholds of a harbor porpoise (*Phocoena phocoena*) for playbacks of multiple pile driving strike sounds, The Journal of the Acoustical Society of America 134: 2302-2306.

Kastelein RA, Steen N, Gransier R & de Jong CAF, 2013b. Brief Behavioral Response Threshold Level of a Harbor Porpoise (*Phocoena phocoena*) to an Impulsive Sound. Aquatic Mammals 39(4): 315-323.

Kastelein RA, Gransier R, Hoek L & Rambags M, 2013c. Hearing frequency thresholds of a harbour porpoise (*Phocoena phocoena*) temporarily affected by a continuous 1.5 kHz tone. Journal of the Acoustical Society of America 134:2286-2292.

Kastelein RA, Van Heerden D, Gransier R & Hoek L, 2013d. Behavioral responses of a harbor porpoise (*Phocoena phocoena*) to playbacks of broadband pile driving sounds. Marine Environmental Research 92: 206-214.

Kastelein RA, Hoek L, Gransier R, Rambags M & Claeys N, 2014a. Effect of level, duration, and inter-pulse interval of 1-2 kHz sonar signal exposures on harbour porpoise hearing. Journal of the Acoustical Society of America 136: 412-422.

Kastelein RA, Gransier R, Schop J & Hoek L, 2014b. Frequency of greatest temporary hearing threshold shift in harbor porpoises (*Phocoena phocoena*) depends on the noise level. Journal of the Acoustical Society of America 136: 1410-1418.

van Kooten T, Leopold M, Lucke K, Aarts G, Geelhoed S, Brasseur S, van Bemmelen R, Joost M, Stöber N & Wendeln H, 2012. MEP-Gemini-T0. Monitoring and evaluation plan for the ecological monitoring regarding the pre-construction phase of Gemini Offshore Wind Farm.

Kyhn LN & Tougaard J, 2009. Monitoring abundance by acoustic methods. Oral presentation AMPOD symposium, Stralsund.

Kyhn, LN Tougaard J, Teilmann J, Wahlberg M, Jørgensen PB & Bech, NJ, 2008. Harbour porpoise (*Phocoena phocoena*) static acoustic monitoring: laboratory detection thresholds of T-PODs are

reflected in field sensitivity. Journal of the Marine Biological Association of the United Kingdom, 88(6), 1085–1091.

Lucke, K, in prep. Measurement of Underwater Sound at the GEMINI Windpark Site. Centre for Marine Science and Technology, Curtin University, Perth, Australia

Lucke K, Siebert U, Lepper PA & Blanchet M-A, 2009. Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. Journal of the Acoustical Society of America, 125 (6): 4060-4070.

Pierpoint C, 2008. Harbour porpoise *(Phocoena phocoena*) foraging strategy at a high energy, near-shore site in south-west Wales, UK. Journal of the Marine Biological Association of the United Kingdom, 88(6): 1167–1173.

van Polanen Petel T, Geelhoed S & Meesters E, 2012. Harbour porpoise occurrence in relation to the Prinses Amaliawindpark. IMARES Report number C177/10, IMARES Wageningen UR.

Prins TC, Twisk F, van den Heuvel-Greve MJ, Troost TA & Van Beek JKL, 2008. Development of a framework for Appropriate Assessments of Dutch offshore wind farms. Imares rapport Z4513.

R Development Core Team, 2009. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0. http://www.R-project.org.

Scheidat M, Gilles A, Kock KH & Siebert U, 2008. Harbour porpoise *Phocoena phocoena* abundance in the southwestern Baltic Sea. Endangered Species Research 5: 215-223.

Scheidat M, Tougaard J, Brasseur S, Carstensen J, Polanen Petel T van, Teilmann J & Reijnders P, 2011. Harbour porpoisesa (*Phocoena phocoena*) and wind farms: a case study in the Dutch North Sea. Environ Res Lett 6: 1-10.

Scheidat M, Verdaat H & Aarts G, 2012. Using aerial surveys to estimate density and distribution of harbour porpoises in Dutch waters. Journal of Sea Research 69: 1-7.

Schuchardt B, Storz G, Todeskino D, 2009a. Offshore windpark 'BARD Offshore NL 1': milieueffectrapport. In. Planungsgemenischaft Umweltplanung Offshore Windpark, for BARD Engineering Gmbh, Emden

Schuchardt B, Storz G, Todeskino D, 2009b. Offshore windpark 'GWS Offshore NL 1': Milieueffectrapport. In. Planungsgemenischaft Umweltplanung Offshore Windpark, for BARD Engineering Gmbh, Emden.

Siebert U, Gilles A, Dähne M, Peschko V, Krügel K, Benke H, Lucke K, Müller S, Adler S & Sundermeyer J, 2012. Ergänzende Untersuchungen zum Effekt der Bau- und Betriebsphase im Offshore-Testfeld „alpha ventus“ auf marine Säugetiere. StUKplus Fortschrittsbericht 2011.

Siebert U, Gilles A, Dähne M, Peschko V, Ruser A, Meyer-Klaeden O, Viquerat S, Giewat H & Ronnenberg K, 2013. Ergänzende Untersuchungen zum Effekt der Bau- und Betriebsphase im Offshore-Testfeld „alpha ventus“ auf marine Säugetiere. StUKplus Fortschrittsbericht 2012.

Teilmann J, Akamatsu T, Miller LA, Dietz R, Tougaard J & Siebert U, 2005. Echolocation behaviour of a wild harbour porpoise during diving. Pp 12-16 In: Abstract Book of the 16th Biennal Conference On The Biology of Marine Mammals, San Diego, California.

Teilmann J, Christiansen CT, Kjellerup S, Dietz R & Nachman G, 2013. Geographic, seasonal, and diurnal surface behavior of harbor porpoises. Marine mammal science 29(2): E60–E76.

Teilmann J, Sveegaard S, Dietz R, Krag Petersen I, Berggren P & Desportes G, 2008. High density areas for harbour porpoises in Danish waters. NERI Technical Report No. 657. National Environmental Research Institute, University of Aarhus.

Teilmann J, Tougaard J, Carstensen J & L Renvald, 2009. Baseline monitoring of harbour porpoises - Rødsand 2 Offshore Wind Farm. NERI Commissioned Report to E-ON. Roskilde, Demark, NERI.

Thompson PM, Lusseau D, Barton T, Simmons D, Rusin J, Bailey H, 2010. Assessing the responses of coastal cetaceans to the construction of offshore wind turbines. Mar Pollut Bull 60:1200–1208

Tougaard J, Carstensen J, Bech NL & Teilmann J, 2006a. Final report on the effect of Nysted Offshore Wind Farm on harbour porpoises. Annual report to EnergiE2. Roskilde, Denmark, NERI.

Tougaard J, Carstensen J, Wisz MS, Teilmann J, Bech NI & Skov H, 2006b. Harbour porpoises on Horns Reef in relation to construction and operation of Horns Rev Offshore Wind Farm. Technical report to Elsam Engineering A/S. Roskilde, Denmark, National Environmental Research Institute.

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

Verfuß UK, Miller LA & Schnitzler H-U, 2005. Spatial orientation in echolocating harbour porpoises *(Phocoena phocoena*). Journal of Experimental Biology 208: 3385-3394.

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

Villadsgaard A, Wahlberg M & Tougaard J, 2007. Echolocation signals of wild harbour porpoises, *Phocoena phocoena.* Journal of Experimental Biology 210(1): 56-64.

Wright AJ, Akamatsu T, Nørgaard Mouritsen K, Sveegard S, Dietz R & Teilmann J, 2013. Silent porpoise: Potential sleeping behaviour identified in wild harbour porpoise. Pp 123 In Abstract book of the 27th conference of the European Cetacean Society. Setubal, Portugal.

## Appendix 1. Coordinates for aerial transects and CPOD-positions

Coordinates of transect lines in the Gemini-study area.

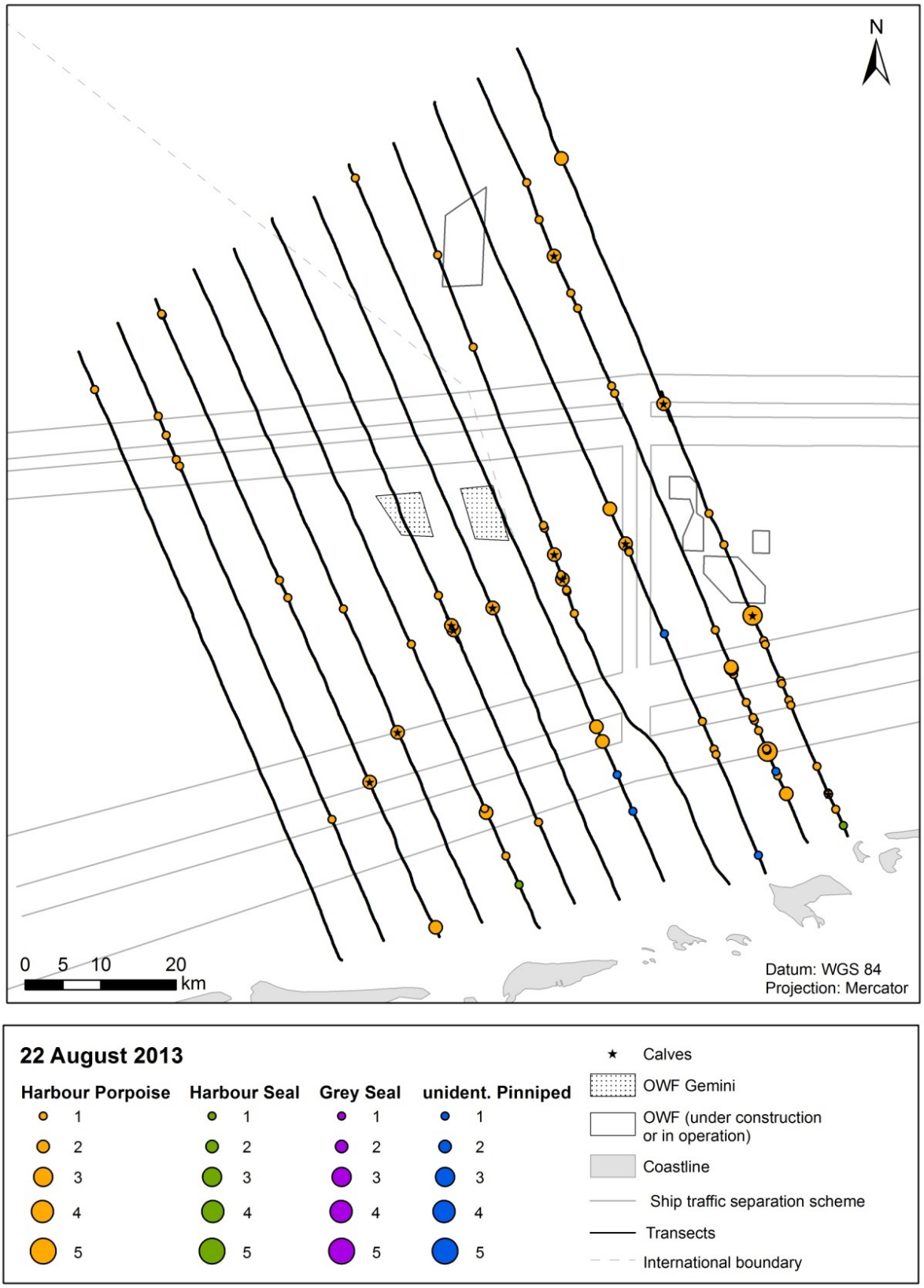
| Start or end transect line | WGS 84 Latitude (N) | WGS 84 Longitude (E) | x (ETRS89, Zone31) Northing | y (ETRS89, Zone31) Easting |
|---|---|---|---|---|
| D09_S | 53.46 | 5.83 | 688188.47 | 5927358.57 |
| D09_N | 54.21 | 5.21 | 643895.38 | 6009161.40 |
| D08_N | 54.24 | 5.28 | 648785.26 | 6012981.87 |
| D08_S | 53.47 | 5.93 | 694364.71 | 5929003.35 |
| D07_S | 53.48 | 6.02 | 700703.88 | 5930355.72 |
| D07_N | 54.28 | 5.36 | 653667.02 | 6016807.69 |
| D06_N | 54.31 | 5.44 | 658540.67 | 6020638.85 |
| D06_S | 53.49 | 6.12 | 707133.61 | 5931548.34 |
| D05_S | 53.50 | 6.22 | 713663.91 | 5932564.81 |
| D05_N | 54.34 | 5.51 | 663406.20 | 6024475.34 |
| D04_N | 54.37 | 5.59 | 668327.36 | 6028233.80 |
| D04_S | 53.50 | 6.32 | 720313.97 | 5933372.60 |
| D03_S | 53.52 | 6.41 | 725968.73 | 5935959.01 |
| D03_N | 54.41 | 5.67 | 673151.21 | 6032029.61 |
| D02_N | 54.44 | 5.75 | 678033.76 | 6035934.44 |
| D02_S | 53.55 | 6.50 | 731584.72 | 5938610.84 |
| D01_S | 53.55 | 6.59 | 737978.20 | 5939881.20 |
| D01_N | 54.48 | 5.83 | 683332.35 | 6040364.26 |
| G03_N | 54.52 | 5.91 | 688609.97 | 6044952.35 |
| G03_S | 53.60 | 6.66 | 741923.43 | 5945437.29 |
| G02_S | 53.63 | 6.74 | 747279.19 | 5948498.43 |
| G02_N | 54.56 | 5.99 | 693790.91 | 6049626.96 |
| G01_N | 54.59 | 6.08 | 698731.79 | 6053704.38 |
| G01_S | 53.64 | 6.83 | 753161.48 | 5950653.83 |

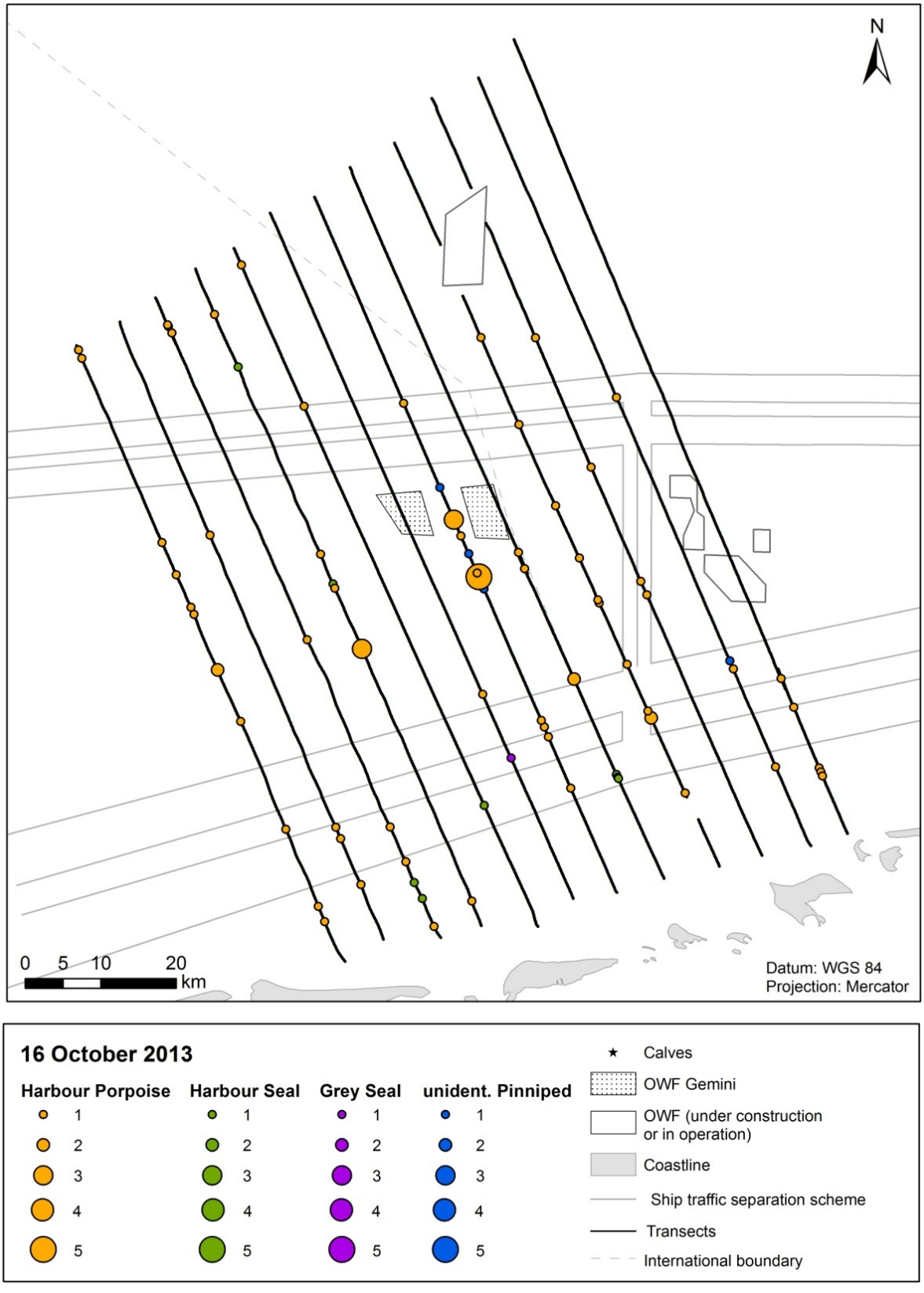
*Location of CPODs in the Gemini-study area. Coordinates in UTM 31N ETRS89 see Table 4.*

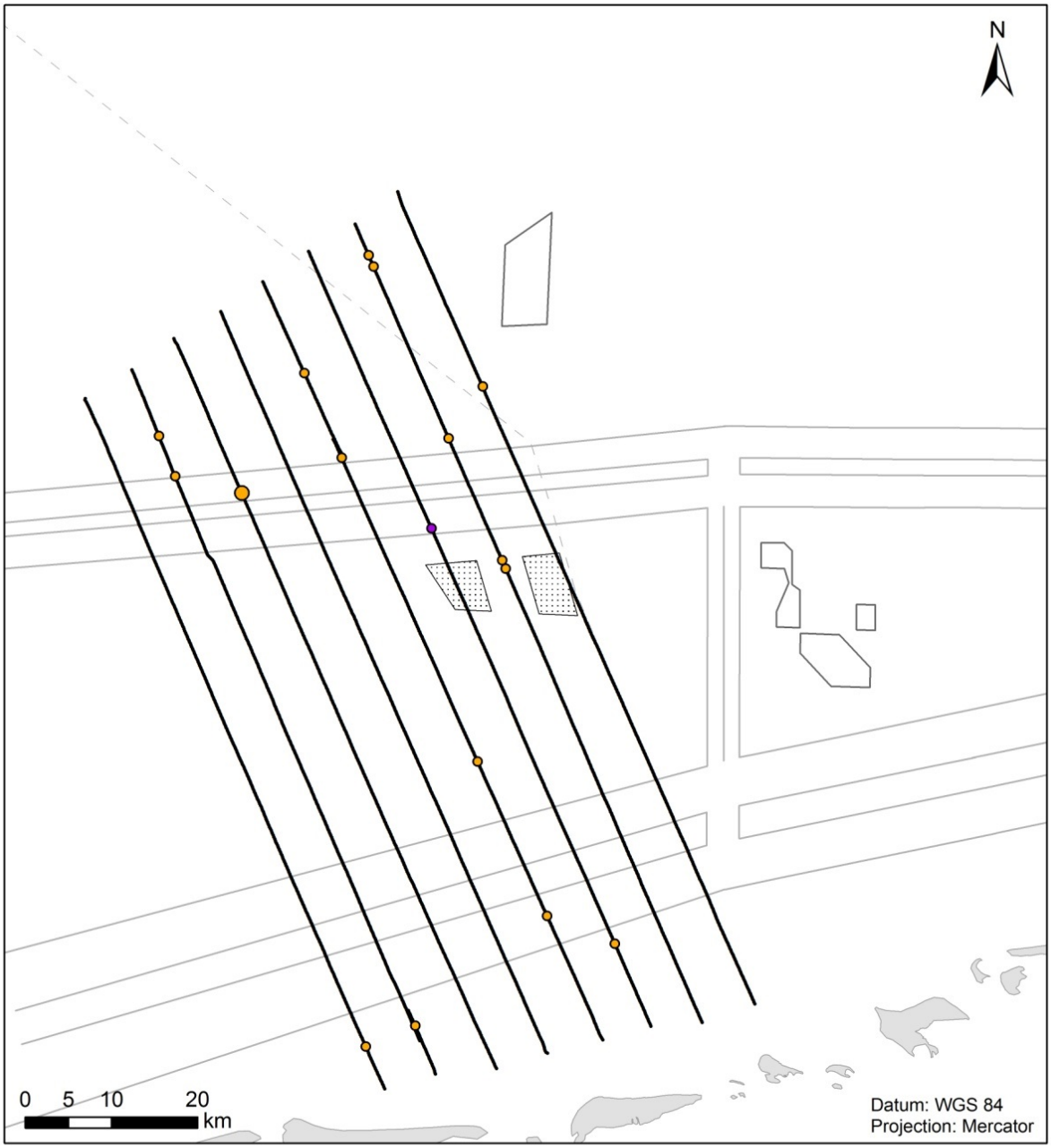
| | | ETRS89, Zone 31 | |
|---|---|---|---|
| | Location | North | East |
| GEM 01 | 40km west of Gemini | 647356.71 | 5983721.70 |
| GEM 02 | 20km west of Gemini | 667068.68 | 5987102.22 |
| GEM 03 | 10km west of Gemini | 676924.69 | 5988793.22 |
| GEM 04 | 5km west of Gemini | 681852.69 | 5989638.92 |
| GEM 05 | ZeeEnergie North | 687321.67 | 5994210.29 |
| GEM 06 | ZeeEnergie center | 689219.69 | 5990903.08 |
| GEM 07 | ZeeEnergie South | 690782.71 | 5988177.62 |
| GEM 08 | between ZeeEnergie and Buitengaats | 694339.68 | 5991781.29 |
| GEM 09 | Buitengaats North | 697784.69 | 5996029.50 |
| GEM 10 | Buitengaats center | 699098.71 | 5992630.79 |
| GEM 11 | Buitengaats South | 700693.67 | 5988518.05 |
| GEM 12 | 7.5km south of Buitengaats | 703407.68 | 5981508.58 |
| GEM 13 | 15km south of Buitengaats | 706121.74 | 5974499.13 |
| GEM 14 | in German waters | 704823.66 | 5989782.85 |
| GEM 15 | 30km west of ZeeEnergie | 657215.76 | 5985401.43 |

## Appendix 2. Aerial surveys - Tracks and marine mammal sightings

Sightings from all marine mammals – Harbour porpoises, harbour seals, grey seals and unidentified seals are presented for each flight carried out during the survey 2013-2014 for the Gemini wind farms. The figures also show the transect lines flown on each survey. Gaps in the transect lines are equivalent with disturbances within the GPS-connection.


N
0 5 10 20
km
Datum: WGS 84
Projection: Mercator
22 August 2013
Harbour Porpoise
Harbour Seal
Grey Seal
unident. Pinniped
1
2
3
4
5
Calves
OWF Gemini
OWF (under construction or in operation)
Coastline
Ship traffic separation scheme
Transects
International boundary

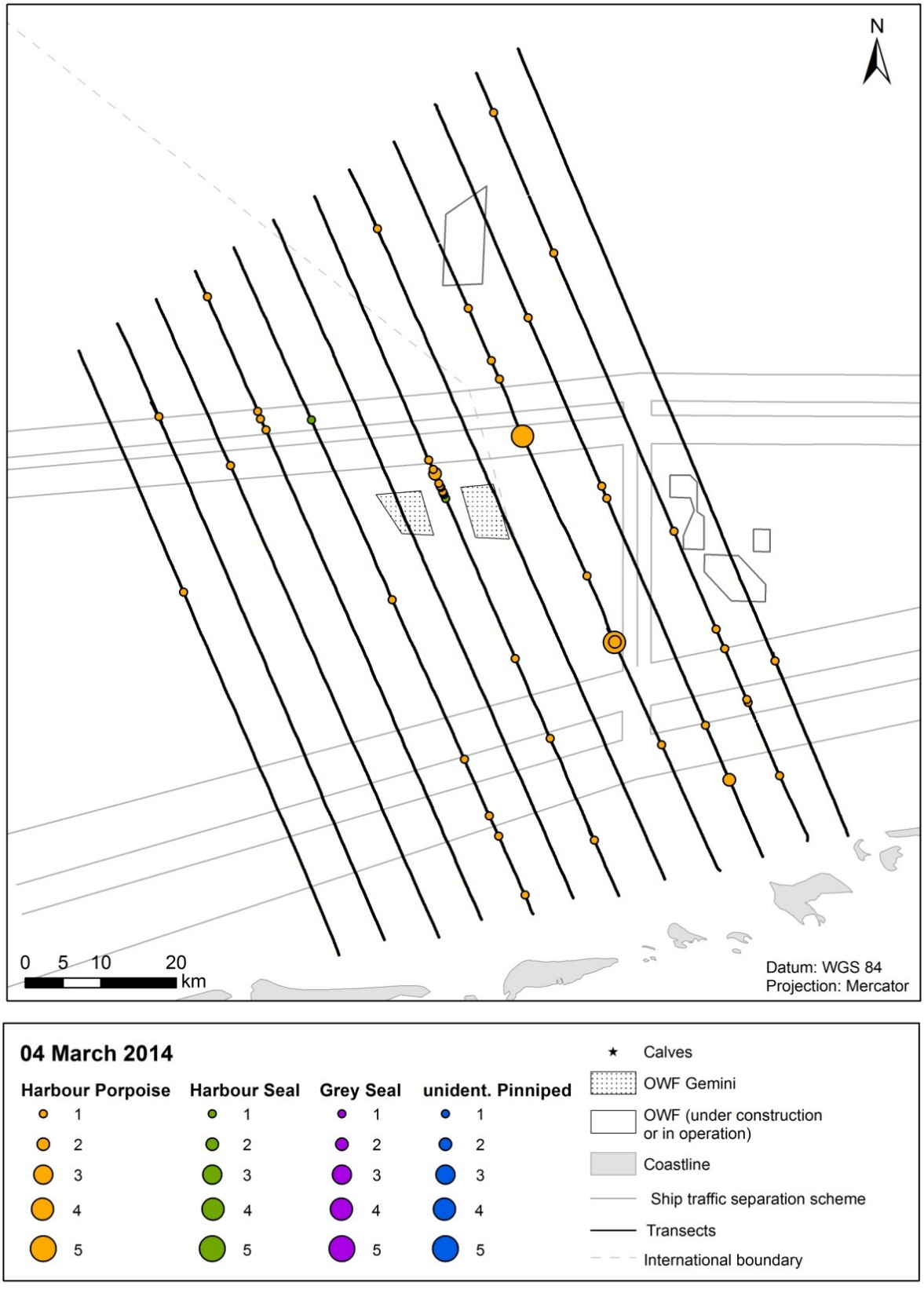

N
0 5 10 20
km
Datum: WGS 84
Projection: Mercator
16 October 2013
Harbour Porpoise
Harbour Seal
Grey Seal
unident. Pinniped
1
2
3
4
5
Calves
OWF Gemini
OWF (under construction or in operation)
Coastline
Ship traffic separation scheme
Transects
International boundary

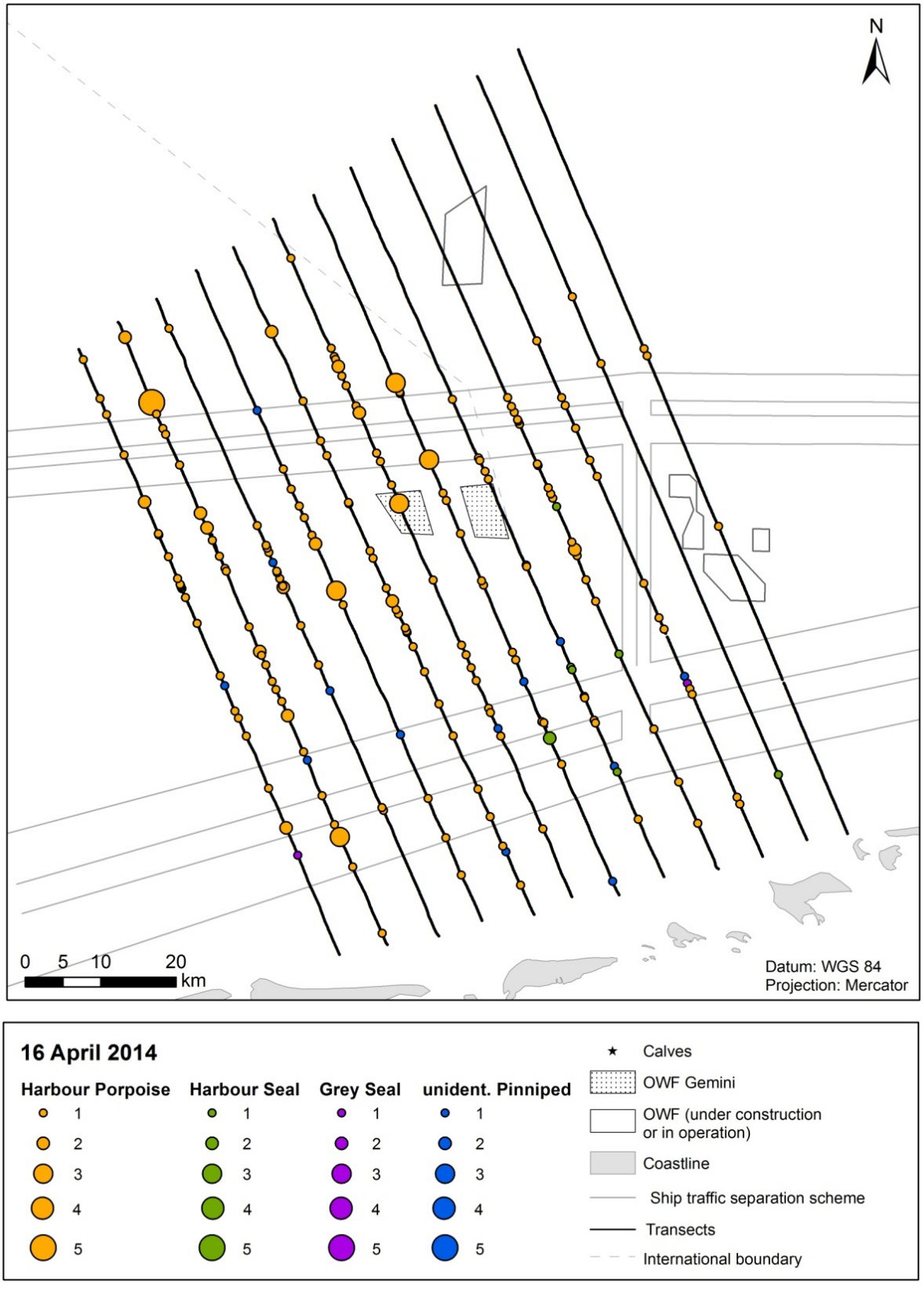


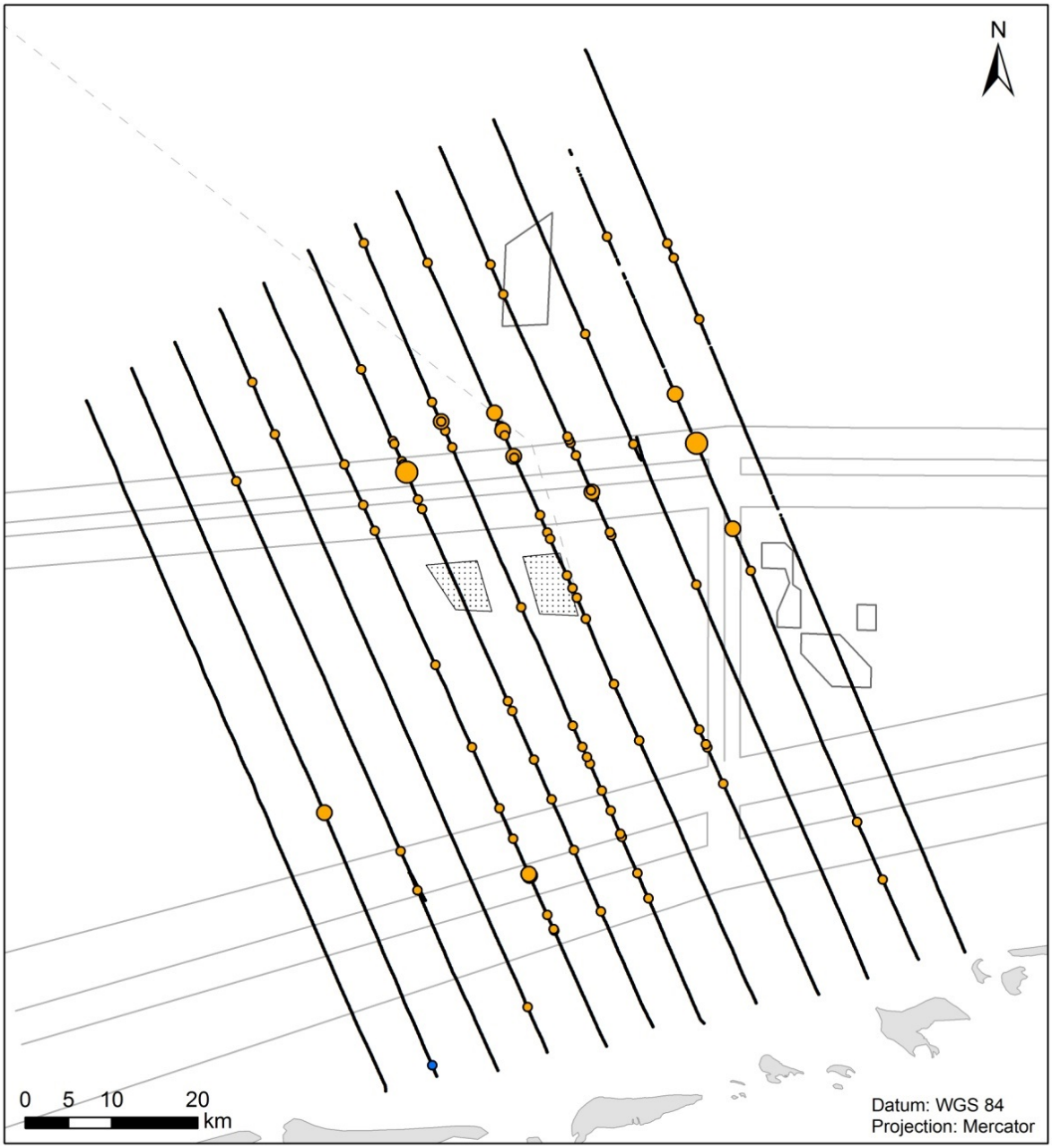

**19 February 2014**

| Harbour Porpoise | Harbour Seal | Grey Seal | unident. Pinniped |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 2 | 2 | 2 |
| 3 | 3 | 3 | 3 |
| 4 | 4 | 4 | 4 |
| 5 | 5 | 5 | 5 |

