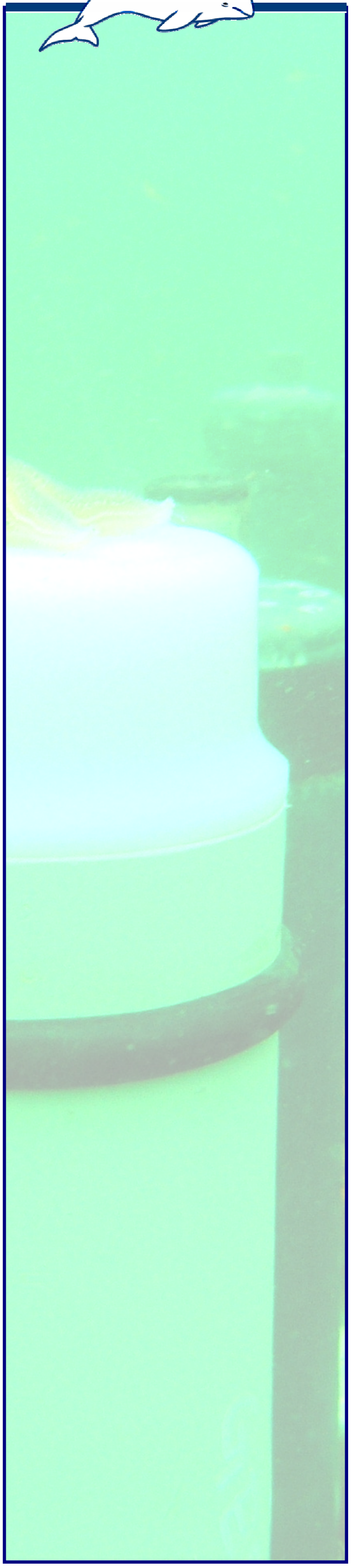

# AMPOD

## 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

[*]Ursula Verfuß, [*]Sven Adler, [*]Anja Brandecker, [*]Michael Dähne, [~$]Ansgar Diederichs, [*]Anja Gallus, [*]Anne Herrmann, [*]Kathrin Krügel, [+]Klaus Lucke, [#]Jonas Teilmann, [#]Jakob Tougaard, [°]Nick Tregenza, [+]Ursula Siebert, [*]Harald Benke

**[*]German Oceanographic Museum**
**[#]National Environmental Research Institute**
**[+]Research and Technology Centre Westcoast**
**[~]BIOCONSULT SH**
**[$]Universität Hamburg**
**[°]University of Exeter**

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# TABLE OF CONTENT

# 1. Summary

In the expansion of regenerative energy, the offshore-wind farms take up a special relevance. Locations at sea benefit from a unique availability of wind energy, making them attractive for the installation of wind farms. However, construction and operation of a wind farm has an influence on the marine environment. Therefore applicants for wind farm projects in German waters are committed by the German Federal Maritime and Hydrographic Agency (BSH) to conduct an environmental impact study by regulations outlined in the "Standards for the Environmental Impact Assessment" (so called StUK3). Amongst others, the StUK is describing how to investigate the habitat use of harbour porpoises with the help of acoustic data loggers, the porpoise detectors (PODs). These devices register echolocation click sounds of porpoises, which are used for orientation and foraging as well as for communication.

The AMPOD-project "Application and analysis methods for the deployment of T-PODs in environmental impact studies for wind farms: Comparability and development of standard methods" aimed for developing standard methods and guidelines for the application of PODs in static acoustic monitoring (SAM) programs in environmental impact studies (EIS) for wind farms. The influences of technical as well as environmental parameters on the data gained were investigated with calibration and field trials. Furthermore, different analysis methods were compared. This knowledge helps for a better interpretability and comparability of results obtained in SAM studies. Cooperation with Danish, British and German institutes involved in SAM studies, mainly with regards to offshore wind farm EIS, gave a great opportunity to establish standard methods for conducting static acoustic monitoring.

In the final project phase, the results of the AMPOD-project and of recent POD-applications in SAM projects were presented at a symposium. Furthermore recommendations were developed, giving guidelines on how to conduct SAM with PODs and proposing a standard procedure for POD application and data analysis.

The results of the AMPOD-project show the importance of calibrating PODs. Adjusting the devices to a standard sensitivity helps to gather comparable data. A model is introduced that is applicable to align data recorded with PODs of different sensitivity deployed in shallow waters. In water depths of 20 m and more we found that T-PODs deployed at different depths retrieved significantly different data, caused by either the harbour porpoises' preference of sojourning at certain water depths or of thermoclines interfering with the detection abilities of the T-PODs. It is therefore important and recommended to keep the deployment depth of monitoring devices in a study constant. Above a certain level of background noise received by the monitoring devices, data will be affected by either the noise masking true detections or by a rise of the false detection rate. Analysis of data should therefore always consider the recorded background noise, and either exclude or adjust data retrieved at noise levels that affect data comparability.

# 2. State-of-the-art of science and technology

The possibility of long term continuous monitoring with little man power does make SAM a powerful and useful tool for environmental impact studies like those requested in the course of building offshore wind farms. Offshore wind farms take up a special relevance within the expansion of regenerative energy. Locations at sea deliver a unique availability of wind energy, making them an attractive platform for the installation of wind energy farms. However, it should be noted that construction and operation of a wind farm has an influence on the marine environment. This is why applicants for wind farm constructions in German waters are asked by the German Federal Maritime and Hydrographic Agency (BSH) to conduct an environmental impact assessment study by regulations outlined in the “Standards for the Environmental Impact Assessment” (so called StUK3). Amongst others, StUK3 describes how the habitat use of harbour porpoises should be investigated on the basis of T-POD recordings.

Denmark is one of the leading countries in building offshore wind farms and in conducting the corresponding environmental impact studies. The National Environmental Research Institute (NERI, Aarhus University) in Denmark successfully used porpoise detectors to investigate the effect of construction and operation of wind farms on harbour porpoises. Long term deployment of T-PODs in the Nysted Offshore wind farm, situated about 10 km southwest of Gedser, DK in the Fehmarnbelt, and 4 km south of the sandbarrier Rødsand, showed a decrease in harbour porpoise abundance during construction compared to the baseline study, with no recovery during the first year of operation (Tougaard et al. 2005). During the second year of operation, the indicators used to determine harbour porpoise abundance were still significantly affected. Nevertheless, a tendency towards a return to levels as recorded before construction was visible (Tougaard et al. 2006).

The harbour porpoise (*Phocoena phocoena*) is the only resident cetacean species in the North and Baltic Sea. In former times, this species was highly abundant and widely distributed across the Baltic Sea. Within the last fifty years, the harbour porpoise population decreased drastically (Benke & Siebert 1994, Kinze 1995, Kröger 1986, Rejnders 1992, Siebert et al. 1996). National and international agreements such as ASCOBANS, HELCOM, OSPARCOM and the Red List of endangered species Germany (Boye et al. 1998) set the harbour porpoise under protection.

Over the last years, the research effort on harbour porpoises in the German North and Baltic Sea increased remarkably. This is mainly due to enterprises to build offshore wind farms and plans of creating Nature Protection Reserves as advised by Natura 2000.

In 2001 the German Oceanographic Museum started a 2-years project, financed by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), for testing and applying a newly developed method to monitor harbour porpoises using an autonomous passive acoustic monitoring device, the T-POD (Timing POrpoise Detector) (Verfuß et al. 2004a). Five further closely cooperating projects of the German Oceanographic Museum, financed by the BMU and the German Agency for Nature Conservation (BfN), proved that static acoustic monitoring (SAM) with T-PODs is a very powerful tool for investigating the habitat use of harbour porpoises. Long term SAM has been conducted for more than seven years, year round, from summer 2002 on. At times up to 42 measuring positions were placed throughout the German Baltic Sea. The results revealed geographic differences in the percentage of monitoring days with porpoise registrations, decreasing from west to east, and a seasonal variation with fewer days with porpoise registrations in winter than in summer (Verfuß et al. 2006, 2007, 2008). The study proved a year around presence of harbour porpoises in the entire German Baltic Sea but with seasonal migration in and out of the German Baltic Sea. Long term SAM turned out to be a very efficient method to reveal temporal changes as well as geographical differences in the relative abundance of harbour porpoises in the areas of interest. Passive acoustic monitoring proved to be especially valuable in areas with low harbour porpoise density, where visual monitoring using the line transect method have wide confidence intervals (Gillespie et al. 2005, Scheidat et al. 2008, Verfuß et al. 2007, summarized in Verfuß et al. 2009a).

Besides monitoring the relative abundance of harbour porpoises, the above mentioned projects showed that SAM with T-PODs additionally enables the observation of the harbour porpoises' behaviour within an area of interest. Synchronized video- and high frequency sound recordings of harbour porpoises conducting different behavioural tasks in a semi-natural outdoor pool showed a close correlation between the porpoises' echolocation pattern and their behaviour (Verfuß and Schnitzler, 2002). The study revealed the use of echolocation for orientation, and the use of landmarks for navigation (Verfuß et al. 2005), recognizable within the echolocation sound pattern. Furthermore the echolocation behaviour of harbour porpoises indicates foraging behaviour (Verfuß et al. 2009b). T-PODs register the echolocation sound pattern of harbour porpoises. The analysis of data gained in the above mentioned projects of the German Oceanographic Museum showed that the behaviour of harbour porpoises in the field can be categorized into different orientation patterns as well as into foraging (Meding et al. 2005, Meding 2005). This knowledge can be used to evaluate the harbour porpoises' behaviour within the area of interest.

The conference of the European Cetacean Society (ECS) in Gdynia, Poland in April 2006 showed the increasing use of T-PODs for investigating dolphins and porpoises in monitoring studies. More than 10% of the investigations presented in oral talks used T-PODs for monitoring (http://www.ecs2006gdynia.univ.gda.pl/abstract.html). Recent publications show the successful use of T-PODs in a variety of different research approaches (e.g. Bailey et al. 2010, Carlström et al. 2009, Simon et al. 2010, Todd et al. 2009).

A workshop "Static acoustic monitoring of odontocetes: current issues and developments" (http://www.ecs2006gdynia.univ.gda.pl/workshops5.html), associated to the ECS conference showed the widely spread use and usefulness of T-PODs, but also the need for standard methods to compare results from different studies.

NERI as well as the German Oceanographic Museum independently developed a calibration method for T-PODs to determine the receiving characteristics of each individual device. The calibration helps to estimate the recording properties of a T-POD for being able to compare data received with different devices. An intracalibration at sea, a deployment of an array of several T-PODs at the same spot of a porpoise rich area, reveals a correlation of the recording properties from different devices. Intracalibrations have been conducted by BIOCONSULT (Diederichs et al. 2002), NERI (Kyhn et al. 2008) and the German Oceanographic Museum (Verfuß et al. 2004a, b), each with their own T-PODs and own application settings, to investigate the comparability of data each research group gained with their individual T-POD. Kyhn et al. (2008) as well as Verfuß et al. (2004) also correlated the receiving characteristics of the devices with the corresponding recording properties.

Although SAM with T-PODs has been successfully conducted by different research groups, the problem of comparability of data remains:

The T-POD is a hydro-acoustic autonomous data logger, with the option for the user to choose different application settings. It is always under further development like most electronic devices for research. Therefore up to now five product versions exist with modifications applied. The corresponding software has also been under further development. In the current project the influence of using different versions and different settings on the gathered data was investigated. Next to these technical influences, oceanographic parameters, conditions of the measuring site, the application method as well as weather conditions can influence the data acquisition. Furthermore different analysis parameters can be used to analyse the data, also influencing the comparability of data. Therefore, further investigations were necessary to develop a better knowledge of technical, environmental, methodical and analytical influences on data gained in different wind farm locations in Germany and Denmark, different studies or in the same study with different T-POD versions or devices with different receiving characteristics to give overall comparability of the results.

Aim of the project presented here is to facilitate the utilisation of T-PODs and to enhance/reach the comparability of results from different areas and different investigators. Cooperation with NERI and other institutes deploying T-PODs gave the project a great opportunity for developing a standard method and guidelines accepted by the research community. Furthermore, the calibration methods developed at the German Oceanographic Museum and NERI was tested and compared.

A brochure was developed giving guidelines on how to conduct SAM with T-PODs proposing a standard procedure for T-POD application and data analysis. Furthermore a symposium was held at the German Oceanographic Museum presenting results of this and other projects dealing with SAM.

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# 3. Project aims

Aim of the project was to develop standard methods and guidelines for the application of T-PODs in static acoustic monitoring programs in environmental impact studies for wind farms. Research was undertaken to reveal the influence of technical, methodical as well as environmental parameters on data gained with static acoustic monitoring (SAM). Furthermore, different analysis methods were compared. This knowledge helps for a better interpretability and comparability of results presented in SAM studies.

Following topics were conducted:

### Calibration

NERI as well as the German Oceanographic Museum developed a method of calibrating T-PODs. This calibration gives insights into the receiving characteristics of the devices, like the sensitivity and the receiving beam pattern. The methods differ in the calibration signal used for measuring the T-PODs' receiving characteristics and the analysis method. The comparability of the results was discussed bilaterally and tested. Therefore T-PODs of both institutions came under scrutiny of both methods. In addition to the comparison of both methods, the influence of different T-POD settings, as used in different investigations, on the sensitivity was tested in the calibration tank. This gives also insights into the comparability of data.

### Intracalibration

Intracalibration is the synchronized application of several T-PODs in a small distance from each other. This allows the comparison of data from devices that potentially recorded the same data. This way, data from different T-POD versions and settings can be compared to each other. Intracalibrations was conducted in selected areas in Denmark and Germany. Next to deploying several T-PODs in an array at the same depth, devices were deployed simultaneously at different depths to reveal the influence of different methodical applications on the data received.

### Broadband sound recordings

Broadband sound recordings with a hydrophone connected to hydrophone amplifiers and a portable PC containing a 5 MHz data acquisition card was conducted synchronously to POD-recordings. These kinds of recordings give information on background noise and other potential disturbing sources that can influence the data acquisition. The recordings give furthermore an acoustic characterisation of different investigation sites and its possible influences on the data acquisition.

### Analysis of data

Field data of more than three years from up to 42 measuring positions, acquired within the different projects of the German Oceanographic Museum as well as from measuring positions obtained by our co-operation partners were analysed with different parameters. Parameters used by the NERI research teams in their environmental impact study and proposed by the StUK and the T-POD programme, respectively, served as analysis basis. The influence of the measuring site, depth as well as the technical properties of the devices on the data and their comparability was considered.

### Adjustment of analysis methods

The insights gained from the investigations mentioned above were presented to the cooperating Danish and German institutions in order to agree on standard methods and recommendations that are accepted by all sites.

### Publication of results

Results of this project were introduced to and discussed with the scientific community at international conferences. They were presented and discussed at workshops associated with the conferences. A brochure was developed giving guidelines on how to conduct SAM with T-PODs proposing a standard procedure for T-POD application and data analysis. Furthermore a symposium was held at the German Oceanographic Museum presenting the results of this and cooperating projects as well as applications of T-PODs in SAM projects of other countries.

# 4. Co-operations

This project was conducted in cooperation with

**National Environmental Research Institute (NERI)**

Aarhus University
Frederiksborgvej 399, 4000 Roskilde, Denmark

**Research and Technology Centre Westcoast**

University of Kiel
Hafentörn 1, 25761 Büsum, Germany

**BIOCONSULT SH**

Brinckmannstr. 31, 25813 Husum, Germany

**Universität Hamburg**
Abteilung Tierökologie und Naturschutz
Martin-Luther-King Platz 3, 20146 Hamburg, Germany

**University of Exeter**

Cornwall Campus
Centre for Ecology and Conservation
Tremough, Penryn TR10 9EZ, United Kingdom

# 5. Detailed description

## *5.1. Calibration of T-PODs*

### 5.1.1. Introduction

Timing porpoise detectors (T-PODs) are autonomous data logger registering the length and time of occurrence of specific acoustic ultrasound events. PODs proved to be a valuable tool not only for the investigation of the echolocation behaviour around fishing nets (e.g. Tregenza, 1998, Carlström et al., 2009), but also for monitoring the presence of harbour porpoises in areas of interest (e.g. Bailey et al. 2010, Simon et al. 2010). They were used in long term studies of harbour porpoise presence in the German Baltic Sea (Verfuß et al. 2007, 2008), in environmental impact studies accompanying wind farm constructions (Carstensen et al. 2006, Diederichs et al. 2007) and around offshore gas installation sites (Todd et al. 2009). Since market introduction, the T-POD was continuously further developed leading to the existence of five product versions with more or less pronounced differences in the acoustic properties of the recording system. All five T-POD versions were used in field studies. Furthermore, the settings, which determine the acoustic characteristics of the sound events that shall be logged, can be chosen user defined, and is therefore partly chosen differently in different studies.

Against this background, it is highly disputable if data recordings retrieved with different T-POD versions and/or different settings can be aggregated and interpreted together. The present study sheds light on this aspect. Under controlled conditions, T-PODs of different versions were calibrated in a test tank with standard procedures developed by the German Oceanographic Museum. Based on the study results, guidelines for the deployment of T-PODs could be developed.

### 5.1.2. Methods

T-PODs were calibrated at the German Oceanographic Museum using a 1.0 m x 0.7 m fibre glass pool with a water depth of 0.68 m. A sound transmitter (TC4013, Reson A/S, DK) and a receiver (reference hydrophone TC4014, Reson A/S, DK or a T-POD, respectively) were placed in medial water depth at a distance of 0.5 m to each other and centred up relative to the pool sides (Figure 1). The distance between transmitter, receiver and tank boundaries was chosen for avoiding interference of the calibration signal with the echoes arising from surface and tank wall reflections. A series of harbour porpoise echolocation clicks (Figure 2) was used to

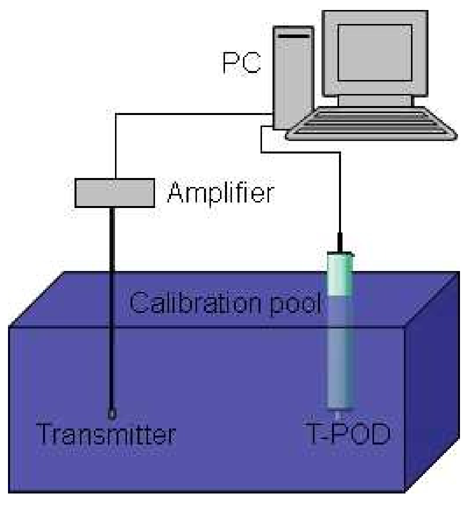


**Figure 1 Calibration set-up as used by the German Oceanographic Museum.**

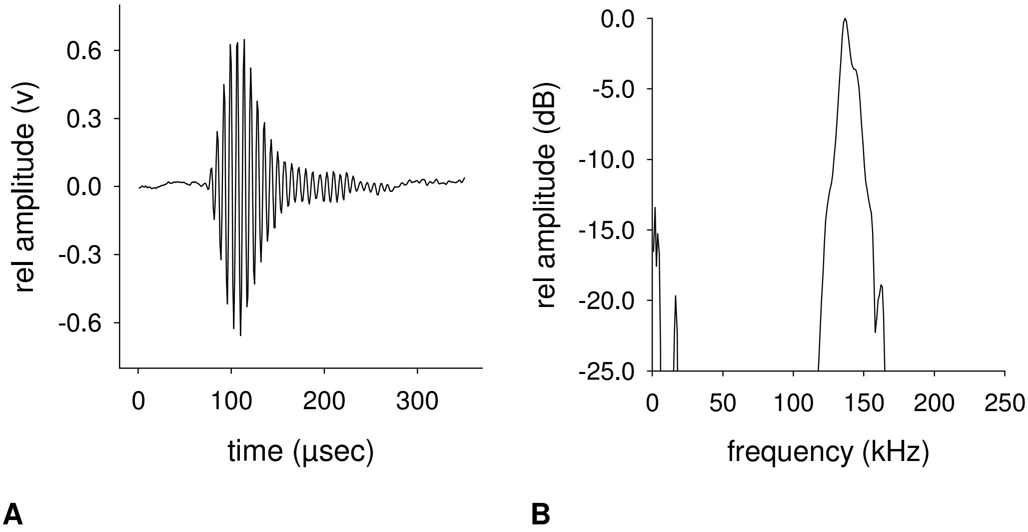


**Figure 2 Amplitude-time signal (A) and power spectrum (B) of the harbour porpoise echolocation click used for calibration.**

determine the minimum receiving level of the T-POD. The series consists of a total of 26 sequences out of ten clicks each (Figure 3). The amplitude of the ten-clicks-sequences was at first reduced by 3 dB (second and third sequence) and then by 2 dB (fourth to 26th sequence), resulting in an overall reduction in the sound pressure level of 52 dB. After the 10$^{th}$, 15$^{th}$, 20$^{th}$ and 25$^{th}$ sequence a click with high amplitude serves as marker for a better counting of the recorded packages during analysis. The harbour porpoise echolocation click had a peak frequency (frequency with most energy, i.e. 0 dB in Figure 2B) of 136.7 kHz. Its bandwidth is given in Table 1.

The sound sequence is transmitted through a sound card (National Instruments: PCI-6110E) via a power amplifier (T&A: A1220) and the transmitter into the pool. At the beginning of each calibration day, the sequence is picked up by the control hydrophone, connected to a filter/amplifier unit (ETEC: A1101) and digitized with the sound card. The control recordings serve for the determination of the sound pressure level picked up by the receiver (hydrophone and T-POD, respectively). The transmitted and received sound sequence is monitored by a digital oscilloscope (Tektronix: TDS-210). After this measurement, the control hydrophone is replaced by the T-POD for calibration.

Calibration was performed with version-specific standard settings (Table 2). For the determination of the receiving beam pattern, the T-POD is rotated by 45° around its vertical axis after each transmission until a rotation of 360° is completed. This adds up to eight positions treated.

**Table 1 Bandwidth (-3 dB, -6 dB, -10 dB, -20 dB) as well as lower and upper frequency limit of the harbour porpoise echolocation click shown in Figure 2.**

| | bandwidth (kHz) | frequency limit (kHz) lower | upper |
|---|---|---|---|
| -3 dB | 7.3 | 133.8 | 141.1 |
| -6 dB | 15.6 | 131.8 | 147.5 |
| -10 dB | 21.5 | 128.9 | 150.4 |
| -20 dB | 37.6 | 120.1 | 157.7 |

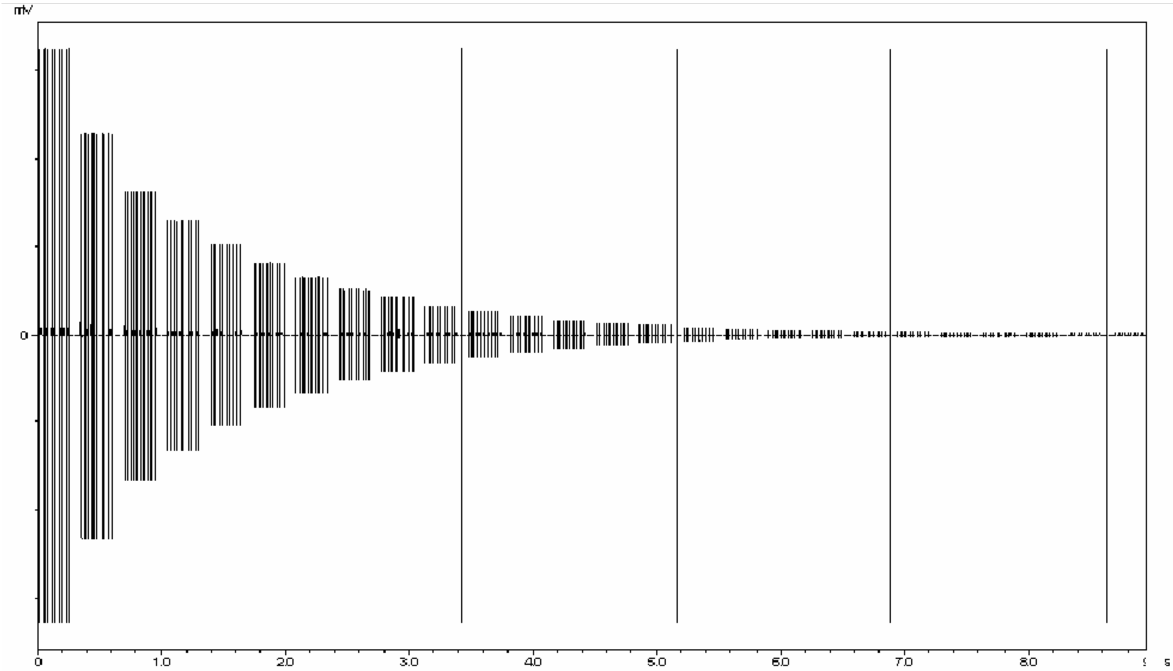


**Figure 3 Amplitude-time signal of the echolocation click series used for calibrating T-PODs. This series consists of sequences of ten clicks as shown in Figure 2 with decreasing amplitude (see text for details). High amplitude clicks separate the 10th, 15th, 20th and 25th sequence.**

For the determination of the sound pressure level threshold, at which a T-POD stops logging clicks, the packages recorded by the T-POD are counted. The receiving threshold is calculated as follows:

$RS_{POD} = RL_{max} – 2 \times P$, with

$RS_{POD}$ = receiving sensitivity of the T-POD

$RL_{max}$ = sound pressure level of the clicks of the first package from the calibration sequence received by the control hydrophone (maximum receiving level)

P = number of packages recorded by the T-POD. The last package of which not all ten clicks are recorded counts as decimal number giving the number of recorded clicks (e.g. 6.7 = 6 packages + seven clicks of the sevenths package).

With this standard procedure, the minimum receiving level threshold (receiving sensitivity)

**Table 2 Standard settings for version V1 to V5 T-PODs for the calibration conducted at the German Oceanographic Museum.**

| Setting | V1 | V2 | V3 | Setting | V4 | V5 |
|---|---|---|---|---|---|---|
| A-Filter-Frequency | 130 | 130 | 130 | A-Filter-Frequency | 130 | 130 |
| B-Filter-Frequency | 90 | 90 | 90 | B-Filter-Frequency | 92 | 92 |
| Ratio A/B | 1 | 6 | 6 | Click bandwidth | 5 | 5 |
| A-Filter sharpness | 10 | 10 | Short | Noise adaptation | + | + |
| A-Filter sharpness | 18 | 18 | Long | | | |
| Minimum intensity | 0 | 6 | 6 | Sensitivity | 12 | 12 |
| Limit on clicks logged | none | None | none | Limit on clicks logged | none | None |

and receiving beam pattern was determined for any tested T-POD. The receiving sensitivity can be adjusted with the setting option “minimum intensity” (version 1 to 3) and “sensitivity” (version 4 and 5). For investigating the span of adjustability, the receiving level threshold was determined for different of those setting options.

Furthermore, the influence of the setting options “selectivity (Ratio A/B)” of version 3 T-PODs, “click bandwidth” (version 4) and “noise reduction” (version 4) on the receiving sensitivity was tested on selected of T-PODs.

**Data base**

The receiving beam pattern and mean receiving sensitivity over the eight beam positions was determined for:

- 9 T-PODs of version 2 (V2)
- 49 V3 T-PODs
- 48 V4 T-PODs
- 21 V5 T-PODs.

No V1 T-POD was available for calibration. Therefore, this type could not be tested. 98 T-PODs have been calibrated two to ten times. The mean values of the results of repetitive calibrations were taken for the analysis of the receiving sensitivity and directionality to ensure that each T-POD was included only once. Changes in the receiving sensitivity over time revealed by the repetitive calibrations were also analysed.

The sensitivity curve, which is the change of receiving sensitivity with altered minimum intensity (V2 – V4), or sensitivity (V4, V5) setting, respectively, was determined on that beam position with the receiving sensitivity closest to the mean receiving sensitivity of the T-POD. For each calibration result, the difference between the highest and lowest minimum receiving sensitivity adjustable (span) was determined (incl. repetitive calibration results). For characterising the adjustability of the different T-POD versions, the 10%, 25%, 50%, 75% and 90% percentiles of the span for the different versions were determined.

Next to this, the receiving sensitivity of five V3 T-PODs was determined, each on four positions (90° rotation), with three different sensitivities (1, 6 and 15) and different selectivity values (2, 5, 8, 10, 12 and 14). The same has been done with five V4 T-PODs with different band width values (2, 3, 4, 6, 7, 8). Furthermore the receiving sensitivity was determined of five V4 and two V5 T-PODs, each with three different sensitivity values (1, 6, 15) and noise reduction on and off, respectively.

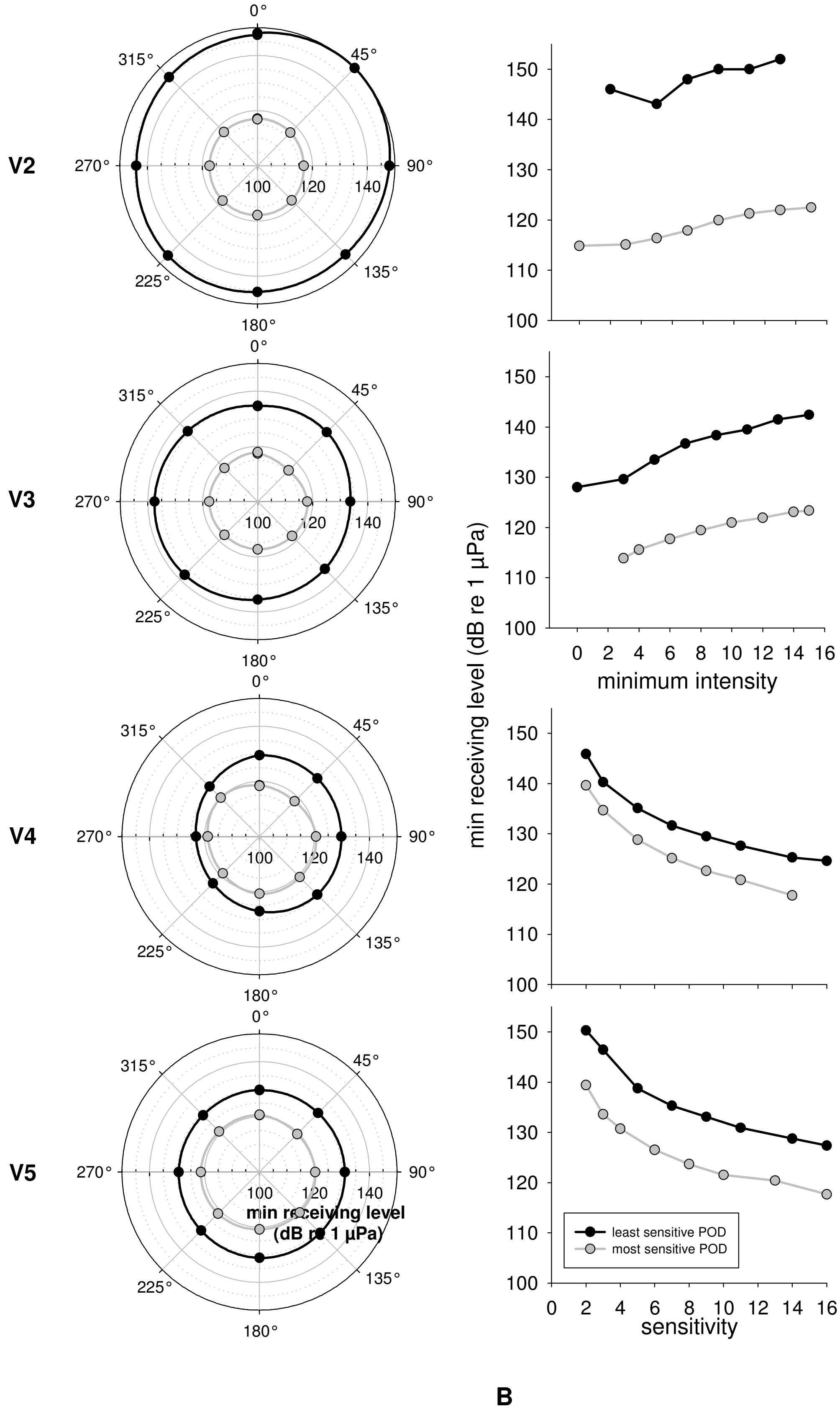


**Figure 4 Horizontal receiving beam pattern (A) and sensitivity curve (B) of the least sensitive (black line) and most sensitive (grey line) T-PODs of version V2 to V5 T-PODs.**

### 5.1.3. Results

With increasing version number the receiving sensitivity of individual T-PODs gets more comparable to each other, i. e. more standardized, with a better adjustability (Figure 4). The mean receiving sensitivity of the calibrated T-PODs is (Figure 5):

- 129.0 (+/- 8.0 standard deviation s.d.) dB re 1 µPa for V2
- 124.4 (+/- 3.7) dB re 1 µPa for V3
- 123.1 (+/- 1.5) dB re 1µPa for V4
- 125.0 (+/- 2.5) dB re 1µPa for V5 T-PODs.

While the difference in receiving sensitivity of the calibrated V2 T-PODs is more than 27 dB, it is 18.3 dB for V3, 6.4 dB for V4 and 8.8 dB for V5 T-PODs. The standard deviation of the mean receiving sensitivity over the eight positions, representing a measure for the roundness of the receiving beam pattern, is (Figure 5):

- 1.4 (+/- 0.8) dB for V2
- 1.2 (+/- 0.7) dB for V3
- 0.8 (+/- 0.6) dB for V4
- 1.0 (+/- 0.6) dB for V5 T-PODs.

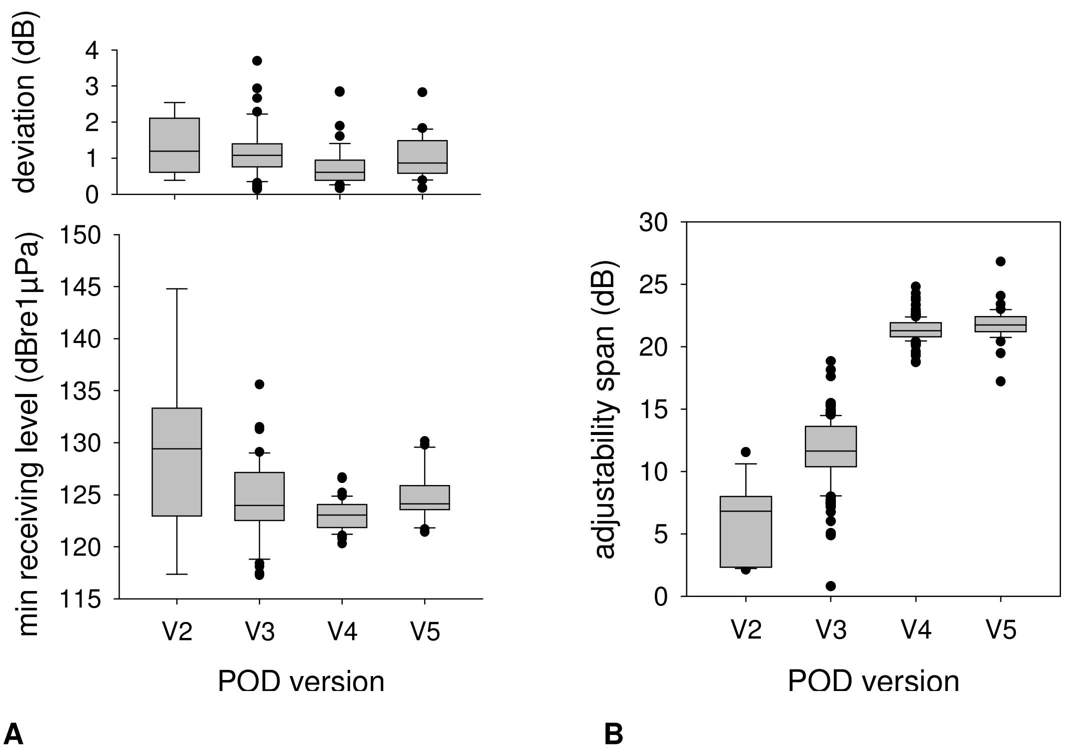


**Figure 5 Mean minimum receiving level of calibrated T-PODs, and its standard deviation over eight horizontal positions for each POD (A) as well as the adjustability span (B) as calibration results of nine V2, 49 V3, 48 V4 and 21 V5 T-PODs. Shown are the median (black line within grey box), the 25% and 75% quantiles (lower and upper grey box boundaries), the 10% and 90% quantiles (lower and upper whiskers) as well as the outliers (black dots).**

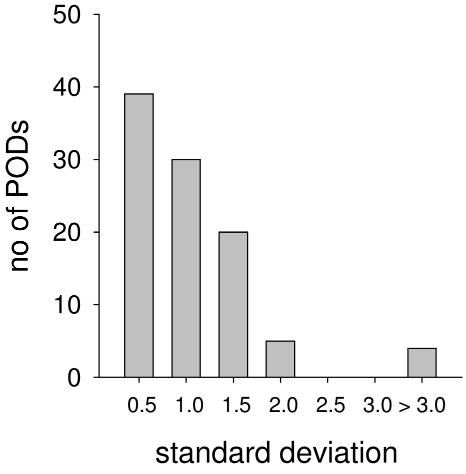


**Figure 6 Number of T-PODs showing a specific standard deviation of the minimum receiving level as obtained by repetitive calibrations over time.**

Adjustability of the sensitivity in V2 T-PODs is small compared to their successors, within a range of (Figure 4, Figure 5):

- 6.0 (+/- 3.2) dB for V2
- 11.7 (+/- 2.6) dB for V3
- 21.4 (+/- 0.9) dB for V4
- 21.8 (+/- 1.3) dB for V5.

Most T-PODs did hardly change their acoustic properties over time, while some showed a considerable change in their minimum receiving level (Figure 6). The standard deviation of the minimum receiving level over repetitive calibrations was less than 0.5 dB for 40% of the T-PODs. Further 31% showed a standard deviation of less than 1 dB, 25% of the standard deviation was between 1 and 2 dB. 4% had a standard deviation greater than 3 dB with a maximum of 6.2 dB.

The setting option “selectivity (ratio A/B)” in V3 T-PODs hardly affected the receiving sensitivity in test tank situations (Figure 7A). In contrast, in V4 T-PODs the chosen “Click bandwidth” option has an influence on the receiving sensitivity: the sensitivity increases with increasing “click bandwidth” number, i.e. the minimum receiving level threshold decreases (Figure 7B). The influence of the “click bandwidth” setting on the intensity is independent from the sensitivity setting (Figure 7B). The maximum sensitivity difference is around seven dB between the lowest and highest setting number.

The option “noise reduction” did not have any effect on the receiving sensitivity of V4/V5 T-PODs. All calibrated T-PODs showed similar results with noise reduction off and on, with a mean difference in sensitivity between both calibrations of 0.3 (+/-0.2) dB.

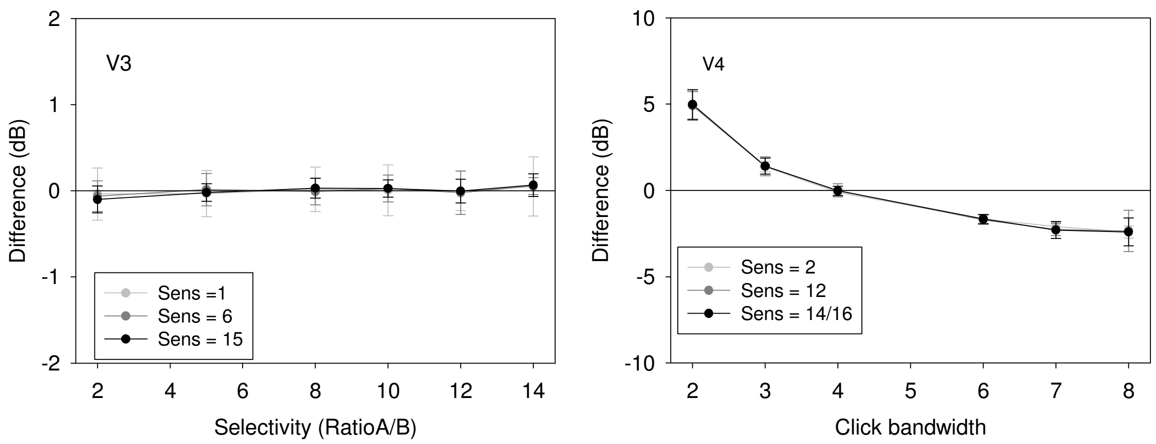


**Figure 7 Influence of the setting option „selectivity“ (A) and „click bandwidth” (B) on the receiving sensitivity of T-PODs.**

### 5.1.4. Discussion

With increasing version number T-PODs are more standardized. The difference in sensitivity between the devices is smaller in versions that are more recent. Furthermore the receiving beam pattern is more (often) radial symmetric in more recent versions. Receiving sensitivity is well adjustable from version 3 on, which is hardly given for version 2. This enables the user to adjust single units of the same or different versions to a defined receiving sensitivity for obtaining comparable data when using several measuring positions, like done by Verfuß et al. 2007, 2008. They have chosen a receiving sensitivity of 127 dB re 1 $\mu Pa_{pp}$ to be used on each measuring position in the German Baltic Sea by adjusting the setting “minimum intensity” or “sensitivity”, respectively, for their V3 to V5 PODs.

Although in most T-PODs the receiving sensitivity staid stable over time, some PODs showed a considerable change in their minimum receiving level, affecting data comparability. This could be due to hard knocks that can affect the sensitivity of acoustic devices. We therefore recommend calibrating devices in use at least once a year. Furthermore, the detectors should be calibrated after reparation and after any lost and found event, as in both cases the acoustic properties may be changed.

The setting option “selectivity” did not have any obvious effect on the receiving sensitivity of the T-PODs in tank calibration. This setting determines the energy ratio needed that is picked up by two filters. The first filter (filter A) is set to the frequency of interest (i.e. 130 kHz for harbour porpoises), and the second filter, the reference (filter B) is set to a frequency that is absent in a (in this case) harbour porpoise echolocation click (90 kHz on default). The energy picked up by the first filter has to be higher to a specific ratio than the energy picked up by the second filter to cause a registration by the T-POD. As in test tank situation no energy around 90 kHz is played back or present from else where, it was to expect that changes in this setting option does not effect the sensitivity of the T-POD in calibration.

The setting option “click bandwidth” did have an effect on the receiving sensitivity of all T-PODs. This was the name given to the selectivity setting of previous versions which was now applied to a revised filter design (see also chapter 7.2), and did show a fall in detection threshold at higher values as seen in Figure 7B.

The noise reduction option did not have any effect on the receiving sensitivity of the T-PODs calibrated. Noise reduction set to “on” shall reduce the background noise recorded by the T-PODs in the field. As in test tank conditions no background noise was present, it is to expect that this option does not have any effect on the receiving sensitivity. Field tests are necessary to gain insights into the comparability of data obtained with and without noise reduction.

One has to be aware that these test tank calibrations happen under controlled conditions with no background noise and one specific echolocation click type. Field-tests with T-PODs of different versions of the same sensitivity and of the same version with different sensitivity, as well as different setting options have been performed to investigate the comparability of data retrieved by those different options and the applicability of the calibration results on field data. Those tests and their results will be presented in chapter 5.4.

## 5.1.5. References

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## 5.2. Comparison of calibration procedures from NERI and GOM

### 5.2.1. Introduction

Calibration of T-PODs has been proven a necessary tool in order to retrieve comparable data from T-PODs (see chapter 5.1 and chapter 5.4). Two research institutions in Europe developed a standard calibration procedure for T-PODs, the National Environmental Research Institute (NERI) in Denmark and the German Oceanographic Museum (GOM) in Germany. The calibration procedure of the GOM is described in chapter 5.1. NERI is using a similar set up with a sound card transmitting a calibration sequence via an attenuator and hydrophone transmitter to a receiving hydrophone that picks up sound via an amplifier and a filter system to measure the sound pressure level of the loudest click series used for calibration. T-PODs are calibrated in a wooden round outdoor pool, larger than the calibration pool of the GOM, and with damping characteristics due to the wooden walls of the tank. A series of synthetic generated high frequency clicks is used for calibration resembling echolocation clicks of harbour porpoises. In the present study, the T-PODs are calibrated with the different calibration methods to compare the results of these calibration procedures.

### 5.2.2. Methods

Five T-PODs, two of version V3 and V5, respectively, and one V4 were calibrated with the standard settings as described in chapter 5.1 at the GOM with the GOM standard procedure (see chapter 5.1), playing back the GOM-calibration series described in chapter 5.1, as well as the NERI-calibration series described below. For testing the influence of the setting option “ratio” (V3) and click bandwidth (V4, V5), those T-PODs were furthermore calibrated with both series and altering ratio or click bandwidth. Three T-PODs, one V5 and two V3, were calibrated at NERI with the NERI-standard procedure using as well the NERI-and GOM-series. One of the V3-T-PODs (POD nr. 347) was calibrated at both places.

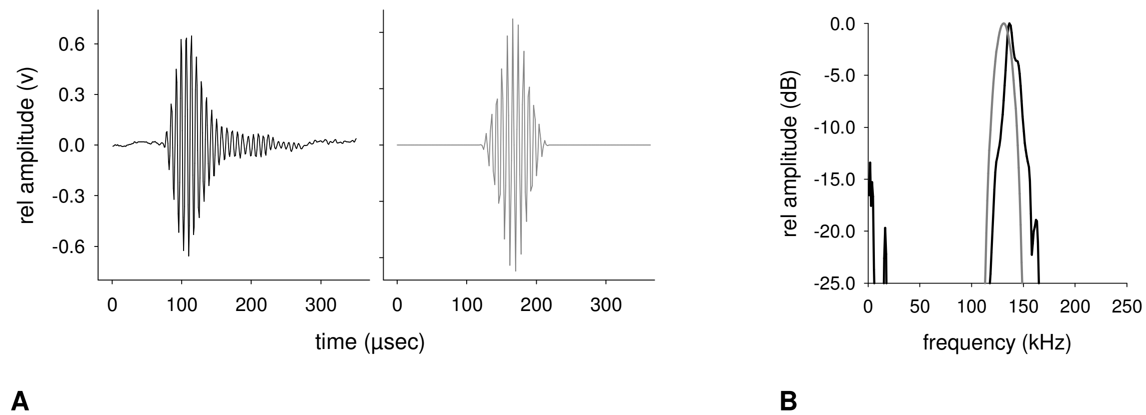


**Figure 8 Comparison of the NERI and GOM calibration signals. A shows the amplitude-time signal of the harbour porpoise click as used for calibration by GOM (left black signal) and the synthetically generated porpoise like click as used for calibration by NERI. The power spectrum of both signals is shown in B (black line: GOM-signal, grey line: NERI signal), giving a peak frequency (@ 0dB) of 136.7 kHz and 130.9 kHz, as well as a -3 dB bandwidth of 7.3 and 14.6 kHz, respectively, for the GOM and NERI-signal.**

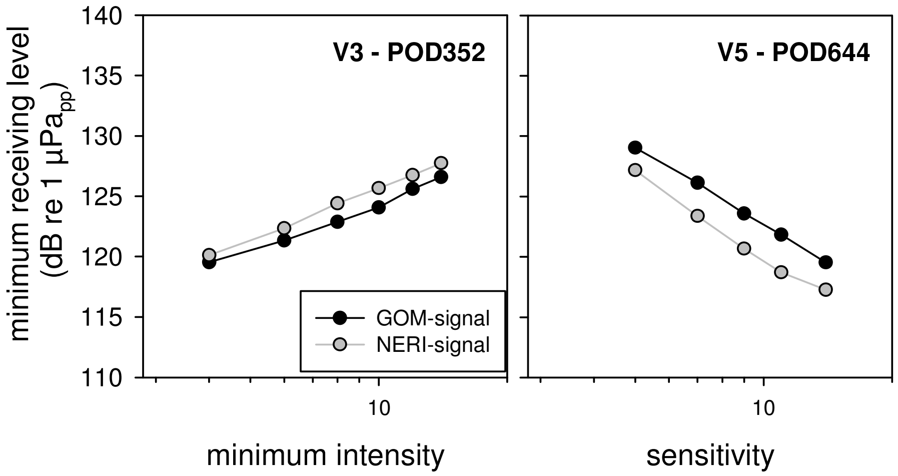


**Figure 9 Sensitivity curve for a V3 and a V5 T-POD calibrated with the GOM-signal (black dots) and the NERI-signal at GOM.**

The NERI-calibration series consists of 30 packages out of 10 synthetic generated high frequency clicks each with the same amplitude. The amplitude of the clicks decrease in 1 dB steps with each package, which results in a span of 30 dB of amplitude change covered by the calibration sequence. The synthetic generated high frequency click consists of a 100 µsec long 130 kHz tone with a cosine amplitude modulation (Figure 8).

