Effectiveness of a sealscarer in deterring harbour porpoises (*Phocoena phocoena*)

and its application as a mitigation measure during offshore pile driving

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1. SUMMARY

Offshore pile driving during windfarm construction goes along with substantial noise emissions into the water column, which may harm marine mammals. To avoid injuries from acute sound pulses, low level acoustic deterrent devices (pinger) and high level acoustic harassment devices (sealscarer) are used to keep porpoises and seals out of the danger zone around the construction site. In this study we investigated the response of harbour propoises (*Phocoena phocoena*) to a Lofitech sealscarer by conducting two studies: one based mainly on passive acoustic monitoring (C-PODs) and to some extend aerial surveys in the German North Sea and one applying a combination of visual observations from the top of a cliff and passive acoustic monitoring in the Danish Baltic Sea.

During the study in the German North Sea we deployed 16 C-PODs along three transects running from the deployment location of the sealscarer to a maximum distance of 7.5 km. Ten trials with activated sealscarer could be conducted. During the first trial we also conducted aerial survey flights, one before and one during sealscarer activity in a 990 km² area around the location of the sealscarer. Sealscarer deployment lead to a decrease in porpoise click recordings compared to the time before deployment at all distances studied, but this decrease was only statistically significant in 0 m, 750 m, 3000 m and 7500 m. In 1500 m and 5000 m distance relatively low porpoise activity during the baseline, an outlier and low sample size lead to non-significant effects. At the POD in 0 distance, porpoise activity during sealscarer activity was reduced by 95 % compared to the time before (porpoises were recorded only once), at the PODs in 750 m distance it was reduced by 86 %. An aerial survey revealed a significant decrease in porpoise density within the survey area (covering a maximum distance of 15 km to the sealscarer) from 2.4 porpoises/km² before to 0.3 porpoises/km² during sealscarer operation, thus a reduction in porpoise density by 88 %. The minimal distance to the sealscarer at which a porpoise was sighted increased from 2.5 km before to 6.3 km during sealscarer operation. Results from the aerial survey therefore confirm the reduction in porpoise activity found by POD-recordings and show that this is indeed caused by animals leaving the area around the sealscarer and not only a reduction in acoustic activity.

Three C-PODs deployed at 450 m distance to the sealscarer at the Danish study site in the Baltic Sea, similarly showed a significant reduction in porpoise activity during sealscarer activity. Here not a single porpoise click was recorded during a total of 15 hours when the sealscarer was active and when at least one POD recorded analysable data. Sighting rates significantly decreased during sealscarer activity and dropped down to only 1 % compared to other times. During 28 hours of observations with active sealscarer, only three porpoise observations were obtained within the 1 km radius: one observation at about 1 km distance and two at about 800 m distance. Two more observations were made at distances beyond 1 km. Out of seven cases when porpoises were exposed to sealscarer noise at distances between 300 and 700 m, porpoises immediately disappeared and were not observed again at six times, once the porpoise showed a clear avoidance reaction afterwards. In 15 cases, porpoises were exposed to the sealscarer at distances between 1.1 and 3.3 km. In six cases there was a clear reaction in that porpoises again immediately disappeared (1.1 and 1.7 km) or turned around and swam directly away from the sealscarer (1.6, 1.9, 2.3 and 2.4 km). In two cases there was a possible avoidance reaction: In one case a mother-calf group swam

away from the sealscarer after a 1.5 min delay (2.2 km) and in the other case it was unclear whether the porpoise reacted to the sealscarer or an approaching motorboat (2.0 km). In one case reactions were unclear (1.7 km) and in six cases porpoises showed no obvious avoidance reaction (2.1, 2.7, 3.0, 3.2, 3.2 and 3.3 km).

Noise measurements from the Lofitech sealscarer (which emits pulsed signals at a main frequency of 14 kHz with a source level of about 190 dB re 1 µPa) in the North Sea and the Baltic Sea revealed that sound attenuation with distance was greater at the Baltic than at the North Sea study site, probably linked to a less sandy seabed and deeper water at the North Sea study site. Clear porpoise reactions were found down to noise levels of about 119 dB re 1µPa_{rms}, at the Baltic Sea study site (where this noise level was reached at distances of about 2.4 km) and about 113 dB re 1µPa_{rms} at the North Sea study site (where it is reached at a distance of about 7.5 km according to extrapolation following the Thiele approximation). Noise measurements at the North Sea study site showed substantial variability above 2 km distance and at distances beyond this are based on extrapolation and therefore probably rather imprecise. However, porpoise showed some variability in their reactions at these noise levels. At the closest approach distance of 800 m, the sound level of the sealscarer was about 132 dB re 1µPa_{rms}. From this study it can thus be concluded that the Lofitech sealscarer has a significant deterring effect on harbour porpoises down to noise levels of at least about 119 dB re 1µPa_{rms} and that it highly depends on the topography at what distance this noise levels is reached and therefore how far the deterring effect on porpoises reaches.

However, while there may be a relatively far reaching deterring effect of the sealscarer on porpoises, almost complete deterrence could only be achieved within a radius of about 700 m at the Baltic Sea study site, while at the North Sea study site a porpoise recording even occurred right next to the sealscarer. Therefore, even the use of a sealscarer cannot rule out the possibility of the occasional porpoise still being present inside the danger zone. However, the relatively high deterring effect in the vicinity shows, that the deployment of a Lofitech sealscarer during offshore pile driving activities can greatly reduce the risk of physical injury posed to harbour porpoises by offshore pile driving.

2. ZUSAMMENFASSUNG

Offshore-Rammarbeiten verursachen hohe Schallemissionen, die zu Hörschäden bei marinen Säugetieren führen können. Um Hörschäden bei diesen Tieren vorzubeugen, werden vor und während der Rammarbeiten Vergrämungsgeräte (Pinger und Sealscarer) eingesetzt, um Schweinswale und Robben aus der Gefahrenzone um eine solche Baustelle zu vertreiben. In dieser Studie untersuchten wir die Vertreibungswirkung eines Lofitech Sealscarers auf Schweinswale in 2 Ansätzen. Einer davon wurde in der Deutschen Nordsee mit einer Kombination von passivem akustischen Monitoring (C-PODs) und Flug-Transekten durchgeführt und ein weiterer in der Dänischen Ostsee, in der passives akustisches Monitoring und Beobachtungen von einem Kliff kombiniert wurden.

Hierzu wurden 16 C-PODs in sternförmiger Anordnung bis zu einer Distanz von 7.5 km zum Ausbringungsort des Sealscarers in der Nordsee ausgebracht. Es konnten zehn Experimente durchgeführt werden. Während des ersten Experiments wurde zusätzlich jeweils ein Schweinswalerfassungsflug vor und einer während des Sealscarer-Einsatzes in einem 990 km^2 großen Gebiet um den Ausbringungsort durchgeführt. Der Sealscarer-Einsatz führte in allen untersuchten Distanzen zu einer Reduzierung der Schweinswalaufzeichnungen gegenüber der Zeit zuvor, diese war jedoch nur in 0 m, 750 m und 3000 m und 7500 m Entfernung statistisch signifikant. In 1500 m und 5000 m Distanz führten eine nur geringe Schweinswalaktivität während der Baseline, ein Ausreißer und eine niedrige Stichprobengröße zu statistisch nicht signifikanten Effekten. Am POD, welcher direkt neben dem Sealscarer ausgebracht war, reduzierten sich die Schweinswalaufzeichnungen während des Sealscarer-Einsatzes um 95 % verglichen mit dem Basiswert. An den PODs in 750 m Distanz reduzierte sich die Schweinswalaktivität während des Sealscarer-Einsatzes um 86 %. Die Schweinswalerfassungsflüge ergaben eine signifikante Reduzierung der Schweinswaldichte im gesamten Untersuchungsgebiet (welches eine maximale Distanz von 15 km zum Ausbringungsort des Sealscarers abdeckt) von 2,4 Schweinswalen/km² vor auf ca. 0,3 Schweinswale/km² während des Sealscarer-Einsatzes, also eine Reduzierung der Dichten um 88 %. Die minimale Distanz zum Sealscarer, in der ein Schweinswal gesichtet wurde, erhöhte sich von ca. 2,5 km vor auf ca. 6,3 km während des Sealscarer-Einsatzes. Die Ergebnisse der Erfassungsflüge bestätigen die Reduzierung der Schweinswalaktivität, welche anhand der POD-Aufnahmen festgestellt wurde. Sie verdeutlichen weiterhin, dass dies tatsächlich darauf zurückzuführen ist, dass die Tiere das Gebiet um den Sealscarer herum verlassen und nicht lediglich ihre Echolokalisationsrate reduzieren.

Drei C-PODs, die in 450 m Distanz zum Sealscarer in der Dänischen Ostsee ausgebracht wurden, ergaben ebenfalls eine signifikante Reduzierung der Schweinswalaktivität. Hier wurde kein Schweinswal während der 15 Stunden in denen der Sealscarer aktiv war und mindestens ein POD auswertbare Daten lieferte registriert. Die Sichtungsraten reduzierten sich innerhalb des 1 km Radius‘ um den Sealscarer signifikant auf nur 1 % des Ausgangswertes. Während der 28 Stunden, in denen der Sealscarer angeschaltet war, wurden dreimal Schweinswale innerhalb des 1 km Radius gesichtet, einmal in ca. 1 km und zweimal in ca. 800 m Distanz. Zwei weitere Schweinswalsichtungen wurden in über 1 km Distanz gemacht. Von sieben Fällen in welchen der Sealscarer in 300 bis 700 m Entfernung zum Schweinswal angestellt wurde, verschwanden die Schweinswale in sechs Fällen sofort danach und wurden innerhalb des 1 km Beobachtungsradius‘ nicht wieder gesehen. Das andere Mal zeigte der Schweinswal eine klare Meide-Reaktion. In 15 Fällen wurde der Sealscarer in 1,1-3,3 km Distanz vom Schweinswal angestellt. In sechs Fällen wurde eine deutliche Meide-Reaktion festgestellt, wobei die Tiere entweder direkt nach Start des Sealscarers wieder verschwanden (1,1 und 1,7 km) oder ihre Schwimmrichtungen änderten und weiter vom Sealscarer wegschwammen (1,6, 1,9, 2,3 und 2,4 km). In zwei Fällen wurde eine wahrscheinliche Meide-Reaktion festgestellt: In einem Fall schwamm ein Mutter-Kalb-Paar nach einer Verzögerung von ca. 1,5 min vom Sealscarer weg (2,2 km), das andere Mal war unklar, ob die Schweinswale auf den angestellten Sealscarer oder ein sich näherndes Motorboot reagierten (2,0 km). In einem Fall war die Reaktion unklar (1,7 km) und in sechs Fällen zeigten die Schweinswale keine klare Meide-Reaktion (2.1, 2,7, 3,0, 3,1, 3,1, und 3,3 km).

Geräuschmessungen des Lofitech Sealscarers (welcher Signale auf einer Hauptfrequenz von 14 kHz mit einem Quellpegel von ca. 190 dB re 1 µPa aussendet) in der Nord- und Ostsee ergaben eine stärkere Schallabschwächung mit zunehmender Distanz in der Ostsee, was wahrscheinlich mit geringeren Wassertiefen und weniger sandigem Untergrund in der Ostsee in Zusammenhang steht. Deutliche Meide-Reaktionen der Schweinswale wurden ab Schallpegeln von 119 dB re $1µPa_{rms}$ in der Ostsee beobachtet (wo dieser Schallpegel bei ca. 2,4 km Distanz erreicht wurde) und ab 113 dB re $1µPa_{rms}$ in der Nordsee (wo dieser Pegel nach Extrapolation unter Anwendung der Thiele Formel bei ca. 7,5 km Distanz erreicht wurde). Die Schallmessungen in der Nordsee in Distanzen über 2 km wiesen eine erhebliche Varianz auf und da sie in größeren Distanzen auf Extrapolation beruhen, sind diese Werte wahrscheinlich sehr unpräzise. Allerdings reagierten nicht alle Tiere bei diesen Lautpegeln, so dass hier eine gewisse Varianz vorherrscht. In einer Entfernung von 800 m, die der beobachteten minimalen Annährungsdistanz eines Schweinswals an den Sealscarer in der Ostsee entspricht, lag der Geräuschpegel bei ca. 132 dB re $1µPa_{rms}$. Aus dieser Studie kann somit geschlossen werden, dass der Lofitech Sealscarer ab einem Lautpegel von mindestens ca. 119 dB re $1µPa_{rms}$ eine Meidereaktion bei Schweinswalen bewirkt, es stark von den topographischen Bedingungen abhängt bei welcher Distanz dieser Lautpegel erreicht wird und wie weit somit der Vertreibungseffekt reicht.

Es kann daher von einer deutlichen vertreibenden Wirkung des Lofitech Sealscarers auf Schweinswale ausgegangen werden, allerdings konnte eine komplette Vertreibung während der Studie in der Ostsee nur bis zu einem Radius von ca. 800 m erreicht werden. Während der Studie in der Nordsee wurde sogar ein Schweinswal von dem POD direkt neben dem Sealscarer aufgezeichnet, während dieser aktiv war. Dies verdeutlicht, dass auch durch den Einsatz eines Sealscarers die Anwesenheit von Schweinswalen im Gefahrenbereich um Rammarbeiten nicht ganz ausgeschlossen werden kann. Dennoch zeigt die hohe Vertreibungswirkung des Lofitech Sealscarers im Nahbereich des Einsatzgebietes, dass dessen Einsatz vor Offshore-Rammarbeiten ein Verletzungsrisiko für Schweinswale erheblich reduzieren kann.

3. INTRODUCTION

As part of the worldwide expansion of renewable energies, offshore windfarming is expected to soon play a major role in this field. In Germany the first windfarm was built in 2010 and after the planning phase of several windfarms is coming to an end, there will supposedly be much offshore construction work in the near future. Several windfarms have already been built in Denmark, and here plans for many more also exist. Most windfarms, especially those in deep waters, are going to be installed using foundations that are driven into the seabed. This goes along with considerable noise emissions into the water column, which can reach levels that cause hearing damage in marine mammals (Madsen *et al.* 2006, Thomsen *et al.* 2006, Southall *et al.* 2007, Nehls *et al.* 2008). Three species of marine mammals are common to the German and Danish North Sea and Baltic Sea: the harbour porpoise (*Phocoena phocoena*), the harbour seal (*Phoca vitulina*) and the grey seal (*Halichoerus grypus*). All three are listed in annex II of the EU habitat directive, while the harbour porpoise is also listed in annex IV. Article 12 of the EU habitat directive prohibits "deliberate capture or killing" of these species as well as "deliberate disturbance especially during the period of breeding, rearing and migration". It also prohibits "deterioration or destruction of breeding and resting habitats". Furthermore, the harbour porpoise and the grey seal are also listed on the German Red List as critically endangered and the harbour seal as endangered (Haupt *et al.* 2009). It is thus essential during the development of the offshore wind industry that disturbance and injury of these animals are going to be prevented or at least kept at a minimum which can be tolerated. It is common practice in several EU member states that permits are issued under the provision that injury of marine mammals is to be avoided. This often includes the instruction to deter animals out of the danger zone, where potential injury may occur. How far such a danger zone reaches is not easy to define. Southall *et al.* (2007) state an M-weighted SEL level of von 198 dB re 1 µPa²s, where a permanent Threshold Shift (PTS) may occur in high-frequency cetaceans such as the harbour porpoise. Noise measurements during pile driving at the Danish Offshore windfarm Horns Rev II yielded a cumulative SEL level of 194 dB re 1 µPa²s at 720 m distance (Brandt *et al.* 2011). According to Southall *et al.* (2007) animals staying at that distance would thus not have suffered PTS. However, recent measurements by Lucke *et al.* (2009) on a porpoise kept in captivity showed that Temporary Threshold Shift (TTS) occurred at a noise level of 164 dB re 1 µPa²s. This is 19 dB below the level where Southall *et al.* (2007) predicted TTS to occur. This highlights that also PTS levels currently discussed are estimates and that some caution is required when predicting and interpreting danger zones.

Devices currently used for deterring seals and porpoises can be divided into two groups: "Acoustic Deterrent Devices (ADDs)" also called „Pinger" and „Acoustic Harassment Devices (AHDs)" also called „Sealscarer". Pingers are used to reduce the by catch of harbour porpoises in fisheries by keeping them away from fishnets, which are difficult to be detected by the animals' sonar. Depending on the model, pingers emit acoustic signals with a main frequency between 3 and 120 kHz and harmonics up to 180 kHz, designed to match the frequencies with the animals' most sensitive hearing. Pingers are used to either keep porpoises away from fish nets or to alert them to the existence of fish nets so that they locate them and do not swim into them. This means that the acoustic signals do not need to have a far reaching range and thus usually have a source level of only between 115 and 155 dB re

1 µPa @ 1m. The deterring effect of pingers on harbour porpoises was found to reach up to between 100 and 200 m (Koschinski & Culik 1997 (Lien pinger), Cox *et al.* 2001 (Dukane Met Mark TM 1000)), where it is assumed that the animals avoid acoustic signals, which they perceive as unpleasant (Kraus 1999). Some studies found a further reaching effect up to between 300 and 400 m (Culik *et al.* 2001, Carlstrom *et al.* 2009). If pingers are used over a longer period of time this may lead to habituation effects in harbour porpoises (Koschinski & Culik 1997, Cox *et al.* 2001, Carlstrom *et al.* 2009). For seals, which have their best hearing abilities at a lower frequency range of 0.1 to 70 kHz (Turnbull & Terhune 1993, 1995, Kastak & Schustermann 1998, Kastelein *et al.* 2008b), pingers are probably not very effective. Assuming an effective deterring effect on harbour porpoises up to 200 m, one would have to deploy at least 24 pingers with a distance of 400 m between them to keep harbour porpoises out of a 1 km radius around an offshore construction site. Furthermore, pingers would have to be deployed starting in the centre and gradually moving outward so as to enable the animals to swim away from the centre and not confuse them. To follow such a specific spatial and temporal plan of pinger deployment around a pile driving site is regarded as not applicable. Furthermore, the deployment of such a large number of pingers around a construction site with extensive shipping activity holds the risk of pinger loss, which may then lay active on the seabed for several years to come and accidentally keep porpoises away from this area. To use a single deterrent device with a further reaching deterring effect that can thus be used as a punctual deterrent source may be more promising.

Sealscarers, on the other hand, were developed to keep seals away from fish farms and reduce economic damage due to predation. These devices emit acoustic signals at a much lower frequency range between 10 and 20 kHz, where both seals and porpoises have good hearing. The source level of these sounds is between 170 and 198 dB re 1 µPa @ 1m and thus much louder than that of pingers. The deterring effect on seals is stated to be about 300 m according to the manufactures. Seals are known to habituate to sealscarers, especially in circumstances where the sound indicates food availability (Götz & Janik 2010, Mate & Hervey 1986 cited in Kraus 1999). This can lead to a so called “dinner bell effect”, where animals are actually attracted by the sound (Götz & Janik 2010, Mate & Hervey 1986 cited in Kraus 1999). Harbour porpoises, on the other hand, are probably deterred over much larger distances (Johnston 2002, Olesiuk *et al.* 2002). In situations where sealscarers are used to deter seals from fish farms, the much further reaching deterring effect on harbour porpoises is an unwanted side effect, and concern has been raised over the unwanted exclusion of porpoises from possibly critical habitat (Johnston 2002, Olesiuk *et al.* 2002, Götz & Janik 2010). With respect to offshore construction activities, on the other hand, these devices may offer the opportunity to deter seals from the vicinity and harbour porpoises from even further reaching danger zones before the start of pile driving. Until now only the Airmar dB II Plus sealscarer was tested with respect to its deterring effect on harbour porpoises in the field. This sealscarer has a source level of 189 dB re 1 µPa @ 1 m and emits signals with a main frequency at 10 kHz. Both studies were conducted in Canada and concluded that a deterrence effect probably reaches beyond a distance of 3.5 km.

In 2009 and 2010 we conducted a study with the aim to investigate the effects of the sealscarer on harbour porpoises at also greater distances (up to 7.5 km) and with a greater precision at the smaller distances. Because so far only the Airmar sealscarer was tested with respect to its effect on porpoises in the field, we tested the Lofitech sealscarer, which is often used during construction work in German and Danish offshore waters. As it is not really feasible to investigate the effects of the sealscarer on porpoises visually in distances over 1 km, we applied Passive Acoustic Monitoring (PAM) using so called C-PODs. C-PODs are designed to record harbour porpoise echolocation clicks, which they use for orientation and communication, within a range of 200-300 m. As porpoises click almost continuously (Akamatsu *et al.* 2007), using this method, one can investigate whether the number of recorded clicks differs between the time before and the time during sealscarer activation, and thus whether porpoises could be deterred at the different distances from the sealscarer. PAM thus has the advantage of recording porpoise clicks quite accurately in time and space at various distances to the sealscarer. On the other hand, it has the disadvantage that it offers only a small coverage of the overall area and that behavioural differences may also play a role. For example, it cannot be completely ruled out that animals temporarily fall silent or at least reduce echolocation activity after being subjected to loud noise, which will then also lead to a reduction in recordings of porpoise echolocation clicks, despite the fact that the animals are still present. Therefore, we also carried out survey flights in the study area before and after sealscarer activity to address this issue. Furthermore, we conducted extensive visual observations from top of a 20 m high cliff, in front of which the sealscarer was deployed within a marked area. This enabled us to cover a continuous 1 km radius around the sealscarer deployment site with a relatively high precision. As the German study site offshore was unfortunately not suitable for such a study, this part was conducted at the Danish coast of the Baltic Sea at Fyns Hoved. This combination of PAM and visual techniques offers a maximal accuracy to answer the raised questions.

Furthermore, we conducted sound measurements of the Lofitech sealscarer at the study site at Fnys Hoved as well as in offshore waters of the German North Sea in order to link porpoise reactions to specific noise levels and enable future extrapolation to situations with different sound propagation characteristics. In addition sound measurements in the North Sea were also conducted of a different sealscarer model (Airmar) that is also frequently used for mitigation during windfarm construction.

This study aims to investigate the temporal and spatial effects of the Lofitech sealscarer on the behaviour of harbour porpoises and to formulate recommendations for using sealscarers as a mitigation measure during the construction of offshore windfarms. The following specific questions are raised:

- How effective is the Lofitech sealscarer in deterring harbour porpoises?
- How far does such a deterring effect reach?
- How fast do harbour porpoises react to the sealscarer?
- How long does a deterring effect last after the sealscarer is deactivated?
- Are there any habituation effects?

The part of the study using PAM and aerial surveys was conducted in the area around the research platform FINO 3 in the German North Sea. Because previous data from investigations during the construction of the FINO 3 had shown that there is a relatively high porpoise density within the area during the summer months (Brandt *et al.* 2010), this area offered good conditions for a study on the effects of the sealscarer using C-PODs. The second part of the study was conducted at Fyns Hoved on the coast of the Danish Baltic Sea. This area has the advantage of a high land-based observation point, from where coastal waters can be overseen that are also known to harbour high porpoise numbers (Petersen 2007). Here visual scans were conducted, porpoises were tracked with the help of a theodolite and four C-PODs were also deployed.

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4. METHODS

4.1. Acoustic measurements

4.1.1. General

Measurements of the sealscarer sound as a function of distance were conducted at two different study sites: In the German North Sea, north of the Langeoog Island, at about 25 m water depth, and in the Danish Baltic Sea at Fyns Hoved, where the visual survey was performed (see section 3.2.). In addition to the Lofitech Universal Scarer, which was used in the study on the responses of harbour porpoises, some measurements in the North Sea were also made of the Airmar dB Plus II sealscarer (Fig. 1). Basic signal properties of the two units are listed in Tab. 1. The sound generation and timing of the Airmar device are described in detail in a patent (European Patent Office 1997, USPTO 1997).

Tab. 1: Signal properties of Lofitech and Airmar sealscarer. The manufacturers do not specify what kind of sound pressure level is meant (rms, SEL or peak). The Airmar unit can drive four transducers. Every 5 s, one of them is activated. In the experiments, only one transducer was used.

	Lofitech Universal Scarer	Airmar dB Plus II
Frequency	14 kHz (+ weak harmonics)	10 kHz (+ weak harmonics)
Radiated signal	0.5 s tone pulse	burst of 56 tone pulses with 1.5 ms duration each, burst duration 2.5 s
Repetition cycle	random, approx. 0.6 s to 40 s, approx. 15 pulses/minute	20 s
Sound pressure level at 1 m (manufacturer information)	190 dB re 1 µPa	205 dB re 1 µPa (after switching on the level is 20 dB lower and then rises to a maximum over a period of 30 s)

Fig. 1: Left to right: Lofitech transducer with ballast weight attached, Airmar transducer, control units of the two devices.

4.1.2. Measurements in the German North Sea

These measurements were conducted on the 03.06.2010. An autonomous sound recording system was deployed at a fixed position at 53°51.43'N 07°28.70'E. The sealscarers were operated on board the FV Orion, with the transducers 10 m below the sea surface. Starting at the measurement position, the vessel's main engine was stopped and the vessel then drifted away from the hydrophone due to the tidal current. This procedure was repeated several times, while the vessels position was recorded continuously with a GPS receiver. Drift speed was between 0.25 m/s and 0.6 m/s. The recorded tracks are depicted in Fig. 2 and Fig. 3.

The measurement system was fitted with two Brüel & Kjær 8103 hydrophones floating at2 m and 4 m above the sea bottom. They were connected through a charge amplifier built by itap to a Tascam HD-P2 digital recorder. However, only the signal from the lower of the two hydrophones was used. The recorder was set to 16 bit wave file format and a sampling frequency of 192 kHz, providing a useable frequency range up to approx. 70 kHz. The charge amplifier had a gain of 3 mV/pC ±0.5 dB in the frequency range 100 Hz to 100 kHz. For calibration, a 1000 Hz signal of 100 pC_{rms} from a custom-built calibration source was fed to the charge amplifier input before deployment. Fig. 4 shows a photo of the measurement system.