- ★ Calves
- OWF Gemini
- OWF (under construction or in operation)
- Coastline
- Ship traffic separation scheme
- Transects
- International boundary


N
0 5 10 20
km
Datum: WGS 84
Projection: Mercator
04 March 2014
Harbour Porpoise
Harbour Seal
Grey Seal
unident. Pinniped
1
2
3
4
5
Calves
OWF Gemini
OWF (under construction or in operation)
Coastline
Ship traffic separation scheme
Transects
International boundary

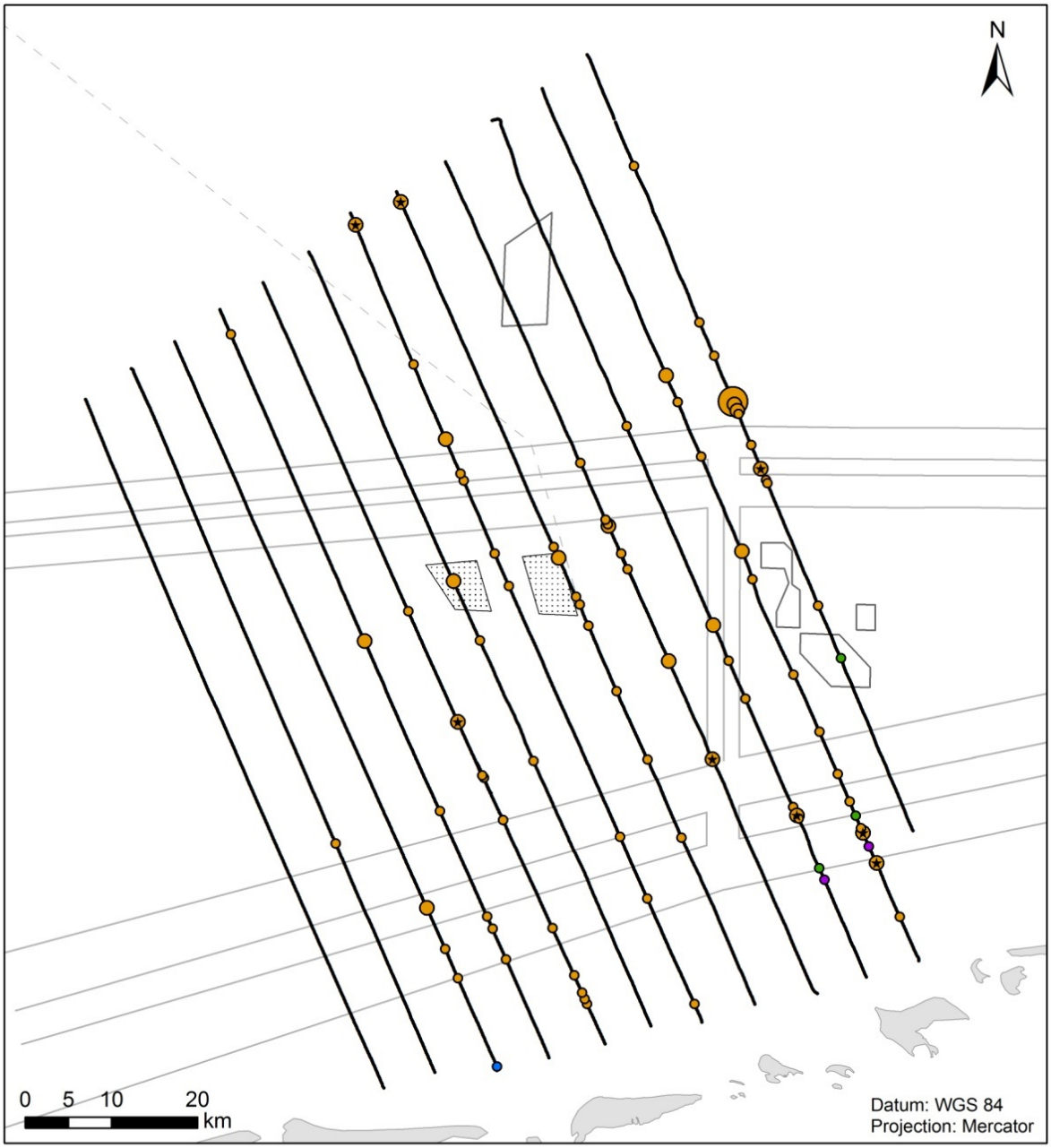

N
0 5 10 20
km
Datum: WGS 84
Projection: Mercator
16 April 2014
Harbour Porpoise
Harbour Seal
Grey Seal
unident. Pinniped
1
2
3
4
5
Calves
OWF Gemini
OWF (under construction or in operation)
Coastline
Ship traffic separation scheme
Transects
International boundary




**05 May 2014**

| Harbour Porpoise | Harbour Seal | Grey Seal | unident. Pinniped |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 2 | 2 | 2 |
| 3 | 3 | 3 | 3 |
| 4 | 4 | 4 | 4 |
| 5 | 5 | 5 | 5 |

- ★ Calves
- OWF Gemini
- OWF (under construction or in operation)
- Coastline
- Ship traffic separation scheme
- Transects
- International boundary



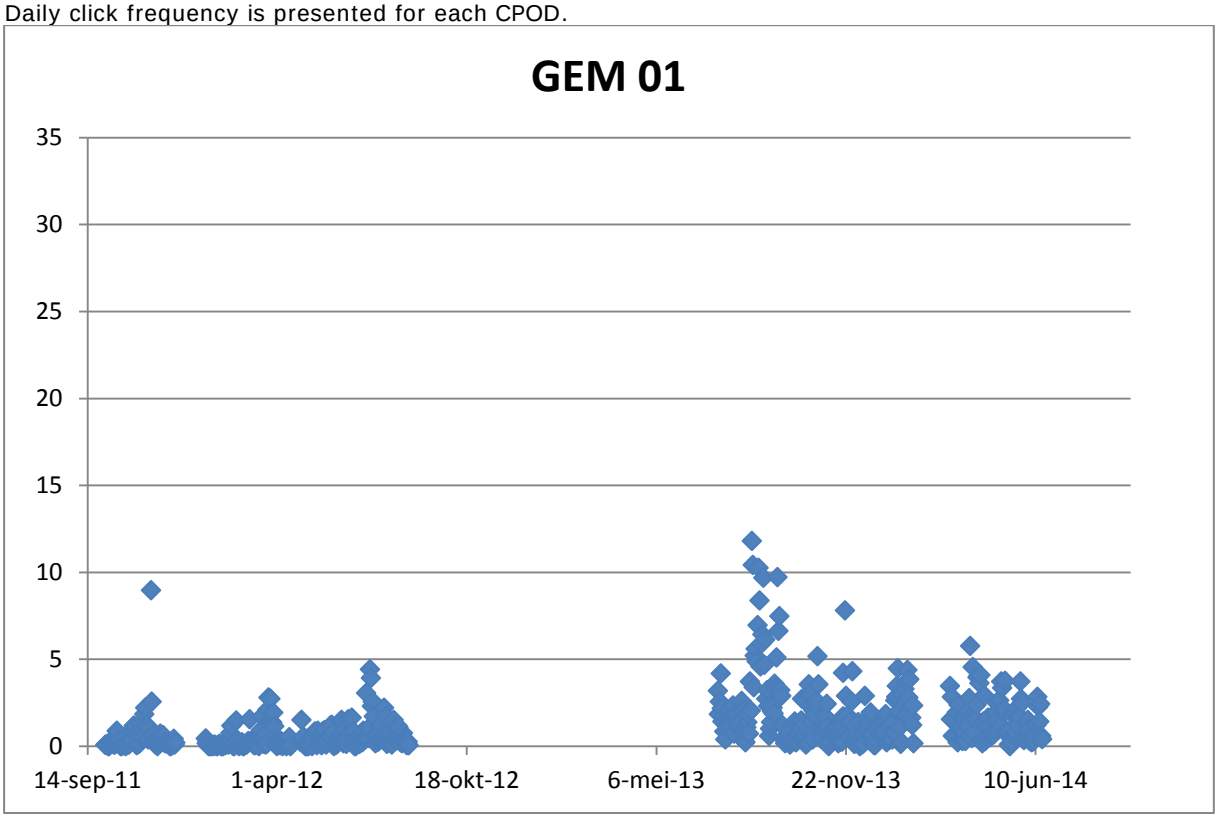

**03 June 2014**

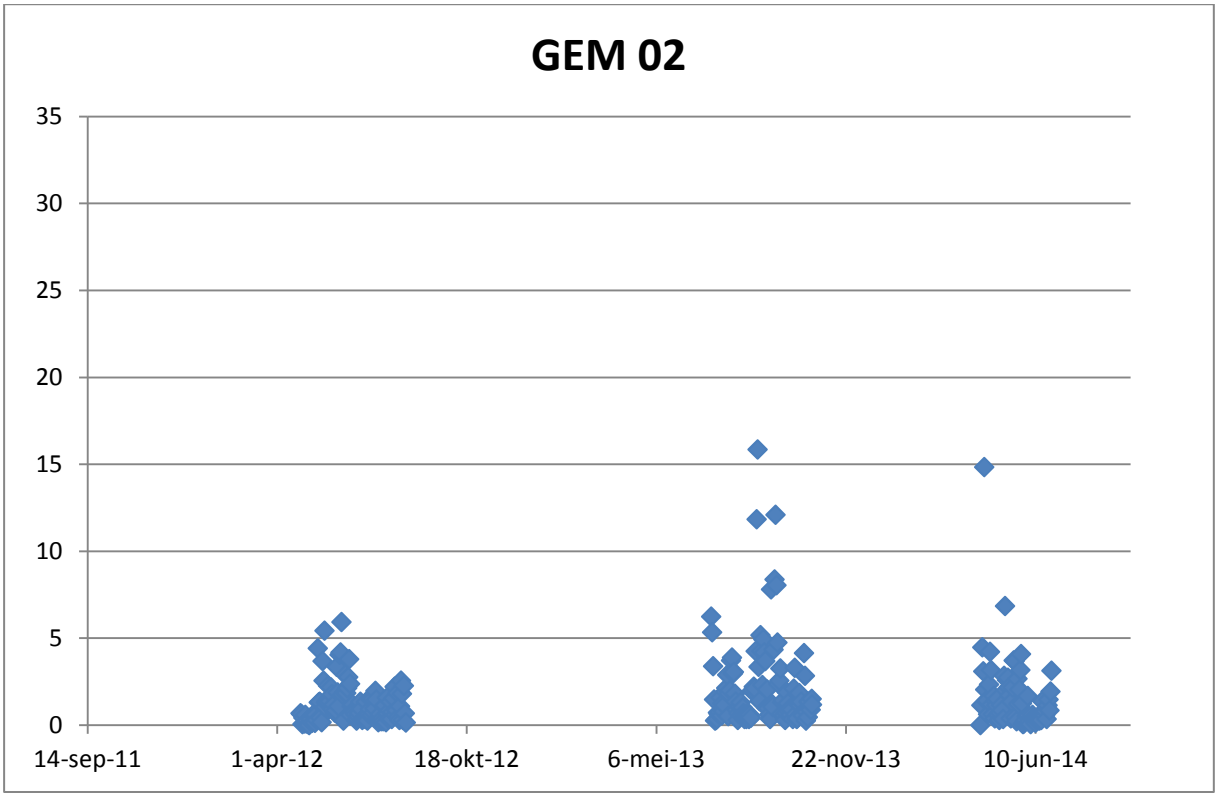
| Harbour Porpoise | Harbour Seal | Grey Seal | unident. Pinniped |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 2 | 2 | 2 |
| 3 | 3 | 3 | 3 |
| 4 | 4 | 4 | 4 |
| 5 | 5 | 5 | 5 |

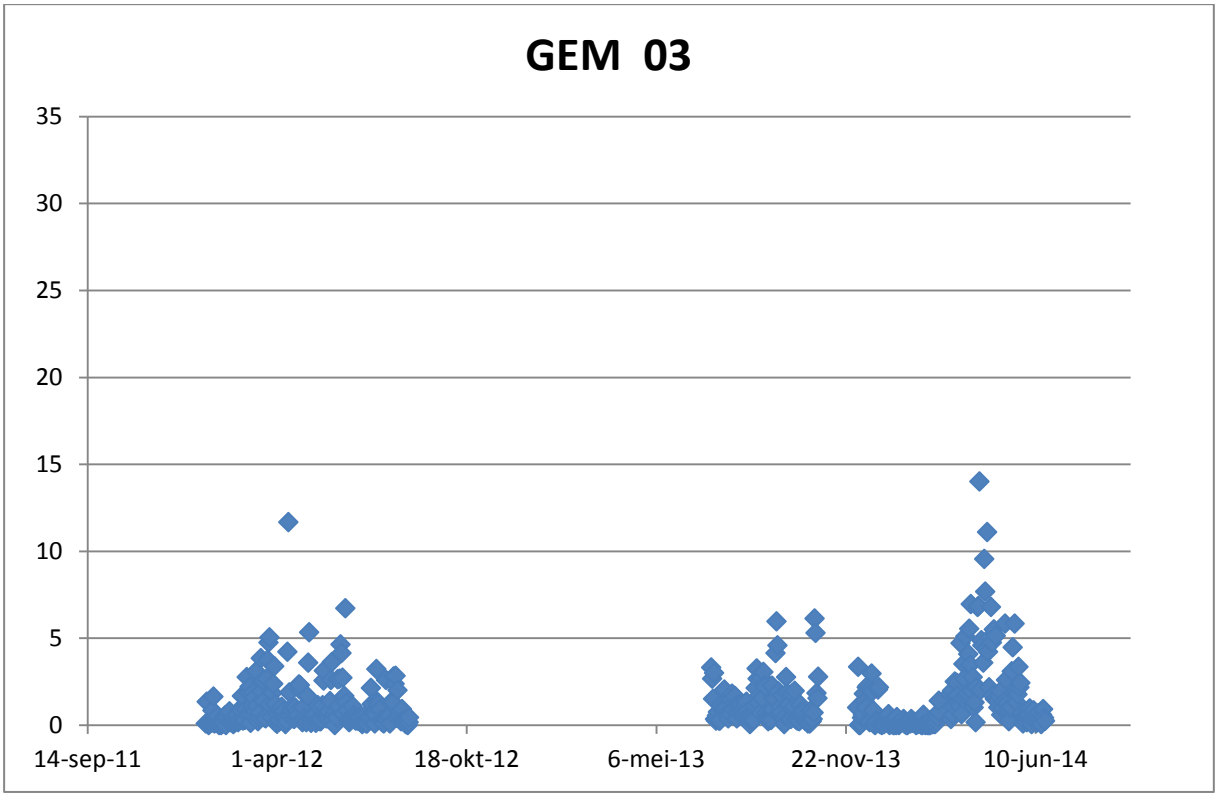
- Calves
- OWF Gemini
- OWF (under construction or in operation)
- Coastline
- Ship traffic separation scheme
- Transects
- International boundary

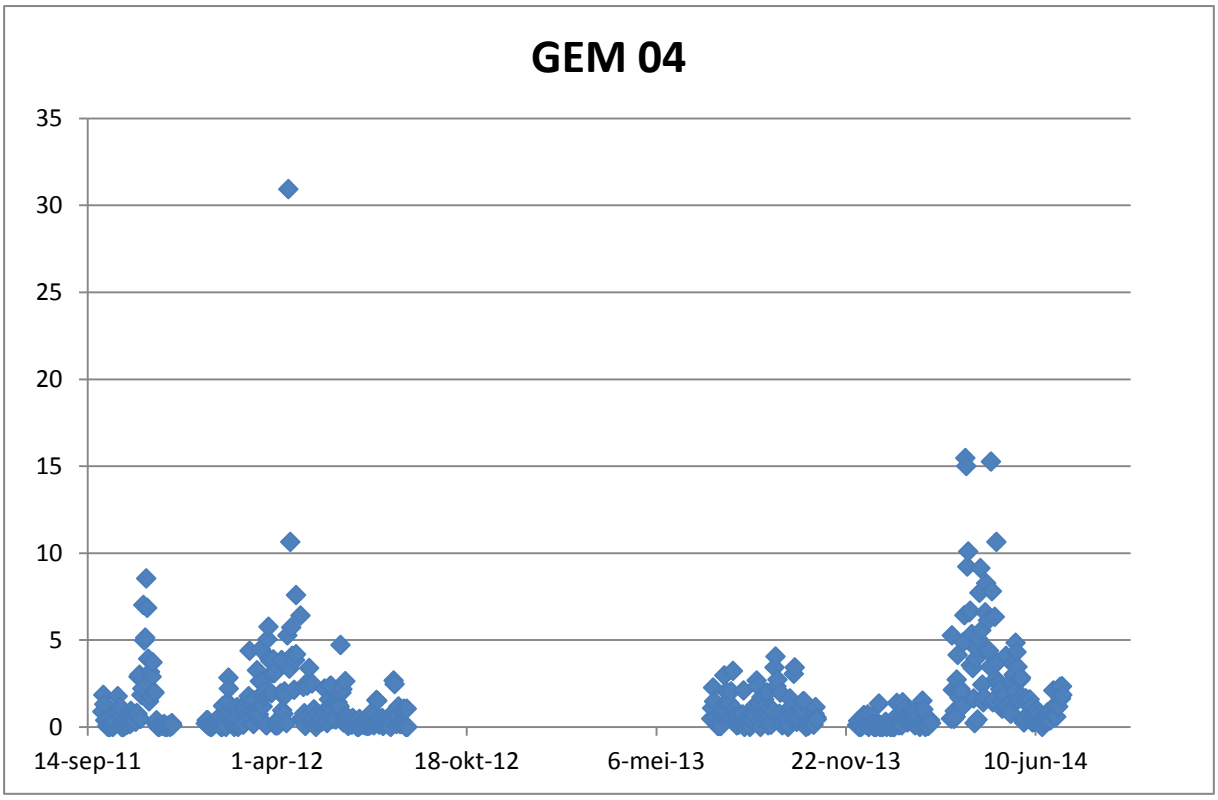
## Appendix 3. Seasonal patterns in acoustic activity of Harbour porpoise

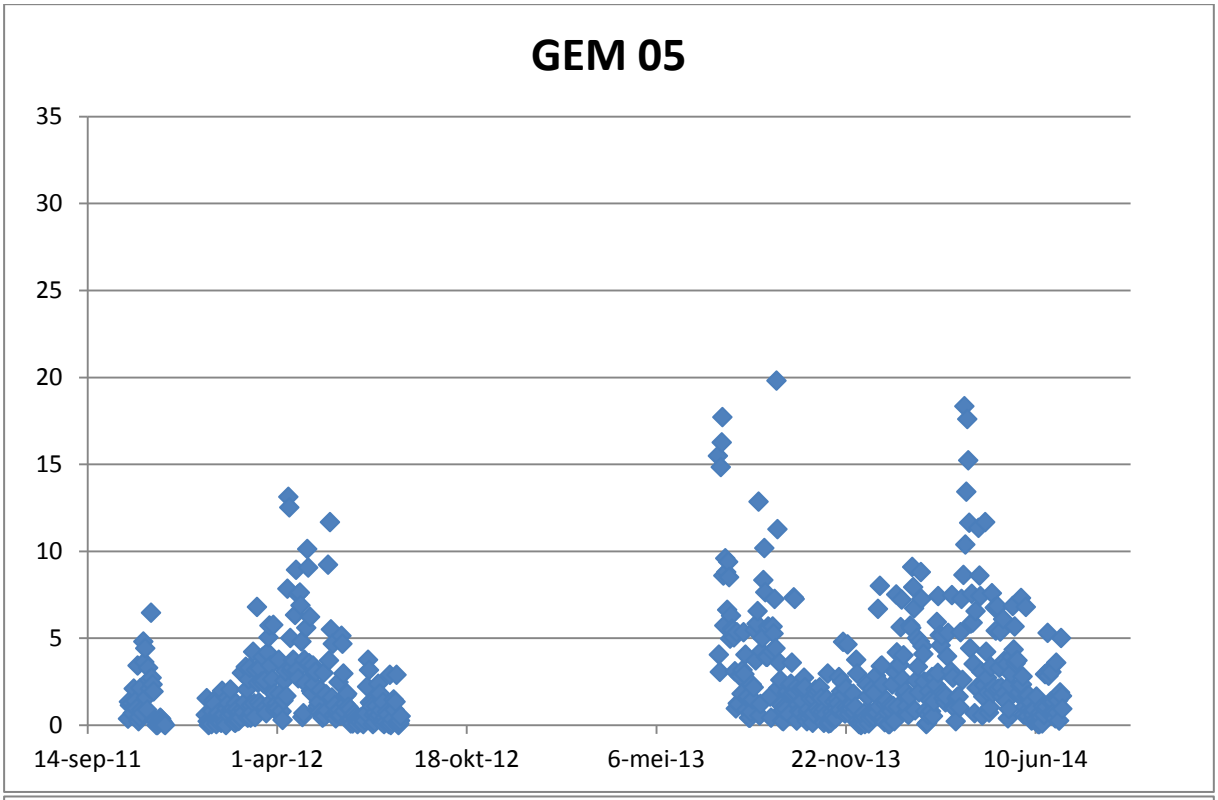
Daily click frequency is presented for each CPOD.

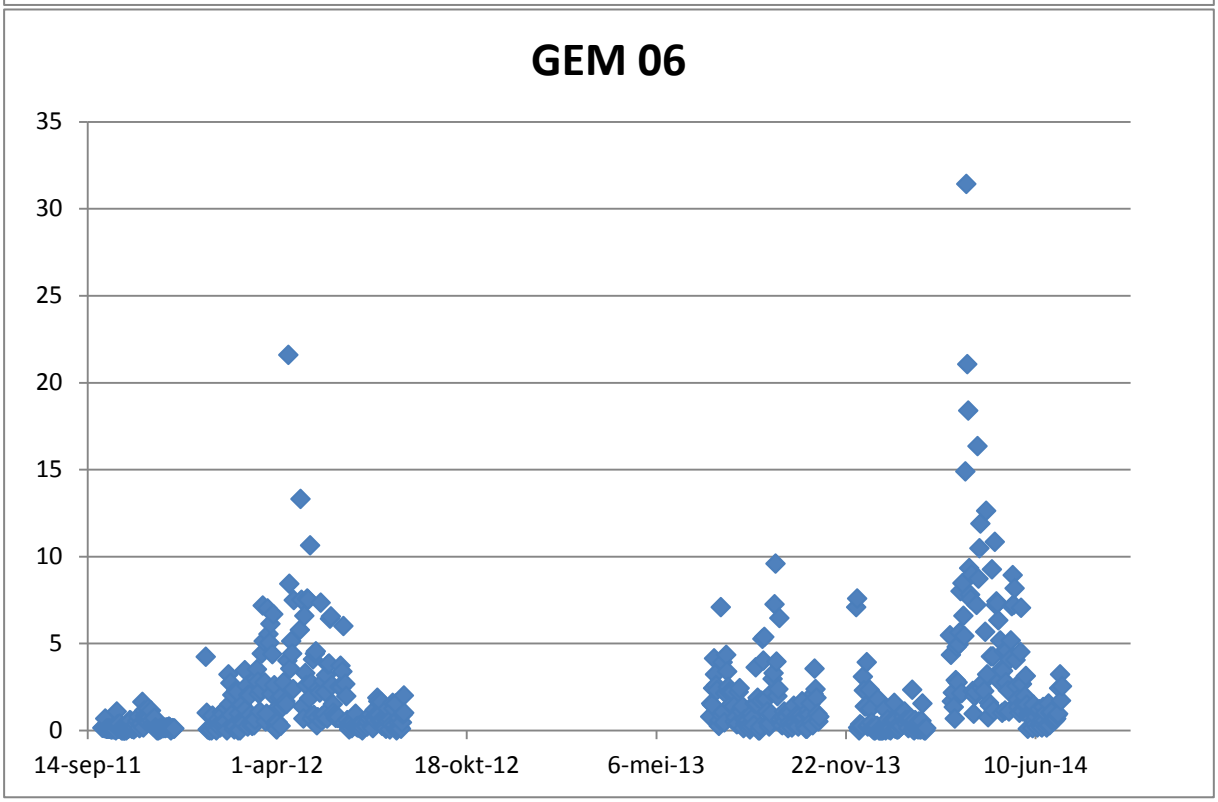


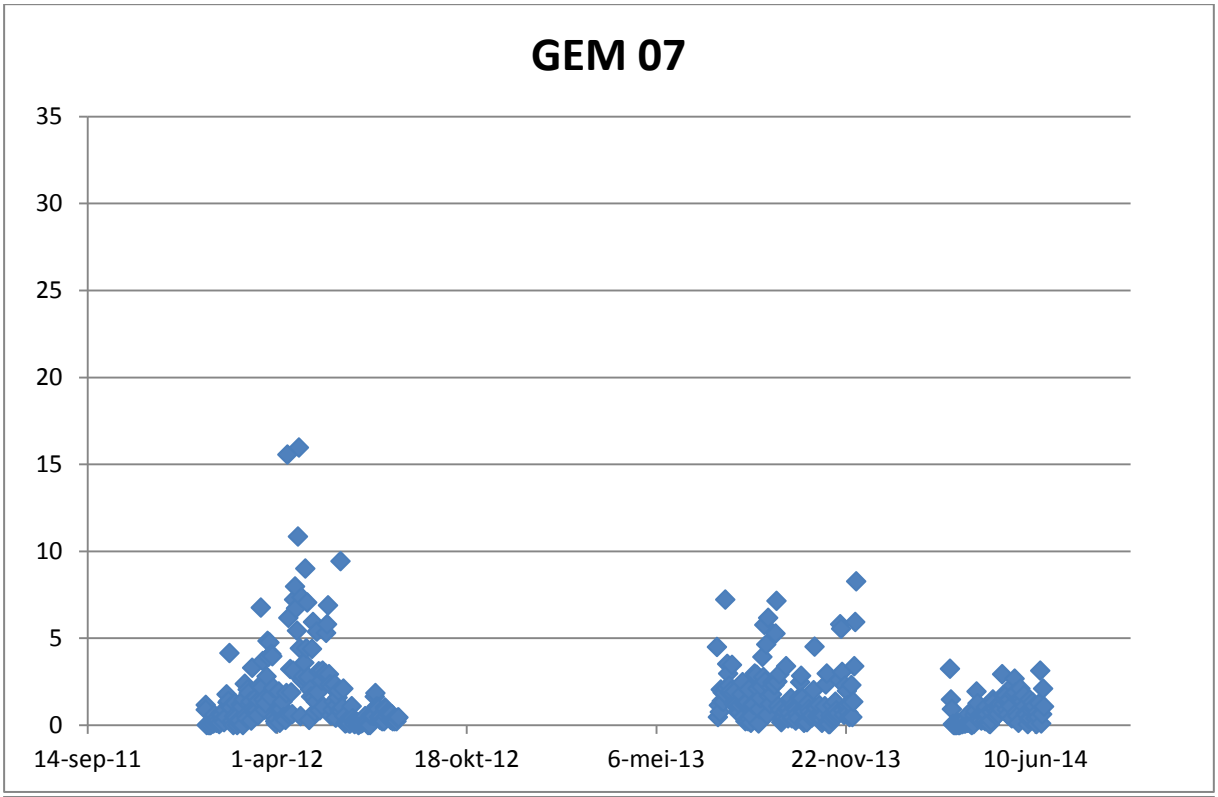



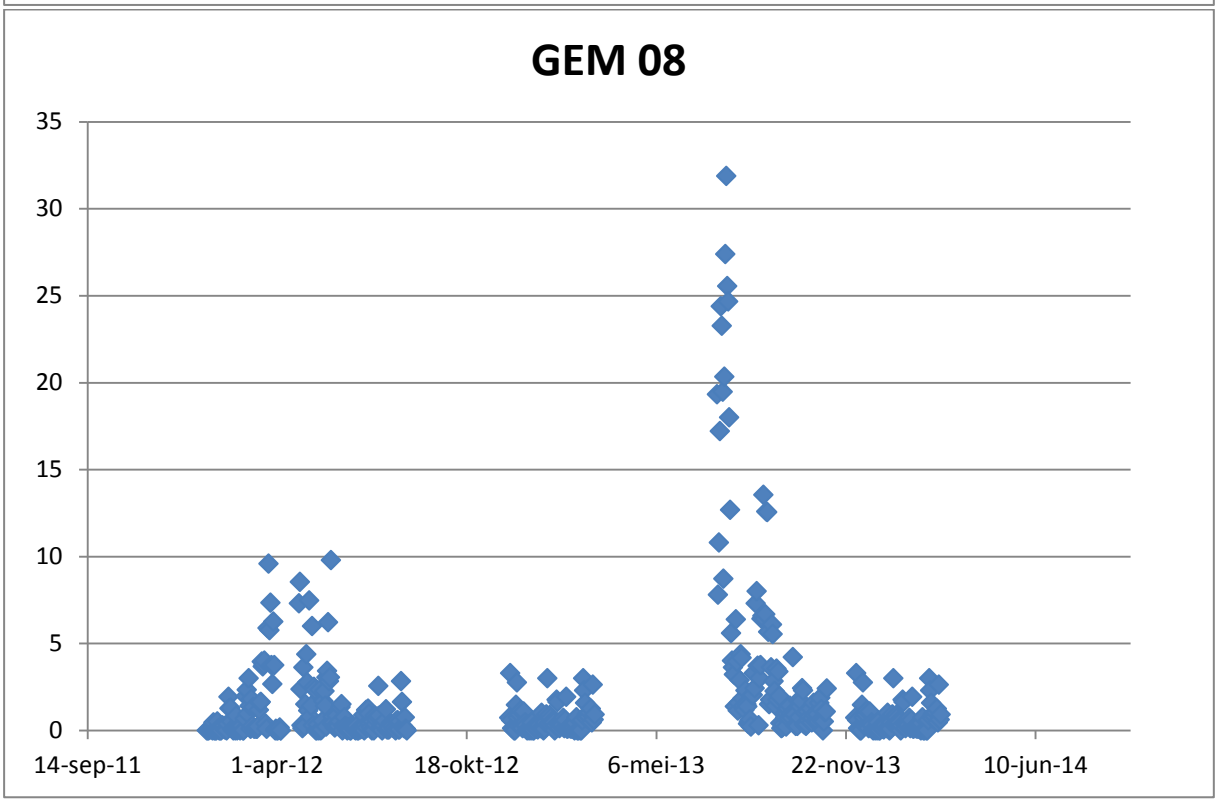

GEM 03
35
30
25
20
15
10
5
0
14-sep-11
1-apr-12
18-okt-12
6-mei-13
22-nov-13
10-jun-14

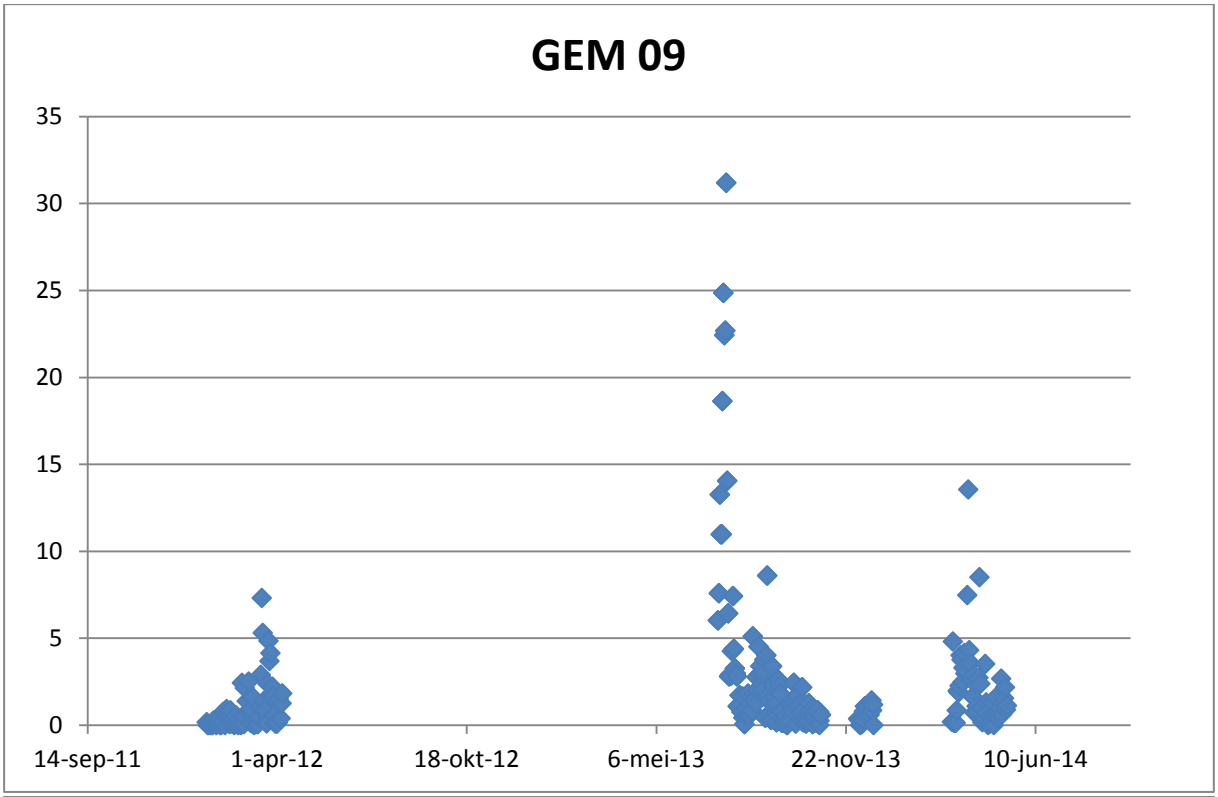

GEM 04
35
30
25
20
15
10
5
0
14-sep-11
1-apr-12
18-okt-12
6-mei-13
22-nov-13
10-jun-14