## 5.2.3. Results

At both calibration places, the minimum receiving level obtained for different settings of the minimum intensity is for all V3-T-PODs to around 0.5 to 1 dB higher for the NERI-signal then for the GOM signal (Figure 9, Figure 10). For the V4 T-POD as well as the V5 T-PODs, the minimum receiving level is 3 to 4 dB lower for the NERI-signal than for the GOM signal (Figure 9, Figure 10). Nevertheless, the progression of the sensitivity curves obtained with both signals is similar (Figure 9). The curve progression mostly follows a linear decrease of minimum receiving level with decreasing (log) minimum intensity and (log) sensitivity, respectively.

Changes in the setting “ratio” does not influence the minimum receiving level of the V3 T-PODs received with both signal times (Figure 11). The “click bandwidth” setting on the other hand does change the minimum receiving level of the V4 as well as of V5s (see also chapter 5.1). The change of the minimum receiving level with subject to the “click bandwidth” setting is similar when comparing the calibration with the NERI and GOM-signal (Figure 11).

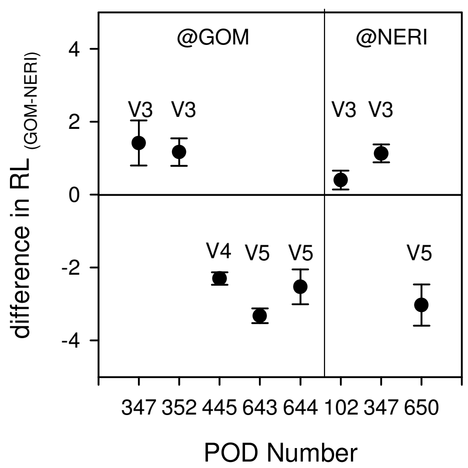


**Figure 10 Mean difference (+/- s.d.) for the minimum receiving level (RL) obtained for each T-POD at different minimum intensity or sensitivity settings as shown in Figure 9. Given is also the version and the place of calibration (GOM or NERI). Please note that T-POD nr. 347 was calibrated at both places.**

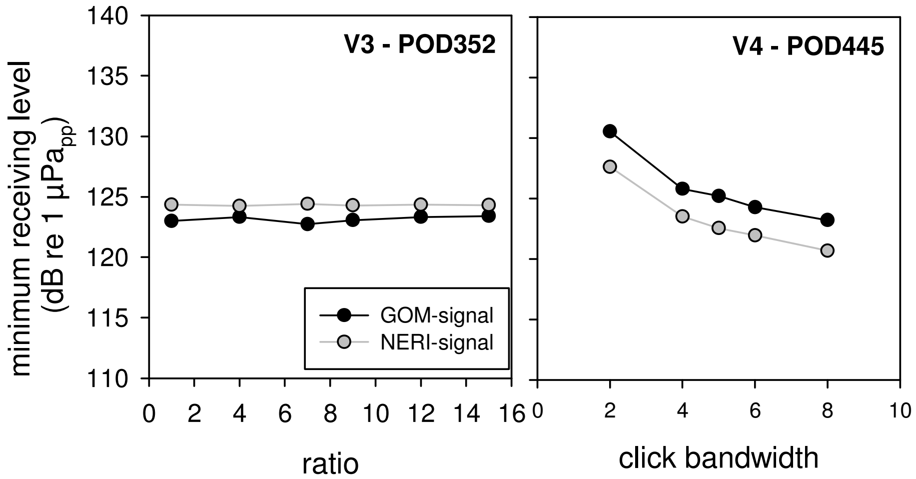


**Figure 11 The influence of the setting "ratio" for a V3 and "click bandwidth" for V5 T-POD on the minimum receiving level, obtained with the GOM-signal (black dots) and the NERI-signal at GOM.**

## 5.2.4. Discussion

The calibration of V3 T-PODs with the different calibration-signal-series of NERI and GOM shows a striking similarity within the calibration accuracy of 1 dB (NERI) to 2 dB (GOM). This let assume that V3 T-PODs are not very sensitive to the difference in length, peak frequency and bandwidth between the NERI and GOM signals. The GOM signal is longer than the NERI signal (~250 µsec versus ~100 µsec). The peak frequency of the GOM signal is with 136.7 kHz slightly higher than the one of the NERI signal with 130 kHz. Furthermore the -3dB bandwidth of the GOM signal is half of that of the NERI signal with 7.3 kHz compared to 14.6 kHz, respectively. This may explain why the sensitivity curve of the V4 and V5 T-PODs is lower when calibrating with the NERI signal. The NERI signals holds more energy around its peak frequency than the GOM signal, which allows the T-POD to detect weaker signals of this synthetic waveform than of the porpoise click used by the GOM. Furthermore, the peak frequency of the NERI signal lies right within the frequency of interest as set in the T-POD settings, as opposed to the GOM signal, of which the peak frequency is slightly higher than the set target frequency.

## 5.3. Calibration of C-PODs

### 5.3.1. Introduction

C-PODs (Cetacean PODs) were developed as a tool to monitor different odontocete species simultaneously registering their echolocation clicks. They were introduced in 2008 as the successor to the widely used T-POD (Timing porpoise detector). Studies using T-PODs were conducted to find differences in the behaviour of harbour porpoises regarding different fishing methods (Carlström et al. 2002, Koschinski et al. 2006), as well as in monitoring studies (Verfuß et al. 2007, 2008) and environmental impact assessments (Carstensen et al. 2006). While all of these studies measured relative porpoise abundance by using the acoustic registrations as a proxy for harbour porpoise presence, only little is known about how this relation can be defined and how it can be used to make results comparable across studies. Tougaard et al. (2006) suggested that this relationship can be defined if a detection function or at least an effective detection range can be estimated, which might be greatly affected by the sensitivity of the used instruments. Kyhn et al. (2008) continued this thought by linking T-POD performance in test tank trials to field experiments. They showed that a relationship exists, and that differences in detection rates can be quite dramatic and result in a large variation of different recorded parameters. For C-PODs, however, no such results exist yet and hopefully standardization will be much tighter, as studies on different T-POD generations already showed a tighter standardization with increasing version number (Dähne et al. 2006, chapter 5.1).

In this study we performed laboratory trials in a small test tank with 86 C-PODs to estimate the variation in sensitivity.

### 5.3.2. Methods

All measurements were carried out at the German Oceanographic Museum in Stralsund in a 0.7 x 1.0 x 0.68 m test tank using calibrated hydrophones (TC 4013 or TC 4014, RESON A/S, DK) as receiver and transmitter (TC 4013, RESON A/S, DK). Setup in the calibration pool is shown in Figure 1 of chapter 5.1.

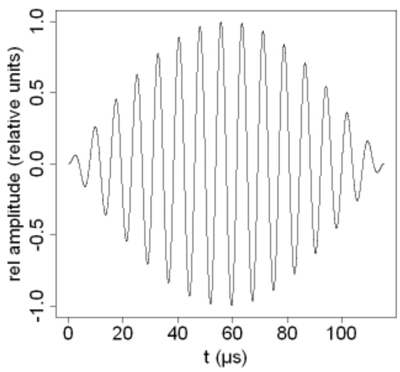


**Figure 12 Amplitude time curve of the 130 kHz calibration signal**

The transmitter was used to send out packets of 10 signals (scaled 15 cycles sine wave signals in cosine envelope, Figure 12) at 10 frequencies (60 to 150 kHz in 10 kHz steps) with a data acquisition card (National Instruments : PCI-6110E) using circuit diagrams designed in Dasylab 7.0 (I.E.D. GmbH, Germany). The amplitude of the signal was adjusted to the transmitting hydrophone's calibration curve so that the maximum outgoing signal was approximately 146 dB re 1 µPa in 1 m = 20 Pa in 1 m at each frequency.

The signal was then picked up by the receiving hydrophone, amplified with a B1501 amplifier (ETEC, DK). Amplification of the amplifier was measured and later used for calculating the receiving level. The amplified signal was recorded with the same National Instruments Sound card via Dasylab and peak-peak measurement were taken using Avisoft 2.2 (Saslab, Germany). The resulting receiving levels were used as baseline measurements and the receiving hydrophone was replaced by a C-POD for sound exposure to the same calibration signals.

Placing of the hydrophones was described in chapter 5.1.

Calibration instruments were marked, so that each device could be removed from the circuit and be reinstalled in exactly the same position. All tests were monitored using a digital oscilloscope (Tektronix: TDS-210).

**C-PODs**

C-PODs are autonomous dataloggers which monitor the frequency band between 20 kHz and 200 kHz. This band includes the echolocation frequencies of most odontocete species except for sperm whales. By analyzing the time-amplitude series they estimate parameters of the waveforms (frequency content, peak amplitude, bandwidth, envelope) and determine whether the recorded sound has tonal components. If the criteria for tonality are met then all parameters are being saved to a non volatile memory. C-PODs can handle up to 16 GB SD (Secure Data)-cards and can run on 10 D-Cells for approximately four month time.

While T-PODs had a variety of settings to adjust their frequency spectrum for different species, C-POD have only minimal user defined settings to make datasets more comparable. There is also no need for species adjustment, as the whole frequency range can be recorded.

C-PODs register the pressure amplitude (P peak-peak, or Ppp) in 8-Bit resolution on a relative scale with values from 0 to 255. While older CPODs were usually set to a minimum registered Ppp value of 5, newer ones are set to 12 to omit electronic interference and weak clicks during field trials. To give a realistic indice of sensitivity all tests were conducted using either a minimum Ppp value of 12 or eliminating values below 12 in a query.

**Receiving beam pattern**

To determine the directionality of the receiving beam pattern, C-PODs were calibrated on 16 positions along their horizontal axis. C-PODs were marked to use the same 16 positions during the next calibration to allow for a direct comparison.

For this measurement 50 signals per frequency were transmitted at each position resulting in 800 signals per C-POD altogether.

The receiving level, which the C-PODs were exposed to, varied around 140 dB re 1 µPa due to a small variation between days. Due to an unexpected variety in sensitivity between measuring devices, the transmitted level had to be reduced by up to 5 dB for some very sensitive devices. This variation was accounted for by calculating a linear regression using a generalized linear model, with receiving level as independent variable and 20log(P peak-peak) values as dependent variable, and with position as a covariate. Data for this model was derived with the calibration procedure as described below.

Graphs and statistical analysis were performed using R 2.11.0 (R Development Core Team, 2010) and the library plotrix (Lemon 2006).

### Relationship between receiving level and Ppp-values

To estimate detection thresholds and the relationship between receiving level and the corresponding Ppp-values, we employed two methodologies, 50 % detection thresholds and linear regression models, both based on the same calibration procedure: Series of 100 signals per packet for the frequencies 60 to 150 kHz were sent out with decreasing amplitude. First two steps were decreased by 3 dB each and then each step further was 2 dB less, with 18 steps. This led to a total range of 36 dB. Signals were send out in 25 ms intervals to allow all echoes to fade before the next click was transmitted. The procedure was carried out at four positions in the horizontal plane. All data recorded were stored in a MS-Access database with custom programmed Visual Basic routines to clean the C-POD-recordings of the direct calibration signals from echoes formed in the tank and to process the large dataset automatically.

### 50 % detection thresholds

To determine the 50 % threshold, all registered clicks within each packet were counted and the two series with the +/- closest values to 50 registered out of 100 transmitted clicks were determined. A linear relation between those two points was assumed and the Ppp value for 50 clicks and the corresponding receiving level was calculated with a linear interpolation. All analysis was automated using Visual-Basic procedures under Microsoft Access.

### Linear model

Generalized linear models were calculated using R 2.11.0 (R development core team, 2010) and the library lme4 (Bates & Maechler 2010). Two models for each C-POD at each frequency were derived – one with position as a random factor and one without. The two models were compared using an ANOVA, and all data sets, for which the two were different from each other ($p_{chi^2} < 1$), were excluded from further analysis, as the four positions for the threshold test might not have been representative for the variations in the horizontal plane. For the remaining C-PODs, the slope and intercept of the regression line were determined, derived from the values gained at all four positions.

Slope and intercept were applied to the data retrieved in the horizontal directivity test to calculate the P peak-peak value for a standard receiving level of 135 db re 1 µPa peak-peak. Furthermore, the corresponding receiving level was calculated for a Ppp value of 12, and compared to the receiving level of the 50% threshold.

## 5.3.3. Results

### Receiving beam pattern

The receiving beam patterns for all C-PODs qualifying for the calculation of a regression line independent of position can be found in Figure 13 and are summarized in Figure 14. Figure 15 shows the frequency dependence of the P (peak-peak) values for a receiving level of 135 dB re 1 µPa for two individual C-PODs from the same series (no. 96 and 98). While the median for 130 kHz is similar, it is obvious, that the variation in the receiving beam pattern leads to different sized boxes and whiskers. C-POD 98 has a much higher variation, than C-POD 96. Horizontal variation within a single C-POD can reach up to 130 digits (CPOD 98 @ 110 kHz) on the 8-Bit P peak-peak scale, corresponding to a difference of 8.5 dB in receiving level, assuming a slope of one and an intercept of -90 .

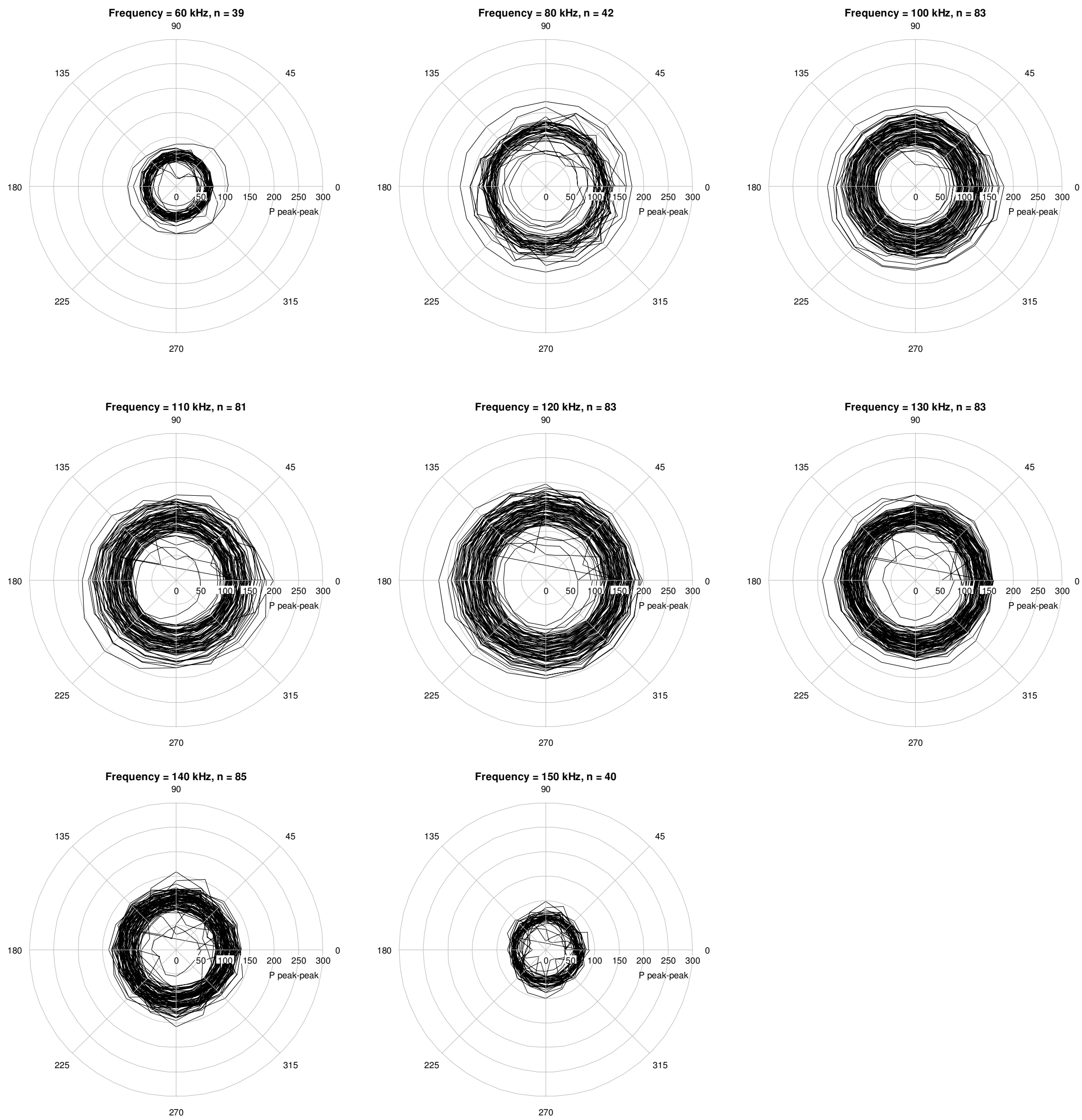


**Figure 13 Horizontal directivity at 60, 80, 100, 110, 120, 130, 140 and 150 kHz, scaled to 135 dB re 1 µPa receiving Level.**

As Figure 14 sums those graphs up, it gives good indices of the comparability of individual devices. The confidence limits at 130 kHz are generally low. The P peak-peak values of the instruments range between 175 to 60, which correspond to a difference of 9.3 dB in receiving level. Instruments are generally more sensitive in the frequency band between 80 and 130 kHz and have sharp drop offs under 80 kHz and over 140 kHz.

**Measurement of 50 % detection thresholds and linear model**

Figure 16 shows the results for two exemplarily chosen C-PODs (96 and 98). C-POD 96 has a nearly homogenous receiving beam pattern, while C-POD 98 has a wider variety in the horizontal plane. While the receiving level at the 50 % threshold of C-POD 96 is similar to the receiving level of the Ppp value of 12, these values differ in C-POD 98, with the receiving level at the 50% threshold being about 4 dB higher than the one at Ppp-value 12. The drop off in recorded clicks per position is slower for C-POD 98 than for 96, probably being caused by an interfering external electro-magnetic field.

Figure 17 gives an overview over the differences between the receiving levels at the 50 % threshold and the Ppp-value of 12 for 130 kHz calibration signals. In most measurements, the receiving level at the 50 % thresholds was lower than at the Ppp-value 12.

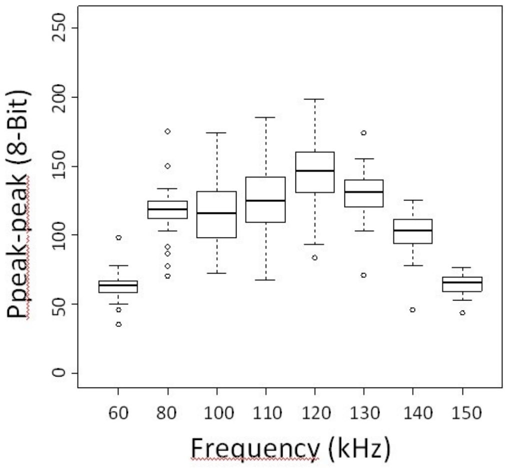


**Figure 14 Boxplot summarizing the values of Figure 11. Shown is the 5%, 25%, 50%, 75% and 95% percentile and outliers of the median P (peak-peak) values as registered by the C-PODs for test signals of different frequency with a receiving level scaled to 135 dB re 1 uPa.**

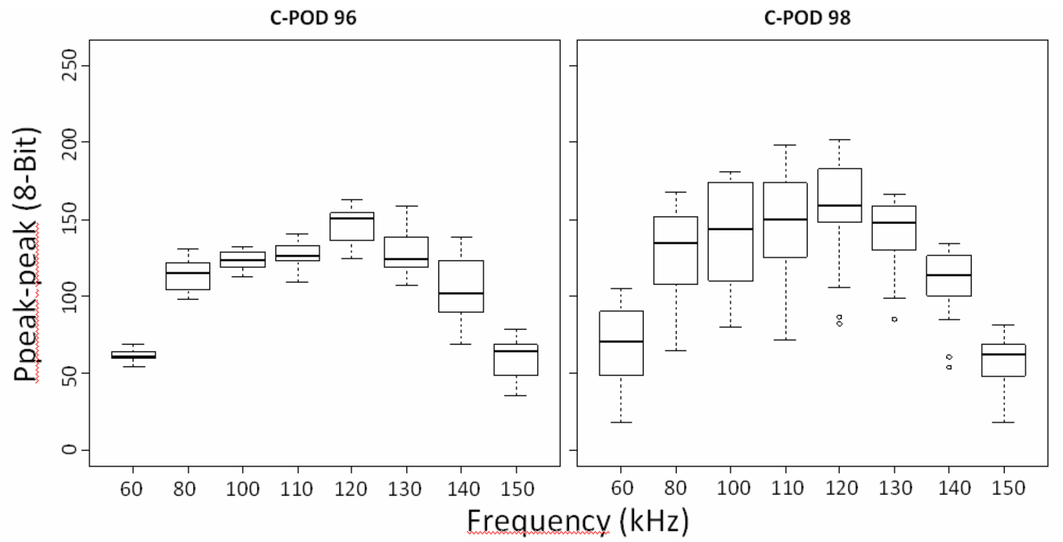


**Figure 15 Boxplot showing the 5%, 25%, 50%, 75% and 95% percentile and outliers of the recorded P (peak-peak) values obtained for individual C-PODs (96 and 98) at four horizontal positions for test signals of different frequencies with a receiving level of 135 dB re 1 µPa. The values are calculated for a receiving level of 135 dB re 1 µPa with the help of a linear regression.**

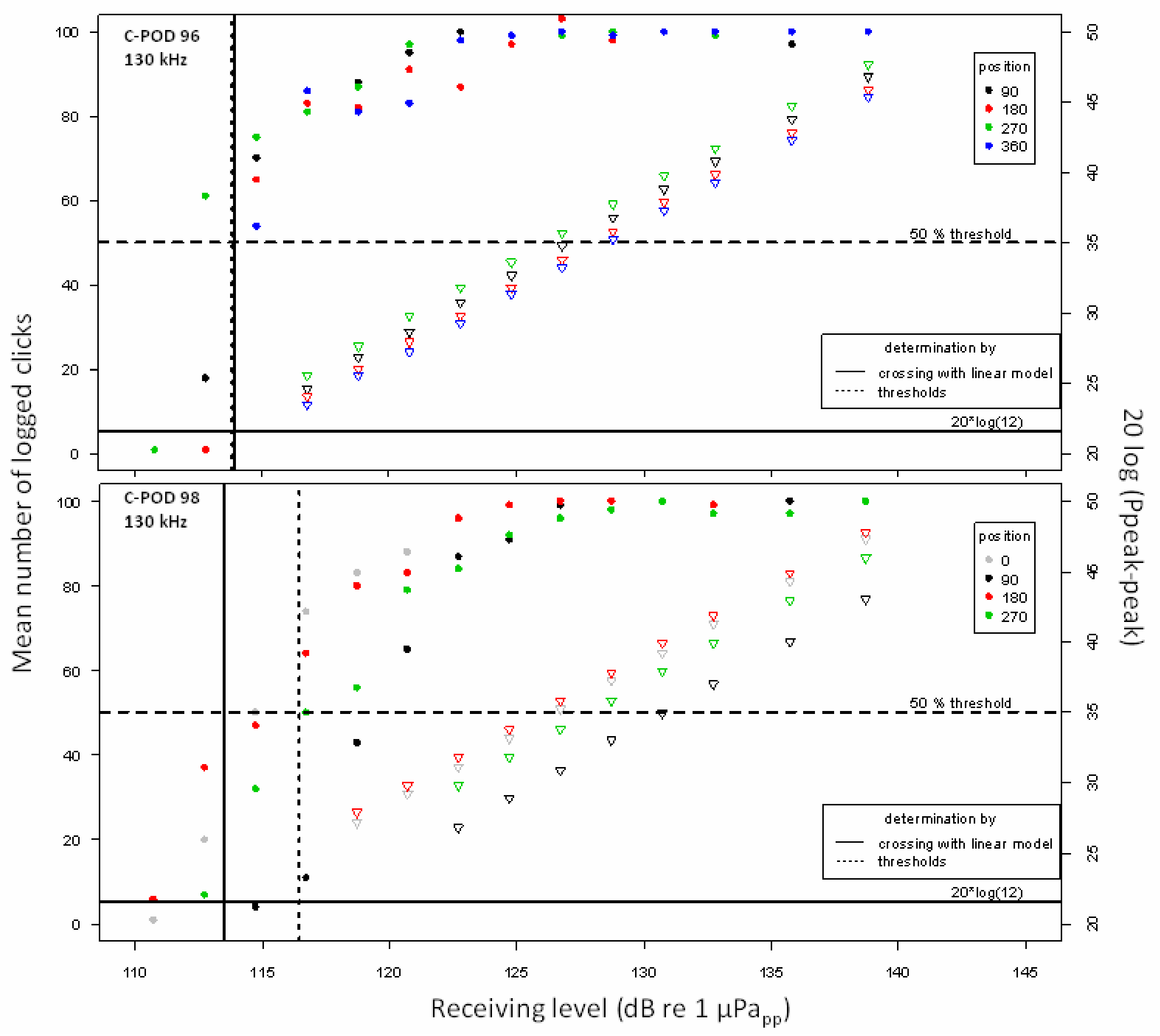


**Figure 16 Detection thresholds of C-POD 96 and 98 at 130 kHz. Number of clicks logged (left y-axis, solid circles) and measured P (peak-peak) values log-transformed with 20log(Ppp) as returned by the C-POD (right y-axis, triangles, values containing less than 80 click-registrations are omitted). The dashed vertical line indicates the receiving level at the 50 % threshold while the solid vertical line indicates the receiving level for the minimum Ppp-value of 12 calculated with a linear regression.**

This was the case for all frequencies above 120 kHz.

Figure 18 show boxplots of the receiving levels corresponding to the 50% detection threshold and the Ppp-value 12 gained from all C-PODs for the different calibration frequencies. For all frequencies boxes are quite slim with 50 % of the data in a 2 to 3 dB range. Minimum – maximum range are mostly less than 10 dB, but for 140 and 150 kHz C-PODs have a wider variation.

Results of the linear models and the 50 % thresholds are very similar for all frequencies except 140 and 150 kHz, where receiving levels are higher for the 50% threshold.

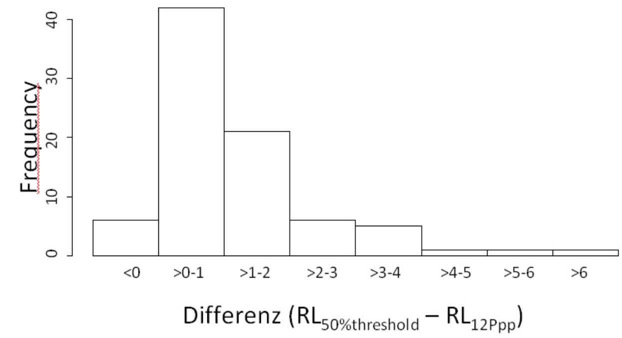


**Figure 17 Histogram of the differences between the receiving levels (RL) at the 50 % detection threshold and the linear regression intercept for P peak-peak value 12 derived for 130 kHz-calibration signals.**

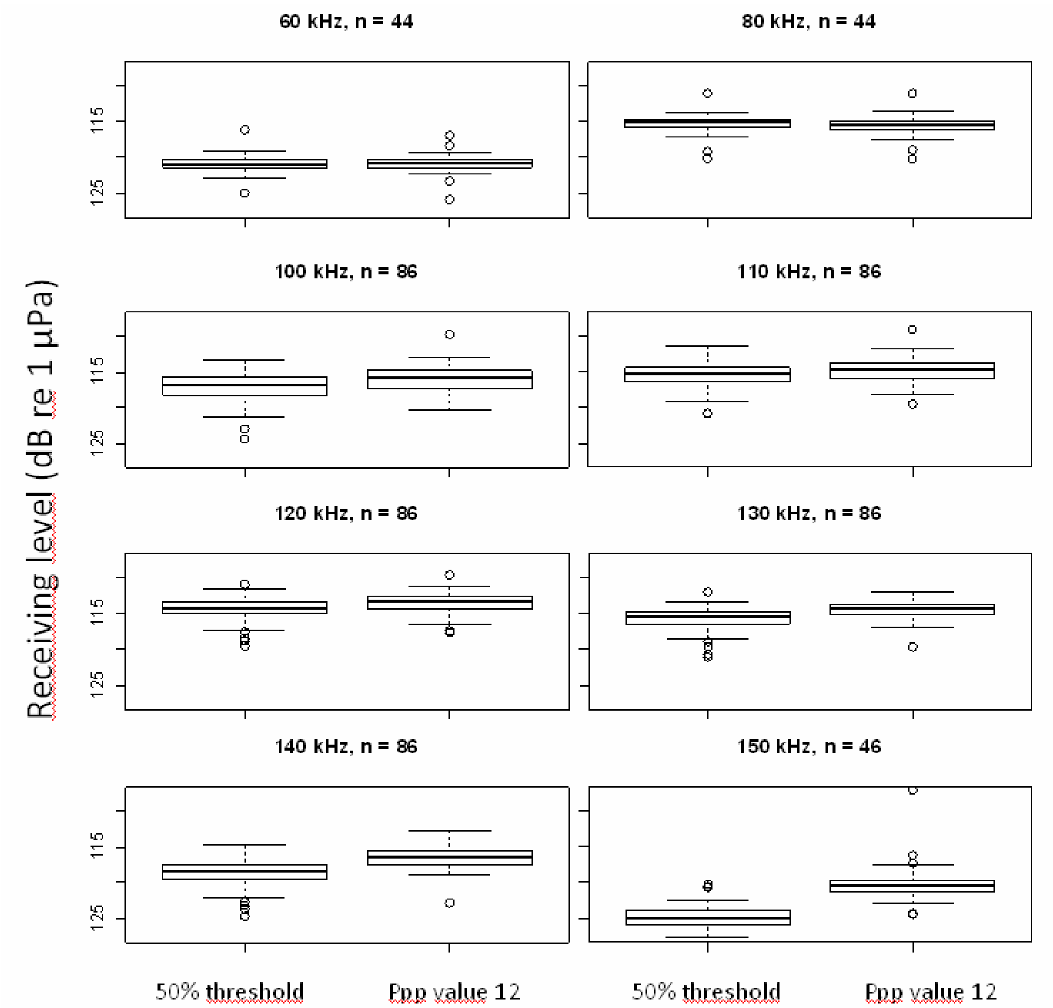


**Figure 18 Boxplots showing the 5%, 25%, 50%, 75% and 95% percentile and outliers of the receiving level corresponding to the 50 % threshold and the Ppp-value 12 for calibration signals of 60 to 150 kHz**

### 5.3.4. Discussion

The present study presents the calibration procedure developed at the German Oceanographic Museum for C-PODs. Two possible ways defining the sensitivity threshold for C-PODs are introduced: the 50% detection threshold, determining the minimum receiving level, at which a C-POD is capturing only 50% of the projected signals, and the linear model method, which correlates the sound pressure level of the received signals with the relative pressure values Ppeak-peak stored by the C-POD. As threshold, the sound pressure level specified by the Ppeak-peak-value 12 is defined, calculated with the linear model. The latter method turned out to be the more reliable one, as especially at higher frequencies, the projected signals were at some occasions not properly picked up by some C-PODs, most likely caused by electromagnetic interference of instruments used in the all day business of the calibration location. This problem would not show up in C-PODs operating at sea.

The calibration procedure of the German Oceanographic Museum shows that omnidirectionality is achieved by C-PODs within 3 dB, with the occasional outlier. Linearity is only given for frequencies between 80 and 130 kHz. The new version 1 C-PODs should extent this range to approximately 150 kHz. These findings are in line with standardization procedure by the manufacturer.

The manufacturer is using a very simple calibration procedure that standardises the amplitude scale but not the detection threshold so that a common uniform detection threshold can be set retrospectively, with a scale value of 12 being the standard value. (Tregenza, pers. comm): In a small calibration tank with very little reverberation, a signal of fixed amplitude (130 kHz sine wave signal in a rectangle envelope) is transmitted and then received by the C-POD. The C-POD is continuously rotated during this procedure and the gain value is adjusted so that mean value of a large number of radial positions for the registered amplitude is 50. Hydrophones with too high variation in the horizontal plane are replaced and the procedure is repeated.

Hydrophones used for C-PODs must cost much less than high quality and high priced equipment for underwater noise measurements to keep a reasonable price for the product. In contrast to low price hydrophones, high quality horizontally omnidirectional hydrophones usually have a less than +/- 3 dB variation in the horizontal plane guaranteed by the manufacturer. Linearity is another issue and the higher the quality and price are, the more linear is the hydrophone in its frequency dependent sensitivity. This can be from low Hz values up to 100 or even 200 kHz, but the amplification required for such linear hydrophones is incompatible with a low-power autonomous device.

The calibration of C-PODs as presented in this study enables an assignment of Ppp-values to absolute sound pressure levels. Ppp-values for amplitude returned by the instrument represent an accurate measurement on a relative scale within each 10 kHz frequency band, but cannot be compared over different frequencies. A standardization and calculation of absolute sound pressure levels would be possible, if calibration curves would be measured by the manufacturer and implemented into his proprietary software C-POD.exe with the option to update the calibration data. Calibration curves should then be updated at least yearly. At present, the software allows read-out of absolute pressure values at different frequencies based on measurements by the National Physical Laboratory, London, of a single C-POD.

Especially for multi species studies, like simultaneously recording bottlenose dolphins and harbour porpoises, the reduced sensitivity for the lower dolphin frequencies should be considered.

It should be taken into account, that the manufacturer has released the newer version 1 C-PODs, which were not tested within these trials, and promises, that sensitivity over 135 kHz should be slightly higher as new hydrophones with different characteristics are being used.

### 5.3.5. Conclusion

C-PODs are quiet well standardized at 130 kHz, but are less standardized at other frequencies. Interestingly enough, the results of this study indicate, that amplitude values in the 100 to 130 kHz are mostly comparable and even at lower frequencies mean values are similar.

As variation even at 130 kHz, occurs and is not negligible, a regular test tank calibration is recommended to ensure, that devices are still working within their specifications. Hard knocks due to at sea handling in rough conditions may affect the acoustic properties of the devices more heavily than a possible slight change in sensitivity over time. At present, only a few instruments have been repeatedly calibrated at the German Oceanographic Museum in a comparably short time frame. Therefore significant changes in sensitivity like seen in T-PODs (see chapter 5.1) were not yet detected in C-PODs. If a regular calibration is not possible, it is advisable to intracalibrate all instruments in various locations in the field, to find at least the outliers with very high or very low sensitivities. This cannot be counted for as a replacement for test tank trials.

PODs should ideally be calibrated prior deployment and from there on, once every year to capture sensitivity changes over the course of time or due to instrument failure/defects. In studies in which low frequencies need to be used, a calibration should be mandatory. Even after a calibration instruments should be rotated in between monitoring positions to rotate the instrument's error as well. Once every year is a compromise between a manageable time schedule and the probable effect of a changed sensitivity – if a significant change in sensitivity show up in repeated calibrations, then it is not possible anymore to attribute a sensitivity to corresponding datasets. Thus data might have to be discarded. A loss of one year of data is already quite a loss for any study. Procedures for a repeated calibration can be simplified, for instance it would be possible just to perform a directivity test at 130 kHz. If that did not change, then all other properties may not have changed as well.

The calibration procedure at the GOM can be drastically speeded up if the linear regression model is used to estimate sensitivity instead of the 50 % thresholds. It would be possible to define the regression slope and intercept with less than 4 measurements at different receiving levels. It would also be advisable to use more positions for the threshold/linear model test.

### 5.3.6. References

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## 5.4. Intracalibration of T-PODs

### 5.4.1. Introduction

During the last decade the use of T-PODs, autonomous data logger for the passive acoustic monitoring of odontocetes increased dramatically. In Germany, T-PODs are mandatory for environmental impact studies in the course of the construction and operation of wind farms. Also in Denmark and in The Netherlands, T-PODs have been used successfully for investigating possible effects of wind farm construction and operation on harbour porpoises (Carstensen et al. 2006, Diederichs et al. 2007). Harbour porpoises have been shown to be significantly affected by underwater noise emissions caused by pile driving activities, leading to a displacement in wide areas around the construction site (Carstensen et al. 2006, Siebert et al. 2010).

Next to the use of these data loggers in environmental impact studies, T-PODs are also a valuable tool for long term monitoring of harbour porpoises in specific areas, e.g. nature protection sites, for evaluating any possible changes in population density. For comparing data of different sites or time frames (like seasons or years), or of different studies, it is useful to know if and how the results, obtained by different T-POD devices, are comparable. Five different T-POD versions are currently in use, with different acoustic characteristics as shown by standard calibration procedures conducted at the German Oceanographic Museum (see chapter 5.1) and the National Environmental Research Institute (Kyhn et al. 2008). Calibration at the German Oceanographic Museum revealed that different devices of the second product version (V2 T-PODs) had a high variety in their sensitivity, i.e. the minimum sound pressure level harbour porpoise clicks need to have to be registered by the T-PODs. Sensitivity was hardly adjustable. With further development of the T-POD (product versions V3 and higher) the sensitivity of the devices became more comparable (standardised) and sensitivity much more adjustable.

The present study investigates the comparability of field data during harbour porpoise monitoring at specific sites with T-PODs of different versions and different sensitivities, and with the setting option “noise reduction” on and off.

**Table 3 Standard settings used for intracalibrating T-PODs of different versions and sensitivities. The setting option “minimum intensity” (V2, V3 T-PODs) and “sensitivity” (V4, V5 T-PODs) has been used for adjusting the sensitivity as obtained by the calibration procedure described in 5.1.**

| Setting | V2 | V3 | Setting | V4 | V5 |
|---|---|---|---|---|---|
| A-Filter-Frequency | 130 | 130 | A-Filter-Frequency | 130 | 130 |
| B-Filter-Frequency | 90 | 90 | B-Filter-Frequency | 92 | 92 |
| Ratio A/B | 6 | 6 | Click bandwidth | 5 | 5 |
| A-Filter sharpness | 10 | Short | Noise adaptation | +/++ | +/++ |
| A-Filter sharpness | 18 | Long | | | |
| Minimum intensity | according to min RL | | Sensitivity | according to min RL | |
| Limit on clicks logged | none | none | Limit on clicks logged | none | none |

## 5.4.2. Methods

T-PODs of version V2 to V5 and of different sensitivities, ranging from 112 to 144 dB re 1 $\mu Pa_{PP}$ have been deployed at the same spot in a porpoise rich area for several days in the years 2003, 2007 and 2008. In 2008, additionally the option "noise reduction on" and "noise reduction off" was compared for V4 and V5 T-PODs of the same sensitivity.

T-PODs have been calibrated with a standard calibration procedure as described in chapter 5.1 before deployment and set to standard settings and specific sensitivities as given in Table 3. The devices have been fixed vertically in an array of PVC-pipes (in 2003) or soft-drink crates (in 2007 and 2008) with the hydrophone ends upwards directed and a spacing of approximately 80 cm (in 2003) or 30 cm (in 2007 and 2008) between neighbouring T-PODs. The array was lowered down to the seafloor at different sites in the Danish Belt Seas. A diver made sure that the T-PODs were standing in vertical position on the sea floor. Deployment time and depth are given in Table 4.

Data obtained during deployment was uploaded to a computer and processed with the inbuilt train filter algorithm version 4.0 of the software T-POD.exe version 8.3. T-PODs register the length and time of occurrence of sound signals that fit the criteria specified by the settings of the device. The T-PODs in the present study were set to register harbour porpoise like clicks. The train filter algorithm is a post processing programme that searches within the raw data for registered clicks building sequences, i.e. series of successive clicks following each other in a specific time pattern. Identified click sequences are then classified into different categories, originating with high probability from cetacean (cet hi), with low probability from cetacean (cet low), or more likely from other sources (doubtful and very doubtful click trains) or boat sonars (boat). In the present study, only cet high and cet low click trains were used for further analysis and considered as an acoustic harbour porpoise registration.

The number of minutes with harbour porpoise registrations per hour was determined for the data sets of each T-POD, named detection positive minutes (dpm), taken per hour. One version 3 T-POD with a sensitivity of 127 dB re 1 µPa was chosen in each intracalibration session as reference ($\text{T-POD}_{Ref127dB}$), to which the data of any other T-POD of the intracalibration set up was compared to ($\text{T-POD}_{Comp}$). X/y-data sets were built for each recording hour with the $dpm_{Ref127dB}$-value of the $\text{T-POD}_{Ref127dB}$ as x-value and the $dpm_{Comp}$-value of $\text{T-POD}_{Comp}$ as y-value, giving information on how many dpm each $\text{T-POD}_{Comp}$ registered within a specific hour compared to the $\text{T-POD}_{Ref127dB}$. A linear relationship was assumed for the correlation:

$dpm_{Comp}/t_{[h]} = F_{dpm} \times dpm_{Ref127dB}/ t_{[h]}$, with $F_{dpm}$ = multiplication factor, $t_{[h]}$ =time unit (hour)

**Table 4 Deployment time and depth of the T-PODs intracalibrated in the years 2003, 2007 and 2008.**

| Year | Date | Monitoring hours | Position | | Depth (m) |
|---|---|---|---|---|---|
| 2003 | 08. - 10.09 | 73 | 55° 36,283 N | 10° 34,273 O | 16 |
| 2007 | 23.07.- 01.08. | 217 | 55°02,645 N | 10°05,503 O | 7.5 |
| 2008 | 06.-12.08. | 144 | 55° 7,750' N | 11°12,120'O | 7.6 |

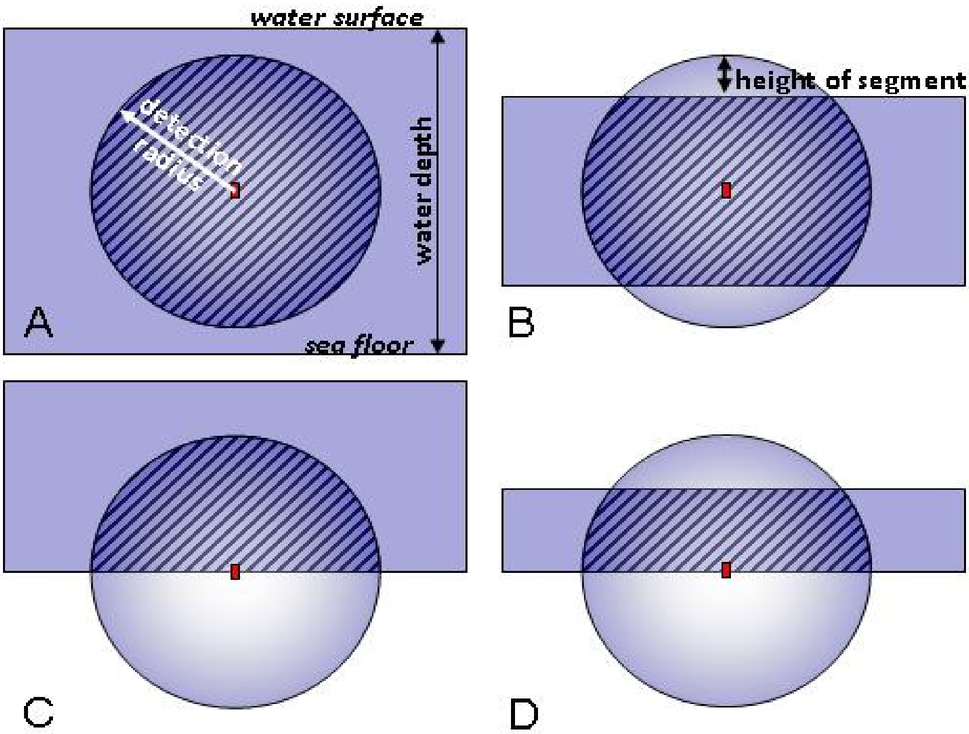


**Figure 19 Detection volume (striped area) of a passive acoustic monitoring device with an ideal omnidirectional receiving beam pattern (red rectangle) in mid water (A, B), with the detection range (2 x detection radius) shorter (A) and longer (B) than the water depth or installed at the sea floor (C, D) with the detection radius shorter (C) or longer (D) than the water depth. The detection volume equals the volume of a sphere (A, B) minus the volume of two segments (B), or it equals the volume of a half sphere (C, D) minus the volume of one segment (D).**

A linear regression analysis was performed on each x/y-data set, determining the slope of regression and its 95% confidence interval, with $dpm_{Ref127dB}/h$ as independent variable (SYSTAT 10, SPSS).

We expect the factor $F_{dpm}$ equalling the ratio $F_{Vol}$ between the detection volume $V_{Comp}$ of the T-POD$_{Comp}$ and the detection volume $V_{Ref127dB}$ of the T-POD$_{Ref127dB,}$ assuming - for simplification - for each T-POD equal detection probability for harbour porpoises at any distance to the device:

$V_{Comp} = F_{Vol} \times V_{Ref127dB}$

$\Rightarrow F_{dpm} \approx F_{Vol}$

If e.g. a T-POD$_{Comp}$ has a detection volume which is twice as large as the one of the T-POD$_{Ref127dB}$, the probability to detect a porpoise is twice as high, and therefore it may gather twice as many dpm. This premises a uniform distribution of harbour porpoises in space.

The calculated factor $F_{Vol}$ equals $F_{dpm,}$ i.e. it is not significantly different from it, if it lies within the +/-95% confidence interval of the slope of regression as obtained by the linear regression mentioned above.

For calculating the detection volume and the ratio $F_{Vol}$ between a T-$POD_{Comp}$ and the corresponding T-$POD_{Ref127dB}$, following assumptions were drawn:

**Assumption:**

Passive acoustic monitoring devices observe their surrounding in three dimensions. Following thoughts apply for devices, which receiving characteristic is omnidirectional, i.e. the detection radius of any angle to the device is constant. Omnidirectional listening devices do have a “blind spot” in their detection volume at the spot at which cables connect to the sound receiving components of the device, resulting in a rather reniform receiving beam pattern. Please note that we do neglect this matter in the following descriptions for simplification matters.

In areas, which are not restricted by any boundaries, e.g. in deep waters, the detection volume of ideal omnidirectional listening devices can be described by a sphere. However, in shallow waters, this sphere is truncated by boundaries, e.g. the water surface and the sea floor.

In deep waters, where the detection range (diameter) of a listening device is smaller than the water depth, and the detection volume is not restricted by any boundaries, it equals the volume of a sphere (detection volume $V_D = 4/3\ \pi r^3$, with r = radius of the sphere, equalling the detection radius) (Figure 19A). In waters, in which the depth is smaller than the detection range, the volume of two spherical segments (volume spherical segment $V_{SS} = 1/3\ \pi h^2(3r-h)$, with r = radius of the sphere, h = height of the segment) have to be subtracted from the volume of the sphere: one equalling the volume that will be diminished by the water surface, with a height corresponding to the difference between the detection radius and the distance of the device to the water surface, the other equalling the volume that will be diminished by the sea floor, with a height corresponding to the difference between the detection radius and the distance of the device to the sea floor (Figure 19B).

In the present field study, in which the porpoise detectors are installed at the sea floor, the detection volume is the volume of a half sphere (Figure 19C) subtracted by a spherical segment with a height of the detection radius minus water depth (Figure 19D). We assume that the factor $F_{dpm}$ between the detection rates of two devices equals the ratio $F_{Vol}$ between the corresponding detection volumes, e.g. a device with a twice as large detection volume compared to another device will have twice as many detections. Figure 20 shows how much the detection volume grows with

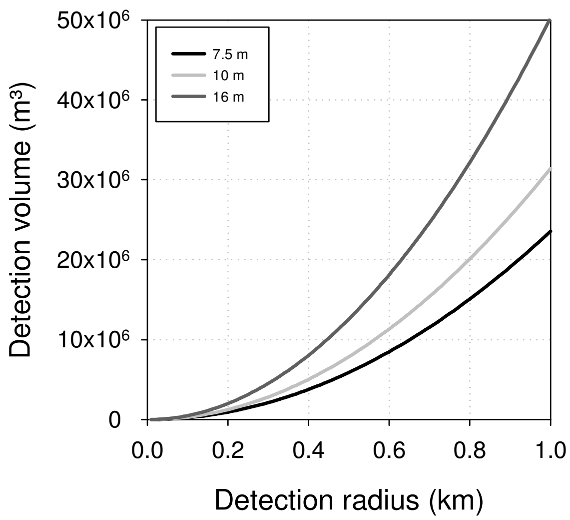


**Figure 20 Detection volume of acoustic monitoring devices with a specific detection radius installed at the sea floor on locations with 7.5, 10 and 16 m water depths.**

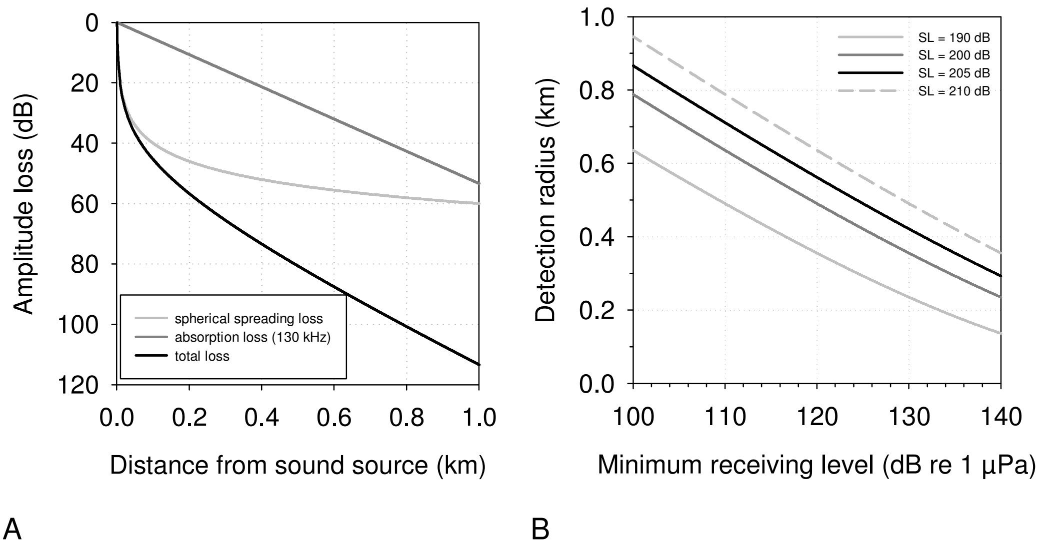


**Figure 21 (A) Propagation loss of a harbour porpoise signal, assuming that the total loss (black) is the sum of a spherical spreading loss (light grey) and an absorption loss calculated for a frequency of 130 kHz. (B) Detection radius of monitoring devices with a specific minimum receiving level for harbour porpoise clicks with source levels (SL) of 190 to 210 dB re 1 µPa and amplitude loss as given in (A).**

increasing detection radius if assuming the monitoring device installed at the sea floor with a water depth of 7.5, 10 or 16 m, respectively.