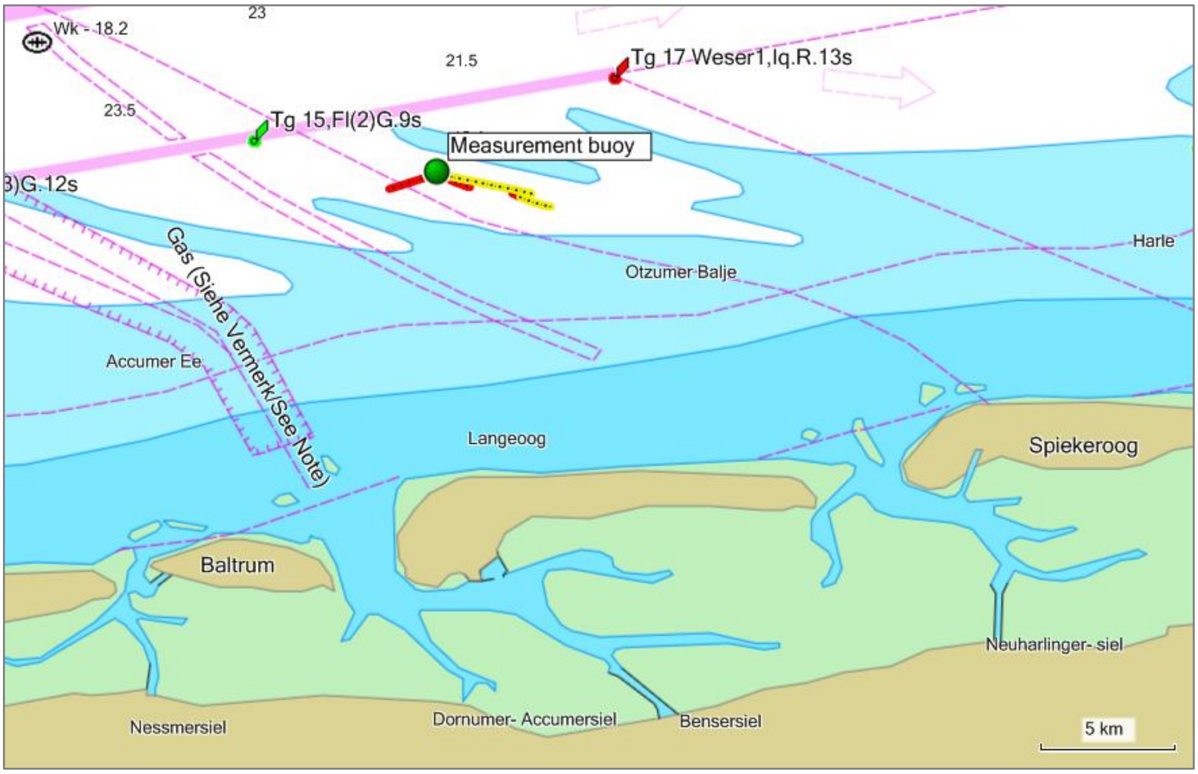

Fig. 2: Measurement location near the East Frisian coast at 53°51.43'N 07°28.70'E

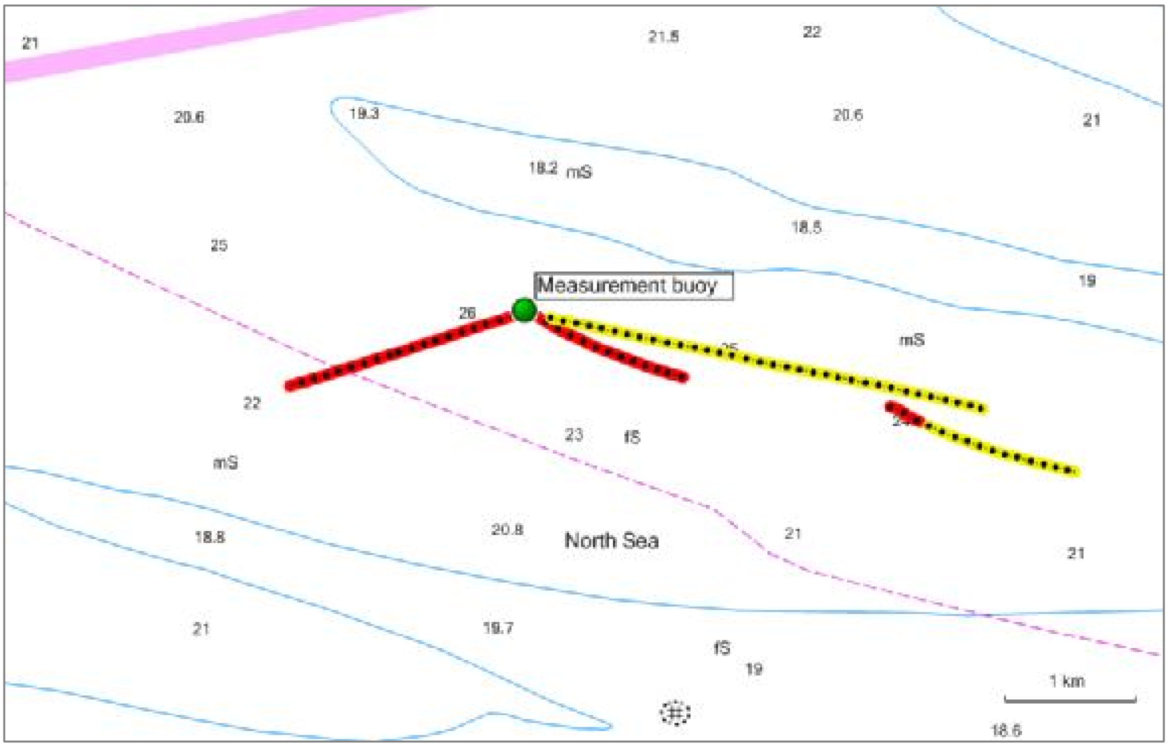

Fig. 3: Drift tracks of FV Orion. Red: Measurement of Lofitech sealscarer. Yellow: Measurement of Airmar sealscarer. The western track was recorded between 08:30 and 09:15 CEST, the eastern ones between 12:00 and 14:30, after the direction of the tidal current had changed.

Fig. 4: Measurement system before deployment. The recording electronics is embedded in the cylindrical steel housing. Arrows in the right-hand photo mark the hydrophones.

4.1.3. Measurements in the Danish Baltic Sea

Measurements at Fyns Hoved were conducted on the 07.10.2010. The Lofitech sealscarer was operated at a fixed location from a moored boat (identical with the anchoring position during the visual study), while the sound was recorded at various distances between 130 m and 3900 m. The positions are shown in Fig. 5 and listed in Tab. 32 in the appendix. In addition to these measurements, two measurements were made when the sealscarer was deployed at two positions further offshore. These positions are identical to two positions where the sealscarer was deployed during the response study. Measurements were then made at the two positions where porpoises were known to react to the sealscarer deployed further offshore (measurement points 18 and 19 in Tab. 32 in appendix).

A Reson TC 4033 hydrophone was used, a Brüel & Kjær 2635 charge amplifier and a Tascam HD-P2 digital recorder (Fig. 6). Calibration was performed with a G.R.A.S. 42AC pistonphone with an RA0078 coupler for the TC 4033. This unit produces a 250 Hz calibration tone with a sound pressure level of 136.1 dB re 1 µPa. The recorder was set to 16 bit wave file format and a sampling frequency of 192 kHz, as in the North Sea measurements. The hydrophone was deployed at 3 m below the water surface, except at the very shallow position 34, where the depth was reduced to 2m in order not to touch the sea bottom.

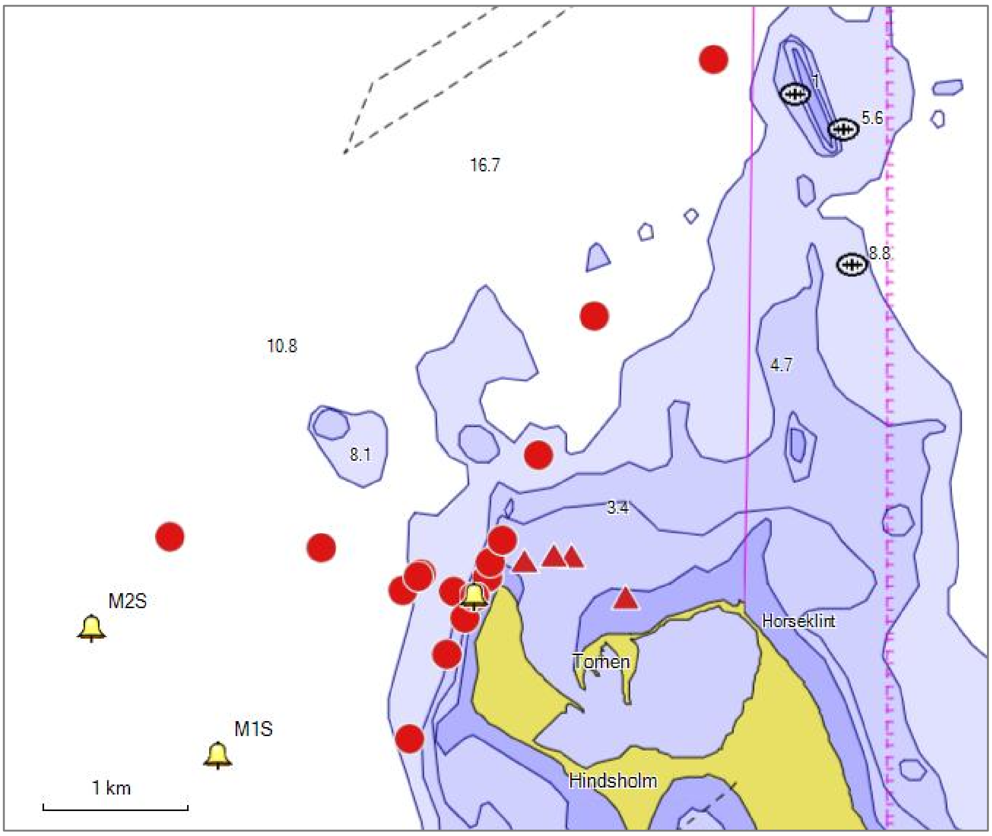

Fig. 5: Acoustic measurements at Fyns Hoved. Yellow, bell-shaped symbol: Position of sealscarer. Filled circles and triangles: Hydrophone positions. The locations marked by triangles were shadowed by land, there was no direct sound path from the sealscarer (hydrophone positions 33 to 36 in Table 3.3.2). At selected points, additional measurements were made for sealscarer positions M1S and M2S.

Fig. 6: Recording equipment and hydrophone used at Fyns Hoved

4.1.4. Evaluation of recorded signals

Prior to further processing, the recordings were high pass filtered in order to reduce low-frequency noise caused by rolling of the boat. This was done with Adobe Audition 1.5 software, using a 4th order Butterworth high pass with a lower limiting frequency of 5 kHz. Averaged sound pressure levels (rms, or equivalent continuous sound pressure level L_{eq}, which is the same) and peak levels were then evaluated by means of MATLAB programs written earlier by itap. Post processing and graphics were done in Microsoft Excel.

The different signal characteristics of the two examined units required different averaging procedures. A common method is to compute an average sound level over a time period of e.g. a few minutes, and then compute the desired short-term values from known on-off times of the sound source. For the Lofitech device, this was not feasible due to its completely irregular timing. Instead, rms values with an averaging time of 125 ms were computed. The analysis was then based on 1 minute of data for the measurement in the North Sea, and 2 minutes for the discrete measurement locations at Fyns Hoved. A threshold algorithm was used to evaluate only periods when the sealscarer was active.

For the Airmar device, the average level of a single pulse is hardly a meaningful value, because of the very short pulse duration. For this reason, rms levels for whole pulse bursts were computed (this was done from averages of 60 s, which contained 3 bursts of 2.5 s length each).

Propagation loss was calculated by finding the best linear fit to the measurement points based on the smallest value for the sum of R^2. This resulted $L = 197 - 20 \log(x)$ for the measurements of the Lofitech sealscarer in the North Sea and in $210 - 27 \log(x)$ for the Lofitech measurements at Fyns Hoved. In addition propagation loss in the North Sea was calculated following the semi-empirical formula for the propagation loss derived by Thiele & Schellstede (1980) for more realistic values at distances over a few kilometres.

4.2. Study in the German North Sea

4.2.1. Study area

This part of the study was conducted in the German North Sea about 80 km west of Sylt near the research platform FINO 3. This area was chosen because a previous study found high porpoise density within this area during the summer months (Brandt *et al.* 2010), offering a good opportunity to study the spatial and temporal effects of the Lofitech sealscarer on harbour porpoises. Furthermore, the area is comparable in topography and hydrography to the areas within the German North Sea, where several windfarms are being planned and where the sealscarer ought to be used during construction work.

4.2.2. POD-data

4.2.2.1 General approach

To detect relative porpoise abundance before, during and after sealscarer activity, we applied Passive Acoustic Monitoring (PAM) and used so called "C-PODs" (www.chelonia.co.org). These are devices especially designed to record harbour porpoise echolocation clicks. Harbour porpoises use echolocation relatively continuously (Akamatsu *et al.* 2007) and emit short high frequency echolocation clicks of a narrow bandwidth centred near 130 kHz, with little energy below 100 kHz (Verboom & Kastelein 1997). Harbour porpoises use echolocation clicks for orientation (Verfuß *et al.* 2005), prey capture (Busnel & Dziedzic 1967, Verfuß *et al.* 2009, Verfuß & Schnitzler 2002) and presumably to some extent for communication (Verboom & Kastelein 1997, Koschinski *et al*. 2008, Clausen *et al.* 2010). These characteristics make harbour porpoises suitable for automatic remote acoustic detection. Harbour porpoise clicks are strongly directional with an opening angle of maximal 16.5° (Au *et al.* 1999). This means that PODs can detect porpoise presence if (1) porpoises produce clicks, (2) porpoises swim within a 200-300 m radius around the POD and (3) porpoises hold their head in the direction of the POD. The probability of detection is therefore highly dependent on the activity of the porpoise and its distance and swimming direction relative to the POD. Presently it is not yet possible to translate porpoise recordings into absolute densities. However, several studies could show a connection between absolute porpoise densities recorded via aerial surveys and POD-data gained from the same area (Diederichs *et al.* 2002, Siebert & Rye 2008. It is therefore assumed that the parameter "porpoise positive time" obtained by means of POD-recordings is a relative measure of the number of porpoises within the study area.

4.2.2.2. C-POD specifications

C-PODs consist of a 80 cm long plastic tube with a hydrophone at one end. Directly underneath the hydrophone there is an amplifier and an electronic filter (Fig. 7). A total of ten 1.5 Volt D-batteries supply enough voltage for the device to run for a minimum of six weeks. Recorded data are saved on an SD-card. The hydrophone omnidirectionally records all acoustic events within a frequency spectrum of 20 to 150 kHz. For each click, centre frequency, frequency trend, duration, intensity (in 8 bit steps), bandwidth and envelope slope are logged. C-PODs are calibrated by the manufacturer for the main frequency of a harbour porpoise click (130 kHz) and standardised to the same acoustic threshold (± 2dB). With the accompanying software CPOD.exe (Chelonia Ltd., UK) one can then filter click trains produced by harbour porpoises from background noise and sort them into four probability classes depending on the probability of being of porpoise origin. For analyses we only used the two highest probability classes. The C-POD is the processor of the often used T-POD. It differs from the T-POD in that it records a much wider frequency spectrum (in order to also record other cetaceans) and saves several click characteristics in a digital form. According to the manufacturer, the C-PODs works analogous to the former T-POD and it is expected that datasets from T-PODs and C-PODs are comparable. However, until now there are no studies on the basis of which this can safely be concluded. Recent investigations, however, indicate that simultaneous recordings by C-PODs and T-PODs produce similar seasonal and diurnal patterns in porpoise activity, but that C-PODs record continuously less data than T-PODs (Diederichs *et al.* 2010b, Verfuß 2010).

Fig. 7: C-PODs

4.2.2.3. C-POD deployment

C-PODs are attached to an anchor stone via a long rope and are deployed about 1.5 m above the seabed. The anchor stone is connected to a second anchor stone, which is attached to a yellow marker ball. In addition a yellow spar buoy was deployed next to it in order to mark its position at sea clearly visible from a distance (Fig. 8). Within a 180 km² large study area, 16 C-PODs were deployed in a star-like pattern, where besides a single POD in the centre, three PODs always had the same distance to the centre. The distance categories were: 0 m, 750 m, 1.5 km, 3 km, 5 km and 7.5 km (Fig. 9). Data collection lasted for about five months between mid Jul and the end of Nov 2009. A total of 1607 POD-days (number of PODs multiplied with number of recording days) could be achieved (Fig. 10). At position 14 one POD went missing, which resulted in 67 POD-days lost. Due to a lost buoy this POD was not replaced, so that no data are available from this position. During 416 POD-days no data could be recorded due to technical problems with the PODs. PODs stopped recording despite sufficient battery life. According to the manufacturer this could be caused by problems with intense background noise. This statement will be further investigated.

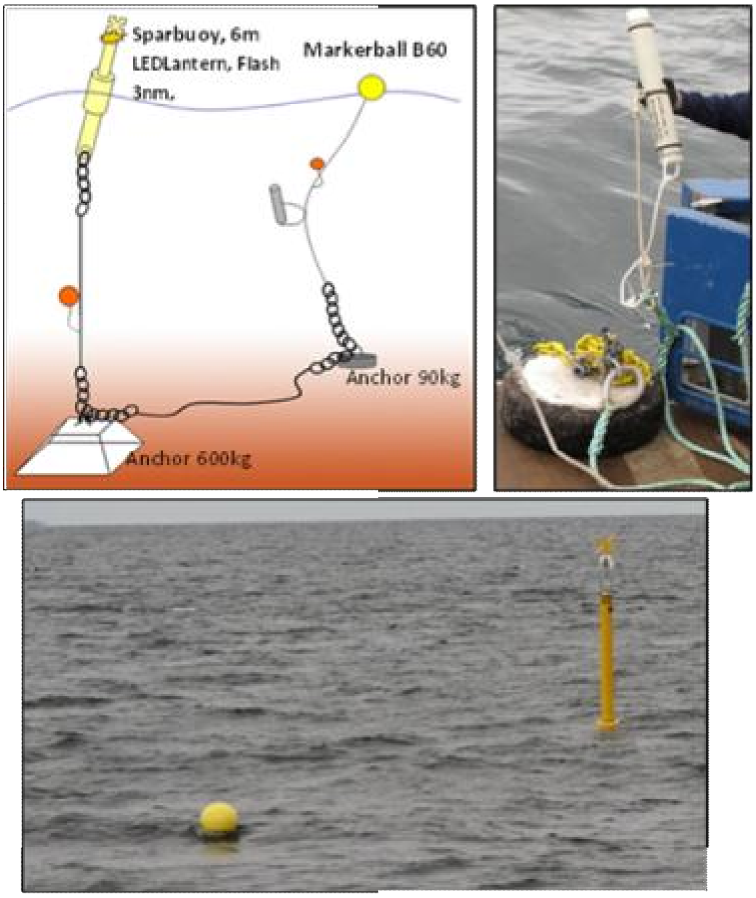

Fig. 8: Anchoring system of C-PODs and deployment of POD and yellow sparbuoy.

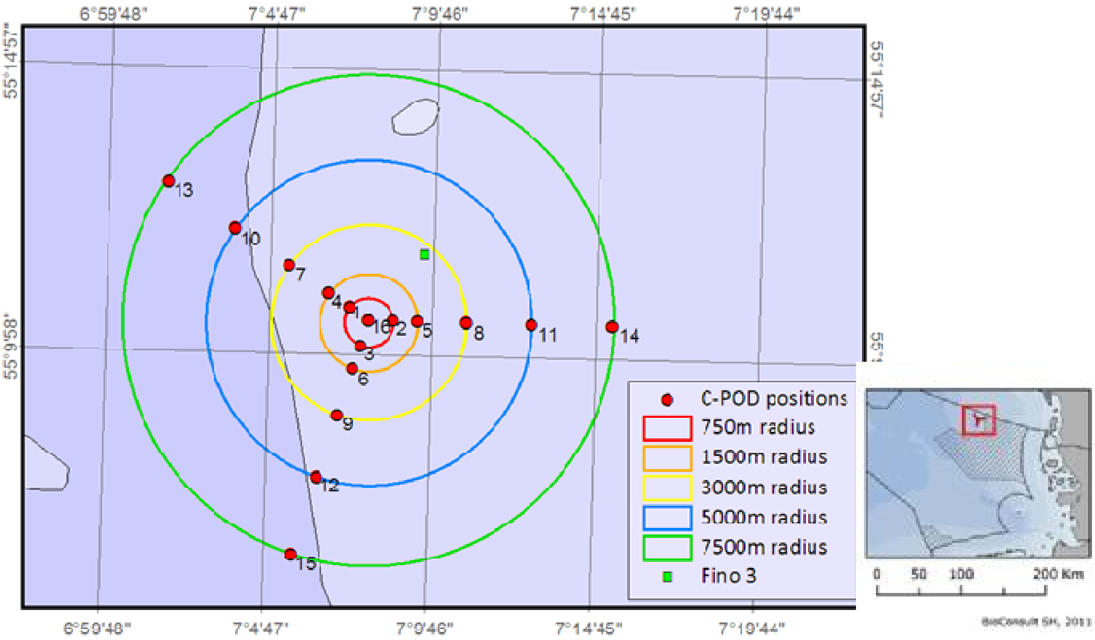

Fig. 9: Positions and distance radii of deployed C-PODs. The sealscarer was deployed at the central position next to C-POD number 16.

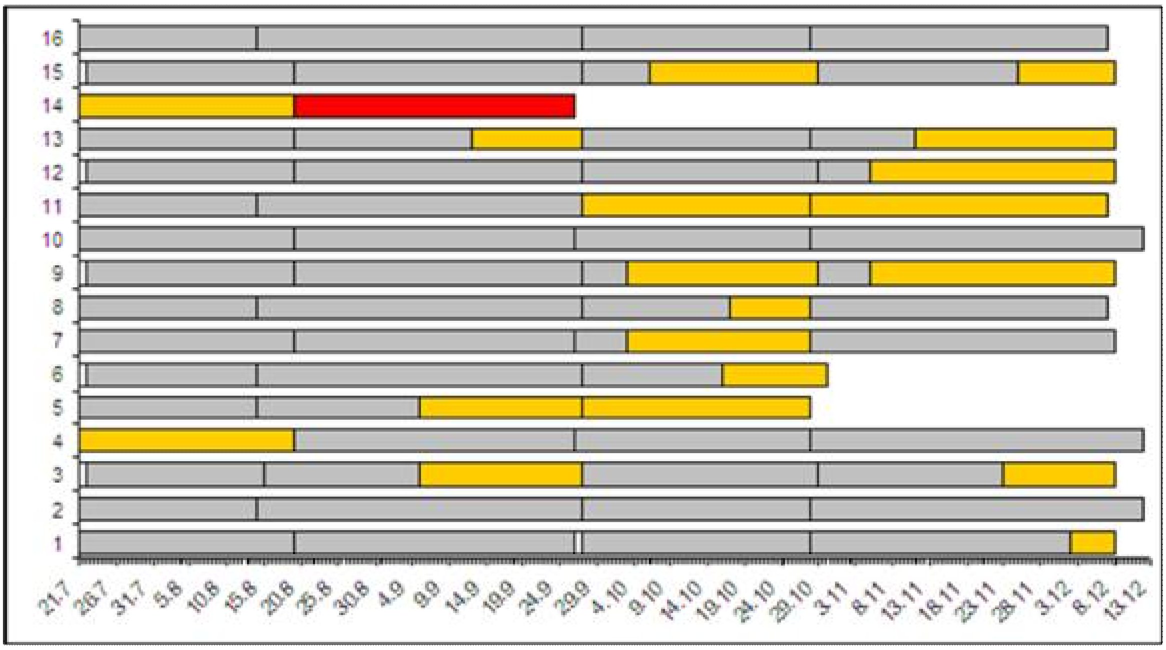

Fig. 10: POD deployment times at the 16 positions (grey: POD recorded data, yellow: POD did not record data due to technical problems, red: POD was lost).

4.2.2.4. Experiments

A total of ten trials with active sealscarer were conducted. The dates can be seen in Tab. 2. To deploy the sealscarer, the boat drove to the central POD-position, anchored, switched the engine and the boat sonar off and deployed the hydrophone in the water column at about 7-10 m below the water surface to ensure that the body of the boat did not obstruct sound propagation. The sealscarer was switched on approximately 15 min after the boat had anchored. The sealscarer was switched off and retrieved out of the water after exactly four hours had passed. After retrieval of the sealscarer the boat left its position. There were at least four days between two consecutive sealscarer trials. Visual observations could only be conducted during the first trial, because weather conditions did not allow for this during the other trials. Apart from the first trial were the boat arrived several hours before the sealscarer was activated, the boat arrived about 15 min before the sealscarer was switched on.

Tab. 2: Dates and times of the ten sealscarer trials and whether data could be obtained at the 16 POD-positions (black X: POD recoded analysable data; grey X: POD recorded data that could not be analysed due to high noise pollution at that position).

Date and time of sealscarer trial	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
10.08.2009 9:24-13:27	X	X	X		X	X	X	X	X	X	X	X	X		X	X
14.08.2009 12:55-16:55	X	X	X		X	X	X	X	X	X	X	X	X		X	X
21.08.2009 9:00-13:00	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
24.09.2010 2:28-6:31	X	X		X		X	X	X	X	X	X	X			X	X
28.09.2010 18:19-22:20	X	X	X	X		X	X	X	X	X		X	X		X	X
07.10.2009 3:12-7:12	X	X	X	X		X		X		X		X	X			X
11.10.2009 21:47-1:47	X	X	X	X		X		X		X		X	X			X
30.10.2009 14:36-18:36	X	X	X	X			X	X	X	X		X	X		X	X
04.11.2009 20:15-0:15	X	X	X	X			X	X	X	X		X	X		X	X
11.11.2009 19:08-23:08	X	X	X	X			X	X		X					X	X

4.2.2.5. Data analyses

To gain an overview about general porpoise activity and the seasonal pattern at the different POD-positions, we analysed the parameter "Porpoise Positive ten Minutes per day" (PP10M/day).

To analyse porpoise activity with respect to sealscarer activity, we used the parameter "Porpoise Positive Minutes per Hour" (PPM/H) and used all hours between 19 hours before and 18 hours after sealscarer activity. These were then grouped into three-hour-blocks and numbered relative to the start of the sealscarer, with the hours during sealscarer deployment being 0. The hour directly before the start of the sealscarer was excluded, because the approaching boat might have caused temporal deterrence of porpoises. We also excluded the first hour after the start of the sealscarer because an effect of the boat could not yet be excluded and so as to allow enough time for porpoises to leave the study area. With the swimming speed of harbour porpoises being described at about 4.2 m/sec (Otani *et al.* 2000), a harbour porpoise could cover a distance of about 15 km in one hour, which was more than enough time to leave the entire study area.

During data analyses we encountered substantial problems with high background noise during some time periods, which probably hindered reliable recordings of harbour porpoise echolocation clicks. High background noise may fill the memory of the POD in only a few days. In order to prevent this, PODs have the option to set a scan limit. This means that if a certain number of clicks are reached during a scan (a scan lasts 1 min), the POD stops recording for the rest of this scan and only starts again at the next scan. For this study we chose a scan limit of 4096 clicks. Using the new version of the program cpod.exe one can export the number of raw clicks recorded during an hour and also the proportion of time that a POD did not record any data because the scan limit was exceeded. To test whether porpoise recordings were affected by high background noise, we looked at whether there was a correlation between porpoise recordings and the time that a POD could not record data during a given hour. Because the parameter PPM/H contains a high proportion of Zeros, we transferred the dataset into a binary dataset and thus tested whether the probability that a porpoise was recorded at least once during an hour depended on the proportion of lost recording time during that hour. As expected there was a significant negative correlation between these two parameters (R^2=0.05, n=30307, p<0.001). A visual checking of this relationship showed that the probability that a porpoise was recorded dropped almost linearly with the amount of recording time lost (Fig. 11). Apart from less time being available to detect porpoises this may be caused by the algorithm being less effective in distinguishing porpoise clicks from background noise if there is a lot of background noise. We therefore decided to exclude hours from the analysis when more than 10 % of recording time was lost as we found this to be a reasonable compromise between excluding unwanted side effect from recorded noise and minimising data loss, which would also compromise the ability to detect effects. This led to about 11 % data loss for the hours before and during sealscarer activity (Tab. 3). Within sealscarer experiments there could therefore be data gaps, and within the pooled three-hour-blocks a different number of hours was included (0-3) that could be analysed. We therefore excluded three-hour-blocks without analysable data and for the others calculated the proportion of PPM in relation to the time that could be analysed during this 3-hour-block (60, 120 or 180 min). Ideally sample size for each 3-hour-block would be the same. However, accepting unequal sample sizes seemed a smaller problem than accepting problems with background noise or reducing the dataset even more (which would have resulted in almost no data for meaningful analyses). If there were no analysable data before or during sealscarer activity at a POD-position, the data set from that trial at that POD-position was completely excluded from analyses. Visual checking of the recorded porpoise clicks indeed confirmed that they were typical harbour porpoise clicks, which was also confirmed by the C-POD manufacturer (Nick Tregenza, pers. comm.). Therefore, it could be ruled out that there were a lot of falsely classified porpoise clicks at position 8 due to background noise.