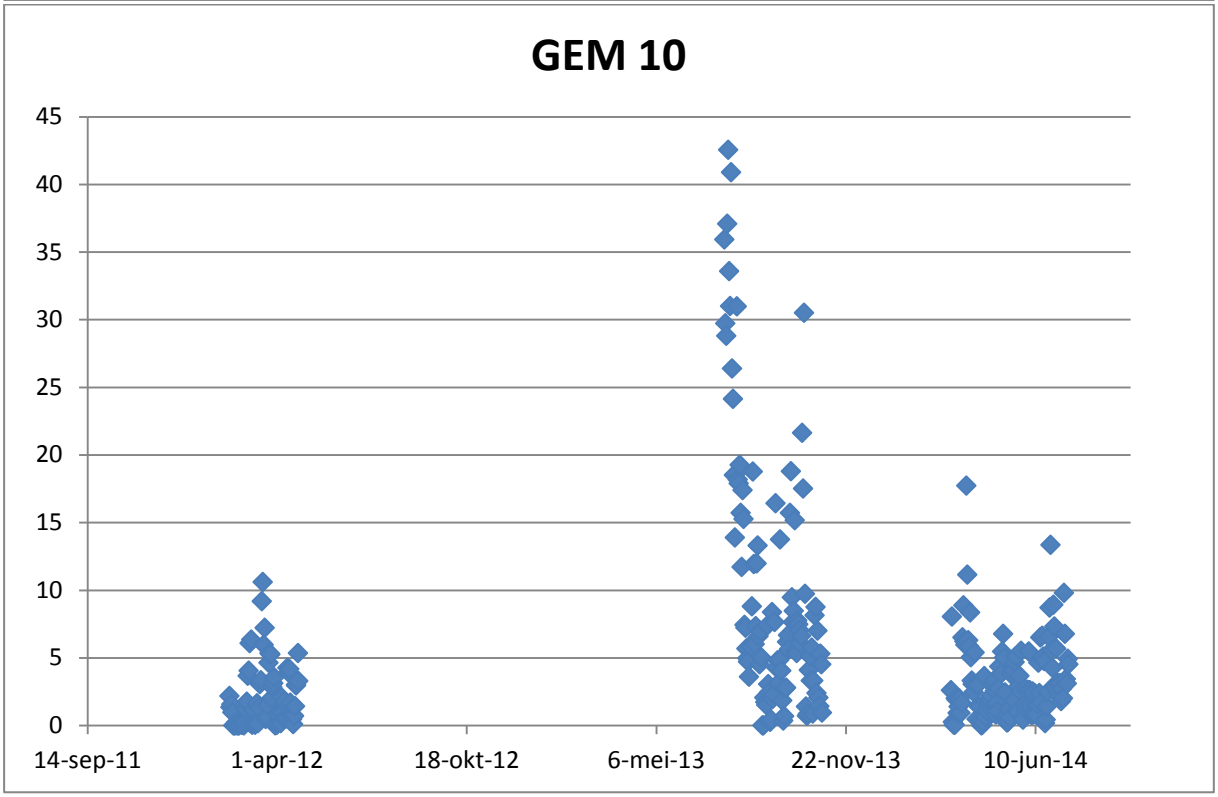

GEM 05
35
30
25
20
15
10
5
0
14-sep-11
1-apr-12
18-okt-12
6-mei-13
22-nov-13
10-jun-14

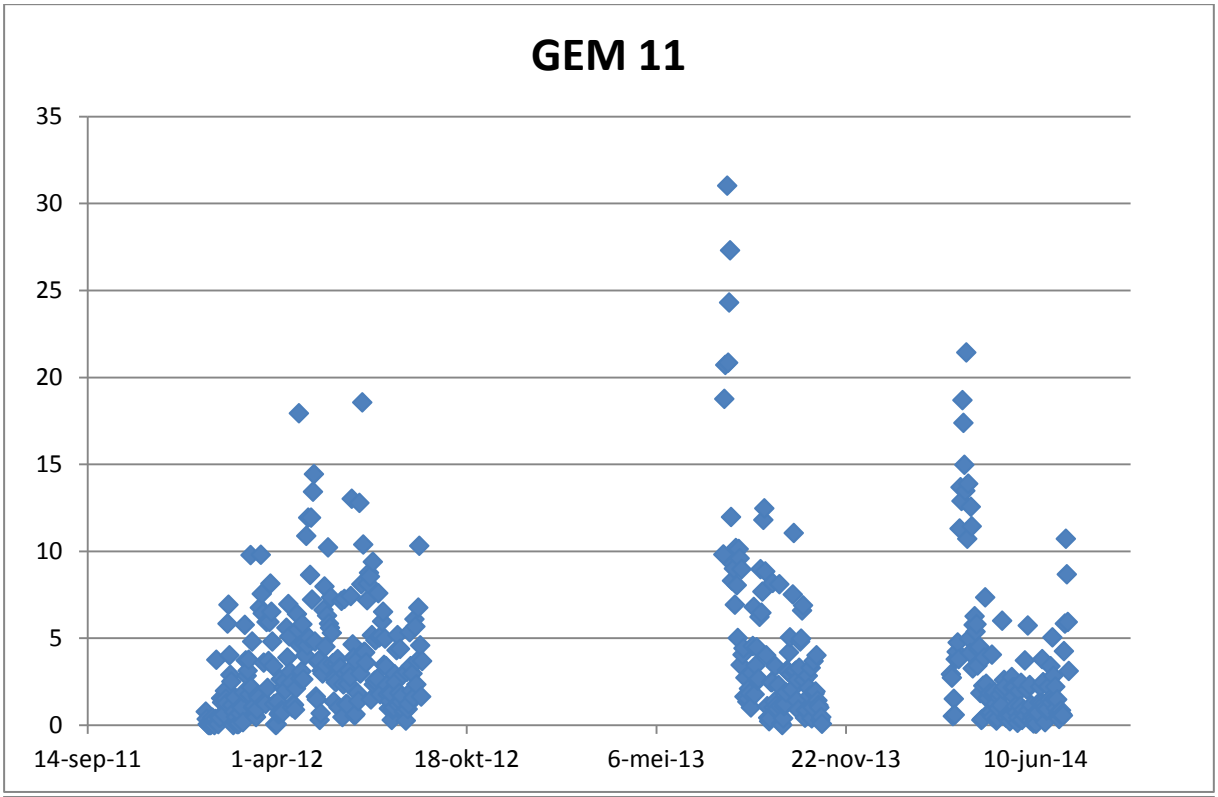

GEM 06
35
30
25
20
15
10
5
0
14-sep-11
1-apr-12
18-okt-12
6-mei-13
22-nov-13
10-jun-14

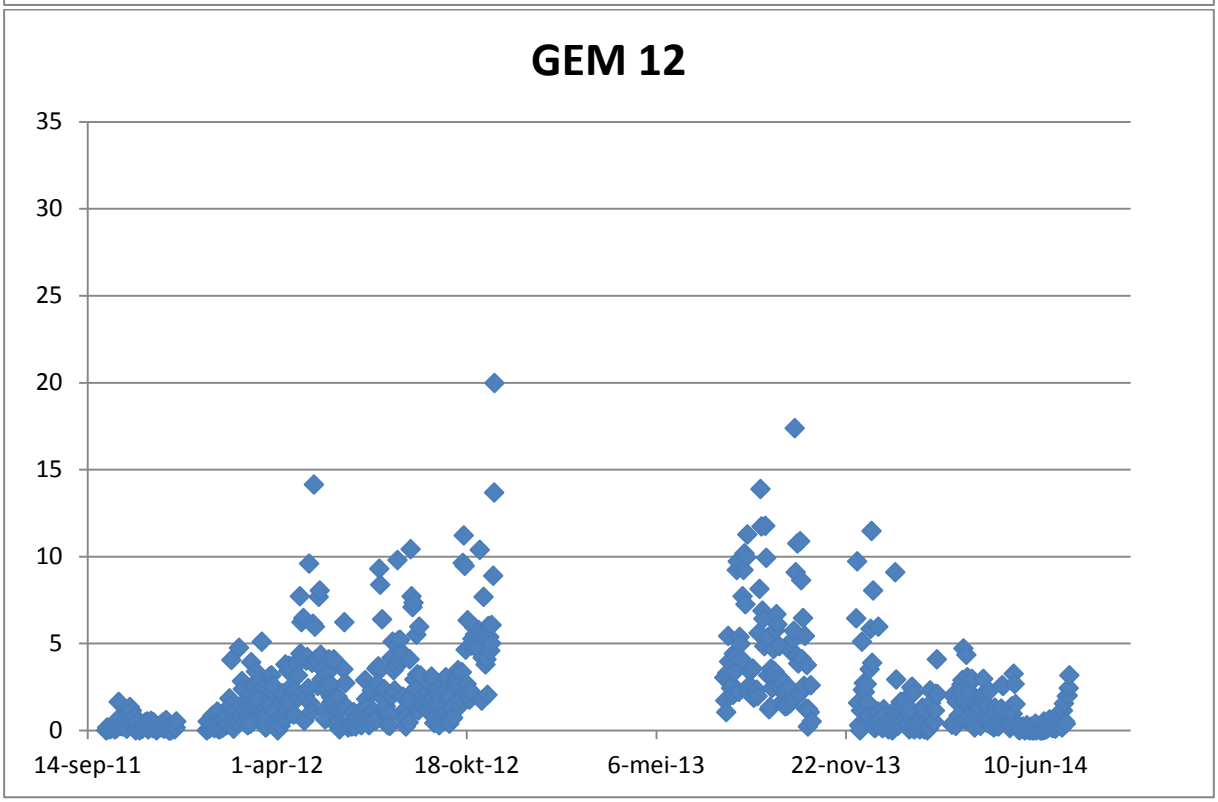

GEM 07
35
30
25
20
15
10
5
0
14-sep-11
1-apr-12
18-okt-12
6-mei-13
22-nov-13
10-jun-14

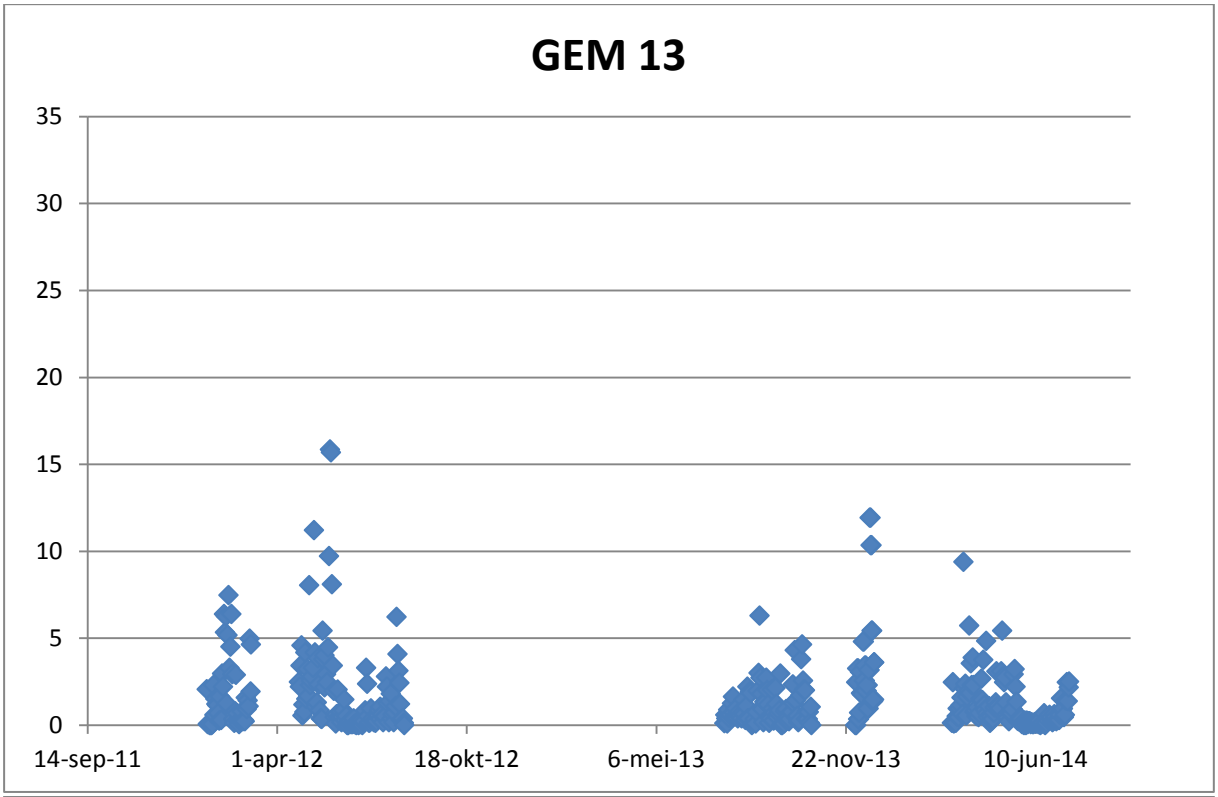

GEM 08
35
30
25
20
15
10
5
0
14-sep-11
1-apr-12
18-okt-12
6-mei-13
22-nov-13
10-jun-14

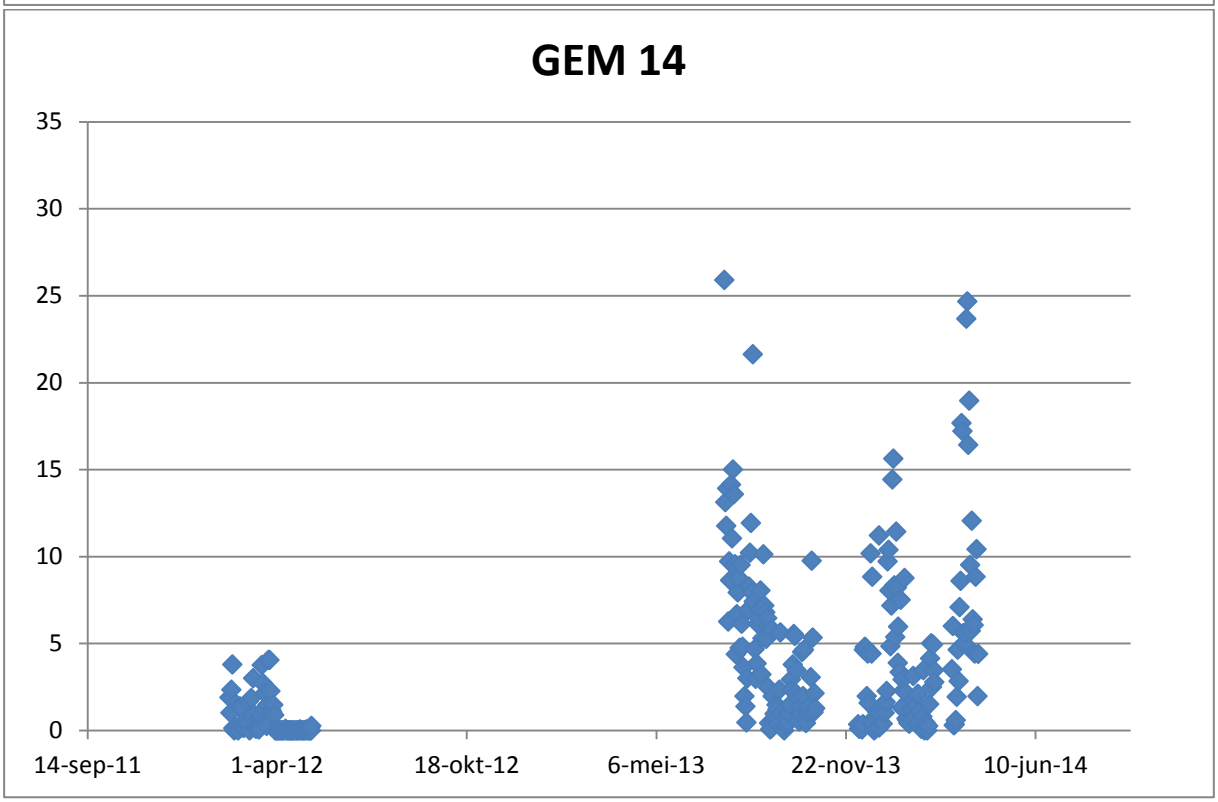

GEM 09
35
30
25
20
15
10
5
0
14-sep-11
1-apr-12
18-okt-12
6-mei-13
22-nov-13
10-jun-14

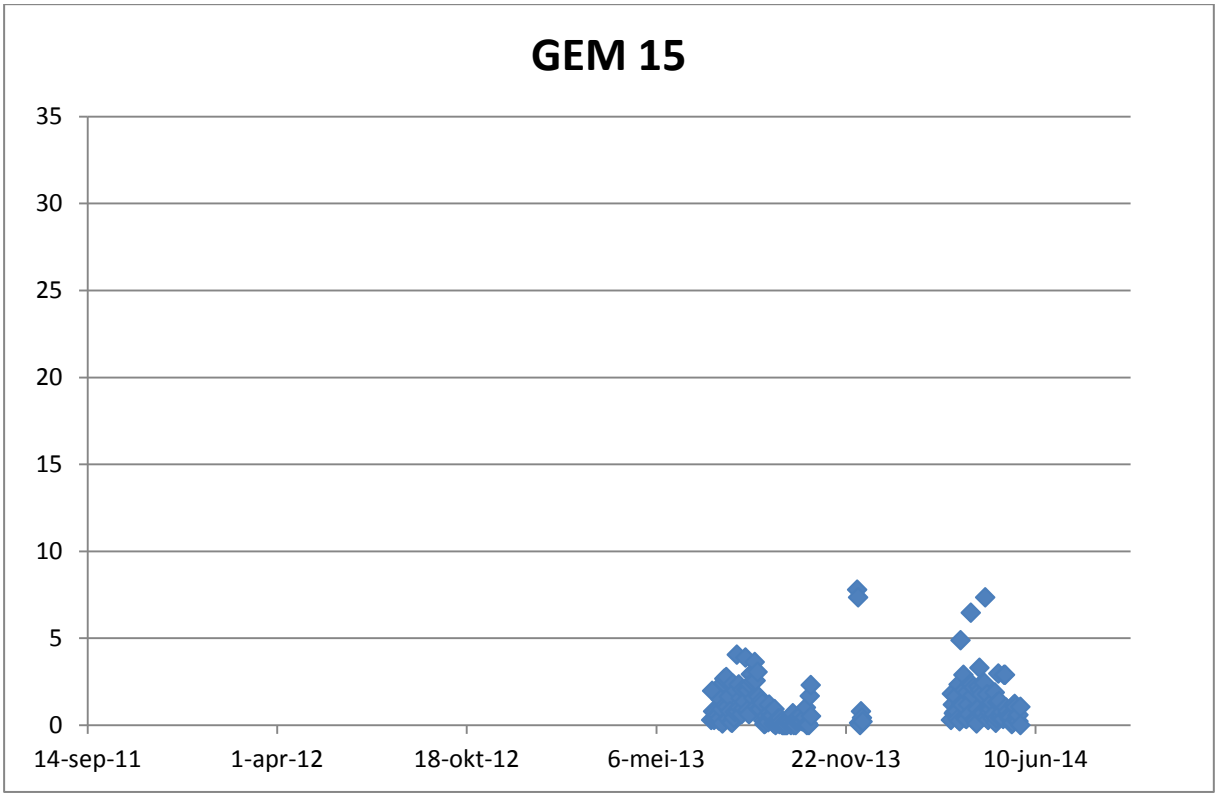

GEM 10
45
40
35
30
25
20
15
10
5
0
14-sep-11
1-apr-12
18-okt-12
6-mei-13
22-nov-13
10-jun-14


GEM 11
35
30
25
20
15
10
5
0
14-sep-11
1-apr-12
18-okt-12
6-mei-13
22-nov-13
10-jun-14


GEM 12
35
30
25
20
15
10
5
0
14-sep-11
1-apr-12
18-okt-12
6-mei-13
22-nov-13
10-jun-14

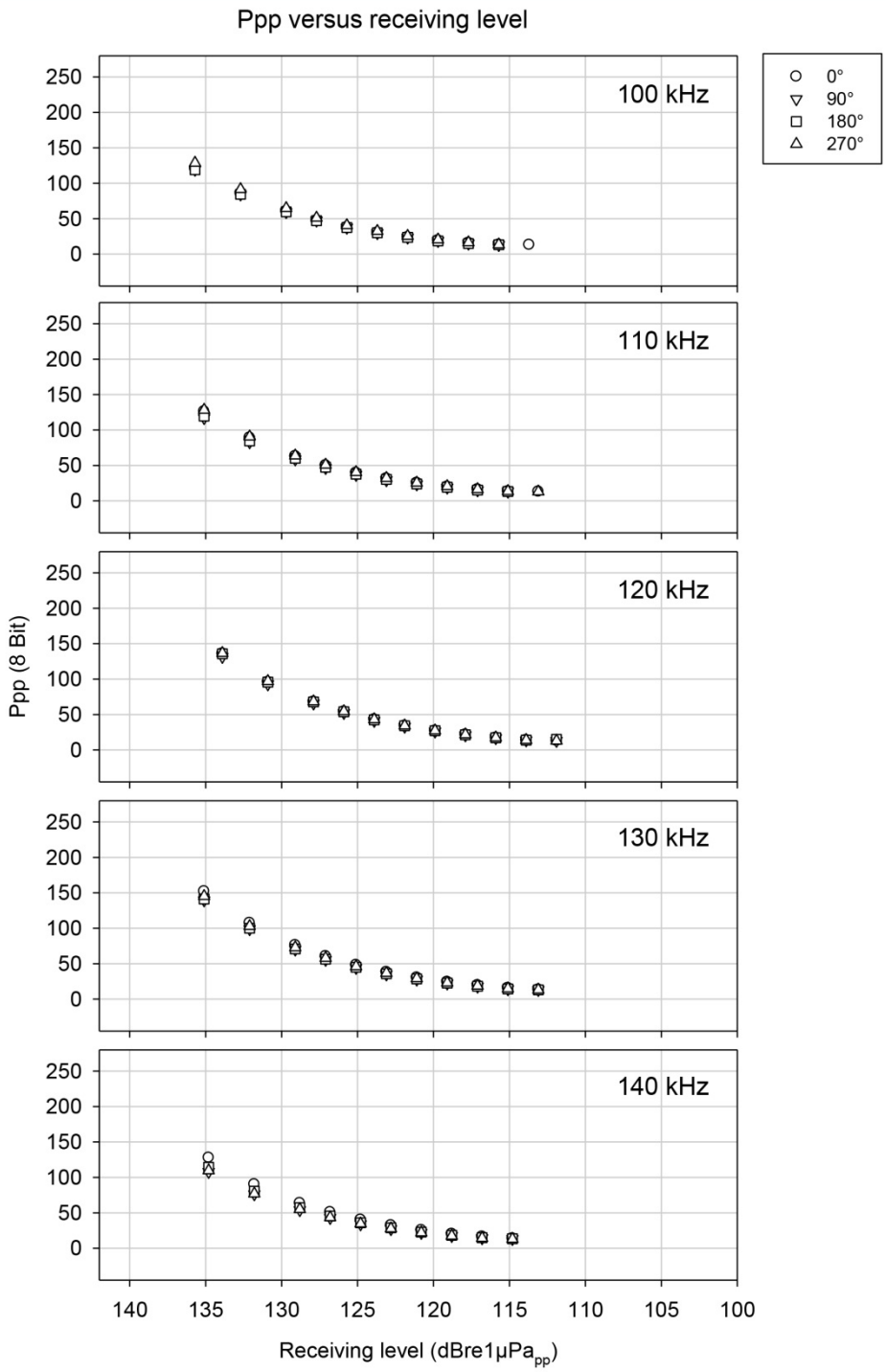

GEM 13
35
30
25
20
15
10
5
0
14-sep-11
1-apr-12
18-okt-12
6-mei-13
22-nov-13
10-jun-14

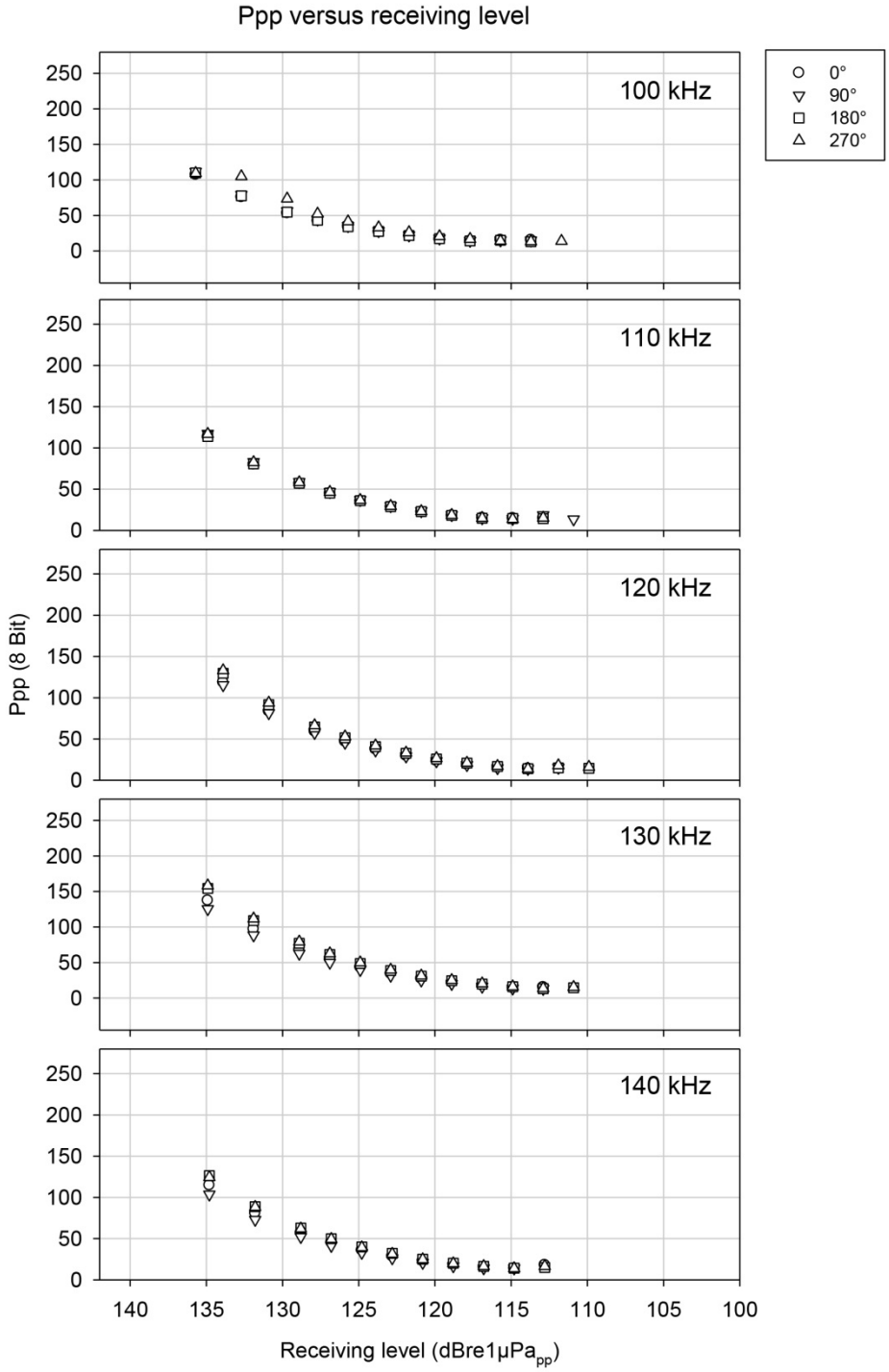

GEM 14
35
30
25
20
15
10
5
0
14-sep-11
1-apr-12
18-okt-12
6-mei-13
22-nov-13
10-jun-14

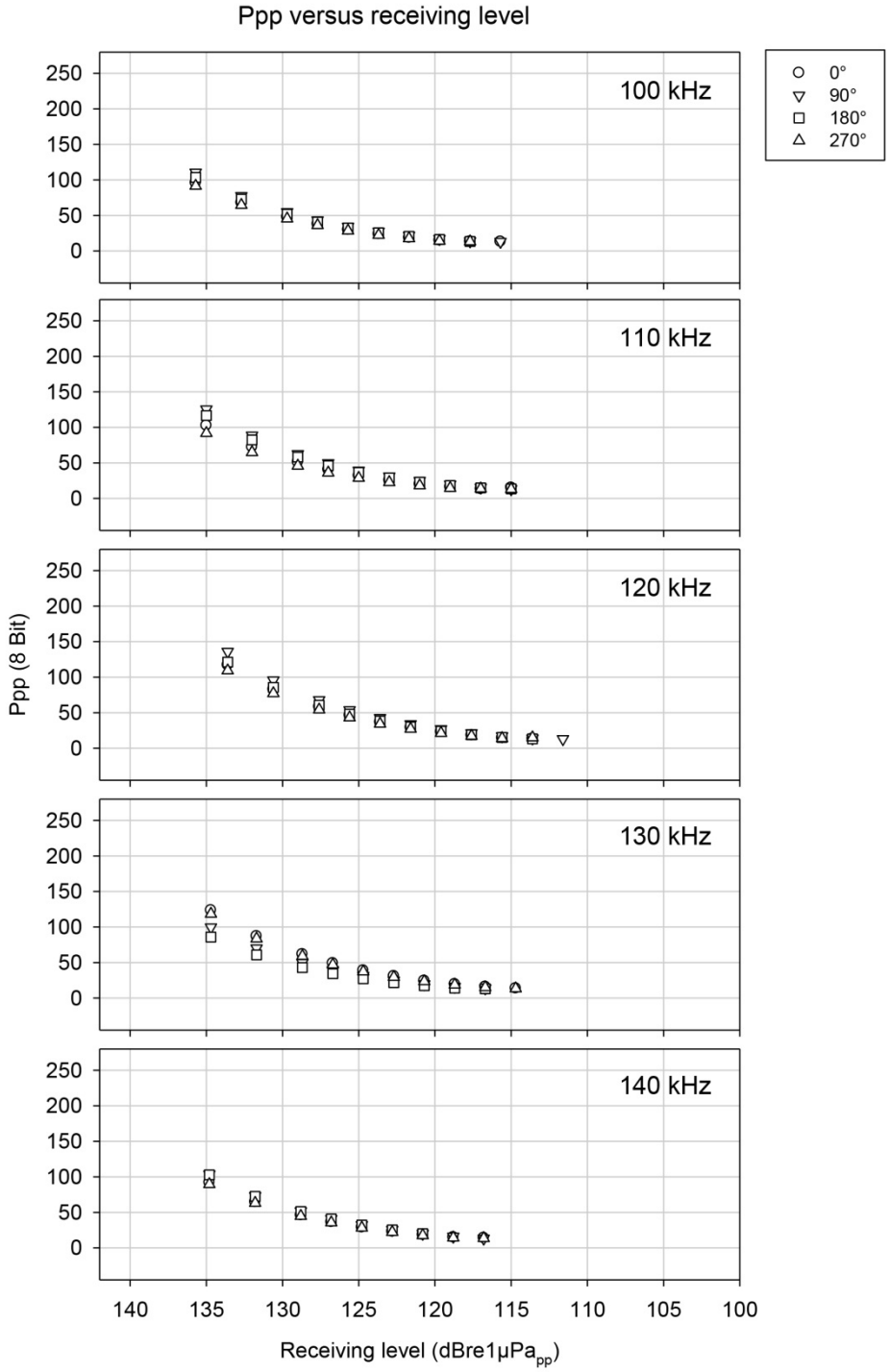

GEM 15
35
30
25
20
15
10
5
0
14-sep-11
1-apr-12
18-okt-12
6-mei-13
22-nov-13
10-jun-14

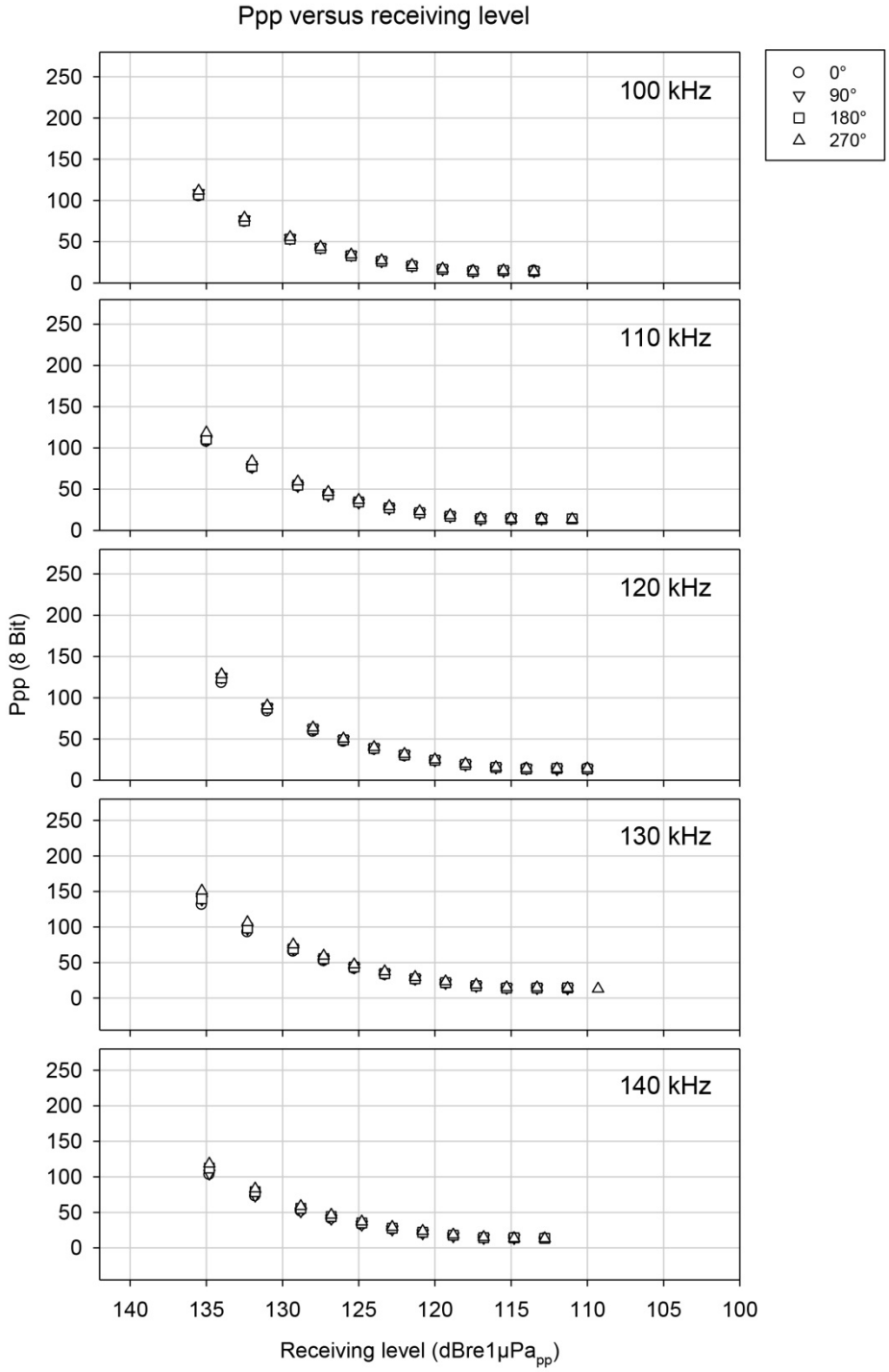
## Appendix 4. Calibration results CPODs: Ppp vs receiving level