To determine the ratio $F_{Vol}$, the detection range of the T-PODs needs to be calculated.

### Detection range:

Harbour porpoises emit echolocation clicks with a source level (sound pressure level at 1 m distance from the sound source) of up to 205 dB re 1 µPa (Villadsgaard et al., 2007). The clicks reduce in energy as they propagate through the water column. The clicks' sound pressure level diminishes due to geometrical spreading loss and absorption of the energy by water molecules. Sound propagation in shallow water is highly variable and site specific, as it is influenced by the acoustic properties of the surface and bottom contours as well as the variation in temperature and salinity affecting the sound speed (Malme 1995). In the present study we use a very simplified model for sound propagation and the energy loss of harbour porpoise clicks, assuming a spherical spreading loss. We calculate the absorption loss at 130 kHz, which is around the main energy of harbour porpoise echolocation clicks, and the filter setting for the T-PODs. We assume a spherical spreading loss for the harbour porpoise clicks, as they are highly directional and short in time. Reflections from the water surface and sea floor will most likely not add back to the energy of a travelling porpoise click as it is the

**Table 5 Theoretical detection distance (m) of T-PODs with specific minimum receiving levels (min RL) for harbour porpoise clicks of various source levels (dB re 1 µPa).**

| | Detection radius for Source level (m) | | |
|---|---|---|---|
| Min RL | 190 | 200 | 205 |
| 150 | 70 | 140 | 180 |
| 140 | 140 | 240 | 290 |
| 130 | 240 | 360 | 420 |
| 127 | 270 | 390 | 460 |
| 120 | 360 | 490 | 560 |
| 110 | 490 | 640 | 710 |

case in cylindrical spreading loss.

Following those assumptions, the sound pressure level (SPL) of harbour porpoises measured at a specific distance D from the porpoise (in km) equals the source level (SL) of the emitted porpoise click minus a spherical spreading loss minus the absorption loss at 130 kHz.

$SPL_D$ = SL – spreading loss – absorption loss

= SL - 20log(Dx1000) - 0.036xfrequency (kHz)$^{1.5}$D

Spreading loss and absorption loss are calculated after equations given in Malme (1995). Figure 21 shows the propagation loss as calculated with the above equations, and the corresponding sound pressure level at various detection distances for harbour porpoise clicks of different source levels.

With the calculation of the propagation loss of harbour porpoise clicks, one can relate the minimum receiving level of specific T-PODs with the corresponding detection distance. The detection radius of a T-POD is given by the distance, at which the sound pressure level of a harbour porpoise click equals the minimum receiving level of the T-POD. Table 5 and Figure 21B give the calculated detection radius of T-PODs with different minimum receiving levels for various harbour porpoise click source levels. With the knowledge of the detection range the detection volume can now be calculated for any T-POD of a specific minimum receiving level.

We calculated the ratio $F_{Vol} = V_{Comp} / V_{T\text{-}POD127dB}$ for T-PODs with a minimum receiving level of 110 to 150 dB re 1 µPa, click source levels from 190 to 210 dB re 1 µPa and a set-up as shown in Figure 19D for water depths of 7.5, 10 and 16 m, respectively. Figure 22 shows the ratio $F_{Vol}$ as calculated for a water depth of 10 m. The ratio $F_{Vol}$ for water depths of 7.5 m or 16 m, respectively, would not noticeably be different (at maximum 1.8 %) from the one calculated for a 10 m water depth, although the detection volumes differ considerably for a T-POD of a specific minimum receiving level at sites of different water depths (see Figure 20). Therefore $F_{Vol}$ calculated for a 10 m depth will serve as reference in the further calculations.

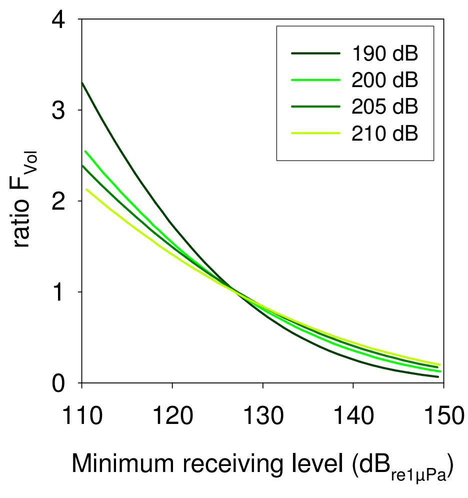


**Figure 22 Ratio $F_{Vol}$ between the detection volume from a $T\text{-}POD_{Comp}$ of a specific minimum receiving level and a reference $T\text{-}POD_{Ref127dB}$ calculated for harbour porpoise click source levels of 190 to 210 dB re 1 µPa (different coloured lines) and a water depth of 10 m, with the devices installed at the sea floor.**

For each T-POD, we calculated the deviation of the factor $F_{dpm}$, as given by the slope of regression, from the calculated ratio $F_{Vol}$, which is the factor that we would expect to obtain following the hypothesis given above. As reference ratio we chose $F_{Vol}$ calculated for a water depth of 10 m and a click source level of 200 dB re 1 µPa.

Deviation = $F_{dpm}$ - $F_{Vol}$

For revealing any influence of the total amount of registered clicks, which resembles the back ground noise, for each data set, the amount of clicks registered per hour (all+) was exported.

### 5.4.3. Results

All data sets showed a highly significant linear regression (p<<0.001, $R^2$ = 0.149 to 0.919). Figure 23 compares the factor $F_{dpm}$, as given by the slope of regression +/- 95% confidence interval, and the ratio $F_{Vol}$, determined for each T-POD of the different intracalibration experiments. For most T-PODs, the slope of regression +/- 95% confidence interval is on or close to the ratio $F_{Vol}$ calculated for the different source levels. Most diverse results give T-PODs with a minimum receiving level of around 132 dB re 1 µPa, with most of their slopes lying either above or below the given ratios $F_{Vol}$. The slopes of T-PODs with 127 dB re 1 µPa cluster around a value of 1.

The deviation from $F_{dpm}$, as given by the slope of regression, from the ratio $F_{Vol}$ for a click source level of 200 dB re 1µPa is shown in Figure 24. For version V2 T-PODs, the slope of regression +/- 95% confidence interval encloses the expected ratio (i.e. it is not significantly different from it) for two out of five T-PODs, while the slope of three PODs is significantly lower. For version V3 T-PODs, five slopes are not significantly different from the expected ratio, seven are significantly lower and three significantly higher than expected. Eight version V4 T-PODs out of eleven show a slope significantly lower than V3 T-PODs, two slopes are significantly higher, one does not show any significant difference. Two version V5 T-PODs show a significantly lower slope, while one is significantly higher and one does not show any significant difference. The difference between the slopes, i.e. $F_{dpm}$, and the ratio $F_{Vol}$ is within

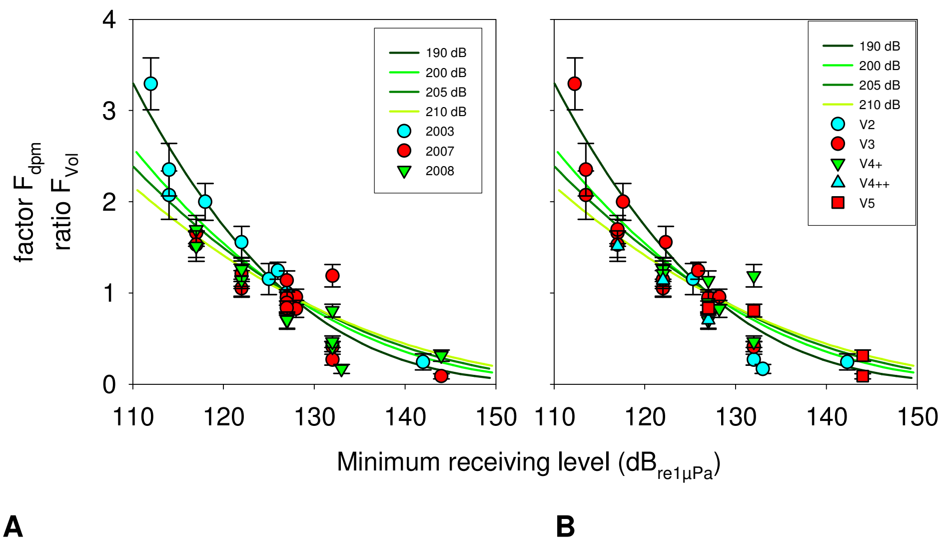


**Figure 23 $F_{dpm}$, as given by the slopes +/- 95% confidence interval of the linear regression between the results of T-PODs with specific minimum receiving levels and of a reference V3 T-POD with 127 dB minimum receiving level, as gained in different years (A: 2003 (blue circle), 2007 (red circle) and 2008 (green triangle) for different versions (B: V2 (blue circle), V3 (red circle), V4 without noise reduction (green triangle), V4 with noise reduction (blue triangle) and V5 (red square)). The coloured lines give the ratio $F_{Vol}$ for comparison as explained in Figure 22.**

a factor of +/- 0.5, except for the most sensitive V3-T-POD with a deviance of around 1. A high number of recorded clicks (all+/h) seem not to have an influence on the slope of regression.

## 5.4.4. Discussion

The intacalibration data show the value of calibrating T-PODs. The registration rate clearly depends on the sensitivity of the T-POD, resulting in more registrations with increasing sensitivity, i.e. decreasing minimum receiving level (Figure 23). The proposed model of an increase in the detection rate depending on the increase in detection volume does fit quite well for the selected monitoring sites, with differences between received factors $F_{dpm}$ and expected ratios $F_{Vol}$ to a reference T-POD lying close to zero, with a difference within a range of +/- 0.5 (Figure 24), except (only) one outlier. The retrieved slope of regression seems not to depend on the version of the T-POD. Figure 23B shows that the results for T-PODs with specific minimum receiving levels are mainly clustered around a specific slope independent of the T-POD-version. This clustering also entails that those T-PODs registered similar amounts of data, as their slopes are not significantly different from each other. The variance of the data to the proposed model may be explained by the relatively short deployment time of one to two weeks for the intracalibration. The distribution of harbour porpoises may not have been uniform, and the source levels of the emitted clicks may vary heavily, resulting in a constant change of the detection range.

The registration of a lot of background noise has a negative influence on the performance of the train detection algorithm (Tregenza 2006, chapter 5.6). In the current study the background noise was at a level that it did not have an influence on the results (Figure 24), otherwise T-PODs with a high amount of all+/h would have shown a large deviance from the expected ratio. The results of the current study lead to the recommendation to calibrate acoustic devices before deployment, to set the deployed devices to the same minimum receiving level if possible and at monitoring sites with similar water depths. Data obtained with T-PODs of different minimum receiving levels or at monitoring sites with different water depths may be adjusted to a reference by calculating and comparing the detection volumes as proposed above. As the model presumes a uniform harbour porpoise distribution, it may not be appropriate for deeper monitoring sites, as harbour porpoises do not sojourn with the same frequency in each depth of the water column (Teilmann et al., 2007).

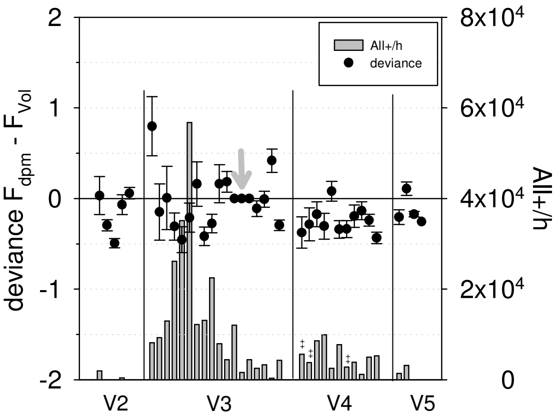


**Figure 24 Deviance of $F_{dpm}$, as expressed by the slope +/- 95% confidence interval, from the ratio $F_{Vol}$ for a click source level of 200 dB re 1µPa for the T-PODs of version 2 to 5. For each version, T-PODs are ordered from lowest to highest minimum receiving level. The grey arrow points at the three 127 dB reference T-PODs. For information, the mean number of all clicks recorded per hour (All+/h) by the specific T-POD is given as grey bars. V4 T-PODs with noise reduction are indicated by '++'.**

### 5.4.5. References

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## 5.5. Deployment of T-POD pairs

### 5.5.1. Introduction

For the acoustic monitoring of harbour porpoises in European waters, T-PODs, autonomous acoustic data loggers, have been used in several research studies (Bailey et al. 2010, Carlström et al. 2009, Carstensen et al. 2006, Diederichs et al. 2007, Simon et al. 2010, Todd et al. 2009). In these studies, different versions of T-PODs, but also different setting options have been used, which may complicate the comparability of the data across the studies. Chapter 5.1 and chapter 5.3.1 deal with the comparability of data gathered by different versions of T-PODs and different settings. The deployment method may also cause a difference in the data obtained by acoustic monitoring. Carstensen et al. (2006) as well as Diederichs et al. (2007) e.g., deployed their T-PODs a few meters above the sea floor, while Verfuss et al. (2007, 2008) moored their devices five to seven meters below water surface. The present study investigates the influence of the deployment depth of T-PODs. This is done by installing T-PODs of the same version and sensitivity at different depths at the same monitoring position. For this, monitoring sites with different water depths were chosen in German and Danish waters. Furthermore, T-PODs of different versions were installed at the same depth at monitoring positions to obtain long term data series for comparative purpose.

### 5.5.2. Methods

Before deployment, T-PODs were calibrated as described in chapter 5.1. Five monitoring sites were selected for the deployment of two T-PODs, respectively, in different depths. At each location, a T-POD was placed two metres above the sea floor, while the other one was moored five to seven metres below sea level. Depending on the water depth at the individual monitoring site, the distance between the devices ranged between one and 20 meter. At one further position, four T-PODs were installed with a vertical spacing of around eight metre between neighbouring PODs. It is likely, that the set up was held in an oblique position by the current, causing shorter vertical distances between the T-PODs. At three positions, different T-POD versions were installed at the same deployment depth. One of this position (SgO) was also equipped with T-PODs at different depths. Please see Table 6 for an overview about the chosen monitoring sites, water depths, deployment methods and monitoring times.

The obtained data was downloaded and processed with the T-POD-software version 8.3.

**Table 6 Monitoring positions used for T-PODs working as double acts at different depths and / or with different versions. Chosen were positions in Danish and German waters of the harbour porpoise monitoring as conducted by the German Oceanographic Museum (GOM) in the German Baltic Sea, by BioConsult-SH in the windfarm area Alpha Ventus, and by the National Environmental Research Institute in the Nysted windfarm.**

| Position | Area | Project | Water depth | T-POD version | T-POD position | different depths | different versions | recording time (days) | recording limit (per 10 sec) | Noise reduction (V4/5 only) |
|---|---|---|---|---|---|---|---|---|---|---|
| P1 | Danish Belt Seas | Intracalibration 2008 | 8 m | 2xV3 | surface, floor | x | | 4.9 | none | - |
| P2 | Danish Belt Seas | Intracalibration 2008 | 13 m | 2xV4 | surface, floor | x | | 5.9 | none | on |
| K71 | Kadet trench | GOM monitoring | 20 m | 2xV4 | surface, floor | x | | 53.9 | 240 | on |
| FeOa | Fehmarnbelt | GOM monitoring | 28 m | 2xV4 | surface, floor | x | | 55.2 | 240 | on |
| SgO | Kadet trench | GOM monitoring | 11 m | 2xV3, 2xV4 | surface, floor | x | x | 42.6 | 240 | on |
| AV | North Sea | Windfarm Alpha Ventus | 40 m | 4xV4 | 8m, 16m, 24m, 32m below surface | x | | 3.4 | 240 | on |
| Nysted1 | Danish Baltic Sea | Nysted windfarm | 9 m | 1xV3, 1xV5 | floor | | x | 27.2 | none | off |
| Nysted2 | Danish Baltic Sea | Nysted windfarm | 8 m | 1xV3,1x V5 | floor | | x | 27.2 | none | off |

The train detection algorithm entailed in this software searches for registrations that come in series, i.e. successive clicks with a time interval of a few hundred milliseconds maximum. These click trains are classified into the categories “cetacean high” (Cet high), “cetacean low” (Cet low) (both together are called Cet all), “doubtful” (?) and “very doubtful” (??), depending on the characteristics of the click train pattern. “Train details” as offered by the T-POD software were exported for these four train classes, giving, amongst others, the recording time and train classification of each identified click train. For statistical analysis, the time units minutes (min), 10 minute periods (10min) and hours (hours) containing identified click trains were selected, separate for following groupings:

- “Cet high”
- “Cet high” + “Cet low” (Cet all)
- “Cet high” + “Cet low” + “?” (Cet all, ?)
- “Cet high” + “Cet low” + “?” + “??” (Cet all - ??)

Those time units were declared as “positive time units”.

Following ratios were determined:

- Detection positive minutes (DPM) per hour *or* per day
- Detection positive 10 minutes (DP10M) per hour *or* per day
- Detection positive hours (DPH) per day

Data of the different T-POD pairs were compared to evaluate the influence of depth and / or T-POD version in a Generalised Linear Mixed Model (GLMM) using the software R (R Development Core Team 2007), with “Date” as random variable. Data of the measuring site “AV”, with T-PODs moored in four different depths were also compared with a Generalised Additive Mixed Model (GAMM) using R.

For investigating the influence of high frequency background noise causing registrations, the total number of clicks (All+) registered in each monitoring minute was exported for each data set. The amount of All+ per hour was calculated. Furthermore the amount of All+ recorded in minutes with train detection was assorted to the corresponding train data.

The difference in background noise, as expressed by All+ per hour, of each T-POD pair from the different positions was analysed with a Mann-Whitney Rank Sum Test, as Normality Test (Shapiro-Wilk) failed on all data sets. Where more than two T-PODs were involved in a study, an ANOVA on Ranks (Kruskal-Wallis One Way Analysis of Variance on Ranks) was performed. Tests were conducted with SigmaPlot V. 11 (Systat Software).

A frequency distribution of the amount of All+ per minute was determined for each data set separately as obtained for the positions and T-PODs mentioned in Table 6, giving the percentage of monitoring minutes with a specific amount of All+ clicks of all monitoring minutes. Following bin sizes were used:

⇒ 0, 1-19, 20-39, 40-59, …, 740-759, >=760 clicks

⇒ 0, 1-199, 200-299, 300-399, … 1300-1399, >=1400 clicks

It has to be mentioned, that some data sets showed a reduced amount of All+, as they were set to record a maximum of 240 clicks per 10 second interval. Furthermore, in some V4 or V5 T-PODs the setting option “noise reduction” was set to “++” (i.e. “on”), in order to reduce the registration of background noise. Details are given in Table 6.

To determine the influence of the background noise on the train detection algorithm, the percentage of minutes with one specific train class in the given All+ bins on the overall positive minutes of this train class was calculated. For this, the whole data set obtained in the present study was used.

### 5.5.3. Results

T-PODs with different deployment depths at the monitoring sites “K71” and “FeOa” with a comparatively deeper water depths recorded significantly different data sets for all train classes and time units ($p<=0.03$, negative effect values in all occasions), except for DPH per day for “Cet high” at “FeOa” ($p=0.28$) (Table 7). The difference decrease with increasing time interval analysed. The negative effect value indicates that the T-POD near the water surface recorded more time units with registrations than the one installed near the seafloor (Table 7,

**Table 7 GLMM and GAMM results of positions “P1”, “P2”, “SgO”, “K71”, “FeOa” and “AV” for the comparison of detection positive minutes (DPM) per hour and detection positive minutes / 10 minutes (DP10M) / hours (DPH) per day for time units containing the train classes “cet high”, “cet all”, “cet all + ?” and “cet high - ??” from T-PODs installed at different depths. Given are the water depth at the station, the number of days monitored, the p-value result from the GLMM or GAMM and the effect size given by the GLMM. P-values <0.001 are marked yellow, p<0.01 orange, p<0.05 red, p>=0.05 grey.**

| | | | | | Unit | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | DPM per hour | | DPM per day | | DP10M per day | | DPH per day | |
| Station | depth | Monitoring days | Method | Classification | effect | p | effect | p | effect | p | effect | p |
| P1 | 8m | 4.9 | GLMM | Cet high | 0.181 | 0.272 | 0.181 | 0.268 | -0.108 | 0.650 | -0.112 | 0.716 |
| | | | | Cet all | 0.176 | 0.176 | 0.176 | 0.169 | 0.175 | 0.300 | 0.108 | 0.643 |
| | | | | Cet all, ? | 0.212 | 0.056 | **0.212** | **0.048** | 0.174 | 0.193 | 0.086 | 0.613 |
| | | | | Cet high - ?? | **0.222** | **0.027** | **0.222** | **0.023** | 0.149 | 0.239 | 0.025 | 0.877 |
| SgO | 11m | 42.6 | GLMM | Cet high | **-0.086** | **<2e-16** | **-0.087** | **0.000** | **-0.061** | **0.000** | -0.030 | **0.017** |
| | | | | Cet all | **-0.071** | **<2e-16** | **-0.070** | **<2e-16** | **-0.037** | **0.000** | -0.015 | 0.142 |
| | | | | Cet all, ? | **-0.057** | **<2e-16** | **-0.056** | **<2e-16** | **-0.020** | **0.002** | -0.005 | 0.595 |
| | | | | Cet high - ?? | **-0.053** | **<2e-16** | **-0.052** | **<2e-16** | **-0.020** | **0.000** | -0.004 | 0.616 |
| P2 | 13m | 5.9 | GLMM | Cet high | 0.035 | 0.381 | 0.035 | 0.357 | 0.000 | 0.995 | -0.016 | 0.770 |
| | | | | Cet all | **0.077** | **0.002** | **0.077** | **0.002** | 0.062 | 0.065 | 0.038 | 0.333 |
| | | | | Cet all, ? | **0.072** | **0.001** | **0.072** | **0.000** | 0.050 | 0.080 | 0.025 | 0.470 |
| | | | | Cet high - ?? | **0.073** | **0.000** | **0.073** | **0.000** | **0.060** | **0.024** | 0.043 | 0.183 |
| K71 | 20m | 53.9 | GLMM | Cet high | **-0.204** | **<2e-16** | **-0.204** | **<2e-16** | **-0.106** | **0.000** | **-0.060** | **0.005** |
| | | | | Cet all | **-0.164** | **<2e-16** | **-0.164** | **<2e-16** | **-0.105** | **<2e-16** | **-0.072** | **0.000** |
| | | | | Cet all, ? | **-0.168** | **<2e-16** | **-0.168** | **<2e-16** | **-0.113** | **<2e-16** | **-0.078** | **0.000** |
| | | | | Cet high - ?? | **-0.166** | **<2e-16** | **-0.167** | **<2e-16** | **-0.111** | **<2e-16** | **-0.076** | **0.000** |
| FeOa | 28m | 55.2 | GLMM | Cet high | **-0.036** | **0.000** | **-0.036** | **0.000** | **-0.019** | **0.001** | -0.007 | 0.280 |
| | | | | Cet all | **-0.033** | **<2e-16** | **-0.033** | **<2e-16** | **-0.021** | **0.000** | **-0.010** | **0.030** |
| | | | | Cet all, ? | **-0.028** | **<2e-16** | **-0.028** | **<2e-16** | **-0.019** | **0.000** | **-0.010** | **0.009** |
| | | | | Cet high - ?? | **-0.027** | **<2e-16** | **-0.027** | **<2e-16** | **-0.019** | **0.000** | **-0.012** | **0.001** |
| AV | 42m | 3.4 | GLMM | Cet high | 0.006 | 0.703 | 0.006 | 0.694 | 0.002 | 0.917 | -0.004 | 0.828 |
| | | | | Cet all | 0.008 | 0.416 | 0.008 | 0.405 | 0.014 | 0.232 | 0.004 | 0.775 |
| | | | | Cet all, ? | 0.007 | 0.456 | 0.007 | 0.448 | 0.015 | 0.159 | 0.008 | 0.566 |
| | | | | Cet high - ?? | 0.005 | 0.538 | 0.005 | 0.533 | 0.014 | 0.177 | 0.007 | 0.590 |
| AV | 42m | 3.4 | GAMM | Cet high | | 0.000 | | 0.008 | | 0.081 | | 0.015 |
| | | | | Cet all | | 0.189 | | 0.314 | | 0.048 | | 0.467 |
| | | | | Cet all, ? | | 0.146 | | 0.309 | | 0.048 | | 0.207 |
| | | | | Cet high - ?? | | 0.217 | | 0.432 | | 0.072 | | 0.110 |

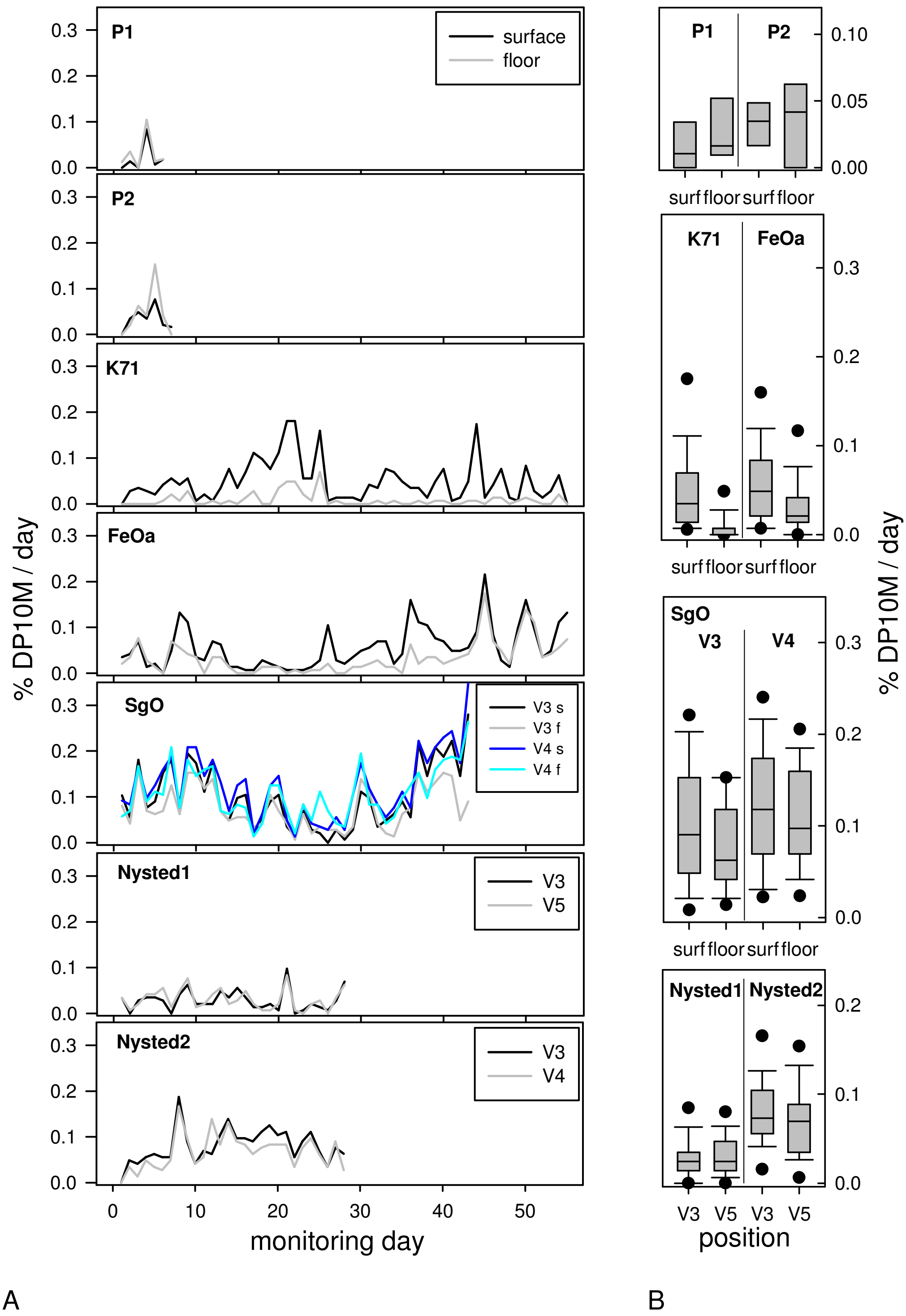


**Figure 25 Percentage of "Cet all"-detection positive 10 minutes per day over the course of monitoring days (A) and in total (B) for the positions "P1", "P2", "K71", "FeOa", "SgO", "Nysted1" and "Nysted2". Different coloured lines in (A) give data from different depths (near surface: surface, surf, s; near sea floor: floor, f) or T-POD versions, respectively. (B) shows the 5, 10, 25, 50, 75, 90, 95% percentile of the %DP10M per day for each data set.**

Figure 25). The data obtained at position P1 does not show any significant differences (P>=0.056), except for train classes "Cet high - ??" for the parameters DPM per hour and day as well as "Cet all, ?" for DPM per day (p>=0.48, positive effect value, i.e. the lower POD registered more positive time units than the upper POD). Data at position P2 were significantly different for DPM per hour and day for "Cet all", "Cet all, ?" and "Cet high - ??",

**Table 8 GLMM results of positions Nysted1, Nysted2 and SgO for the comparison of detection positive minutes (DPM) per hour and detection positive minutes / 10 minutes (DP10M) / hours (DPH) per day for time units containing the train classes "cet high", "cet all", "cet all + ?" and "cet high - ??" from T-PODs of different versions installed at the same depths. Given are the water depth at the station, the number of days monitored, the p-value and effect size arisen from the GLMM. P-values <0.001 are marked yellow, p<0.01 orange, p<0.05 red, p>=0.05 grey.**

| Station | depth | Monitoring days | Method | Classification | minperhour effect | minperhour p | minperday effect | minperday p | 10minperday effect | 10minperday p | hoursperday effect | hoursperday p |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nysted2 | 8m | 27.2 | GLMM | Cet high | -0.014 | 0.749 | -0.016 | 0.716 | -0.019 | 0.723 | -0.027 | 0.668 |
| | | | | Cet all | -0.041 | 0.185 | -0.043 | 0.147 | -0.060 | 0.139 | -0.017 | 0.740 |
| | | | | Cet all, ? | -0.218 | <2e-16 | -0.219 | <2e-16 | -0.289 | <2e-16 | -0.191 | 0.000 |
| | | | | Cet high - ?? | -0.244 | <2e-16 | -0.243 | <2e-16 | -0.301 | <2e-16 | -0.195 | 0.000 |
| Nysted1 | 9m | 27.2 | GLMM | Cet high | 0.044 | 0.580 | 0.086 | 0.254 | 0.025 | 0.785 | 0.047 | 0.647 |
| | | | | Cet all | 0.012 | 0.817 | 0.053 | 0.274 | 0.043 | 0.513 | 0.057 | 0.444 |
| | | | | Cet all, ? | -0.019 | 0.488 | 0.007 | 0.778 | -0.015 | 0.630 | -0.010 | 0.814 |
| | | | | Cet high - ?? | -0.024 | 0.356 | 0.001 | 0.969 | -0.016 | 0.615 | -0.011 | 0.792 |
| SgO | 11m | 42.6 | GLMM | Cet high | 0.472 | <2e-16 | 0.464 | 0.000 | 0.335 | 0.000 | 0.325 | 0.000 |
| | | | | Cet all | 0.414 | <2e-16 | 0.407 | <2e-16 | 0.281 | 0.000 | 0.258 | 0.000 |
| | | | | Cet all, ? | 0.338 | <2e-16 | 0.332 | <2e-16 | 0.273 | 0.000 | 0.246 | 0.000 |
| | | | | Cet high - ?? | 0.263 | <2e-16 | 0.258 | <2e-16 | 0.207 | 0.000 | 0.030 | 0.431 |

as well as for "Cet high - ??" for DP10M per day (p<=0.024, positive effect value). At SgO, data were significantly different for all parameters and all units except DPH per day ($p<2x10^{-16}$, negative effect value).

T-POD data at position "AV" with four different deployment depths did not show any significant difference in the Generalised Linear Mixed Model. However, the application of the Generalised Additive Mixed Model showed differing results for "Cet high" and DPM per hour and day (p<0.008) (Table 7, Figure 26), with the lowest and highest T-POD showing more positive time unit registrations than the middle positioned T-PODs. All other combinations did not show any significant or only a slightly significant difference (p >= 0.015) (Table 7).

The different T-POD versions did not show any significant difference for train classes "Cet high" and "Cet all" at the Nysted windpark positions (p>=0.139). Only the "Nysted2"-site showed a significant difference in the "Cet all, ?" and "Cet high - ??" train classes ($p<2x10^{-16}$, negative effect value). Data obtained for V3 and V4 T-POD pairs were significantly different in nearly all occasions ($p<2x10^{-16}$, positive effect value), except for "Cet high - ??" and DPH per day (p=0.431) (Table 7).

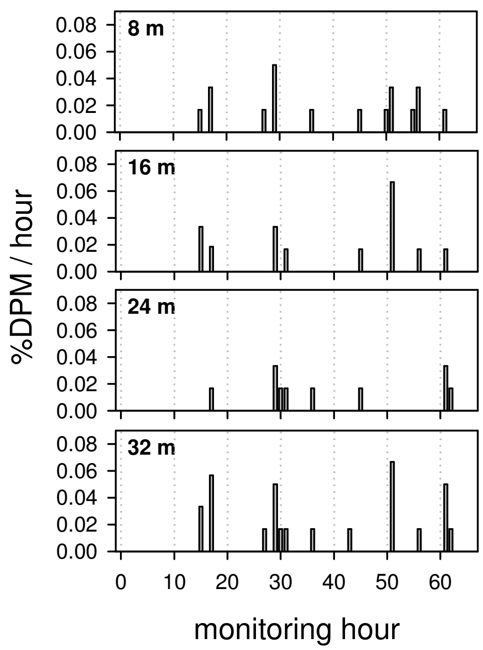


**Figure 26 Percentage of "Cet high"-detection positive minutes per hour over the course of monitoring hours for four T-PODs at different depths at the position AV.**

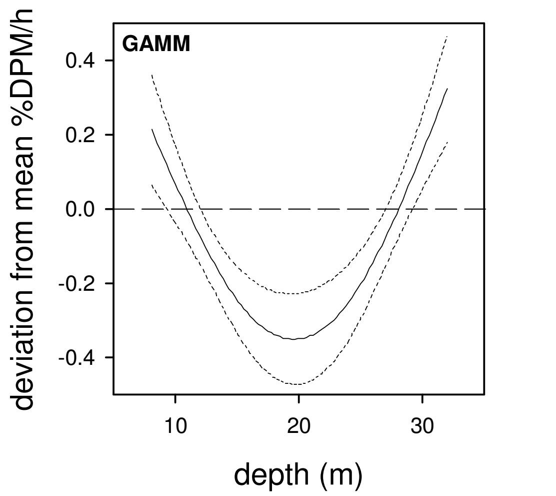


**Figure 27 Effect of the water depth on the percentage of detection positive minutes per hour on the recordings at position AV. Shown is the deviation (black line) and 95% confidence interval (dotted lines) from the overall mean of % DPM / hour registered by the four T-PODs installed at 8m, 16m, 24m and 32m below water surface.**

The amount and quality of the recorded All+ clicks per hour and minutes, respectively, is shown in Figure 29 and Figure 30. Nearly all T-POD pairs recorded a highly significant or a significant different amount of All+ clicks per hour (p<0.001 for "P1", "K71", "Nysted2", p=0.01 for "FeOa", p=0.029 for "P2"). Only the T-POD pair at Nysted1 did not have any significant difference in the recorded background noise (p=0.758).

The four T-PODs at "SgO" also showed a highly significant difference in their recorded background noise (p<0.001), for the pairs at different depths as well as for the pairs with different versions (p<0.001). The four T-PODs at the monitoring site "AV" did not have any significant difference in their background noise (p=0.403).

Except for the T-PODs deployed at "SgO", none of the other T-PODs recorded more than 0.2% of all monitoring minutes in the All+ bins containing more than 300 clicks per minute (Figure 29, Figure 30). At position SgO, background noise was quite high with partly more

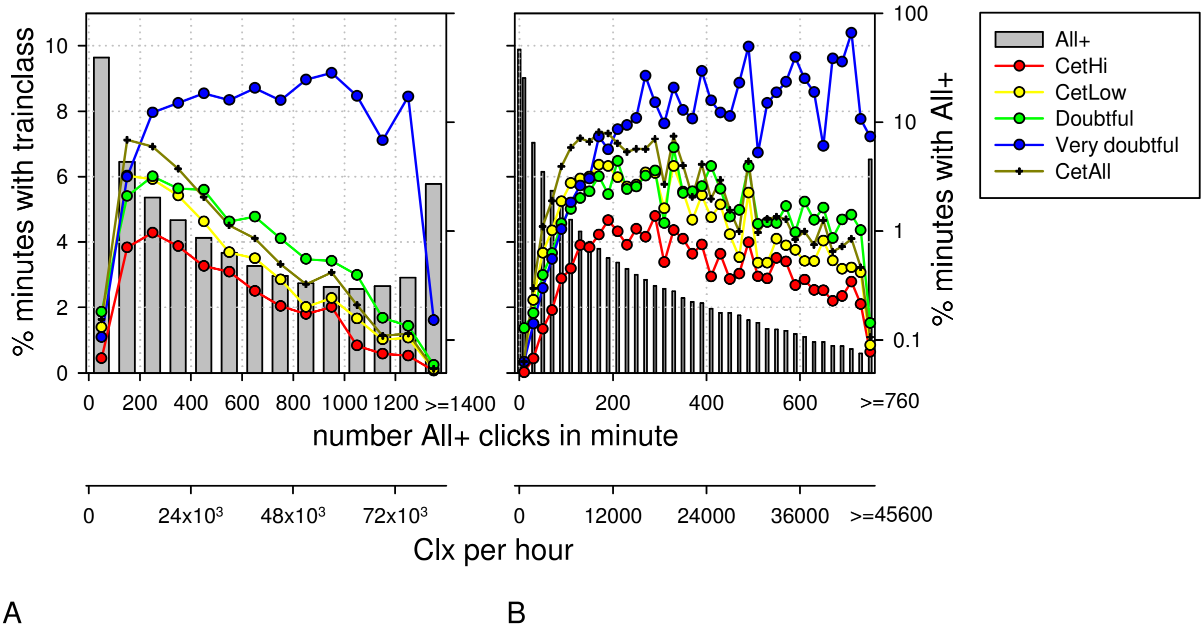


**Figure 28 Percentage of monitoring minutes from all monitoring minutes within the specific All+ bin, containing a train or trains classified as "cetacean high" (red line & dot), "cetacean low" (yellow line & dot), both of those train classes ("Cet All": dark yellow & cross), "doubtful" (green line & dot) or "very doubtful" (blue line & dot). The grey bar show the percentage of minutes within the specific All+ bin from the overall minutes monitored (A: bin size = 100 for All+<1,400 clicks/min, B: bin size = 20 for All+<760 clicks/min). The second x-axis show the corresponding number of clicks (Clx) per hours provided each minute of the hour contains the same amount of clicks.**

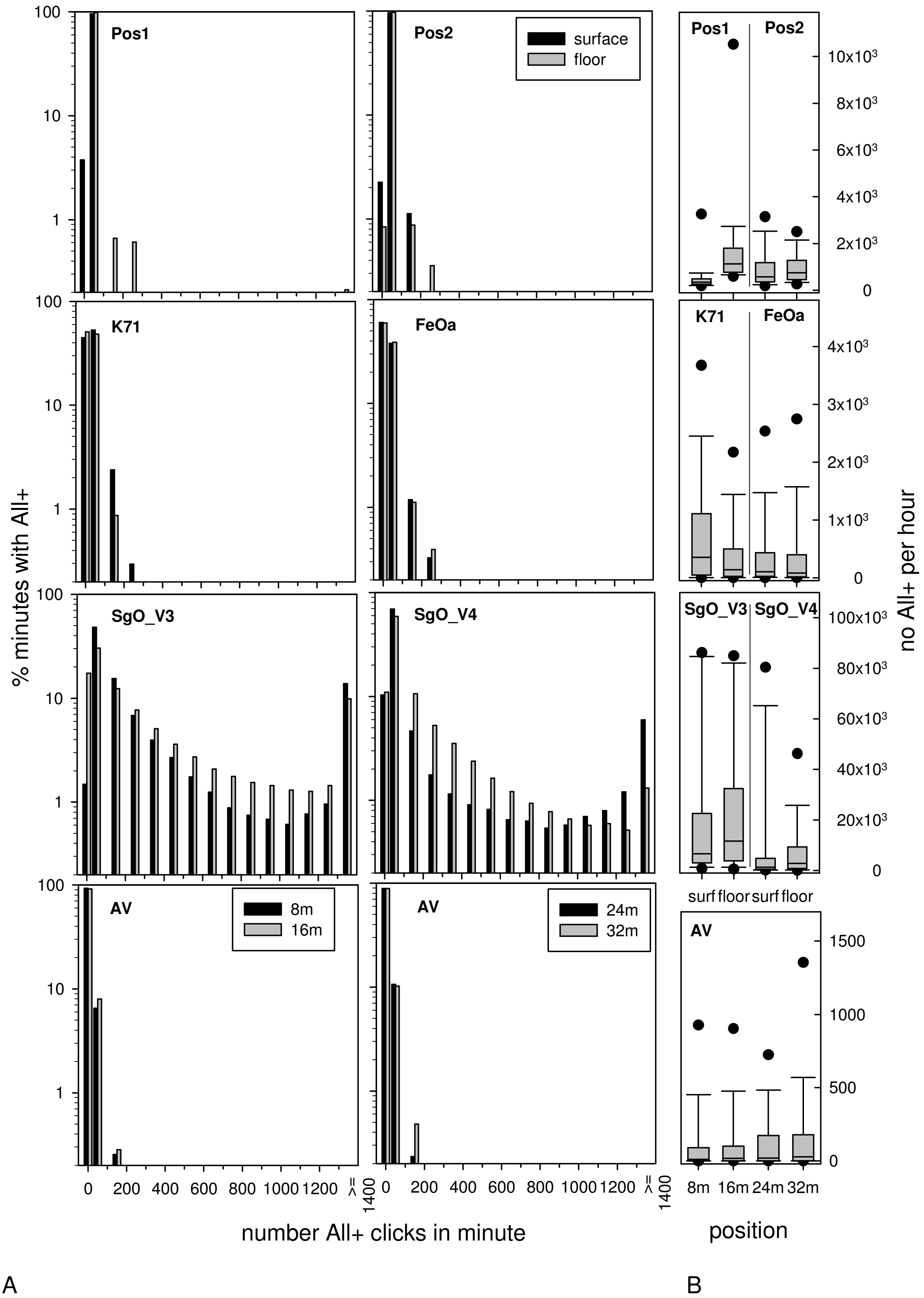


**Figure 29 Amount of registered All+ clicks (background noise) as obtained during the monitoring period at the positions "P1", "P2", "K71", "FeOa", "SgO" and "AV". (A) shows the frequency distribution of All+ per minute, i.e. the % of minutes with a specific amount of All+clicks (bin width = 100 for < 1,400 clicks per minute) from the overall amount of monitoring minutes. Please note, that only all values above 0.2% are visible. (B) gives a box plot showing the 5, 10, 25,50, 75, 90 and 95% percentile of the number of All+ per hour values recorded at the different positions at different depths or different T-POD versions.**

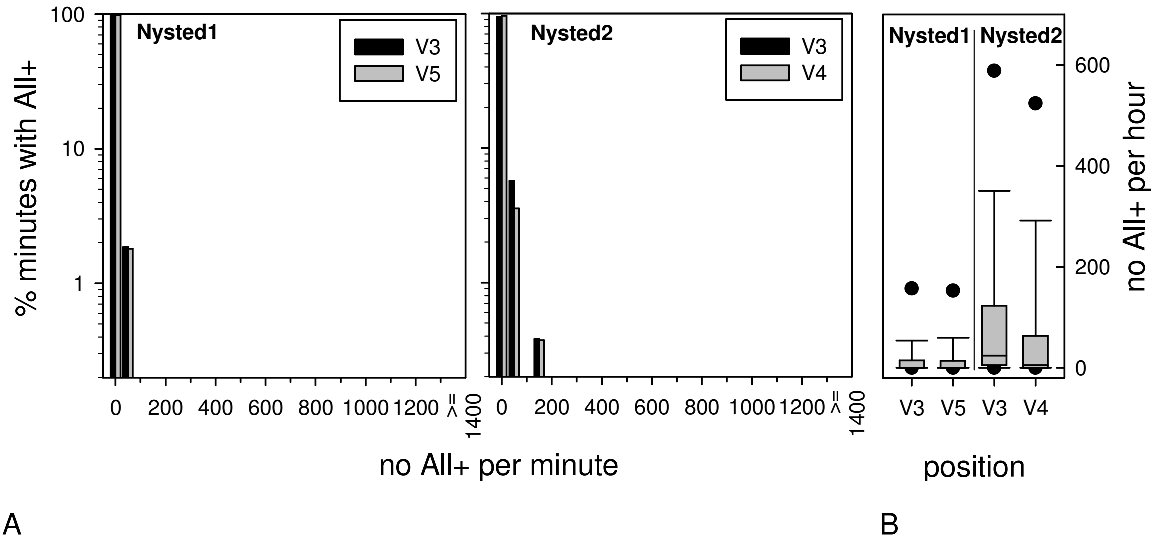


**Figure 30 Amount of registered All+ clicks (background noise) as obtained during the monitoring period at the positions Nysted1 and Nysted2. (A) shows the frequency distribution of All+ per minute, i.e. the % of minutes with a specific amount of All+clicks (bin width = 100 for < 1,400 clicks per minute) from the overall amount of monitoring minutes. Please note, that only all values above 0.2% are visible. (B) gives a box plot showing the 5, 10, 25,50, 75, 90 and 95% percentile of the number of All+ per hour values recorded at the different positions at different depths or different T-POD versions.**

than 80,000 clicks per hour and a frequency higher than 0.5 % of all monitoring minutes in each bin analysed as shown in Figure 29.

Considering all monitoring minutes, the frequency of minutes with specific train classes rises with the number of All+ registered in the corresponding minute until around 200 All+ clicks per minute are reached (Figure 28). For the train classes “Cet high”, “Cet low”, both combined to “Cet all”, and “doubtful”, the frequency keep kind of stable until a maximum of around 400 All+ clicks per minute. For minutes with 400 and more clicks per minute, the frequency of those click train classes decreases with increasing numbers of All+ per minute. For the train class very doubtful the frequency of those trains increases slightly with increasing All+ clicks until 1,000 clicks per minutes are reached.

## 5.5.4. Discussion

Data comparability of T-PODs deployed at the same position at different depths or with different versions is very sensitive to the amount of All+ recorded, i.e. the background noise registered. Devices of different versions (V3 or V5) or at different depths recorded comparable data at monitoring sites in shallow waters. High background noise levels seem to cause incomparability of data. At deep deployment depths, other factors like the diving behaviour of harbour porpoises or oceanographic parameters may cause significant differences in the amount of positive time units registered by the T-PODs installed at different depths.