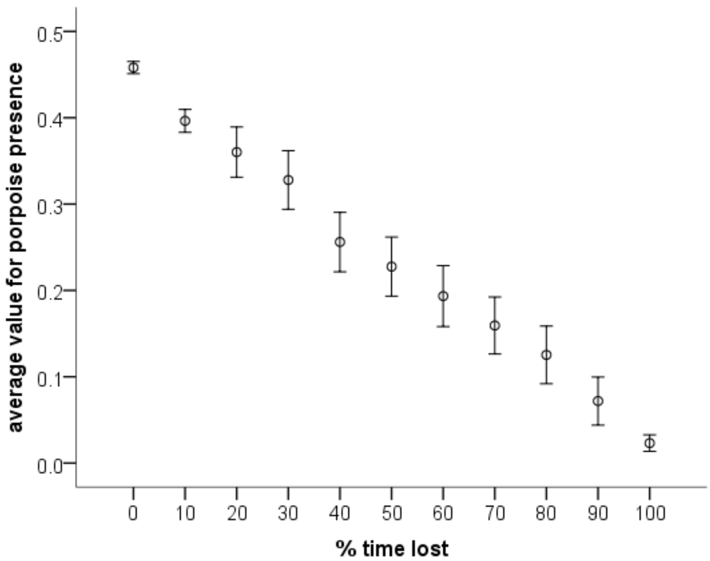

Fig. 11: Relation between the probability of a porpoise click recording and the proportion of time lost during this hour due to noise pollution. Shown are averages of the binary dataset with standard deviation. Values were rounded to the next decimal power.

Tab. 3: Number of POD-hours, where the respective proportion of time was lost due to the scan limit being reached, caused by high background noise.

time lost per hour	N POD-hours	%
0 %	522	75.7
1-10 %	93	13.5
11-20 %	16	2.3
21-30 %	12	1.7
31-40 %	15	2.2
> 40%	35	1.9
sum	690	

To test for the effect of the sealscarer on porpoise recordings we plotted the proportion of PPM for the different three-hour-blocks relative to the time when the sealscarer was active and for the different distances. To compare porpoise activity during sealscarer activity with the time before that (4 to 2 hours before the sealscarer was switched on) we applied a Wilcoxon test for two dependent samples. As this test takes the dependencies within trial and position into account, it also accounts for the strong differences in porpoise activity between trials and positions that are independent of sealscarer activity. Only trials from positions where data existed before and during sealscarer activity were included in this analysis and were used of averages.

To test, whether a decrease in porpoise activity during sealscarer activity happened more often than randomly assumed, we calculated a non-parametric Chi²-test for each distance. Here only datasets where porpoises were recorded at least once during or before the sealscarer was switched on, are included and thus only data where a decrease or increase in PPM could indeed have happened. We assumed that randomly one would find a decrease and an increase in 50 % of cases respectively. Observed values were then compared to expected values. For this test we applied the Yates correction, to account for only two categories and thus only one degree of freedom (Fowler *et al*. 1998). This test was only found sensible if there were at least ten datasets within a distance that could be analysed.

To test if an effect of the sealscarer on porpoises lasted beyond its activity we proceeded in testing for differences in porpoise activity during the three-hours-block before sealscarer activity and the next three-hour-blocks after the sealscarer was switched off, also applying a Wilcoxon test for two dependent samples.

4.2.3. Aerial surveys

4.2.3.1. Data collection

To record harbour porpoise density in the study area before and after the sealscarer is deployed, we conducted aerial surveys following the method described in Diederichs *et al.* 2002, Kahlert *et al.* 2000 and Noer *et al*. 2000. Surveys were conducted along twelve 30 km long transects, running parallel in a west-east direction and with 3 km between them (Fig. 12).

A complete aerial survey before and during sealscarer activity could only be conducted on the 10.08.2009. On the 14.08.2009 one survey flight was completed before the start of the sealscarer. Due to very low sighting and resighting rates we decided to not conduct a second flight and save finances for future surveys. This was because we would not have achieved meaningful density estimates and would have had only very limited power to actually test for a reduction in porpoise numbers. Unfortunately, there was no possibility to conduct another aerial survey during a following sealscarer trial, because either weather conditions were too bad or no plane was available.

Aerial surveys were conducted using a high winged, two-engine plane (Partenavia P 68, Fig. 13). The Partenavia was equipped with bubble windows at the seats behind the pilot and co-pilot. The plane flew with a speed of about 180 km/h at 600 feet (183 m) height along the transects. A GPS recorded the position every 2.5 sec (about every 125 m) and three experienced observers continuously recorded all marine mammal sightings on a dictaphone. One observer sat at each site behind the pilot and co-pilot, while a third observer sat behind these and observed the side with the best sighting conditions. To ensure that observers recorded data independently of each other, all observers carried earphones, which prevented them from hearing each other. For all marine mammal sightings, the observer recorded species, age (adult or juvenile), group size, behaviour (swimming, diving, fleeing and resting), swimming direction and time to the second using the GPS time in UTC. This later enabled to assign a detailed location to every sighting. For every sighting it was further noted whether the animal was seen partly above or completely below the surface when spotted. Furthermore, the sighting angle of the animal relative to the horizon was measured using a clinometer, from which the Euclidian distance of each animal to the transect line could be calculated using the formula: [distance=height above ground x tan (90° - sighting angle)] (Fig. 14).

The surveying of marine mammals can be extremely affected by sea state and sighting conditions (Teilmann 2003). We therefore only conducted surveys at a maximum wind speed of ten knots (5 m/sec) and with sighting distances of at least 5 km. As weather conditions can change rapidly at sea, observers further recorded sea state (in Beaufort), cloud cover (in eights) and sighting condition depending on light and reflection (1 = good, 2 = moderate, 3 = not sufficient) at the beginning of each transect and whenever conditions changed. Only data collected at a maximum sea state of 3 and under optimal sighting conditions were included in the analyses and survey effort was corrected accordingly. The length of transect lines flown under analysable conditions is shown in Tab. 15 in the result section 4.1.2.

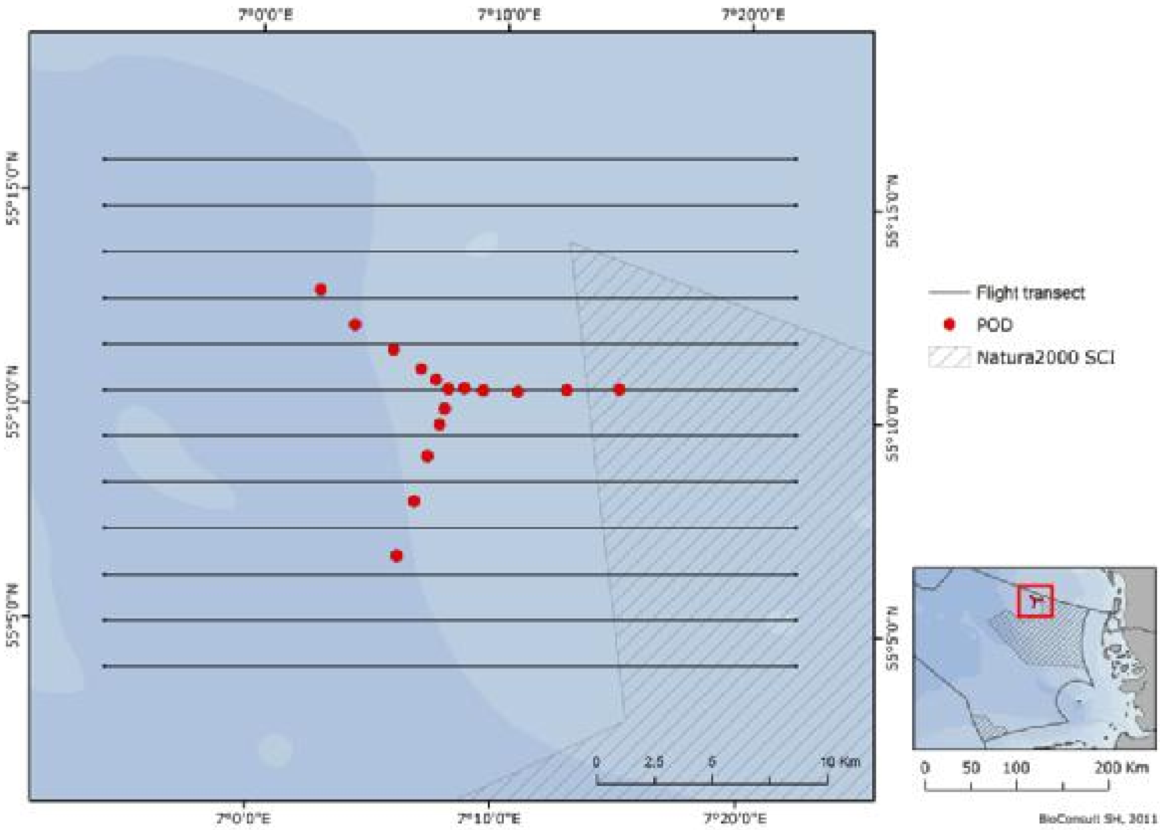

Fig. 12: Map showing the positions of PODs and flight transects.

Fig. 13: Partenavia used for aerial surveys.

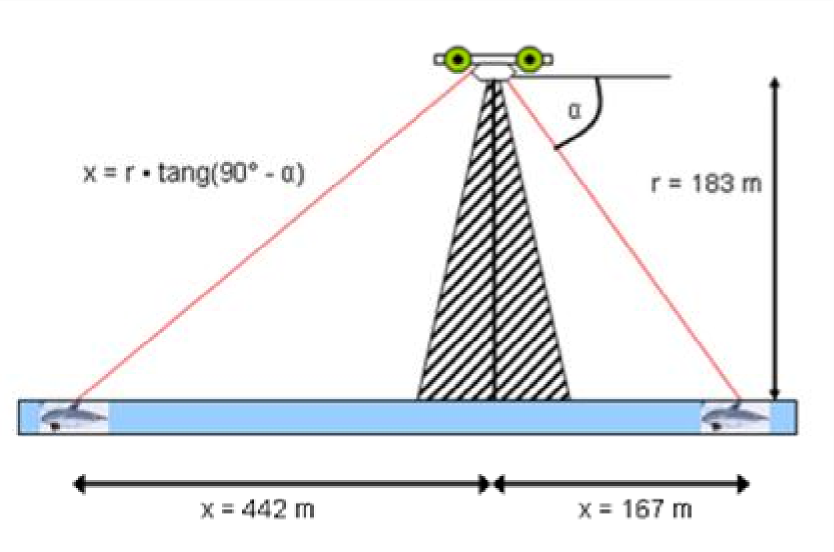

Fig. 14: Distances of sighted porpoises to the g(0)-line measured with the aid of an inclinometer at a flight altitude of 183 m.

4.2.3.2. Data analyses

To study the density and spatial distribution of harbour porpoises in the study area, all data recorded under good sighting conditions by the two observers in the front were used. Data were plotted and analysed in ArcGIS.

To estimate harbour porpoise densities, we followed the „line-transect distance sampling“- method (Thomas *et al.* 2010, Buckland *et al.* 2001). The probability of sighting an animal decreases with increasing distance to the transect line. Using the software DISTANCE (Thomas *et al*. 1998) one can calculate densities using the measured distances of animals to the transect line. Here it is assumed that a) the probability of sightings decreases in a mathematical predictable manner („half-normal“ or „hazard-rate“ model), b) all animals next to the transect line are sighted g(0)=1, and c) animals do not react to the surveying platform.

a) The relationship between the number of harbour porpoise sightings and the distance to the transect line followed a „half-normal Model“, and we could calculate an „Effective Strip Width“ (ESW) in DISTANCE. The ESW describes the size of the area to which all harbour porpoise sightings relate. Despite bubble windows it has to be considered that the area directly underneath the airplane can be covered only to a limited extent. This is taken into account by truncating the sighting data at 85 m distance to the transect line. The calculated ESW-values are shown in the results.

b) In harbour porpoises, one cannot assume that all animals are recorded at the transect line. Some animals are certainly overlooked and some animals will not be close enough to the water surface to be seen. We calculated the actual sighting probability (g(0)<1) by calculating a correction factor following Grünkorn *et al.* (2005). This correction factor is a product of the resighting rate of that flight and data by Teilmann (2000) on the probability of porpoises being in the top 2 m layer of the water column. To calculate the resighting rate we counted how many of the porpoises that were seen by the observer in the back were also seen by the corresponding observer in the front. Only sightings above 25° were used to calculate the resighting rate. The probability of porpoises being present in the top layer down to 2 m of the water column were derived from Teilmann (2000), who studied diving depth and duration of harbour porpoises in the Danish Baltic Sea (Tab. 2).In close proximity to the transect line it is possible to look deeper into the water column than 2 m, however this reduces with increasing distance to the transect line and at further distances one can only spot animals breaking the water surface. We therefore only used the probability of porpoises being in the top 2 m layer.

Harbour porpoise densities were calculated by dividing the total number of porpoises observed by the calculated g(0)-value and then dividing it by the number of km² that were covered during that flight. This is calculated by multiplying the number of kilometre flown under good conditions with the ESW.

To test if there were significant differences in porpoise densities between the survey before and the survey after the sealscarer was switched on, we calculated the mean harbour porpoise density per transect and then compared the density estimates using a Wilcoxon test for two dependent samples.

4.3. Study in the Danish Baltic Sea

4.3.1. Study area

This part of the study took place at Fyns Hoved at the east coast of Denmark. A central marker buoy was deployed 150 m in front of the coast. Ten buoys were moored in the experimental area as visual markers to help localisation of the animals and train trackers using the theodolite. One buoy marked the central anchoring position of the boat 200 m from the coast. Three buoys were deployed at 150 m, three at 450 m and three in 1 km distance to this central anchoring position (Fig. 15). According to the requirements by the Danish Farvandsvæsenet, the buoys at position W3, W2, N3 and S3 were yellow spar buoys, with the one at W3 having a lantern attached, the other six were yellow marker balls. At the positions A, N2, W2 and S2, we further deployed a C-POD to record harbour porpoise echolocation clicks as described in section 3.1.1 above. Observations were conducted from a 20 m high cliff that provides a good overview of this observation area. With about 20 m above sea level and frequent harbour porpoise sightings, this location offered a good observation point to visually observe harbour porpoises swimming near the coast up to a distance of about 1 km and to make relatively accurate distance estimations.

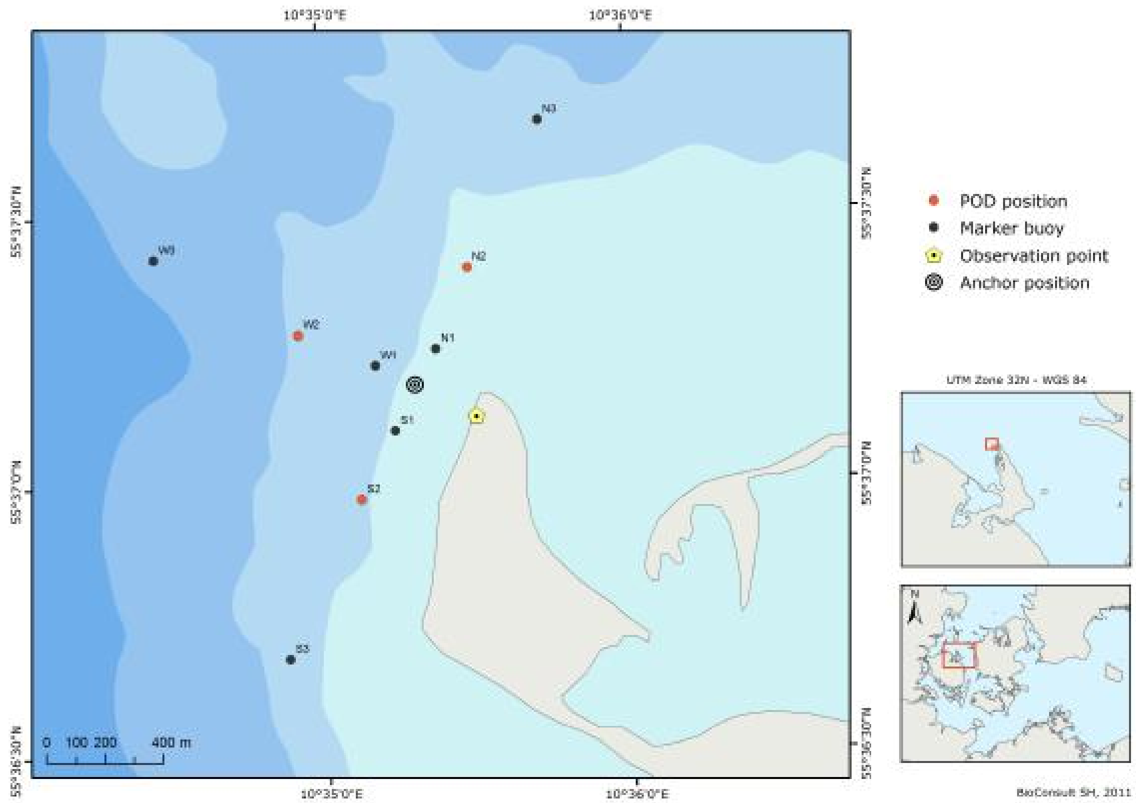

Fig. 15: Map of the study area showing anchoring position, marker buoys, POD-positions and observation point.

4.3.2. POD-data

4.3.2.1. POD deployment

Four C-PODs were deployed in a triangular pattern in front of Fyns Hoved at the positions indicated in Fig. 15 (at N2, W2, S2), each with a 450m distance do the central anchoring position. An additional C-POD was deployed at the central anchoring position where the boat was moored during trials. C-PODs were attached to an anchor stone via a long rope and were deployed about three meters above the seabed in water depths of about 6-10 m. They were attached to the yellow marker balls or yellow spar buoys used to mark the scanning area at sea. The anchor stone was connected to a second anchor stone to avoid drifting of the buoys induced by tidal currents and wave action.

Data collection lasted for about five months from the end of May until the beginning of Oct at all four POD positions. In the beginning, we deployed 2 PODs, one at S2 and one at the N2 from the 02.05.2010 until the 20.05.2010, after which we unfortunately realised that due to technical problems the PODs did not record any data. We then changed the PODs and deployed them at all 4 POD-Positions on the 20.05.2010. A total of 469 POD-days (for all 4 POD-positions when C-PODs recorded) could be achieved. During 87 POD-days no data could be recorded due to technical problems with the PODs. The POD at the anchoring position unfortunately did not record any data, again caused by technical problems. This POD and all other PODs were replaced on the 07.08.2010 (at Anchor, N2, S2) and on the 08.08.2010 (W2). The new PODs recorded until the end of the study season, when they were retrieved from the water on the 07.10.2010.

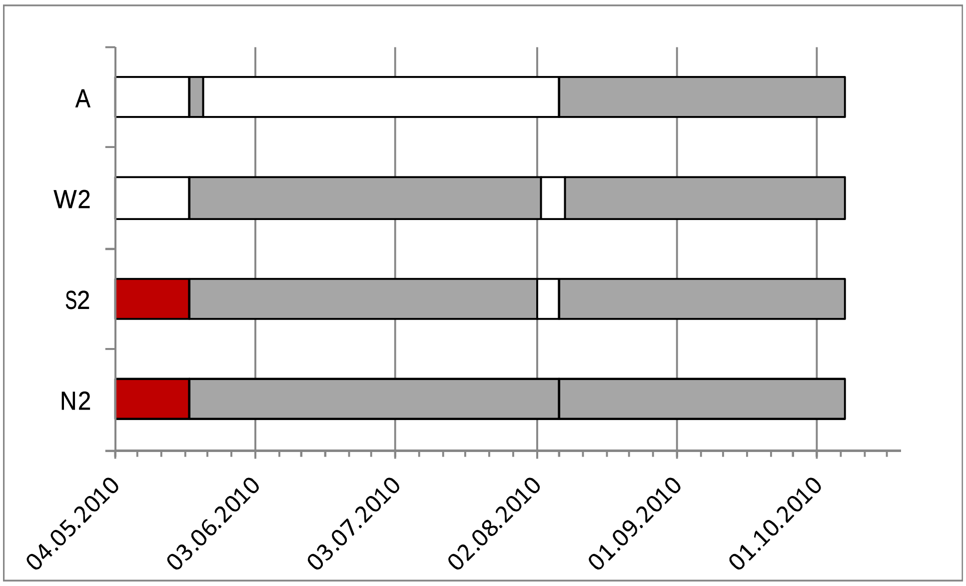

Fig. 16. POD deployment times at the four positions (A, W2, S2, N2) (grey: POD recorded data, white: POD did not record data due to technical problems, red: POD was not deployed).

4.3.2.2. Data analyses

When testing for the effect of the sealscarer on harbour porpoise activity, we used the parameter "Porpoise Positive Minutes per Hour" (PPM/H). Here all hours from 24 hours before the start of the sealscarer to 24 hours after it was switched off were included. These were then grouped into four-hour-blocks and numbered relative to the start of the sealscarer, with the hours during sealscarer deployment being 0. Since we approached the anchoring station several hours before sealscarer activation, there was no need to exclude any data which could have influenced the presence of porpoises in the study area. Differences between “before”, “during” and “after” the sealscarer was switched on were tested with a non-parametric Friedman test for several dependent samples. Since the result was significant we further tested for pairwise differences between “before” and “during” and between “before” and “after” using a Wilcoxon test for two dependent samples.

Similarly to the study in the North Sea, we encountered some problems with background noise. However, these were much smaller than in the North Sea. We proceeded similarly to what is described in section 3.2.2, only that in this case a visual check of the porpoise clicks against the raw data clicks led us to exclude data during hours with more than 3 % time loss. Unlike in the North Sea, high background noise occurred almost only during periods when the sealscarer was active. Visual inspection of the raw data revealed that the sealscarer noise was sometimes recorded by the PODs. These hours therefore had to be excluded, which led to about 8 % data loss (Tab. 4). We therefore excluded 4-hour-bocks without analysable data. For the others we calculated the proportion of PPM in relation to the time that could be analysed during this 4-hour-block (180, 240 min) setting a minimum of at least two analysable hours (Tab. 5). If there were no analysable data during sealscarer activity at a POD-position, the complete data set from that trial at that POD-position was excluded from analyses.

Tab. 4: Number of POD-hours, where the respective proportion of time was lost due to the scan limit being exceeded (caused by high background noise).

time lost per hour	N POD-hours	%
0 %	752	75.5
1 %	93	9.3
2 %	47	4.7
3 %	27	2.7
>4 %	77	7.7
sum	996	

Tab. 5: Shown are the seven trials with sealscarer on and the positions of the C-PODs as well as whether data could be obtained at the 3 POD-positions (black X: POD recorded analysable data, grey X: POD recorded data, but a maximum of 2 hours were excluded from the analysis, empty cell: POD recorded data that could not be analysed due to high noise pollution at that position).

Positions and trials	1	2	3	4	5	6	7
north	X	X	X	X			
west	X	X	X	X			
south	X	X		X			

4.3.3. Visual observations

4.3.3.1. Data collection

The experimental design followed the method used by Carlström *et al.* (2009) who tested the impact of pingers on harbour porpoise on the Scottish West coast and the methods used by Johnston (2002) who tested the effect of a sealscarer on harbour porpoises in Canada.

From an observation point on top of the 20 m high cliff, a radius of up to 1.0 km was observed for porpoise presence. Exact determination of the harbour porpoise positions was obtained through triangulation using a theodolite (e.g. Koschinski *et al.* 2003, Tougaard *et al.* 2006). Observers tracked animals with the help of a theodolite, which enabled determination of the animals' position by using the known height of the observation point and the horizontal angle of the animals' position.

Three people (observer, tracker and recorder) were positioned at the land based observation point (Fig. 17). Every 10 min the observer scanned the 1 km radius first using the naked eye for the near vicinity and then using binoculars to scan the outer area up to 1 km. One complete scan took about 2-3 min. In between scans the area was constantly searched with the naked eye. For each sighting the observer determined the number of animals, their age, behaviour, swimming direction, distance from the anchoring position, time and whether the animal was observed during a scan or in the period between scans. The nine buoys deployed at 150, 450 and 1000 m helped the observer to judge distances accurately. Furthermore, the observer also recoded each boat that passed the observation area, recording the type of boat, driving direction and the nearest distance category (150, 450 or 1000 m) that it crossed. The tracker tracked the nearest sighted harbour porpoise or group of harbour porpoises using the theodolite until this animal/group was out of sight. The recording person inserted the trackers' information into the computer connected to the theodolite (using the software Cyclops). For each porpoise observation we recorded the number of animals, their age and their behaviour at the beginning of the track and whenever any of these parameters changed. When a track was stopped, it was noted whether the animals were lost or swam out of the tracking range. The following behavioural categories were defined: "porpoising" (the animal swam quickly, repeatedly leaping out of the water)," travelling" (the animals swam in a directional movement), "milling" (the animals swam slowly in a defined area, changing direction repeatedly), "resting" (animal lying on the surface or slowly resurfacing repeatedly at the same spot)," feeding" (animal performing obvious chases, sometimes with fish jumping out of the water), "socialising" (animals interacting with each other e.g. chasing each other or swimming in close contact (apart from mother calf pairs)). It was often difficult to determine whether an animal was feeding or not, and some of the behaviour classified as milling might have been feeding. Usually animals could only accurately be tracked up to a distance of about 800 m, before the location error became too large. Covering larger distances was only possible during a sea state of 0 or 0.5, when the footprint that the animal leaves after diving, can be seen for some time after it disappeared. The three people on the cliff switched tasks approximately every hour. Only five different observers were employed for these tasks so differences between observers were kept at a minimum.

Weather conditions were recorded by the observer every 30 min and whenever they changed. This included an estimation of sea state on the Beaufort scale with steps of 0.5, cloud cover in eights, wind direction and speed (in Beaufort), rain and sighting conditions (sun glare). With a general variance of only about 20 cm, tidal change in this area was minor and within the general location error. Therefore we did not correct for this. However, approximately every hour, positions were taken of the buoys to calculate a localization error, including both, errors due to tidal changes and errors due to measurement accuracy. We analysed localisations taken from four buoys at four different distances during four different days over a period of one month, to calculate a general localisation error. This was done by calculating the standard deviance for x and y-coordinates. The results are show in Tab. 6. The standard deviation at the maximal distance of 1250 m from the observation point was ± 13.5 for x and ± 14.6 for y. This includes tidal changes, position changes caused by the currents and localisation errors when handling the theodolite. Positioning errors of porpoises may however be slightly higher, when the localisation had to be taken after the porpoise dove and no footprint was visible. However, care was taken not do make measurements at great distances when the sea was not sufficiently calm to see the whales' footprint.