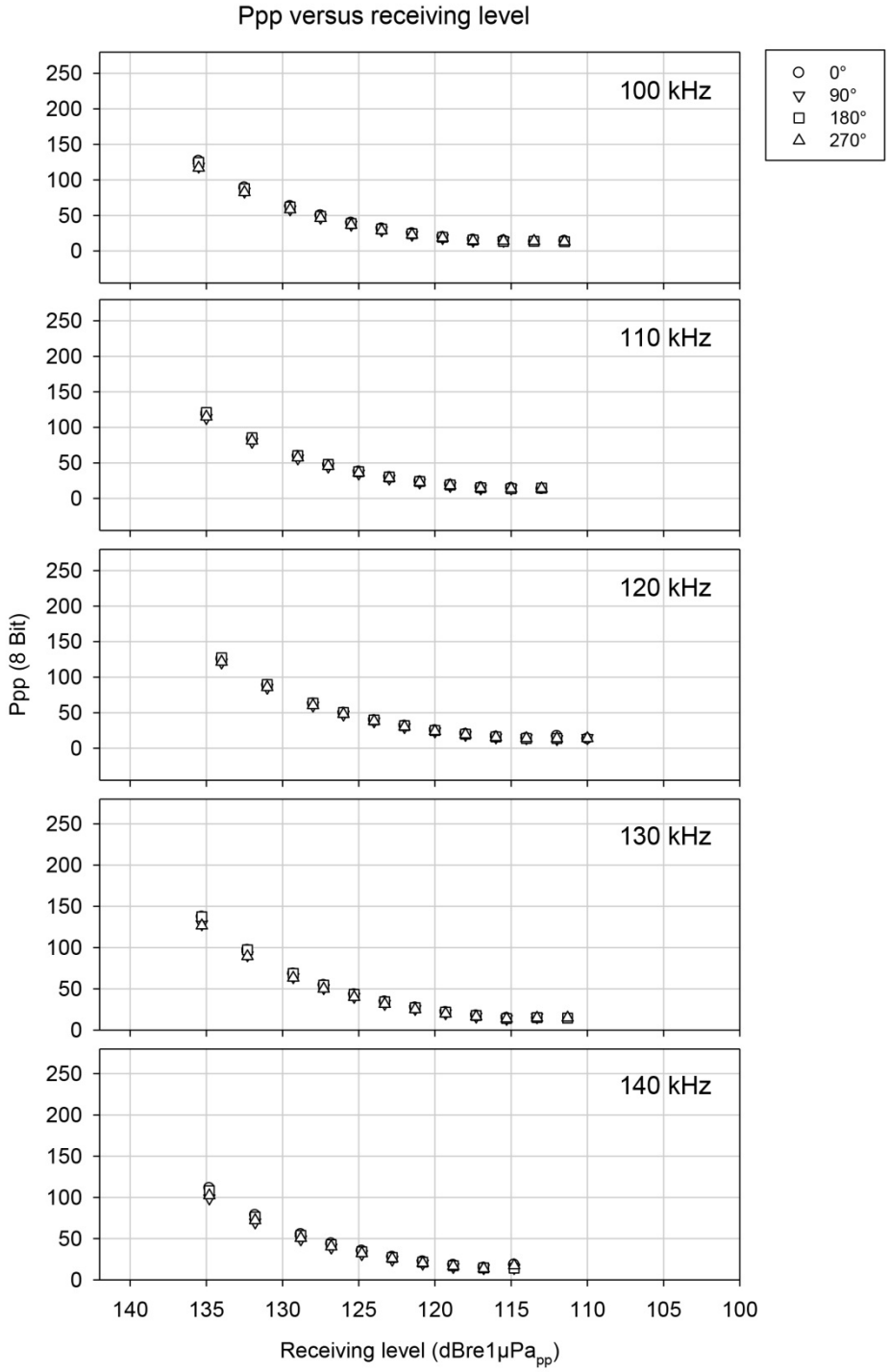
| | | |
|---|---|---|
| POD ID / CAL ID: | 375/478 | IMARES |
| Date of calibration: | 28.01.2014 | |
| Calibrated by: | Anne Herrmann | |

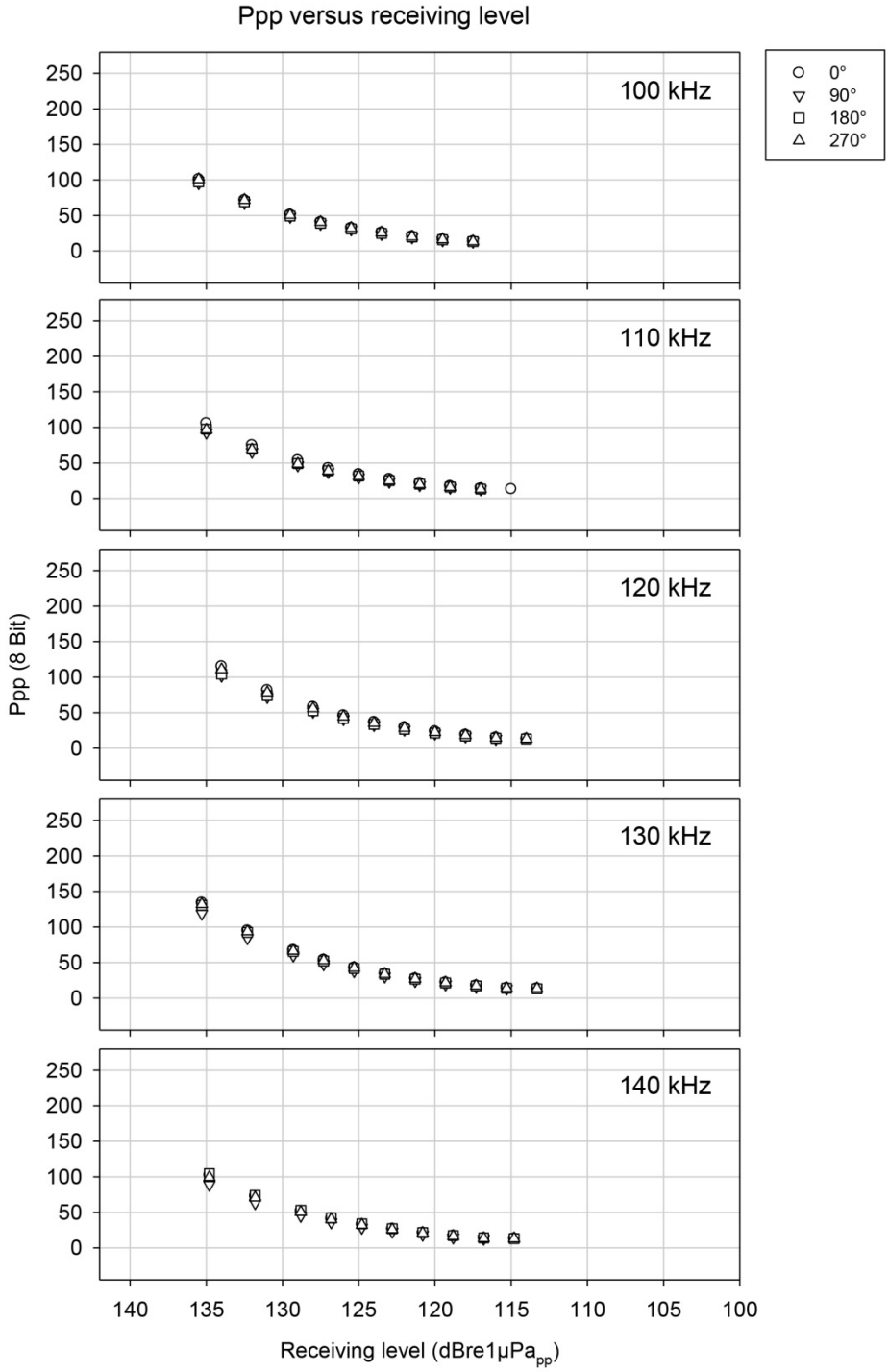


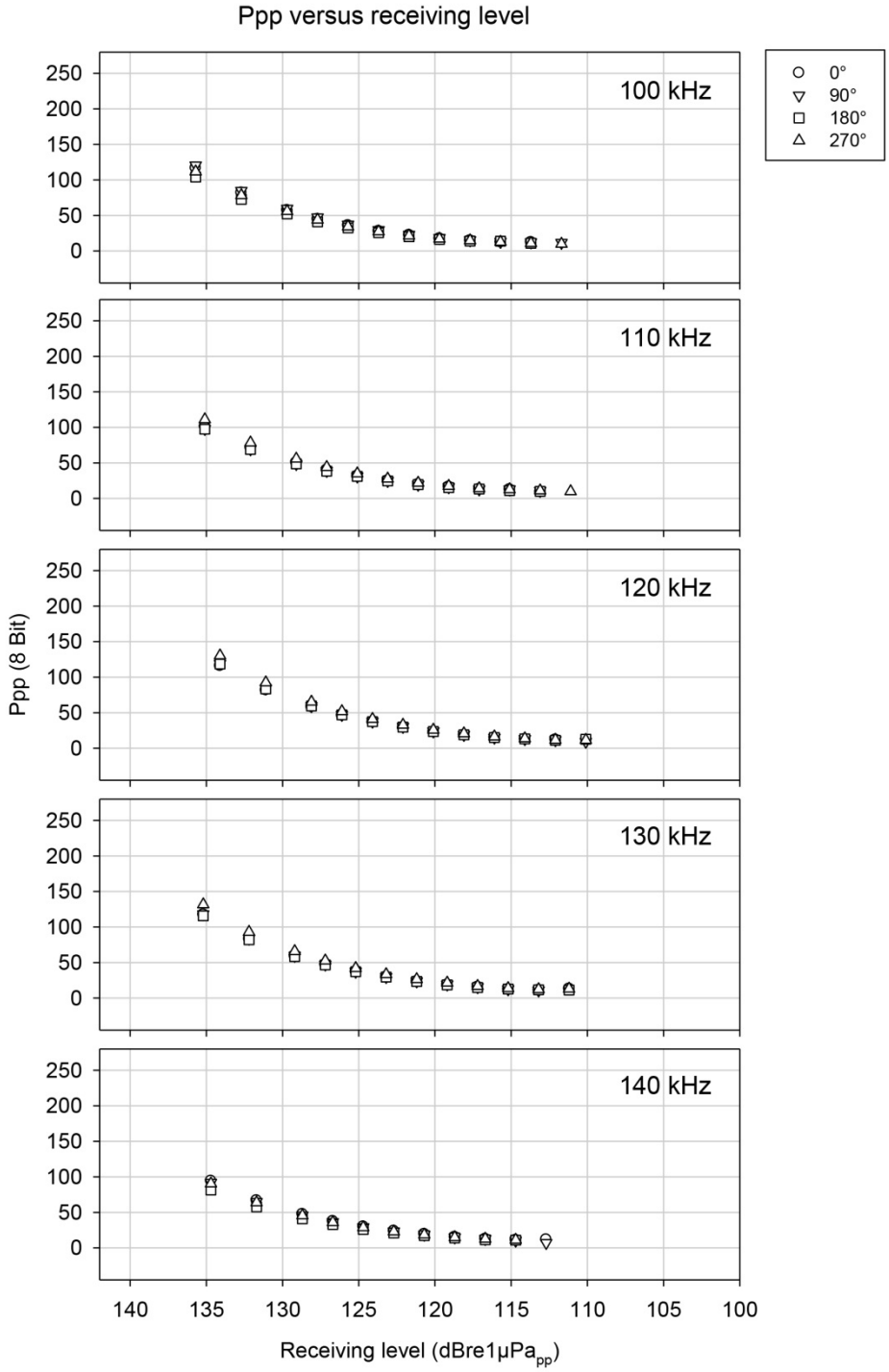

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)
250
200
150
100
50
0
140
135
130
125
120
115
110
105
100

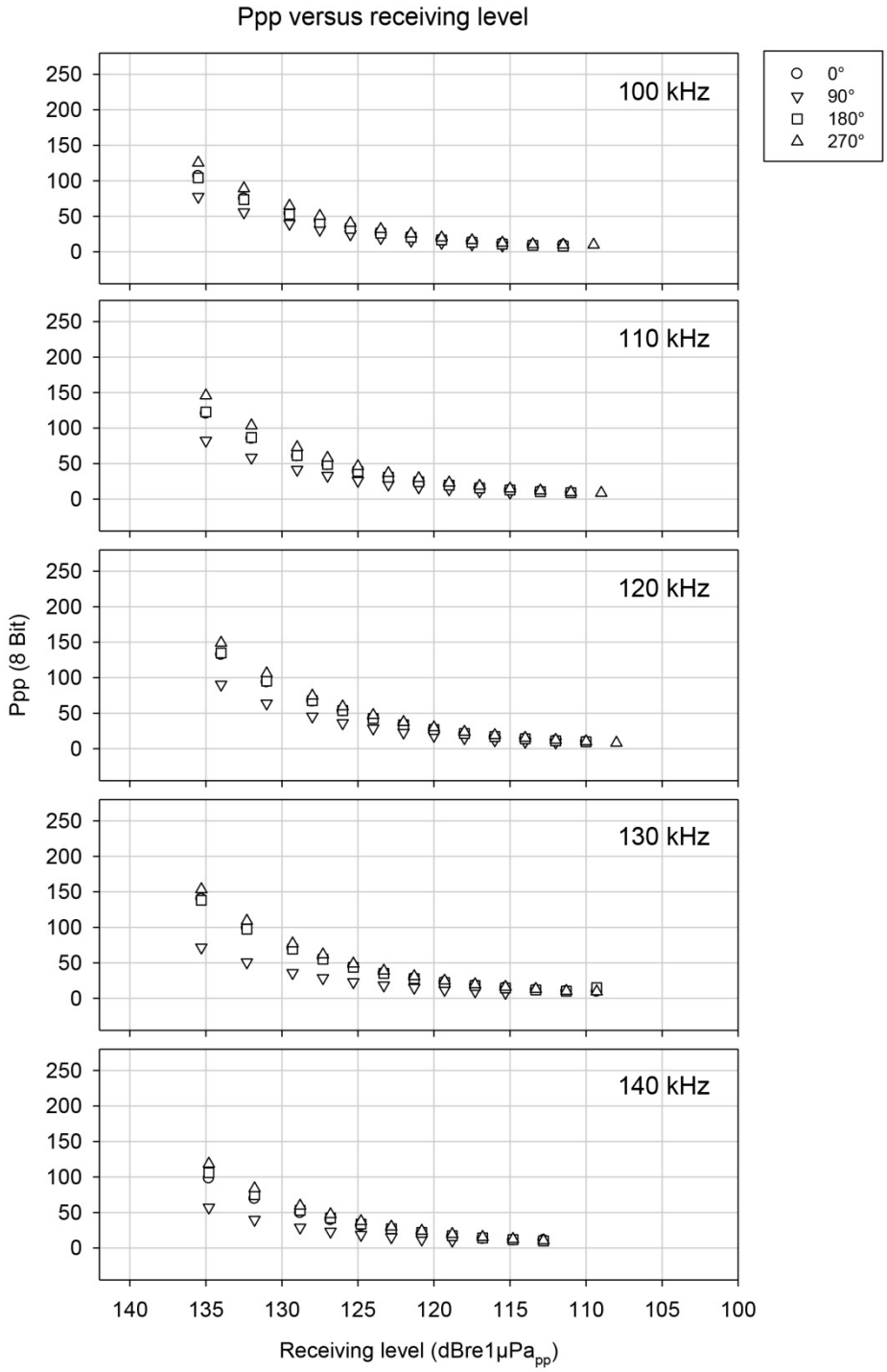

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
0
50
100
150
200
250
140
135
130
125
120
115
110
105
100
Receiving level (dBre1µPa$_{pp}$)

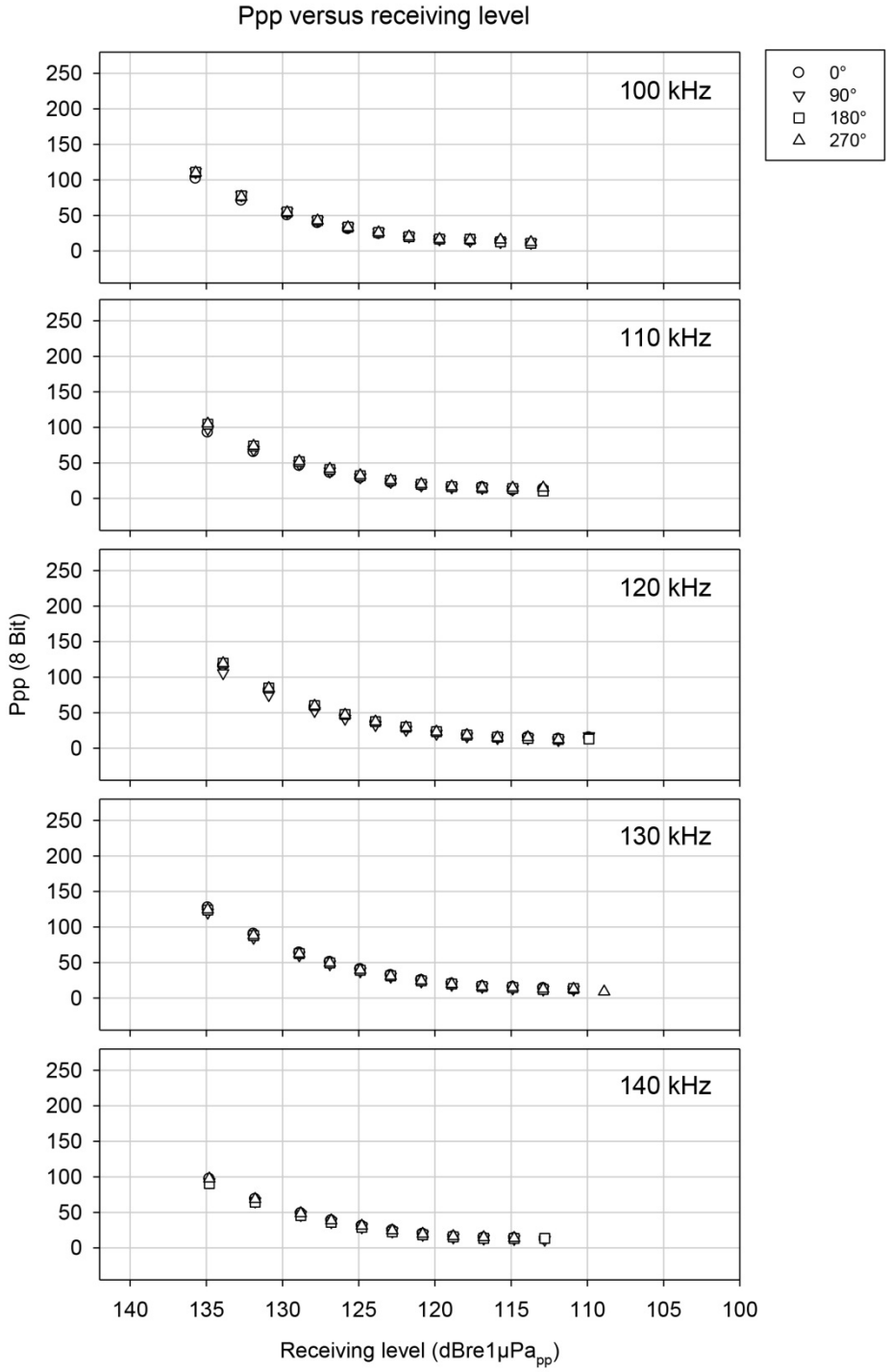

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
0
50
100
150
200
250
140
135
130
125
120
115
110
105
100
Receiving level (dBre1µPa$_{pp}$)

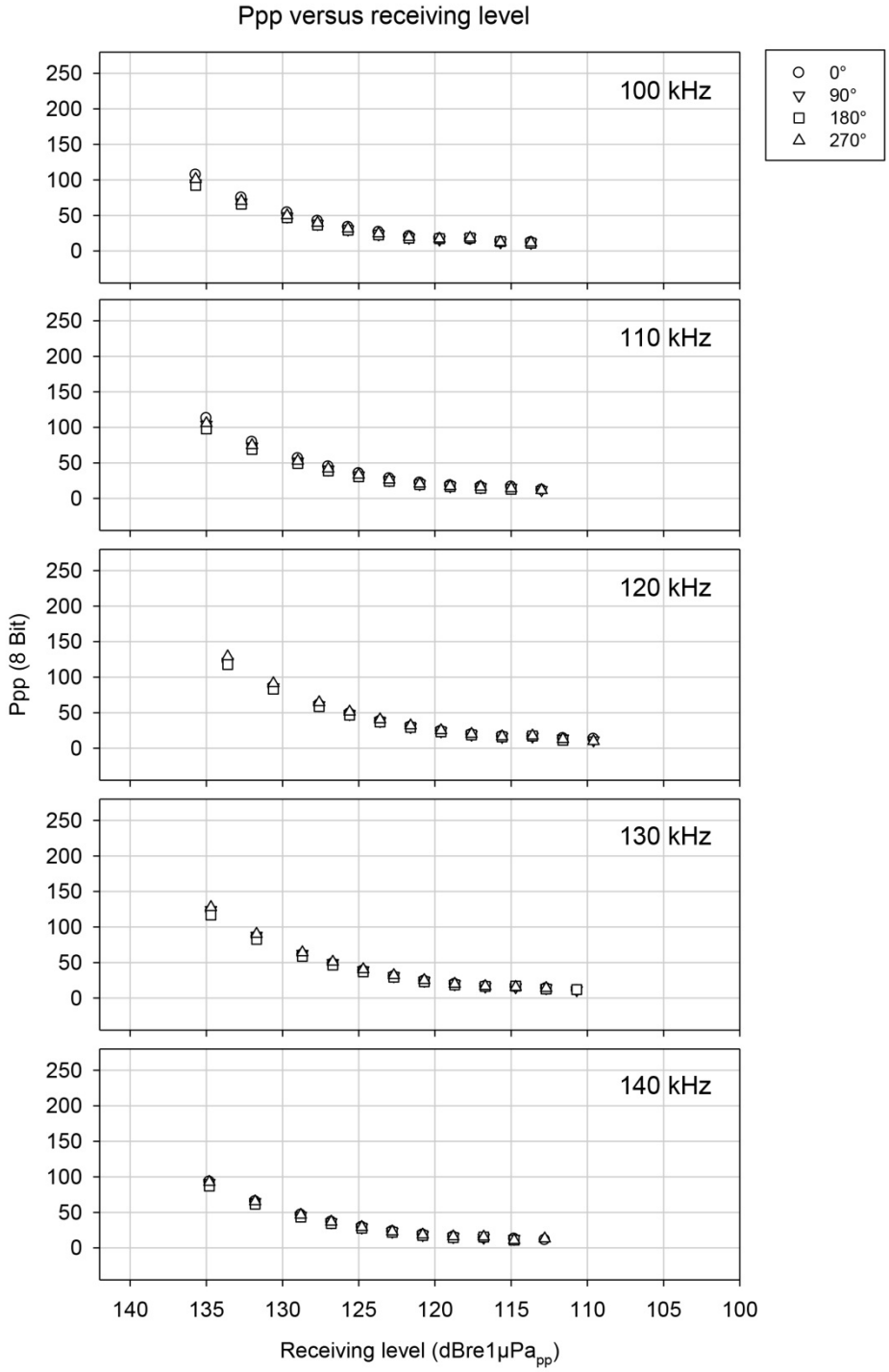

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)

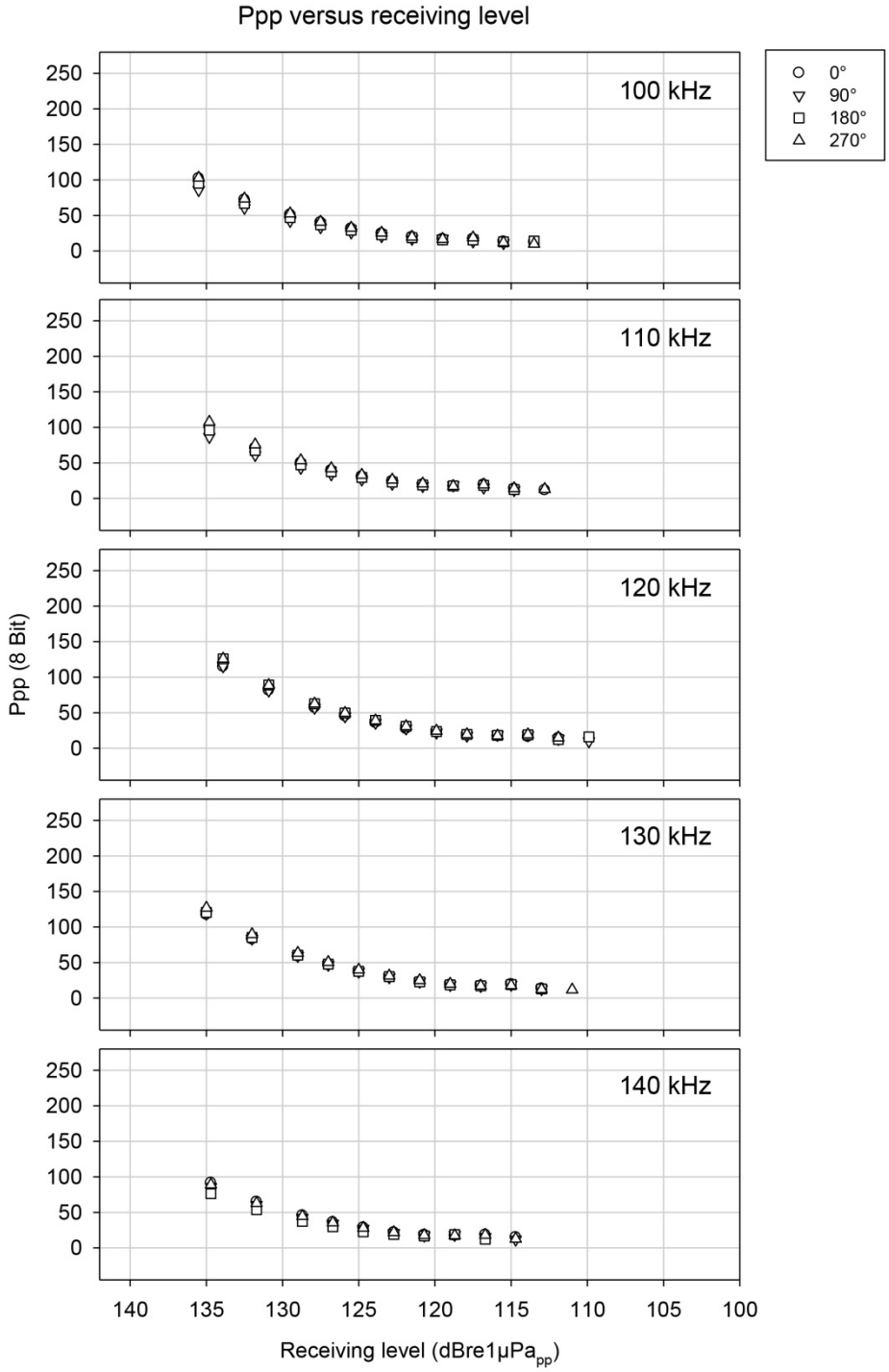

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)

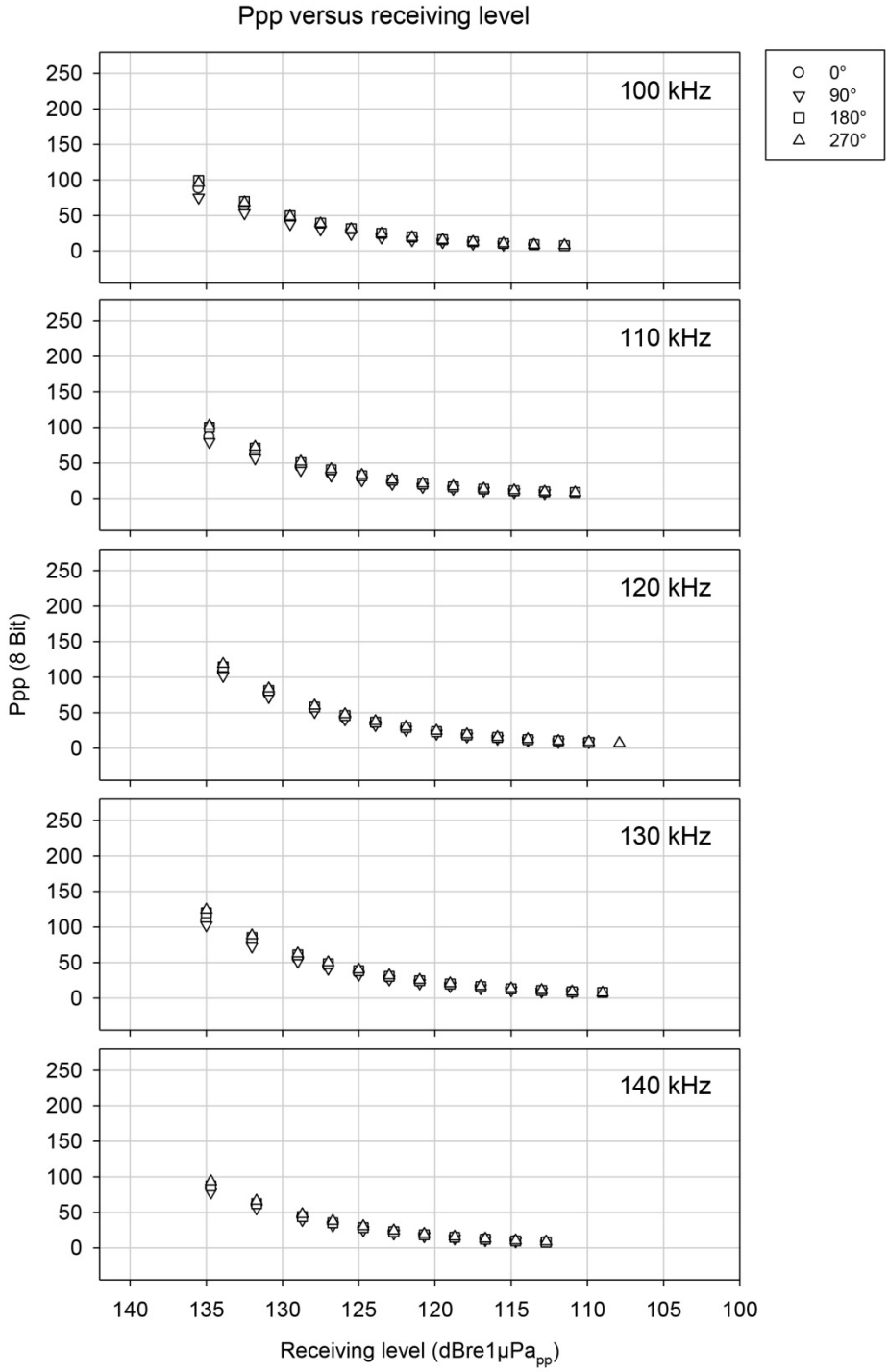

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
0
50
100
150
200
250
140
135
130
125
120
115
110
105
100
Receiving level (dBre1µPa$_{pp}$)

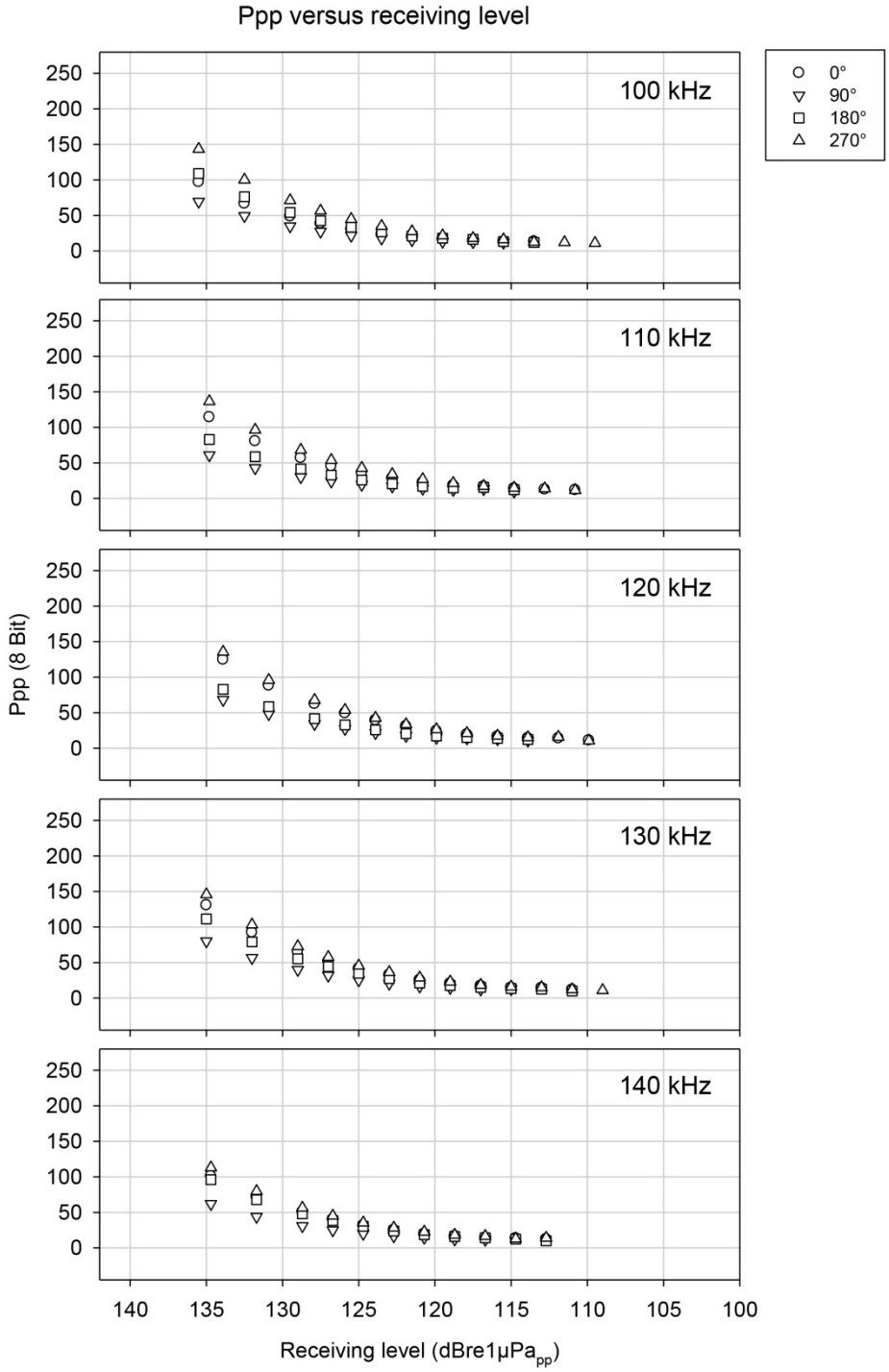

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)
250
200
150
100
50
0
140
135
130
125
120
115
110
105
100