At positions with a low high frequency background noise level like in the Nysted windfarm (Nysted1, 2) and the intracalibration area (P1, P2), which lie in shallow waters, there is no differences in the results with regards to the “Cet high” class for T-PODs installed at different depths (P1, P2) or of different versions (Nysted1, 2). The same is true examining “Cet all”, except for a significant difference when considering detection positive minutes as time unit at position P2 (Table 7). With regard to data obtained by including doubtful train classes (“?”, “??”), significant differences appear for small time units, especially at position “P2”, in which the T-POD at the seafloor registered more positive time units than the near-surface T-POD. These differences may be explained by differences in the frequency distribution of the background noise (All+ per minute) as shown in Figure 29. At both positions the lower T-POD records more than 200 All+ clicks per minute in more than 0.2 % of the overall monitoring minutes. In these minutes the train detection algorithm finds proportional more very doubtful click trains than in minutes with less all+ clicks (Figure 28). This difference in the background noise spectrum is presumably caused by sediment movements at the seafloor that creates a lot of high frequency noise.

The significant more background noise recorded by the V3 T-POD compared to the V4 T-POD at Nysted2 may also explain the highly significant differences in the data considering the doubtful classes in the analysis, while both versions recorded a similar amount of trains with likely cetacean origin (Cet all).

The high amount of background noise in rather shallow waters at the monitoring site “SgO” supposable caused the significant differences in the data pairs for either different depths or different versions, when considering time units smaller than hour per day. While both T-PODs installed at the sea floor recorded significantly more background noise, the V4 T-PODs, with “noise adaptation” set to “on”, registered much less All+ clicks than the V3 T-PODs. In this example, the T-PODs deployed near the water surface registered significantly more positive time units than those at the seafloor, and the V4 T-PODs registered more positive time units than the V3 T-PODs, regardless of the train classes considered. At high background noise levels like recorded from all T-PODs stationed at “SgO”, the percentage of minutes with “Cet high”, “Cet low” or “?” classes decreases with increasing All+ per minutes, while the percentage of minutes with trains classified as “??” is slightly increasing (Figure 28). The high amount of All+ clicks may reduce the train detection algorithm performance finding click trains being classified as “Cet all” or “?”. A decrease in the performance of the train detection algorithm may therefore explain why the T-PODs with a higher amount of background noise at the seafloor and version V3, respectively, registered highly significant less time units with registrations than their counterparts. This effect disappears when using a larger time unit (hours per day).

Installation depth has a large influence on the amount of positive time units, which gets obvious at monitoring sites with a deep deployment depth, e.g. “K71” and “FeOa”. Here the surface-near T-POD registered more positive time units than the T-POD near the seafloor, highly significant for almost all time units. The difference becomes more prominent considering shorter time units. This difference cannot be explained by the differences in background noise, as the number of All+ per minute is mainly below 300 clicks for all T-PODs installed at those positions (Figure 29). While the detection of any train class increases with increasing number of All+ up to a number of 170 All+ clicks per minute, the percentage of minutes with train classes “Cet high”, “Cet low “and “?” keeps stable until the number of All+ per minutes reaches around 300 clicks. With more than 300 All+ clicks per minute the performance of the algorithm slightly starts to decrease. Opposite to this, the percentage of positive minutes increases slowly for train class "??". With a low number of All+ per minute, most registrations will arise from trains emitted by cetaceans, boats, sonars or similar sources, while at high numbers of All+, natural background noise arising from e. g. rough weather causing waves or sand movements may add significantly to the amount of All+, and hamper the algorithm finding cetacean click trains. The significantly higher amount of detections of positive time units regardless of the composition of train classes ("Cet high" only up to "Cet high to ??") near the water surface is likely caused by several reasons. One reason could be the behaviour of the harbour porpoises. Satellite tagging of harbour porpoises showed that porpoises in Danish waters spent more than 55% of their time within the upper five meters of the water column (Teilmann et al. 2007), while being only 20% or less in water depths of five to ten meter below surface, and even less in deeper depth sections. Therefore a T-POD installed near the water surface theoretically has a higher chance of detecting the animals compared to a T-POD installed at the seafloor. A porpoise swimming in the upper meters of the water column can still direct its sonar beam down to the seafloor. Here a secondary effect may lower the detection rate of T-PODs installed at lower depths. Propagating sound in water may be bended by physical effects due to changes in temperature and salinity throughout the sound's pathway. Thermoclines between porpoise and T-POD may reduce the detection probability of the animals by the device.

At the windpark Alpha Ventus the recording time was only three and a half day. The obtained data are not representative for the area: significant differences found only represent just this time window and disappear when gathering data over a longer time period. We still would like to discuss this data to explain what may have caused the found significant differences, or what could explain such differences when found during a longer observation period.

All four T-PODs registered a similar amount of positive minutes per hour (Table 7), except for the categories "Cet high" only (Figure 26, Figure 27, Table 7). The T-PODs moored near-surface and near the sea floor recorded significantly more minutes per hour with "Cet high" trains than the two T-PODs moored between them. Trains categorised as "Cet high" are commonly trains with shorter click intervals than compared to the doubtful train classes, which also contain cetacean click trains next to those of other sources (Verfuß et al. 2007). Click interval is generally an indicator for the distance between the porpoise and the ensonified surrounding that the harbour porpoise focuses on with its echolocation beam (Akamatsu et al. 1998, Verfuß et al. 2005). It may be that, due to the close proximity of boundaries water surface and sea floor, nearby porpoises produce faster trains, i.e. trains with shorter click intervals when facing toward the upper or lower T-PODs, while when echolocating towards the middle T-PODs the porpoises adapt their echolocation to further distances and hence produce trains with longer click intervals. This would explain the comparability of data when including other click train classes next to Cet high into the analysis.

Despite the significant difference in the amount registered data when considering "Cet high" train class, the T-PODs moored near-surface and near the sea floor recorded a similar amount of positive time units (Figure 27). The porpoises may have spend a similar amount of time near the water surface and near the sea floor during the monitoring period, e.g. by foraging benthic fish, causing a regular diving down to the sea floor, or no thermoclines hindered the T-POD near the sea floor in registering harbour porpoises swimming in the upper part of the water column. Further research needs to be done on investigating the effect of harbour porpoise behaviour and oceanographic parameters on the detection performance of T-PODs installed at different depths. It still has to be kept in mind that the monitoring time at position “AV” was quite short, and different results may be derived from a longer observation period. Examining positive time units per day would biologically not be reasonable at this station.

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## 5.6. Analysis of T-POD-data with different parameters

### 5.6.1. Introduction

T-PODs have been used in a wide range of passive acoustic monitoring projects (e.g. Bailey et al. 2010, Carlström et al., 2009, Carstensen et al. 2006, Diederichs et al. 2007, Simon et al. 2010, Todd et al. 2009). A lot of studies use different kind of parameters for analysing the monitoring data. In the present study, data obtained over long time periods and at a wide range of monitoring positions in the North and Baltic Sea are analysed with different parameters to investigate possible correlations between the different parameters.

### 5.6.2. Methods

Data from a total of ten positions of the harbour porpoise monitoring in the German Baltic Sea (Verfuß et al. 2008) was chosen for analysis – five positions in the Fehmarnbelt and adjacent coastal waters and five in the Kadet trench and adjacent coastal waters. These data covered around 3,723 monitoring days, obtained within the time period of March 2005 to November 2006. North Sea data were obtained from 13 positions in the windfarm area Alpha Ventus covering around 763 monitoring days, obtained within the time period of June 2005 to August 2006. Data sets were processed with the train detection algorithm included in the T-POD.exe software V8.3.

Following parameters were considered for analysis:

<u>Detection positive time unit per monitoring unit:</u>

A **detection positive time unit** is a time unit, in which the algorithm detected and classified a click train. Only train classes “Cet high” and “Cet low” were considered for analysis in the present study.

Detection positive time units were as following:

- ⇒ Detection positive minutes (DPM)
- ⇒ Detection positive 10 minutes (DP10M)
- ⇒ Detection positive hours (DPH)
- ⇒ Detection positive days (DPD)

The percentage of detection positive time units was calculated by dividing the number of positive time units by the total number of time units of the corresponding monitoring time period.

As monitoring time period, “day” and “month” was taken, respectively (e.g. DPM per hour, DPD per month).

Encounter & Waiting time

An **encounter** is a time period containing successive train detections (Figure 31) with a time period between click trains not longer than a certain time. This time period is set to 10 minutes in the present study according to Carstensen et al. 2006. A new encounter starts if the time in-between the last click of a click train and the first click of a succeeding click train is longer than 10 minutes. This time is called **waiting time**. The **length of an encounter** is the time between the first and the last click of an encounter.

For the determination of detection positive time units, train details were exported from the data sets with the T-POD.exe version 8.3 and imported into an ACCESS-data base. The %DPM, %DP10M, %DPH and %DPD were determined for each day and month, respectively. X/y data sets were built from the different time units from each monitoring day and month, respectively, for a direct comparison of the different parameters analysed. A non-linear regression was conducted on these data sets with SigmaPlot V11.0 (Systat software).

Starting and ending time of encounters and waiting times with regards to “Cet high” and “Cet low” train classes were exported from the data with the T-POD.exe programme version 7.41, as the export of this parameter is not offered in later T-POD versions. The exported data were imported into the ACCESS-data base mentioned above. The mean number and length of encounter as well as the mean length of waiting time was determined per day and month, respectively, and assorted to the corresponding results of the positive time units.

### 5.6.3. Results

All positive time units are significantly correlated ($R^2$>=0.893, P<0.001) with a hyperbolic function (Figure 33, Figure 32). The parameters show a linear relationship up to ca. 20-40% of the y-value and then the curve flattens.

Number of encounter and length of encounter per month show a hyperbolic decay relationship to the log(waiting time), while the number of encounter and length of encounter per month is linearly correlated (Figure 34).

Mean encounter length and mean waiting time per day over the corresponding time unit (%DPM, %DP10M and %DPH) are shown in Figure 35. The same is given as average per

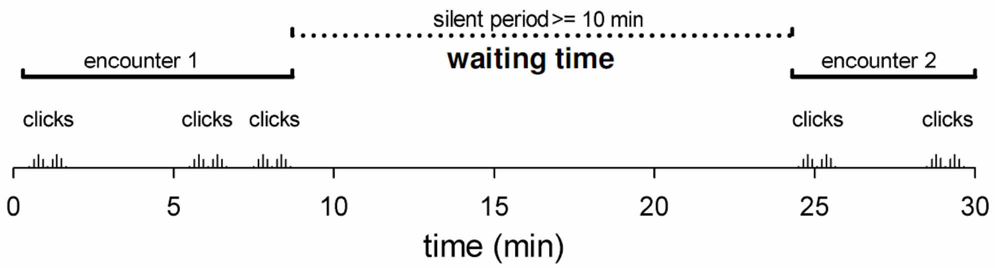
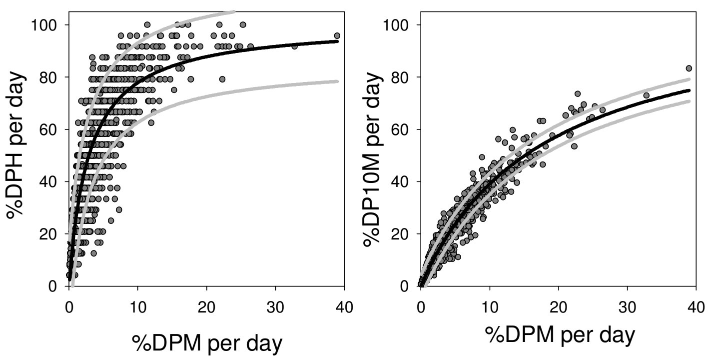



**Figure 31 The first click of a click train starts an encounter, ending with the last click of successive trains with silent periods between each other not longer than a certain time (ten minutes). A silent period longer than ten minutes stops an encounter and starts the waiting time. This will end with the first click of a new click train.**

month in Figure 36.

Short mean encounter lengths per day are only present at low percentage of DPM and DP10M, respectively (Figure 35). With higher DPM-values small encounter lengths disappear. This phenomenon is hardly visible for DPH, starting at values of 80% for DPH per day. No other correlation gets obvious for this parameter. Mean waiting time per day is widely dispersed for small positive time units, but decrease linear with increasing log (time unit) while the variance decrease (Figure 35). Mean waiting time per hour is widely distributed for an encounter length of one, while small waiting times are absent for longer mean encounter lengths. The minimum waiting time detected decrease with increasing encounter length per day (Figure 35). No other correlation gets obvious.




A B

**Figure 33 Correlation between detection positive hours (DPH) per day (A) / detection positive 10 minutes (DP10M) per day (B) and detection positive minutes (DPM) per day. Black lines give the predicted mean, grey lines the 95% confidence interval of the non-linear (hyperbolic) correlation.**

Mean encounter length per month shows a two clustered distribution when in dependency with any detection positive time unit (Figure 36). While the first cluster at low detection positive time units are derived by data from the Baltic Sea, the cluster at higher values of % positive time units are from data of the North Sea. The latter shows a linear relationship between encounter length and positive time unit. Mean waiting time per month is negatively correlated with each positive time unit per month with a log-log-linear correlation (Figure 36), except with regard to DPD when reaching 100% of positive days.

The log mean waiting time per month is also negatively correlated with the mean encounter length per month.

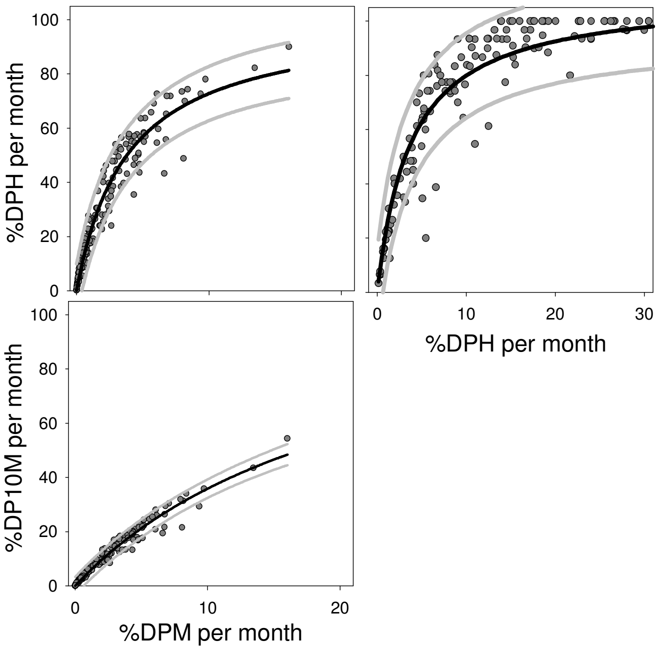



**Figure 32 Correlation between detection positive hours (DPH) per month and detection positive minutes (DPM) / detection positive hours (DPD) per month as well as detection positive 10 minutes (DP10M) per month and detection positive minutes (DPM). Black lines give the predicted mean, grey lines the 95% confidence interval of the non-linear (hyperbolic) correlation.**

## 5.6.4. Discussion

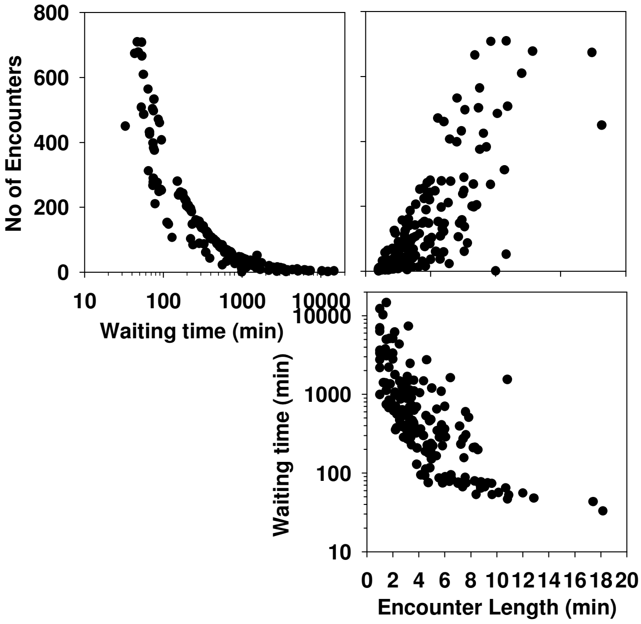



**Figure 34 Correlation between the mean number of encounters, mean waiting time and mean encounter length per months.**

Detection positive time units are highly correlated with each other showing a hyperbolic function (Figure 33, Figure 32). There is a more or less linear relationship between a shorter time unit to a longer one for positive time units up to 20 to 40%. In this region the parameters should be directly comparable. Beyond 20 to 40% it is advisable to use a finer scale unit as with the shorter time unit, changes in the amount of positive time units get more obvious. Nevertheless it is advisable to examine several time units. The analysis and presentation of data with different time units may give further insights into the behaviour and habitat use of the harbour porpoises in the area monitored. Above 20 to 40% of a longer time unit, those values get more dispersed for a specific shorter time unit (Figure 33, Figure 32), speaking for differences in the habitat use of different monitoring positions or monitoring time. E.g. while porpoises can be detected on 10% of the minutes monitored, those can be distributed within 60% to 85% of the monitoring hours. The porpoises may either stay in the area for a longer time within each hour in an area, or a shorter time per hours but visit the area more frequently, i.e. more hours per day.

While for the parameters encounter per day there is no obvious correlation with positive time units, except for a need of a certain amount of %DPM to retrieve longer encounters, waiting time decrease with increasing % of positive time units, which should be expected, as detections of porpoises end any waiting time period.

We'd like to give further thoughts to the parameters encounter and waiting time:

Due to the definition of encounter and waiting time (Figure 31), a monitoring period consists of the same number of encounters and waiting times, not considering the start and end of the monitoring period, at which waiting time and encounters are truncated, and therefore shouldn't be considered. This leads to the assumption that the sum of mean encounter length (mean EncL) and mean waiting time (mean Wait) multiplied by the number of encounters (No Enc) equals (nearly) the monitoring time:

No Enc x (mean Wait + mean EncL) ~= monitoring time

Or

No Enc x (mean Wait + mean EncL) / monitoring time ~= 1

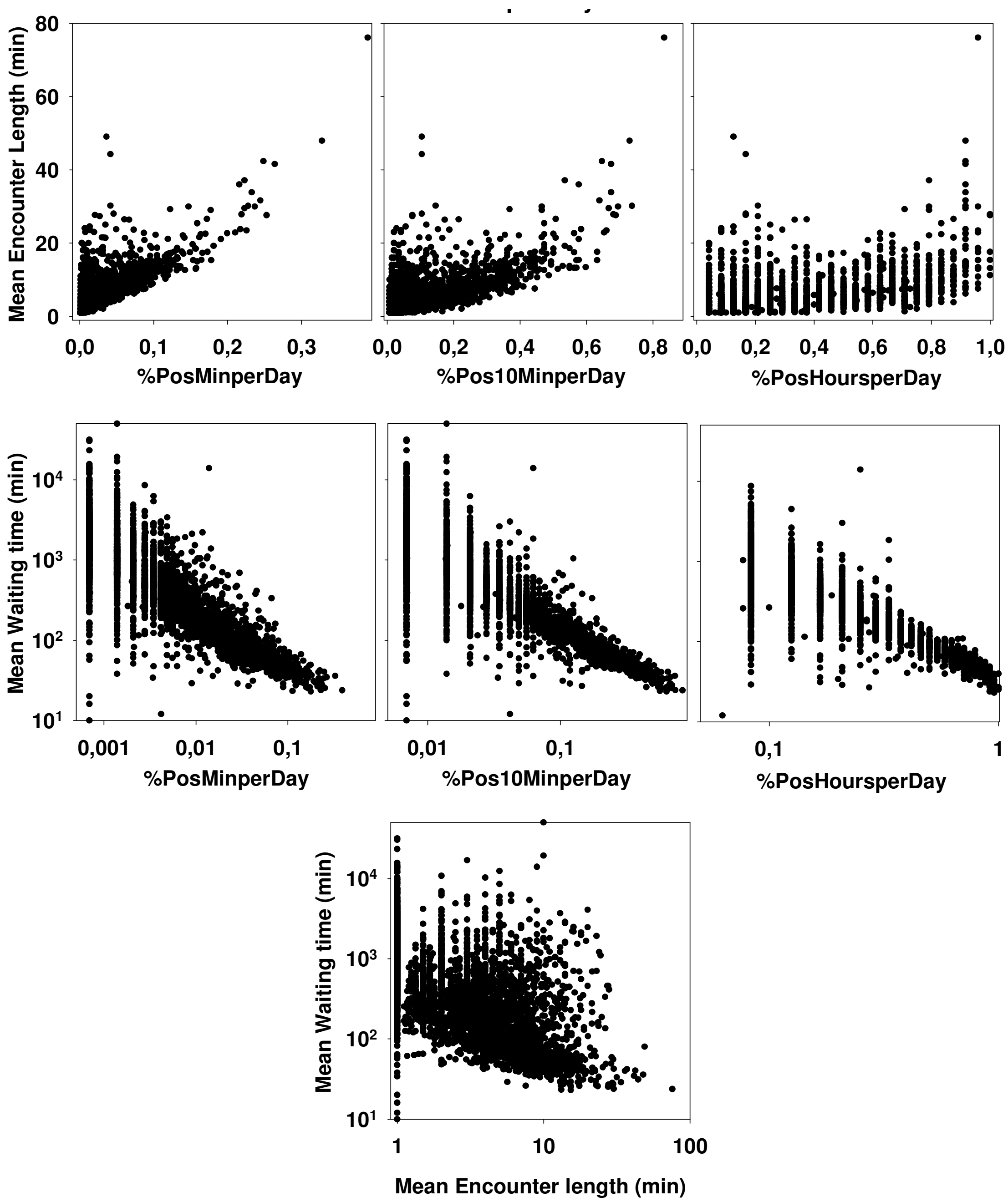



**Figure 35 Mean encounter length and mean waiting time per day versus percentage of positive minutes / 10 minutes and hours per day.**

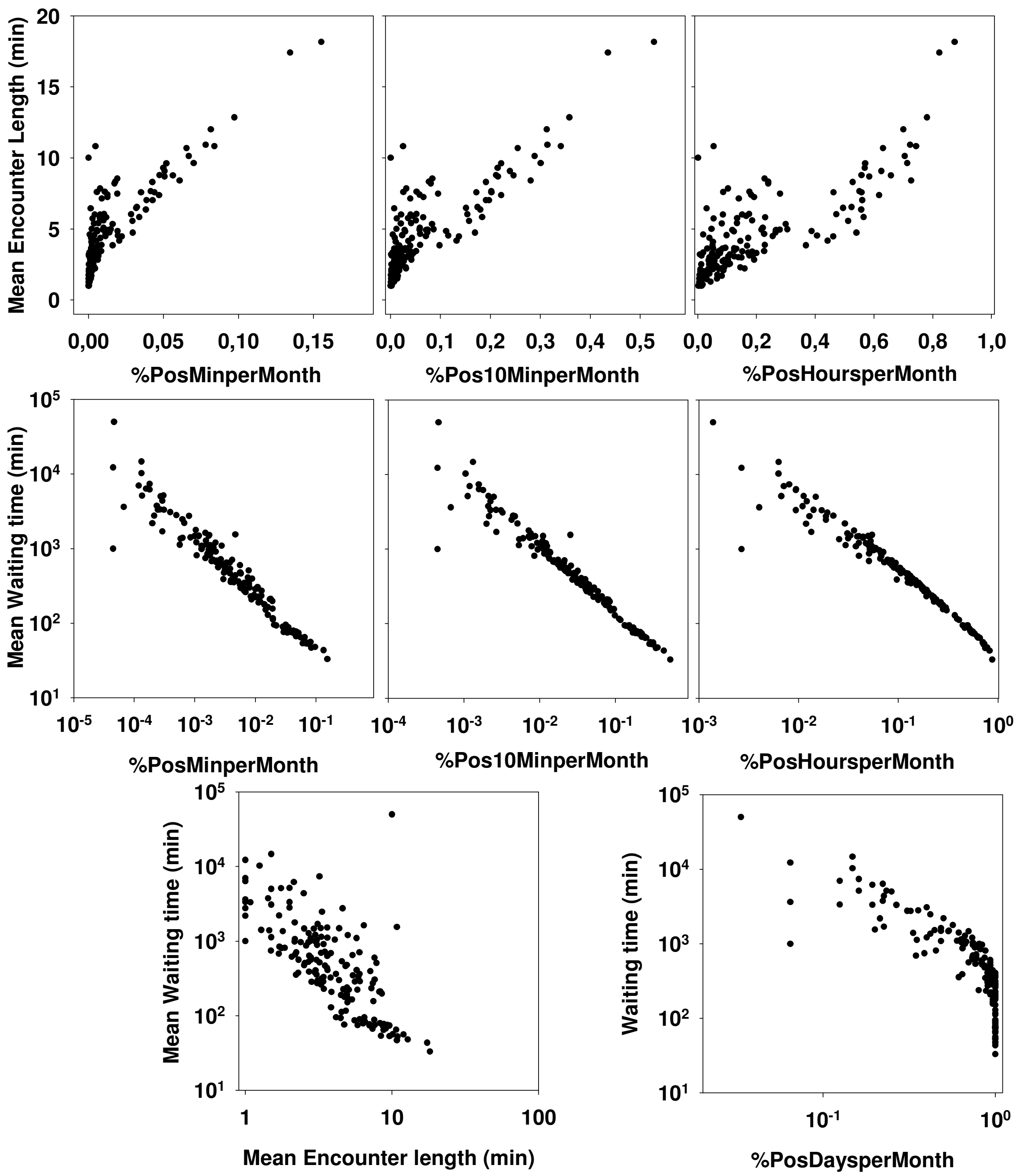



**Figure 36 Mean encounter length and mean waiting time per month versus percentage of positive minutes / 10 minutes and hours per month.**

We calculated the ratio of No Enc x (mean Wait + mean EncL) and monitoring time for a monitoring time of one month to verify this relation. It reveals that this relation is obvious for months with a high number of encounters (> ~ 75) (Figure 37).

Encounter length is usually quite small in comparison to waiting time (Figure 37). Therefore the encounter length may be neglectable in the formular:

No Enc x (mean Wait) / monitoring time ~= 1 (Figure 37)

This is true to some extent.

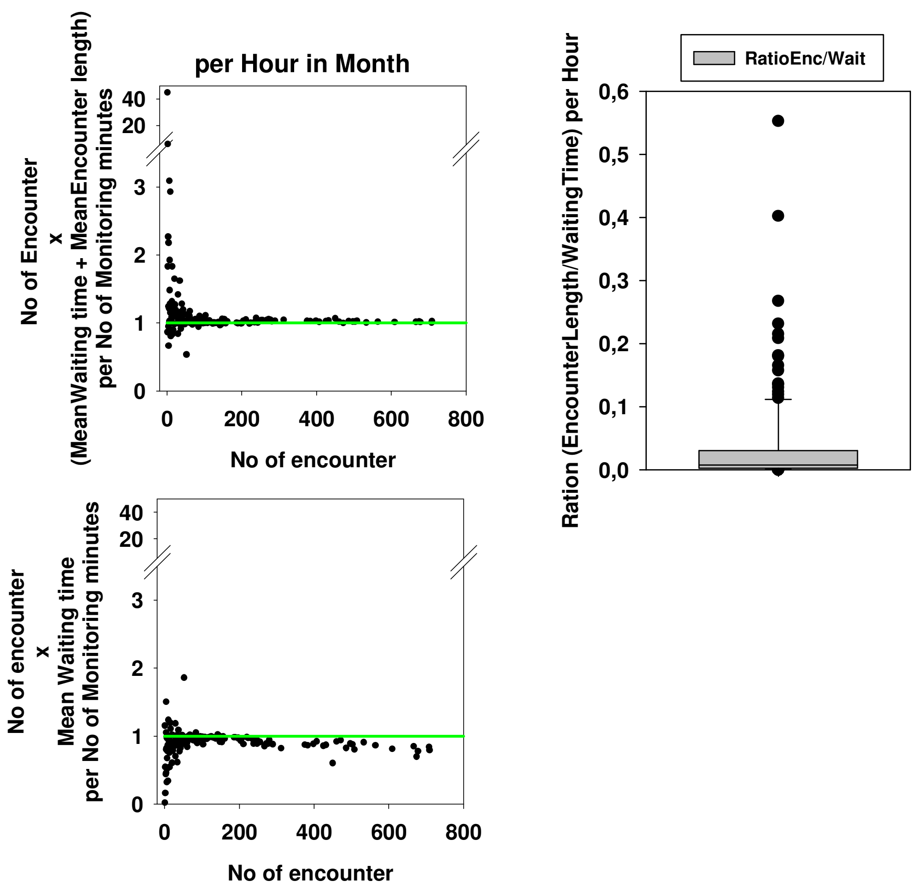



**Figure 37 Calculated value of the expression "number of encounters times (mean waiting time + mean encounter length) per monitoring minutes" versus the number of encounter per hour in one month (upper left graph). Calculated value of the expression "number of encounters times mean waiting time per monitoring minutes" versus the number of encounter per hour in one month (lower left graph). Ratio build from the mean encounter length and mean waiting time per hour (right graph). Explanation see text.**

## 5.6.5. References

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## *5.7. Comparison of C-POD and T-POD data with broadband recordings*

During the intracalibration field research as described in chapter 5.4, broadband recordings should have been done during the monitoring period at the anchoring place of the intracalibration rig. In both years of AMPOD-intracalibrations, 2007 and 2008, weather conditions were too bad to conduct proper recordings at the anchoring positions. Therefore in 2008, sound recordings were done in a calm bay with synchronous recordings of a T-POD and a C-POD. All three recording devices picked up a harbour porpoise approaching the set-up. Data were analyzed in the frame of a student work and presented as poster at the ECS-conference 2009.

### 5.7.1. Introduction

C-POD, a new generation of click detector and successor of the T-POD, was released recently for the acoustic monitoring of odontocetes (www.chelonia.co.uk). While T-PODs register the time of occurrence and duration of porpoise-like click sounds, C-PODs give additional information like frequency and amplitude of clicks. For ongoing studies the question is: How comparable are data obtained by these two POD models?

### 5.7.2. Methods

A C-POD, a T-POD and a hydrophone were fixed in a wooden rig (Figure 38) and moored one meter below water surface in the Danish Belt Sea. They picked up echolocation click trains of a harbour porpoise approaching the research vessel. Hydrophone data were digitized at a sampling rate of 400 kHz. Sound parameters of the POD-data were exported and compared to hydrophone data, which were analysed with Avisoft (Saslab).

Following sound parameters were chosen:

**T-POD**

⇒ Click interval ($CI_{TPOD}$), i.e. the time in-between two successive clicks

⇒ Length of click ($D_{TPOD}$), as registered by the T-POD

**C-POD**

⇒ Click interval ($CI_{C\text{-}POD}$)

⇒ Length of click ($D_{C\text{-}POD}$), derived by the product of *Number of cycles* and *Average frequency* of a signal as given by the C-POD

⇒ Frequency ($F_{C\text{-}POD}$), the *Average frequency* of a signal as given by the C-POD

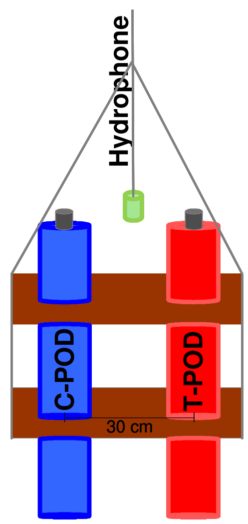



**Figure 38 Array of T-POD (red), C-POD (blue) and hydrophone (green) in a rack consisting out of two wooden plates (brown) and rope holding the array one meter below water surface.**

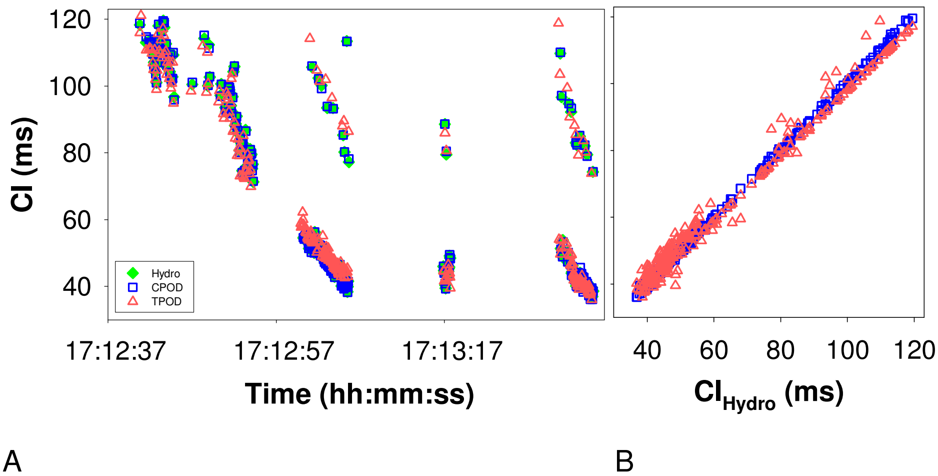



**Figure 39 Click interval over time (A) as analysed for the T-POD (red), C-POD (blue) and the hydrophone (green). (B) shows the Click interval of the T-POD and C-POD depending on the click interval as obtained from the hydrophone data.**

⇒ Amplitude ($A_{C\text{-}POD}$), as given as a relative value ($P_{pp}$) by the C-POD

**Hydrophone**

⇒ Click interval ($CI_{Hydro}$)

⇒ Amplitude ($A_{Hydro}$): as peak to peak value from the amplitude-time signal

⇒ Frequency ($PF_{Hydro}$): as peak frequency of the corresponding power spectrum

⇒ Click length ($D_{Hydro}$): as time in-between the visually recognizable start and end of a click

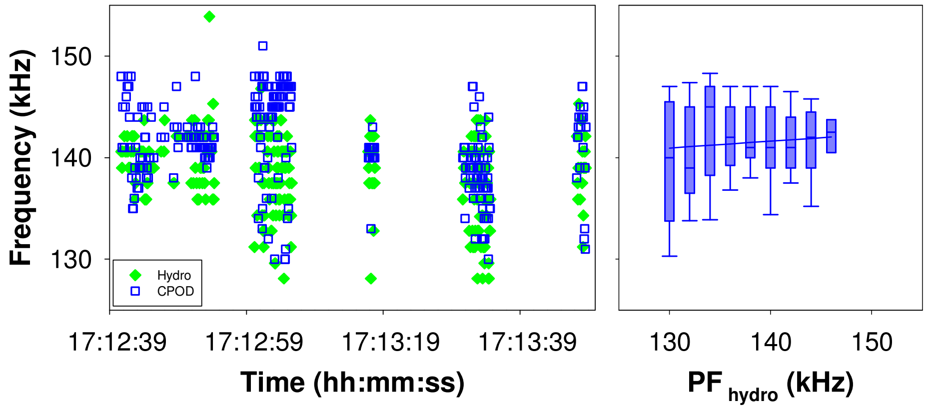
Click interval was used to allocate the sound parameters of the same click gained by the different systems (Figure 39). $PF_{Hydro}$/$AF_{C\text{-}POD}$ data pairs were grouped into $PF_{Hydro}$-classes (2kHz bin-width) and quartiles of AFC-POD were determined. A regression analysis was done over the $AF_{C\text{-}POD}$-median / $PF_{Hydro}$-class pairs. $D_{Hydro}$/$D_{C\text{-}POD,TPOD}$ pairs were grouped into $D_{Hydro}$-classes (50 µs bin-width) to determine the quartiles of $D_{C\text{-}POD,\ TPOD}$. A regression analysis was performed over the corresponding x/y data pairs. $A_{Hydro}$/$A_{C\text{-}POD}$ data pairs were grouped into $A_{Hydro}$-classes (20 mV bin-width) and quartiles of $A_{C\text{-}POD}$ were determined. Also here a regression analysis was performed over the corresponding x/y data pairs.

## 5.7.3. Results

$CI_{Hydro}$ matches well with $CI_{C\text{-}POD}$ and reasonable with $CI_{TPOD}$ .

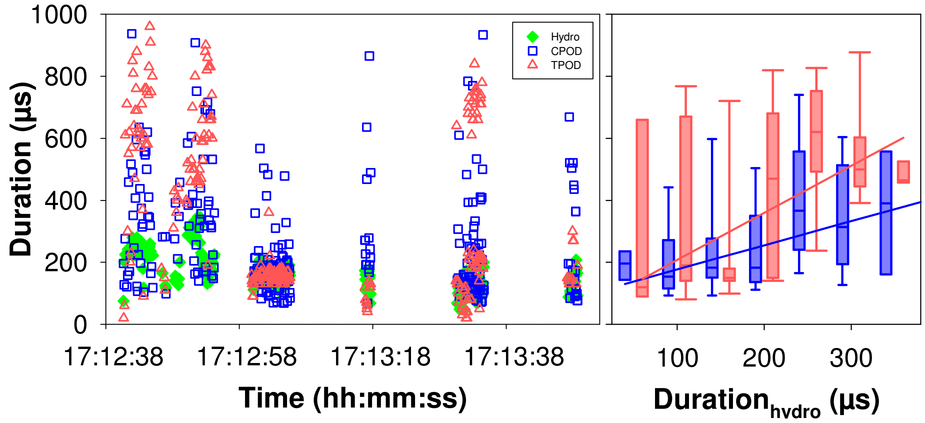
$PF_{Hydro}$ and $AF_{C\text{-}POD}$ cover the same frequency range (Figure 40A). Regression analysis of the $PF_{Hydro}$-classes/$AF_{C\text{-}POD}$-median pairs showed no correlation (R2=0.05; P=0.57) (Figure 40B).

While $D_{Hydro}$ is around 200 µs, $D_{C\text{-}POD}$ and $D_{TPOD}$ are more dispersed (Figure 41A). Regression analysis of $D_{Hydro}$-classes/$D_{C\text{-}POD,T\text{-}POD}$-median pairs showed a significant positive correlation ($R^2$=0.73; P=0.02 / $R^2$=0.67 P=0.02) (Figure 41B).



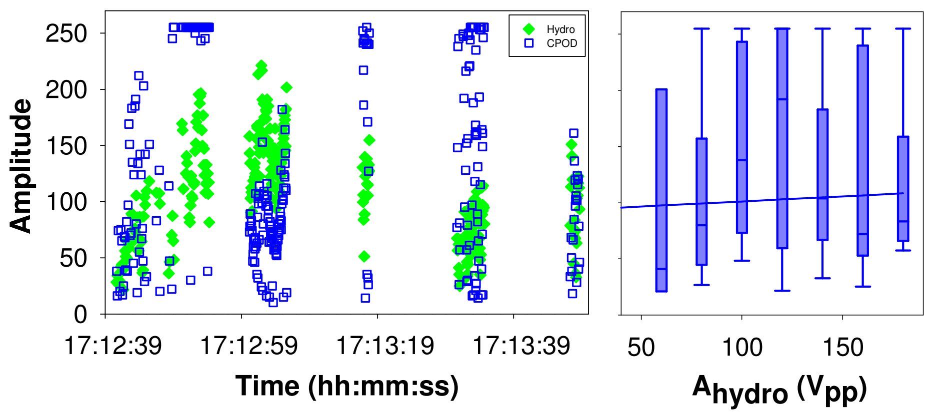

A B

**Figure 40 Frequency over time (A) as analysed for the C-POD (blue) and the hydrophone (green). (B) shows the frequency distribution (10, 25, 50, 75, 90% percentile) of the C-POD grouped in frequency bins as obtained from the hydrophone data.**




A B

**Figure 41 Duration over time (A) as analysed for the T-POD (red), C-POD (blue) and the hydrophone (green). (B) shows the duration distribution (10, 25, 50, 75, 90% percentile) of the T-POD and C-POD grouped in duration bins as obtained from the hydrophone data.**




A B

**Figure 42 Amplitude over time (A) as analysed for the C-POD (blue) and the hydrophone (green). (B) shows the amplitude distribution (10, 25, 50, 75, 90% percentile) of the C-POD grouped in amplitude bins as obtained from the hydrophone data.**

$A_{Hydro}$ and $A_{C\text{-}POD}$ are both relative values for the sound pressure of the porpoise clicks. They do not match well (Figure 42A). Regression analysis of the $A_{Hydro}$-classes/$A_{C\text{-}POD}$-median pairs showed no correlation ($R^2$=0.02; P=0.74) (Figure 42B).

### 5.7.4. Discussion

All three systems successfully recorded a visually confirmed harbour porpoise. Frequencies, depict by data of C-POD and hydrophone, were in the frequency range of porpoise echolocation. The mismatch between average and peak frequency may be due to calculation differences in the analysis. The prolonged click duration in T-POD- and C-POD-data may be caused by reflections of the set-up. The hydrophone is receiving echoes earlier because of its middle position, resulting in a shorter mean duration of the clicks. Amplitude differences may be caused by receivers being exposed differently to the narrow porpoise echolocation beam.

The C-POD proves to be a valuable successor of the T-POD, giving additional information about the recorded signal. A different set-up that won’t reflect back the harbour porpoise clicks may have given a better match of the parameters compared.

# 6. Guidelines

Based on the findings within the AMPOD project and the experience gained during the acoustic monitoring of harbour porpoises in environmental impact studies as well as in population monitoring we recommend the following:

**Clearly define the aim of your study before starting it**

Think about how many measuring positions you need, and where to set them up, to be able to answer the questions raised.

**Keep your data comparable**

Different deployment methods, different devices, the same devices with different sensitivities, different settings, different analysis programmes, may result in incomparability of data.

1.) Calibrate your recording devices before deployment – at least once a year, after repair, or after any event that may have affected the receiving sensitivity (e.g. hard knocks).

2.) Use devices of the same detection threshold to facilitate comparability of data, or make sure that you receive comparable data with devices of different sensitivity.

3.) Use devices of the same version to facilitate comparability of data, or make sure that you retrieve comparable data with devices of different versions.

4.) Use the same settings throughout the study period, or make sure that data retrieved with different settings are comparable.

5.) Use the same deployment locations throughout the study period.

6.) Use the same deployment depth on each measuring position. Ideal would be several devices anchored at different deployment depths of the same measuring position.

7.) Use proper statistics with a corresponding research design if direct comparability of data retrieved by the devices used is not given

8.) Analyze data that you wish to include into the same study with the same program. If new data shall be compared with data of previous studies, re-analyse those data if necessary.

9.) In publications, give an exact description of the monitoring device, its version, its sensitivity, its settings, the deployment method, deployment depth, analysis program (name, version, last changing date), and a clear definition of the parameters analyzed.

10.) Remember the aim of your study before analysing the data. Think about which parameters are useful to answer the questions raised.

11.) Look into the literature if those parameters you wish to analyze are already named and defined, and use those names if feasible. Define the parameters you use properly.

12.) Review your data to find out if the amount of false alarms and background noise allows you to use your data as they are. If not, adapt them accordingly.

13.) Do a power analysis on your retrieved data to assure that you are in fact able to detect significant differences with the set up you've chosen. Retrieve baseline data if possible (they probably exist from other studies already?)

14.) It is recommended to retrieve more data points than the minimum proposed by the power analysis, as the variance of data is changing a lot during the course of time, or you may not receive as many data points as you would want to achieve due to loss of data (malfunction or loss of devices).

15.) In environmental impact studies, a BACI design (BACI: Before After Control Impact) is recommended. The area should be monitored well before, during and after the impact. A true reference area, monitored in the same time period, but not being affected by the impact, reveals the general trend of the dynamic in animal density.

Following parameters are recommended to be used in static acoustic monitoring studies:

- Percent of detection positive time units per monitoring time unit
- Choose the length of the time unit with regard to
  - Animal density in study area
  - Question raised (e.g. Long term / short term effect studies)
- Waiting time
- Encounter duration

# 7. Appendix

## *7.1. Calculating sample size*

*This chapter is a summary of a cancelled talk authored by Sven Adler, University of Rostock, Germany, at the AMPOD-symposium (see chapter 7.3).*

In terms of environmental management it is always a critical question how many samples must be taken to prove a hypothesis. If the distribution functions of animals or plants and the related parameters of the distribution are known, power analysis provide a way to find the optimal sample size, to answer the question whether the parameters of a distribution are changed between locations, seasons or years.

In terms of marine mammals, it is of interest, how many samples are required to prove whether a population is increasing or decreasing in relation to a fixed location or time. E.g. if the mean number of harbour porpoises is 2 animals/km² in the Baltic Sea in the year 2010 (number of samples =9, standard deviation = 0.1), how many samples are required in the year 2015 to find out whether the mean number of porpoises has changed to 1.8 animals/km² or 2.2 animals/km² (delta= $mean_{2015}$-$mean_{2010}$ = 0.2 animal/km²)?

Functions for standard statistical software provides calculation for power analysis based on normal distributed data, calculating to a given delta, standard deviation, and power, the number of samples (n) that are at least required to prove delta. The n depends on delta and the given standard deviation, assuming that the standard error is equal for both populations.

Using the open source statistical Software R (R Development Core Team) the following code will solve the problem described above:

***power.t.test(sd=0.1,power=0.95,delta=0.2,sig.level=0.05,type="two.sample",alternative ="one.sided" )***

Output:

*Two-sample t test power calculation*

*n = **6.23***

*delta = 0.2*

*sd = 0.1*

*sig.level = 0.05*

*power = 0.95*

*alternative = one.sided*

The output of the function tells us, that at least 7 samples are required to find a significant decrease of the population with 10% of the mean.

The same result can be found using a simulation. Applying a random generator for normal distributed data (in R: rnorm) with the standard deviation of 0.1 and a mean 10% less than 2 animals (1.8) the n can be calculated using the following loop, whereas the calculated p value is the probability to find a significant difference between the mean of the two populations:

```
result<-matrix(ncol=2,nrow=30)
for (k in 2:30)
        res<-NA
        s<-0
        for (i in 1:1000)
        {
                sample1<-rnorm(mean=2,sd=0.1,n=9)
                sample2<-rnorm(mean=1.8,sd=0.1,n=k)
                res[i]<-t.test(sample1,sample2)[[3]]
                if (res[i]>0.05)
                        s<-s+1
        }
        p<-1-s/1001
        result[k,1]<-k
        result[k,2]<-p
}
```

(For explanation of the algorithm see standard literature about R and S-PLUS (e.g. Venables and Riply 2002, Crawley 2007, Dalgaard 2008, respectively the help files available at the R homepage (http://www.r-project.org/)

For receiving the results of this simulation, which kind of probability of detecting a significant difference you can gain with a certain amount of samples, type result to the R-console after running the simulation.

As can be seen from Figure 43, the number of required n calculated by the loop is the same as was calculated by the function power.t.test. In contrast to the function power.t.test where it is assumed that the standard deviation is equal between both samples, in the loop the standard deviation of the second sample can be varied, as it can not be assumed that the standard deviation between two samples is equivalent, dealing with marine animals. E.g., if the standard deviation would be higher in the second population (sd=0.15 or sd=0.2) the number of the sample size that is required to find a significant decrease is much higher (n = 15, n = 23, Figure 44).