A small boat with one person was positioned in the bay at the central anchoring position from the third day of observation onwards (Fig. 18). Observations started 15 min after the boat was anchored and the engine switched off. During days with sealscarer trials a sealscarer was activated from this boat.

Tab. 6: Localization error at four different distances from the observer point. Given are standard deviations for x and y coordinates and the maximum distance that points were apart.

Position	Distance	S.D. of X	S.D of Y	Max distance of X	Max distance of Y	N
Anchor	250 m	± 6.6	± 3.3	21.8	12.3	27
W1	400 m	± 6.3	± 6.4	14.6	15.6	7
W2	650 m	± 8.1	± 9.3	23.5	26.6	7
W3	1250 m	± 13.5	± 14.6	38.6	39.8	7

Observations were only conducted during calm weather conditions (at maximum sea state of 2 Beaufort) between 01.05.2010 and 07.08.2010 during nine days without sealscarer deployment (baseline data) and seven days with sealscarer deployment (Tab. 7). During the first four days we deliberately collected baseline data, where animals were not influenced by any prior experience of the sealscarer. During the following days we conducted blind trials, where the skipper threw a coin to randomly decide whether the sealscarer will be deployed or not, without the observers on the cliff knowing the outcome. The sealscarer was deployed in the water (but not yet switched on) once the boat anchored at the central position. We then conducted observations for a minimum of one hour before the sealscarer was switched on. After this hour we usually waited for a porpoise to be at a distance between 150 and 700 m of the sealscarer and until we had at least 5 localisations of this animal until we told the skipper to switch on the sealscarer. Depending on the outcome of the coin throw she either did this or not. The sealscarer was then active for a continuous four hours before it was switched off and observation continued as long as weather- and light conditions permitted. This procedure was chosen so as to obtain an hour of baseline data before the sealscarer was switched on and then be able to study whether an animal changed its travelling path as a result of sealscarer activity. A summary of the field days completed can be found in Tab. 7.

The sealscarer used was a model from Lofitech (www.lofitech.no). It emits pulsed signals at a frequency between 13.5 and 15 kHz with pauses between less than one sec and up to 40-90 sec long. Signal strength is about 189 dB re 1 µPa @ 1 m according to the manufacturer. The sealscarer was powered by a car battery on board the boat. The boat operator and the observer on top of the cliff were in contact using mobile phones. An exact protocol of the sealscarer activity was kept by the skipper.

Fig. 17: Boat with skipper anchored at the central position where the sealscarer was deployed.

Fig. 18: Observer position on top of the cliff. The observer on the right is tracking porpoises with a theodolite, the observer in the middle is entering the data into the computer and the observer on the left is conducting standardised scans using binoculars.

Tab. 7: Dates of observation days at Fyns Hoved with observation times and trial type information

No	Date	Time (UTC)	Type
1	11.05.2010	10:00-18:00	baseline
2	21.05.2010	9:50-16:35	baseline
3	22.05.2010	14:10-19:10	baseline
4	04.06.2010	14:40-18:40	baseline
5	15.06.2010	13:00-17:00	baseline
6	23.06.2010	15:00-20:00	sealscarer
7	24.06.2010	7:50-15:30	sealscarer
8	27.06.2010	4:50-12:50	baseline
9	09.07.2010	9:20-15:10	baseline
10	10.07.2010	5:50-15:20	sealscarer
11	17.07.2010	7:00-16:10	sealscarer
12	27.07.2010	8:00-16:40	sealscarer
13	01.08.2010	10:00-16:30	sealscarer
14	02.08.2010	6:50-14:40	baseline
15	06.08.2010	9:40-19:00	baseline
16	07.08.2010	7:50-16:00	sealscarer
17	05.09.2010	4:30-14:30	response study
18	06.09.2010	7:00-16:00	response study
19	25.09.2010	9:10-17:10	response study
20	25.08.2011	8:30-16:50	response study

4.3.3.2. Data analyses

To analyse whether the sighting rate of harbour porpoises significantly declined during sealscarer activity, we first had to see what factors were generally influencing sighting rates. Therefore we first tested the effects of date, hour and sea state on the number of porpoises seen during each scan, using only data from the nine days when the sealscarer was not activated. We calculated a GLM fitted to a Poisson distribution, using the number of porpoises seen per scan as the response variable and entered day, hour and sea state as linear predictor variables. To also allow for a quadratic relationship of day and hour we further included day^2 and $hour^2$ as linear predictors. We then proceeded by backwards selection, excluding non-significant terms by stepwise choosing the least significant one until only significant terms were retained in the final model.

In a second step we then only used the data from the days when the sealscarer was activated, built the same GLM as done with the baseline data, only now including “sealscarer” as a factor with three categories (before, during and after sealscarer activation). This model was run with all distance classes pooled, and then for each of the three distance classes separately to see at what distances sighting rates were still influenced by the sealscarer.

As these GLM analyses were based on scans as a unit, values for porpoise sighting were rather small. To get a better estimate on the scale at which porpoise sightings were reduced, we also pooled the sighting data into 4-hour-blocks, to get an estimate on how extensive an area was used by porpoises during times with and without sealscarer activity. The disadvantage of this approach is that we could no longer control for hour or sea state. We pooled the first four hours of sighting data obtained during each of the nine days without sealscarer activity and the four hours during which the sealscarer was active at the seven days with sealscarer experiments. These were then compared using a non-parametric Mann Whitney-U-test for two independent samples. This was also done for all distances combined and for the three different distance categories separately.

4.3.4. Response study

4.3.4.1. Data collection

In addition to the trials with and without sealscarer, we conducted four days of observations at the end of the study period, where we specifically studied the responses of harbour porpoises to the sealscarer when it was deployed at greater distances than 1 km. For this purpose the skipper drove the boat further away from the coast (to distances between 1.5 and 3.5 km). He then waited until the observers notified him to switch the sealscarer on. Before this, he made sure that no porpoise was within a 150 m radius around the boat. The observers on the cliff asked the skipper to switch the sealscarer on, once they had spotted a porpoise within 700 m distance of the central buoy and had obtained at least 5 locations using the theodolite. The skipper was asked to activate the sealscarer at all but one of the cases during a given day and to randomly decide when not to activate it. Thus, the observers at the cliff did not know whether or not the sealscarer was switched on. Animals were then tracked as long as possible and the skipper noted down the time when the sealscarer was activated (also the hypothetical times when it was not in fact switched on). The sealscarer was then left active for 5 min, and the next trial began with at least 15 min passed since the last trial. We obtained nine tracks with active and three tracks with inactive sealscarer when it was between 1.2 and 2.6 km from the porpoise at the time of activation.

4.3.4.2. Data analyses

Data were extracted from Cyclops and uploaded to ArcGis 9, to visualise the tracks that porpoises swam with and without the sealscarer active. First we show all six tracks directly before the sealscarer was switched on that we could obtain during the seven trials when the sealscarer was deployed at the anchoring position and was switched on for four continuous hours. Then we show all 15 tracks that were obtained during the response study, when the sealscarer was deployed at greater distances between 1.2 km and 3.3 km from the porpoise. The harbour porpoise reactions are all qualitatively described and the tracks depicted in maps where the position of the deployed sealscarer is also indicated. During 13 tracks we were able to follow the animal after the sealscarer was switched on. In these cases we split the track up into before and after sealscarer start. These tracks were plotted in Arc View. Using the Arc View extension animal movement, a value for the directionality of both parts of these five tracks was obtained as long as each part contained at least three positions. Using the function “test for site fidelity” we also tested whether the track was more dispersed or constrained as randomly expected or if it was just random. The program tests this by calculating random walks in taking the distances of the actual walk and fitting random angles using a Monte Carlo simulation (Hooge *et al*., 2000). As recommended by Hooge *et al*. (2000) we chose to create 100 random walks using the first location as a starting point. The program then creates an R^2 value and tests if the actual walk differs from the 100 random walks created. This was also done for the tracks of the blind trials, when the sealscarer was not activated. In addition to that, we calculated the following parameters for each part of the track (before and during sealscarer): mean step length (mean distance between consecutive resurfacings), mean heading relative to the sealscarer, distance of last point before sealscarer activation and last one during sealscarer activity to the sealscarer and swimming speed (sum of all distances between resurfacings divided by time from first to last location of a track).

5. RESULTS

5.1. Acoustic measurements

5.1.1. General results

Fig. 19 shows typical examples of rms sound level versus time for the Lofitech sealscarer signal. Levels as a function of distance for the Lofitech sealscarer are depicted in Fig. 20. Due to background noise and self-noise from the boat, peak levels were only evaluated up to a distance of approx. 1 km. The estimated measurement uncertainty is ±3 dB. The level decrease with distance is significantly stronger than for spherical wave propagation without absorption or other losses, which at Fyns Hoved corresponds to a transmission loss of 27 log D (see Fig. 21). In the North Sea, the measured sound level decrease with distance is much closer to spherical spreading (Fig. 21). It should be noted, however, that a simple approximation formula for the transmission loss like k log D is only valid for moderate ranges up to a few kilometers. At large distances, the sound absorption in sea water (about 1 dB/km at 10 kHz, Francois & Garrison, 1982) and at rough sea wave-generated air bubbles, yield an additional level decrease. This was taken care of by also fitting a formula developed specifically for the North Sea by Thiele & Schellstede (1980) to gain estimates of sound levels at further distances (Fig. 24).

The actual sound levels measured at the different positions at Fyns Hoved are shown in Tab. 8 and Tab. 9, with the latter showing the values from positions around the tip of the island without a direct sound path. These values in the sound shadowed zone are depicted as red triangles in Fig. 20. It can be seen that sound levels in the shadowed zone are about 10-20 dB lower than at comparable distances with unobstructed sound paths.

Mathematically, the difference between peak and rms level for the Lofitech signal should be 3 to 4 dB, but on average, the difference measured under real conditions is larger than 10 dB. This is because the amplitude fluctuates quite strongly (Fig. 22). This is typical for such pure tone signals and is mainly caused by variations of the propagation path, mainly due to waves and small changes of the distance between sound source and receiver.

The results for the Airmar sealscarer are shown in Fig. 23. While the peak levels are similar to the Lofitech, the rms levels are roughly 15 dB lower. This is due to signal structure; within a 2.5 s burst, the Airmar device is only 56 x 1.5 ms = 84 ms "on". Hence it is more difficult to evaluate in terms of audibility than the Lofitech (see section 5.3.3 in this report) and the two devices are difficult to compare.

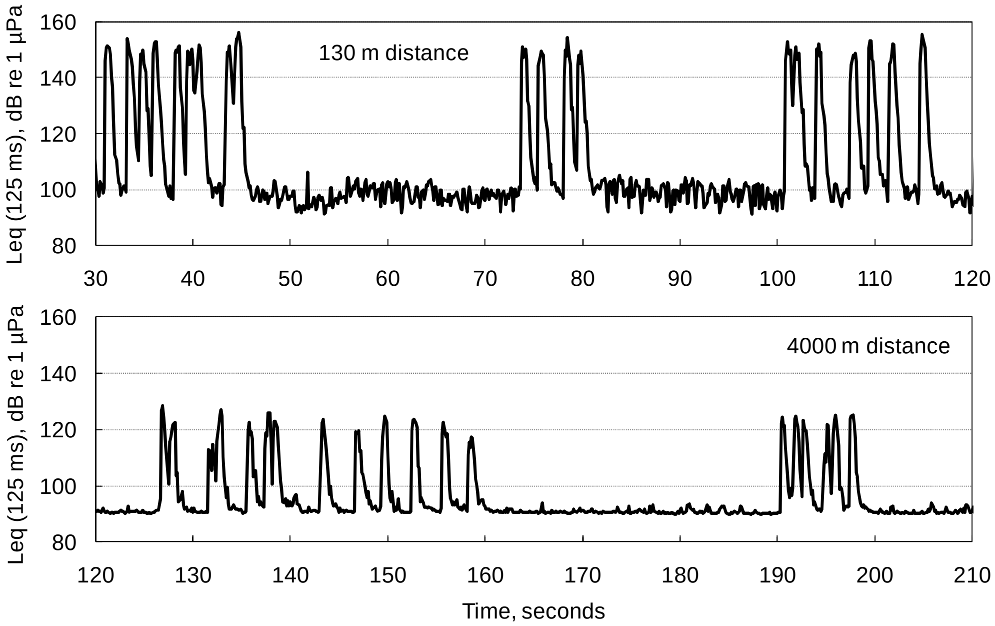

Fig. 19: Typical rms sound pressure level (125 ms averaging) of the Lofitech sealscarer for two measurement distances at Fyns Hoved. The higher background level at 130 m from the sealscarer was probably caused by stronger wave-induced self-noise at this position close to the shore.

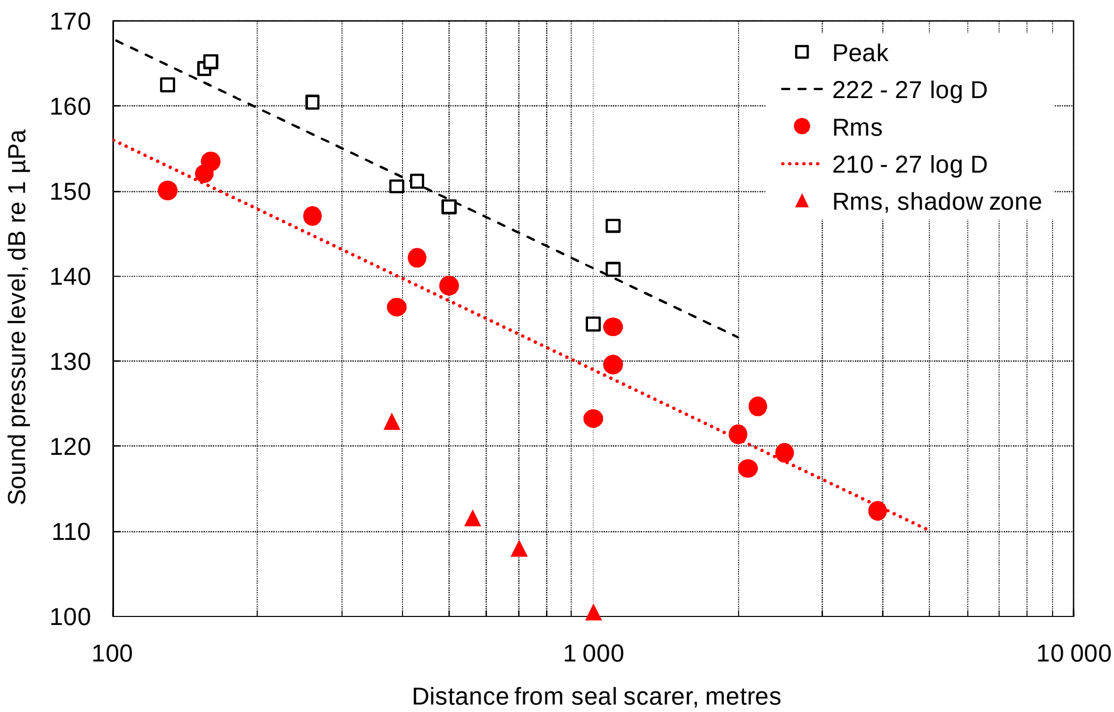

Fig. 20: Rms (125 ms averaging) and peak sound pressure level versus distance of the Lofitech device at Fyns Hoved. Values are listed in Tab. 9 and Tab. 10.Red triangles represent measurement points around the inlet without an unobstructed path to the sound source.

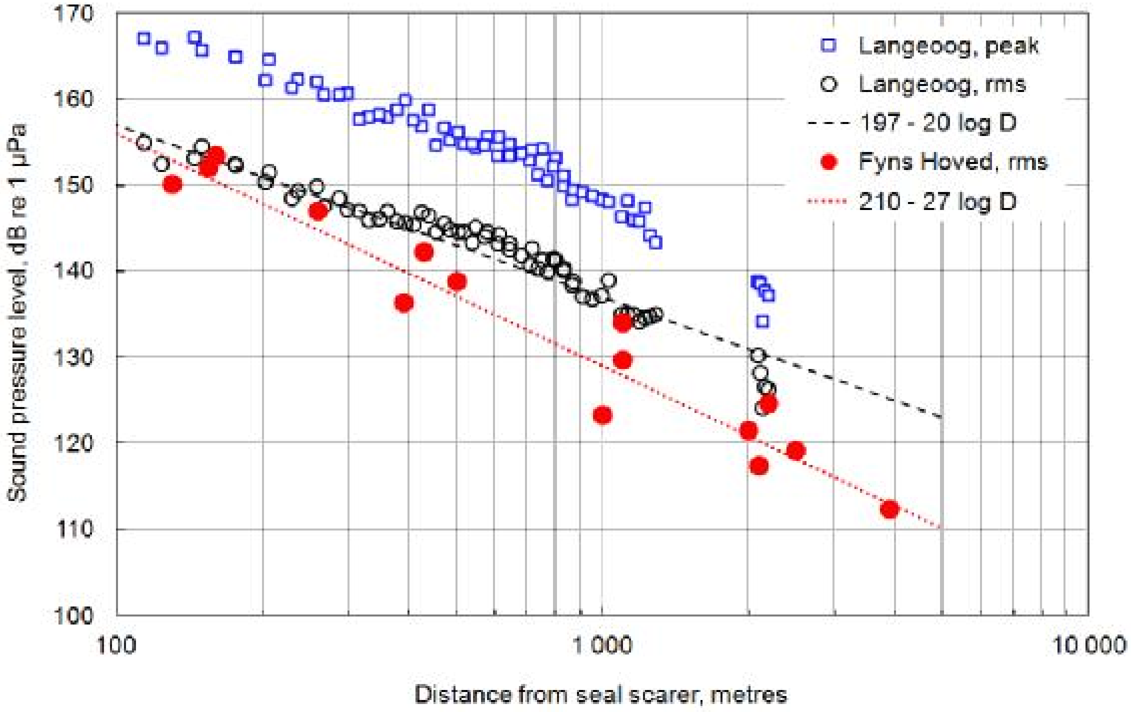

Fig. 21: Sound pressure levels of the Lofitech device measured in the North Sea, compared to the measurement at Fyns Hoved.

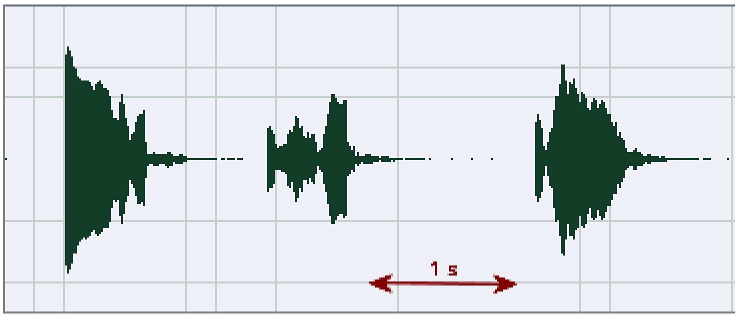

Fig. 22: Exemplary pattern of sound pressure versus time of the Lofitech device (3 pulses, distance 160 m). Although the amplitude produced by the device is constant within each pulse, the amplitude fluctuates due to propagation effects. This is typical for pure tone signals like these.

Tab. 8: Levels measured from the Lofitech sealscarer at Fyns Hoved (closed red circles in Fig. 21). For the measurement locations, see Tab. 32 in the appendix.

Measurement number	Distance from sealscarer in m	RMS, dB re 1 µPa	L_{peak}, dB re 1 µPa
1	130	150	163
2	260	147	160
3	390	136	151
4	1000	123	134
5	2000	121	
6	3900	112	
11	160	154	165
12	500	139	148
13	1100	130	141
14	2200	125	
15	1100	134	146
16	430	142	151
17	155	152	164
18	2500	119	
19	2100	117	

Tab. 9: Levels measured from the Lofitech sealscarer in the "shadow zone" at Fyns Hoved (red triangles in Fig. 21). For the measurement locations, see Tab. 32 in the appendix.

Measurement number	Distance from sealscarer, m	RMS, dB re 1 µPa
7	700	108
8	1000	101
9	560	112
10	380	123

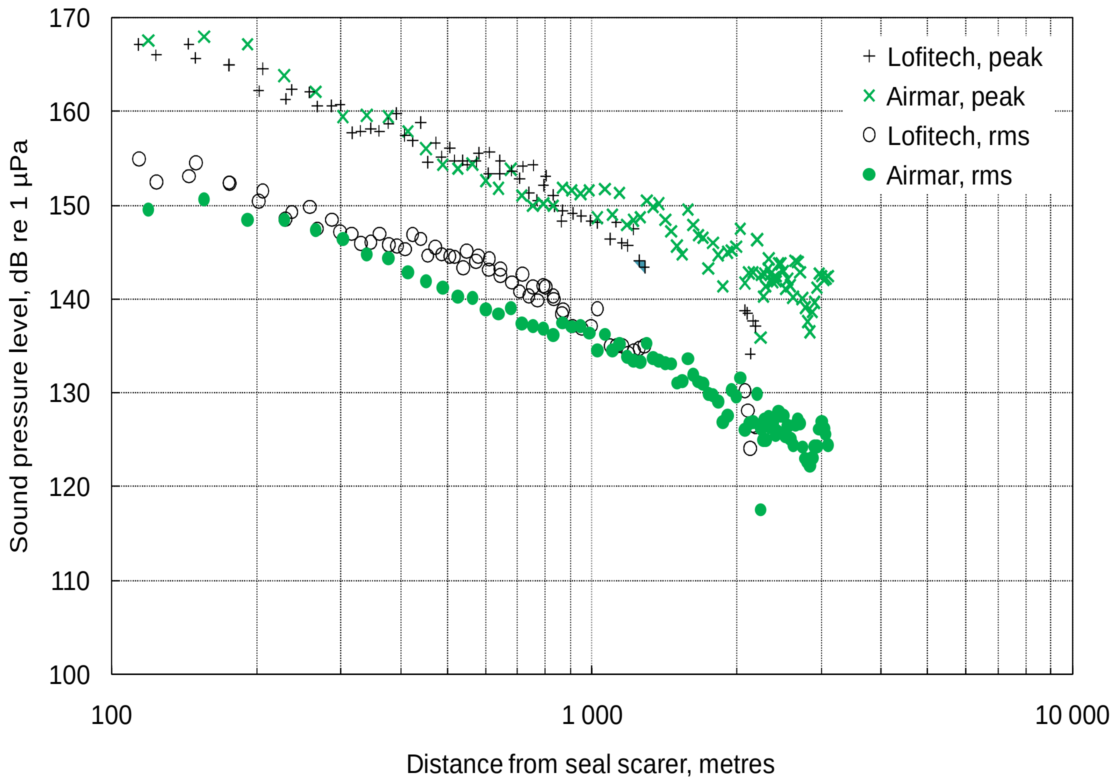

Fig. 23: Rms (125 ms averaging) and peak sound pressure level for the Airmar sealscarer measured in the North Sea, compared to the Lofitech unit.

5.1.2. Source level and sound exposure level

Of special interest is the source level, which is the measured sound pressure level scaled to a reference distance of 1 m. In this concept, the source is thought as punctual, i.e. without dimension. The scaling from some measurement distance down to 1 m is not trivial. The dB-linear approximations in Fig. 21 for example, which are valid for a limited distance range, would yield different source levels for the North Sea and the Baltic Sea for the same device (197 vs. 210 dB re 1 µPa), which is nonsensical. Furthermore, the values appear to be quite high. In general, source level values are only meaningful if the underlying measurement distance and the propagation model are specified.

Another approximation for transmission loss, which has been designed especially for the North Sea with its predominantly sandy bottoms and for a distance range from 1 m to several 10 km , is the so-called Thiele formula (Thiele & Schellstede 1980):

$$TL = (16.07 + 0.185\,F)\,(\log(R) + 3) + (0.174 + 0.046\,F + 0.005\,F2)\,R\,,$$

where F = 10 log(f / kHz) und R is the distance in km. Fig. 24 shows the North sea measurements from both sealscarers as Fig. 23 but with added Thiele approximation. This leads to the source levels listed in Tab. 10. Source levels of the Lofitech sealscarer are similar to the ones specified by the manufacturer, however. Source levels of the Airmar are 10-15 dB lower than specified by the manufacturer (compare Tab. 1). It has to be noted, however, that no measurements were made directly next to the sealscarer and that estimated source levels are highly dependent on the approximation formula used (in this case Thiele). Therefore, these values have to be treated with caution.

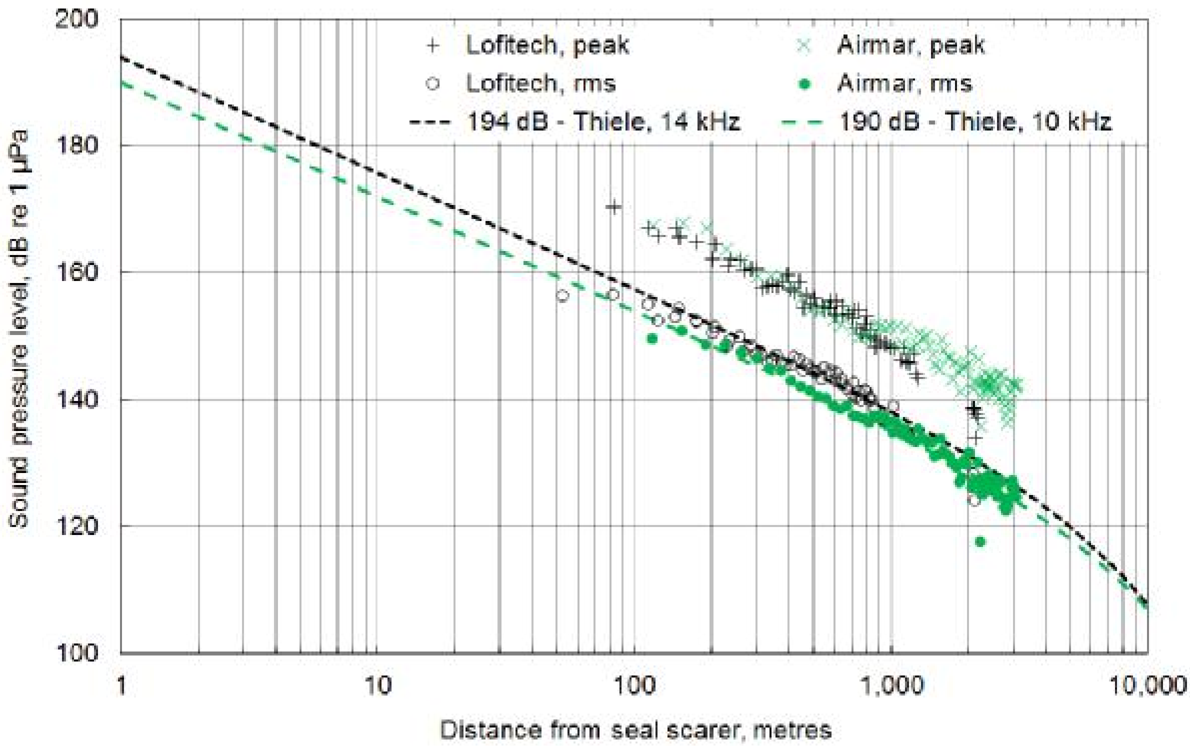

Fig. 24: Rms and peak levels measured in the North Sea as in Fig. 4.3.5, but with added approximation formula for spherical spreading with absorption.