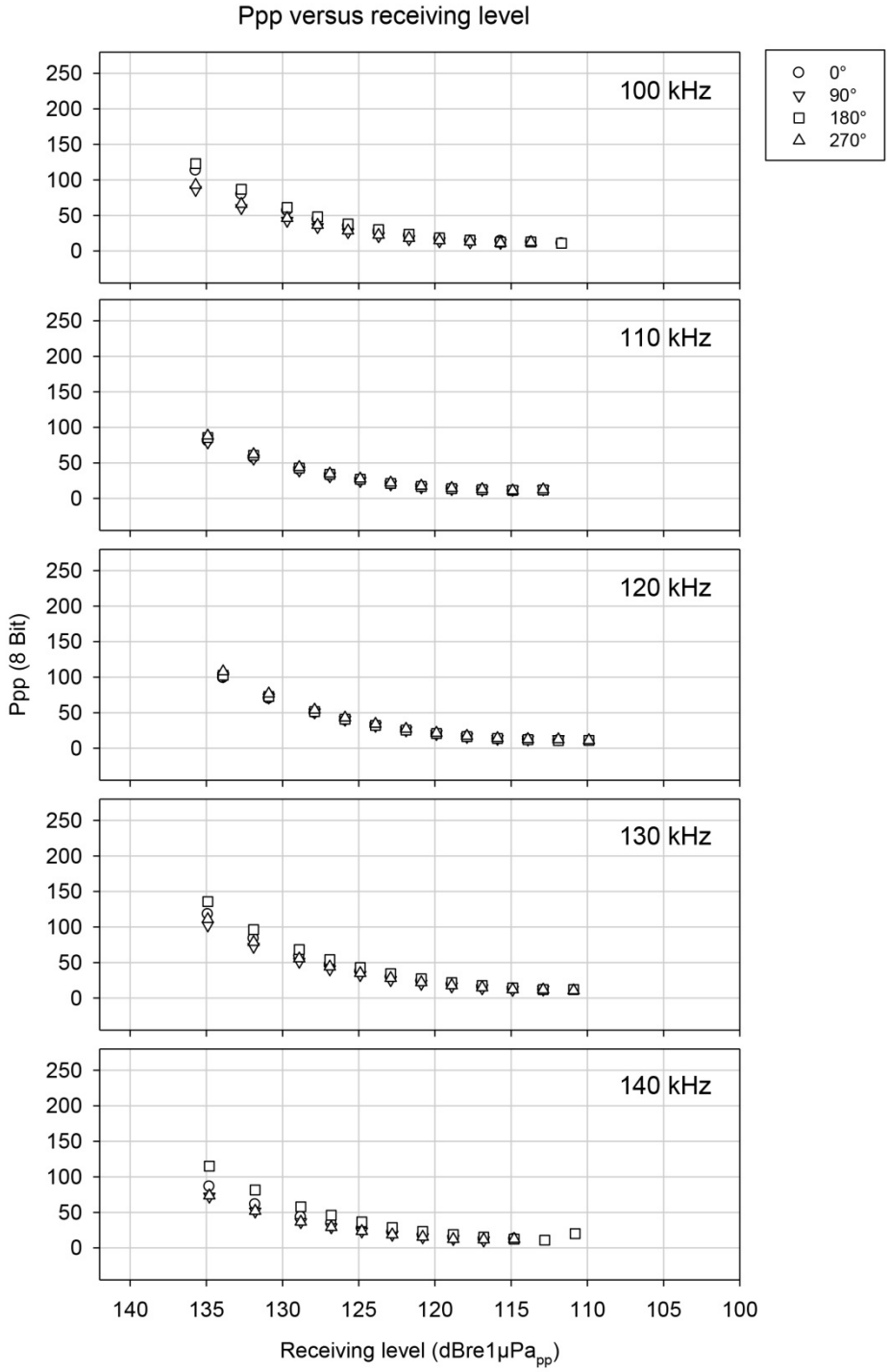

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)

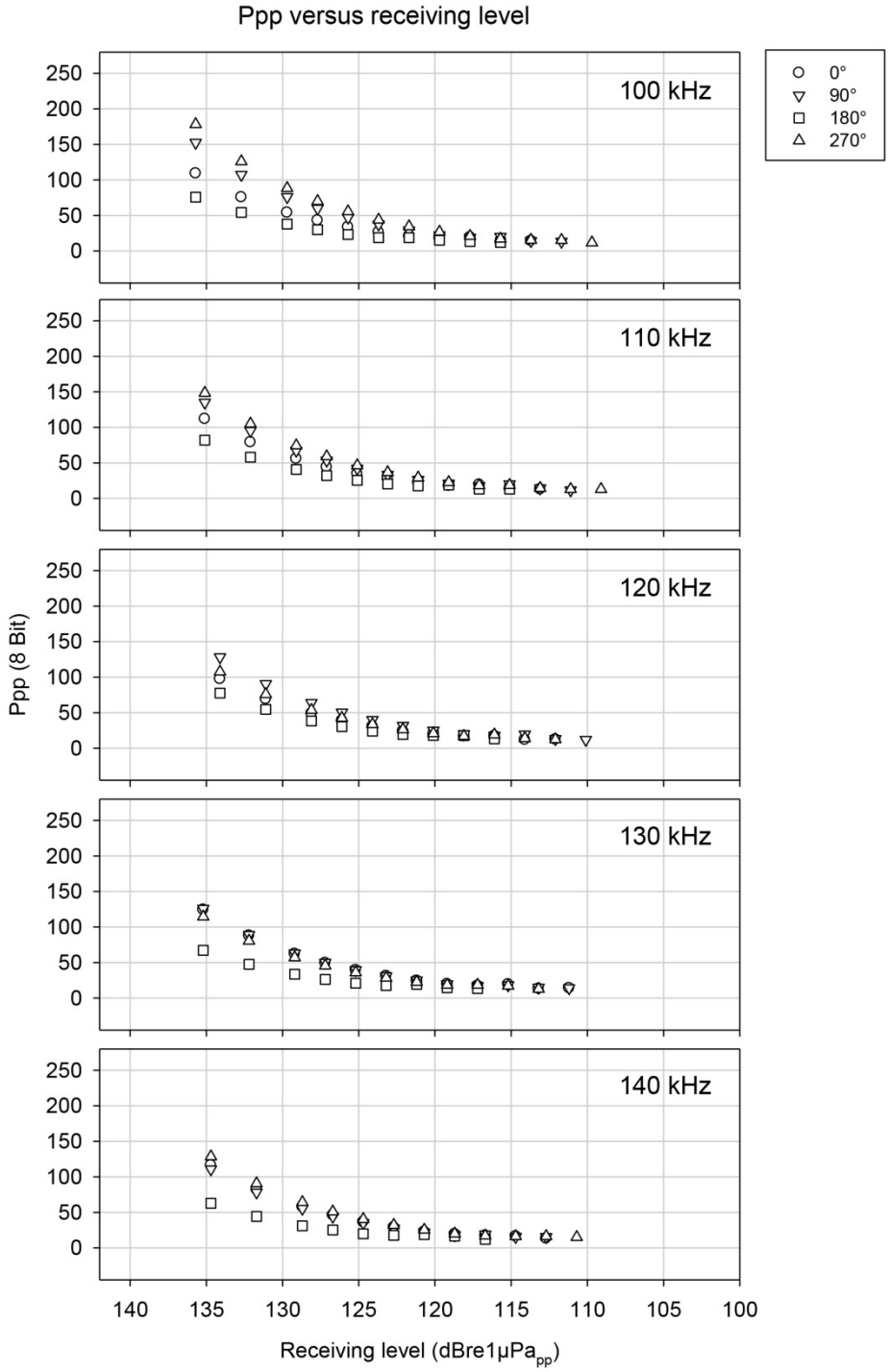

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)

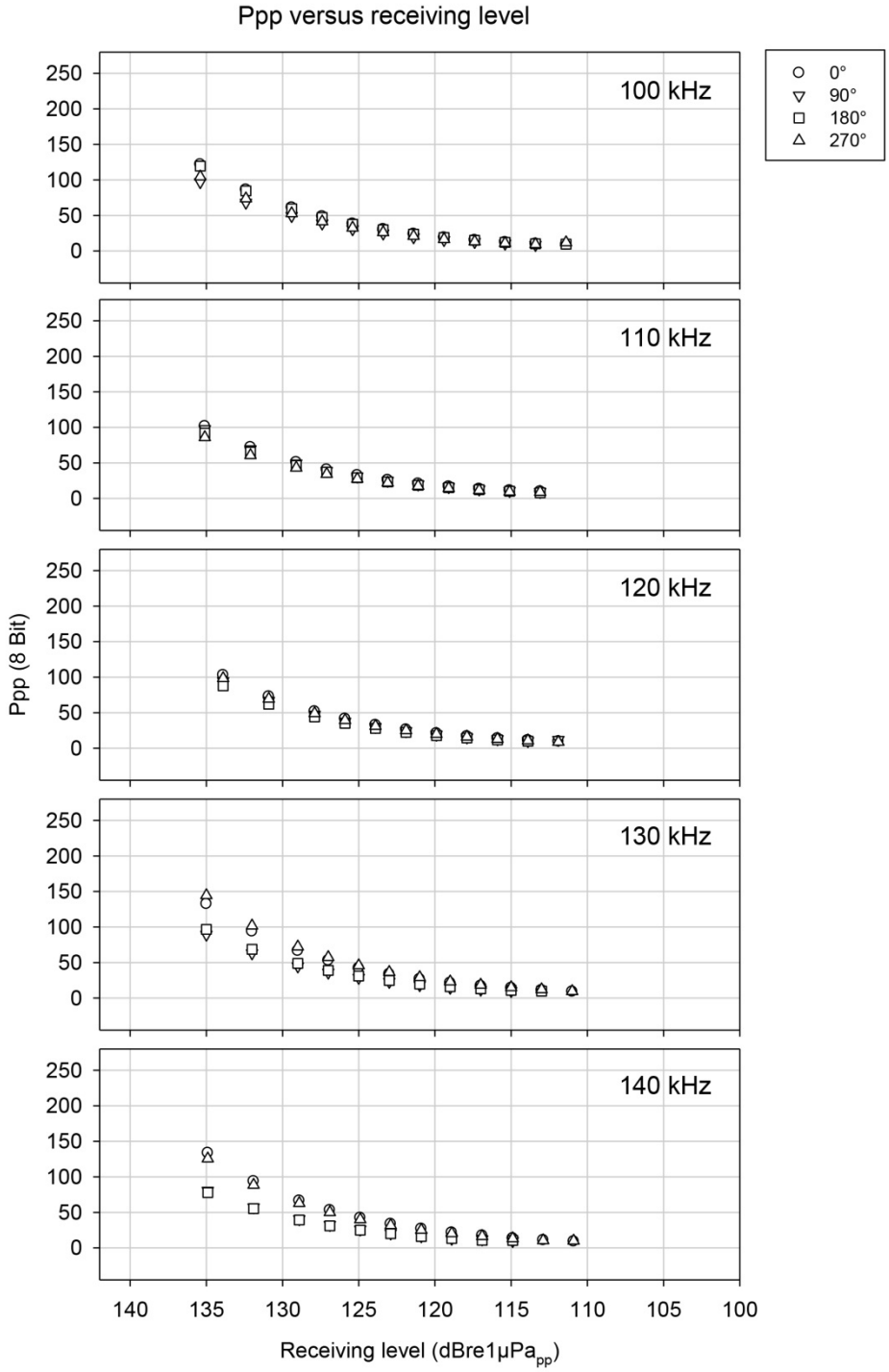

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)

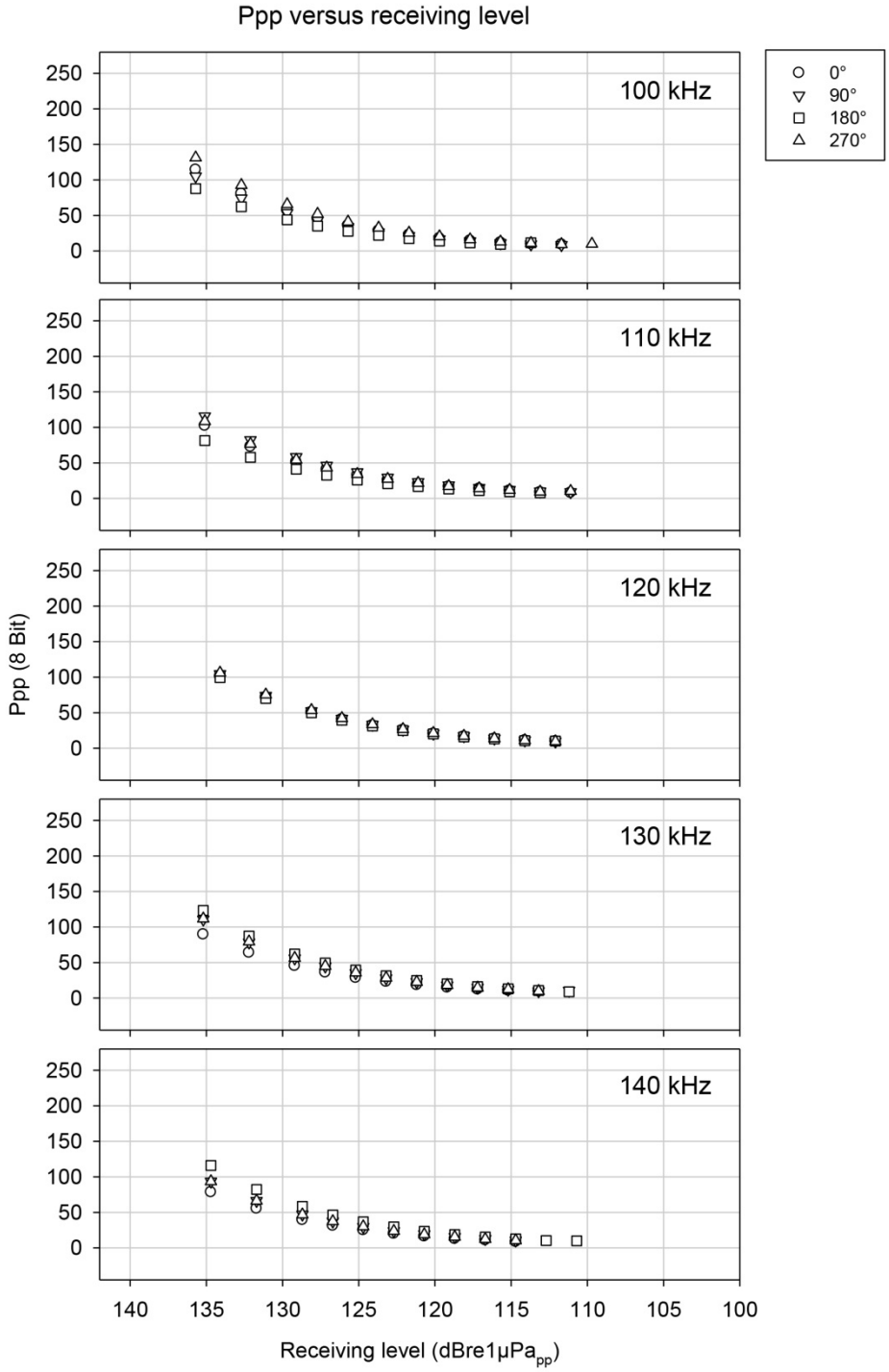

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)

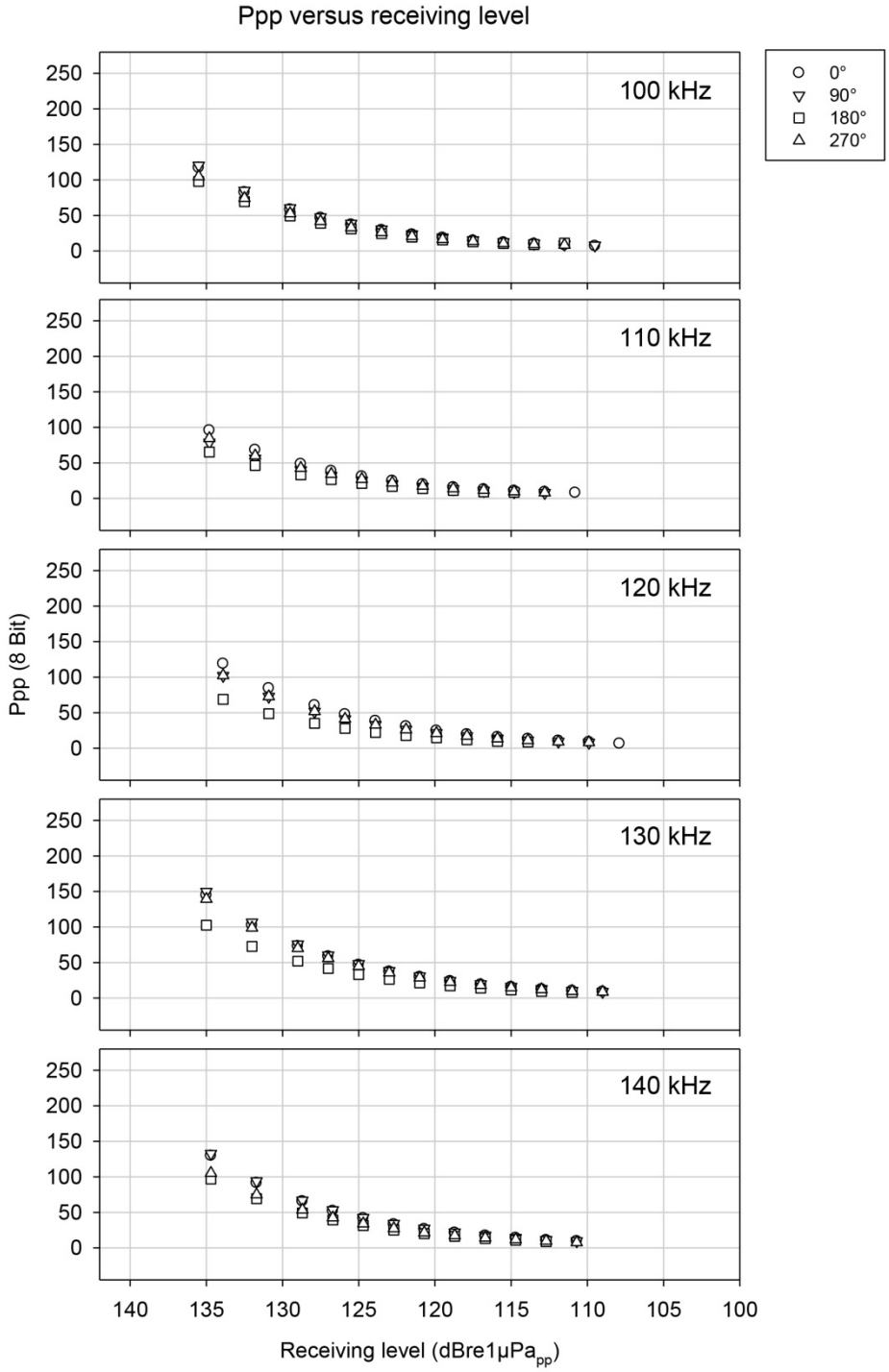

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)

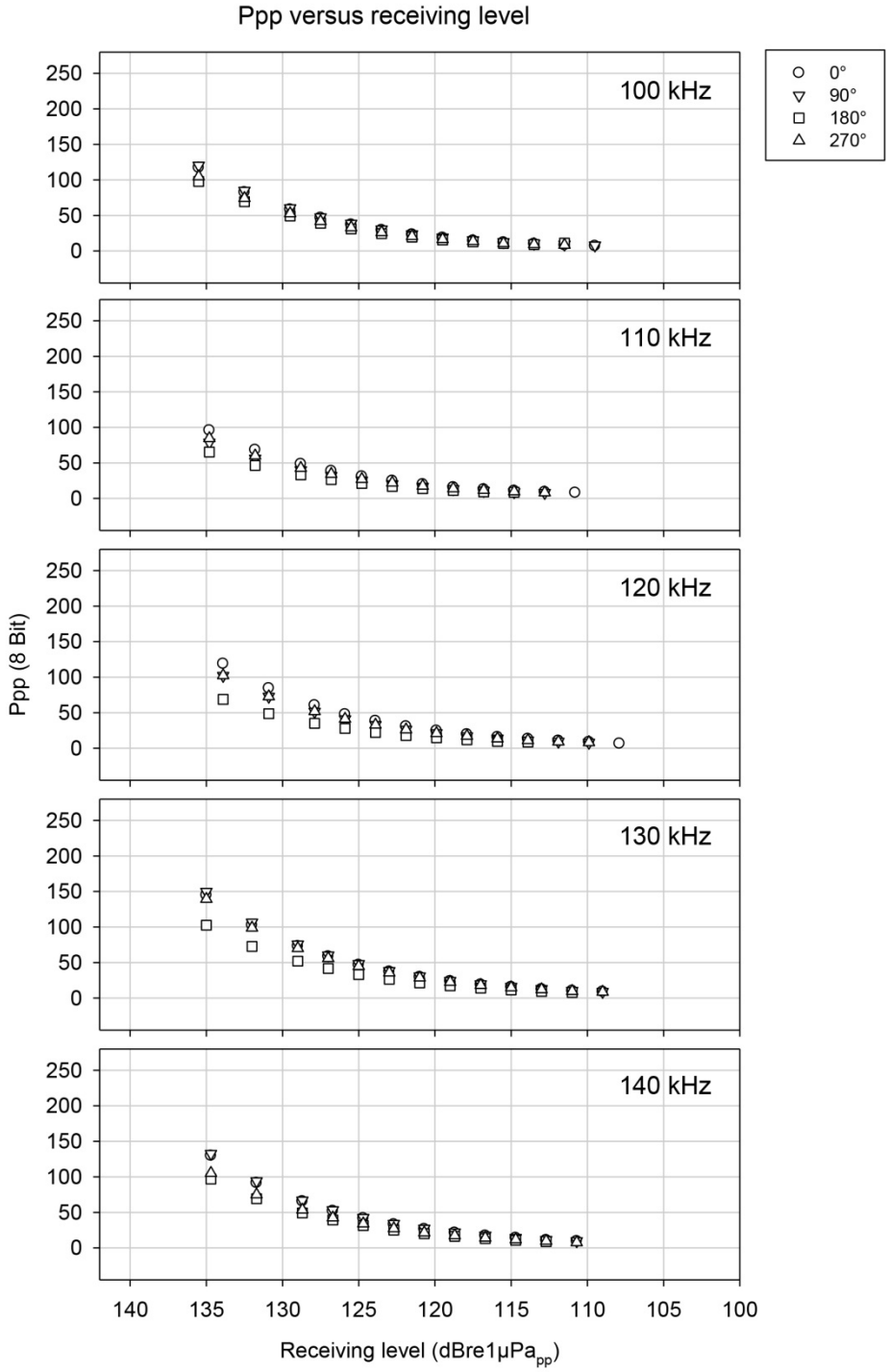

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
0
50
100
150
200
250
140
135
130
125
120
115
110
105
100
Receiving level (dBre1µPa$_{pp}$)

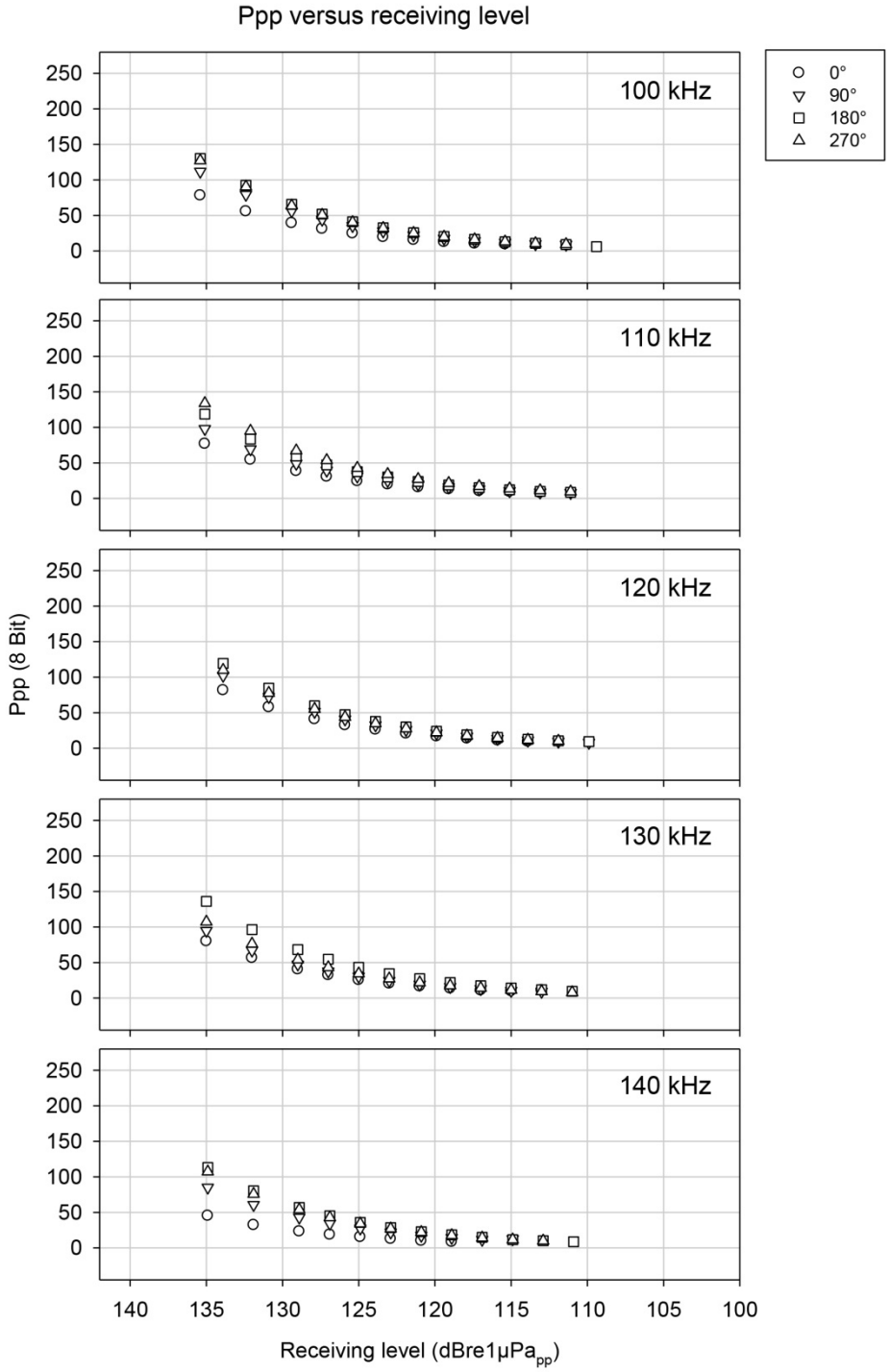

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
0
50
100
150
200
250
140
135
130
125
120
115
110
105
100
Receiving level (dBre1µPa$_{pp}$)

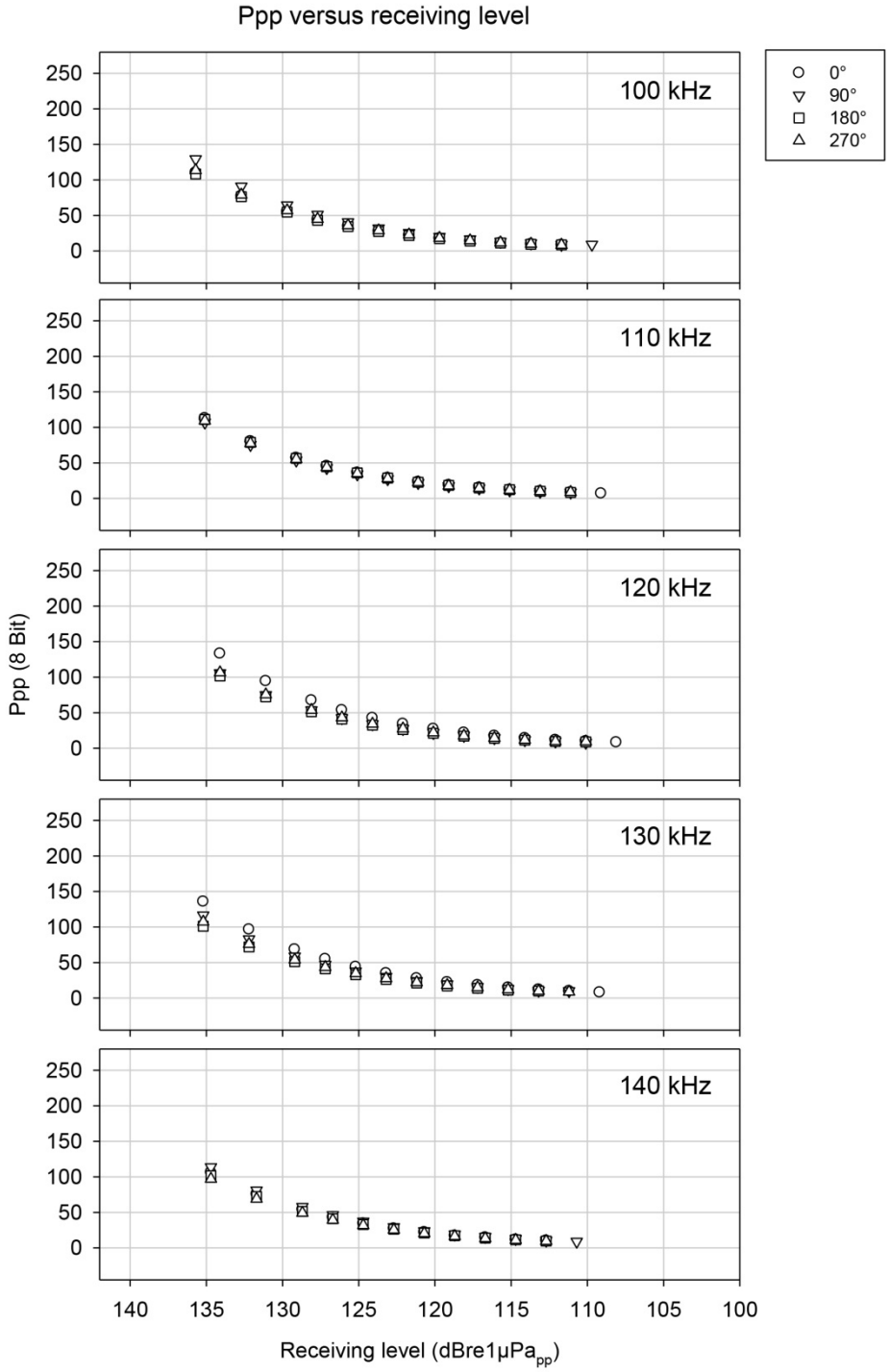

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
0
50
100
150
200
250
140
135
130
125
120
115
110
105
100
Receiving level (dBre1µPa$_{pp}$)

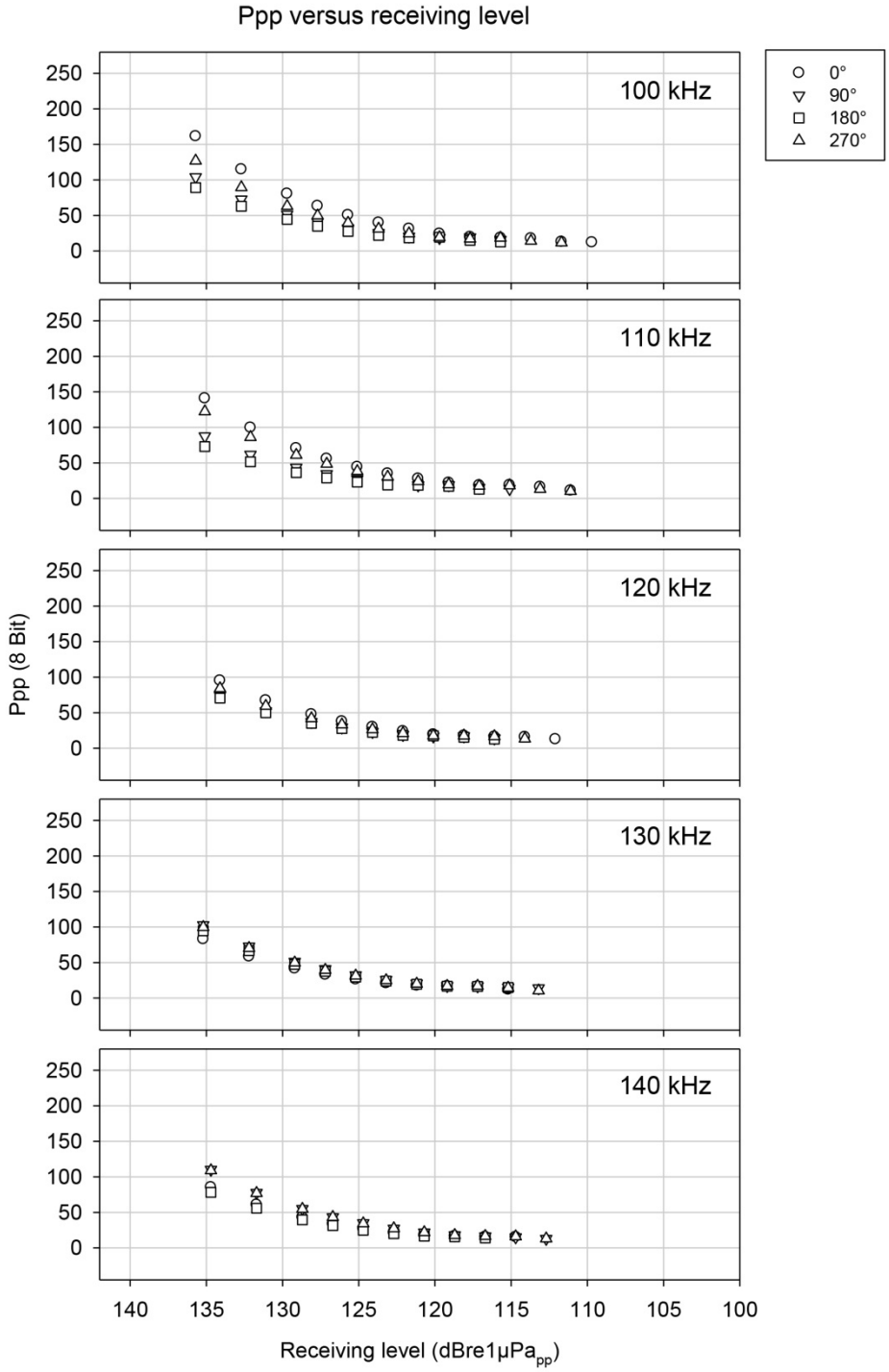

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)