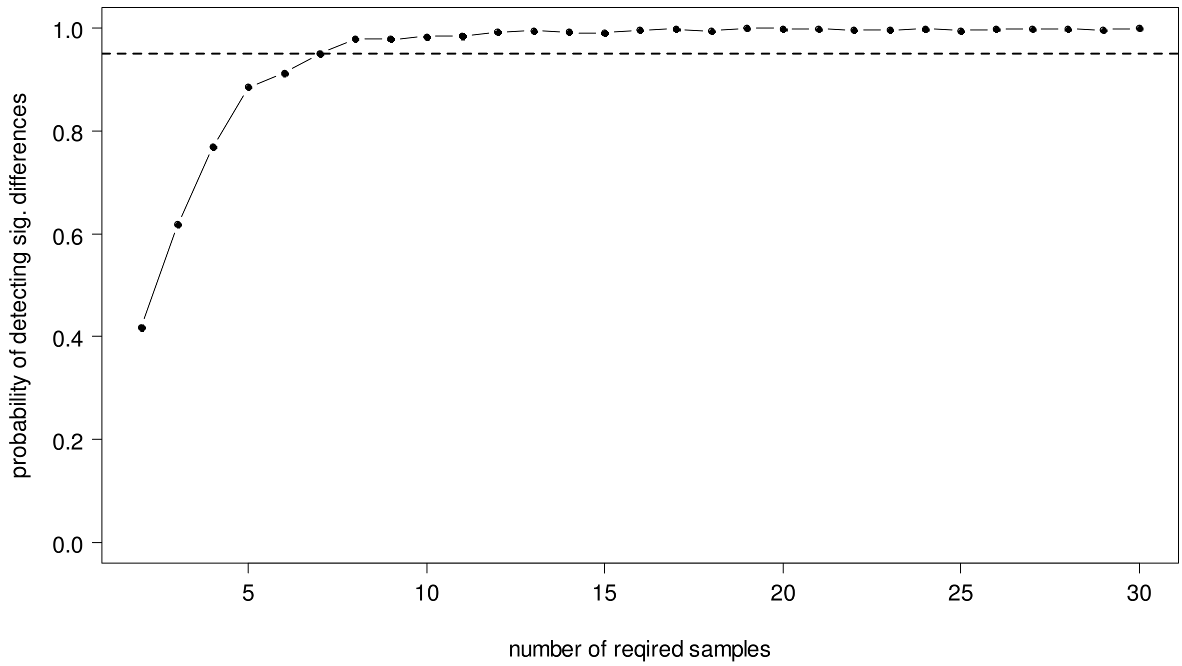



**Figure 43 Required number of samples to find significant differences higher than 10% from the given mean = 2 and the related standard deviation of 0.1.**

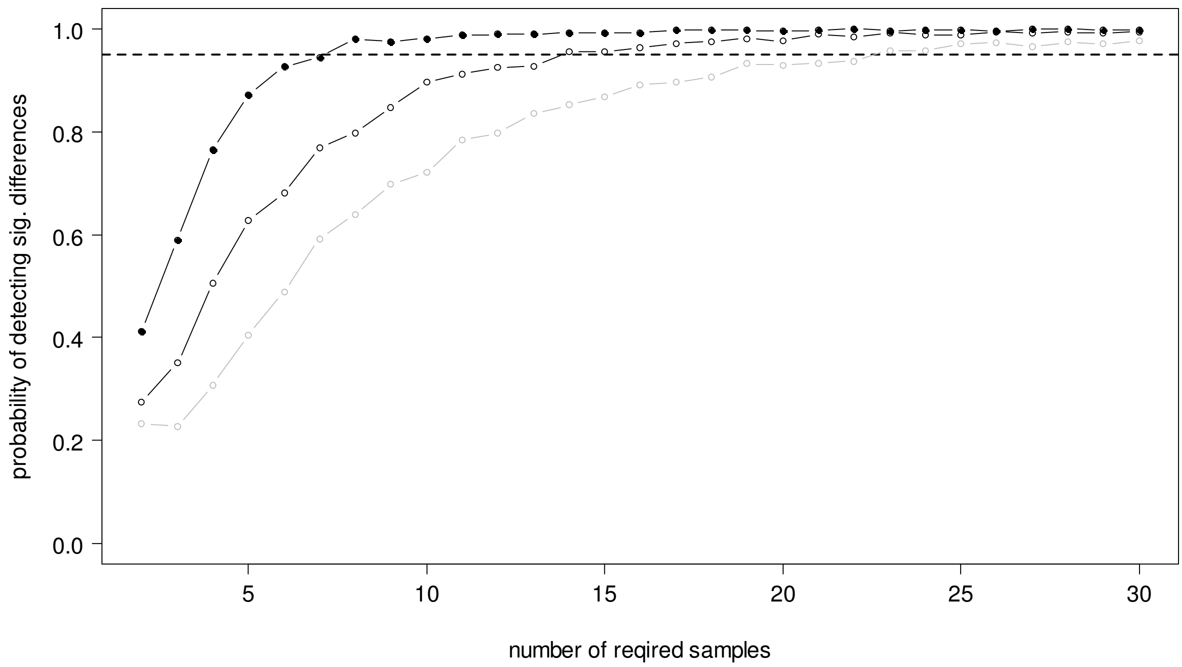



**Figure 44 Required number of samples to find significant differences higher than 10% from the given mean = 2 and the related standard deviation (sd) of 0.1 (black circles), sd = 0.15 (open, black circles) and sd = 0.2 (open, grey circles).**

This kind of simulation can be done for each assumed differences in the means and differences in the standard deviations. On the other hand the underlying distribution (normal distributed) and the related function *rnorm* and *t.test* can be replaced by others, more appropriate functions, that express the distribution of the marine mammals more correctly. In areas with high species abundances the use of normal, lognormal, gamma, or poisson distribution might be adequate, in areas in which you receive data sets with many zeros, the use of a negative binomial function is more appropriate.

Such kind of simulation studies can therefore calculate the required number of samples much more flexible as standard functions in statistical software packages. Required are base line studies, where the standard deviation should be low in comparison with the mean, as this would be reducing the required samples size dramatically.

## *7.2. History of 'POD' design, click detection, and other issues*

*This chapter is contributed by the POD-manufacturer: Nick Tregenza, Chelonia Ltd.*

### 7.2.1. Proto-POD and T-POD

#### Origin and design

In 1991-2 volunteer observers on the gill netting fleets of Cornwall, UK, and southern Ireland found a large by-catch of porpoises (*Phocoena phocoena*) where a large decline in small cetaceans was already known. To provide a constructive way forwards a tool was needed to reveal the porpoises' movements around the nets. The first POD (POrpoise Detector), retrospectively called the 'Proto-POD', was developed to meet this need.

It was based on a system for detecting porpoise clicks from a moving yacht that had already been developed by Oliver Chappell, Russell Leaper and Jonathan Gordon (Chappell et al. 1996) with funding from IFAW (International Fund for Animal Welfare). To distinguish porpoise clicks from the huge numbers of marine broadband clicks it compared, within a click, the energy at porpoise frequencies with the energy at lower frequencies. The IFAW detector also measured the amplitude of transient events, and detected clicks on both a bandwidth-related criterion, and an environmentally determined amplitude criterion.

The first POD did not embody any concept of a click as a spike in intensity. It continuously compared four bands of ultrasound and counted periods when the energy in the porpoise band exceeded each other band by separately user-defined ratios. It was, in effect, a simple analogue spectrum analyser. The spike concept was replaced with a single amplitude threshold to simplify the system avoid the complexities of a moving threshold based on non-porpoise spikes levels. It ran for 10 days, and stored, in different duration classes, counts of clicks that had met the user-defined selection criteria. Because of the flexible detection configuration a range of experiments on porpoise detection were possible.

<u>Lessons learned from the Proto-POD:</u>

1. False positives from boat sonars at porpoise frequencies are a problem that could not be overcome by adjustment of click selection parameters.
2. No 2-filter detection configuration was as good as the 3 and 4 filter configurations possible with this system (but filter bandwidth was not adjustable in those tests).
3. Insensitive configurations can have very high specificity v. background noise, but not high specificity v. boat sonars.
4. Dolphins could be detected with this system, but with very high false positive levels.
5. D-cells are structurally weak and must be protected from the axial loads produced by end impacts on the housing.
6. Porpoise group-size estimation from these data was very poor.

re (2), Ed Harland, of Chickerell Bioacoustics, who contributed to the development of the Proto-POD, described a porpoise-only detector (SPUD) that was at an advanced stage of development at the ECS, Gdynia, Workshop on SAM of porpoises. This uses FFTs to provide multiple passband outputs, and potentially great flexibility of configuration. The commercial version is awaited.

re (4): Dolphin clicks are not very distinctive. Their detection could be approached by analysis of the characteristics of clicks in temporal clusters, but this appears to have serious limitations and temporal information that could be used to identify trains also appeared to be a valuable method for these animals.

<u>Improving the Proto-POD</u>

To extend the role of the POD to fishery interactions with dolphins and reduce (1) above alternative designs were considered.

A stereo system could show a common directional origin for groups of clicks and had been demonstrated by the IFAW team, now including Douglas Gillespie. This was rejected because of the impact on battery and memory size, and potentially poor performance on (1).

Analysis of the characteristics of groups of clicks (quasi-trains) appeared very powerful for porpoises, much weaker for dolphins and boat sonars, and costly on power, memory and complexity.

So a POD that logged click times, the T-POD, was designed, to make post-processing for trains possible. Various design compromises, mainly to increase running time on batteries, were selected from the range of possible configurations:

<u>T-POD design</u>

A two filter analogue system was adopted, on the estimation that the known penalty of (2) could be outweighed by the second signal detection stage of train detection.

To optimally minimise the penalty of (2) flexibility of filter passband width (‘Q’) and centre frequency were included.

To enable dolphin detection without prior knowledge of the frequency of their clicks the system stepped through 6 user-defined sets of configuration each minute, each of which could have a different target and reference filter, ratio etc.

Click time and duration were the only parameters logged.

<u>…and evolution of versions</u>

Successive versions of the T-POD had different features based on evidence from previous versions:

V1 T-PODs allowed testing of optimal Q values for target and reference filters.

- An unreliable angle mercury-free tilt switch was replaced in V1.
- An unsatisfactory lid design was replaced.
- An immersion switch was abandoned.

In V2 and V3s:

- Optimal Q value selection for target and reference filters was now made automatic.

- the transducer design was changed to improve sensitivity.
- the filter design was changed to reduce power consumption.
- the true-RMS detector in the V1 was replaced by an amplitude detector in the V2 (and later) as the former consumed too much power, and the only suitable component became difficult to obtain.
- an inadequately-specified comparator was changed – this was the main difference between V2 and V3, and had the effect that some of the few V2 PODs that were made gave poor discrimination of weak clicks, logging many non-porpoise clicks.
- V2 and V3 T-PODs allowed adjustment of integration periods ( the duration of smoothing of the target and reference filter outputs). Few users ever changed the default settings which had been based on sea-trials and were frequency dependent, so these were made automatic in subsequent versions.
- An angle sensor replaced the tilt switch
- Various changes were made to the housing to reduce leakage risk.
- Changes were made to the transducer connection, board mounting, battery pack and other items to reduce the incidence of damage from prolonged vibration.
- The lid design was further modified.

In V4s and V5s:

- Integration period settings were automated.
- A second register of frequency settings was introduced to give more flexibility in detection of low-frequency species.
- Noise adaptation was introduced.
- Board design was revised to reduce internal interference.
- Standardization of sensitivity was introduced.
- The transducer element was replaced to give slightly increased sensitivity.
- Solvent based adhesives were replaced.
- Multiple revisions of battery pack design.
- V5s were the same as V4s, but were normally operated at their lowest detection threshold as this removed the need for a range of higher amplifier gain levels to support even lower thresholds.

<u>Minimum threshold … Sensitivity</u>

All T-PODs had a user-controlled setting of this type with 16 settings, 0 being the lowest threshold. It was re-named sensitivity on a scale with 16 as the maximum sensitivity. This parameter allowed users to adjust PODs to match their own test results, if they fell within the available range. It also made possible settings that would reduce the number of 'dolphin-like' clicks. The measured threshold values were given in the POD specifications.

<u>Ratio …. click bandwidth</u>

Detection occurs when the Target ( A ) band amplitude exceeds the Reference ( B ) band by this user-controlled ratio. Click bandwidth was = 7 – ratio. So a narrowband click would exceed a high value of the ratio and be detected, and this setting was later described as a low click bandwidth. Simon et al. (2010) monitoring the Cardigan Bay MPA in Wales showed that a higher ratio (lower click bandwidth) was desirable in an area with many dolphins and porpoises as it improved the species discrimination, but it also involved a small loss of sensitivity, so user-control was retained for this selection criterion.

Noise adaptation

This feature was introduced in V4 and later PODs. If ON it had the effect of rapidly slightly raising the ratio criterion in response to high input levels from the filters. The half decay time of this adaptation, after the inputs fall below the threshold for this adaptation, was around 10ms. Its main effect was to reduce the number of clicks logged in the cluster of multipath replicates that follow a loud click, and to reduce the number of clicks logged during bursts of non-cetacean noise clicks. This markedly improved memory life and performance in noisy situations, but did not remove the need for users to identify periods in which noise may be impairing performance. It did not affect detection thresholds under ‘normal’ (quiet) conditions.

Calibration

V4 and later T-PODs were standardised at manufacture. This adjusted the amplifier gain to give a 50% detection rate of a standard signal during rotation of the POD through 360 degrees.

During standardisation a variable level of background electromagnetic noise at POD frequencies (which are also radio frequencies) could produce significant changes in apparent sensitivity. This effect could be increased by the noise adaptation, so standardisation was carried out with noise adaptation OFF and the POD in a rotating, steel, screening housing. At the location used for standardisation the effect of varying levels of RF interference has been demonstrated repeatedly. The source is not generally known except that some active *laptop computers* do generate such interference.

The tank used to calibrate PODs was improved during the production of V4s. The amplitude of the loudest echo after the surface reflection was reduced to less than 10% of the direct path signal.

For C-PODs temperature compensation was introduced to the standardization after C-POD 400 as it became apparent that this was a significant factor.

**End of the T-POD**

The low-power Smart-Media memory cards used in V5 T-PODs were replaced by more power-hungry versions (this change was never announced!) so that running times dropped substantially.

A larger battery pack and split housing were introduced and partly compensated for this. These memory cards then disappeared from the market and a memory adapter was added to allow a different card to be used.

A switch chip on the analogue board became hard to source. All available chips were bought by Chelonia and work was started on a V6 surface mount version of the analogue processor to allow more modern versions of this switch to be used.

The surface-mount 'V6' T-POD showed significant differences in performance from the V5 although the circuit models had not revealed this.

Meanwhile work was already under-way on a digital POD, the C-POD. At this time it also became clear that the T-POD digital processor would have to be changed as the newer memory card was now also only available in high-power versions (probably to meet ever-rising speed requirements in the camera market).

The workload involved in these issues and in developing and testing three boards for two different detectors, plus various revisions to the software that they would require, was going to create an excessively long gap before either could be supplied, so the incomplete V6 T-POD was abandoned.

### 7.2.2. C-POD

The digital replacement – the C-POD - addressed some major shortcomings in the type of detector used in T-PODs. These were:

1. The need to predict the frequency (pitch) of dolphin clicks.
2. The very limited information on each click that could be used in species recognition, including the discrimination of noise trains and real trains.
3. The lack of information on ambient noise.

The C-POD detector design was based on desk analysis trials on a large set of wideband, 5MHz sampling rate, recordings of dolphin clicks. The method selected uses zero-crossing analysis to measure the bandwidth of sound in successive, overlapping, time windows of various lengths. Zero-crossings, for suitable short signals, allow accurate frequency read-out and large dynamic ranges (the ratio of the weakest signal the system can handle correctly to the loudest).

The C-POD records, for every click, the dominant frequency of the first 10 cycles, the final zero-crossing interval, the amplitude of the 1st, 5th and loudest waves, and an index of the click bandwidth, along with the time of occurrence and duration.

This sounds very different from the T-POD, but is functionally surprisingly similar. Any tonal click that is louder than the atonal background noise will be recognised as tonal, and its frequency can be estimated. Signals weaker than the background will not be recognised. The background has the same function as the T-POD reference filter and the bandwidth measure has the same function as the ratio between filter inputs in the T-POD. In both instruments the electronic background within the instrument is most often louder than 'normal quiet' acoustic backgrounds. The acoustic background used within the C-POD is limited by a high-pass input filter, that can be controlled by the user, and by the inherent fall-off of transducer sensitivity at high frequencies, which cannot be controlled by the user, and by the sampling rate of the instrument.

Other changes included:

- a revised transducer element design to give a flatter frequency response
- improved shock resistance of the transducer

- improved vibration tolerance
- more accurate thermometer
- more accurate timing
- all chlorinated plastics removed
- an optional mid-housing mooring to reduce the angle of lean in currents
- revised lid design to make all lids interchangeable
- bi-directionally sprung battery housing

**C-POD detection threshold**

The adjustment of the detection threshold of the C-POD is done retrospectively using the amplitude of each click. Any value above 12 can be set correctly for any POD as all C-PODs can detect a signal that both meets the tonality (bandwidth) criterion and has an amplitude of 12 on the sound pressure level scale that records the maximum peak-to-peak amplitude within a click.

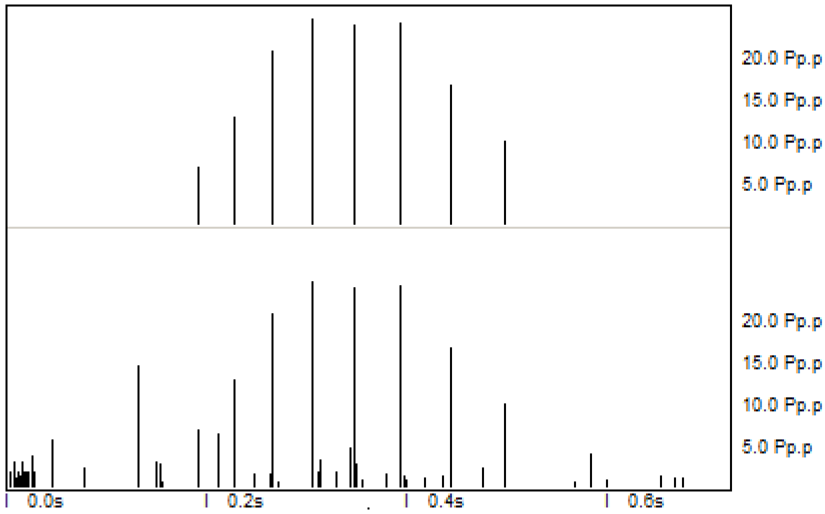
There is a reasonable case for logging only clicks louder than the uniform threshold value (12 on the C-POD SPL scale), but this has not been done because the 'personal best' i.e. weakest detectable clicks, of a set of C-PODs may show less variance than the sampling error in studies where detections are few. In such cases the statistical power of a study may be improved by using all detections even though the 'personal best' thresholds of different instruments are less uniform than the 'uniform threshold'.

The absolute SPL for scale values of 12 varies with frequency and can be viewed in Pascals in C-POD.exe by selecting this option on the view+ page of the menu. The frequency scale is given in the specification on www.chelonia.co.uk. (Note: The C-POD pressure scale runs from 3 to 255, with many loud clicks registering 255. Conversion of these point pressure values to decibels, a unit of relative intensity, not pressure, involves assumptions that are known to be invariably and substantially false in this situation, and the decibel itself is deprecated by the ICWM. )

To make this post-processing detection threshold uniform the amplitude scale of each C-POD is standardised as a temperature compensated average of the radial values obtained when a POD is rotated at 0.5rpm in a sound field with 300 clicks per second. The test signal is a square pulse of 12 cycles of a sine wave. The abrupt transition at each end is not ideal but has some practical advantages.

### The train filter

The filtering effect of the train detection process is shown below:




Each vertical line represents the maximum peak-to-peak amplitude of a click in Pascals. All clicks in the raw data are shown in the lower panel. Only those clicks identified as belonging to a train are shown in the upper panel.

Trains are more or less regularly spaced series of similar elements. Cetacean trains show variation in the temporal spacing of clicks over time, and the similarity of the clicks is reduced by the changing orientation of the animal, propagation effects, and by changes in the click produced, especially in the case of broad-band dolphin clicks.

The train detection is based on a simple probability model of a train:

The probability, *p* of a click falling within some distance from the centre of the interval between the one before and the one after is determined by the Poisson distribution, the prevailing rate of arrival of clicks, *a,* the size of the interval, *i*, and the regularity of trains (that defines how close to the centre the click must be) so the probability of the whole identified train arising by chance from random sources will be the product of successive *p* values, and thresholds for acceptance of trains can be set using this.

There several important qualifications: *a* varies rapidly over time; the clicks in the train need to be subtracted from the count used to estimate *a* and this becomes a recursive process; low values of *i* are favoured; consequently estimation of the likelihood of false trains being found in real data sets is very unsatisfactory. Auto-correlation is a simple rigorous method for detection of trains with unvarying spacing of elements, and is of use in cetacean train detection within short time windows, but the search for a simple and rigorous method that can be applied to longer cetacean trains has been unsuccessful so far (although at a purely intuitive level it feels as though there should be one!), so the model, above, is in practice useful, but has to be empirically validated. These notes point to the shortcomings of train detection:

1. Slow click-rate trains are less likely to be recognised.
2. Irregular trains are less likely to be recognised.

3. Noise clicks impair cetacean train detection.
4. Multiple overlapping trains from cetaceans can impair train detection.

Black boxes v. transparency

Train detection and classification, in common with all but the simplest pattern recognition systems, is sufficiently complex that it is not possible to predict its performance from examination of the algorithm (Theodoridis and Koutroumbas, 2009). By virtue of their complexity alone such processes are 'black boxes' that require external validation.

In practice even much simpler electronic instruments, from hydrophones to oscilloscopes, are also generally sold and used as black boxes with published empirical transfer functions that are generally more accurate than any transfer function that might have been modelled using 'transparent' information on the components, circuits, logic etc. Even theoretically simple and transparent methods, e.g. for acoustic array-based range estimation can produce unexpected errors. Empirical validation is always required and is the basis of the scientific method.

Science has always made extensive use of non-transparent methods and progress has more often than not depended on them e.g. litmus was used in titrations to determine atomic weights even though no one knew how it worked or could predict the conditions in which it might fail.

In this context I take the view that transparency is not an appropriate requirement. It would be of value to developers of cetacean detectors, but it would make investment in the development and the maintenance of the PODs (despite the rapidly changing patterns of component availability) much more risky, because the intellectual property in the design had been given away freely to potential competitors. The same factors leads manufacturers in general to withhold or patent key design details of all the instruments they sell. Chelonia has not patented any aspect of the PODs.

Train classification

Both train detection (that answers the question: Is there a sequence of clicks that came from a train source as opposed to arising by chance from independent sources?) and train classification (that seeks to identify the 'species' of source) for T-PODs went thorough a number of versions, each of which was fully retrospectively applicable to earlier data files. The same principle will be applied to C-POD train detection, which at present has only a provisional version of the train filter.

Comparability of train detection versions

Because all data can be re-analysed with any version of the train detection this is, from the perspective of AMPOD, changes in the train filter are less critical than hardware changes that affect detection, but re-analysis does cost time, so issue of new train filter versions for the C-POD will be kept to a minimum.

Early train classifiers used a set of train descriptors that were compared with values derived from known porpoise trains. They did not work well on some dolphin species that had less coherent trains, and the process was changed to one that aimed to exclude chance trains (wrongly extracted from noise) rather than identify trains matching porpoise trains.

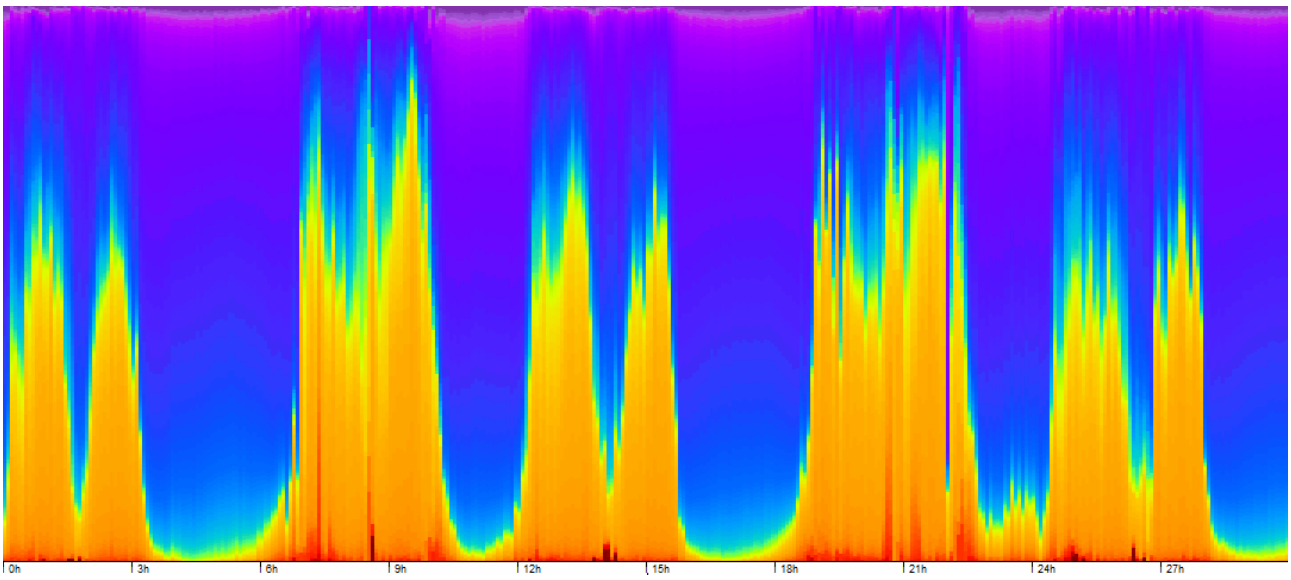
The V1 C-POD train filter is based on the T-POD train filter and has a lot of room for improvement.  A major part of that process is a shift to non-parametric methods that are more resistant to outliers which are usually non-cetacean clicks that were wrongly classified as falling within a train.

**Ambient noise**

<u>Sediment transport noise</u>

The first version of TPOD.exe required settings files to adapt the probability structure to data from deployments of PODs over sand which sometimes had very high rates of logging non-cetacean clicks.  At the time we were not aware of the source of these clicks.

C-POD data from the same locations gives much more detail of these clicks and shows that they are often part of a population of clicks that shows trends in frequency. The C-POD can have much wider criteria for accepting clicks that the T-POD because it has a much larger memory and each click is logged with descriptors that allow, for example, porpoise-like clicks to be differentiated from non-porpoise-like clicks retrospectively.  It gives a different kind of picture of ambient noise from that obtained by broad-band recording. In particular low frequency tones are excluded by higher frequencies as, for tones with the same number of cycles, these are shorter.




The graphic above shows the distribution of frequency of tones logged in the Bristol Channel, a macrotidal estuary, over 30 hours. The frequency of tones is shown by colour (red = 20kHz, Violet = 140kHz), and a clear tidal pattern can be seen including even the difference between alternate tides.

We now realize that the source of most ultrasound logged in shallow water is sediment transport noise which has been identified and investigated by Thorne et al. (1986, 1988) who showed that it corresponds closely to rigid body radiation that arises when particles collide with each other, with fine sand producing tonal noise at porpoise frequencies. This has explained a lot of earlier T-POD data and clearly demonstrates that, with widespread tonal sources at porpoise frequencies:

- a wider-band detector gives valuable information on the acoustic scene
- such information opens up the field of acoustic ecology in relation to echo-location
- the identification of individual clicks as porpoise clicks from spectrum and waveform alone will always be unreliable.

Boat sonars, ADCPs

Boat sonars most often appear as clusters of tones that are very close to the frequency of the source, but sometimes quite strong harmonics are detected especially at the end of the multipath cluster. Because of their high source level and long duration, large clusters of tones, are commonly received from each sonar pulse. Embling has found that in 60m of water a C-POD could detect the sonar of a marine research vessel whenever it was within 1km.

Acoustic Doppler Current Profilers (ADCPs) operating at nominal frequencies far above the range of the POD sometimes also produce porpoise frequencies and can be wrongly identified as porpoises.

### 7.2.3. Future developments

Work is at present under-way on a new C-POD that will have a different central processor (an anticipated low-power version of the current CPU has never been produced, so there is a risk that its production life may be suddenly ended if the manufacturer chooses to invest manufacturing resources in a more recent product). It will also have

- longer running times
- lower internal noise levels
- external noise adaptation
- temperature compensated gain during use
- improved transducer housing design
- improved logging limits
- the ability to capture and store selected compressed waveforms
- features to support very long deployments (>1year on 10 alkaline D-cells)
- features to support online deployments

### 7.2.4. References

Chappell, O., Leaper, R. and Gordon, J. (1996) “Development and performance of an automated harbour porpoise click detector.” Rep. Int. Whal. Commn., 46, 587-594.

Simon, M., Nuuttila, H., Reyes-Zamudio, M. M., Ugarte, F., Verfuss, U., and Evans, P. G. H. (2010) “Passive acoustic monitoring of bottlenose dolphin and harbour porpoise, in Cardigan Bay, Wales, with implications for habitat use and partitioning.” Journal of the Marine Biological Association of the United Kingdom doi:10.1017/S0025315409991226

Theodoridis, S., Koutroumbas, K. (2009) “Pattern Recognition” 4th edition. Academic Press.

Thorne, P.D., (1986) “Laboratory and marine measurements on the acoustic detection of sediment transport.” J. Acoust. Soc. Am. 80 (3), 899-910.

Thorne, P.D. (1990) “Seabed generation of ambient noise.” Journal of the Acoustical Society of America, 87, 149 153.

## *7.3. Final symposium*

In the frame of the AMPOD-project, a symposium was organized and held at the 28th and 29th October 2009. The symposium presented the results of the AMPOD-project and of recent POD-applications in SAM projects. Furthermore a draft version of recommendations was presented, giving guidelines on how to conduct SAM with PODs and proposing a standard procedure for POD application and data analysis. The proposals given in the recommendations were discussed with the symposium participants to approve the suggested guidelines.

### 7.3.1. Programme

**Wednesday 28.10.2009**

***13:45 – 14:30 Registration***

***14:30 Opening remarks***
Dr. Harald Benke, Director

*German Oceanographic Museum,Germany*

*Chair:* Dr. Ursula Verfuß

***14:40 The StUK and its evaluation***
Dr. Klaus Lucke

*FTZ Westküste, University of Kiel, Germany*

***15:20 The AMPOD-project - aims and outcomes***
Dr. Ursula Verfuß

*German Oceanographic Museum, Germany*

***16:00 Coffee break***

***16:30 AMPOD-outcome: Acoustic properties of SAM-devices***
Michael Dähne

*German Oceanographic Museum, Germany*

***17:10 Monitoring abundance by acoustic methods***
Line Kyhn

*National Environmental Research Institute, Aarhus University, Denmark*

***17:50 Using SAM to monitor the effect of human activities***
Dr. Jakob Tougaard

*National Environmental Research Institute, Aarhus University, Denmark*

***19:30 Reception & Flying Dinner in the OZEANEUM'S North Sea***

**Thursday 29.10.2009**

*Chair:* Dr. Jakob Tougaard

***09:00 Effects of pile driving activities measured with SAM***

Ansgar Diederichs

*BioConsult-SH, Germany*

***09:40 Porpoises and PODS, investigating anthropogenic activities in Dutch waters***

Dr. Tamara van Polanen Petel

*Institute for Marine Resources &* Ecosystem*, The Netherlands*

***10:20 The AQUAclick 200 Porpoise Click Logger***

Andy Smerdon

*Aquatec Group Limited, United Kingdom*

Dr. Mats Amundin

*Kolmarden Zoo/Linkoping University*

***11:00 Coffee break***

***11:30 Presentation and discussion of the draft guidelines-brochure***

Dr. Ursula Verfuß

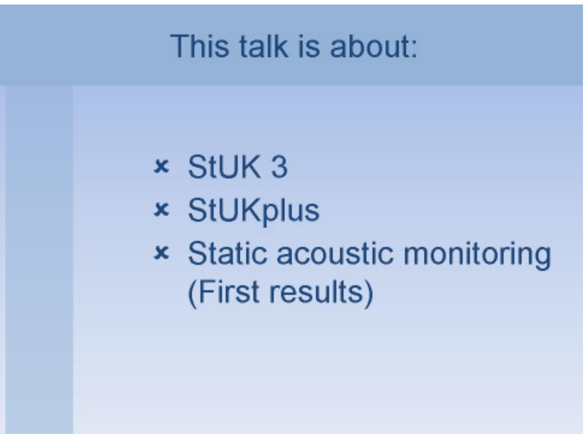
*German Oceanographic Museum*

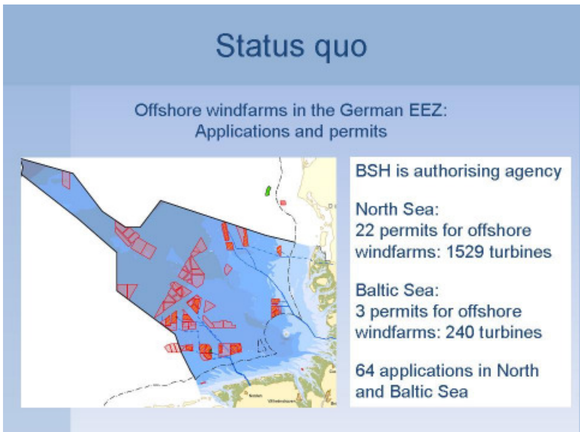
***13:00 Closing remarks***

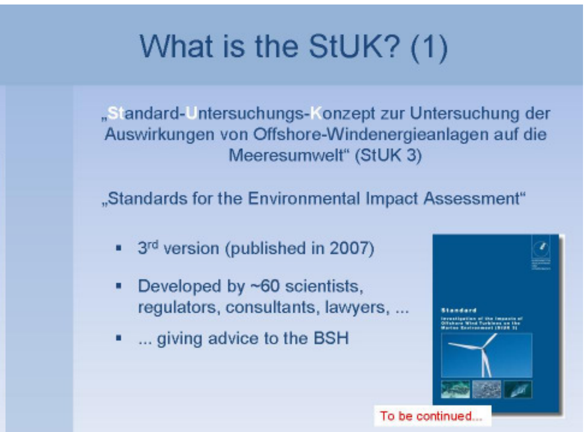
## 7.3.2. Talk slides

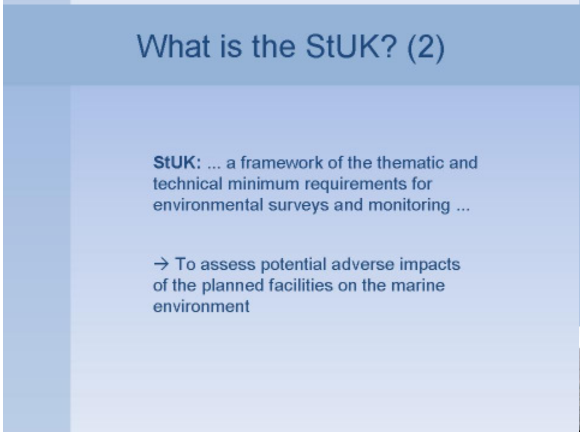
### The StUK and its evaluation

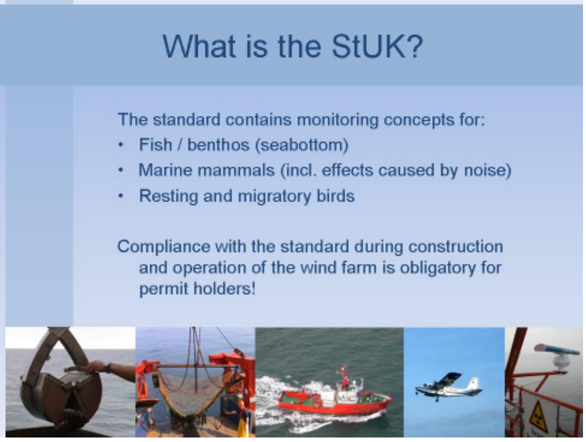
Dr. Klaus Lucke, *FTZ Westküste, University of Kiel, Germany*

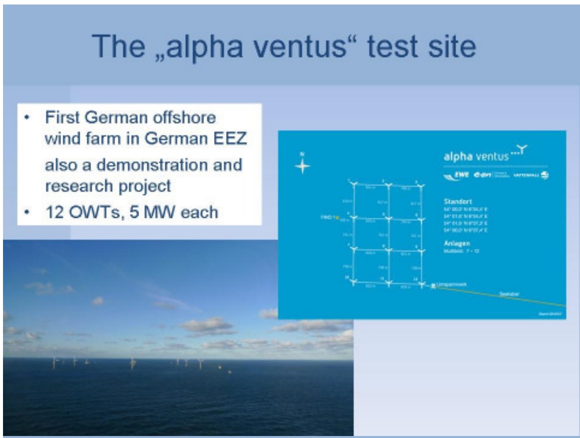



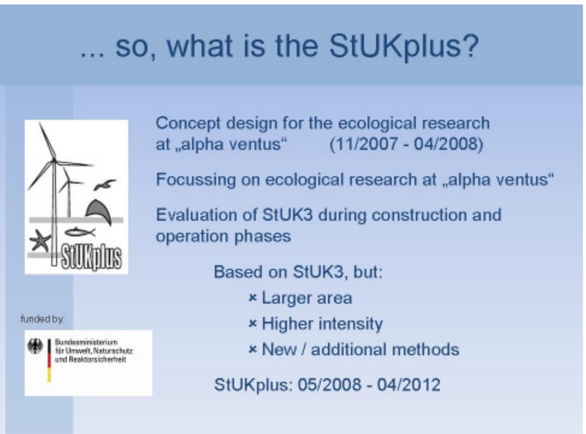



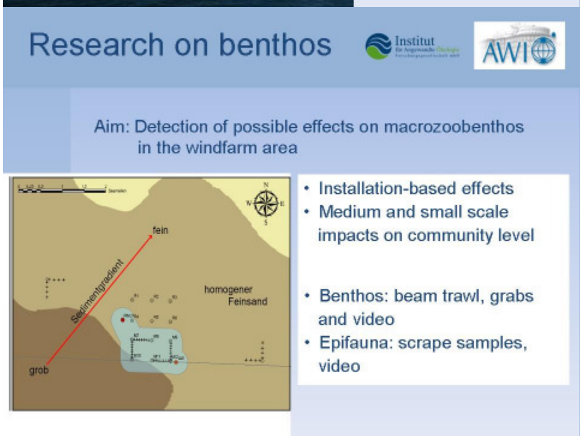



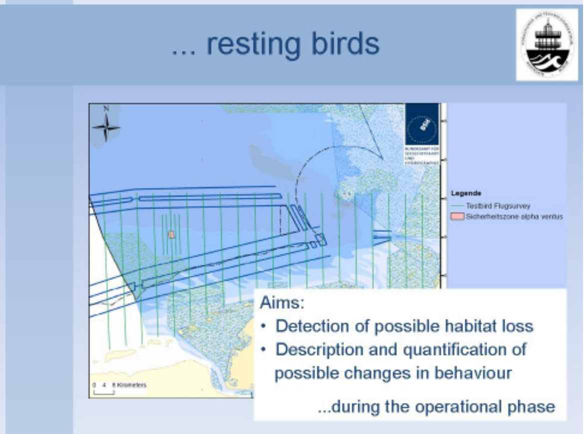



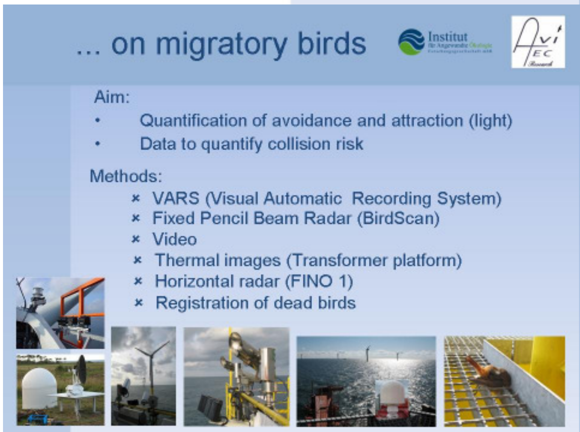



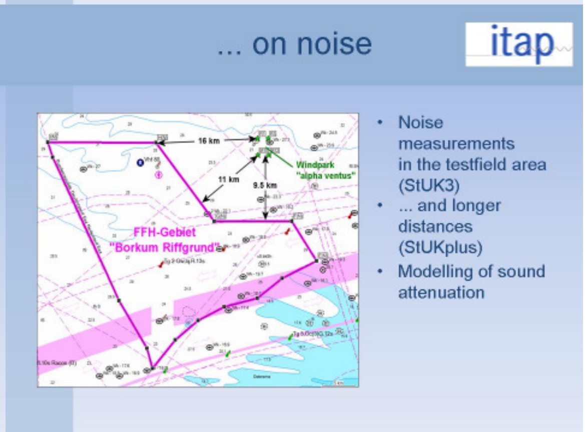

The „alpha ventus“ test site
First German offshore wind farm in German EEZ
also a demonstration and research project
12 OWTs, 5 MW each
alpha ventus

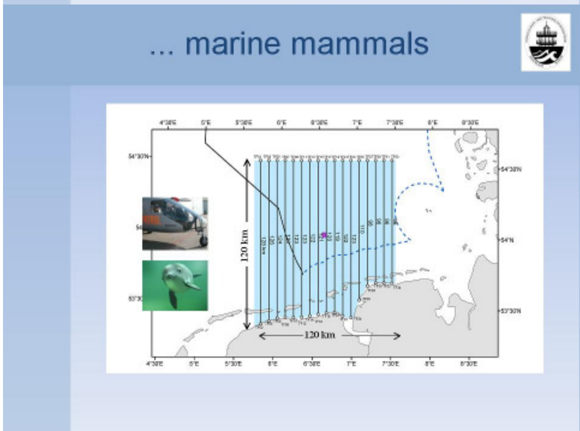

... so, what is the StUKplus?
StUKplus
funded by:
Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit
Concept design for the ecological research at „alpha ventus“ (11/2007 - 04/2008)
Focussing on ecological research at „alpha ventus“
Evaluation of StUK3 during construction and operation phases
Based on StUK3, but:
× Larger area
× Higher intensity
× New / additional methods
StUKplus: 05/2008 - 04/2012

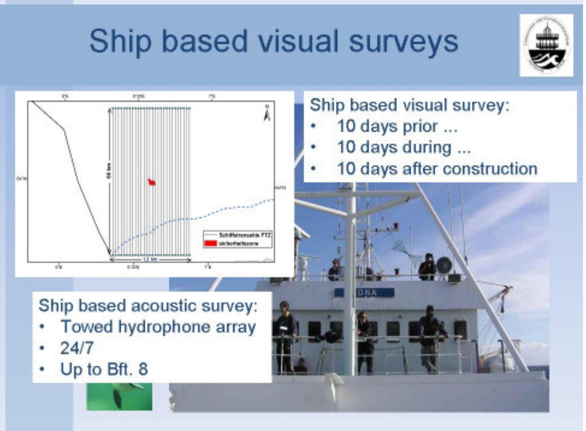

Research on benthos
Institut für Angewandte Ökologie
AWI
Aim: Detection of possible effects on macrozoobenthos in the windfarm area
fein
Sedimentgradient
homogener Feinsand
grob
Installation-based effects
Medium and small scale impacts on community level
Benthos: beam trawl, grabs and video
Epifauna: scrape samples, video


... resting birds
Legende
Testfeld Flugsurvey
Sicherheitszone alpha ventus
Aims:
Detection of possible habitat loss
Description and quantification of possible changes in behaviour
...during the operational phase


... on migratory birds
Institut für Angewandte Ökologie
Avi EC
Aim:
Quantification of avoidance and attraction (light)
Data to quantify collision risk
Methods:
× VARS (Visual Automatic Recording System)
× Fixed Pencil Beam Radar (BirdScan)
× Video
× Thermal images (Transformer platform)
× Horizontal radar (FINO 1)
× Registration of dead birds


... on noise
itap
16 km
11 km
9.5 km
Windpark "alpha ventus"
FFH-Gebiet "Borkum Riffgrund"
Noise measurements in the testfield area (StUK3)
... and longer distances (StUKplus)
Modelling of sound attenuation


... marine mammals
120 km
120 km


Ship based visual surveys
Ship based visual survey:
10 days prior ...
10 days during ...
10 days after construction
Ship based acoustic survey:
Towed hydrophone array
24/7
Up to Bft. 8

## Data evaluation

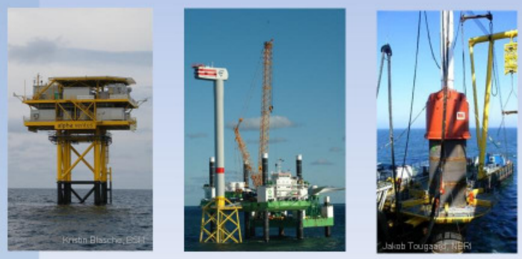
Combined data evaluation from:

- Long-time research programmes
- Environmental assessment studies
- Effect monitoring
- Accompanying research
- Oceanographic, chemical & geological datasets

- Development of assessment criteria
- Regional, large-scale & international
- Interactions & cumulative effects

## Construction

September 2008: Transformer platform (Jacket)
April – September 2009: 12 OWTs (Jacket + Tripod)




## Pile driving activity

itap

12 OWTs:

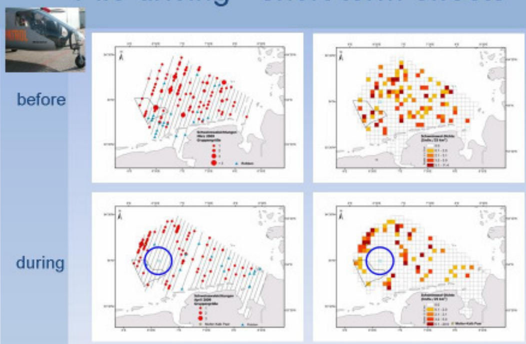
>15,000 hammer strikes per OWT (on avg.)