Tab. 10: Source levels derived from the North Sea measurements by applying the Thiele approximation for transmission loss

Device	Source level, dB re 1 µPa @ 1 m		
	RMS	SEL	Peak
Lofitech	194 (Averaged over 0.5 s pulse)	190 (One 0.5 s pulse)	205
Airmar	190 (Averaged over 2.5 s burst)	194 (One 2.5 s burst)	206

The sound exposure level (SEL) for a single tone pulse from the Lofitech sealscarer is thus 3 dB lower than the corresponding Thiele curve (Fig. 24). The SEL of a single burst from the Airmar device is 4 dB higher than the corresponding Thiele curve in Fig. 24. These single-burst SELs are sketched in Fig. 25. For longer time intervals T of several minutes or more, the cumulative SEL is given by

$$SEL_{cum} \approx SEL_{single} + 10 \log (15T/60\ s) \quad \text{for Lofitech, and}$$

$$SEL_{cum} = SEL_{single} + 10 \log (3T/60\ s) \quad \text{for Airmar,}$$

because the Lofitech device emits approx. 15 bursts per minute on average and the Airmar exactly 3 bursts per minute. SEL_{single} values are listed in Tab. 10 in column "SEL". Cumulative SELs computed in this way for various distances from the Lofitech sealscarer are shown in Fig. 26. Values for the Airmar sealscarer are approx. 3 dB lower.

Note: Southall *et al.* (2007) have proposed to express broadband sound levels, especially SEL values, as "M"-weighted levels, that is, to apply a frequency weighting that reflects the reduced hearing sensitivity at the upper and lower frequency end of the animal's hearing range. However, for "high-frequency Cetaceans" like the harbour porpoise, the M-weighting is virtually 0 dB between 500 Hz and 50 kHz. That is, at the sealscarer operating frequencies, M-weighted and unweighted levels are equal.

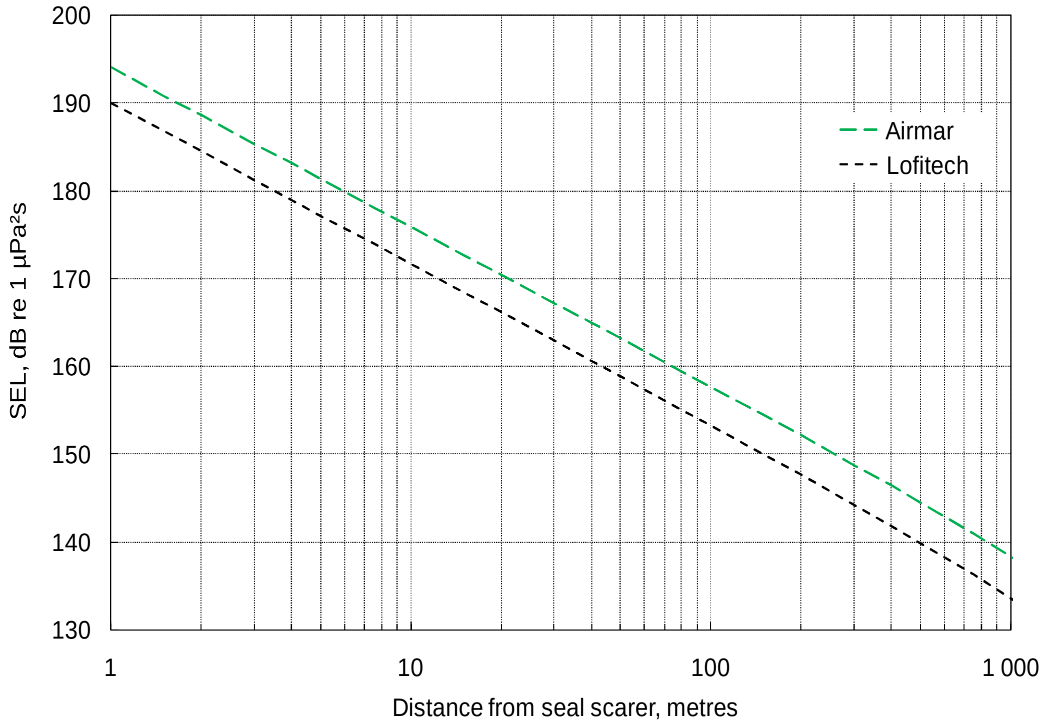

Fig. 25: Sound exposure level for a single burst from the sealscarers, based on Thiele approximation for the transmission loss.

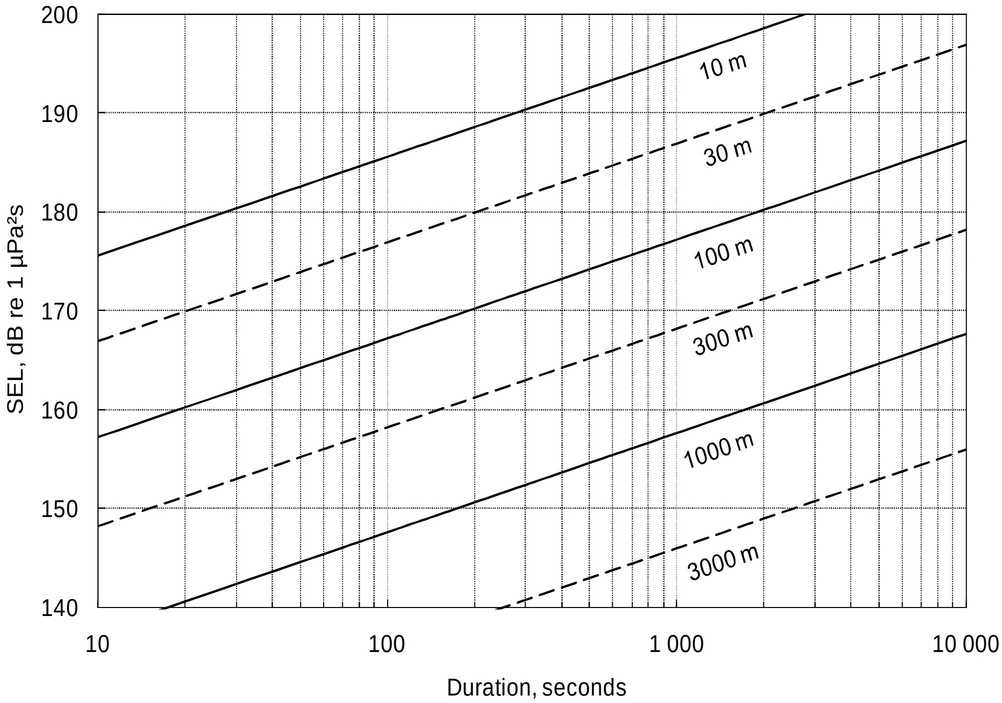

Fig. 26: Cumulative SELs for various fixed distances from the Lofitech sealscarer, computed for the North Sea (Thiele approximation used for transmission loss). Values for time periods below about 100 seconds may vary, because the calculation is based on an *average* pulse rate of 15/minute, while the actual number of pulses is subject to the device's random timing.

5.2. German North Sea

5.2.1. POD-data

5.2.1.1. Spatial and temporal habitat use by harbour porpoises

As can be seen in Fig. 27 there was a slight seasonal pattern in porpoise activity during the study period. Apart from positions along the southwest transect, this pattern was characterised by higher porpoise activity at the beginning of Jul, when the study started, followed by a decline and lower activity between Aug and Oct. While activity stayed low along the northwest transect, porpoise activity again increased in the central area towards the end of the study period in Nov. Along the southwest transect, porpoise activity was generally low and mainly stayed below 20 % PP10M/day. There was no clear seasonal pattern along this transect apart from porpoise activity being slightly higher in Aug and Sep than in Oct and Nov. At position 14, data were available for only a few days. We therefore did not analyse these with respect to the effects of the sealscarer. However, to retrieve information on habitat usage by harbour porpoises, we still include these data in the figures showing seasonal patterns.

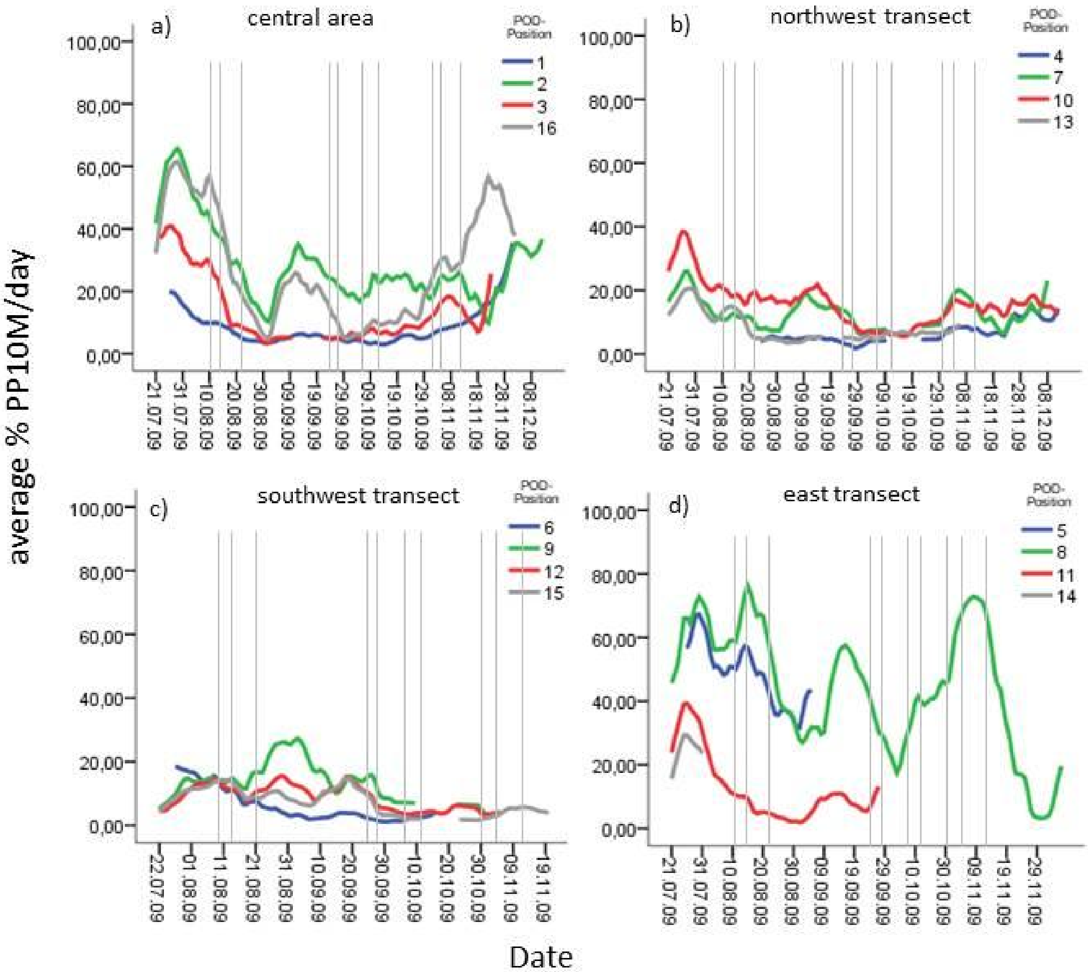

Fig. 27: Seasonal pattern of harbour porpoise activity („PP10M/day") shown as moving averages over the last ten days at the different POD-positions with one graph for all positions along a transect line and in the central area. Days when a sealscarer experiment took place are depicted as vertical grey lines. Note the different scaling of y-axes.

Harbour porpoise activity was highly different between single POD-positions (Fig. 28, Tab. 33 in appendix). There was generally more porpoise activity along the western part of the east transect at positions 16, 2, 5 and 8, where the median over all days lay between 24 and 49 % PP10M/day. Especially at positions 5 and 8 porpoise activity was high with medians of 47 and 49 % PP10M/day respectively and maxima of even 89 and 99 % PP10M/day. At the remaining positions porpoise activity was markedly lower with medians between 6 and 15 % and maxima around 62 % PP10M/day.

Data thus show strong spatial differences in porpoise activity with slightly different seasonal patterns depending on position.

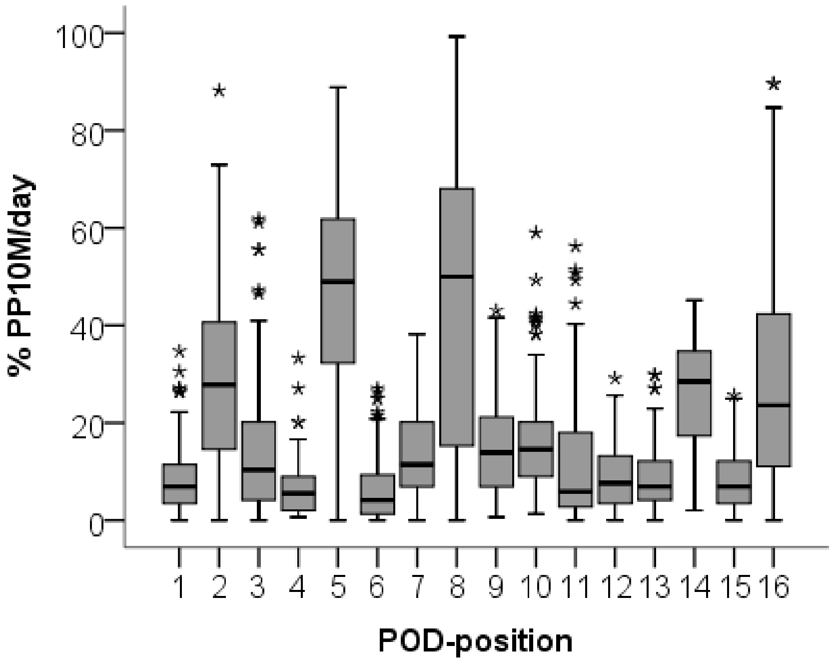

Fig. 28: Porpoise activity as „PP10M/day“ at the single POD-positions shown as boxplots with outliers (stars).

5.1.1.2. Sealscarer effects

In Fig. 29 porpoise activity is shown for the times before, during and after sealscarer activity. Here it can clearly be seen that at almost all distances porpoise activity markedly declined when the sealscarer was active as compared to the time before. In Fig. 30 this is again shown summarised for the different distances and pooled over the corresponding POD-positions.

At the position close to the sealscarer (position 16) a decrease in porpoise activity during sealscarer activity was observed during seven experiments, while an increase was never observed (Fig. 29, Tab. 11). Porpoise activity was significantly less during sealscarer activity than before ($Z=-2.38$; $n=9$, $p<0.05$) and was reduced from an average of 2.6 % PPM in the three hours before the sealscarer was switched on, to 0.1 % while it was switched on (Fig. 30, Tab. 12). At the three PODs with a distance of 750 m, a decrease was observed 20 times and an increase twice (Fig. 29, Tab. 11). This decrease in % PPM was also significant ($Z=-3.36$; $n=27$, $p<0.01$), and % PPM was reduced from an average of 4.0 % before to 0.6 % during sealscarer activity (Fig. 30, Tab. 12). In 1500 m distance a decrease was observed nine times, an increase once. PPM decreased from an average of 2.4 % before to 1.1 % during sealscarer activity, but this difference was not statistically significant ($Z=-1.79$; $n=13$, $p=0.07$). In 3000 m distance, there was again a significant decrease from 10.1 % before to 2.5 % during sealscarer activity (Fig. 30, Tab. 12; $Z=-3.03$; $n=20$, $p<0.01$), and a decrease was observed 16 times, while an increase was found at two times (Fig. 29, Tab. 11). At the POD-positions in 5000 m distance PPM was similar before and during sealscarer activity with 0.9 % before and 0.8 % during sealscarer activity, and there was no significant difference ($Z=-1.33$; $n=21$, $p=0.18$). A decrease was observed ten

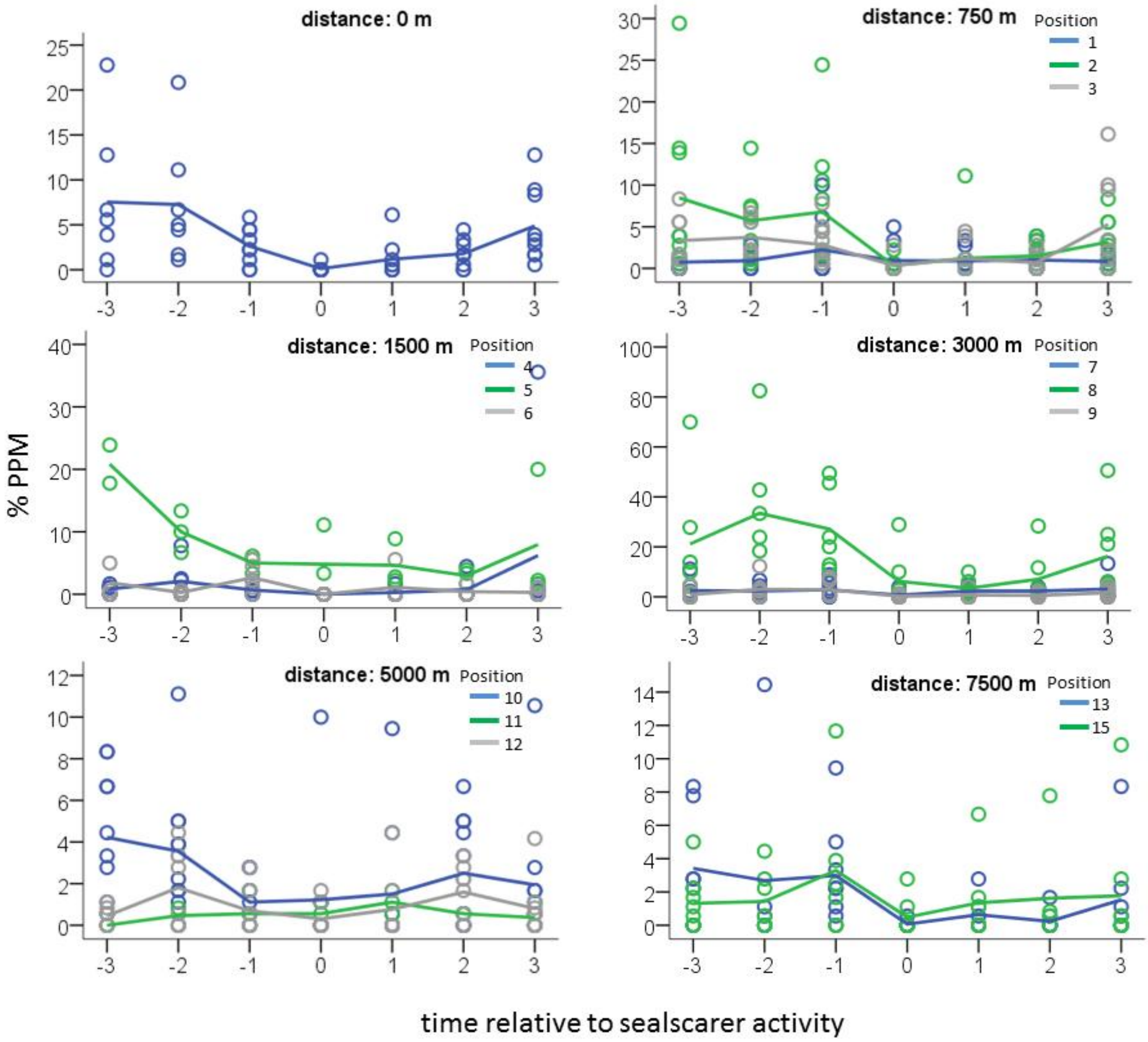

Fig. 29: Harbour porpoise activity (% PPM) recorded by PODs at different distances before, during and after sealscarer activity (-3: 8-10 h before, -2: 5-7 h before, -1: 4-2 h before, 0: 3 h during, 1: 1-3 h after, 2: 4-6 h after, 3: 7-9 h after). Interpolation lines (shown per position) and points are colour coded for different positions. In contrast to Fig. 30 all three hour blocks that could be analysed are included.

times, an increase six times (Fig. 29, Tab. 11). In 7500 m distance there was a decrease from an average of 3.1 to 0.1 % PPM, which again was statistically significant (Fig. 30, Tab. 12; $Z=-2.87$; $n=14$, $p<0.01$). A decrease in porpoise activity was observed twelve times, an increase once (Fig. 29, Tab. 11). To test whether a decrease during sealscarer activity was observed more often than would randomly be expected (so in 50 % of cases), we used a Chi^2-test, if there was porpoise activity before or during sealscarer activity in at least ten cases (at lower sample sizes such a test is not reasonable). At 750 m ($Chi^2=6.6$; $df=1$; $n=22$; $p<0.05$), at 3000 m ($Chi^2=4.7$; $df=1$; $n=18$; $p<0.05$) and at 7500 m distance ($Chi^2=3.9$; $df=1$; $n=13$; $p<0.05$), a decrease during sealscarer activity was observed significantly more often than randomly expected, while this was not the case at 1500 m ($Chi^2=2.5$;

df=1; n=10; p>0.05) and 5000 m distance (Chi²=0.3; df=1; n=16; p>0.05). At 0 m distance sample size was too small to test this (Tab. 11).

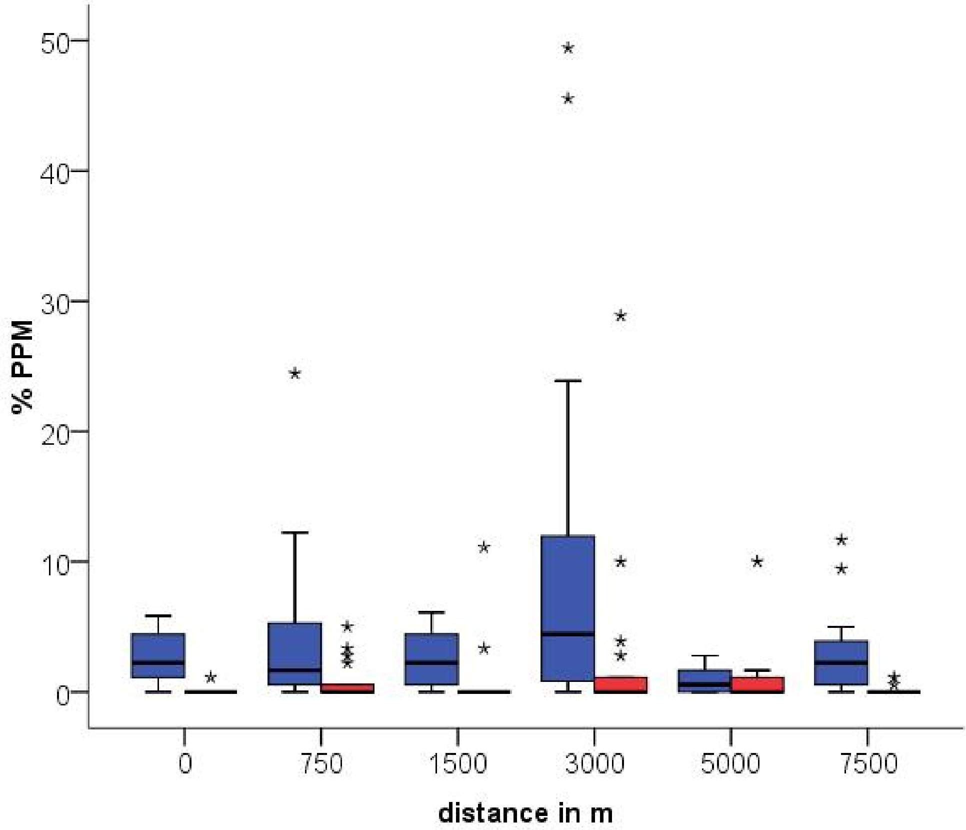

Fig. 30: Harbour porpoise activity before (blue bars) and during (red bars) sealscarer activity shown as box-whisker-plots with outliers (stars). Only data from trials were porpoise activity could be recorded before and during sealscarer activity are included.

To summarise, a decrease in porpoise activity during sealscarer activity was observed at all distances. However, at 1500 m and 5000 m distance this decrease was not statistically significant. However, porpoise activity recorded before sealscarer activity at POD-positions in 1500 m and 5000 m distance was already very low before the sealscarer was activated (Tab. 12). This means that the effect that may be found due to sealscarer activity is very limited. At the maximum distance of 7500 m that was investigated, porpoise activity before the start of the sealscarer was higher than at 1500 m and 5000 m distance, and consequently a statistically significant sealscarer effect could be found. At the POD-position nearest to the sealscarer, porpoises were almost completely absent during sealscarer activity, and in 750 m porpoise activity declined by about 86 % during sealscarer activity relative to the time before. At the remaining distances porpoise activity declined by between 9 % and 96 %, with a greater magnitude of the effect at positions where porpoise activity before sealscarer activity was high. As this figure is highly dependent on porpoise activity during the baseline, which varies greatly between the different distance categories, this value may not be very meaningful to quantify the sealscarer effect in an area with already low baseline activity. Furthermore, it has to be bared in mind that the high variability in porpoise activity between different POD-positions strongly affects the power of proofing a statistically significant effect.

Tab. 11: Number of cases, where porpoise activity decreased, increased, was the same or where no porpoises were recorded either before or during sealscarer activity. Further, the information of whether or not a Chi²-test revealed a significantly higher than expected frequency of decreases during sealscarer activity is given. Significance levels are coded as follows: n.s.: p>0.05, *: p≤0.05. In 0 m distance no test could be calculated due to low sample sizes.

Distance in m	Position	Decrease	Increase	Same	Both 0	Significance
0	16	7	0	0	2	
	sum	7	0	0	2	
750	1	4	1	0	4	
	2	9	0	1	0	
	3	7	1	0	0	
	sum	20	2	1	4	*
1500	4	3	0	0	2	
	5	2	1	0	0	
	6	4	0	0	1	
	sum	9	1	0	3	n.s.
3000	7	6	0	0	2	
	8	5	1	0	0	
	9	5	1	0	0	
	sum	16	2	0	2	*
5000	10	7	2	0	1	
	11	1	2	0	0	
	12	2	2	0	4	
	sum	10	6	0	4	n.s.
7500	13	8	0	0	0	
	15	4	1	0	1	
	sum	12	1	0	1	*

Tab. 12: Averages (calculated over the number of trials) of % PPM before and during sealscarer activity, and change in % at the single POD-positions of each distance and averaged over POD-positions at each distance. Sample sizes are given in brackets. Only trials were data could be analysed both before and during sealscarer activity are included. Averages including all three hour blocks are given in the appendix (Tab. 36).