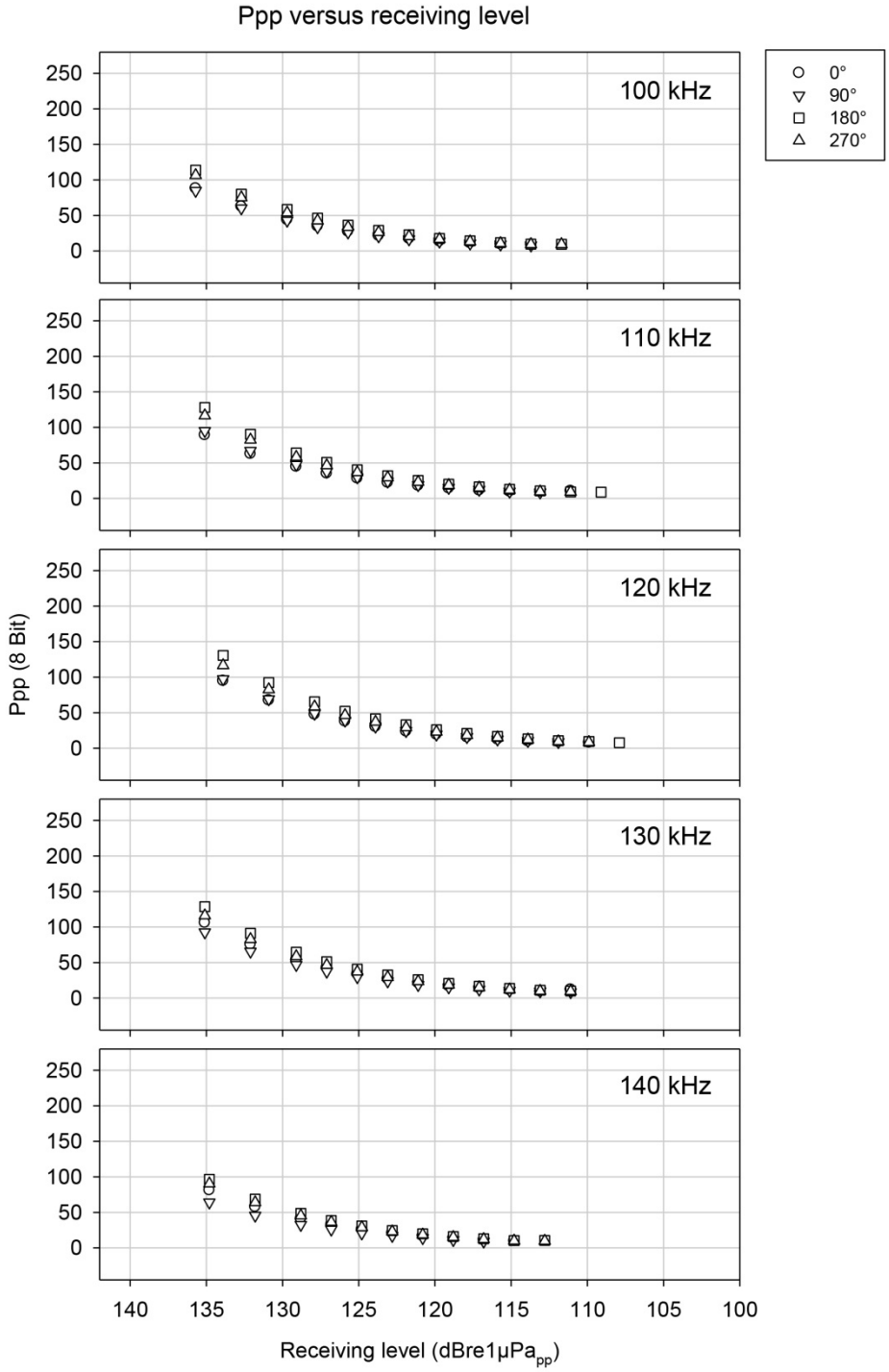

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)

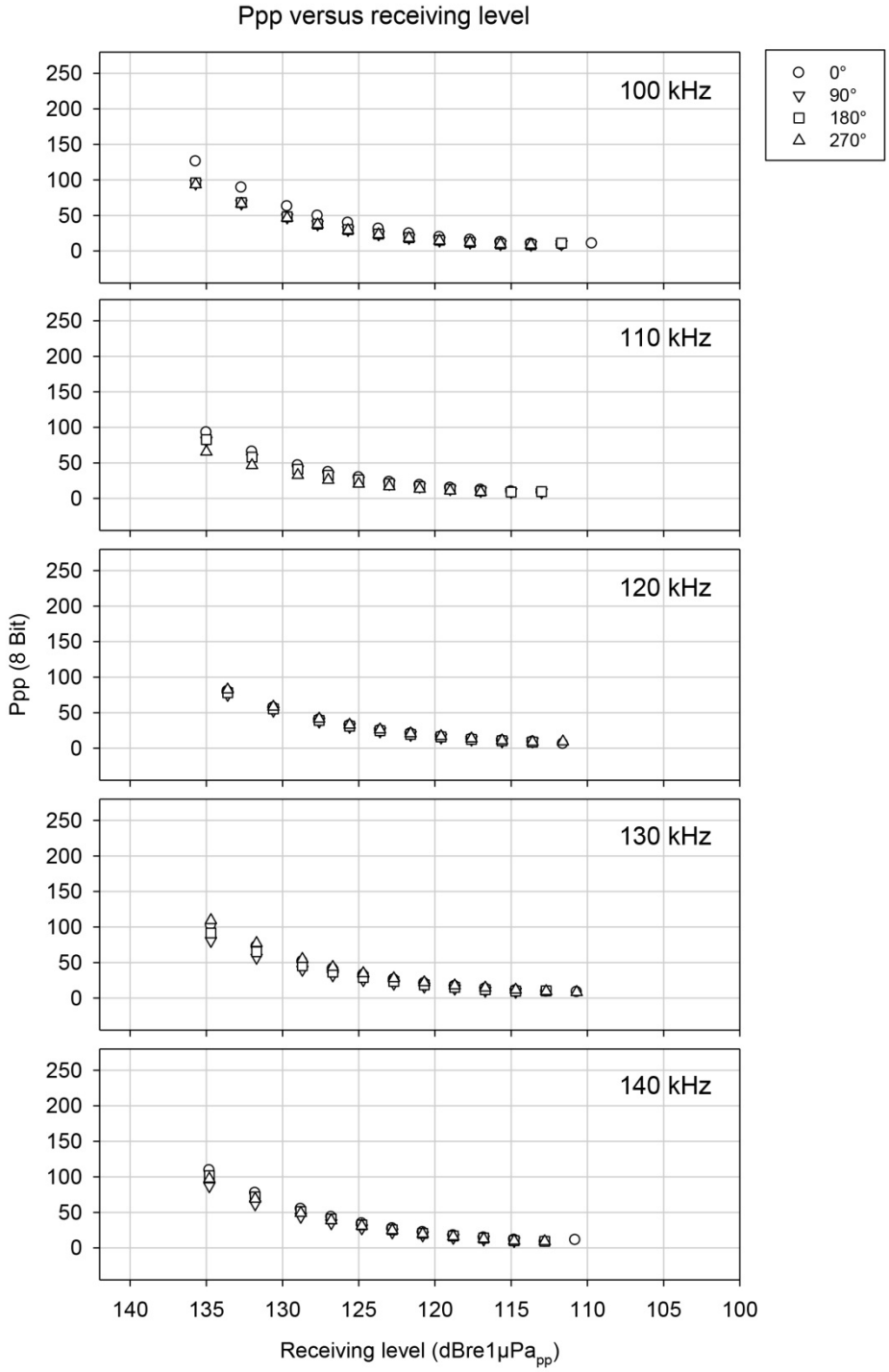

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)

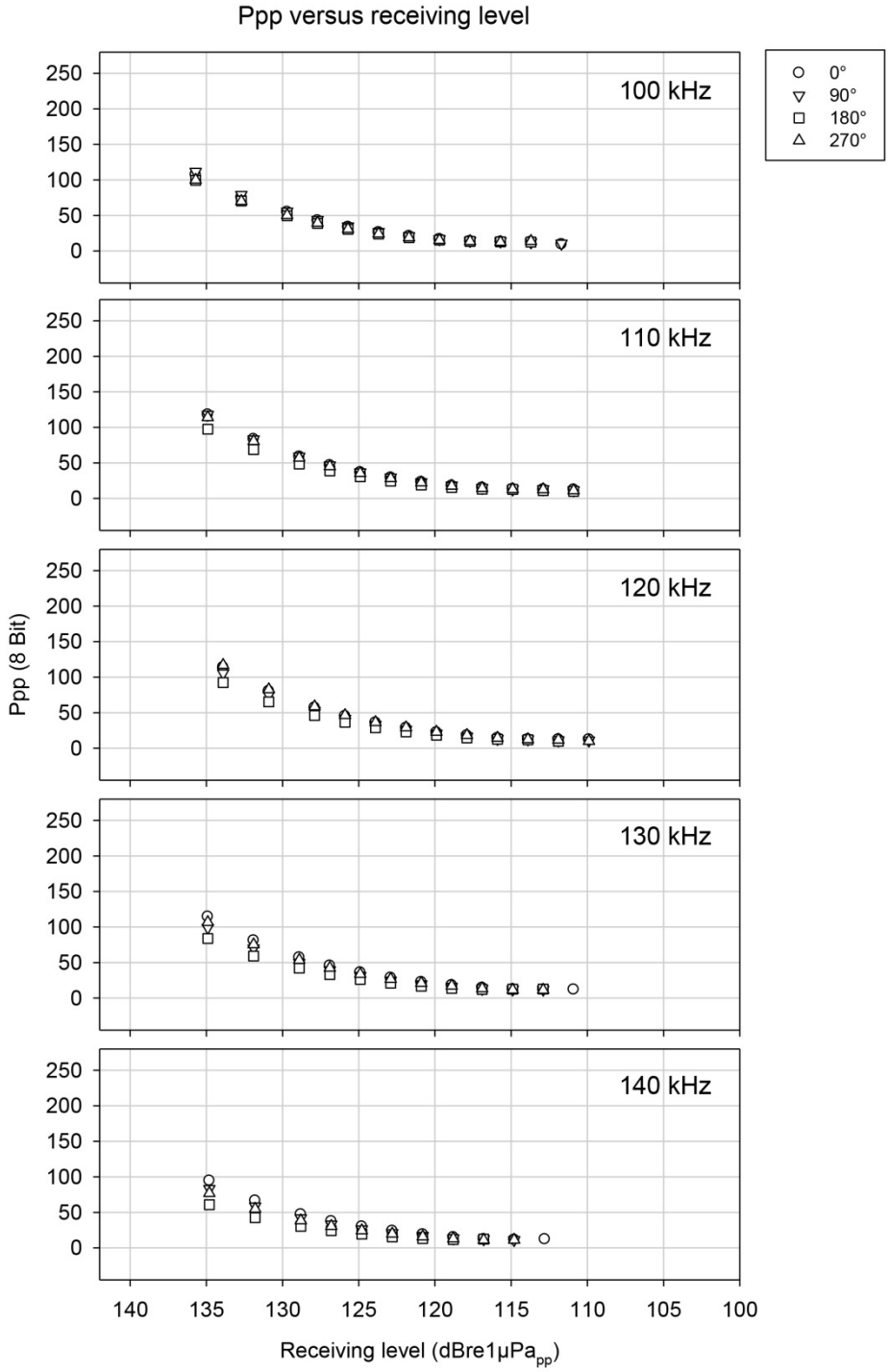

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)

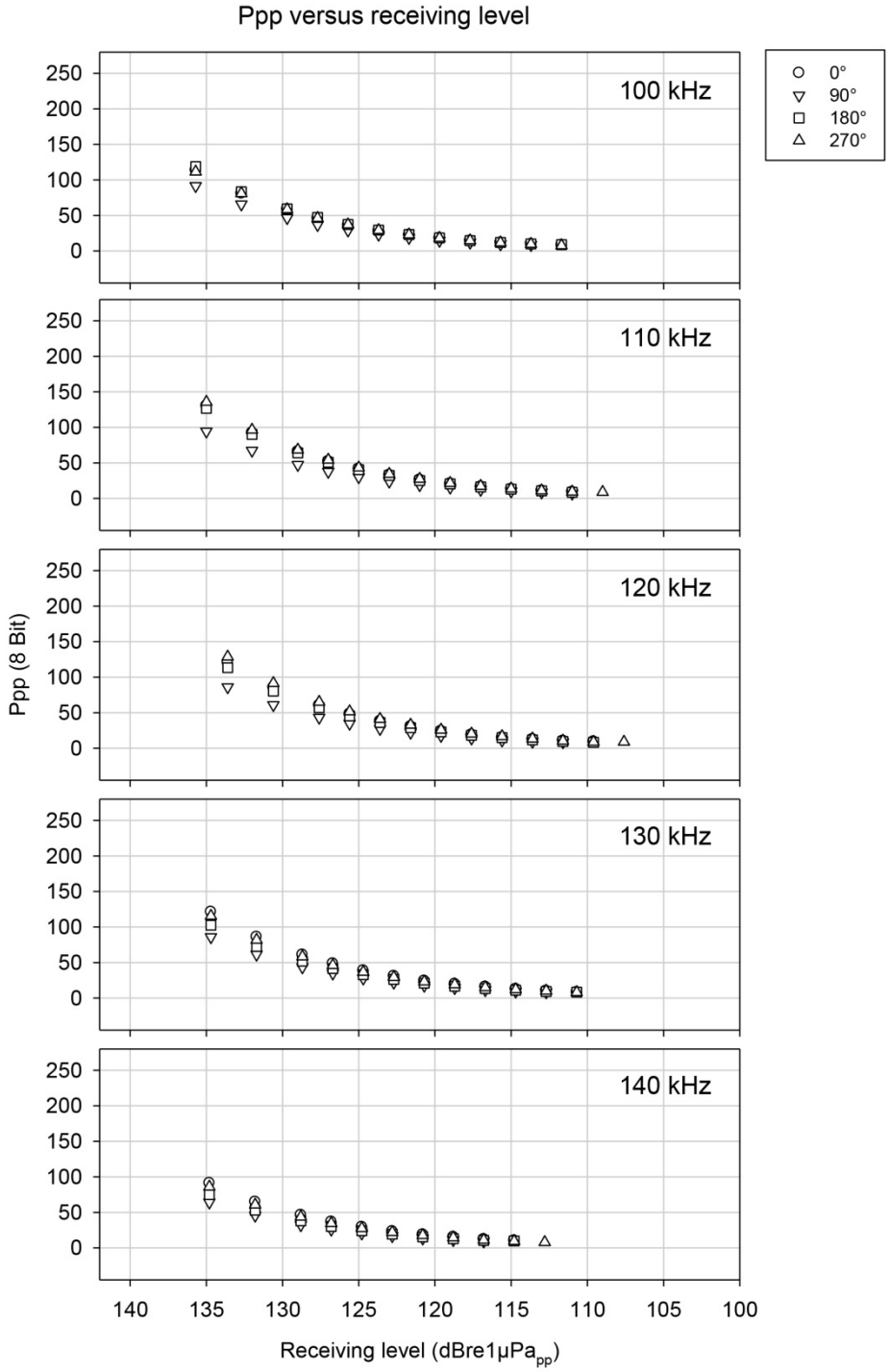

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
0
50
100
150
200
250
140
135
130
125
120
115
110
105
100
Receiving level (dBre1µPa$_{pp}$)

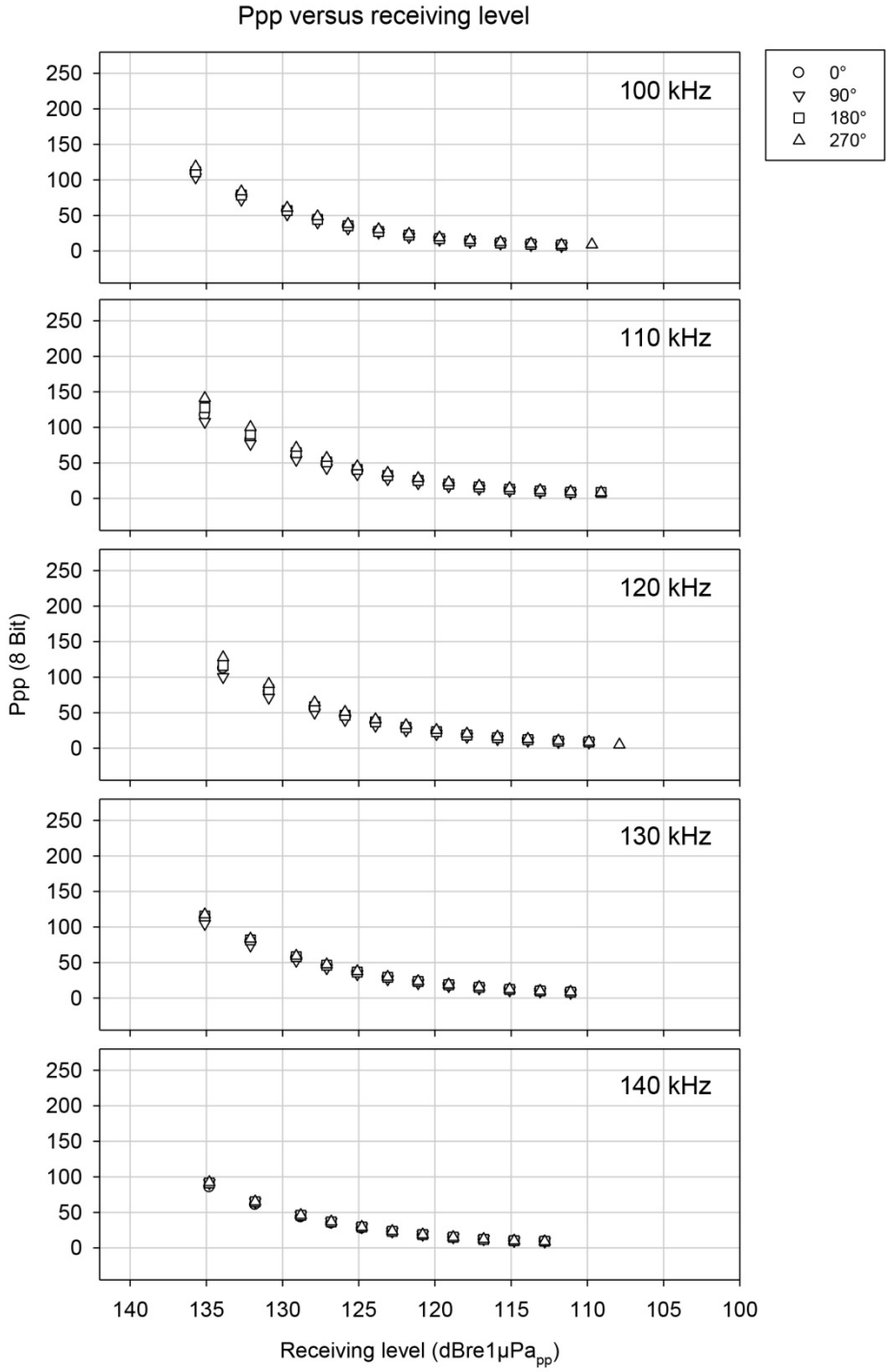

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)

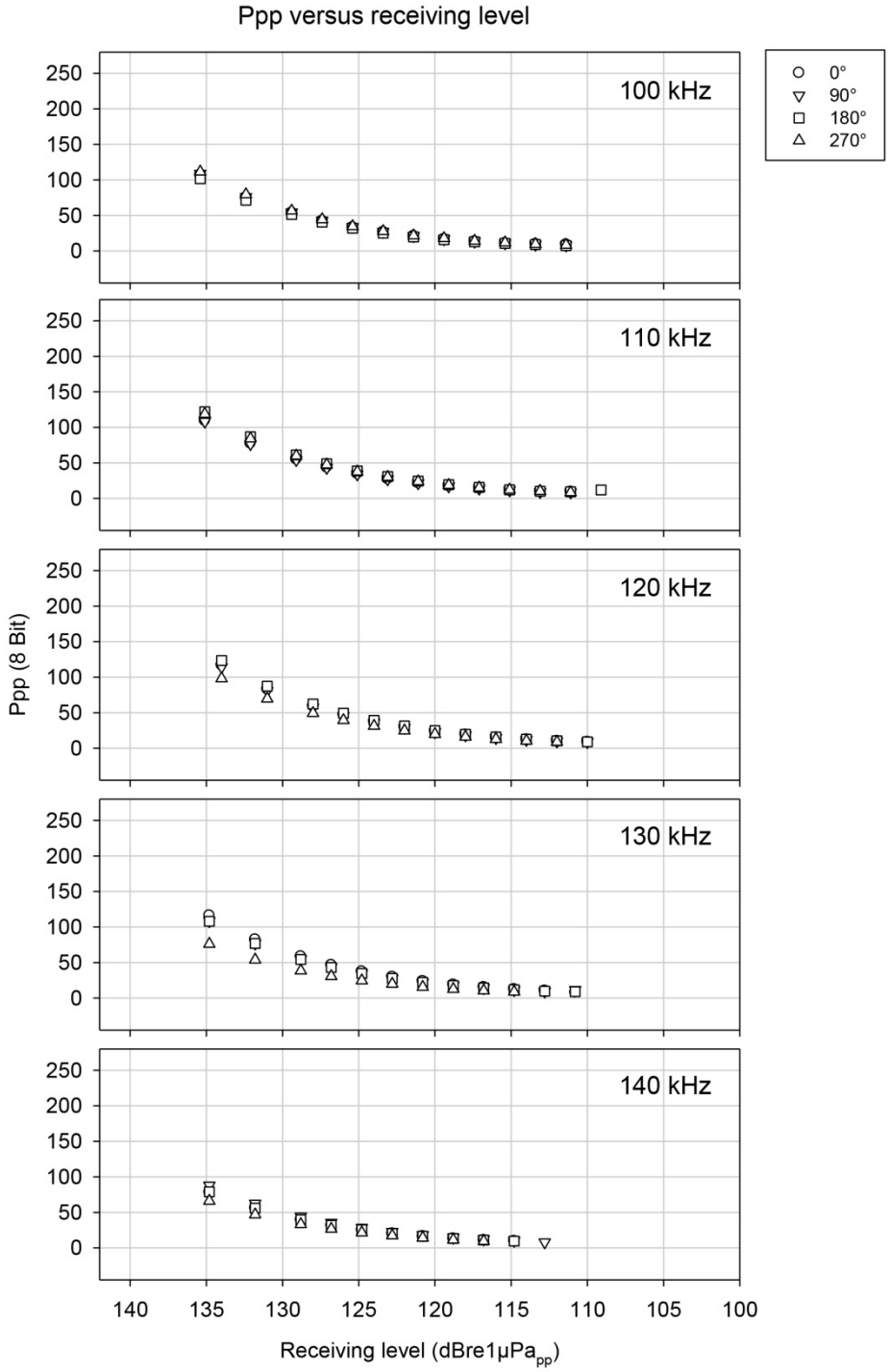

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
0
50
100
150
200
250
140
135
130
125
120
115
110
105
100
Receiving level (dBre1µPa$_{pp}$)

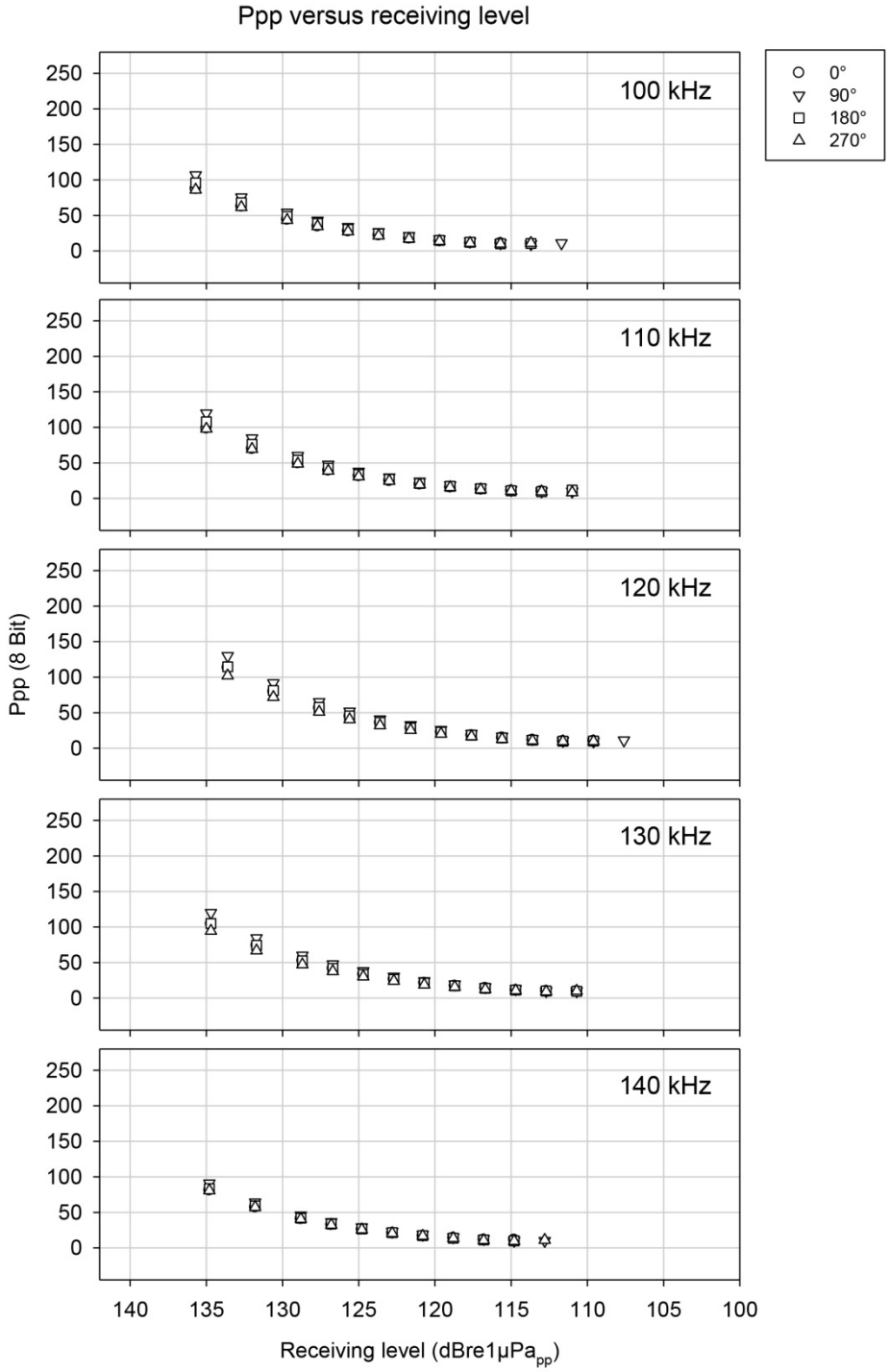

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
0
50
100
150
200
250
140
135
130
125
120
115
110
105
100
Receiving level (dBre1µPa$_{pp}$)

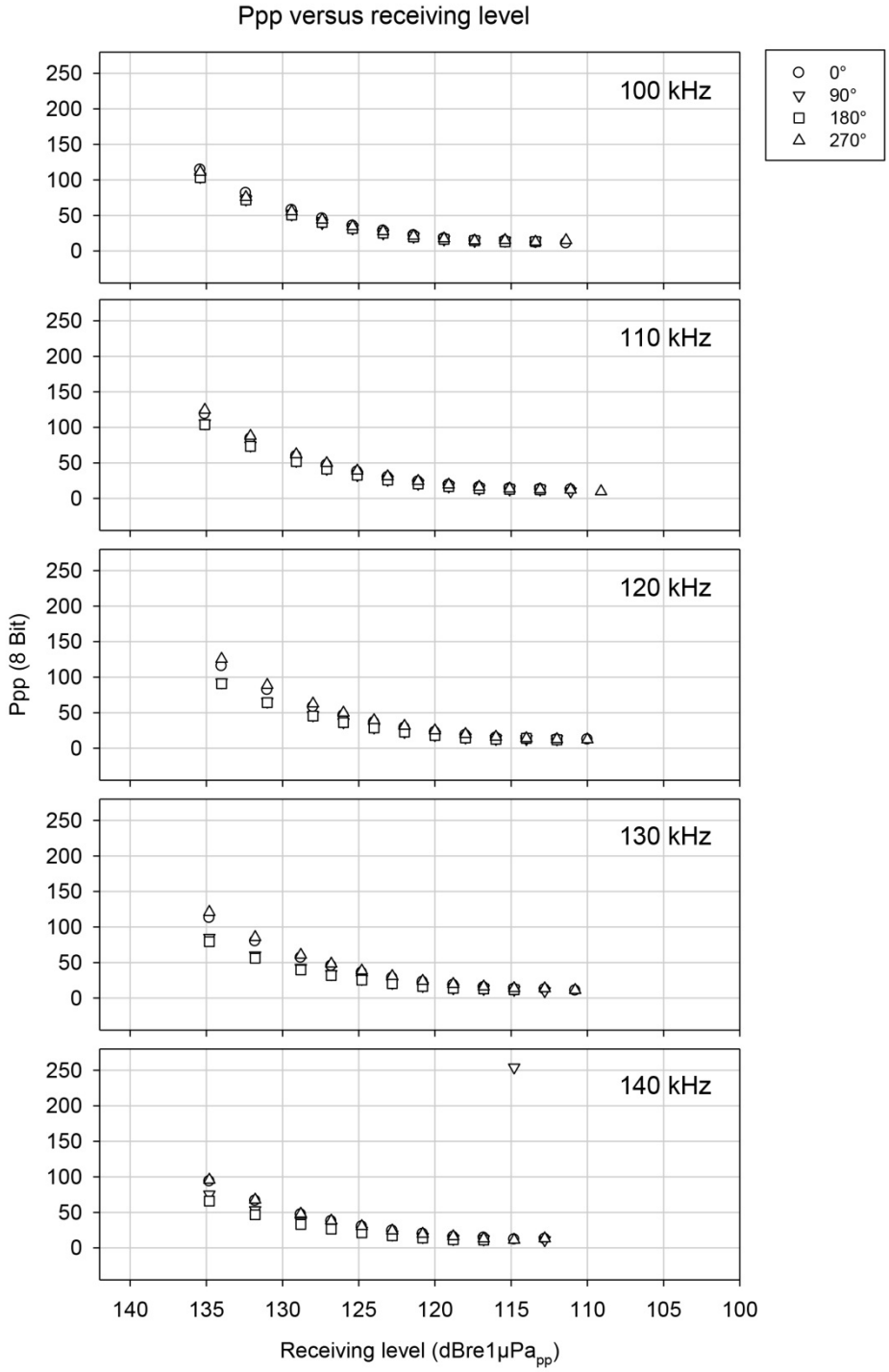

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)

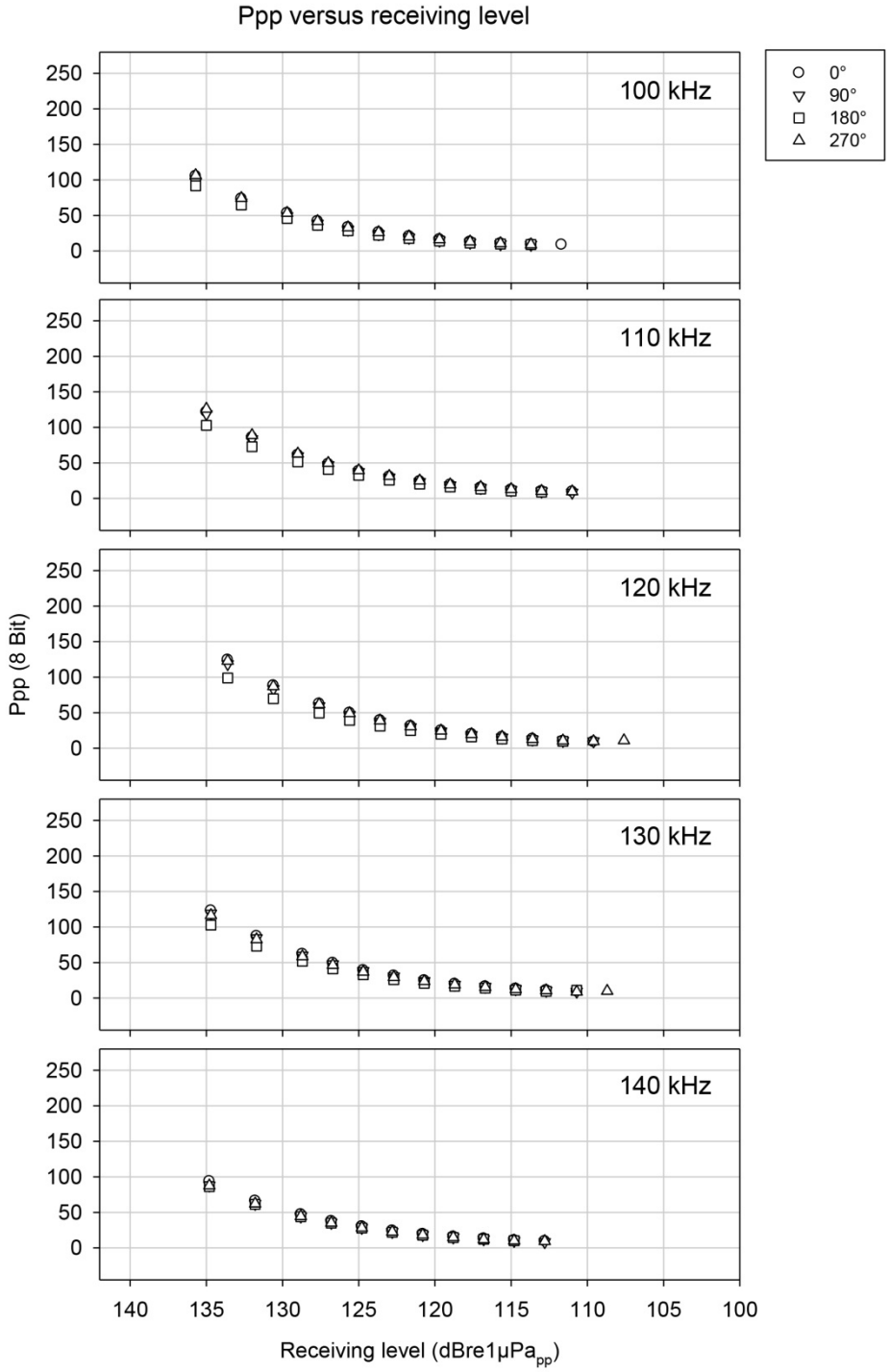

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
0
50
100
150
200
250
140
135
130
125
120
115
110
105
100
Receiving level (dBre1µPa$_{pp}$)