42 days of pile driving over period of 146 days (avg.: 1,700 imp./day)

Source levels:
>200 dB SEL
>230 dB SPL

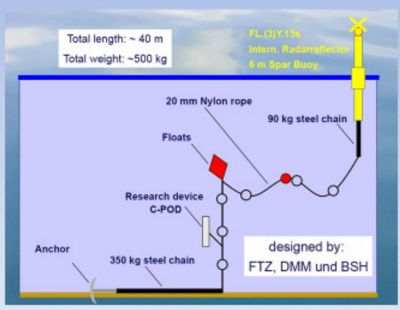
BARD (simult. activity)

## Pile driving - short term effects

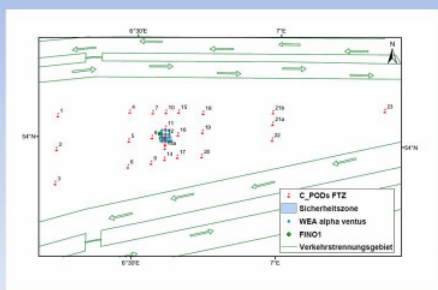



http://www.bfn.de/habitatmare/de/downloads/monitoring/BfN-Monitoring_Schweinswale_2008-2009.pdf

## Pile driving – long term effects?

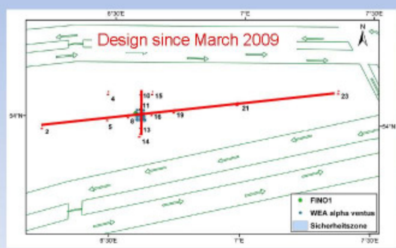


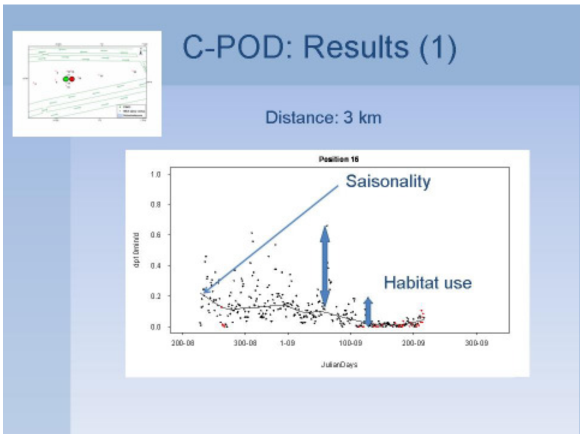

## C-POD – Initial research design

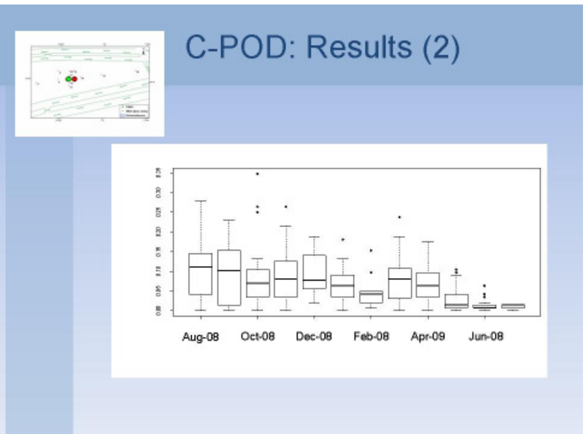


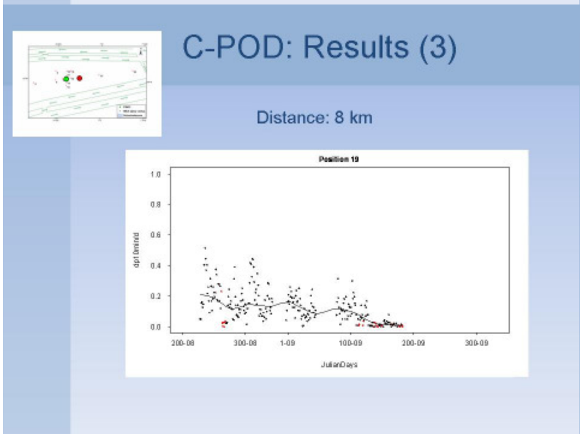

## ... an unforeseen problem

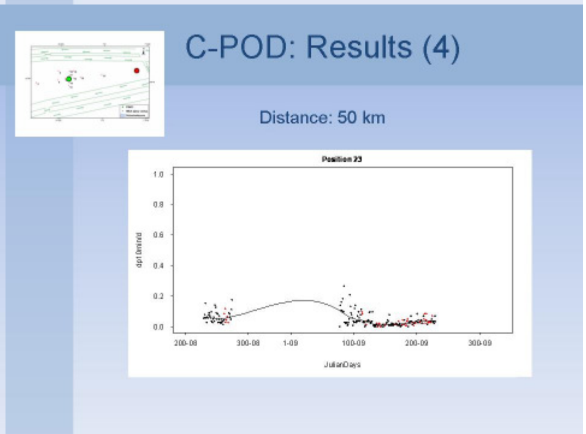
## C-POD – Recent research design

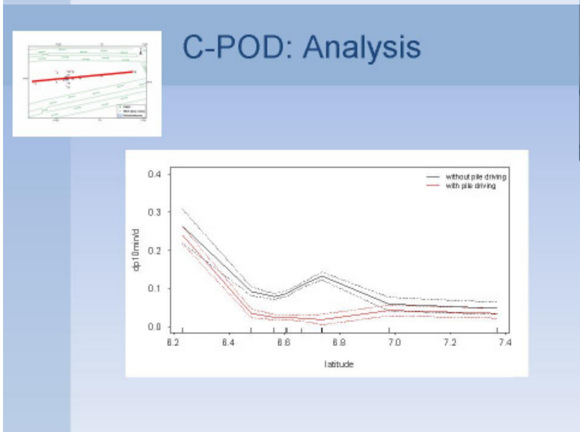


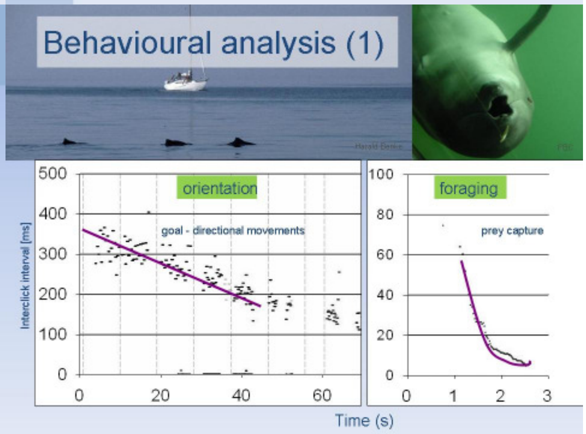

C-POD: Results (1)
Distance: 3 km
Position 16
Saisonality
Habitat use
JulianDays


C-POD: Results (2)
Aug-08
Oct-08
Dec-08
Feb-08
Apr-09
Jun-08

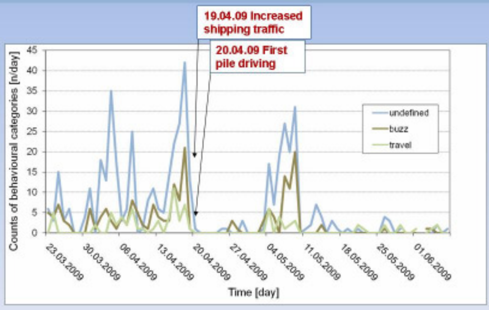

C-POD: Results (3)
Distance: 8 km
Position 19
JulianDays


C-POD: Results (4)
Distance: 50 km
Position 23
JulianDays


C-POD: Analysis
without pile driving
with pile driving
dp10min/d
latitude


Behavioural analysis (1)
orientation
goal - directional movements
foraging
prey capture
Interclick interval [ms]
Time (s)

## Behavioural analysis (2)

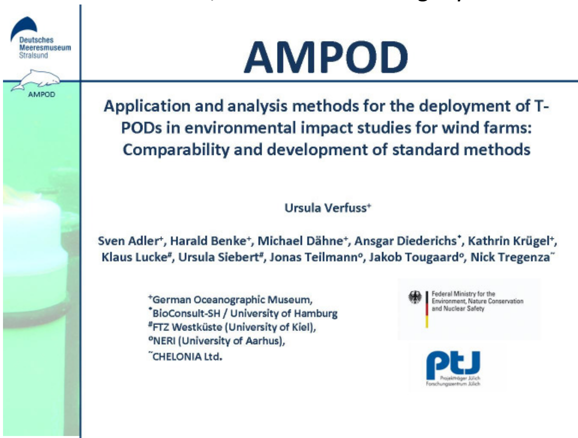


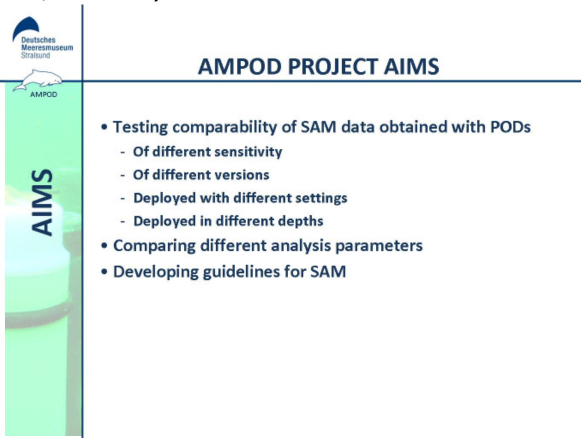

## Conclusions

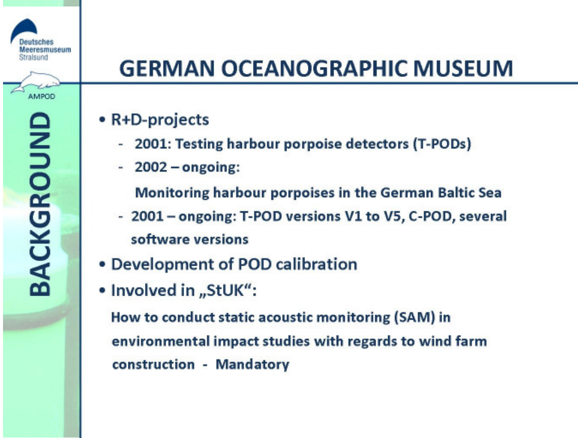
- Evaluation ongoing
- Potential interference of different research projects:
  → Coordination (BSH) is crucial
- Change in short- and long-term habitat use (quantitative + qualitative)
- Unequivocal results for repeated pile driving in 2009
- Analysis of external factors (non-OWT noise sources) ongoing

## The AMPOD-project - aims and outcomes

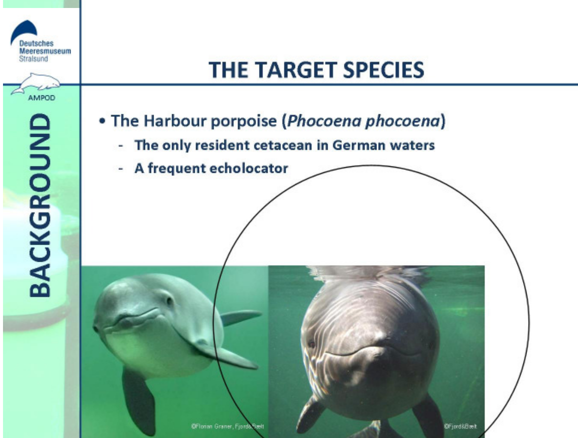
Dr. Ursula Verfuß, *German Oceanographic Museum, Germany*

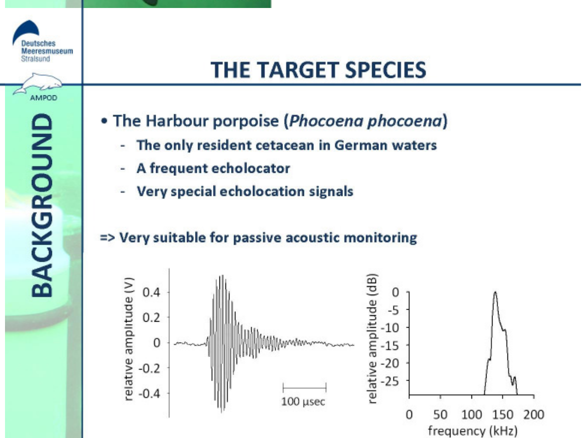


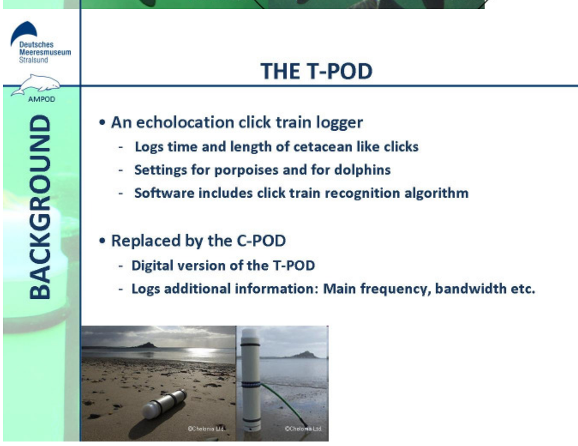



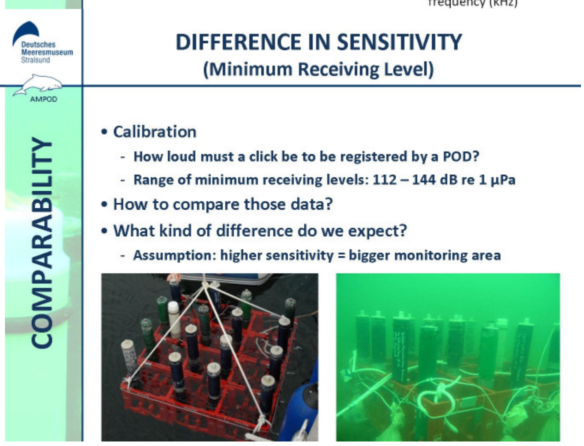



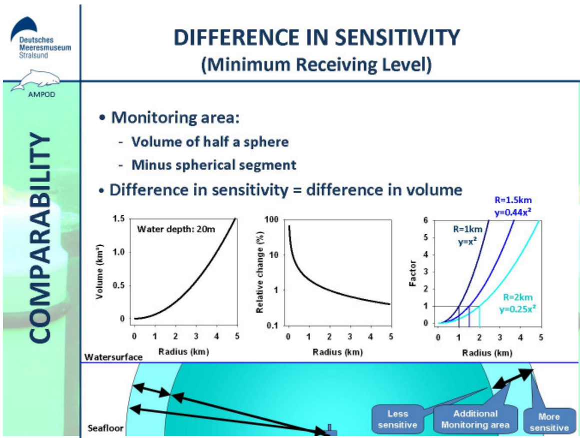


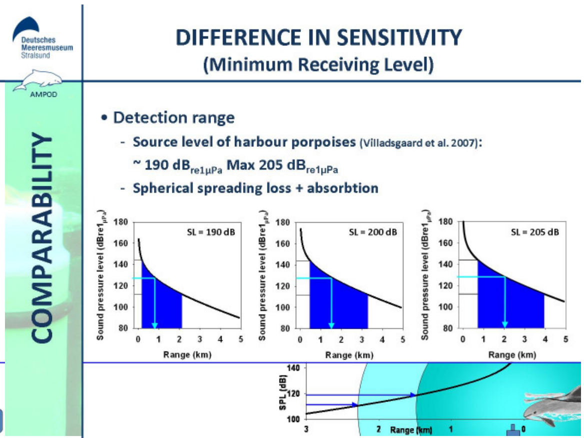


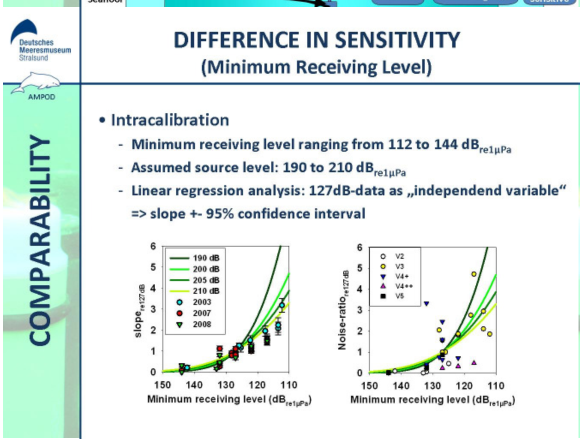



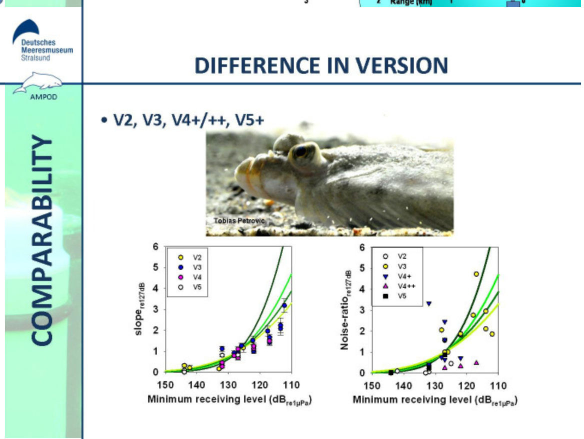



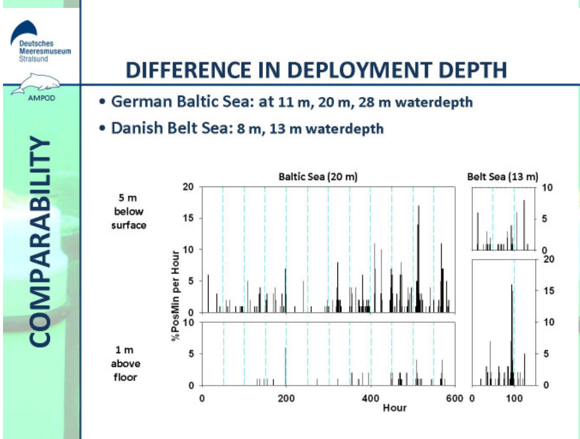



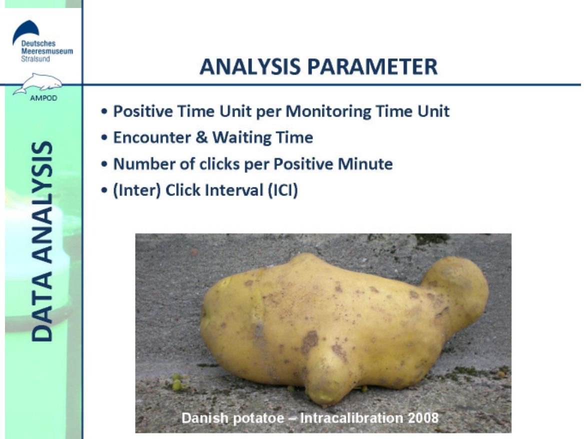

Deutsches Meeresmuseum Stralsund
AMPOD
COMPARABILITY
DIFFERENCE IN SENSITIVITY
(Minimum Receiving Level)
• Monitoring area:
- Volume of half a sphere
- Minus spherical segment
• Difference in sensitivity = difference in volume
Water depth: 20m
Volume (km³)
Radius (km)
Relative change (%)
Factor
R=1km
y=x²
R=1.5km
y=0.44x²
R=2km
y=0.25x²
Watersurface
Seafloor
Less sensitive
Additional Monitoring area
More sensitive

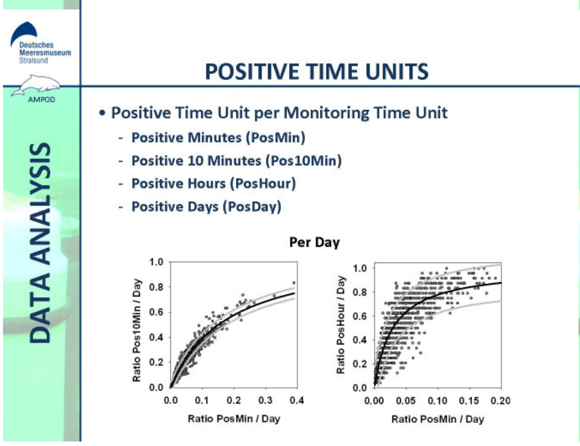

Deutsches Meeresmuseum Stralsund
AMPOD
COMPARABILITY
DIFFERENCE IN SENSITIVITY
(Minimum Receiving Level)
• Detection range
- Source level of harbour porpoises (Villadsgaard et al. 2007):
~ 190 dBre1µPa Max 205 dBre1µPa
- Spherical spreading loss + absorbtion
SL = 190 dB
SL = 200 dB
SL = 205 dB
Sound pressure level (dBre1µPa)
Range (km)
SPL (dB)

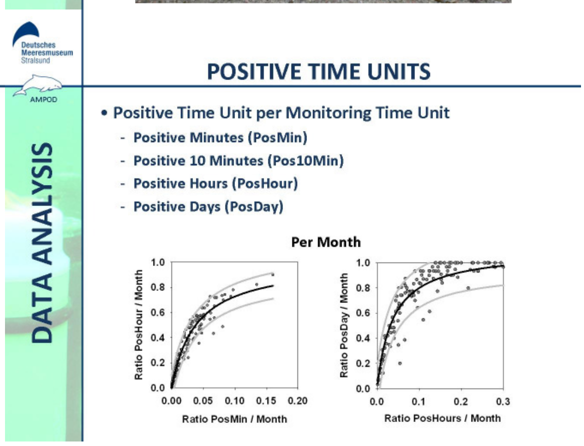

Deutsches Meeresmuseum Stralsund
AMPOD
COMPARABILITY
DIFFERENCE IN SENSITIVITY
(Minimum Receiving Level)
• Intracalibration
- Minimum receiving level ranging from 112 to 144 dBre1µPa
- Assumed source level: 190 to 210 dBre1µPa
- Linear regression analysis: 127dB-data as „independend variable“
=> slope +- 95% confidence interval
190 dB
200 dB
205 dB
210 dB
2003
2007
2008
slope re127dB
Noise-ratio re127dB
V2
V3
V4+
V4++
V5
Minimum receiving level (dBre1µPa)

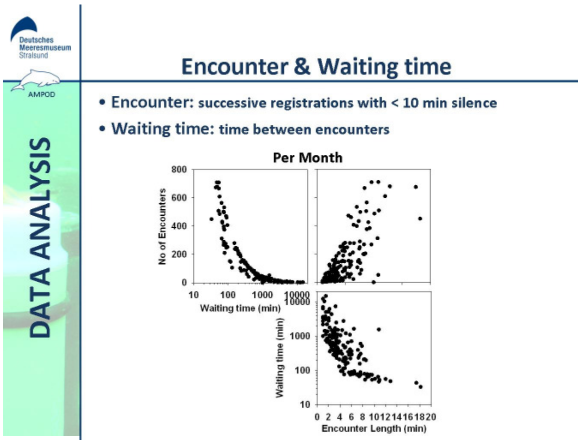

Deutsches Meeresmuseum Stralsund
AMPOD
COMPARABILITY
DIFFERENCE IN VERSION
• V2, V3, V4+/++, V5+
Tobias Petrovic
V2
V3
V4
V5
V4+
V4++
slope re127dB
Noise-ratio re127dB
Minimum receiving level (dBre1µPa)

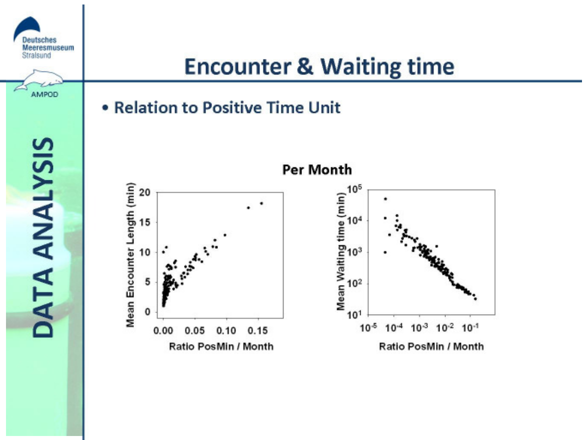

Deutsches Meeresmuseum Stralsund
AMPOD
COMPARABILITY
DIFFERENCE IN DEPLOYMENT DEPTH
• German Baltic Sea: at 11 m, 20 m, 28 m waterdepth
• Danish Belt Sea: 8 m, 13 m waterdepth
Baltic Sea (20 m)
Belt Sea (13 m)
5 m below surface
1 m above floor
%PosMin per Hour
Hour

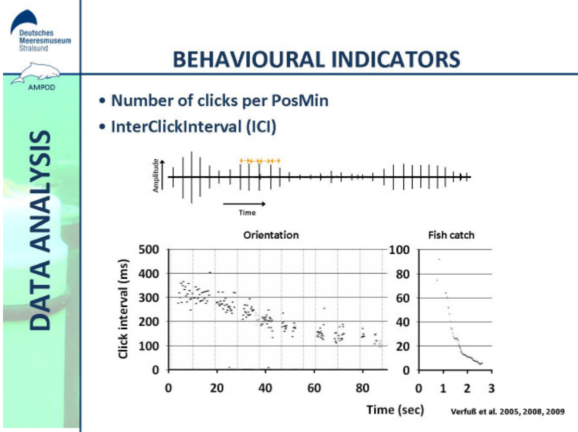

Deutsches Meeresmuseum Stralsund
AMPOD
DATA ANALYSIS
ANALYSIS PARAMETER
• Positive Time Unit per Monitoring Time Unit
• Encounter & Waiting Time
• Number of clicks per Positive Minute
• (Inter) Click Interval (ICI)
Danish potatoe – Intracalibration 2008

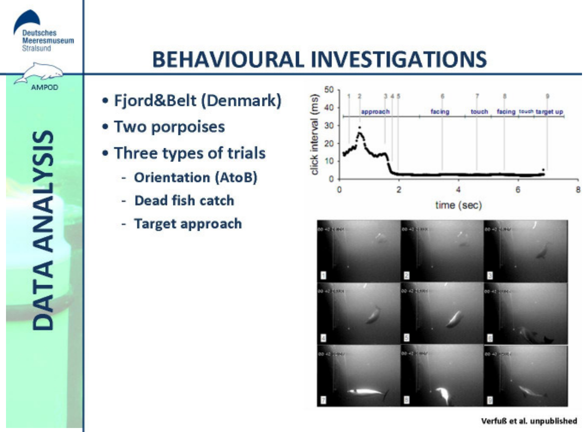

Deutsches Meeresmuseum Stralsund
AMPOD
DATA ANALYSIS
POSITIVE TIME UNITS
• Positive Time Unit per Monitoring Time Unit
- Positive Minutes (PosMin)
- Positive 10 Minutes (Pos10Min)
- Positive Hours (PosHour)
- Positive Days (PosDay)
Per Day
Ratio Pos10Min / Day
Ratio PosMin / Day
Ratio PosHour / Day
Ratio PosMin / Day

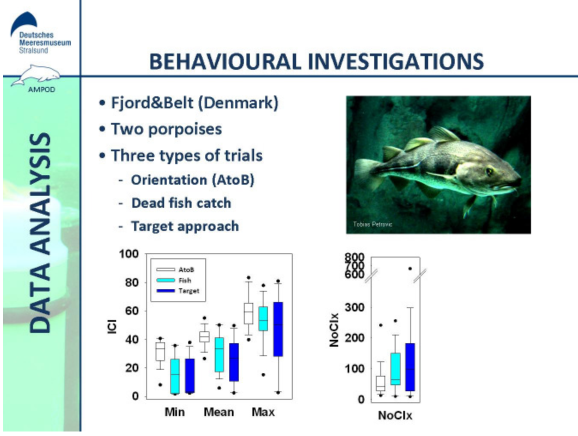

Deutsches Meeresmuseum Stralsund
AMPOD
DATA ANALYSIS
POSITIVE TIME UNITS
• Positive Time Unit per Monitoring Time Unit
- Positive Minutes (PosMin)
- Positive 10 Minutes (Pos10Min)
- Positive Hours (PosHour)
- Positive Days (PosDay)
Per Month
Ratio PosHour / Month
Ratio PosMin / Month
Ratio PosDay / Month
Ratio PosHours / Month

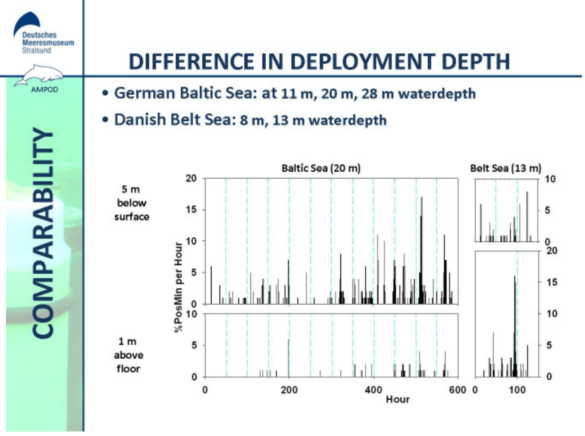

Deutsches Meeresmuseum Stralsund
AMPOD
DATA ANALYSIS
Encounter & Waiting time
• Encounter: successive registrations with < 10 min silence
• Waiting time: time between encounters
Per Month
No of Encounters
Waiting time (min)
Waiting time (min)
Encounter Length (min)

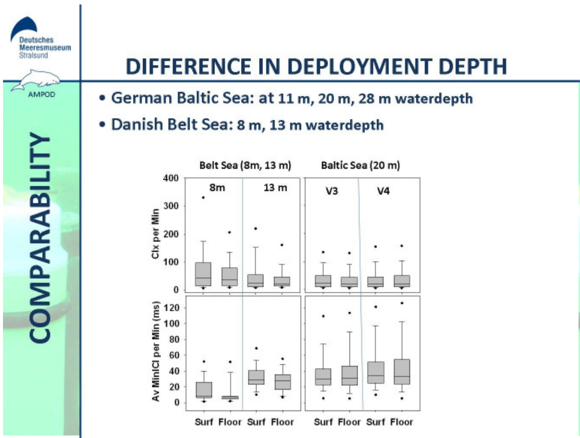

Deutsches Meeresmuseum Stralsund
AMPOD
DATA ANALYSIS
Encounter & Waiting time
• Relation to Positive Time Unit
Per Month
Mean Encounter Length (min)
Ratio PosMin / Month
Mean Waiting time (min)
Ratio PosMin / Month

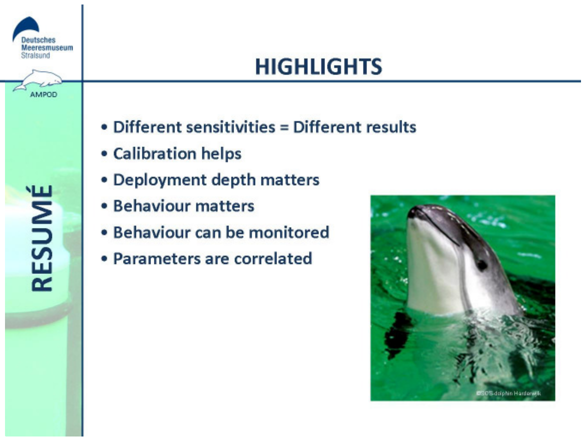

Deutsches Meeresmuseum Stralsund
AMPOD
DATA ANALYSIS
BEHAVIOURAL INDICATORS
• Number of clicks per PosMin
• InterClickInterval (ICI)
Amplitude
Time
Orientation
Fish catch
Click interval (ms)
Time (sec)
Verfuß et al. 2005, 2008, 2009


Deutsches Meeresmuseum Stralsund
AMPOD
DATA ANALYSIS
BEHAVIOURAL INVESTIGATIONS
• Fjord&Belt (Denmark)
• Two porpoises
• Three types of trials
- Orientation (AtoB)
- Dead fish catch
- Target approach
click interval (ms)
approach
facing
touch
target up
time (sec)
Verfuß et al. unpublished


Deutsches Meeresmuseum Stralsund
AMPOD
DATA ANALYSIS
BEHAVIOURAL INVESTIGATIONS
• Fjord&Belt (Denmark)
• Two porpoises
• Three types of trials
- Orientation (AtoB)
- Dead fish catch
- Target approach
Tobias Petrenc
ICI
AtoB
Fish
Target
Min
Mean
Max
NoClx
NoClx


Deutsches Meeresmuseum Stralsund
AMPOD
COMPARABILITY
DIFFERENCE IN DEPLOYMENT DEPTH
• German Baltic Sea: at 11 m, 20 m, 28 m waterdepth
• Danish Belt Sea: 8 m, 13 m waterdepth
Baltic Sea (20 m)
Belt Sea (13 m)
5 m below surface
1 m above floor
%PosMin per Hour
Hour


Deutsches Meeresmuseum Stralsund
AMPOD
COMPARABILITY
DIFFERENCE IN DEPLOYMENT DEPTH
• German Baltic Sea: at 11 m, 20 m, 28 m waterdepth
• Danish Belt Sea: 8 m, 13 m waterdepth
Belt Sea (8m, 13 m)
Baltic Sea (20 m)
8m
13 m
V3
V4
Clx per Min
Av MinICI per Min (ms)
Surf Floor Surf Floor
Surf Floor Surf Floor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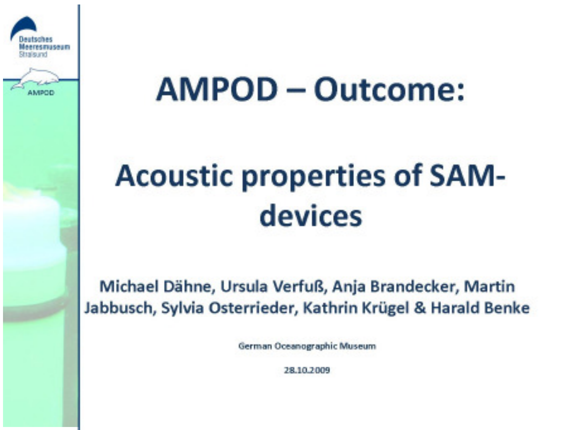
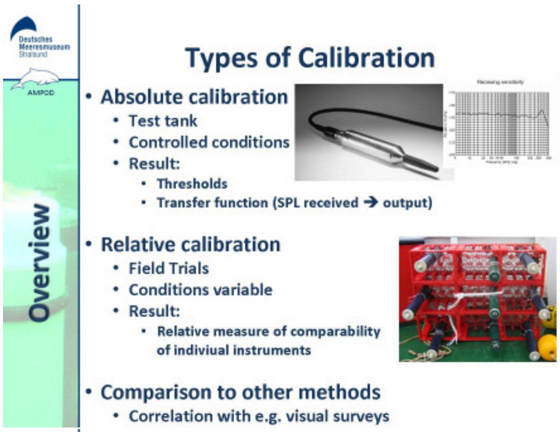
RESUMÉ
HIGHLIGHTS
• Different sensitivities = Different results
• Calibration helps
• Deployment depth matters
• Behaviour matters
• Behaviour can be monitored
• Parameters are correlated

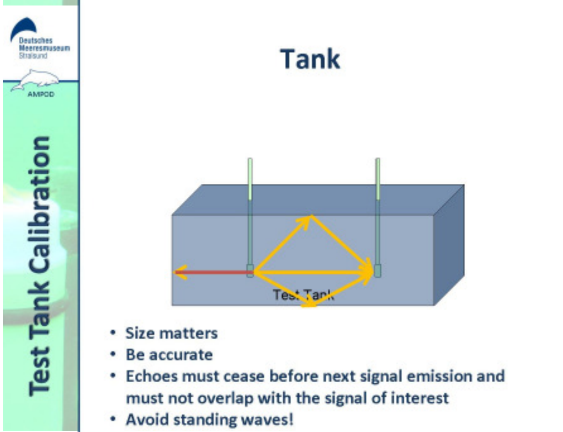

Deutsches Meeresmuseum Stralsund
AMPOD
THE END
ACKNOWLEDGEMENTS
A big thanks to everybody helping with the work done in this project, especially Anja Brandecker, Stefan Bräger, Anne Herrmann, Martin Jabbusch, Johann Subklew, Fjord&Belt, Projektträger Jülich

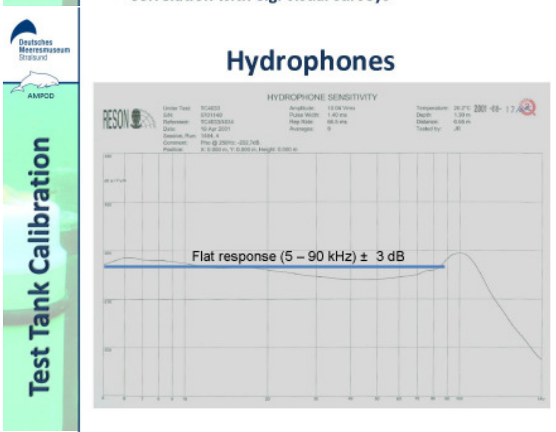
### AMPOD-outcome: Acoustic properties of SAM-devices

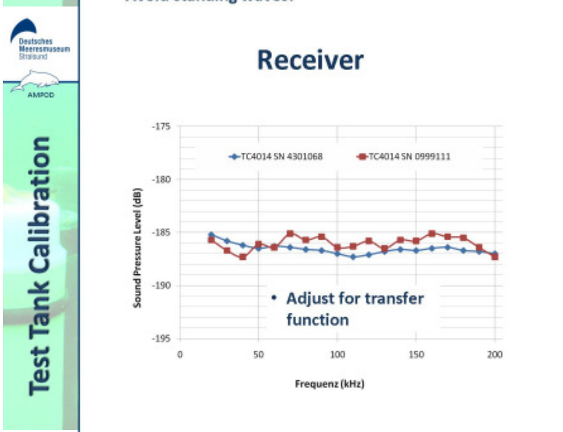
Michael Dähne, *German Oceanographic Museum, Germany*

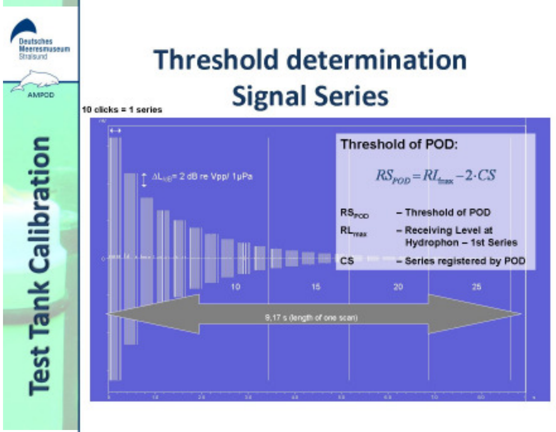


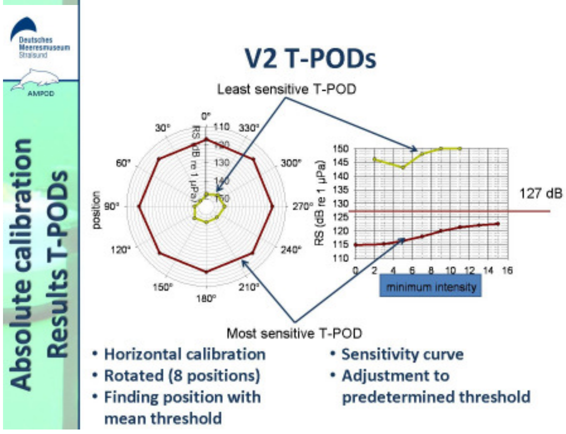



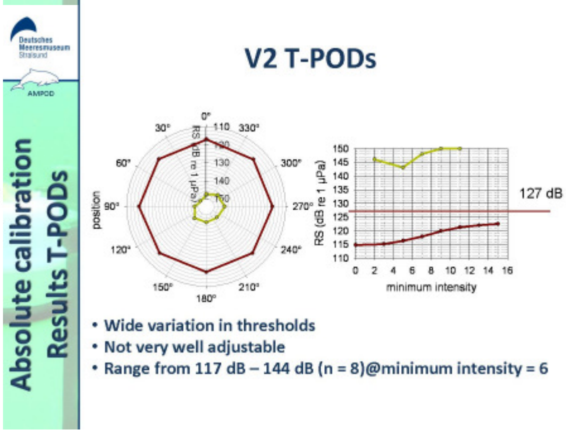



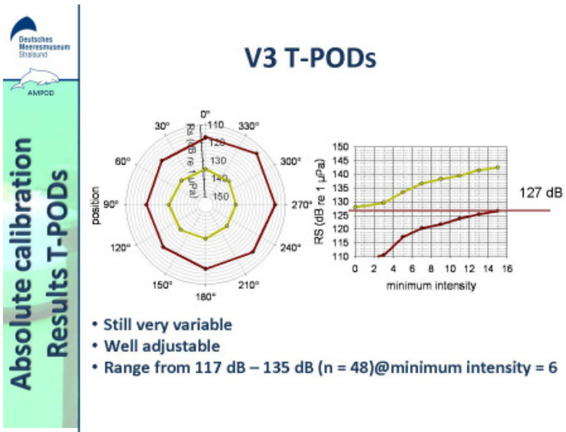



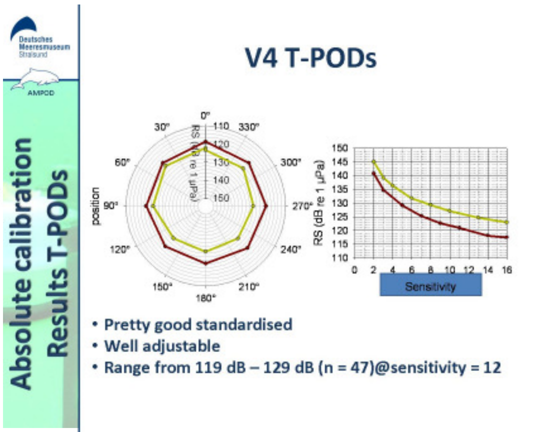



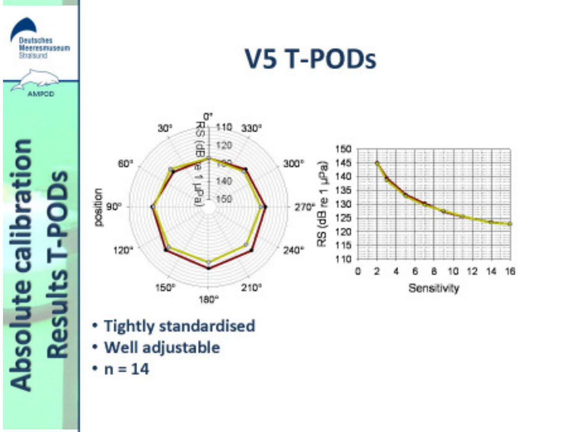



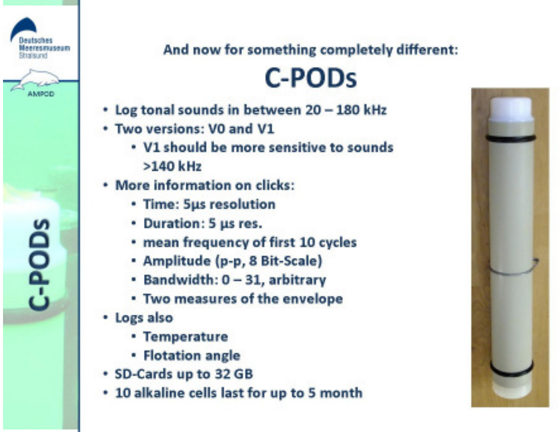



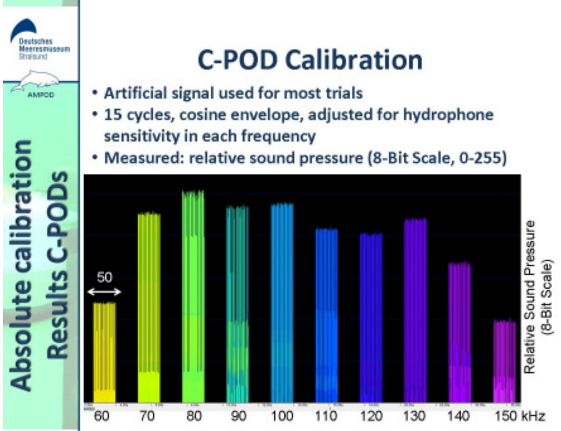



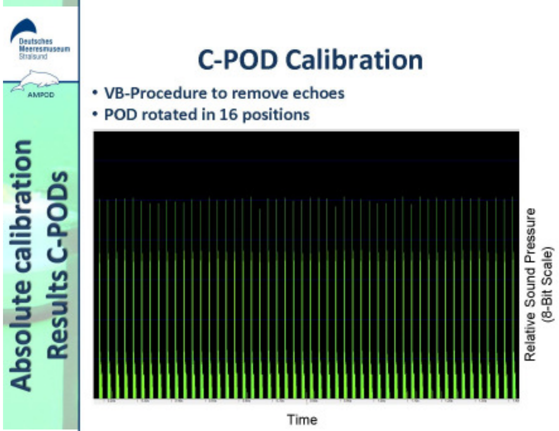

Absolute calibration
Results T-PODs
V3 T-PODs
127 dB
minimum intensity
• Still very variable
• Well adjustable
• Range from 117 dB – 135 dB (n = 48)@minimum intensity = 6

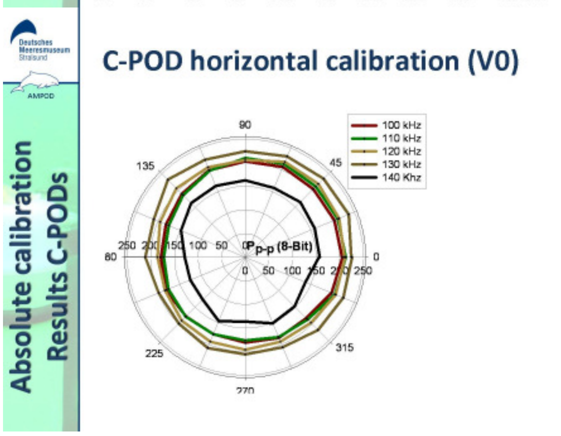

Absolute calibration
Results T-PODs
V4 T-PODs
Sensitivity
• Pretty good standardised
• Well adjustable
• Range from 119 dB – 129 dB (n = 47)@sensitivity = 12

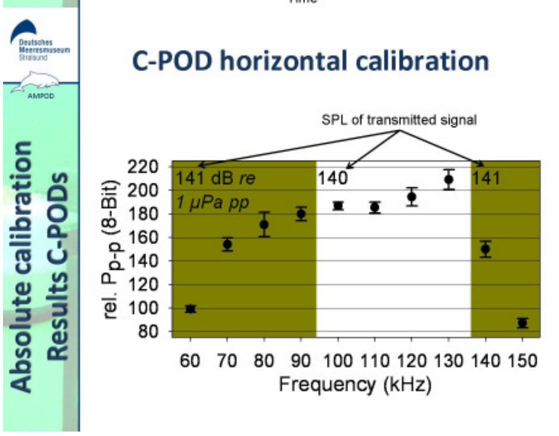

Absolute calibration
Results T-PODs
V5 T-PODs
Sensitivity
• Tightly standardised
• Well adjustable
• n = 14

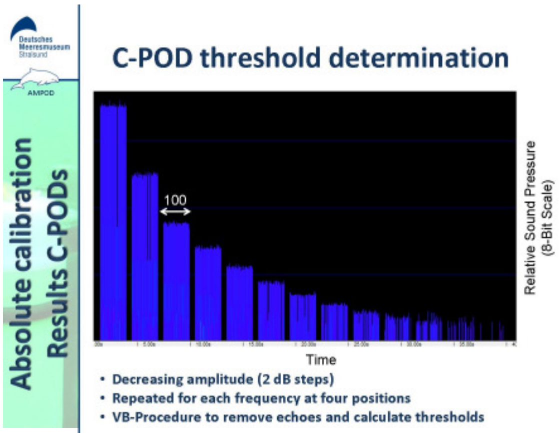

C-PODs
And now for something completely different:
C-PODs
• Log tonal sounds in between 20 – 180 kHz
• Two versions: V0 and V1
• V1 should be more sensitive to sounds >140 kHz
• More information on clicks:
• Time: 5µs resolution
• Duration: 5 µs res.
• mean frequency of first 10 cycles
• Amplitude (p-p, 8 Bit-Scale)
• Bandwidth: 0 – 31, arbitrary
• Two measures of the envelope
• Logs also
• Temperature
• Flotation angle
• SD-Cards up to 32 GB
• 10 alkaline cells last for up to 5 month

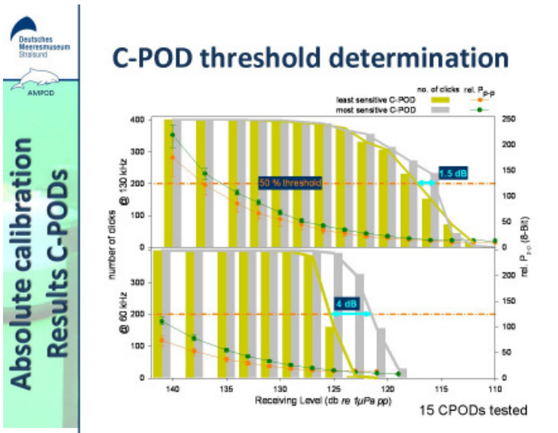

Absolute calibration
Results C-PODs
C-POD Calibration
• Artificial signal used for most trials
• 15 cycles, cosine envelope, adjusted for hydrophone sensitivity in each frequency
• Measured: relative sound pressure (8-Bit Scale, 0-255)
50
Relative Sound Pressure (8-Bit Scale)
60 70 80 90 100 110 120 130 140 150 kHz

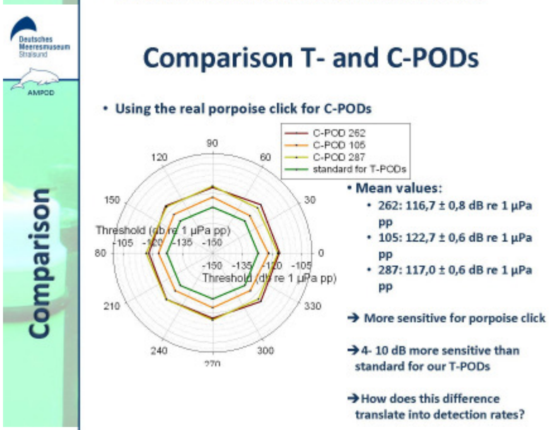

Absolute calibration
Results C-PODs
C-POD Calibration
• VB-Procedure to remove echoes
• POD rotated in 16 positions
Relative Sound Pressure (8-Bit Scale)
Time

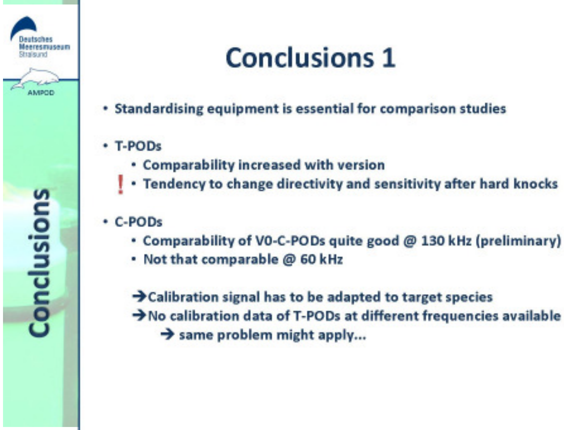

Absolute calibration
Results C-PODs
C-POD horizontal calibration (V0)
100 kHz
110 kHz
120 kHz
130 kHz
140 Khz
Pp-p (8-Bit)

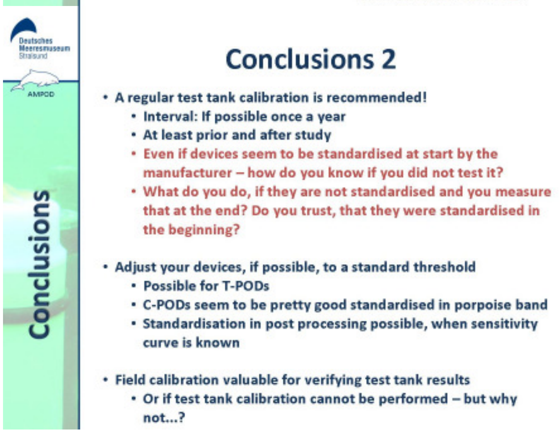

Absolute calibration
Results C-PODs
C-POD horizontal calibration
SPL of transmitted signal
141 dB re 1 µPa pp
140
141
rel. Pp-p (8-Bit)
Frequency (kHz)

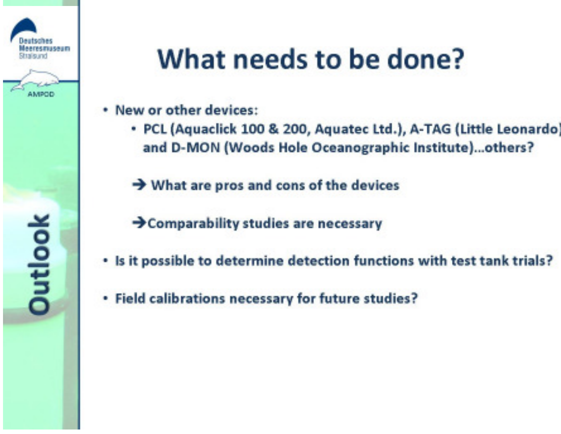

Absolute calibration
Results C-PODs
C-POD threshold determination
100
Relative Sound Pressure (8-Bit Scale)
Time
• Decreasing amplitude (2 dB steps)
• Repeated for each frequency at four positions
• VB-Procedure to remove echoes and calculate thresholds


Absolute calibration
Results C-PODs
C-POD threshold determination
least sensitive C-POD
most sensitive C-POD
50 % threshold
1.5 dB
4 dB
Receiving Level (db re 1µPa pp)
15 CPODs tested


Comparison
Comparison T- and C-PODs
• Using the real porpoise click for C-PODs
C-POD 262
C-POD 105
C-POD 287
standard for T-PODs
• Mean values:
• 262: 116,7 ± 0,8 dB re 1 µPa pp
• 105: 122,7 ± 0,6 dB re 1 µPa pp
• 287: 117,0 ± 0,6 dB re 1 µPa pp
→ More sensitive for porpoise click
→ 4- 10 dB more sensitive than standard for our T-PODs
→ How does this difference translate into detection rates?