Distance in m	POD-position	Average % PPM before sealscarer (n)	Average % PPM during sealscarer (n)	Change in %
0	16	2.62 (9)	0.12 (9)	-95.42
	average	2.62 (9)	0.12 (9)	-95.42
750	1	2.22 (9)	1.05 (9)	-52.27
	2	6.78 (10)	0.33 (10)	-95.13
	3	2.57 (8)	0.35 (8)	-86.38
	average	4.01 (27)	0.58 (27)	-85.54
1500	4	0.67 (5)	0.00 (5)	-100.00
	5	5.00 (3)	4.82 (3)	-3.60
	6	2.67 (5)	0.00 (5)	-100.00
	average	2.44 (13)	1.11 (13)	-54.51
3000	7	2.85 (8)	0.69 (8)	-75.61
	8	27.13 (6)	7.22 (6)	-73.39
	9	2.87 (6)	0.19 (6)	-93.38
	average	10.14 (20)	2.50 (20)	-75.35
5000	10	1.11 (10)	1.22 (10)	+9.91
	11	0.55 (3)	0.55 (3)	0.00
	12	0.69 (8)	0.35 (8)	-60.76
	average	0.87 (21)	0.79 (21)	-9.20
7500	13	2.99 (8)	0.07 (8)	-97.66
	15	3.29 (6)	0.19 (6)	-94.25
	average	3.12 (14)	0.12 (14)	-96.15

Even though there was an obvious and significant reduction in porpoise activity during sealscarer deployment at the nearest distances, this was not a complete deterrence of all porpoises. At all distances occasional porpoise clicks were recorded by PODs during sealscarer activity. At the nearest distance at POD-position 16 this was the case only during the first trial (Fig. 29), when porpoise clicks were recorded during two minutes. This accounts for about 0.13 % of all min, during which the POD recorded data at this position during sealscarer activity (Tab. 34 in appendix). During seven out of ten trials porpoise clicks were recorded by at least one of the PODs deployed at 750 m distance (four times at position 1, three times at position 2 and once at position 3, Fig. 29). This amounts to 0.56 % of total recording time during sealscarer activity. The longest duration, when porpoises were recorded during sealscarer activity at 750 m distance was 9 min (at position 1 during trial 9). In 1500 m distance porpoise clicks were recorded five times during four different trials: Twice at position 5 and three times at position 7. The longest time that porpoise clicks were recorded during sealscarer activity at this distance was 20 min at position 5 during the first trial. These five porpoise recordings during sealscarer activity in combination with only low baseline activity lead to a non-significant sealscarer effect at 1500 m distance.

The proportion of porpoise-positive-three-hours (% PP3H) before and during sealscarer activity are shown in Fig. 31 for single POD-positions (a) and averaged over position at the different distance categories (b). Similarly to the analyses on the basis of minutes one can also see a clear decrease in % PP3H during sealscarer activity as compared to the time before. However, the decrease here is substantially less clear at 3 km distance than what was found on the minute-basis. This is due to porpoises being present relatively often at position 8, even when the sealscarer was active, but spending less time there during sealscarer activity than before sealscarer activity (Fig. 29, Fig. 31b). Activity generally decreased at that distance also, but in five out of six cases porpoises were still present during sealscarer activity.

To summarise, a clear decline in porpoise activity appeared in both parameters (% PPM and % PP3H) during sealscarer activity. The magnitude of this decline varied between the two parameters (Tab. 13) and highly depended on how high porpoise activity was during the baseline.

Tab. 13: Proportional reduction by which porpoise activity was reduced during sealscarer activity when compared to the time before at the different distances, calculated over the sums for PP3H and PPM.

Distance in m	POD-position	% change in PP3H	% change in PPM
0	16	-83	-95
750	1-3	-69	-86
1500	4-6	-80	-55
3000	7-9	-50	-75
5000	10-12	-50	-9
7500	13, 15	-72	-96

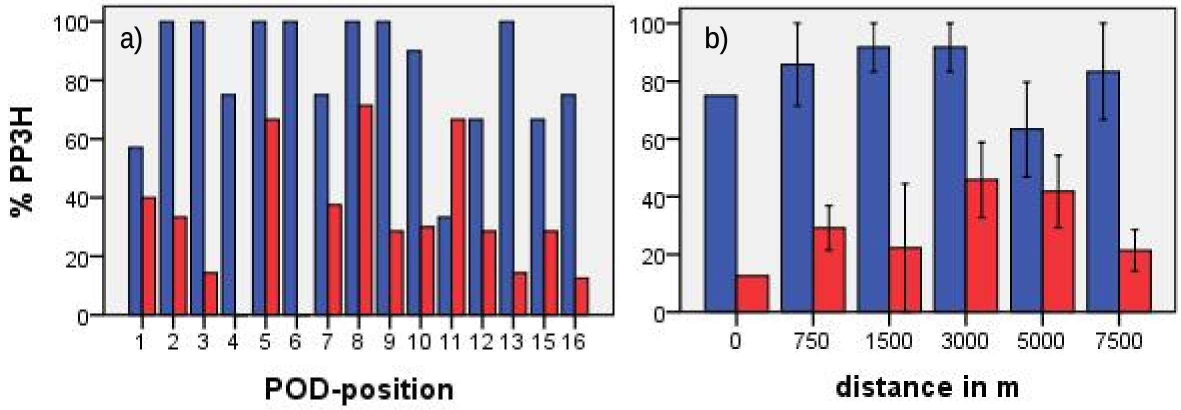

Fig. 31a-b: Proportion of porpoise-positive-three-hours (PP3H) before (blue bars) and during (red bars) sealscarer activity at the single POD-positions (a) and averaged over POD-positions for the six distance categories (b). Averages are calculated over POD-position and error bars show ± 1 SE (b). Included are only fully covered three-hour-blocks.

When looking at the different three-hour-blocks after sealscarer activity it seems that there is a gradual recovery in porpoise activity (Fig. 32). At some distances significant differences to the baseline were found up until the second 3-h-block (4-6 hours afterwards). In the third three-hour-block there were no longer any statistically significant difference in porpoise activity to that before the sealscarer was activated (Tab. 14). Here it has to be considered that sample size at position 16 (n=6) was relatively small, which complicates the detection of significant effects. However, looking at the data also gives the impression that porpoise activity had probably completely recovered within the third 3-h-block after sealscarer activity (Fig. 32).

Tab. 14: Results from Wilcoxon test, to check whether porpoise activity in the 3-hour-blocks during and after sealscarer activity are significantly different from the 3-h-block before sealscarer activity at the different distances (-1: 3-h-Block before sealscarer (1-4 h before start), 0: 3-h-block during sealscarer, 1: first 3-h-block after sealscarer, 2: second 3-h-block after sealscarer, 3: third 3-h-block after sealscarer; n.s.: p>0.05, *: p≤0.05, **: p≤0.01).

Distances	-1 to 0	-1 to 1	-1 to 2	-1 to 3
0	*	n.s.	n.s.	n.s.
750	**	*	*	n.s.
1500	n.s.	n.s.	*	n.s.
3000	**	*	n.s.	n.s.
5000	n.s.	n.s.	*	n.s.
7000	**	*	n.s.	n.s.

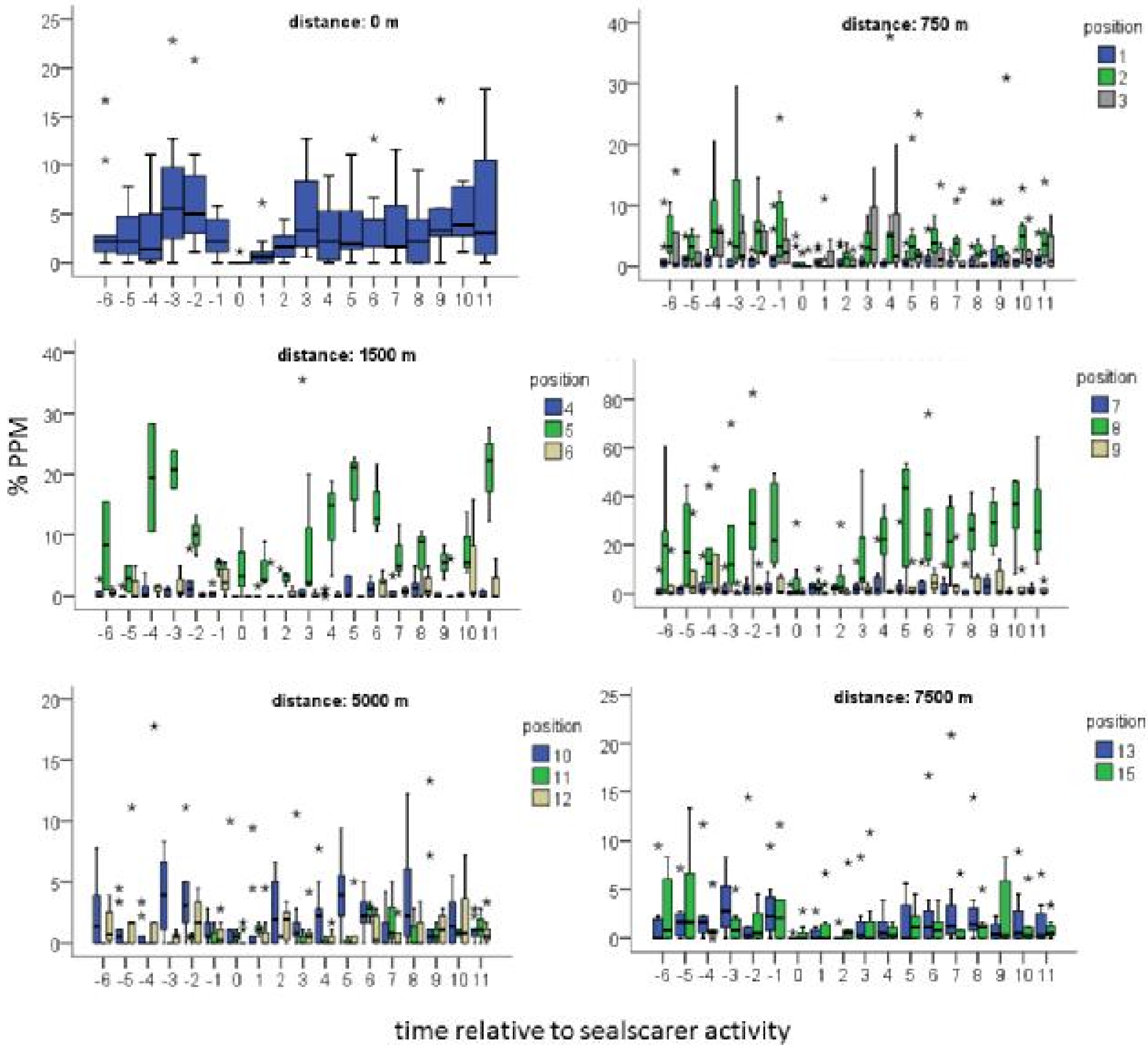

Fig. 32 : Proportion of porpoise positive minutes (% PPM) during three-hour-blocks before during and after sealscarer activity (-3: 8-10 h before, -2: 5-7 h before, -1: 4-2 h before, 0: 3 h during, 1: 1-3 h after, 2: 4-6 h after, 3: 7-9 h after, etc..) at the different distances shown separately for each POD-position.

5.2.2. Aerial surveys

Aerial surveys for harbour porpoise density could be completed before and during sealscarer activity on the 10.08.2009. The first survey took place between 07:09 and 09:24 UTC. The sealscarer was activated from 09:24 to 13:24 UTC. The second flight was conducted from 11:14 to 13:27 UTC. Both surveys started in the south of the study area. During the first flight before the sealscarer was activated, eleven transects could be covered by only one observer (one-sided effort) because of too much sun reflection at the other side. One transect could be covered by observers at both sides (two-sided effort). During the second flight when the sealscarer was active, one transect could be covered with both-sided effort, ten with one-sided effort and one transect could not be covered at all, as sighting conditions were too bad due to strong sun reflection (Fig. 33a-b). This amounts to a total survey effort of 391.6 km during the first and 361.3 km during the second flight that could be analysed (Tab. 15).

The resighting rate was 0.65, and the probability of porpoises being present in the top 2 m water layer according to data by Teilmann (2000) is 0.52. This gives a g(0) value of 0.34, which was used for analysing porpoise densities in this study.

The aerial survey before sealscarer activity revealed a harbour porpoise density of 2.42 harbour porpoises/km² calculated over the entire area (Tab. 15). Calculated as an average over the 12 transects, one gets a density estimate of 2.38±1.92 harbour porpoises/km². The second survey revealed a total density of 0.25 harbour porpoises/km² (Tab. 15). Averaged over the 12 transects this yields 0.28±0.39 harbour porpoises/km². Densities during the two separate surveys were significantly different, both when calculating a Wilcoxon test for two dependent samples ($Z= -2.85$, $n= 11$, $p< 0.01$) and when calculating a Mann Whitney U-test for two independent samples ($Z_{12,11}= -3.31$, $p< 0.01$). The first test has the advantage that the same transects can directly be compared between the two surveys, but has the disadvantage that the one transect, which could only be covered during the first survey has to be excluded from analyses. With the second test all transects can be included in the analyses, but it has the disadvantage that it cannot take data dependency (and thus location of the transects) into account and therefore has less power.

Apart from transect 2, porpoise density was less at all transects during the second survey, when the sealscarer was active, than during the first survey before sealscarer activity (Tab. 15). At transect 2 there was a higher porpoise density probably due to less survey effort during the second flight; there was one observation of a porpoise at this transect during both surveys (Tab. 15).

A total of 38 harbour porpoises were sighted during the first survey before the sealscarer was active (Tab. 15). Of these, seven were located within a 7.5 km radius of the sealscarer, where PODs were deployed (Fig. 33a). Of the 38 porpoises observed, two were calves. The shortest distance at which a harbour porpoise was seen from the not activated sealscarer was 2.5 km (Fig. 33a). During the second survey after the sealscarer was switched on, only a total of four harbour porpoises were seen in the entire study area, of which only one was located within the 7.5 km radius of the now active sealscarer (Fig. 33b). No porpoise calves were observed during this survey (Fig. 33b). The shortest distance of a porpoise sighting to the active sealscarer was 6.3 km.

During the first survey, highest porpoise density was found in the southern part of the survey area (Fig. 33a, Tab. 15). The two calves were sighted in the south eastern part within the Natura 2000 area (Fig. 33a). During the second survey such a concentration of porpoises could no longer be confirmed. Densities were now low in the entire survey area. Two porpoises were observed in the northern half and two in the southern half of the study area (Fig. 33b, Tab. 15).

An additional aerial survey was conducted on the 14.8.2010. Here only four harbour porpoises were sighted by the two main observers in the front and there was only one re-sighting by the third observer in the back. This made it impossible to calculate a meaningful g(0)-estimate to determine porpoise density. Furthermore, such low density provides only very limited power to actually test for a reduction in porpoise numbers during sealscarer activity. Because of these reasons, we decided not to complete a second survey with the sealscarer active during that day and save finances for better future opportunities. Unfortunately, there was no possibility to conduct another aerial survey during a following sealscarer trial, because either weather conditions were too bad or no plane was available.

Tab. 15: Porpoise density during the two survey flights on the 10.08.2009 before and during sealscarer deployment calculated for single transects and the whole surveys. Transects are numbered from north to south. Transect 1 could only be covered during the first flight but not the second.

Survey	Transect	Number of porpoise sightings	Effort (m)	ESW (m)	g(0)	Porpoises/km²
before	1	1	30140	128	0.34	0.76
before	2	1	60140	128	0.34	0.38
before	3	2	29950	128	0.34	1.53
before	4	1	30060	128	0.34	0.76
before	5	1	30240	128	0.34	0.76
before	6	1	29990	128	0.34	0.77
before	7	3	30180	128	0.34	2.28
before	8	3	30210	128	0.34	2.28
before	9	8	30170	128	0.34	6.09
before	10	6	29980	128	0.34	4.60
before	11	6	30180	128	0.34	4.57
before	12	5	30310	128	0.34	3.79
before	total	38	391550	128	0.34	2.42
sealscarer	1		0			
sealscarer	2	1	30090	128	0.34	0.76
sealscarer	3	1	30100	128	0.34	0.76
sealscarer	4	0	30090	128	0.34	0.00
sealscarer	5	0	30120	128	0.34	0.00
sealscarer	6	0	30160	128	0.34	0.00
sealscarer	7	0	30110	128	0.34	0.00
sealscarer	8	1	30040	128	0.34	0.76
sealscarer	9	1	30070	128	0.34	0.76
sealscarer	10	0	59980	128	0.34	0.00
sealscarer	11	0	30220	128	0.34	0.00
sealscarer	12	0	30310	128	0.34	0.00
sealscarer	total	4	361290	128	0.34	0.25

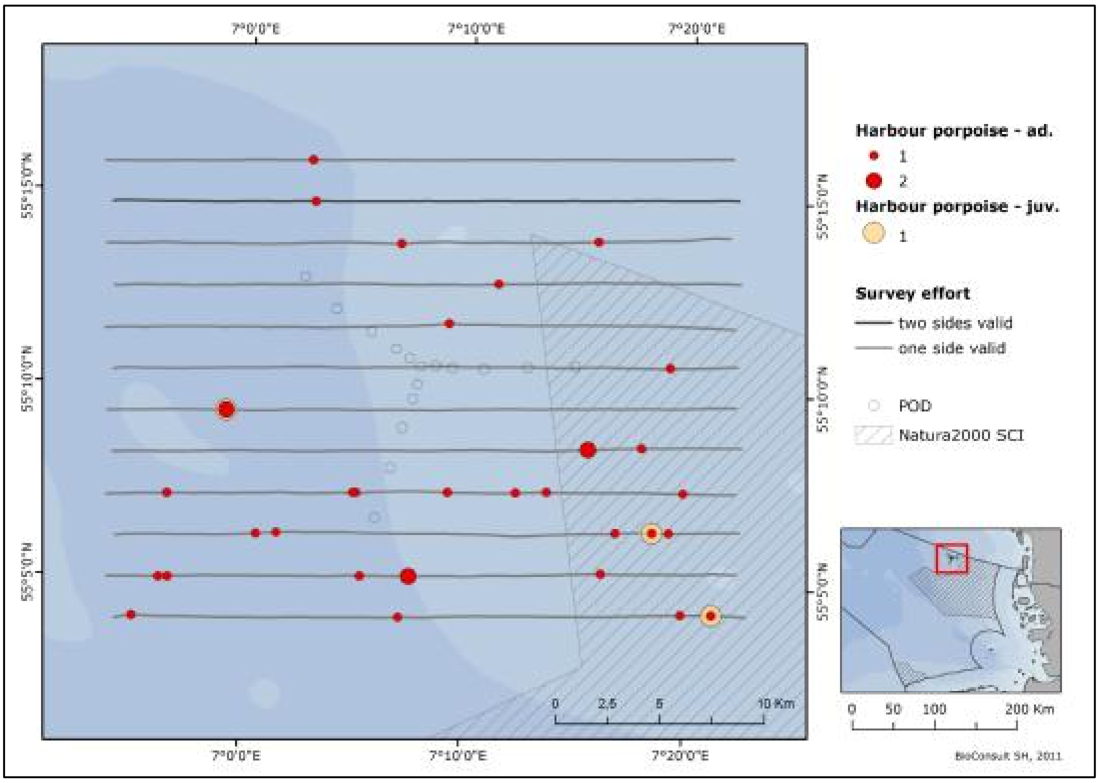

Fig. 33a: Harbour porpoise sightings and survey effort during the aerial survey on the 10.08.2009 before sealscarer deployment.

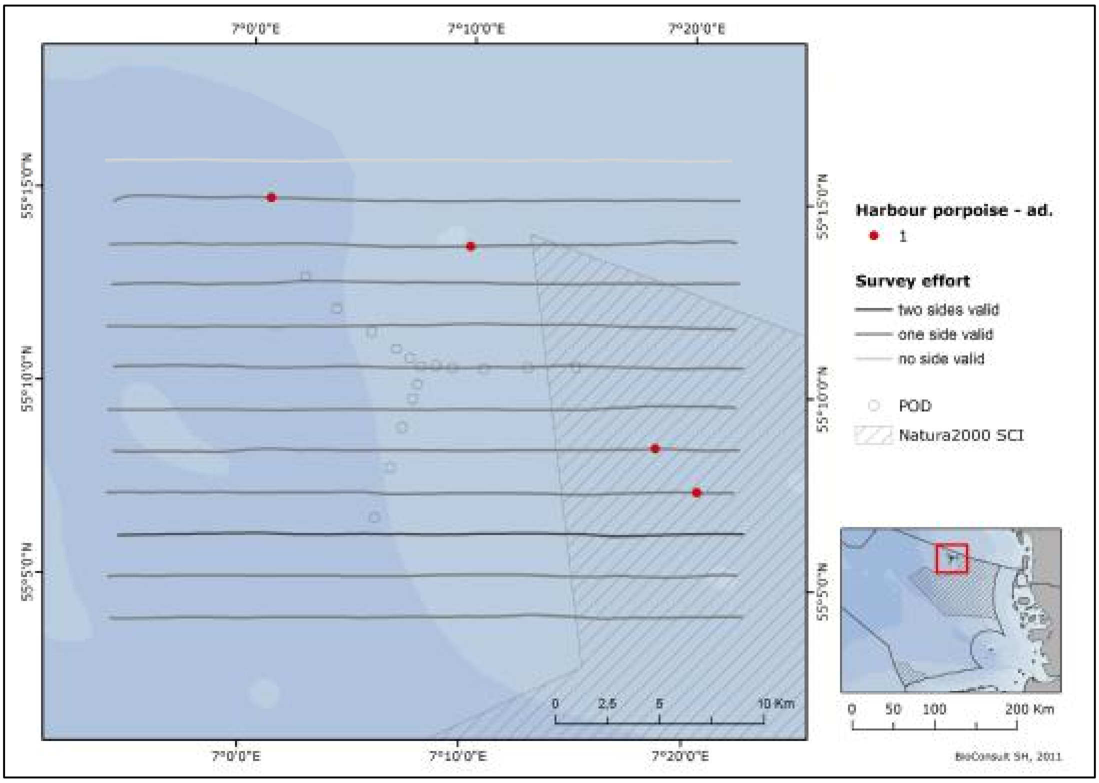

Fig. 33b: Harbour porpoise sightings and survey effort during the aerial survey on the 10.08.2009 during sealscarer deployment.

5.3. Study in the Danish Baltic Sea

5.3.1. POD-data

5.3.1.1. Spatial and temporal habitat use

As can be seen in Fig. 43 the seasonal pattern in harbour porpoise activity was very similar at the three different POD-positions: PPM/day fluctuated between 5 % and 20 % at the beginning of the study period in May and Jun. It then markedly decreased until reaching minimal values between only 2 % and 10 % between the end of Jul and the beginning of Aug. It then again increased until reaching maximal values towards the end of the study period in Sep. During the first half of the study period, porpoise activity was highest at position west, the one furthest from the coast (about 700 m). However, in September this changed and most times there was more activity at positions north and south (both about 250 m from the coast). Median values for each position are given in Tab. 16.

Tab. 16: Median, average, min and max values for PP10M/day at the four different POD-positions at Fyns Hoved.

POD-position	Median % PP10M/ day	Average % PPM/day	Min. - max. % PPM/day	N days
North	7.64	9.97	0-38.89	138
South	6.60	9.50	0-45.41	134
West	10.07	11.01	0.69-32.64	134
Anchor	9.72	11.66	0.69-40.97	63
Total	*8.68*	*10.54*	*0.35.-39.41*	*469*

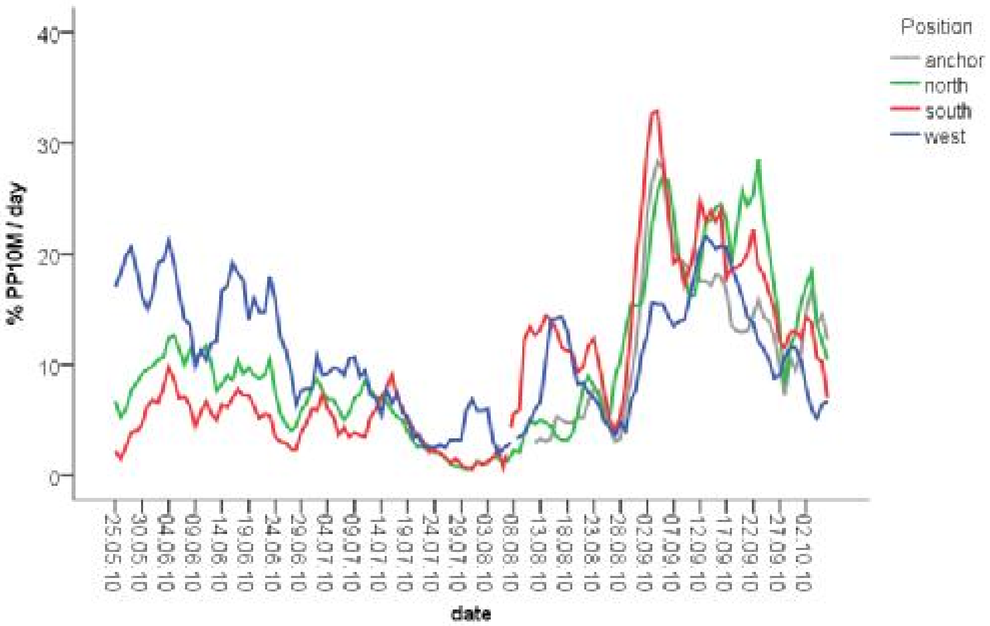

Fig. 34: Seasonal pattern of harbour porpoise activity (moving averages over the last 5 days) as recorded by C-PODs in porpoise positive ten minutes per day, with the four different POD-positions shown in different colours.

5.3.1.2. Sealscarer effects

PPM/4 h significantly differed when comparing the time before, during and after sealscarer activity at all three POD-positions (Friedmann test, Chi^2= 8.22, p=0.016, n=11; Fig. 35, Tab. 17-Tab. 18). We therefore proceeded by pairwise comparing the time blocks before sealscarer activity with during and before with after. It turned out that porpoise activity significantly declined during sealscarer activity at all three POD-positions from an overall median of 0.83 PPM/ 4 h before the start of the sealscarer to 0 PPM/4 h during sealscarer activity (Wilcoxon, Z=2.207, p=0.27, n=11; Tab. 18). Porpoise activity remained at an overall median of 0 PPM/4 h during the 4 hours following the time when the sealscarer was active, which was also still significantly different from the time before (Wilcoxon, Z=2.106, p=0.35, n=11). Porpoise activity was still significantly lower during 5-8 hours afterwards (Wilcoxon, Z=2.060, p=0.039, n=11). However, this was only caused by less porpoise activity at position west, while 9-12 hours afterwards porpoise activity did no longer significantly differ from before (Wilcoxon, Z=1.620, p=0.105, n=11; Fig. 36). The values for each trial and a longer time period before and after sealscarer activity are shown in Fig. 36.

While the sealscarer was active, not a single porpoise click was recorded at any of the three POD-positions, during the four trials when data could be recorded by PODs (a total of 15 hours where at least one of the PODs yielded analysable data and a total of 35 analysable POD-hours). After the sealscarer was switched off it took on average 131 min until the first harbour porpoise was again recorded (Tab. 19).

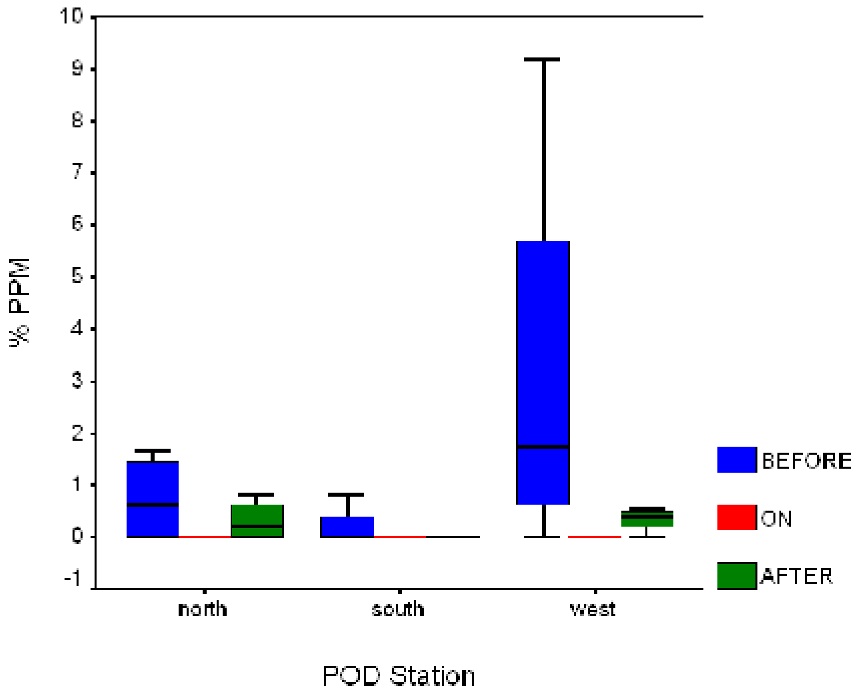

Fig. 35: Boxplot showing the % PPM per four hours for the seven trials during the four hours before (blue bars), during (red bars) and after (green bars) the sealscarer was active for the three different POD-positions.