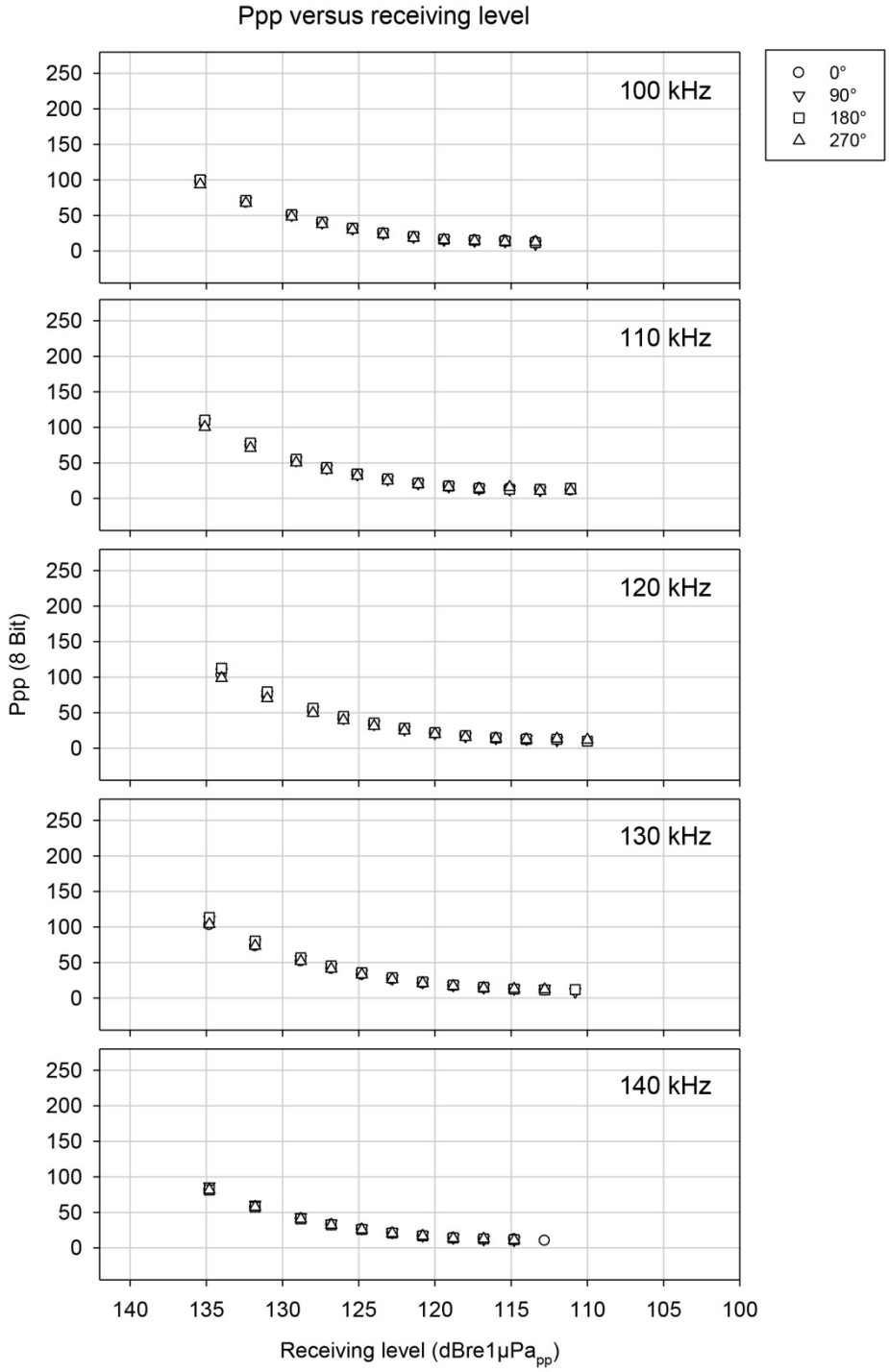

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
0
50
100
150
200
250
140
135
130
125
120
115
110
105
100
Receiving level (dBre1µPa$_{pp}$)


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


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

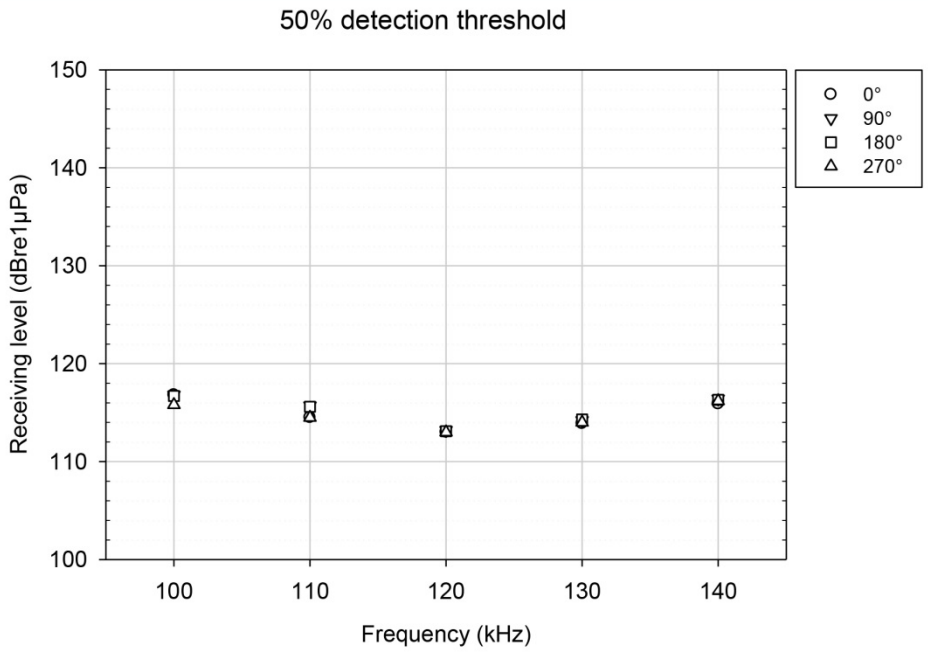

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)


Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
Receiving level (dBre1µPa$_{pp}$)

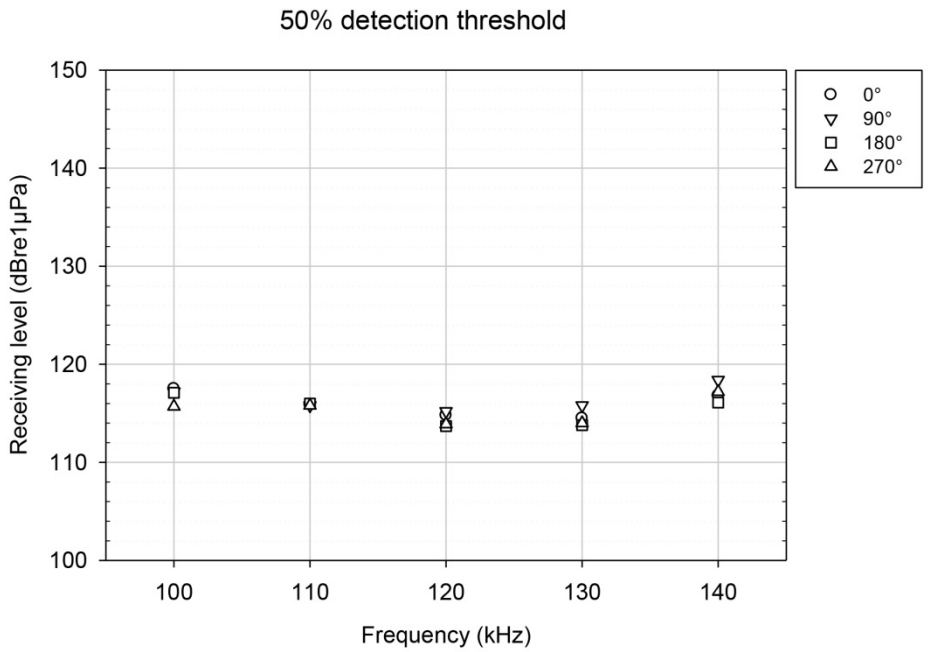

Ppp versus receiving level
100 kHz
110 kHz
120 kHz
130 kHz
140 kHz
0°
90°
180°
270°
Ppp (8 Bit)
0
50
100
150
200
250
140
135
130
125
120
115
110
105
100
Receiving level (dBre1µPa$_{pp}$)

## Appendix 5. Calibration results CPDs: Ppp vs frequency

| | | |
|---|---|---|
| POD ID / CAL ID: | 375/478 | IMARES |
| Date of calibration: | 28.01.2014 | |
| Calibrated by: | Anne Herrmann | |




| | | |
|---|---|---|
| POD ID / CAL ID: | 377 / 482 | IMARES |
| Date of calibration: | 04.02.2014 | |
| Calibrated by: | Anne Herrmann | |

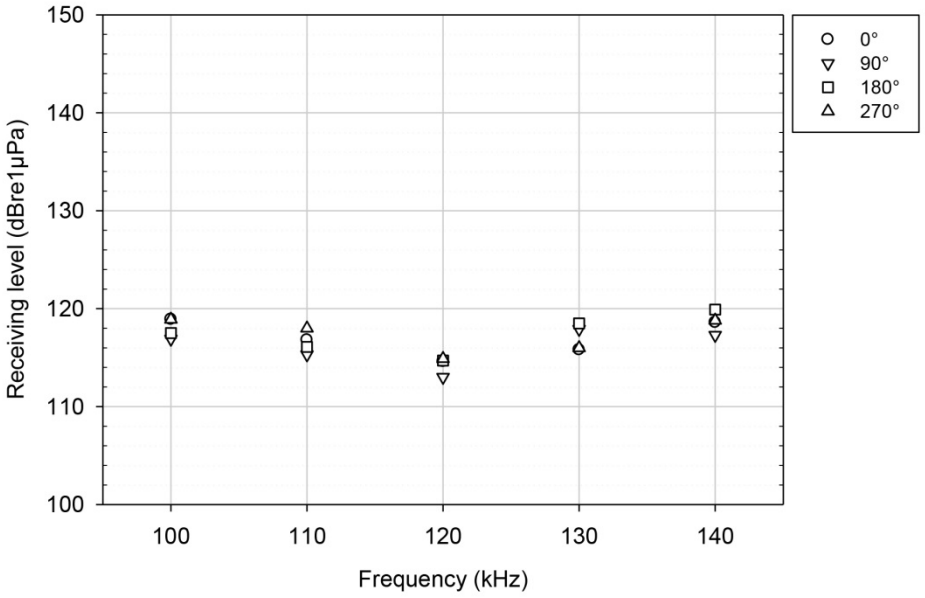


POD ID / CAL ID: 390 / 480
Date of calibration: 30.01.2014
Calibrated by: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

50% detection threshold

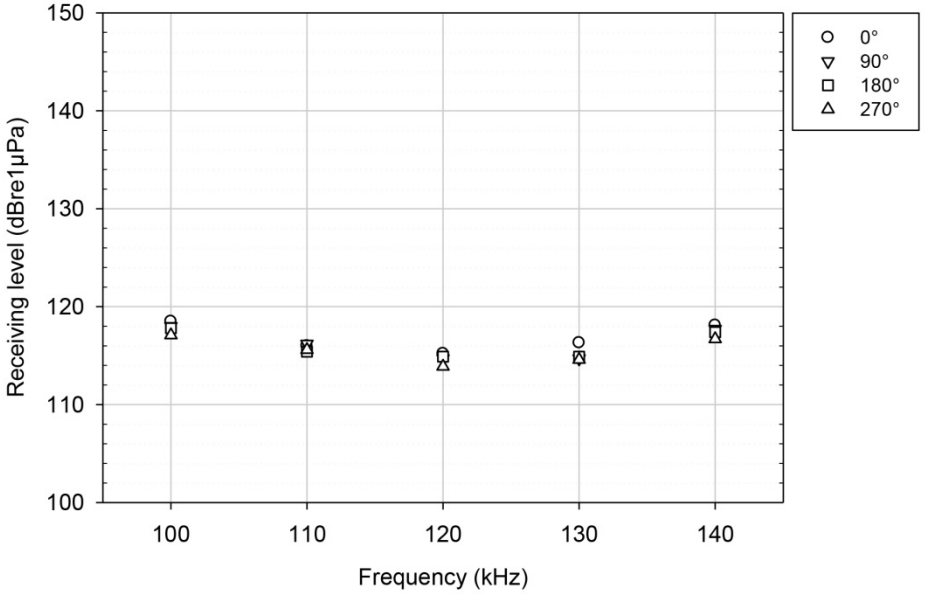



POD ID / CAL ID: 393 / 479
Date of calibration: 29.01.2014
Calibrated by: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

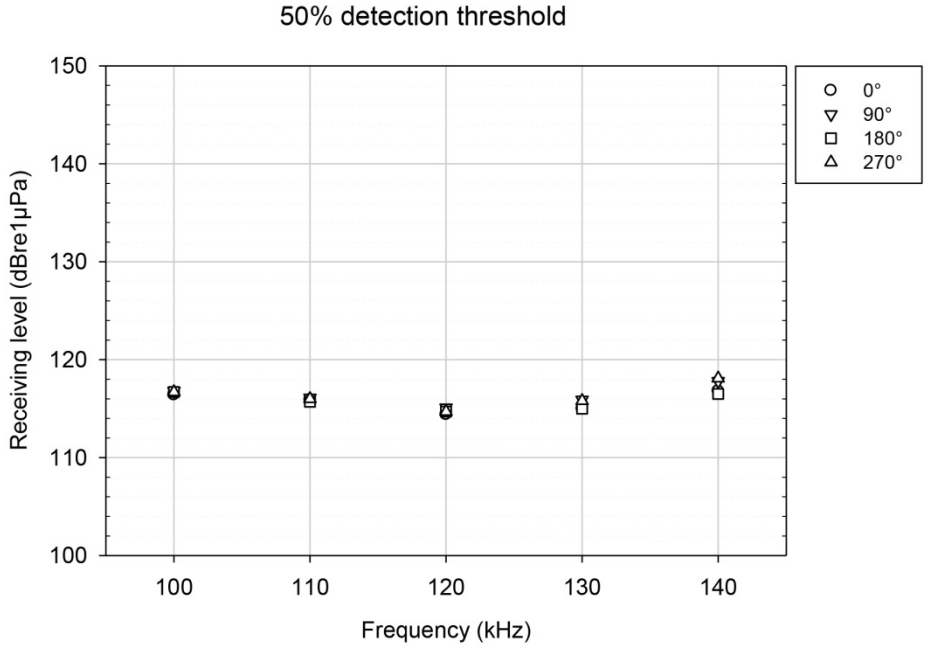
50% detection threshold



POD ID / CAL ID: 395 / 479
Date of calibration: 29.01.2014
Calibrated by: Anne Herrmann

IMARES

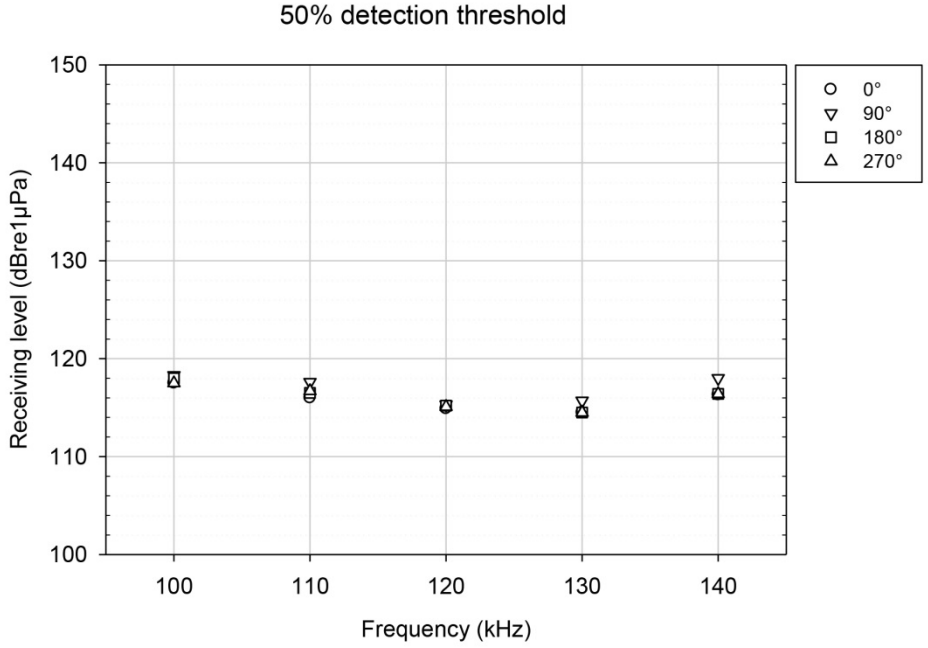
Deutsches Meeresmuseum Stralsund




POD ID / CAL ID: 397 / 479
Date of calibration: 29.01.2014
Calibrated by: Anne Herrmann

IMARES

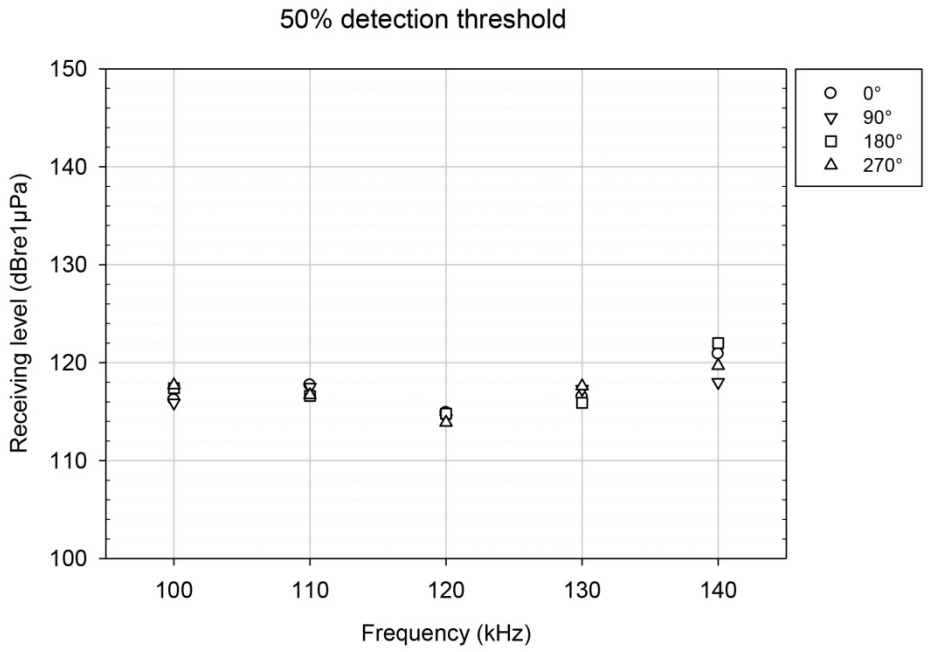
Deutsches Meeresmuseum Stralsund



POD ID/KAL ID: 714/453
Datum der Kalibrierung: 17.07.2013
Bearbeiter/in: Anne Herrmann

IMARES

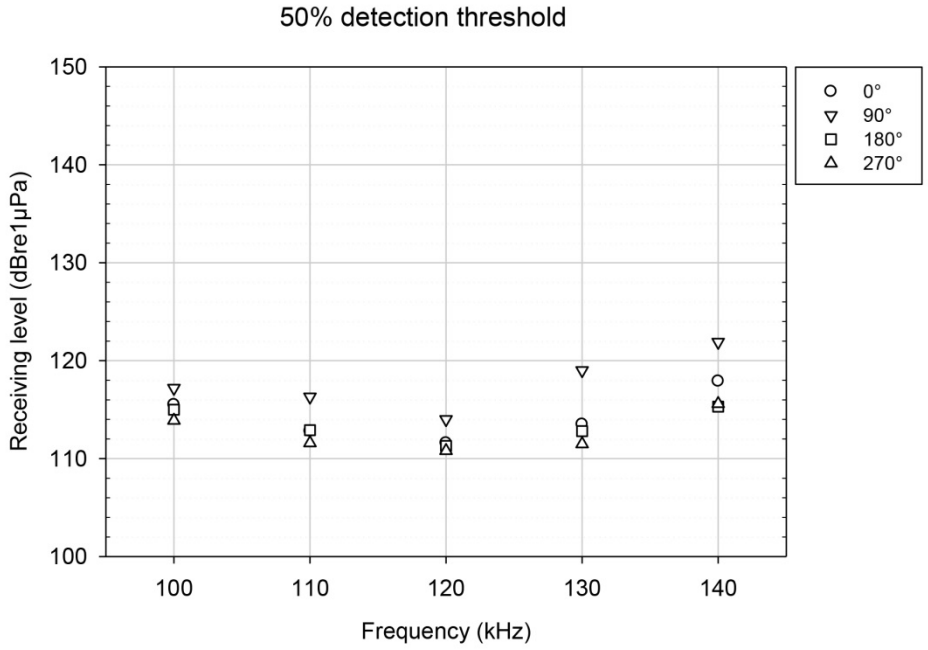
Deutsches Meeresmuseum Stralsund




POD ID / CAL ID: 716 / 479
Date of calibration: 29.01.2014
Calibrated by: Anne Herrmann

IMARES

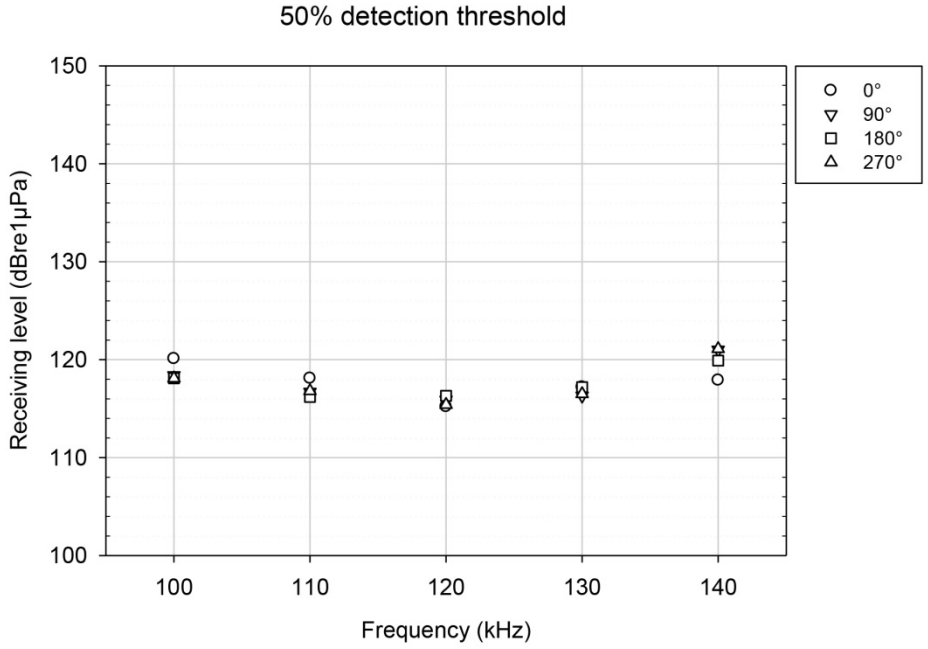
Deutsches Meeresmuseum Stralsund



POD ID / CAL ID: 717 / 482
Date of calibration: 04.02.2014
Calibrated by: Anne Herrmann

IMARES

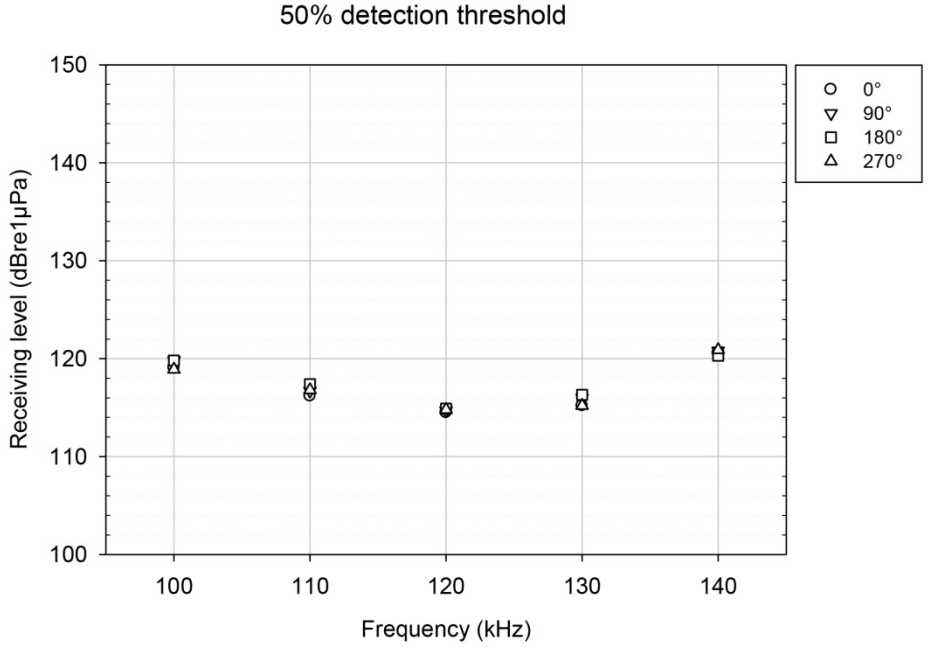
Deutsches Meeresmuseum Stralsund




POD ID / CAL ID: 719 / 480
Date of calibration: 30.01.2014
Calibrated by: Anne Herrmann

IMARES

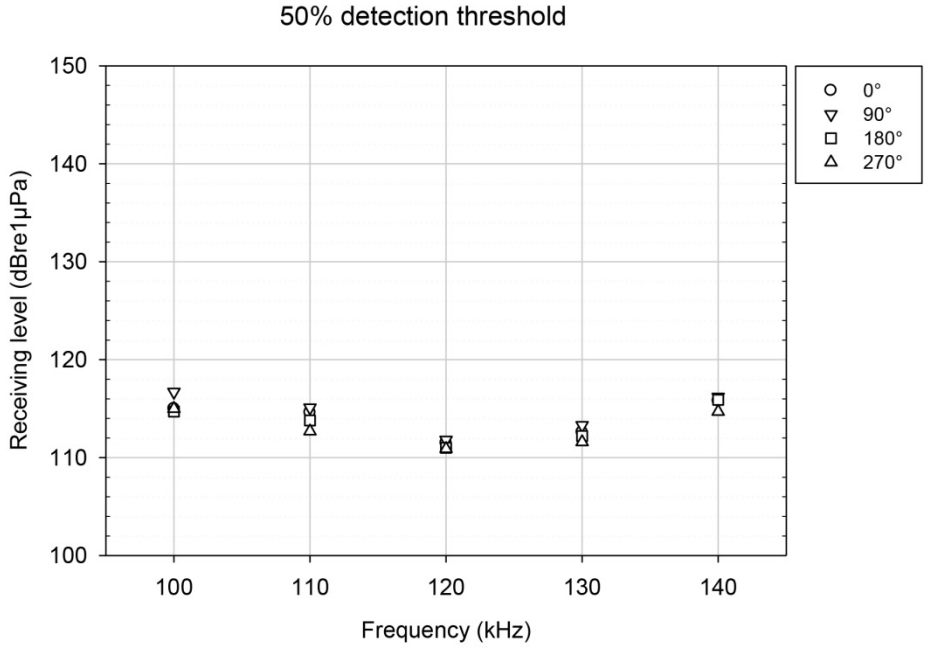
Deutsches Meeresmuseum Stralsund



POD ID/KAL ID: 862/454
Datum der Kalibrierung: 18.07.2013
Bearbeiter/in: Anne Herrmann

IMARES

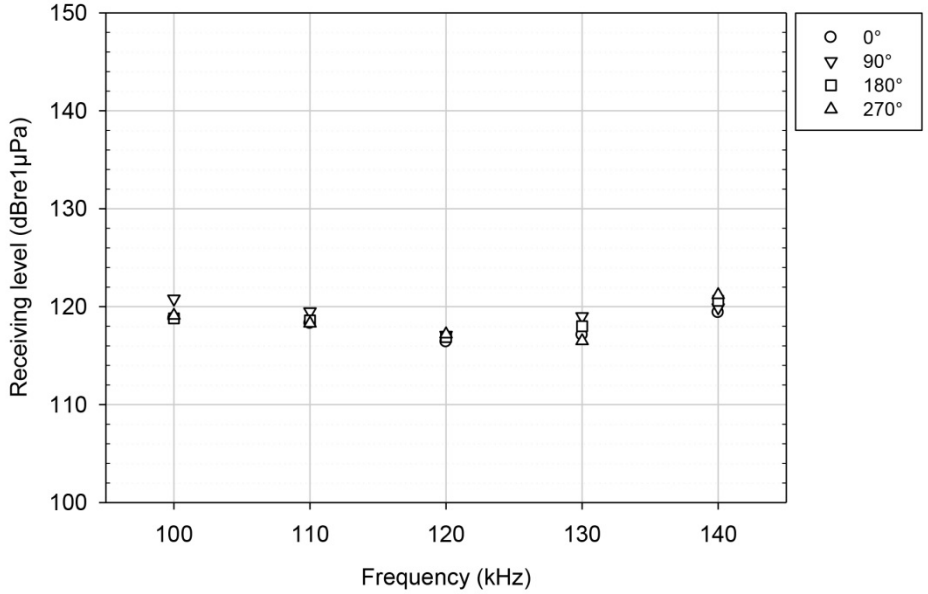
Deutsches Meeresmuseum Stralsund




POD ID/KAL ID: 889/454
Datum der Kalibrierung: 18.07.2013
Bearbeiter/in: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

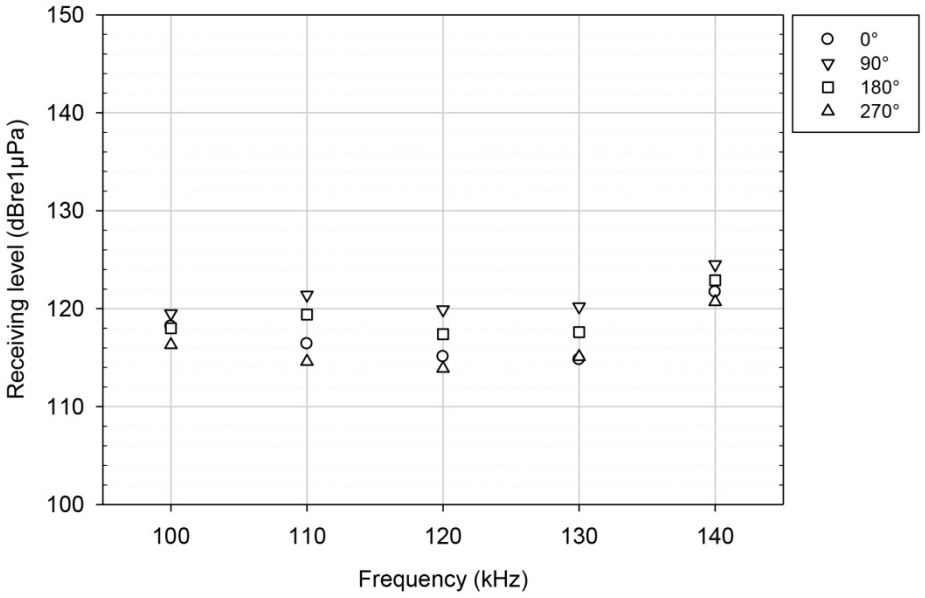


POD ID/KAL ID: 1519/454
Datum der Kalibrierung: 18.07.2013
Bearbeiter/in: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

50% detection threshold

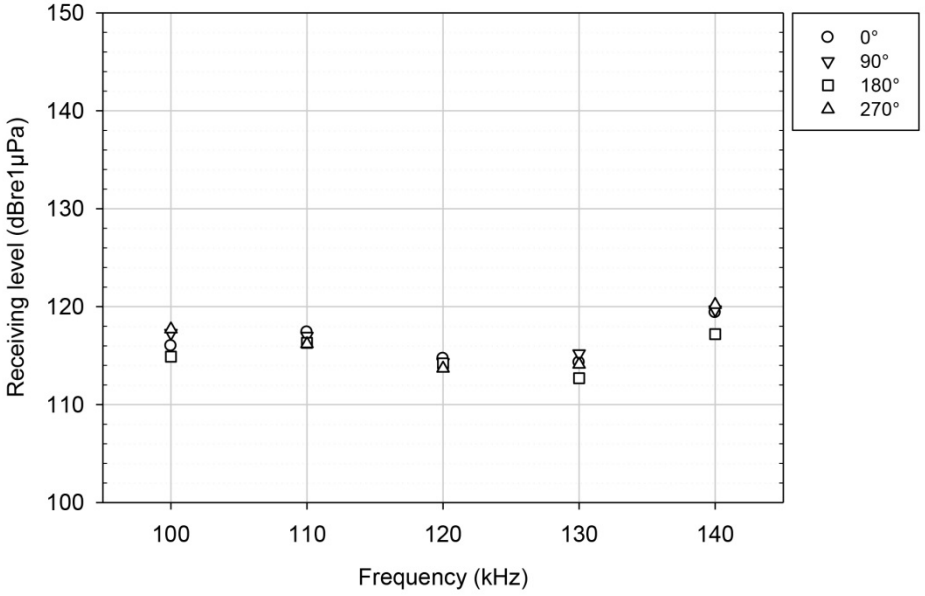



POD ID / CAL ID: 1741 / 482
Date of calibration: 04.02.2014
Calibrated by: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