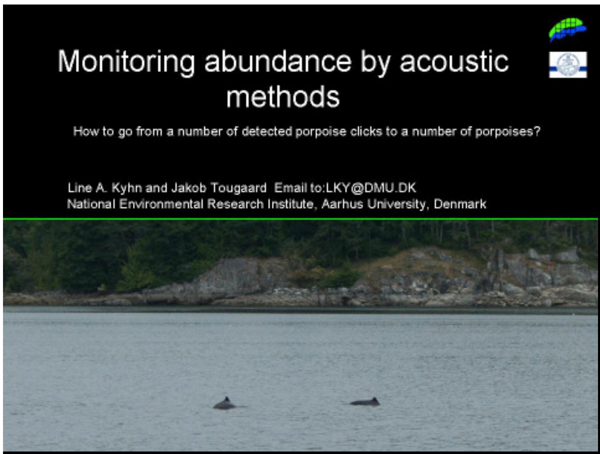

Conclusions
Conclusions 1
• Standardising equipment is essential for comparison studies
• T-PODs
• Comparability increased with version
! • Tendency to change directivity and sensitivity after hard knocks
• C-PODs
• Comparability of V0-C-PODs quite good @ 130 kHz (preliminary)
• Not that comparable @ 60 kHz
→ Calibration signal has to be adapted to target species
→ No calibration data of T-PODs at different frequencies available
→ same problem might apply…

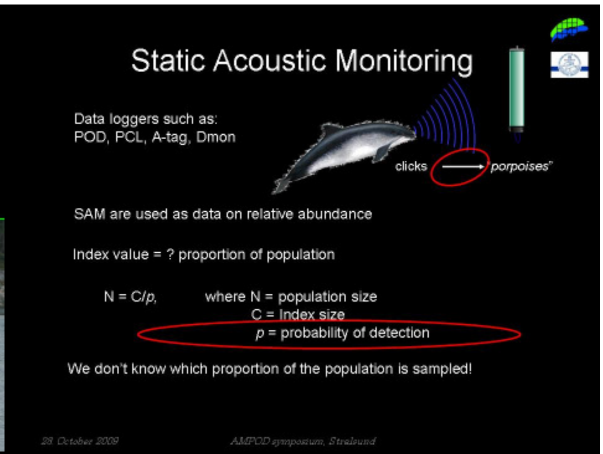

Conclusions
Conclusions 2
• A regular test tank calibration is recommended!
• Interval: If possible once a year
• At least prior and after study
• Even if devices seem to be standardised at start by the manufacturer – how do you know if you did not test it?
• What do you do, if they are not standardised and you measure that at the end? Do you trust, that they were standardised in the beginning?
• Adjust your devices, if possible, to a standard threshold
• Possible for T-PODs
• C-PODs seem to be pretty good standardised in porpoise band
• Standardisation in post processing possible, when sensitivity curve is known
• Field calibration valuable for verifying test tank results
• Or if test tank calibration cannot be performed – but why not…?

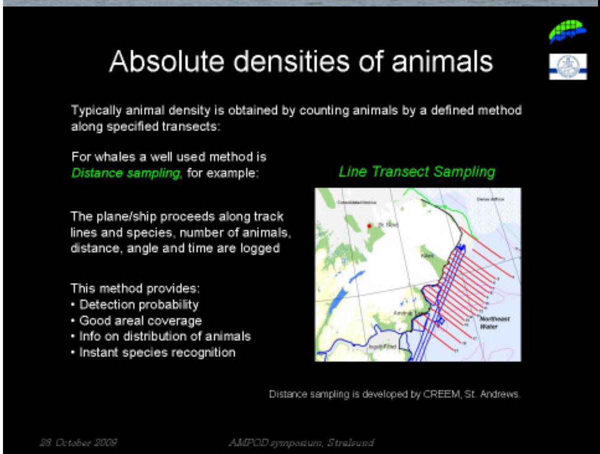

Outlook
What needs to be done?
• New or other devices:
• PCL (Aquaclick 100 & 200, Aquatec Ltd.), A-TAG (Little Leonardo) and D-MON (Woods Hole Oceanographic Institute)…others?
→ What are pros and cons of the devices
→ Comparability studies are necessary
• Is it possible to determine detection functions with test tank trials?
• Field calibrations necessary for future studies?

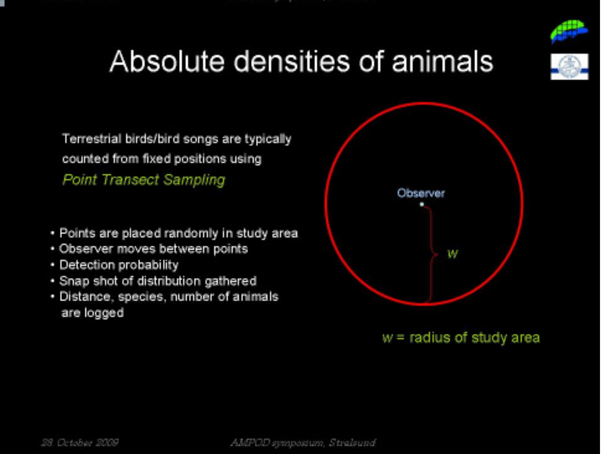
## Monitoring abundance by acoustic methods

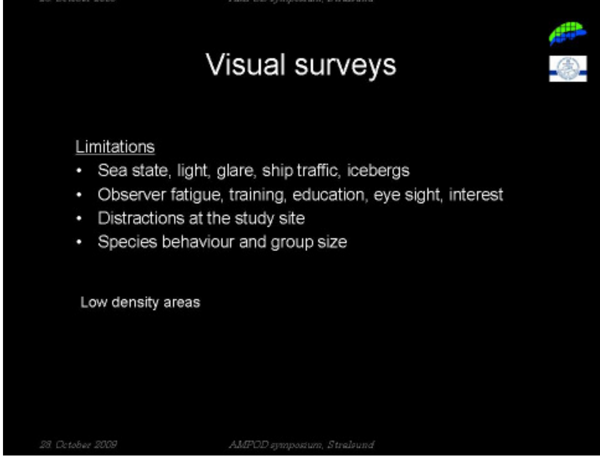
Line Kyhn, *National Environmental Research Institute, Aarhus University, Denmark*

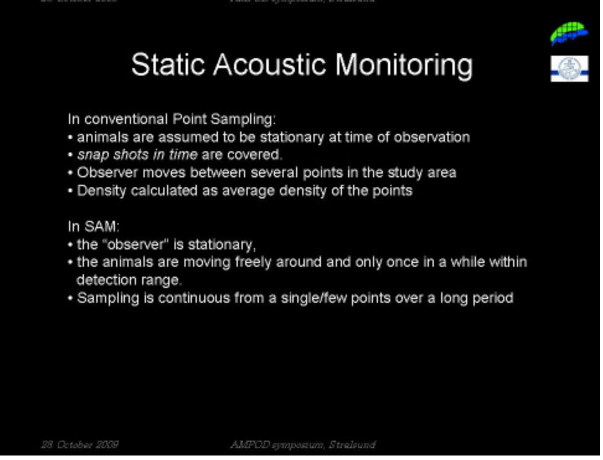


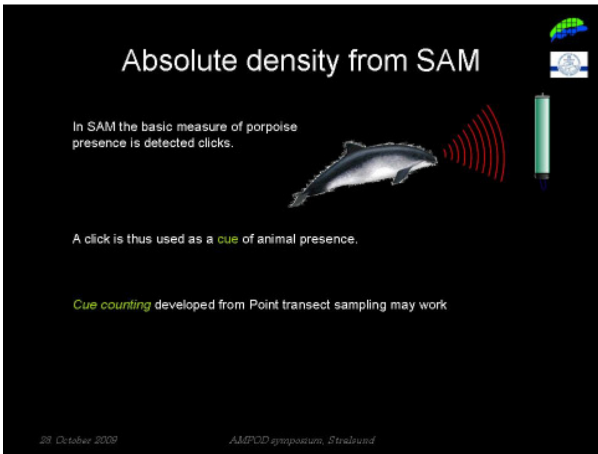



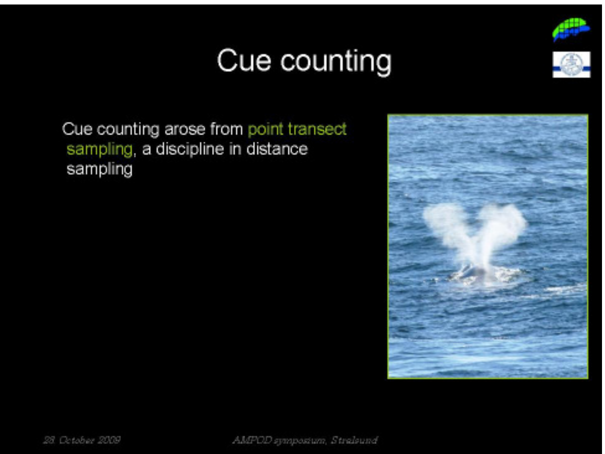



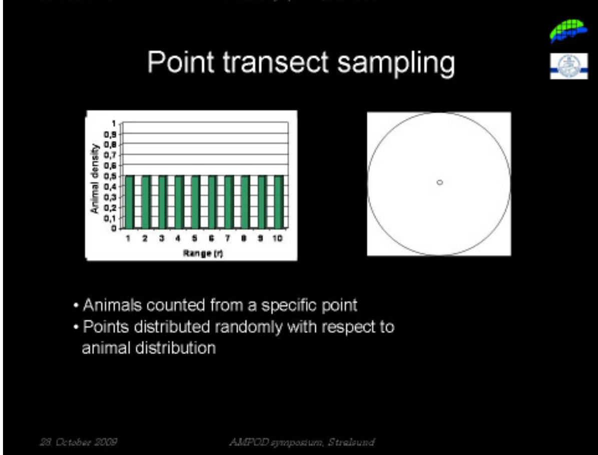



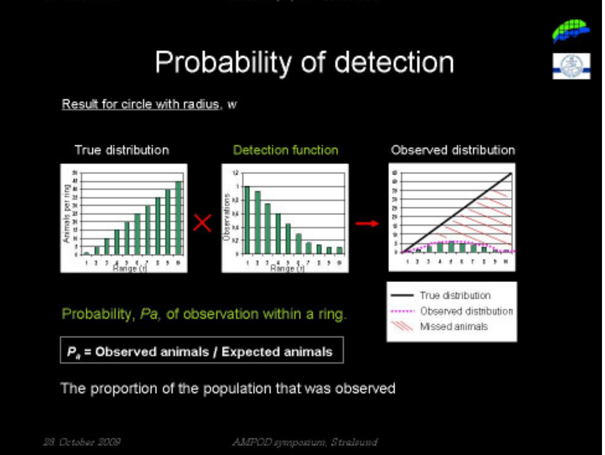



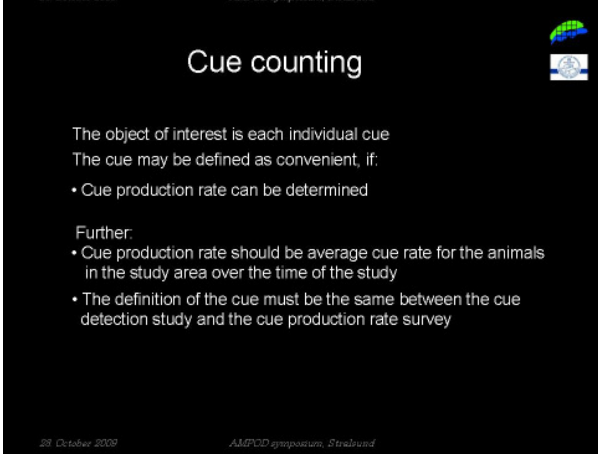



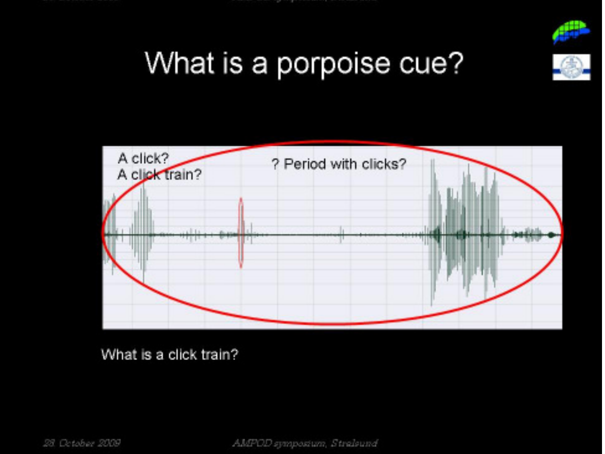

Absolute density from SAM
In SAM the basic measure of porpoise presence is detected clicks.
A click is thus used as a cue of animal presence.
Cue counting developed from Point transect sampling may work
28 October 2009
AMPOD symposium, Stralsund

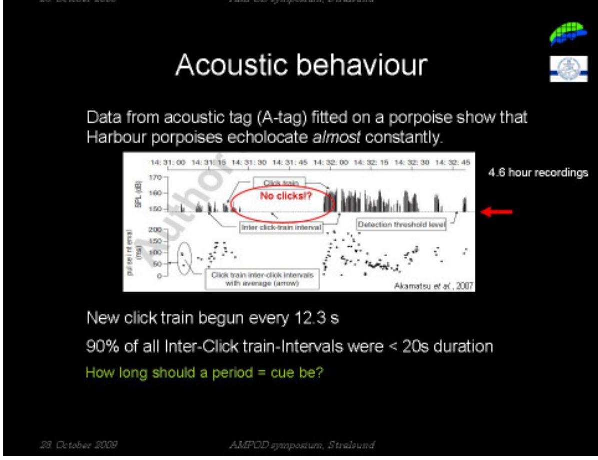

Cue counting
Cue counting arose from point transect sampling, a discipline in distance sampling
28 October 2009
AMPOD symposium, Stralsund


Point transect sampling
Animal density
Range (r)
• Animals counted from a specific point
• Points distributed randomly with respect to animal distribution
28 October 2009
AMPOD symposium, Stralsund


Probability of detection
Result for circle with radius, w
True distribution
Detection function
Observed distribution
True distribution
Observed distribution
Missed animals
Probability, Pa, of observation within a ring.
Pa = Observed animals / Expected animals
The proportion of the population that was observed
28 October 2009
AMPOD symposium, Stralsund


Cue counting
The object of interest is each individual cue
The cue may be defined as convenient, if:
• Cue production rate can be determined
Further:
• Cue production rate should be average cue rate for the animals in the study area over the time of the study
• The definition of the cue must be the same between the cue detection study and the cue production rate survey
28 October 2009
AMPOD symposium, Stralsund


What is a porpoise cue?
A click?
A click train?
? Period with clicks?
What is a click train?
28 October 2009
AMPOD symposium, Stralsund


Acoustic behaviour
Data from acoustic tag (A-tag) fitted on a porpoise show that Harbour porpoises echolocate almost constantly.
4.6 hour recordings
No clicks!?
Click train
Inter click-train interval
Detection threshold level
Click train inter-click intervals with average (arrow)
Akamatsu et al., 2007
New click train begun every 12.3 s
90% of all Inter-Click train-Intervals were < 20s duration
How long should a period = cue be?
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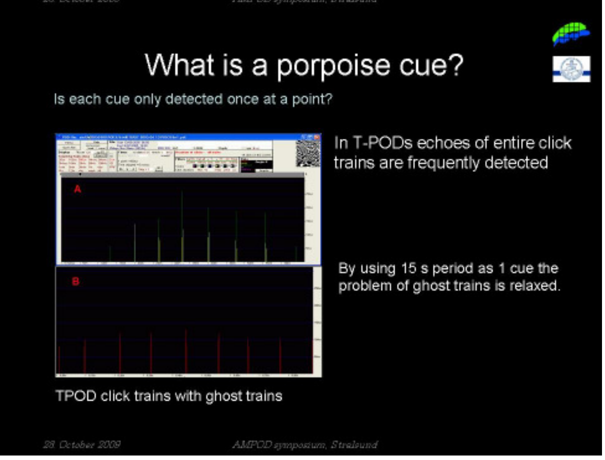
What is a porpoise cue?
Is each cue only detected once at a point?
In T-PODs echoes of entire click trains are frequently detected
By using 15 s period as 1 cue the problem of ghost trains is relaxed.
TPOD click trains with ghost trains
28 October 2009
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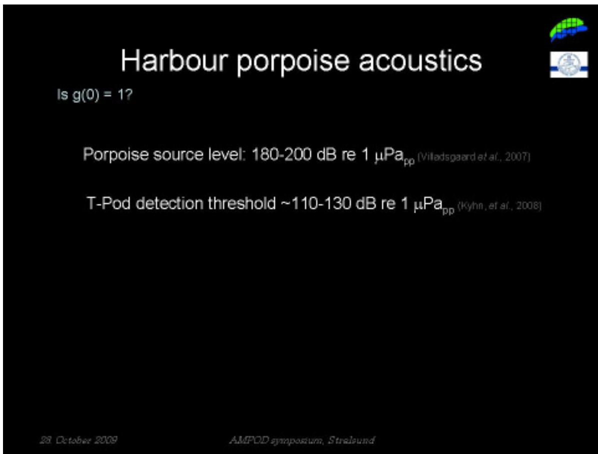
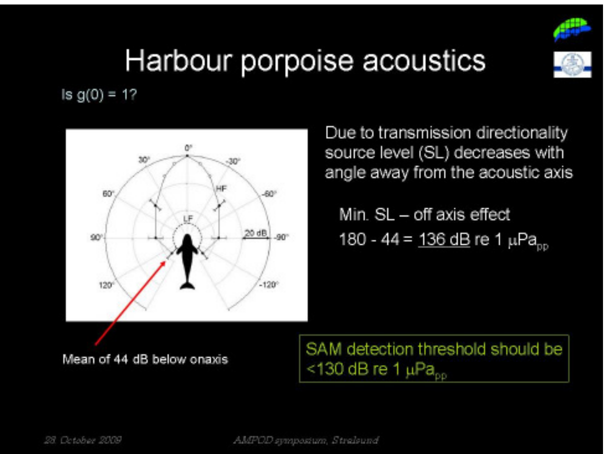

Harbour porpoise acoustics
Is g(0) = 1?
Porpoise source level: 180-200 dB re 1 µPa pp (Villadsgaard et al., 2007)
T-Pod detection threshold ~110-130 dB re 1 µPa pp (Kyhn, et al., 2008)
28. October 2009
AMPOD symposium, Stralsund


Harbour porpoise acoustics
Is g(0) = 1?
Due to transmission directionality source level (SL) decreases with angle away from the acoustic axis
Min. SL – off axis effect
180 - 44 = 136 dB re 1 µPa pp
Mean of 44 dB below onaxis
SAM detection threshold should be <130 dB re 1 µPa pp
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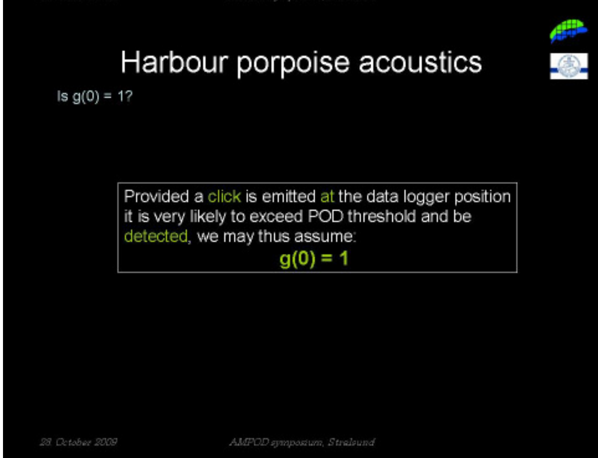
Harbour porpoise acoustics
Is g(0) = 1?
Provided a click is emitted at the data logger position it is very likely to exceed POD threshold and be detected, we may thus assume:
g(0) = 1
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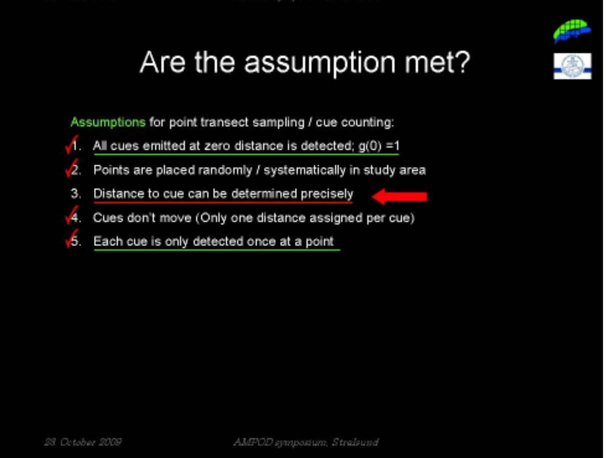
Are the assumption met?
Assumptions for point transect sampling / cue counting:
1. All cues emitted at zero distance is detected; g(0) =1
2. Points are placed randomly / systematically in study area
3. Distance to cue can be determined precisely
4. Cues don't move (Only one distance assigned per cue)
5. Each cue is only detected once at a point
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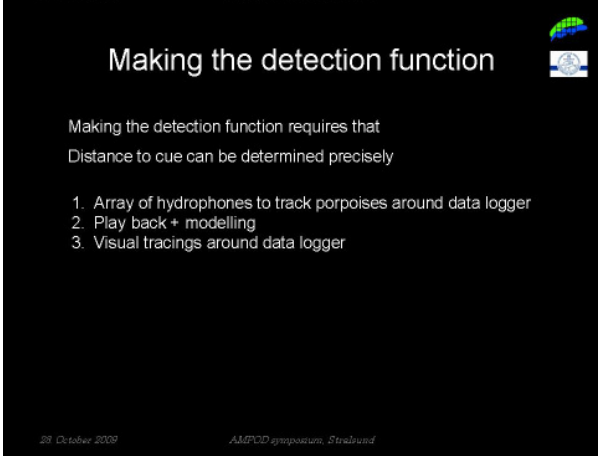
Making the detection function
Making the detection function requires that
Distance to cue can be determined precisely
1. Array of hydrophones to track porpoises around data logger
2. Play back + modelling
3. Visual tracings around data logger
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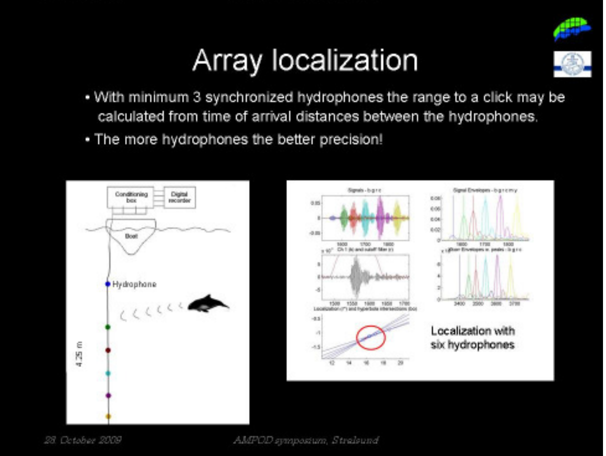
Array localization
• With minimum 3 synchronized hydrophones the range to a click may be calculated from time of arrival distances between the hydrophones.
• The more hydrophones the better precision!
Conditioning box
Digital recorder
Boat
Hydrophone
4.25 m
Localization with six hydrophones
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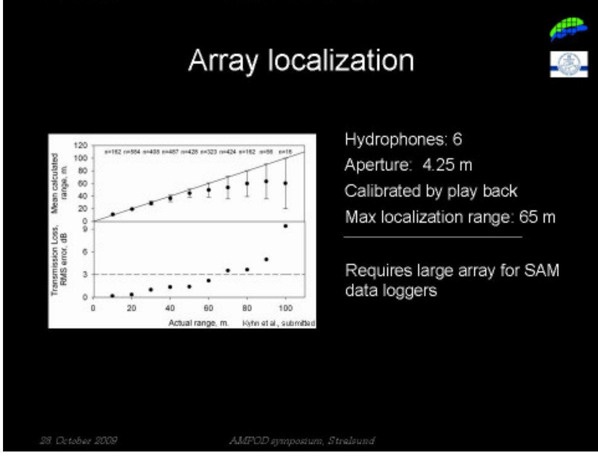
Array localization
Hydrophones: 6
Aperture: 4.25 m
Calibrated by play back
Max localization range: 65 m
Requires large array for SAM data loggers
Mean calculated range, m
Transmission Loss, RMS error, dB
Actual range, m
Kyhn et al., submitted
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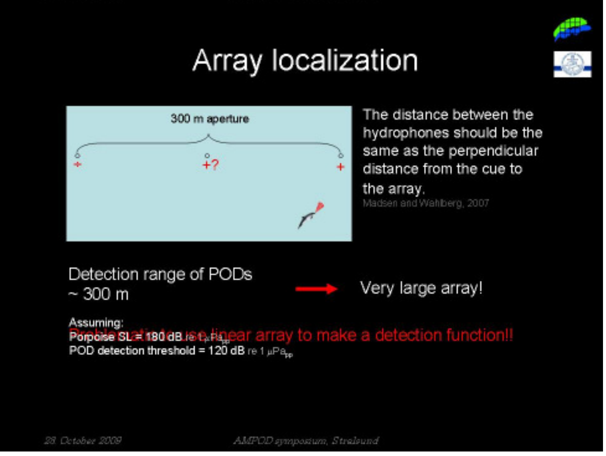
Array localization
300 m aperture
The distance between the hydrophones should be the same as the perpendicular distance from the cue to the array.
Madsen and Wahlberg, 2007
Detection range of PODs
~ 300 m
Very large array!
Assuming:
Porpoise SL = 180 dB re 1 µPa pp
POD detection threshold = 120 dB re 1 µPa pp
linear array to make a detection function!!
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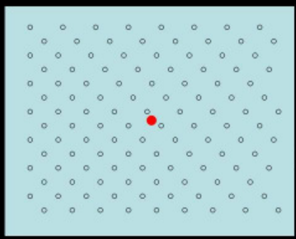
## Web of hydrophones




Cues may be very precisely located!
Very laborious data work
Very expensive equipment
Likely only possible in former military facilities…

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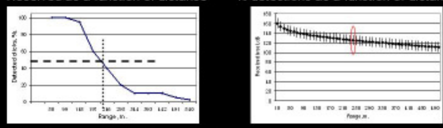
## Playback + model

Artificial porpoise clicks emitted at increasing distance from POD
At the study site!

Received as a function of distance % detections as a function of distance



Model swimming behaviour of porpoises using data on directionality and behaviour

Problems:
How to build such a model? Is this approach presentable?

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## Visual localization

Theodolite tracings
Exact distances to PODs may be obtained.

Drawbacks

Assumption:
Distance between porpoise and POD = distance between cue and POD

Porpoises at the surface and down again within 1 cue

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## Visual localization

Problems:
- Exact synchronization between POD and theodolite tracks is essential!
- If more than one porpoise is present at a time, whose click train is detected – what distance to use?

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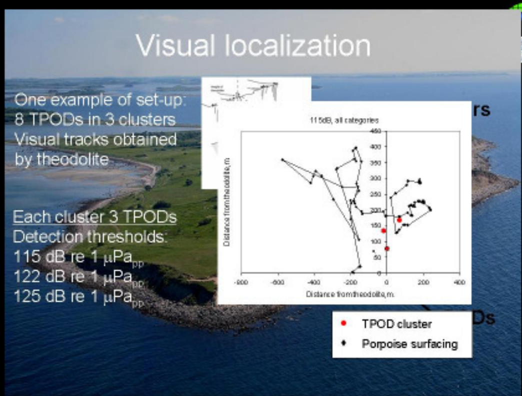


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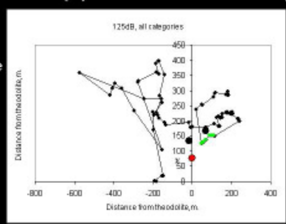
## The visual approach

Suggestion in cooperation with CREEM:

1. Visual tracings from theodolite
2. Interpolate between observations
3. Divide track in 15s periods = cues

1. For each cue find distance to POD
2. For each cue check POD detections




- It appears possible!
- Each detection threshold requires a detection function
- Essential to calibrate POD

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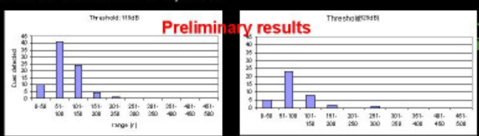
1 example:
1 TPOD with detection threshold of 115dB
36 tracks divided into 15 s periods




Distribution of detected distances

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## Generality of detection function

Having established a detection function, is it valid outside
that point in the study area?
the entire study area?
the season?
the species?
the data logger type?

→ Must know the variation to know where we must stratify

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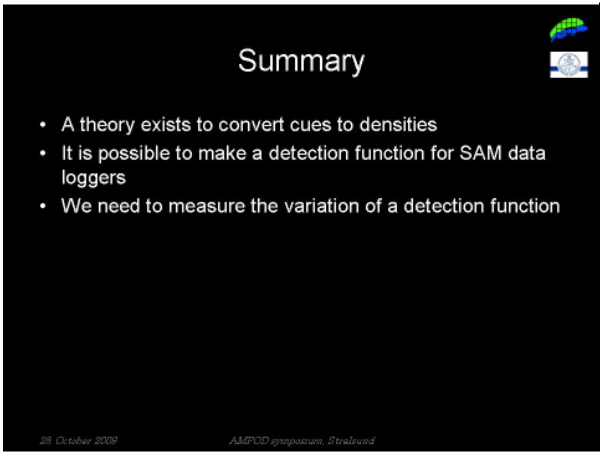
Summary
• A theory exists to convert cues to densities
• It is possible to make a detection function for SAM data loggers
• We need to measure the variation of a detection function
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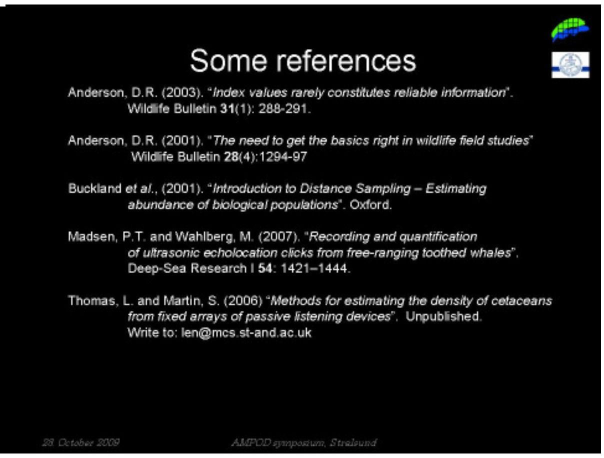
Some references
Anderson, D.R. (2003). "Index values rarely constitutes reliable information". Wildlife Bulletin 31(1): 288-291.
Anderson, D.R. (2001). "The need to get the basics right in wildlife field studies" Wildlife Bulletin 28(4):1294-97
Buckland et al., (2001). "Introduction to Distance Sampling – Estimating abundance of biological populations". Oxford.
Madsen, P.T. and Wahlberg, M. (2007). "Recording and quantification of ultrasonic echolocation clicks from free-ranging toothed whales". Deep-Sea Research I 54: 1421–1444.
Thomas, L. and Martin, S. (2006) "Methods for estimating the density of cetaceans from fixed arrays of passive listening devices". Unpublished. Write to: len@mcs.st-and.ac.uk
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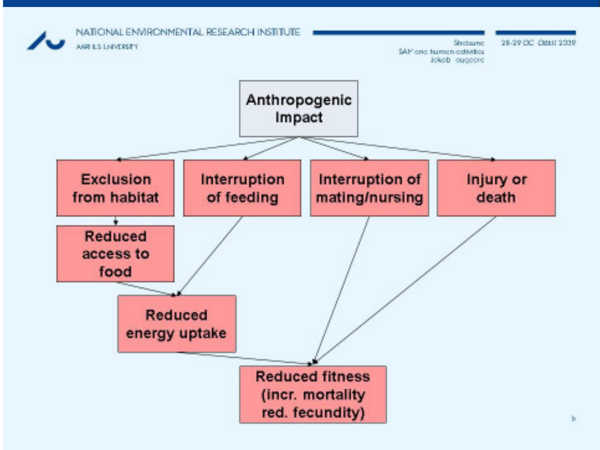
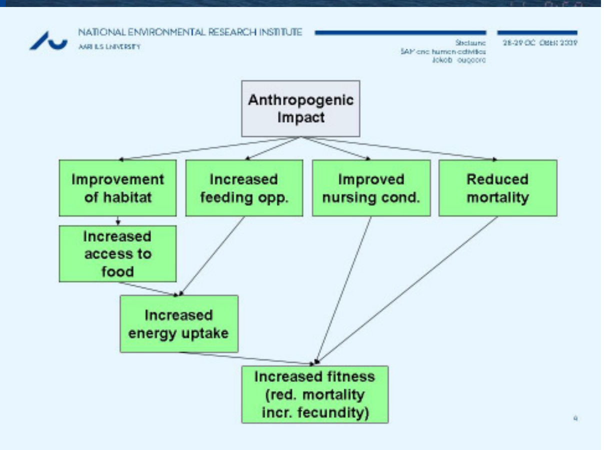
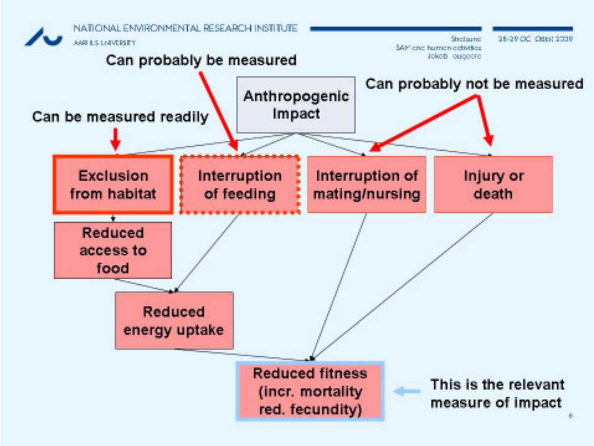
## Using SAM to monitor the effect of human activities

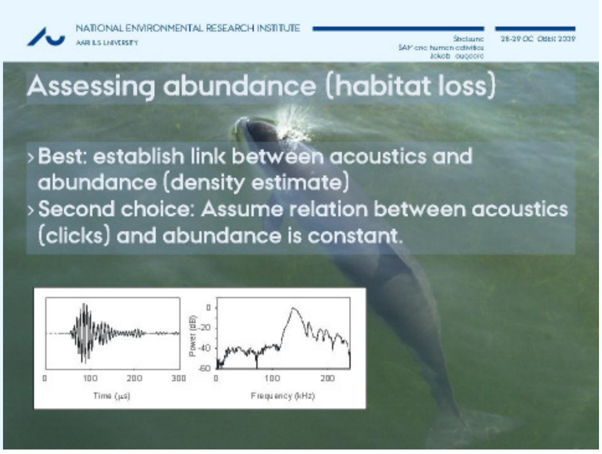
Dr. Jakob Tougaard, *National Environmental Research Institute, Aarhus University, Denmark*

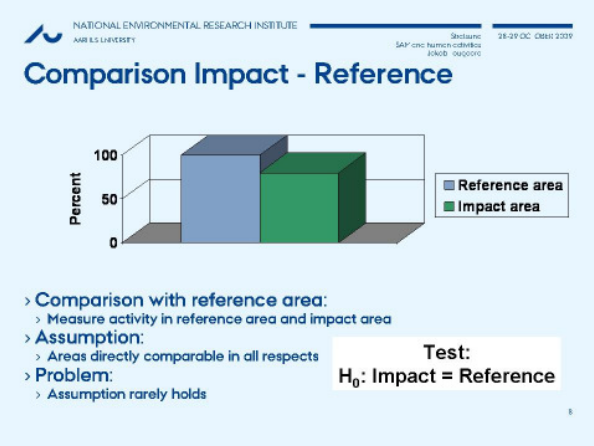


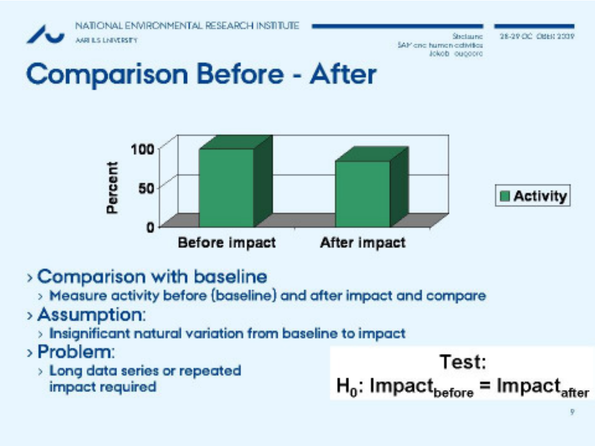


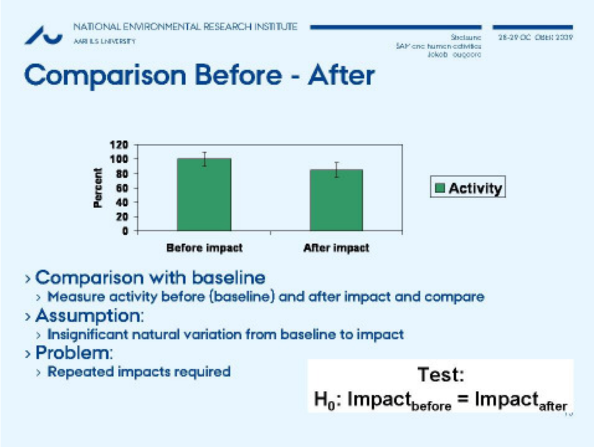



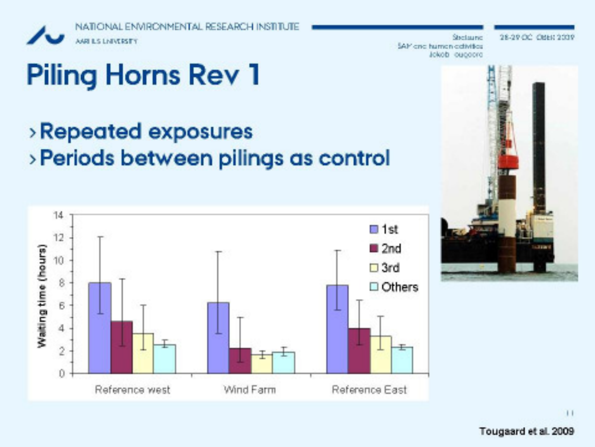




NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
Comparison Impact - Reference
100
50
0
Percent
Reference area
Impact area
› Comparison with reference area:
› Measure activity in reference area and impact area
› Assumption:
› Areas directly comparable in all respects
› Problem:
› Assumption rarely holds
Test:
$H_0$: Impact = Reference


NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
Comparison Before - After
100
50
0
Percent
Before impact
After impact
Activity
› Comparison with baseline
› Measure activity before (baseline) and after impact and compare
› Assumption:
› Insignificant natural variation from baseline to impact
› Problem:
› Long data series or repeated impact required
Test:
$H_0$: $Impact_{before} = Impact_{after}$


NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
Comparison Before - After
120
100
80
60
40
20
0
Percent
Before impact
After impact
Activity
› Comparison with baseline
› Measure activity before (baseline) and after impact and compare
› Assumption:
› Insignificant natural variation from baseline to impact
› Problem:
› Repeated impacts required
Test:
$H_0$: $Impact_{before} = Impact_{after}$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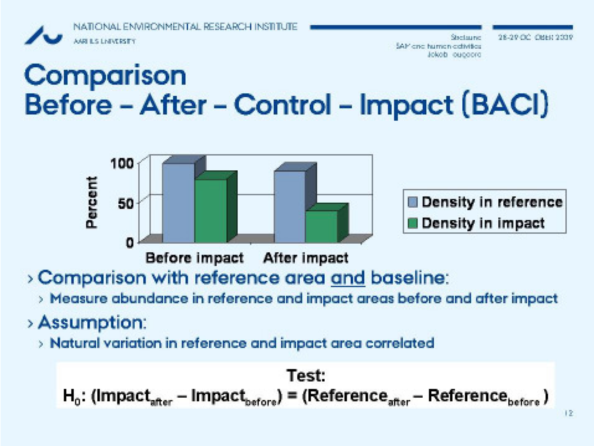
Piling Horns Rev 1
› Repeated exposures
› Periods between pilings as control
Waiting time (hours)
1st
2nd
3rd
Others
Reference west
Wind Farm
Reference East
Tougaard et al. 2009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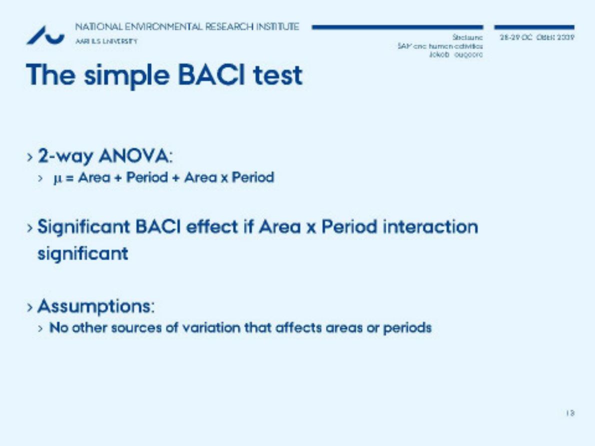
Comparison
Before – After – Control – Impact (BACI)
100
50
0
Percent
Before impact
After impact
Density in reference
Density in impact
› Comparison with reference area and baseline:
› Measure abundance in reference and impact areas before and after impact
› Assumption:
› Natural variation in reference and impact area correlated
Test:
$H_0$: $(Impact_{after} - Impact_{before}) = (Reference_{after} - Reference_{before})$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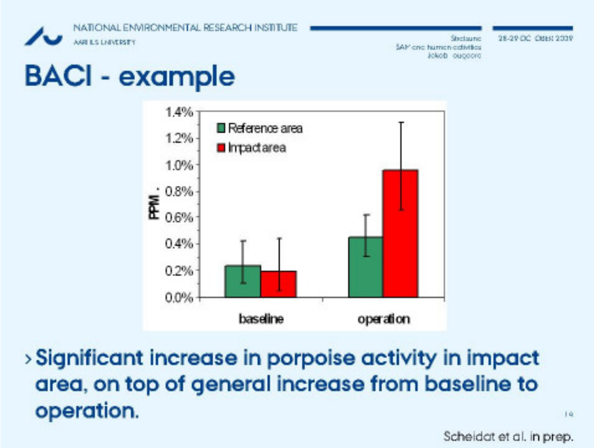
The simple BACI test
› 2-way ANOVA:
› μ = Area + Period + Area x Period
› Significant BACI effect if Area x Period interaction significant
› Assumptions:
› No other sources of variation that affects areas or periods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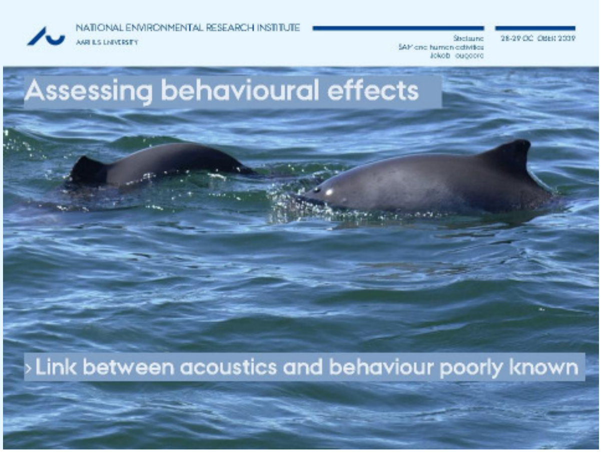
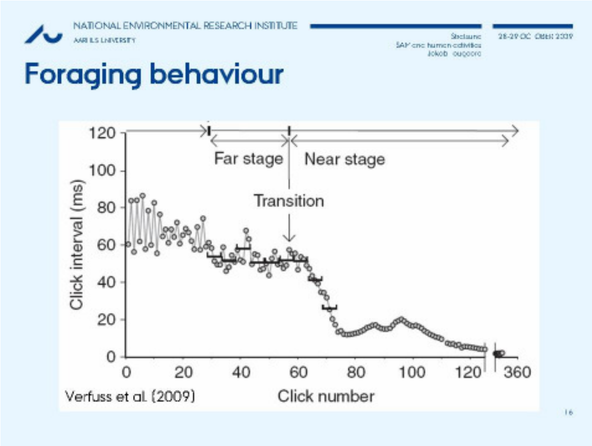
BACI - example
1.4%
1.2%
1.0%
0.8%
0.6%
0.4%
0.2%
0.0%
PPM
Reference area
Impact area
baseline
operation
› Significant increase in porpoise activity in impact area, on top of general increase from baseline to operation.
Scheidat et al. in prep.


NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
Assessing behavioural effects
› Link between acoustics and behaviour poorly known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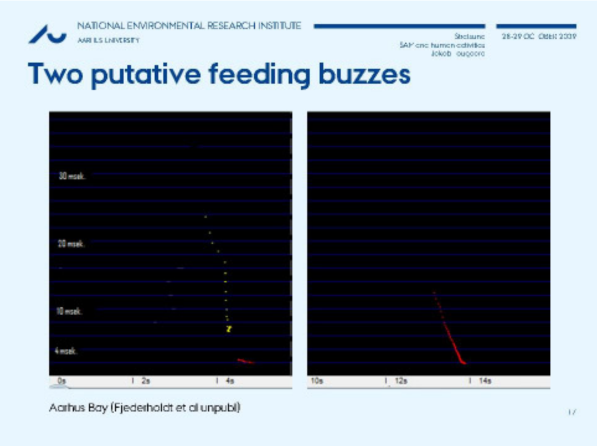
Foraging behaviour
Far stage
Near stage
Transition
Click interval (ms)
Click number
Verfuss et al. (2009)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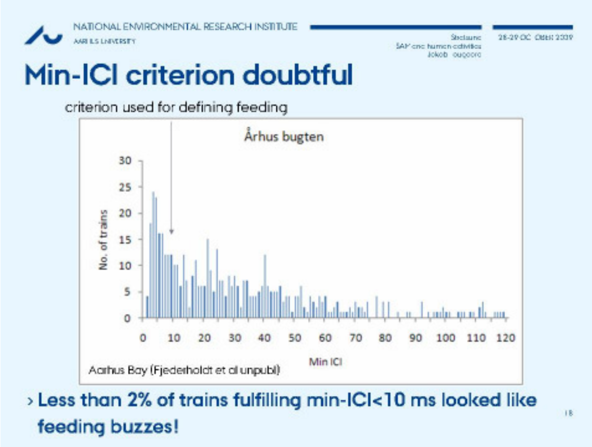
Two putative feeding buzzes
Aarhus Bay (Fjederholdt et al unpubl)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Min-ICI criterion doubtful
criterion used for defining feeding
Århus bugten
No. of trains
Min ICI
Aarhus Bay (Fjederholdt et al unpubl)
› Less than 2% of trains fulfilling min-ICI<10 ms looked like feeding buzzes!