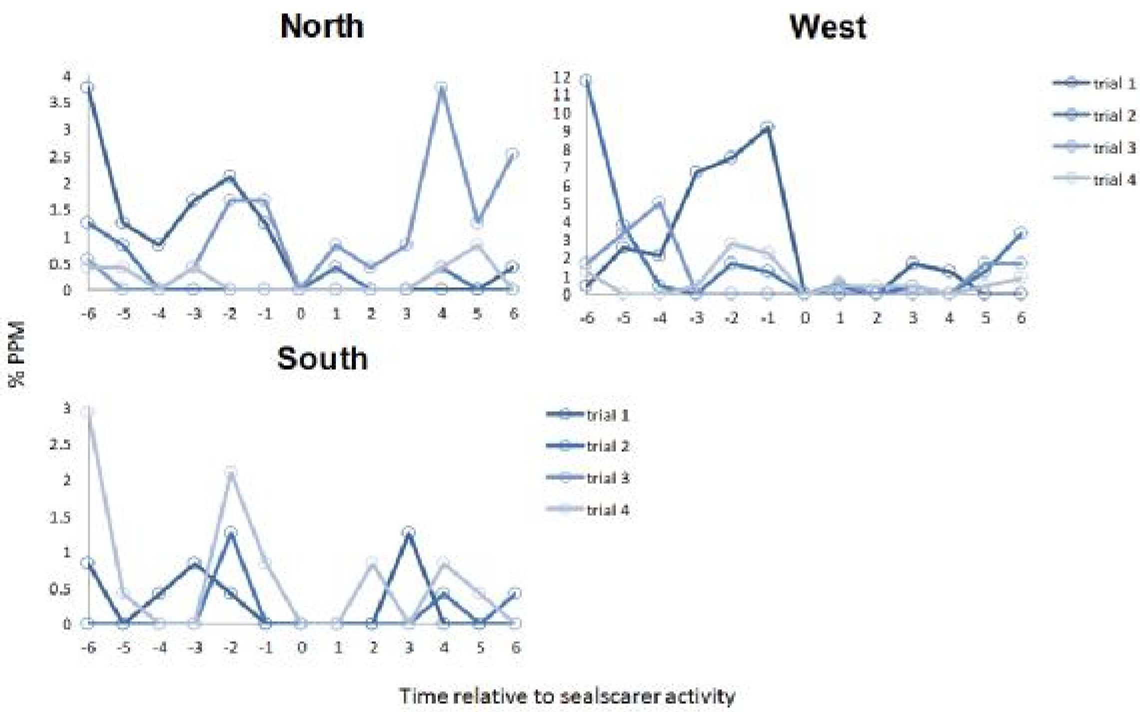

Fig. 36: Harbour porpoise activity in % PPM during the four-hour-blocks before (-6 to -1), during (0) and after (1 to 6) sealscarer activity at the three different POD-positions (north, west and south). Different trials are shown in different colours.

Tab. 17: Averages ± standard deviation of PPM during the 4 hours before, during and after sealscarer activity and sample size. Also given is the average over all values in the lowest row.

POD-position	Average ± SD % PPM / 4 h before sealscarer	Average ± SD % PPM / 4 h during sealscarer	Average ± SD % PPM / 4 h after sealscarer	N
North	0.73 ±0.86	0±0	0.31±3.40	4
South	0.21±0.42	0±0	0.00±0.00	3
West	3.16±4.1	0±0	0.34±0.24	4
overall	3.67±2.58(	0±0 (	0.22±0.29	11

Tab. 18: Median values of PPM during the 4 hours before, during and after sealscarer activity and sample size. Also given is the average over all values in the lowest row.

POD-position	Median % PPM / 4 h before	Median % PPM / 4 h during	Median % PPM / 4 h after	N
North	0.63	0	0.2	4
South	0	0	0	3
West	1.74	0	0.42	4
overall	0.83	0	0	11

Tab. 19: Duration in min that it took after the sealscarer was switched off until the first harbour porpoise click was again recorded at any of the three POD-positions, as well as the time of the last porpoise click until the sealscarer was switched on.

Trial number	min until first porpoise recording
1	136 (West)
2	211(North)
3	104(West)
4	73(West)
Average (± SD)	131±59.21

5.3.2. Visual observations

5.3.2.1. Parameters influencing sighting rates

Neither day ($F=0.29$, $df=1$, $p=0.59$) nor day² ($F=0.43$, $df=1$, $p=0.51$) had a significant effect on harbour porpoise sighting rate and were therefore removed from the final model. There was therefore no clear seasonal trend in the sighting data, and all days during which observations were carried out were relatively good comparable. Results from the final model, in which only significant parameters were retained, are shown in Tab. 20. Hour and hour² had a significant effect on sighting rate, indicating a slight quadratic relationships with sighting rates increasing during the morning hours and decreasing during the evening (Fig. 38a). Further, sea state had an effect on the sighting rate, in that according to expectations the sighting rate decreased with increasing sea state indicated by a significant negative linear relationship (Tab. 20). When plotted as a Boxplot, it becomes apparent that sighting rates were comparable at a sea state of 0 and 0.5 Bft but decreased at 1 and 1.5 Bft. Surprisingly the sighting rate was slightly higher again at 2 Bft (Fig. 38b).

Fig. 37: Harbour porpoise mother and calf pair swimming near one of the 450 m distance to sealscarer marker balls.

Tab. 20: Results of the GLM investigating the effects of time of day, date and sea state on the sighting rates of harbour porpoises (porpoise per scan). Only data from baseline days without sealscarer deployment are included in this model.

Dependent variable: sighting rate of harbour porpoises					
Parameter	B	Sum of Squares	F	df	p
Hour	0.64	29.07	14.47	1	<0.001
Hour²	-0.03	27.65	13.77	1	<0.001
Sea state	-0.49	20.30	10.11	1	<0.01
Residuals		769.26		386	

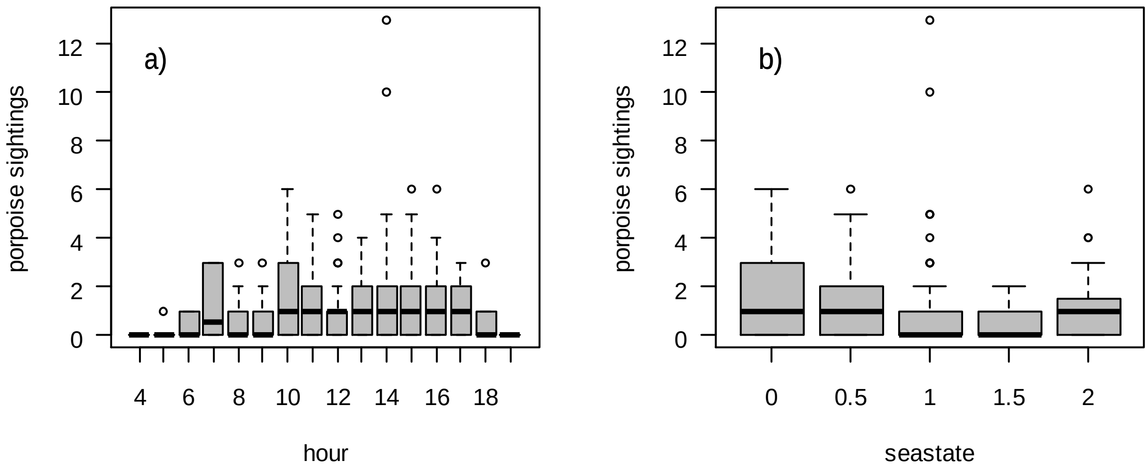

Fig. 38: Boxplots showing the number of harbour porpoises seen during scans in relation to a) time of day and b) sea state. Only data from days without active sealscarer are included.

5.3.2.2. Sealscarer effects

When the final model defined above was run including the data collected during days when the sealscarer was active (but excluding the hours after the sealscarer was again switched off) and “sealscarer” was included as a factor, all four parameters from above still had a significant effect on the sighting rate of harbour porpoises (Tab. 21). However, “sealscarer” explained most of the variance in the data, as seen from the F-value and the sum of squares-value for this parameter, which were by far the highest (Tab. 21). This was the case when the model was run for all distances pooled and when run for each distance separately (Tab. 21). As can be seen in Fig. 39, sighting rates were significantly lower when the sealscarer was active as compared to when it was not active at all distance categories.

Tab. 21: Results from a GLM testing the effect of the sealscarer on the sighting rates of harbour porpoises for the three different distance categories and for all distances combined. All data apart from the hours after the sealscarer was active are included.

Dependent variable: sighting rate of harbour porpoises (porpoises / scan) at 0-150 m distance					
Parameter	B	Sum of Squares	F	df	p
Hour	-7.51	4.24	2.96	1	0.09
Hour²	0.86	3.20	2.23	1	0.14
Sea state	-0.03	11.96	8.35	1	<0.01
Sealscarer	-1.42	26.20	18.28	1	<0.001
Residuals		921.66		643	
Dependent variable: sighting rate of harbour porpoises (porpoises / scan) at 151-450 m distance					
Parameter	B	Sum of Squares	F	df	p
Hour	-3.60	5.69	4.04	1	<0.05
Hour²	0.42	3.15	2.24	1	0.14
Sea state	-0.01	19.40	13.78	1	<0.001
Sealscarer	-0.75	117.63	83.58	1	<0.001
Residuals				643	
Dependent variable: sighting rate of harbour porpoises (porpoises / scan) at 451-1000 m distance					
Parameter	B	Sum of Squares	F	df	p
Hour	-3.11	22.20	11.22	1	<0.001
Hour²	0.59	25.36	12.82	1	<0.001
Sea state	-0.02	6.21	3.14	1	0.08
Sealscarer	-0.26	202.90	102.53	1	<0.001
Residuals	-4.23	1272.49		643	
Dependent variable: sighting rate of harbour porpoises (porpoises / scan) at all distances (0-1000 m)					
Parameter	B	Sum of Squares	F	df	p
Hour	0.44	21.62	12.99	1	<0.001
Hour²	-0.02	19.87	11.95	1	<0.001
Sea state	-0.45	26.17	15.73	1	<0.001
Sealscarer	-4.72	342.22	205.71	1	<0.001
Residuals		1069.69		643	

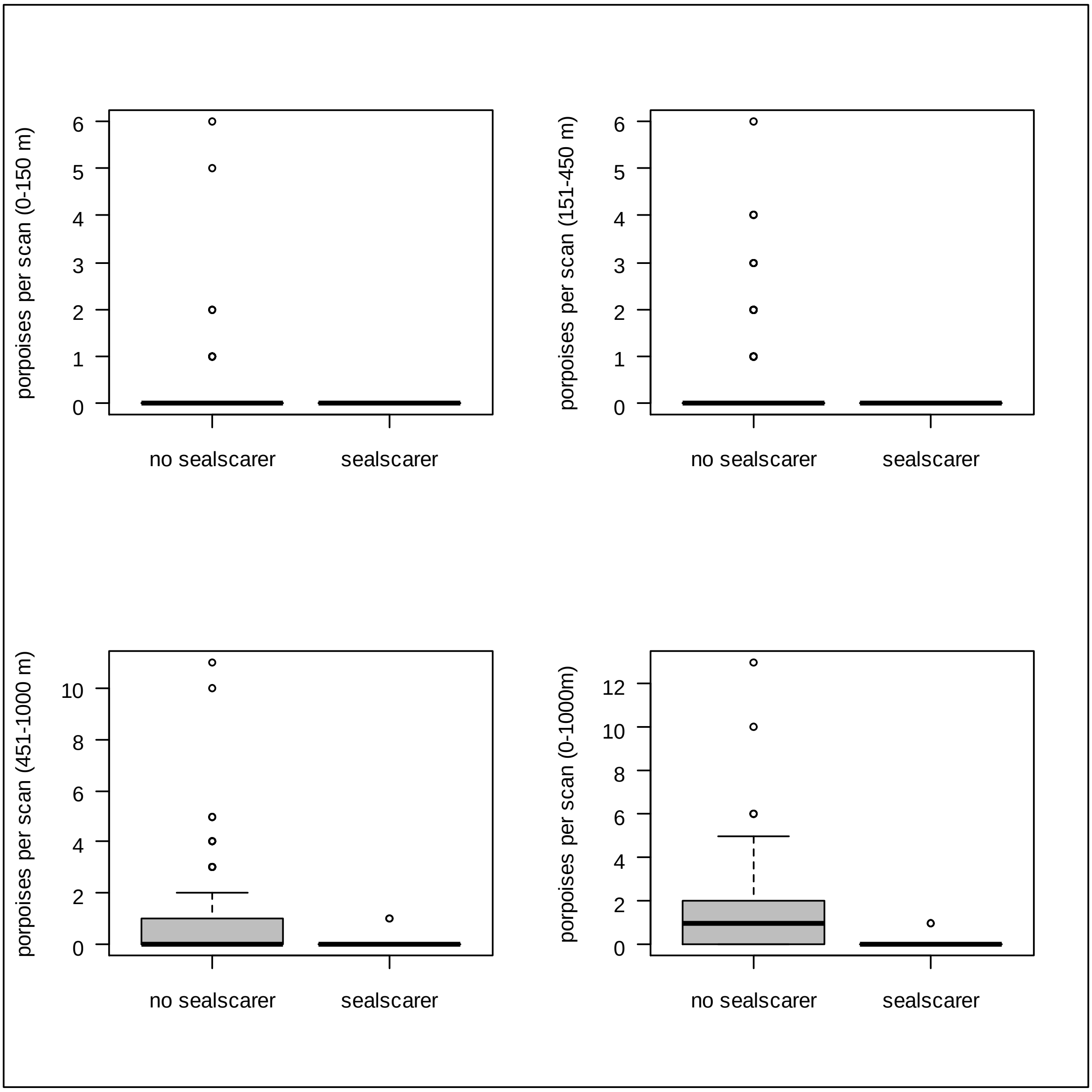

Fig. 39: Boxplots showing the number of harbour porpoises seen during scans when the sealscarer was active and when it was not active for the three distance categories and for all distances combined. Data from times after sealscarer activity are excluded.

We then compared the times before, during and after the sealscarer was active only including data from the days when a sealscarer experiment took place. We re-ran the same model from above including only these data and added the sealscarer as a factor with three categories (before, during and after sealscarer activity). Again, the sealscarer was the most important factor determining sighting rates when all distances were combined and at all three distances, when checked separately (Tab. 22). Fig. 40 shows the sighting rates before, during and after sealscarer deployment for all distances combined. Here it can be seen that the significant effect of the sealscarer was mainly caused by reduced sighting rates during sealscarer activity as compared to before. The hours after sealscarer deployment (1-3 hours after) still showed lower sighting rates than before but already higher ones than during sealscarer activity.

Tab. 22: Results from a GLM testing the effect of "scaring phase" on the sighting rates of harbour porpoises for the three different distance categories and for all distances combined. Only data from days where the sealscarer was on are included.

Dependent variable: sighting rate of harbour porpoises (porpoises/scan) at 0-150 m distance					
Parameter	B	Sum of Squares	F	df	p
Hour	1.45	0.62	2.54	1	0.11
Hour²	-0.04	0.24	0.99	1	0.32
Sea state	-2.54	2.24	9.22	1	<0.01
Sealscarer		5.05	10.40	2	<0.001
Residuals		81.30		335	
Dependent variable: sighting rate of harbour porpoises (porpoises/scan) at 151-451 m distance					
Parameter	B	Sum of Squares	F	df	p
Hour	-0.28	0.79	1.14	1	0.29
Hour²	0.01	0.97	1.40	1	0.24
Sea state	-0.34	1.62	2.33	1	0.13
Sealscarer		48.46	34.86	2	<0.001
Residuals		232.87		335	
Dependent variable: sighting rate of harbour porpoises (porpoises/scan) at 451-1000 m distance					
Parameter	B	Sum of Squares	F	df	p
Hour	0.29	1.50	1.11	1	0.29
Hour²	-0.01	1.22	0.90	1	0.34
Sea state	-0.70	15.78	11.62	1	<0.001
Sealscarer		131.26	48.33	2	<0.001
Residuals		454.88		335	
Dependent variable: sighting rate of harbour porpoises (porpoises per scan) at 0-1000 m distance					
Parameter	B	Sum of Squares	F	df	p
Hour	0.11	0.32	0.26	1	0.61
Hour²	-0.00	0.14	0.12	1	0.73
Sea state	-0.60	17.06	13.79	1	<0.001
Sealscarer		181.75	73.50	2	<0.001
Residuals		414.19		335	

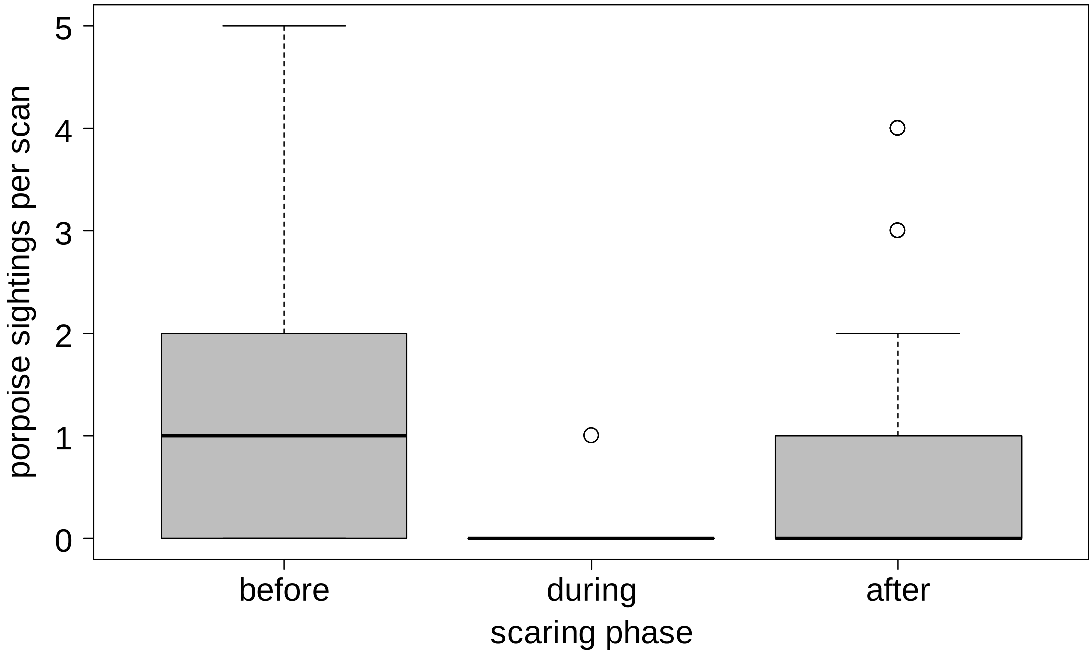

Fig. 40: Boxplots showing the number of harbour porpoises seen during scans before, during and after the sealscarer was active. Only data from trials with the sealscarer active are included.

In the models calculated above, we used the unit porpoise sightings per scan as the response variable. Significant effects of the parameter "sealscarer" confirmed a significant deterring effect on harbour porpoises. The number of harbour porpoises seen during each scan decreased from a mean of 0.86 porpoises/scan to a mean of 0.01 porpoises/scan. This is a decrease down to only 1.2 % of the normal sighting rate. However, this value may be relatively imprecise, because a sighting rate of 0.86 is already quite low, and the sighting rate within the closest distance category is even lower. To achieve a better indication of how porpoise activity within the study area decreased due to sealscarer deployment and to be able to study this separately for the three distance categories we pooled the sighting data for the four hours during which the sealscarer was active when an experiment was conducted (7 days) and compared them to four pooled hours during the days when no sealscarer experiment took place (9 days). Sighting rates were significantly lower when the sealscarer was active at all distance categories: 0-150 m (U-test, $Z_{7,9}$= -2.56, p<0.05), 151-450 m ($Z_{7,9}$= -3.17, p<0.001), 451-1000 m ($Z_{7,9}$= -3.39, p<0.001) and at all distances combined ($Z_{7,9}$= -3.39, p<0.001) (Fig. 41). Sighting rates declined from a mean of 2.1 porpoise sightings/4 hours to 0.0 porpoise sightings/4 h during the sealscarer experiment at 0-150 m distance, a decrease down to 0 %. A similar effect was found at 151-450 m distance, with sighting rates declining from a mean of 8.4 sightings/4 h to 0.0 sightings/4 h. At 451 – 1000 m distance there was a decrease from 20.4 sightings/4 h to 0.3 sightings/4 h, a decrease down to 1.5 %. Within the whole observation area with a radius of 1 km around the sealscarer location, sighting rates thus declined from a mean of 31 sightings/4 h to a mean of 0.3 sightings/4 h, a reduction down to 1.0 % (Tab. 23).

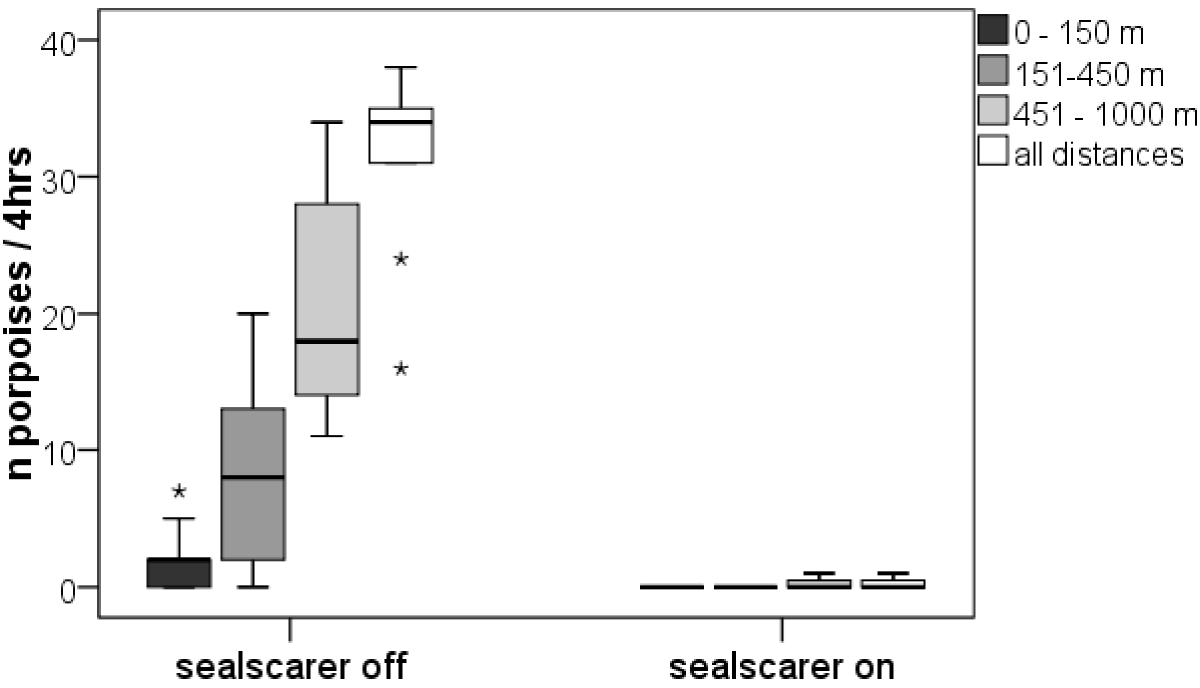

Fig. 41: Boxplots showing the sighting rates during days when the sealscarer was off and during days when the sealscarer was on at the different distance categories and for all distances combined. Note that an increase at the greater distances is simply due to the larger area within these radii, so a greater possibility for porpoises being present. Note that an increase at the greater distances is simply due to the larger area within these radii, so a greater possibility for porpoises being present.

Tab. 23: Mean (±SD) and median values of porpoise sightings/4 h during the first four hours at days when the sealscarer was inactive (n= 9) and the four hours at days when the sealscarer was active (n= 7).

Distance	Mean sighting rates ± SD with sealscarer off (n=9)	Mean sighting rates + SD with sealscarer on (n=7)	Median sighting rates with sealscarer off (n=9)	Median sighting rates with sealscarer on (n=7)
0-150 m	2.1 ± 2.4	0 ± 0	2	0
151-450 m	8.4 ± 6.7	0 ± 0	8	0
451-100 m	20.4 ± 8.5	0.3 ± 0.5	18	0
0-1000 m	31 ± 6.9	0.3 ± 0.5	34	0

During the seven trials when the sealscarer was active (28 h in total), two harbour porpoises were seen during standardised scans within the 1 km radius around the sealscarer. These were both at distances of about 1000 m, right on the edge of the observation area. One was seen 85 min after the sealscarer was switched on, the other one 21 min after sealscarer activation. One was only spotted once and could not be tracked. The other one could be observed over 15 min and tracked over 11 min (described in more detail in the next section) and showed a closest approach distance of

798 m. This was the closest distance to the sealscarer, at which a harbour porpoises was ever observed while the sealscarer was on. During one additional occasion one porpoise was seen between standardised scans at a distance of about 800 m 79 min after the sealscarer was switched on (same date as the one approaching to 798 m). At two additional occasions a porpoise was seen at distances above 1000 m: one time at a distance > 1000 m, not further specified 24 min after sealscarer activation and one time at an estimated distance (using the theodolite) of about 1800 m 10 min after sealscarer activation (Tab. 24). All these five animals were single adults. A calf was never observed while the sealscarer was active.

Tab. 24: All harbour porpoise sightings during the 28 hours while the sealscarer was active with date, time, group specifications, closest approach distance and time after sealscarer activation.

Date	Sighting time	Time of sealscarer activation	Time since sealscarer start	Group	Closest approach distance
23.06.10	16:50 (in scan)	15:24:50	85 min	1 ad	1000 m
24.06.10	10:30 (between scans)	10:06:05	24 min	1 ad	>1000m
27.07.10	10:15 (between scans)	10:04:30	10 min	1 ad	1800 m
01.08.10	11:35-11:50 (in scan)	10:56:00	21-54 min	1 ad	798 m
01.08.10	12:15 (between scans)	10:56:00	79 min	1 ad	800 m

Tab. 25: Shown are the mean (± SD) and median sighting rates of harbour porpoises per hour relative to the time of sealscarer activity. Hours 1-4 are the hours during which the sealscarer was active and are highlighted as bold.