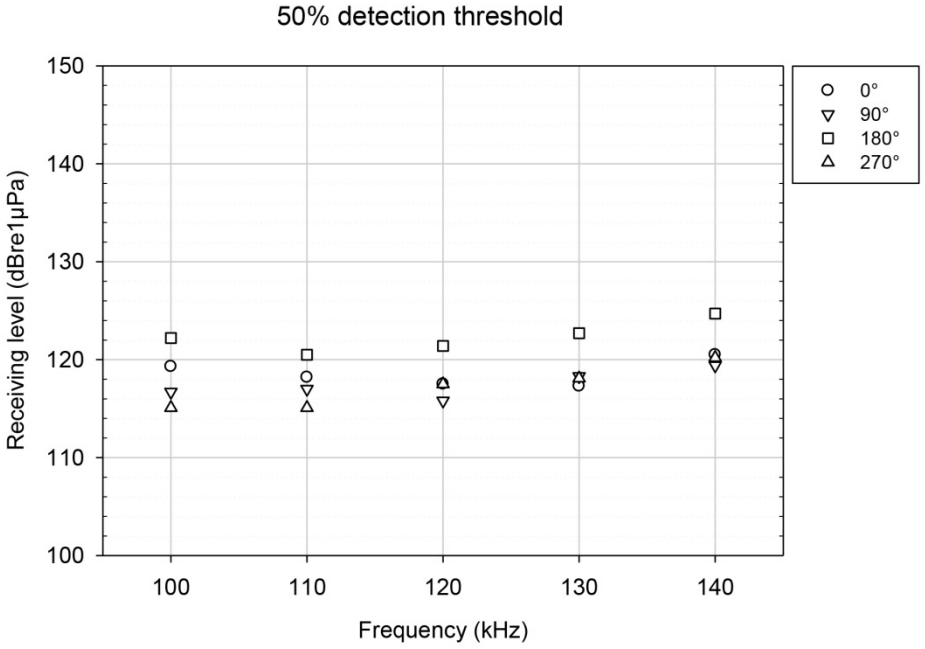
50% detection threshold



POD ID/KAL ID: 1744/453
Datum der Kalibrierung: 17.07.2013
Bearbeiter/in: Anne Herrmann

IMARES

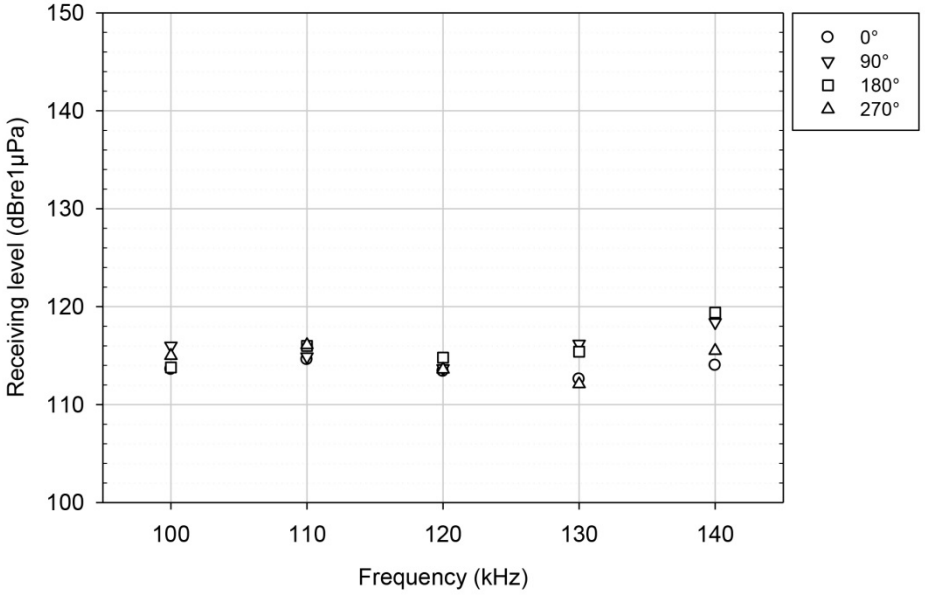
Deutsches Meeresmuseum Stralsund




POD ID/KAL ID: 1748/455
Datum der Kalibrierung: 22.07.2013
Bearbeiter/in: Anne Herrmann

IMARES

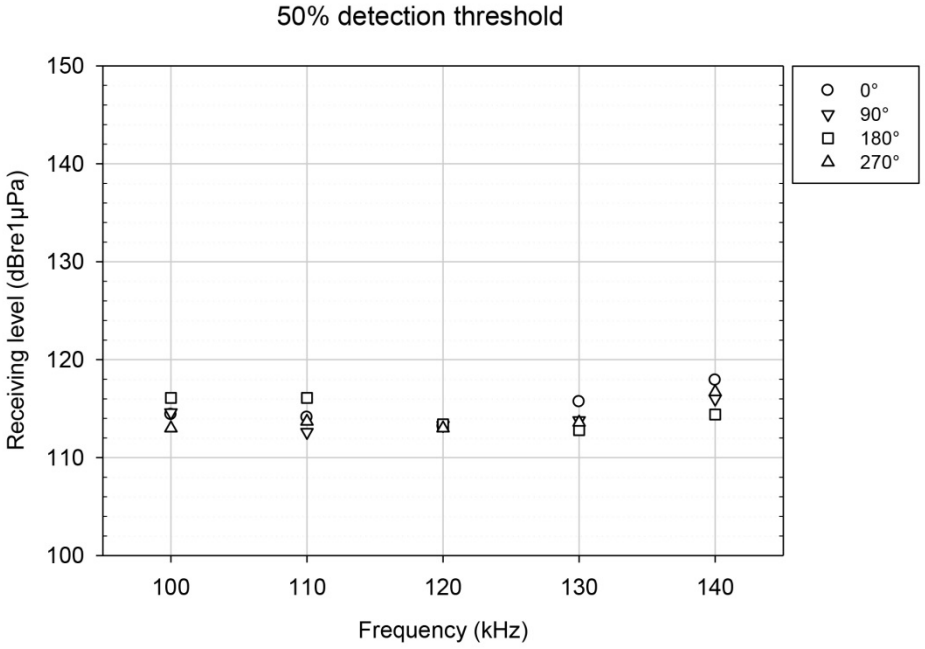
Deutsches Meeresmuseum Stralsund



POD ID/KAL ID: 1751/453
Datum der Kalibrierung: 17.07.2013
Bearbeiter/in: Anne Herrmann

IMARES

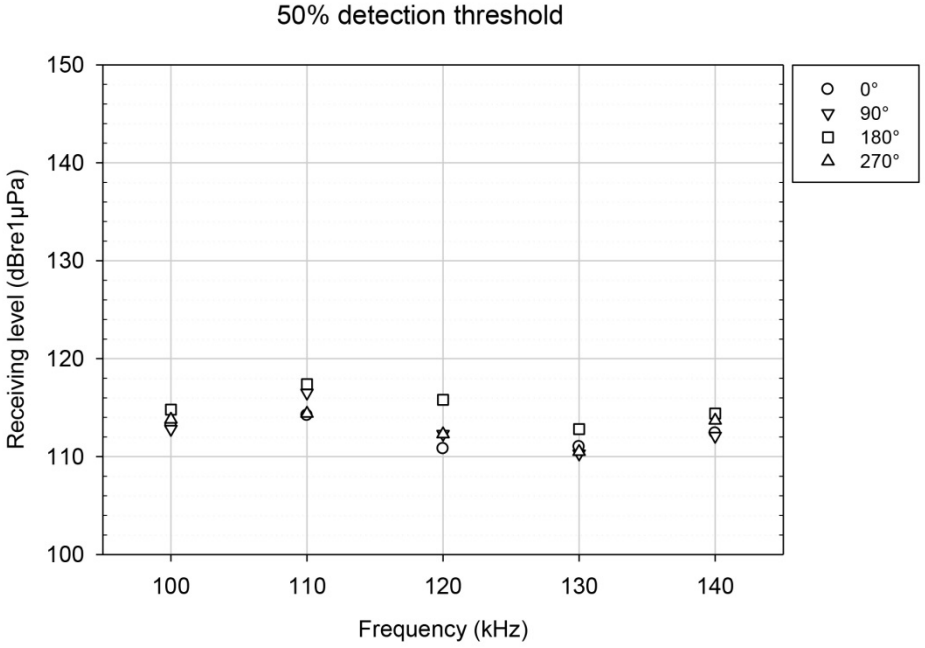
Deutsches Meeresmuseum Stralsund




POD ID/KAL ID: 1752/454
Datum der Kalibrierung: 18.07.2013
Bearbeiter/in: Anne Herrmann

IMARES

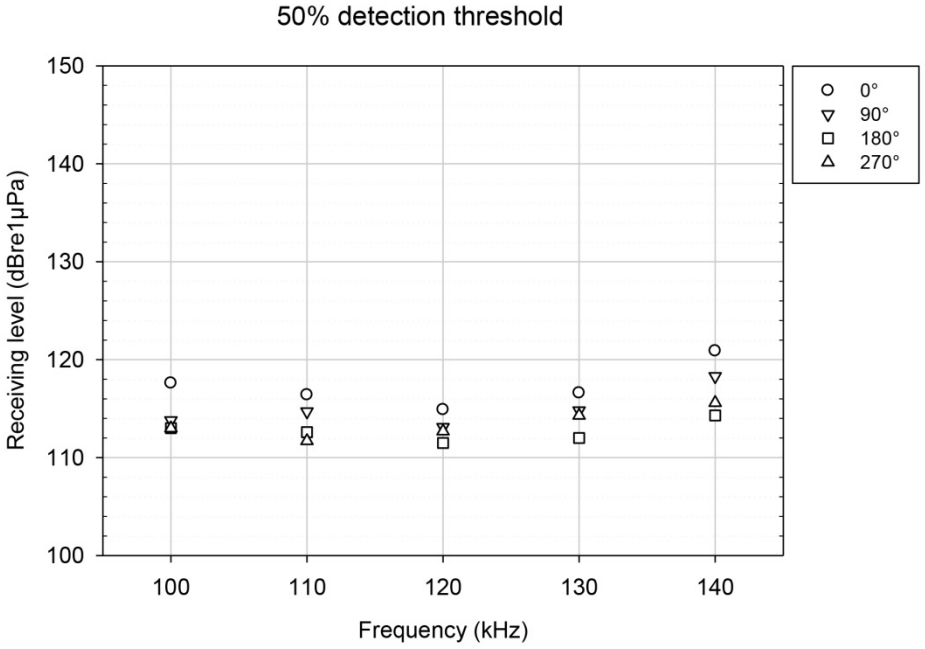
Deutsches Meeresmuseum Stralsund



POD ID/KAL ID: 1755/455
Datum der Kalibrierung: 22.07.2013
Bearbeiter/in: Anne Herrmann

IMARES

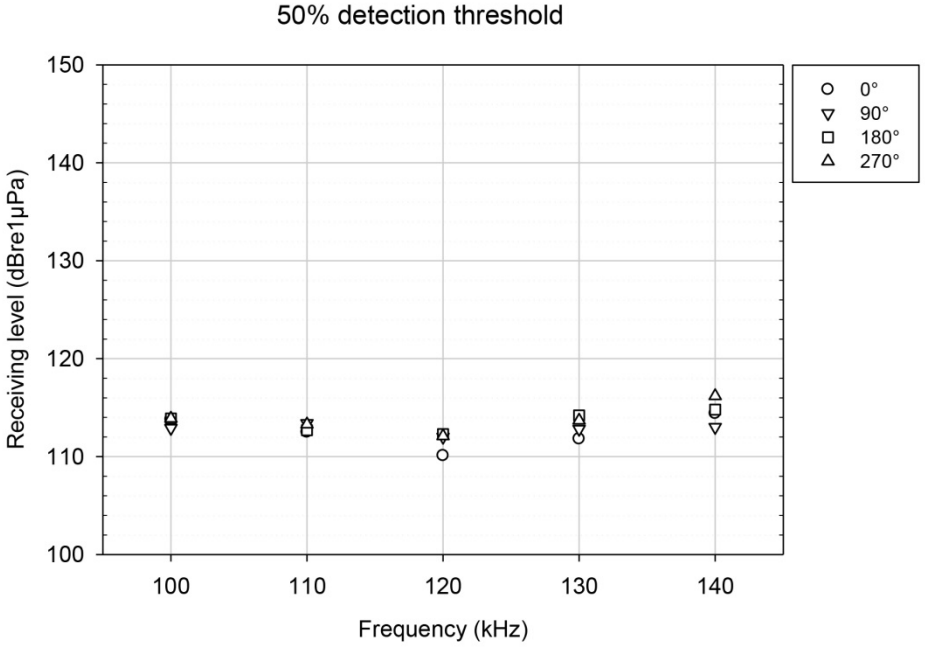
Deutsches Meeresmuseum Stralsund




POD ID/KAL ID: 1816/453
Datum der Kalibrierung: 17.07.2013
Bearbeiter/in: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

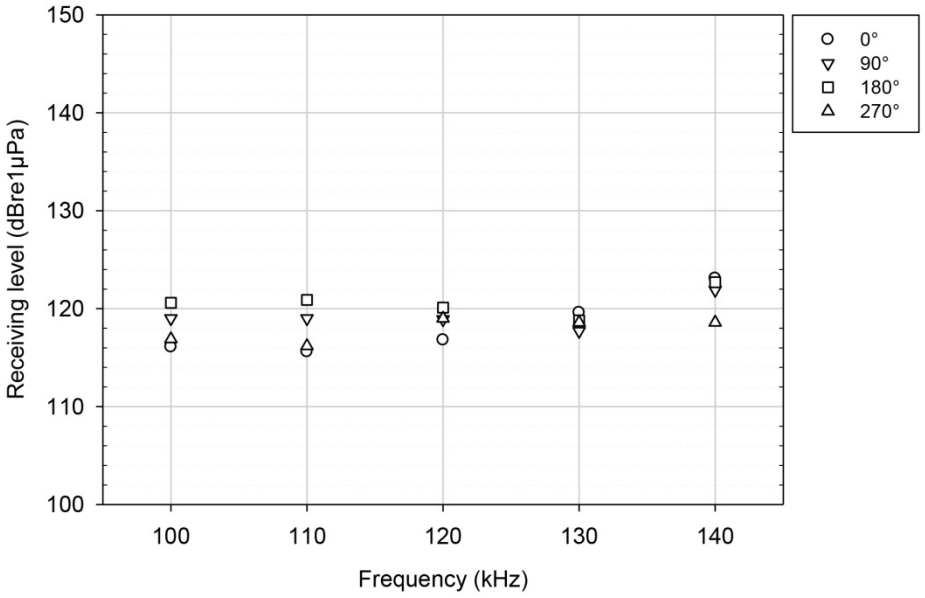


POD ID/KAL ID: 1817/453
Datum der Kalibrierung: 17.07.2013
Bearbeiter/in: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

50% detection threshold

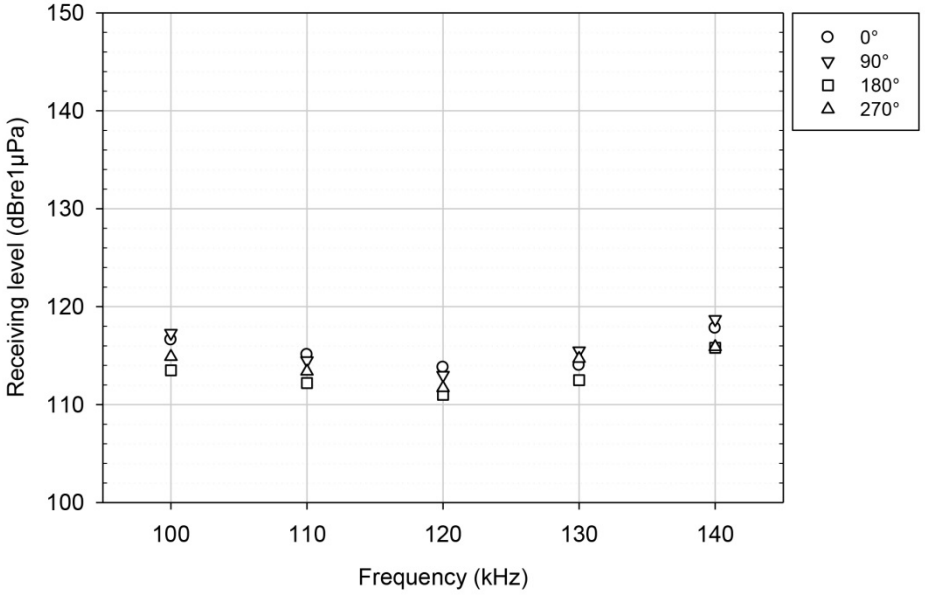



POD ID / CAL ID: 1859/478
Date of calibration: 28.01.2014
Calibrated by: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

50% detection threshold

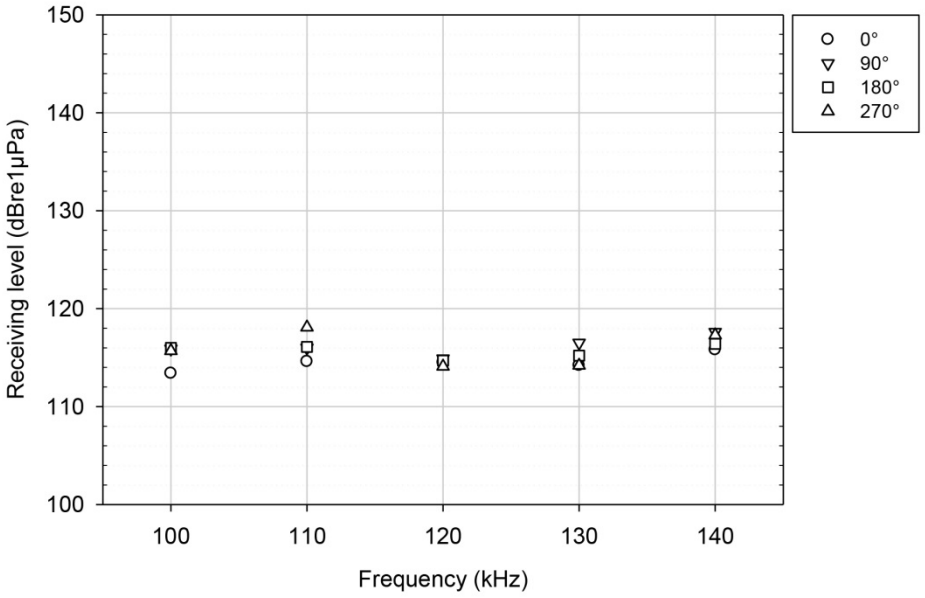


POD ID / CAL ID: 1861 / 480
Date of calibration: 30.01.2014
Calibrated by: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

50% detection threshold

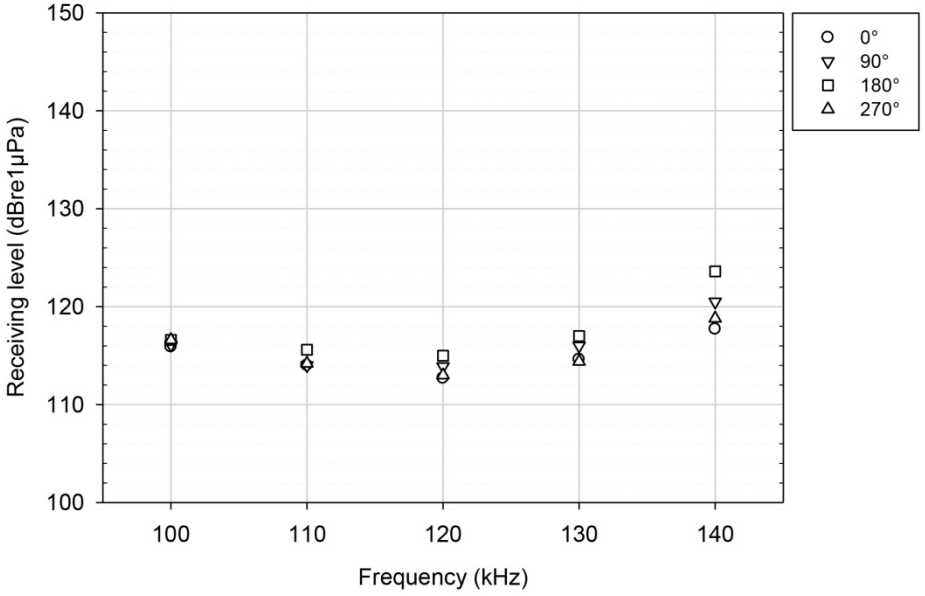



POD ID / CAL ID: 1873 / 482
Date of calibration: 04.02.2014
Calibrated by: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

50% detection threshold

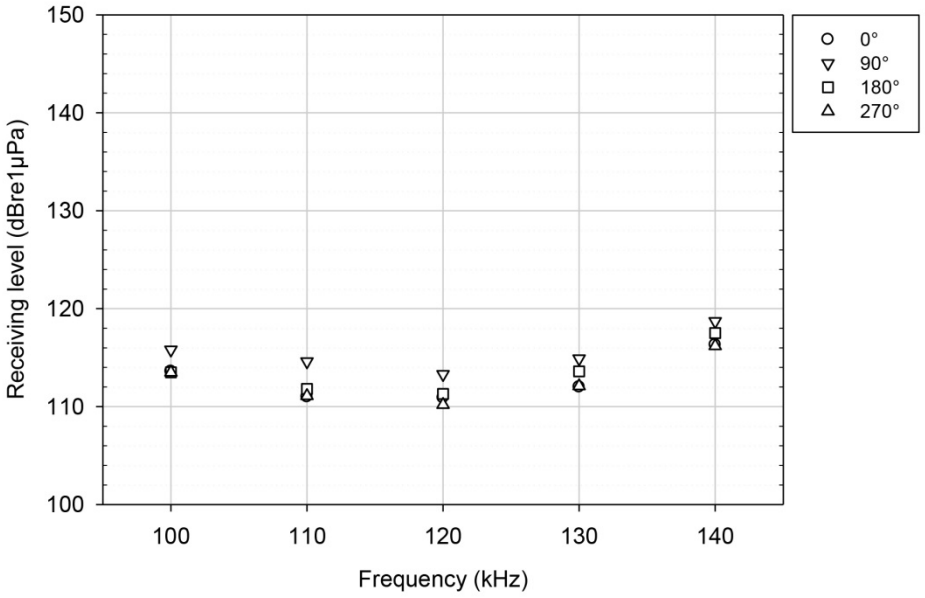


POD ID / CAL ID: 1874 / 480
Date of calibration: 30.01.2014
Calibrated by: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

50% detection threshold

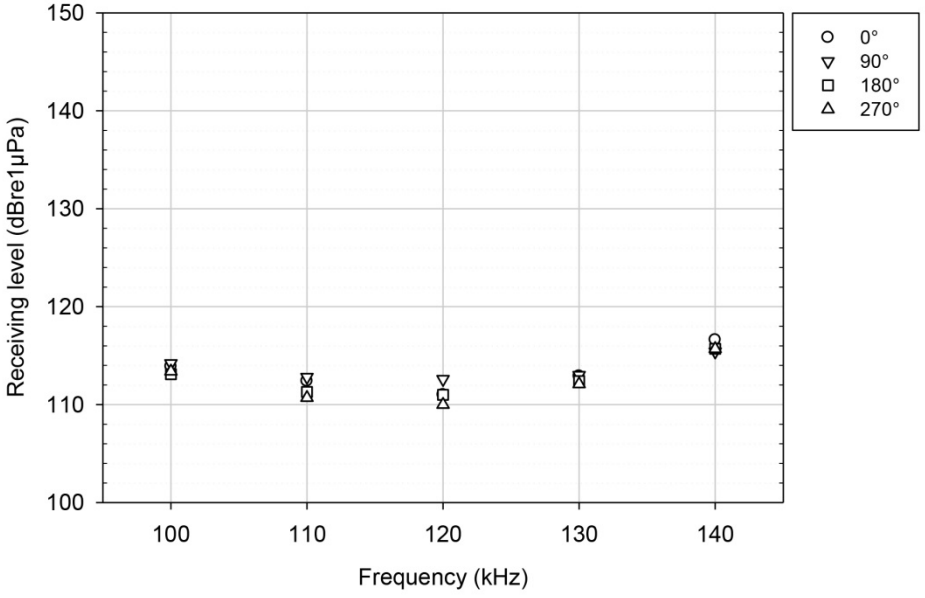



POD ID / CAL ID: 1875/478
Date of calibration: 28.01.2014
Calibrated by: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

50% detection threshold

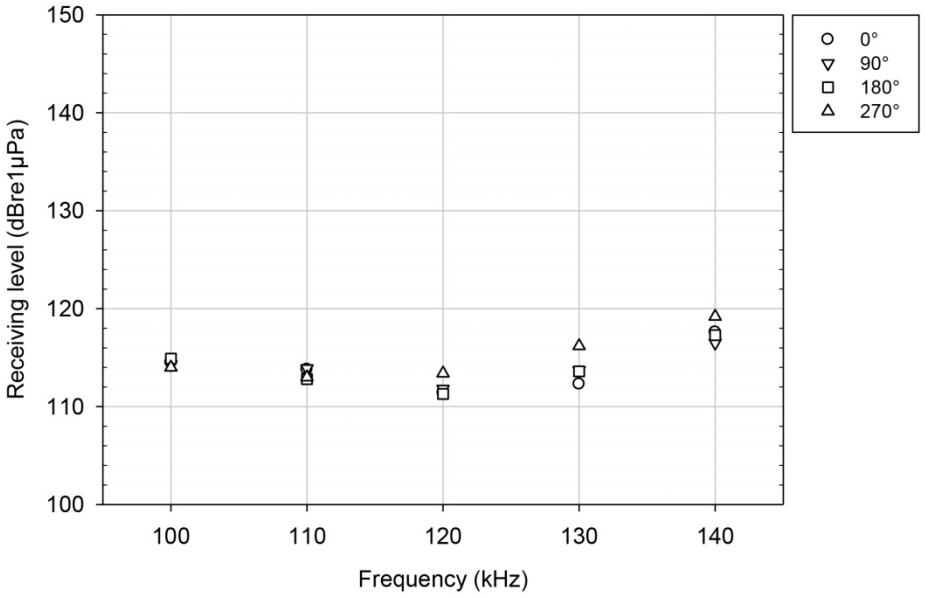


POD ID / CAL ID: 1876 / 481
Date of calibration: 03.02.2014
Calibrated by: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

50% detection threshold

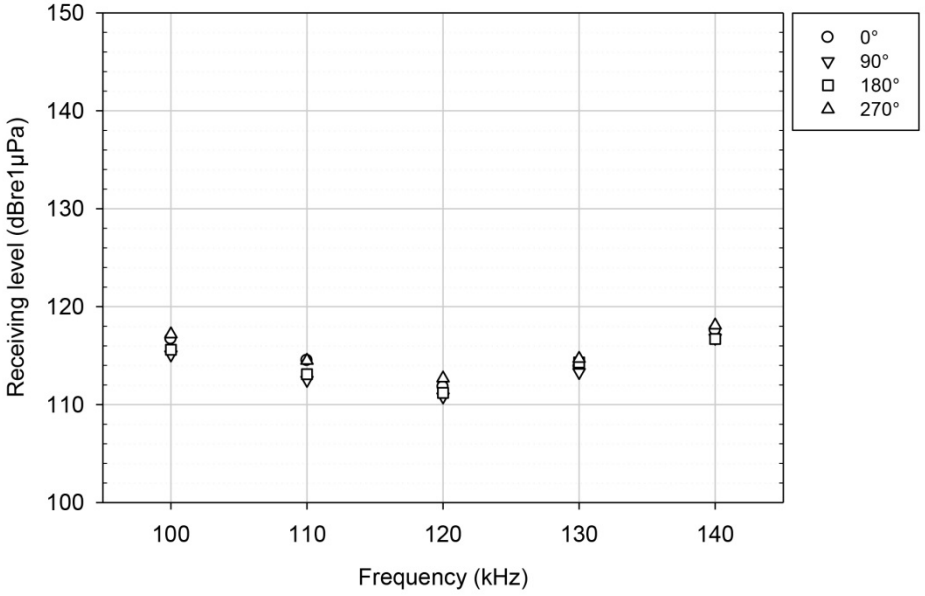



POD ID / CAL ID: 1877 / 480
Date of calibration: 30.01.2014
Calibrated by: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

50% detection threshold

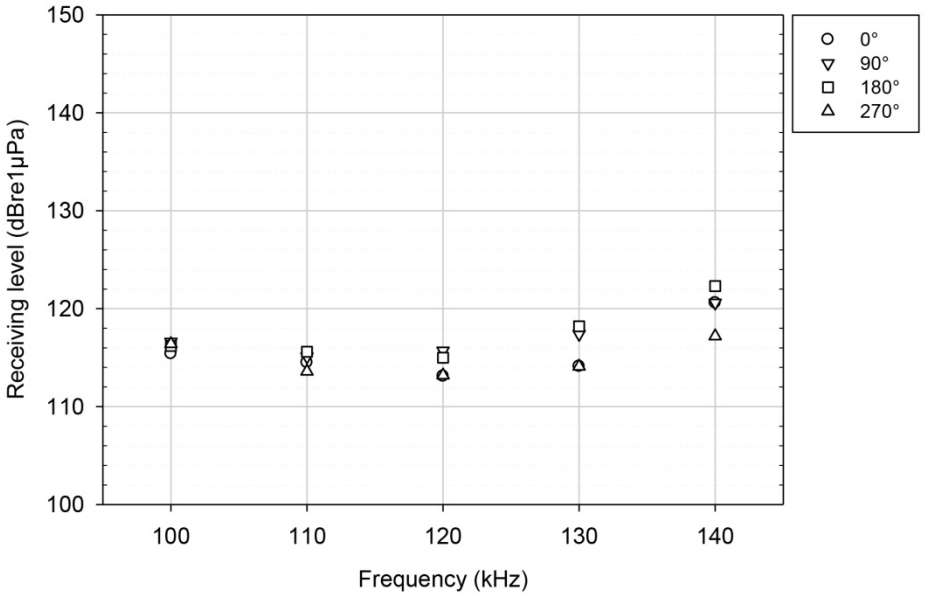


POD ID / CAL ID: 1878 / 481
Date of calibration: 03.02.2014
Calibrated by: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

50% detection threshold

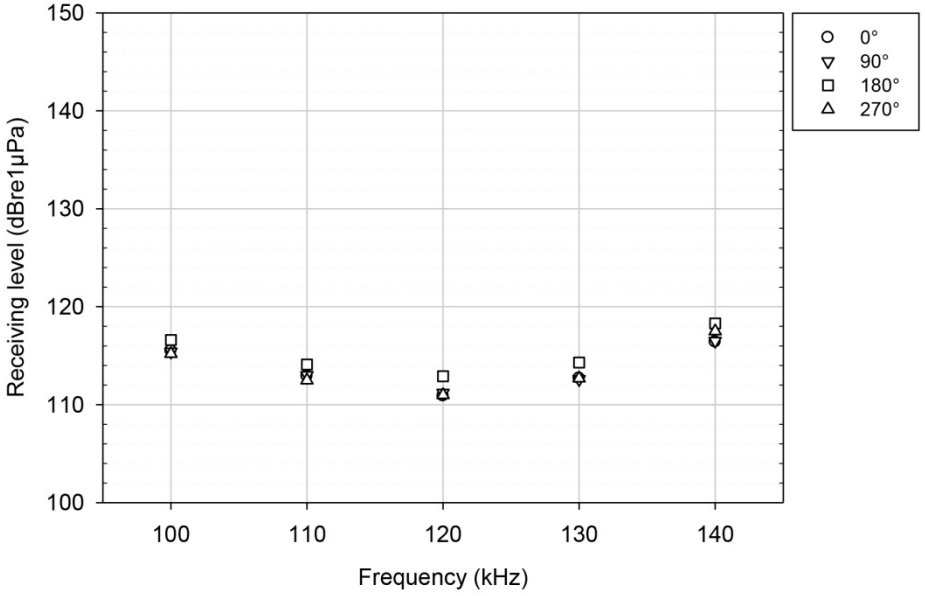


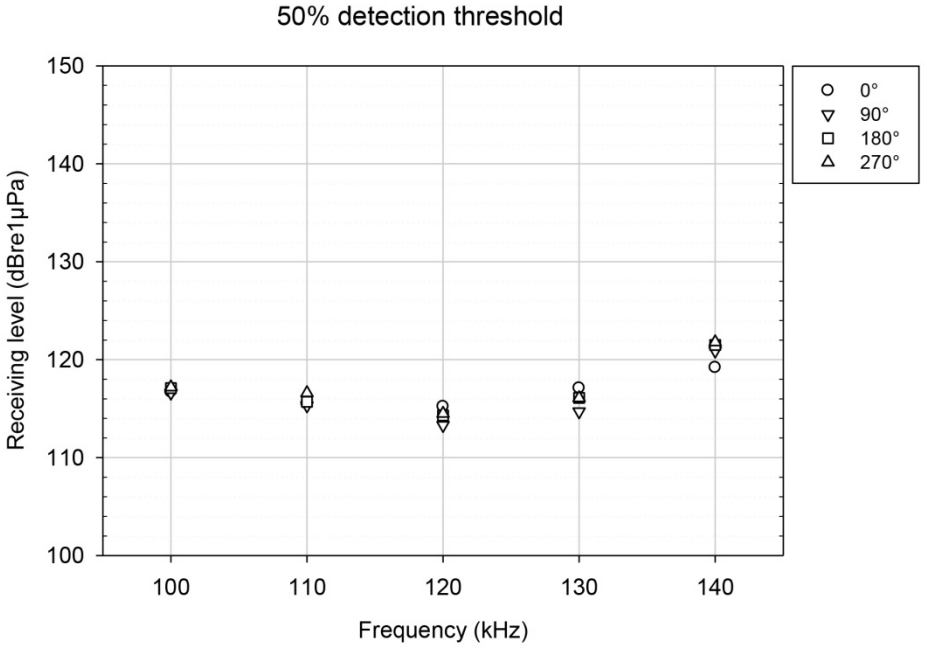

POD ID / CAL ID: 1883 / 480
Date of calibration: 30.01.2014
Calibrated by: Anne Herrmann

IMARES

Deutsches Meeresmuseum Stralsund

50% detection threshold



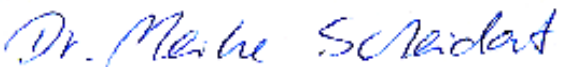

50% detection threshold
Receiving level (dBre1µPa)
150
140
130
120
110
100
100
110
120
130
140
Frequency (kHz)
0°
90°
180°
270°

## Justification

Report C144/15
Project Number: 4302503103-3 GEMINI T0-porpoises

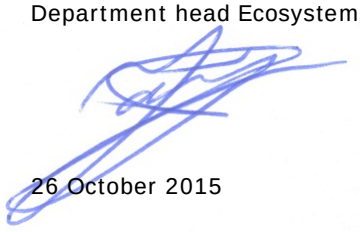
The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Dr. M. Scheidat
Senior Researcher

Signature: 

Date: 26 October 2015

Approved: Drs. J. Asjes
Department head Ecosystems

Signature: 

Date: 26 October 2015