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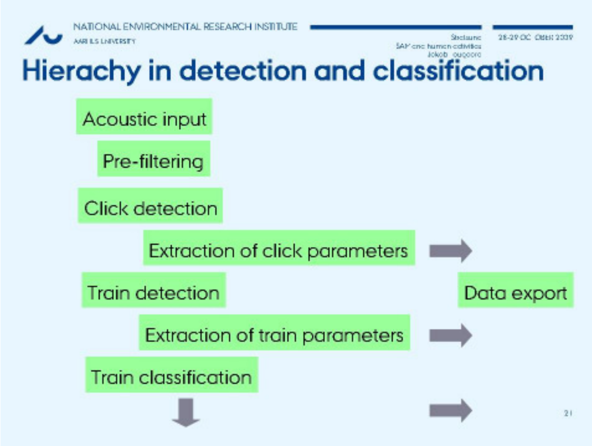
The ideal SAM-device
› Practical issues
› Detection issues
› Classification issues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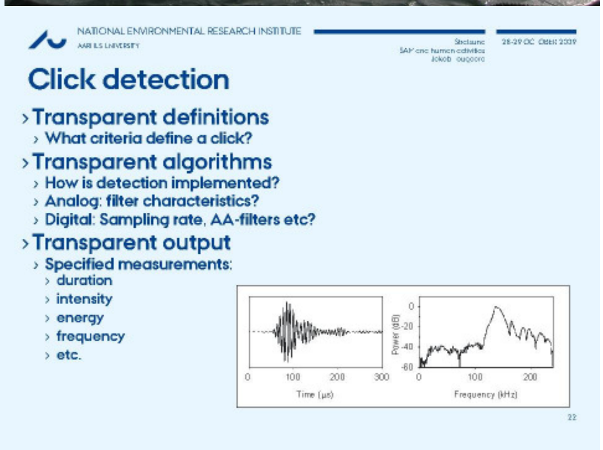
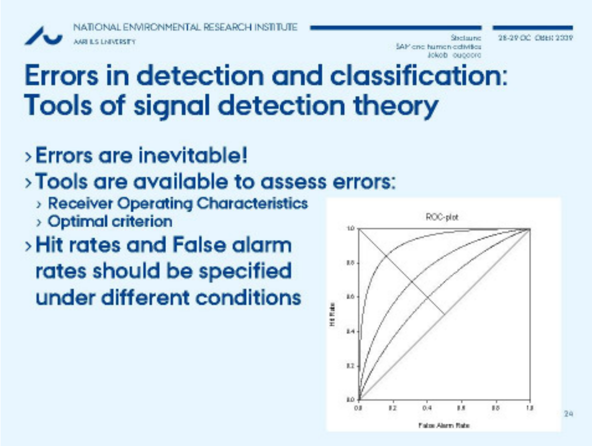
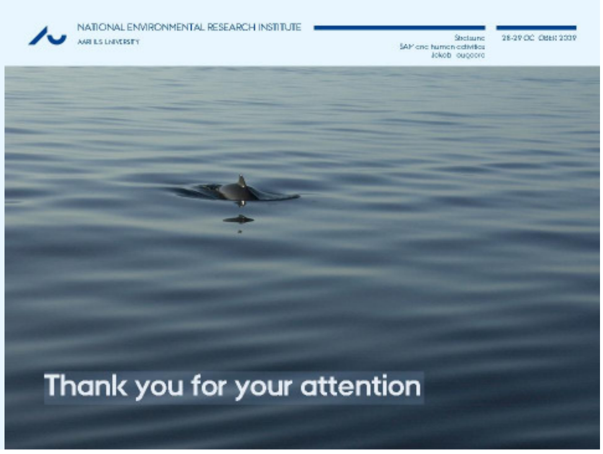
Hierachy in detection and classification
Acoustic input
Pre-filtering
Click detection
Extraction of click parameters
Train detection
Data export
Extraction of train parameters
Train classification

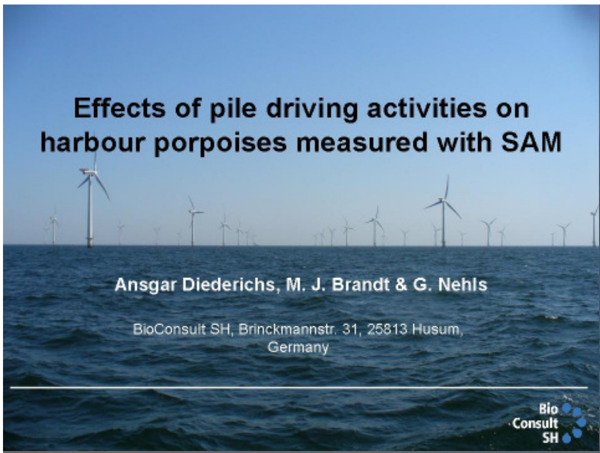

NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
Click detection
› Transparent definitions
› What criteria define a click?
› Transparent algorithms
› How is detection implemented?
› Analog: filter characteristics?
› Digital: Sampling rate, AA-filters etc?
› Transparent output
› Specified measurements:
› duration
› intensity
› energy
› frequency
› etc.
Time (µs)
Power (dB)
Frequency (kHz)

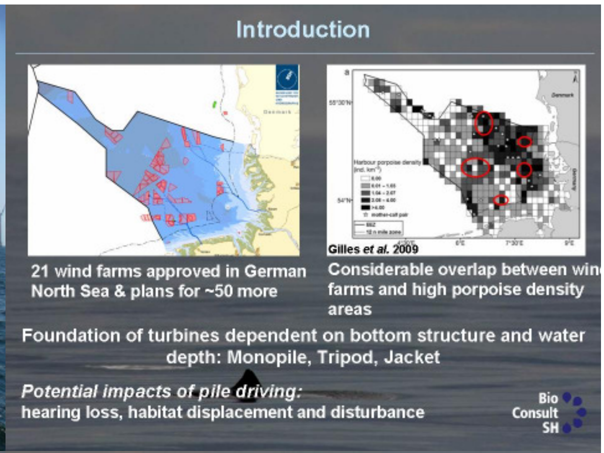

NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
Errors in detection and classification:
Tools of signal detection theory
› Errors are inevitable!
› Tools are available to assess errors:
› Receiver Operating Characteristics
› Optimal criterion
› Hit rates and False alarm rates should be specified under different conditions
ROC-plot

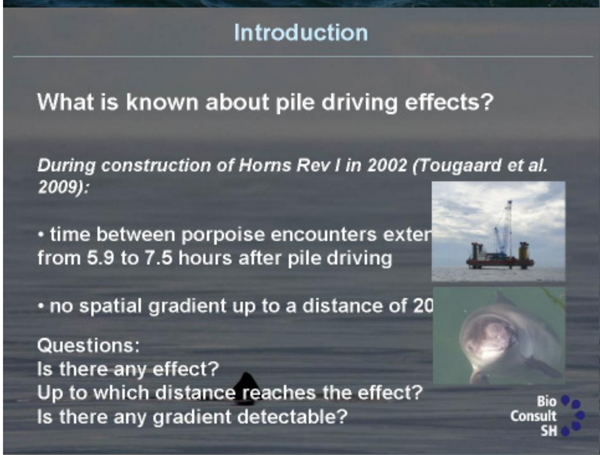

NATIONAL ENVIRONMENTAL RESEARCH INSTITUTE
Thank you for your attention

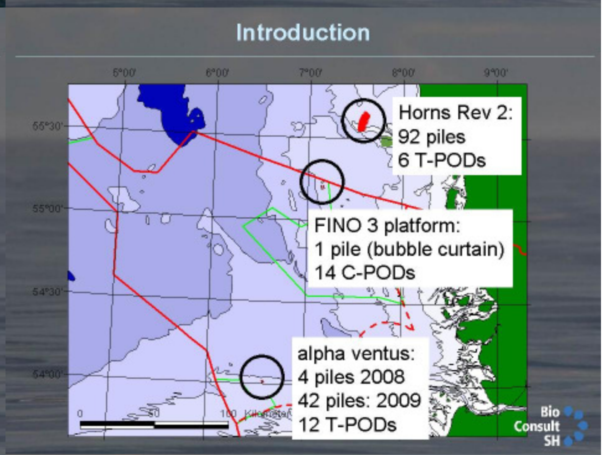
## Effects of pile driving activities measured with SAM

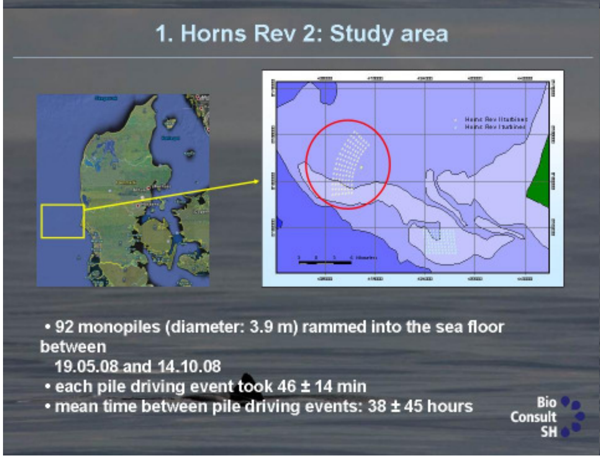
Ansgar Diederichs, *BioConsult-SH, Germany*

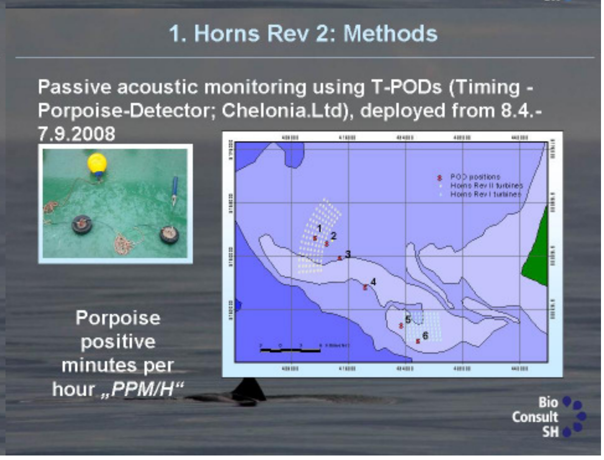


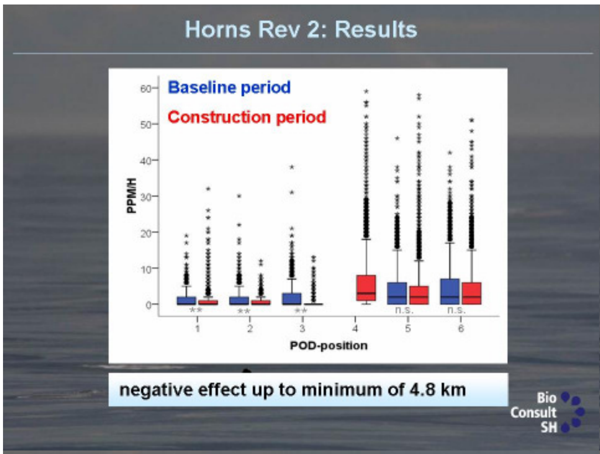



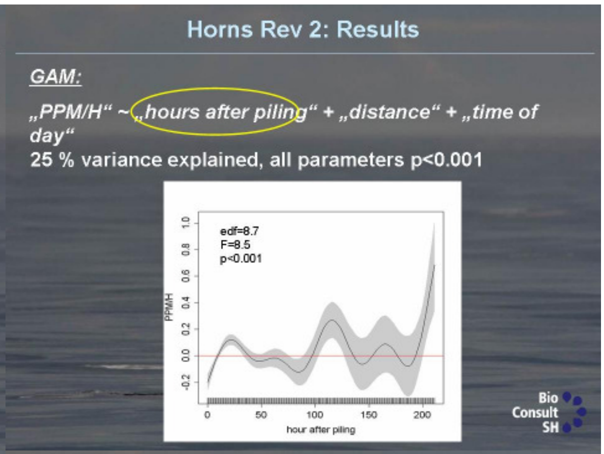



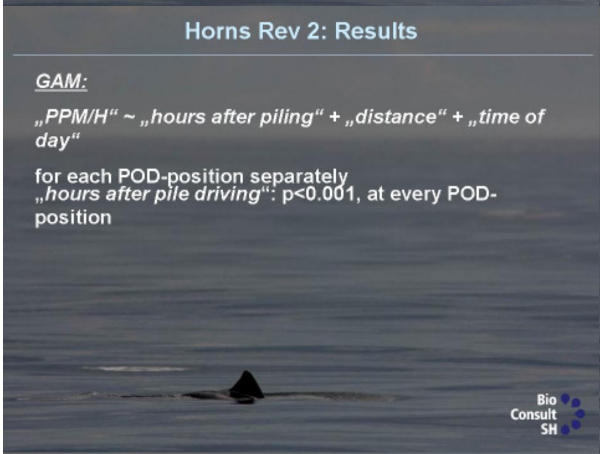



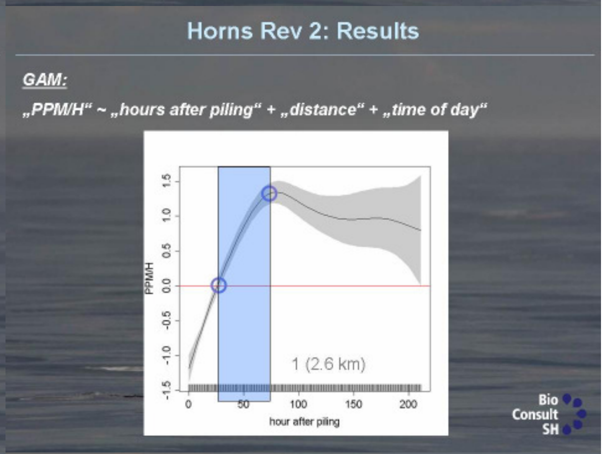



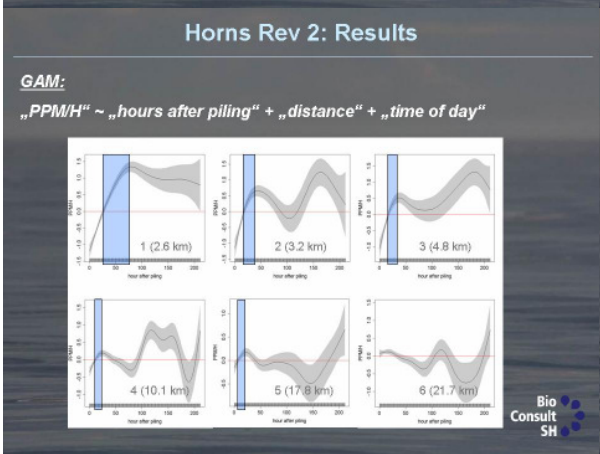



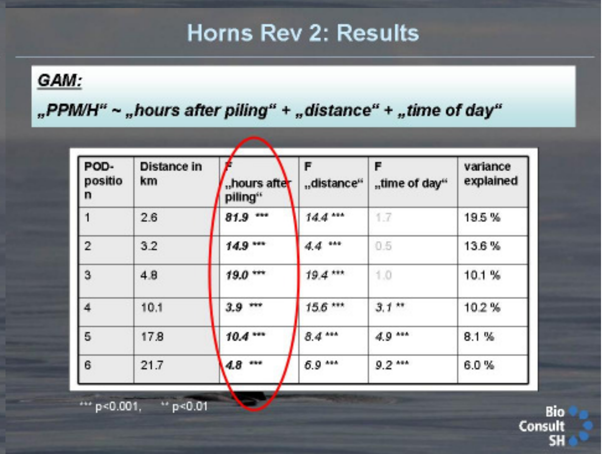


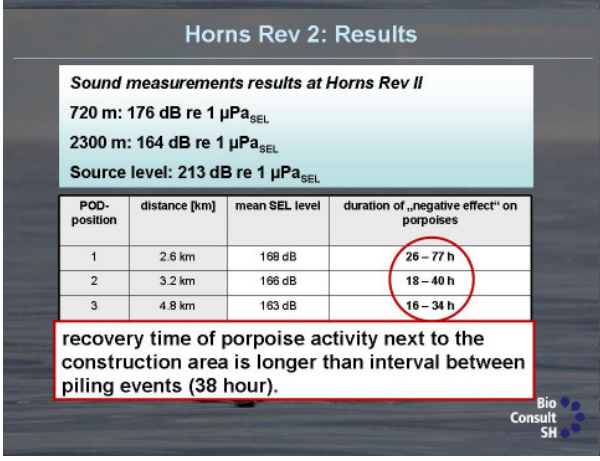



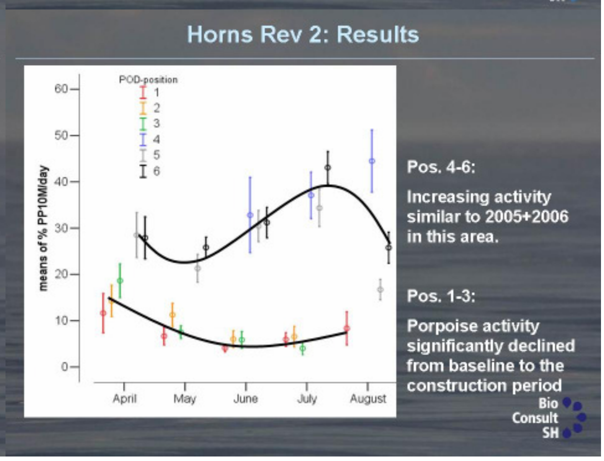



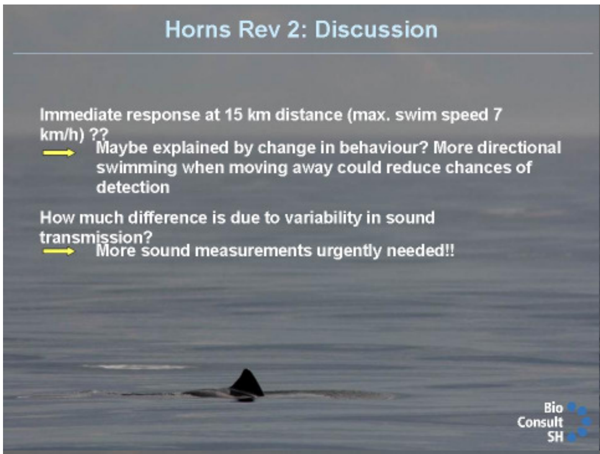

| POD-position | Distance in km | F „hours after piling“ | F „distance“ | F „time of day“ | variance explained |
|---|---|---|---|---|---|
| 1 | 2.6 | *81.9* *** | *14.4* *** | 1.7 | 19.5 % |
| 2 | 3.2 | *14.9* *** | *4.4* *** | 0.5 | 13.6 % |
| 3 | 4.8 | *19.0* *** | *19.4* *** | 1.0 | 10.1 % |
| 4 | 10.1 | *3.9* *** | *15.6* *** | *3.1* ** | 10.2 % |
| 5 | 17.8 | *10.4* *** | *8.4* *** | *4.9* *** | 8.1 % |
| 6 | 21.7 | *4.8* *** | *6.9* *** | *9.2* *** | 6.0 % |

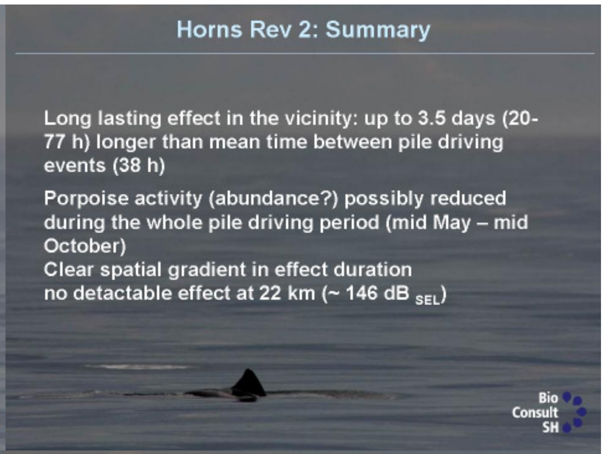
*** $p<0.001$, ** $p<0.01$

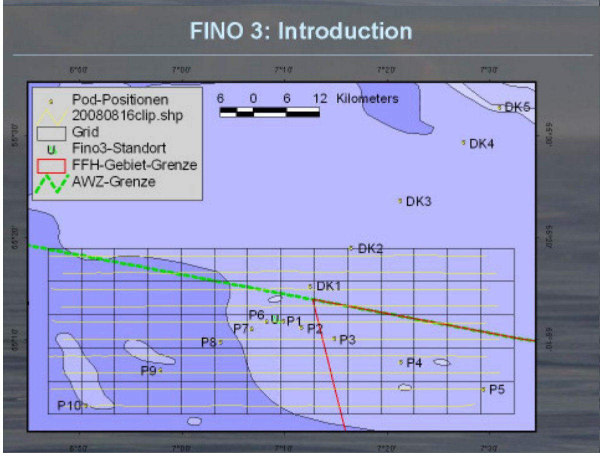


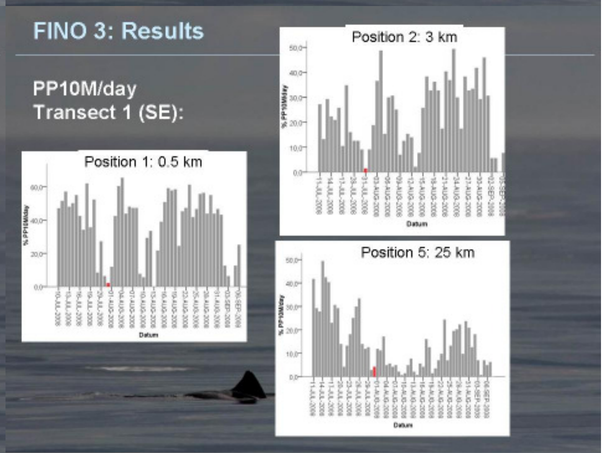

| POD-position | distance [km] | mean SEL level | duration of „negative effect“ on porpoises |
|---|---|---|---|
| 1 | 2.6 km | 168 dB | 26 – 77 h |
| 2 | 3.2 km | 166 dB | 18 – 40 h |
| 3 | 4.8 km | 163 dB | 16 – 34 h |

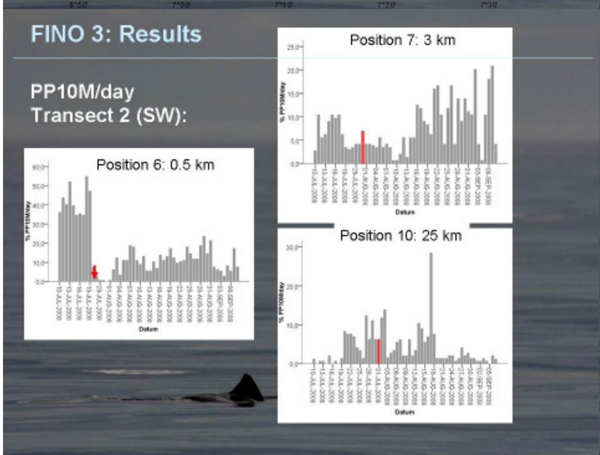


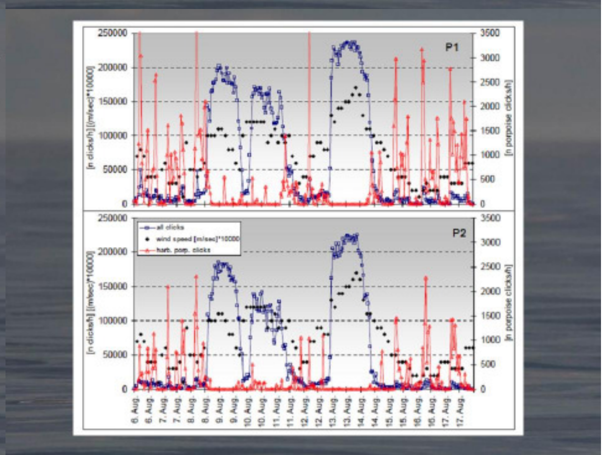

Horns Rev 2: Discussion
Immediate response at 15 km distance (max. swim speed 7 km/h) ??
Maybe explained by change in behaviour? More directional swimming when moving away could reduce chances of detection
How much difference is due to variability in sound transmission?
More sound measurements urgently needed!!
Bio Consult SH

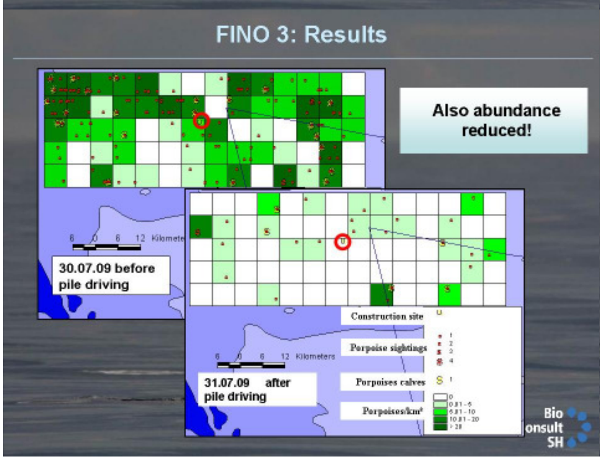

Horns Rev 2: Summary
Long lasting effect in the vicinity: up to 3.5 days (20-77 h) longer than mean time between pile driving events (38 h)
Porpoise activity (abundance?) possibly reduced during the whole pile driving period (mid May – mid October)
Clear spatial gradient in effect duration
no detactable effect at 22 km (~ 146 dB SEL)
Bio Consult SH

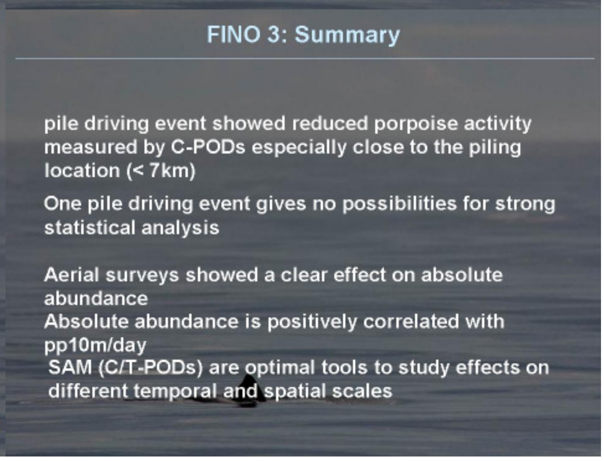

FINO 3: Introduction
Pod-Positionen
20080816clip.shp
Grid
Fino3-Standort
FFH-Gebiet-Grenze
AWZ-Grenze
6 0 6 12 Kilometers
DK5
DK4
DK3
DK2
DK1
P6
P1
P2
P3
P4
P5
P7
P8
P9
P10

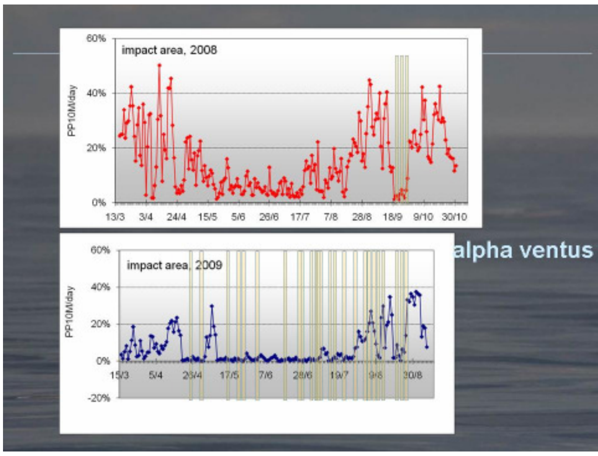

FINO 3: Results
PP10M/day
Transect 1 (SE):
Position 1: 0.5 km
Position 2: 3 km
Position 5: 25 km


FINO 3: Results
PP10M/day
Transect 2 (SW):
Position 6: 0.5 km
Position 7: 3 km
Position 10: 25 km


P1
P2


FINO 3: Results
Also abundance reduced!
30.07.09 before pile driving
31.07.09 after pile driving
Construction site
Porpoise sightings
Porpoises calves
Porpoises/km²
Bio Consult SH

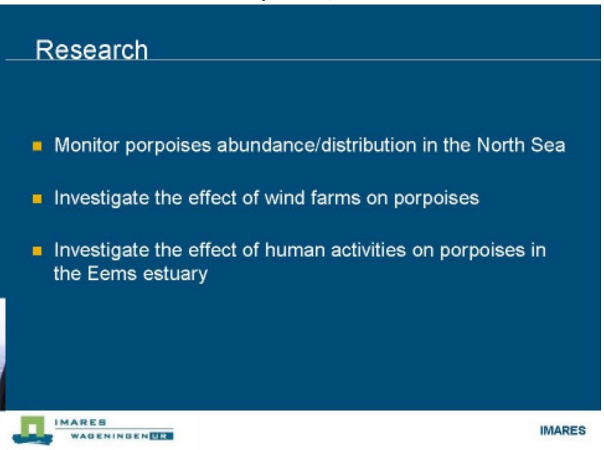

FINO 3: Summary
pile driving event showed reduced porpoise activity measured by C-PODs especially close to the piling location (< 7 km)
One pile driving event gives no possibilities for strong statistical analysis
Aerial surveys showed a clear effect on absolute abundance
Absolute abundance is positively correlated with pp10m/day
SAM (C/T-PODs) are optimal tools to study effects on different temporal and spatial scales

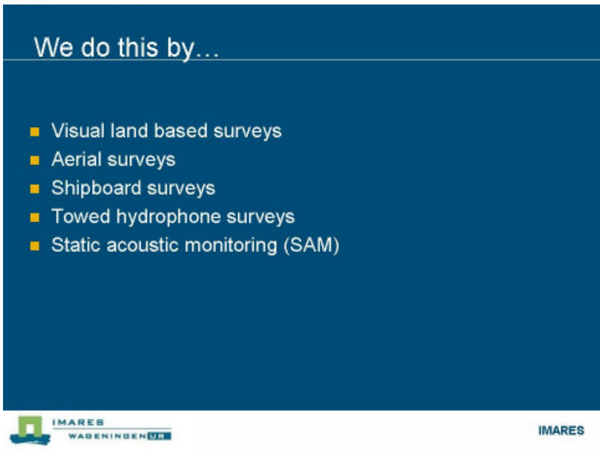

impact area, 2008
PP10M/day
60%
40%
20%
0%
13/3 3/4 24/4 15/5 5/6 26/6 17/7 7/8 28/8 18/9 9/10 30/10
impact area, 2009
60%
40%
20%
0%
-20%
15/3 5/4 26/4 17/5 7/6 28/6 19/7 9/8 30/8
alpha ventus

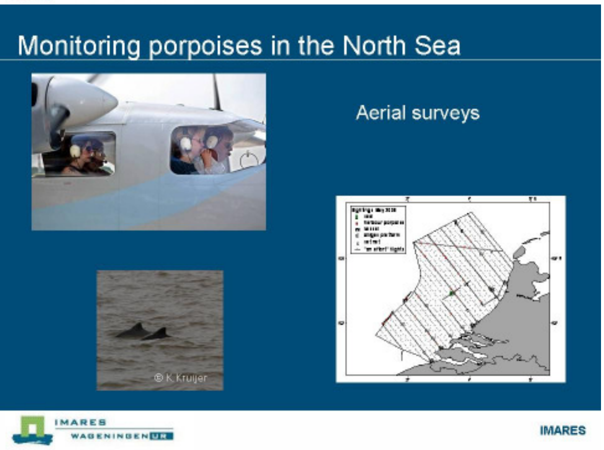

Thank you for your attention!
© C. Hoschle, Fjord&Belt Center
Bio Consult SH

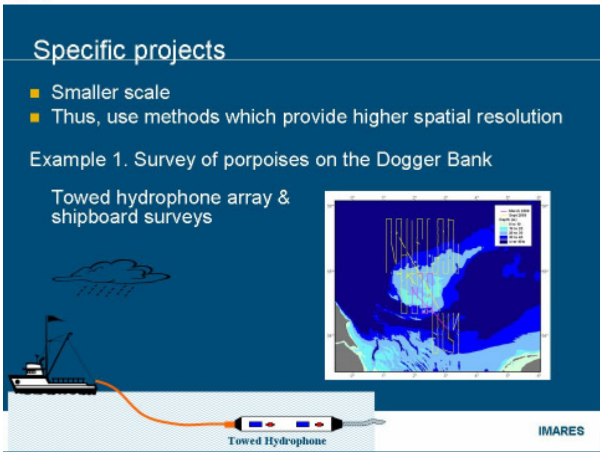
## Porpoises and PODS, investigating anthropogenic activities in Dutch waters

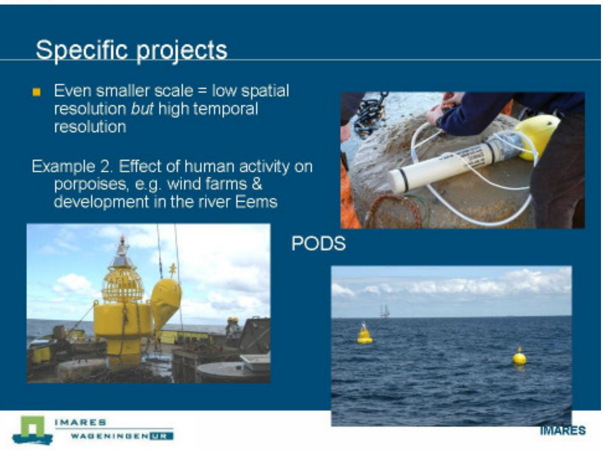
Dr. Tamara van Polanen Petel, *Institute for Marine Resources &* Ecosystem, *The Netherlands*

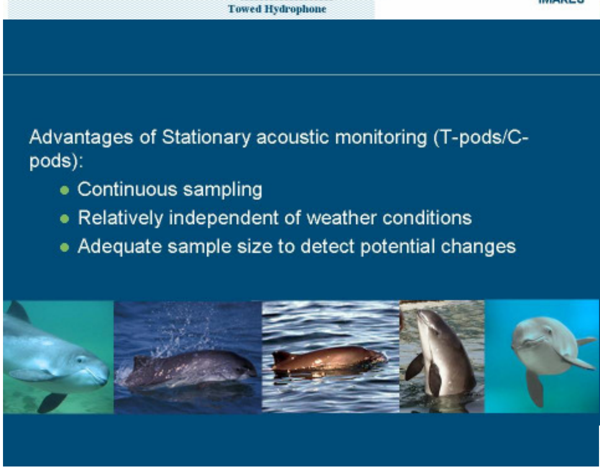



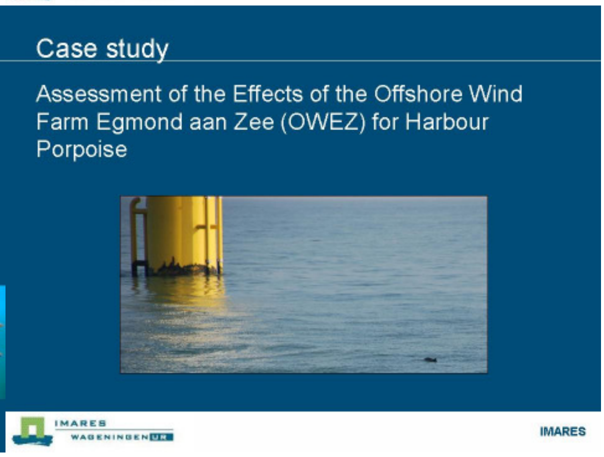



## Study design

- The study follows a BACI (Before After Control Impact) design
- A total of 8 T-pods were deployed:
  - 3 to the north of the park
  - 2 in the park and
  - 3 to the south of the park
- Deployment was planned to last 12 months prior to construction (T0) (2003/2004) and 24 months after construction (T1) (2007/2009)
- Power analysis conducted using the T0 data


## Calibration of T-pods

- Started with 8 V3 T-pods
- These were deployed simultaneously in a porpoise rich area in Denmark
  - Tied to a chain at a depth of 50 m
  - 50 cm apart
  - 19 days
- Aim was to test:
  - T-pod sensitivity (individual differences)
  - Change in sensitivity over time
- Results:
  - Comparable, but not identical sensitivities
  - No change in sensitivity over time
- Therefore, deploy the T-pods at the same position throughout the monitoring period. This will ensure that T-pod specific variation will not influence the results of the study

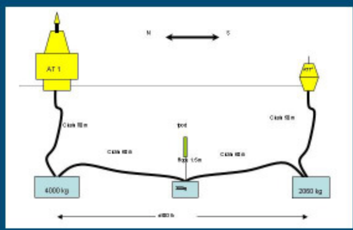
## Calibration of T-pods

- In 2007 a new version (V5) was used in addition to the existing set of V3 T-pods
  - Aim: switch T-pods instead of downloading them at sea
- T-pods of V3 and V5 were strapped together and deployed during T1 (data comparison) to ensure that a change of versions would not have an impact on the analyses
- There were differences between the indicator values from the two types of T-pods, **BUT** the slopes of the intercalibration curves were <u>not</u> significantly different from 1 suggesting that V3 and V5 recorded the same echolocation activity
- Consequently, the two versions could be used interchangeably

## Data collection

- To avoid loss T-pods were anchored using two large buoys and a several weights.

*(world record POD anchoring: 15 tonnes!!)*




## Data collection

- Deployment and retrieval of the T-pods was done with the help of the crew of the *Terschelling*

## Logistical problems

- During the study some data loss occurred. The causes were not always clear, but included
  - *Interaction with fishing vessels*
  - *Breakage of material*
  - *Loss due to storms*
  - *Battery failure*
  - *Filled up memory*
- Nevertheless, enough data was collected to answer the research question

## Data analyses

- Data analyses was done in co-operation with the NERI (National Environmental Research Institute) in Roskilde, Denmark
- Four indicators were chosen for analyses
  - PPM – Porpoise Positive Minutes
  - <u>Clicks</u> per PPM
  - Encounter duration
  - Waiting time

## PPM – Porpoise Positive Minutes

- Proportion of minutes recorded within a day in which one porpoise click train or more could be detected
- Indicator for occurrence of porpoises in an area

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

## Clicks per PPM

- Daily average number of clicks ($x_t$) in those minutes where clicks were detected (N $\{x_t > 0\}$)
- Indicator for click activity of porpoises in an area

$$\frac{1}{N\{x_t > 0\}} \sum_{x_t>0} x_t$$

## Encounter time

- An encounter is defined as a sequence of porpoise clicks separated by more than 10 minutes of silence
- Encounter time is the length of an encounter (number of minutes between two silent periods)
- Indicator for porpoise occurrence in the area


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

## Waiting time

- Waiting time is the length of a silent period (number of minutes in a silent period) between encounters
- Good indicator for porpoise occurrence in an area


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

## BACI analyses

- The four indicators were analysed according to a modified BACI design
- 5 fixed and 3 random factors and combinations thereof were considered
- This analyses ensured that station-specific as well as seasonal variation was taken into account

## Factors considered

| Factor | | levels | description |
|---|---|---|---|
| Area | Fixed | 2 | impact (wind park) vs. control |
| Subarea | Fixed | 3 | control N, control S, impact |
| Station | Random | 8 | AT1 to AT8 |
| Period | Fixed | 2 | Baseline vs. Operation period |
| Year | Random | 5 | 2003, 2004, 2007, 2008, 2009 |
| Month | Fixed | 12 | January - December |
| Pod_type | Fixed | 2 | V3 and V5 T-PODs |
| Pod_id | Random | 20 | Individual T-POD numbers |

## Factors considered

| Factor | | levels | description |
|---|---|---|---|
| Area | Fixed | 2 | impact (wind park) vs. control |
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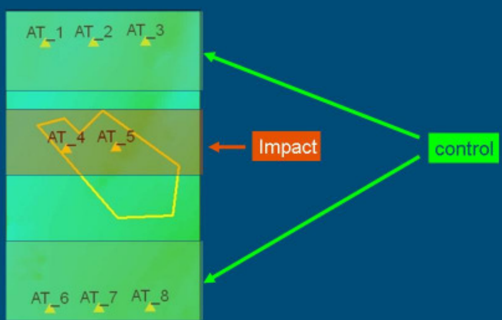
## Factors considered - area




## Factors considered

| Factor | | levels | description |
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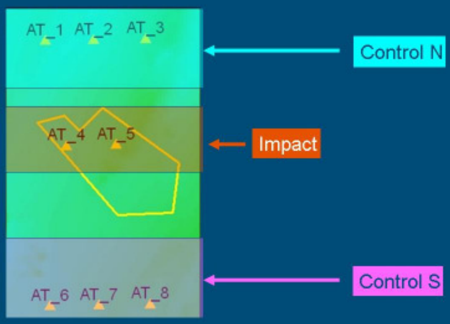
| Month | Fixed | 12 | January - December |
| Pod_typ | Fixed | 2 | V3 and V5 T-PODs |
| Pod_id | Random | 20 | Individual T-POD numbers |

## Factors considered - Subarea




## Factors considered

| Factor | | levels | description |
|---|---|---|---|
| Area | Fixed | 2 | impact (wind park) vs. control |
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| Area | Fixed | 2 | impact (wind park) vs. control |
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| Month | Fixed | 12 | January - December |
| Pod_typ | Fixed | 2 | V3 and V5 T-PODs |
| Pod_id | Random | 20 | Individual T-POD numbers |

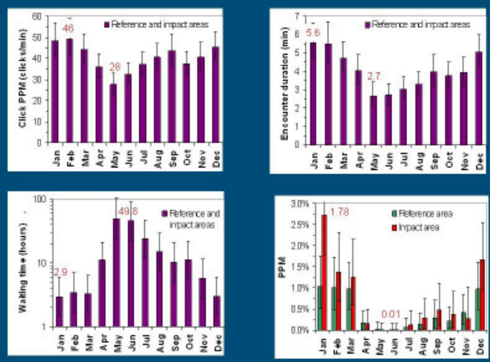
## BACI analyses

- The factor $area_i{\times}period_k$, also referred to as the BACI effect, describes a step-wise change (from T0 to T1) if there is a difference in effect between the wind farm (impact) and the control areas.
- A significant BACI effect implies that changes in activity in the wind farm from T0 to T1 cannot be explained alone by general changes in the area, but must be attributed to the impact (i.e. the presence of the wind farm).
- The general change, if any, between T0 and T1 in the area should be described by the change observed in the control sites

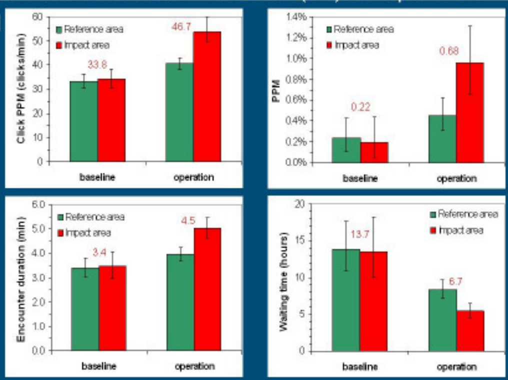
## Results

- In total 5228 active station days with T-pod monitoring data were collected.
- The Control S area had 2081 active data days, Control N 1718 and the impact area 1429
- Data collection varied between stations from 458 station days at AT1 to 838 at AT8
- A total of 2565 station days were recorded with V3 T-pods, 2663 with V5 T-pods

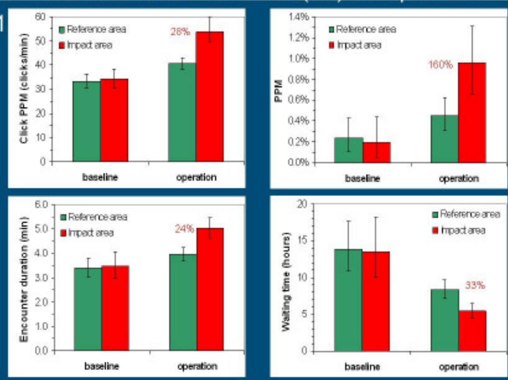
## Seasonal pattern




## Results of the model – baseline (T0) vs. operation (T1




## Results of the model – baseline (T0) vs. operation (T1




## Conclusions

- Significant seasonal pattern of porpoise occurrence with most porpoise activity in winter
- Significant increase in porpoise occurrence between the baseline and the operation period
- Significant increase of harbour porpoises in the impact area vs. the control areas during the operation phase

## Conclusions

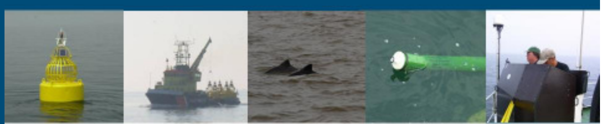
- What does this mean?
  - Porpoises use the wind park during the operation phase
  - There is a change in habitat use during the operation phase with more porpoise activity in the wind park than outside
- What does this not *necessarily* mean?
  - The animals during the operation phase are the same as the ones during the baseline phase
  - Wind parks have a positive impact on a local population level (e.g. an increase in numbers of animals)
  - Porpoises prefer the wind farm to other areas

## Conclusions

- Possible reasons why porpoises are in the wind park
  - Increase in prey species in the park (no or little fishing)
  - Decrease of ambient noise in the park (e.g. more ship traffic outside)
  - Export of existing human activities out of the wind park to adjacent areas (control regions) therefore relatively more disturbance in control areas
  - …others?

IMARES

Any Questions!



IMARES WAGENINGEN UR

IMARES

# 8. Publications

Dähne, M., Verfuß, U. K., Diederichs, A., Meding, A. & Benke, H. (2006). T-POD Test Tank Calibration and Field Calibration. Proceedings of the European Cetacean Society, Gdynia, Poland. Special Issue, 46: 20th annual Meeting (Apr 2006). 34-36.

Dähne, M.; Meding, A.; Verfuß, U.; Honnef, C. G. & Benke, H. (2007). Acoustic Monitoring of harbour porpoises (*Phocoena phocoena*) in low density areas, Poster presented at the 21st Annual Conference of the European Cetacean Society. In: Abstract Book (eds.). Apr/2007. San Sebastian. European Cetacean Society. 57-57.

Dähne, M., Verfuß, U.K., Brandecker, A., Krügel, K., Lucke, K. & Benke, H. (2008). Calibrating click detectors – a methodology to calibrate C-PODs. Poster presented at the 23rd Annual Conference of the European Cetacean Society. In: Abstract Book (eds.). Istanbul. European Cetacean Society.

Hermann, A., Verfuß, U.K., Dähne, M., Bräger, S. & Benke, H. (2008). The C-POD, the T-POD, the hydrophone and the porpoise: A comparison of harbour porpoise echolocation sequences simultaneously recorded by three different acoustic recording systems. Poster presented at the 23rd Annual Conference of the European Cetacean Society. In: Abstract Book (eds.). Istanbul. European Cetacean Society.

Grünkorn, T., Dähne, M., Diederichs, A., Verfuß, U. K., Honnef, C., Benke, H. (2007): What is the right time scale? T-POD calibration as a necessary tool to answer this question. Poster presented at the 21st Annual Conference of the European Cetacean Society. In: Abstract Book (eds.). Apr/2007. San Sebastian. European Cetacean Society.

Simon, M., Nuuttila, H., Reyes-Zamudio, M. M., Ugarte, F., Verfuß, U. K. and Evans, P. H. (2010): Passive acoustic monitoring of bottlenose dolphin and harbour porpoise with implications for habitat use and partitioning. Journal of the Marine Biological Association of the United Kingdom, 90 (5).

Verfuß, U., Adler, S., Brandecker, A., Dähne, Diederichs, A., M., Krügel, K., Lucke, K., Siebert, U., Teilmann, J., Tougaard, J. Tregenza, N. & Benke, H. (2009). AMPOD: Application and analysis methods for the deployment of T-PODs in environmental impact studies for wind farms: Comparability and development of standard methods. Poster präsentiert auf den 3. Wissenschaftstagen des Bundesumweltministeriums zur Offshore-Windenergienutzung. Oldenburg, Deutschland.

Verfuß, U. K., Bräger, S., Dähne, M. & Benke, H. (2009): 4.1. Harbour porpoise. In: Biodiversity in the Baltic Sea. An integrated thematic assessment on biodiversity and nature conservation in the Baltic Sea. Baltic Sea Environment Proceedings.

Verfuß, U. K., Dähne, M., Diederichs, A. & Benke, H. (2007): Applications and analytical methods for T-POD deployment in environmental impact studies for wind farms: comparability and development of standard methods. In: Evans, P. G. H. (Hrsg.): Proceedings of the ECS/ASCOBANS Workshop on "Wind farms and marine mammals". San Sebastian, Spain. S. 27-31.

Verfuß, U. K., Honnef, C. G., Meding, A., Dähne, M., Adler, S., Kilian, A. & Benke, H. (2008): The history of the German Baltic Sea harbour porpoise acoustic monitoring at the German Oceanographic Museum. In: Wollny-Goerke K. & Eskildsen K. (Hrsg.): Marine warm-blooded animals in North and Baltic Seas, MINOS – Marine mammals and seabirds in front of offshore wind energy. Teubner Verlag. Wiesbaden: S. 41-56.

Verfuß, U. K.; Honnef, C. G.; Meding, A.; Dähne, M.; Mundry, R. & Benke, H. (2007). Geographical and seasonal variation of harbour porpoise (*Phocoena phocoena*) presence in the German Baltic Sea revealed by passive acoustic monitoring. Journal of the Marine Biological Association of the United Kingdom 87. P. 165-176.