Hour to scaring	Mean sighting rates ± SD	Median sighting rate	N
-2	5.5 ± 0.7	5.5	2
-1	4.5 ± 2.7	5.0	4
0	6.0 ± 3.7	5.0	7
1	0.15 ± 0.38	0.0	7
2	0.15 ± 0.38	0.0	7
3	0 ± 0	0.0	7
4	0 ± 0	0.0	7
5	2.2 ± 1.5	2.0	5
6	2.8 ± 1.7	2.5	4
7	16.5 ± 5.0	16.5	2

In Fig. 42 and Tab. 25 the sighting rates are shown per hour. Here it can be seen that during all seven trials the sighting rates of harbour porpoises dropped dramatically when the sealscarer was switched on. Apart from one trial, when only one animal was seen, there were at least four animals seen during the hour before the sealscarer was switched on during all other six trials. The mean sighting rate during this hour was 6.0. This rate dropped down to a mean of 0.15 animals per hour during the first two hours that the sealscarer was active (when 0-1 animals were seen) and to 0 during the third and fourth hour of sealscarer activity. Sighting rates quickly recovered in the three hours following sealscarer activity; however, sample size for this time period is only small.

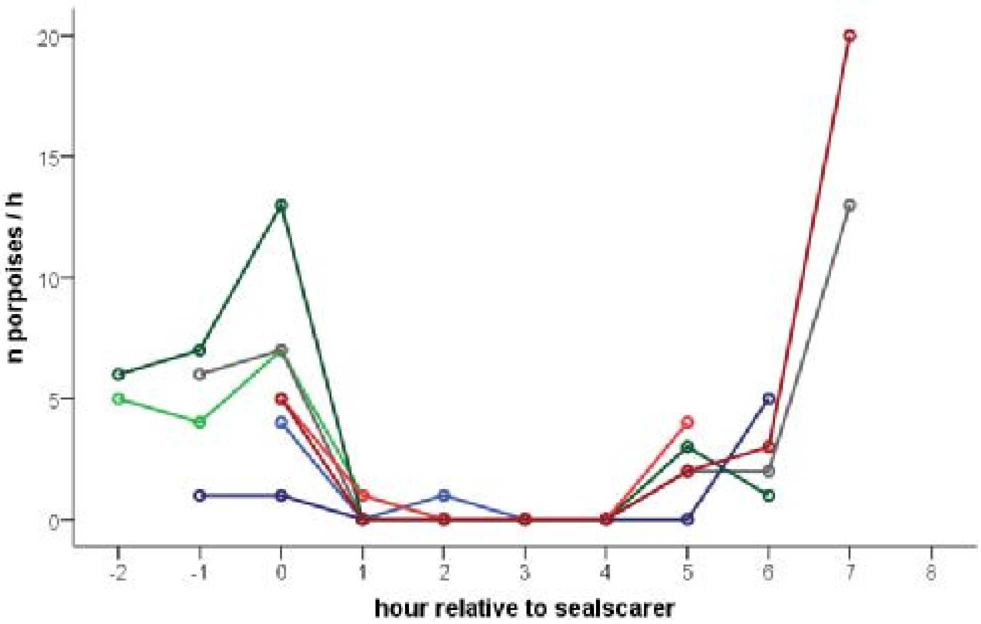

Fig. 42: Sighting rates (number of porpoises seen per hour) for the different dates, relative to the time of sealscarer deployment. The sealscarer was active during the hours 1-4. Different days are shown in different colours.

During five out of the seven days with sealscarer activity a harbour porpoise was seen later. This happened between 34 and 67 min after the sealscarer was switched off. During the first two days observations had to be terminated before a porpoise was seen again. At one time this was 84 min after the sealscarer was switched off, and no porpoise was seen again until then (Tab. 26).

Tab. 26: Number of min that elapsed from the time when the sealscarer was switched off until the first harbour porpoise was seen in the study area at the seven trials. At the first two days observations had to be terminated before the first porpoise sighting.

Date	Time since sealscarer until first porpoise sighting	
23.06.10	-	only observed until 35 min after sealscarer switched off
24.06.10	-	only observed until 84 min after sealscarer switched off
10.07.10	52 min	
17.07.10	57 min	
27.07.10	67 min	
01.08.10	34 min	
07.08.10	47 min	
mean	51 min	

5.3.3. Response study

During all seven trials when the sealscarer was activated for four continuous hours, we were able to track a harbour porpoise just before the sealscarer was switched on. The porpoise swam at distances between 300 and 700 m from the sealscarer when it was last seen before sealscarer activation. Contrary to our expectations in six out of these seven cases, we were not able to track the porpoise after the sealscarer was switched on because it immediately disappeared once the sealscarer was activated and not seen again within the 1 km radius that could easily be observed. This shows that there was an immediate reaction of porpoises to the sealscarer noise. Porpoises probably dove and covered a substantial distance of several hundred meters before resurfacing. Only in one instance (on the 01.08.10) the porpoise could be tracked at three more points after the sealscarer was switched on. Strikingly, this was also the only day, where we could later track a porpoise within the 1 km radius and when a porpoise was seen closer than 1 km to the sealscarer while it was active. The sevenx tracks we obtained immediately before the sealscarer was switched on are shown in Fig. 43. The dates and distances of the last point to the sealscarer are shown in Tab. 27.

Tab. 27: Date of the trial and time from last tracking point to when the sealscarer was switched on. Also given are the distances from the last tracking point to the sealscarer. Parameters are shown for the seven trials where porpoises were exposed to the sealscarer at distances below 1 km. Also given is a subjective description of the observed behavior as it was described in the field.

Date	Trial	Time from last point to sealscarer	Distance of last tracking point to the sealscarer	Subjective description of porpoises' reactions
23.06.10	on	55 s	415 m	reaction (disappeared)
24.06.10	on	5 s	692 m	reaction (disappeared)
10.07.10	on	37 s	684 m	reaction (disappeared)
17.07.10	on	27 s	417 m	reaction (disappeared)
27.07.10	on	23 s	299 m	reaction (disappeared)
01.08.10	B on		392 m before / 779m during	reaction (avoidance)
07.08.10	on	0 s	765 m	reaction (disappeared)

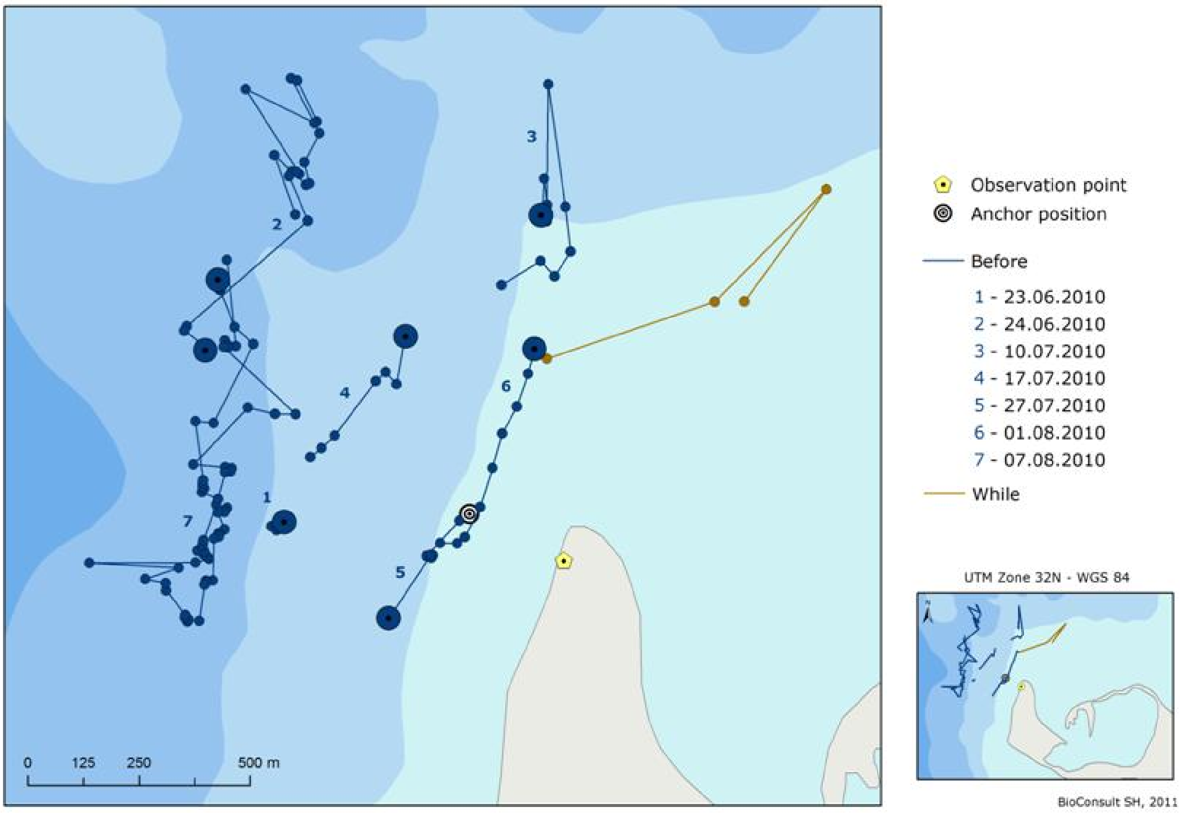

Fig. 43: Map showing the seven different porpoise tracks obtained just seconds before the sealscarer was activated, with the last point before the sealscarer was switched on enlarged. The porpoise of track 6 was located four more times while the sealscarer was on, obviously swimming away from it. The sealscarer was deployed at the central anchoring position, indicated by the black circles.

During four additional days we were able to obtain a total of 15 trials where porpoises could first be tracked without the influence of the sealscarer and consequently exposed to sealscarer noise at distances of between 1.1 and 3.3 km.

During one trial, when the porpoise was 1.1 km away from the sealscarer, the porpoise also immediately disappeared (Fig. 44), just like the six instances described above. During one trial (at a distance of 1.7 km), the porpoise resurfaced once and was then lost after sealscarer activation (Fig. 45). These two cases were also judged as immediate avoidance reactions. During four trials at 1.6, 1.9, 2.3 and 2.4 km distances the porpoises turned after the sealscarer was switched on and swam away from the sealscarer in a more direct movement than before (Fig. 46-Fig. 48and track J in Fig. 49). These cases were judged as avoidance reactions in the field. During the track seen at Fig. 46, two different porpoise groups were tracked before the start of the sealscarer, a mother and calf pair and a single adult porpoise. After the sealscarer was activated the three animals united and swam further away as one group.

In one case at a distance of 2.2 km, a mother calf pair continued to resurface for six times after the sealscarer was switched on but swam away from the sealscarer around the tip of the island in a more direct movement 1 min and 40 sec min after its activation (Fig. 50). Because of the time delay between sealscarer activation and porpoises swimming away from it, this case was difficult to judge as it is unclear whether the animals swam away after a delayed avoidance reaction or because of other reasons. We judged this as a possible avoidance reaction with a question mark. In two further cases, reactions were unclear to us in the field with porpoises continuing to resurface. One mother calf group disappeared shortly after sealscarer activation (at 2.0 km distance) but at the same time was approached by a small motorboat. Therefore, it was unclear if their disappearance was induced by the sealscarer or the approaching boat (track H in Fig. 49). This was also judged as a possible avoidance reaction. The other porpoise group could no longer be tracked after sealscarer activation (at 1.7 km distance) because they swam into an area with intense glare, where tracking was no longer feasible (track I in Fig. 49).

During six trials at distances of 2.1, 2.7, 3.0, 3.2, 3.2 and 3.3 km no clear avoidance reactions could be observed after the sealscarer was turned on (Fig. 51-Fig. 56). Instead the animals continued swimming around the same area without markedly increasing their distance to the sealscarer.

Fig. 57 shows a track that resembled both baseline track (when the sealscarer was not switched on) and a subsequently track with sealscarer on (after the skipper was told to activate it to gain a further trial when observers did not find the porpoise reacting during the blind trial). Here the porpoises first did not show any obvious avoidance reaction during the baseline track, but a clear avoidance reaction when the sealscarer was finally switched on: the porpoises turned around and swam further away in a direct movement. During three more baseline tracks, no obvious reaction of the porpoises was found (Fig. 58-Fig. 59).

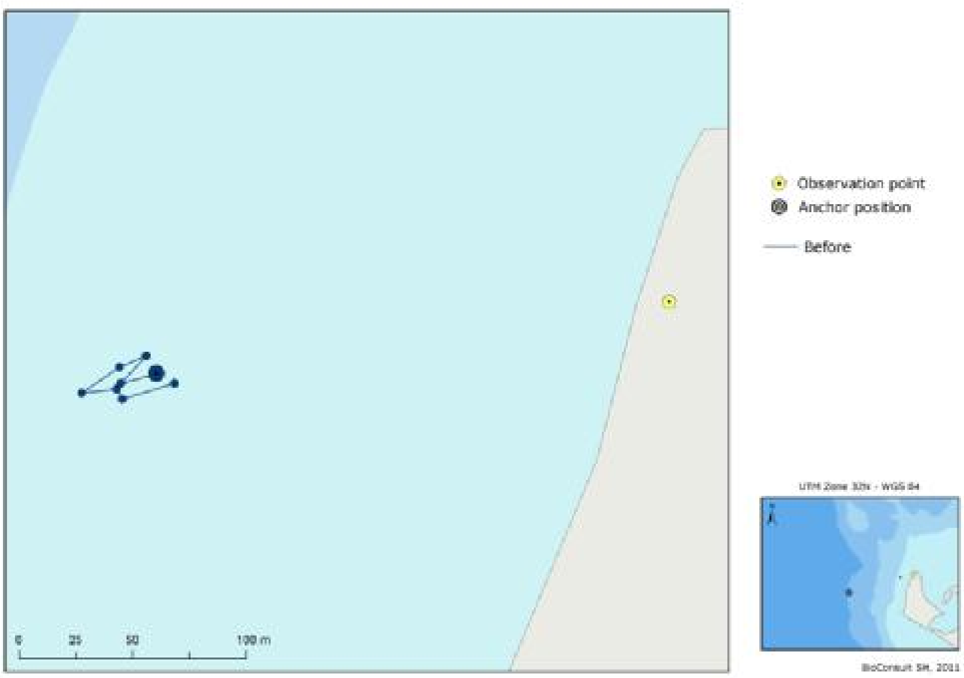

Fig. 44: Track B from 05.09.2010, when the sealscarer was deployed at a distance of 1.1 km (for position see insert map). The porpoise immediately disappeared when the sealscarer was switched on. The last tracking point before the sealscarer was switched on is enlarged.

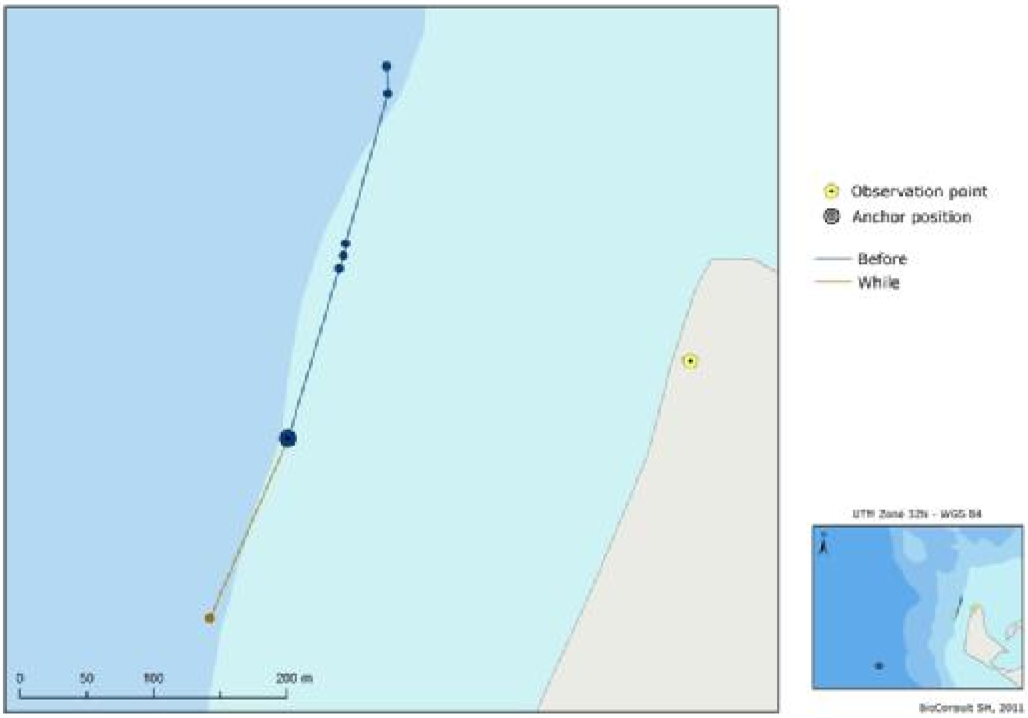

Fig. 45: Porpoise track F from 05.09.2010, when the sealscarer was deployed at a distance of 1.7 km (for position see insert map). The porpoise was only seen again once after the sealscarer was switched on. The last tracking point before the sealscarer was switched on is enlarged.

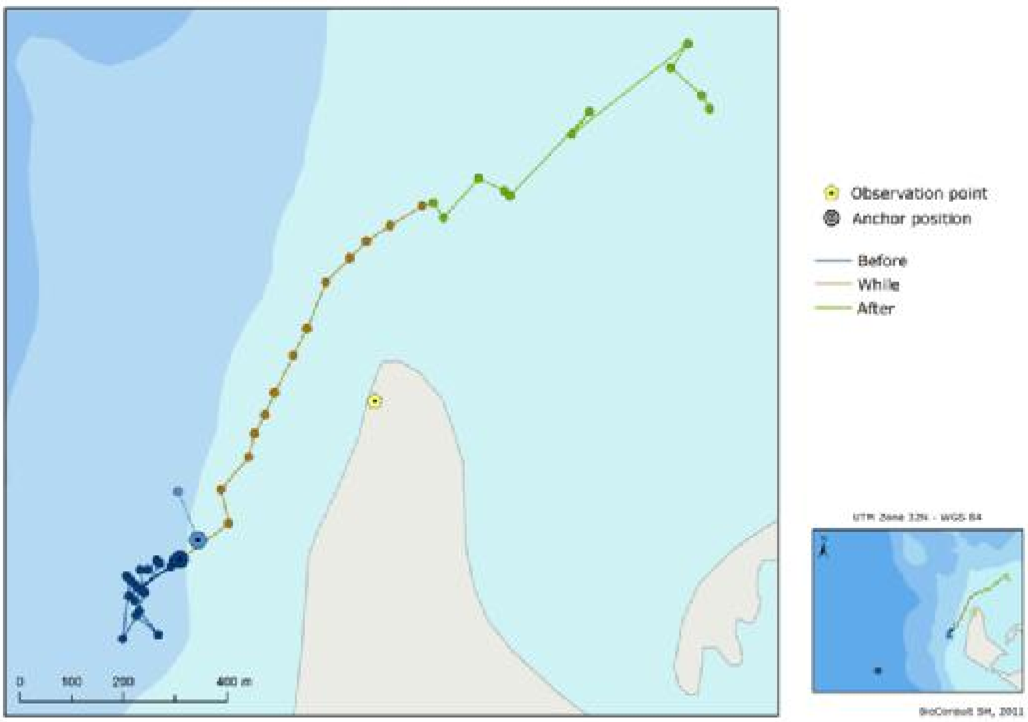

Fig. 46: Porpoise track A from 06.09.2010, when the sealscarer was deployed at 1.6 km distance (for position see insert map) and a clear avoidance reaction was observed. The last resurfacing point before the start of the sealscarer is enlarged. The two different shades of blue show two different porpoises, which then united and swam away together (brown and green points).

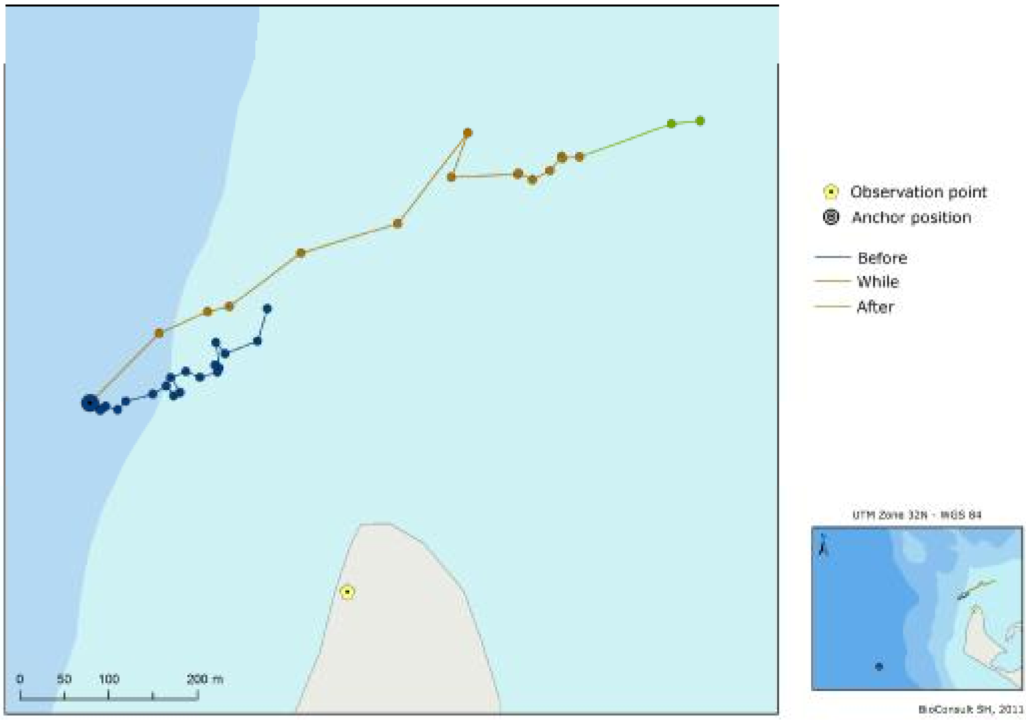

Fig. 47: Porpoise track B from 25.09.2010, when the sealscarer was deployed at 1.9 km distance (for position see inlet map) and a clear avoidance reaction was observed. The last resurfacing point before the start of the sealscarer is enlarged.

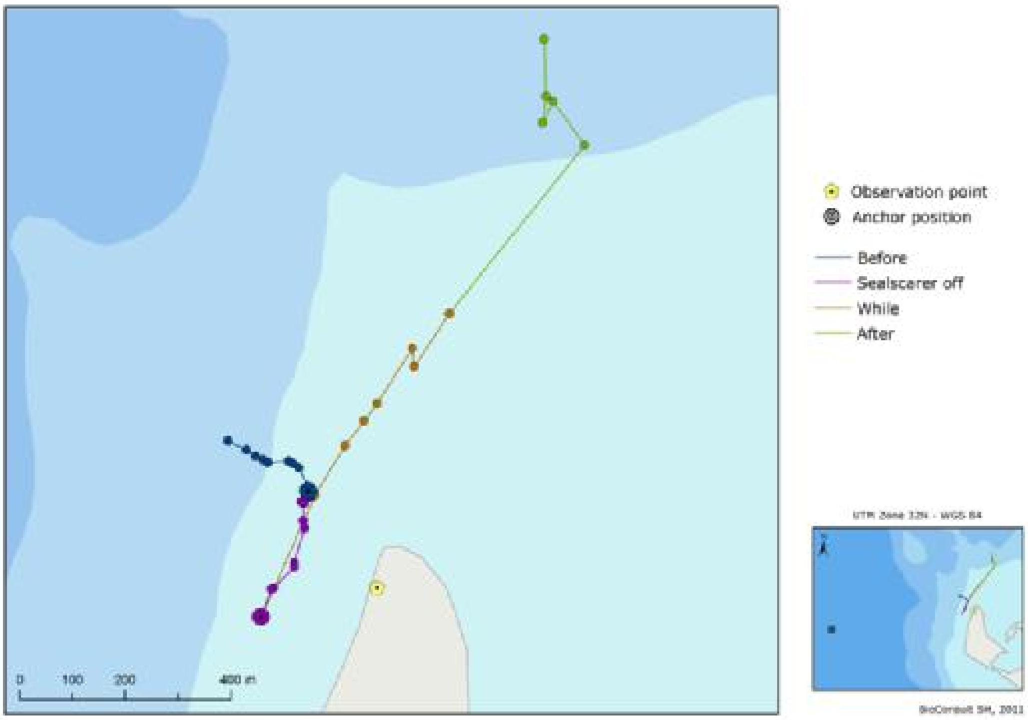

Fig. 48: Porpoise track E from 25.09.2010, when the sealscarer was deployed at 2.4 km distance (for position see inlet map) and a clear avoidance reaction was observed. The last resurfacing point before the start of the sealscarer is enlarged. This track resembled both baseline track (pink) and real sealscarer track (brown).

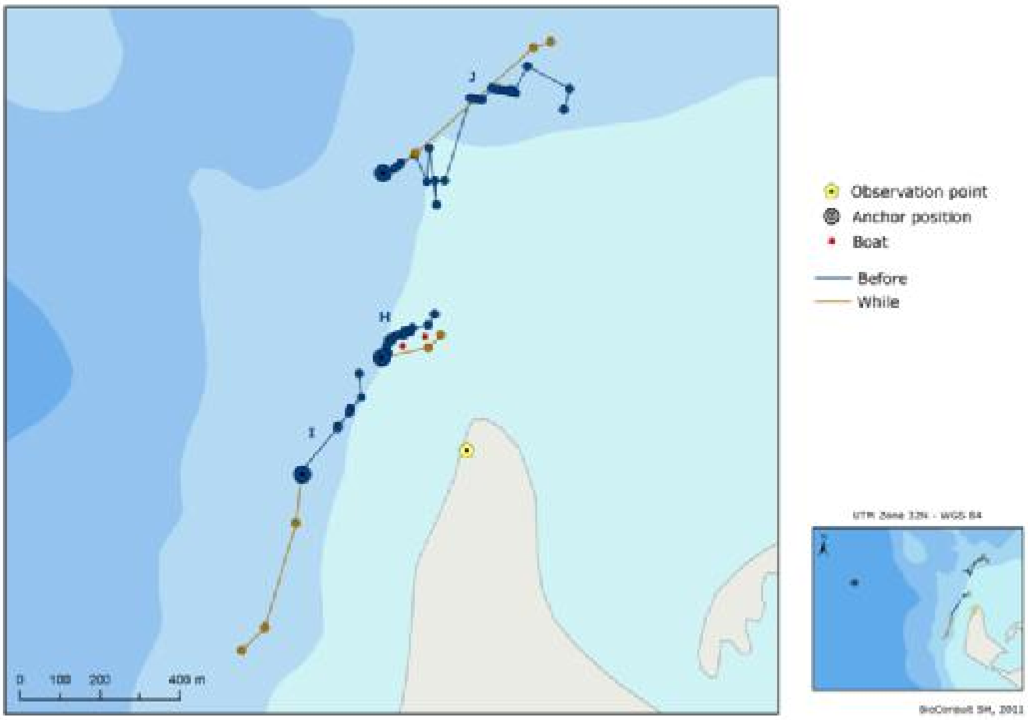

Fig. 49: Porpoise tracks H, I and J from 06.09.2010, when the sealscarer was deployed at distances of 1.7-2.3 km (for position see insert map). Reactions of H (boat interference shown as red dots) possibly resemble avoidance but were difficult to judge. Reactions of I were unclear, J showed a clear avoidance reaction (at 2.3 km). The last tracking points before the sealscarer was switched on are enlarged.

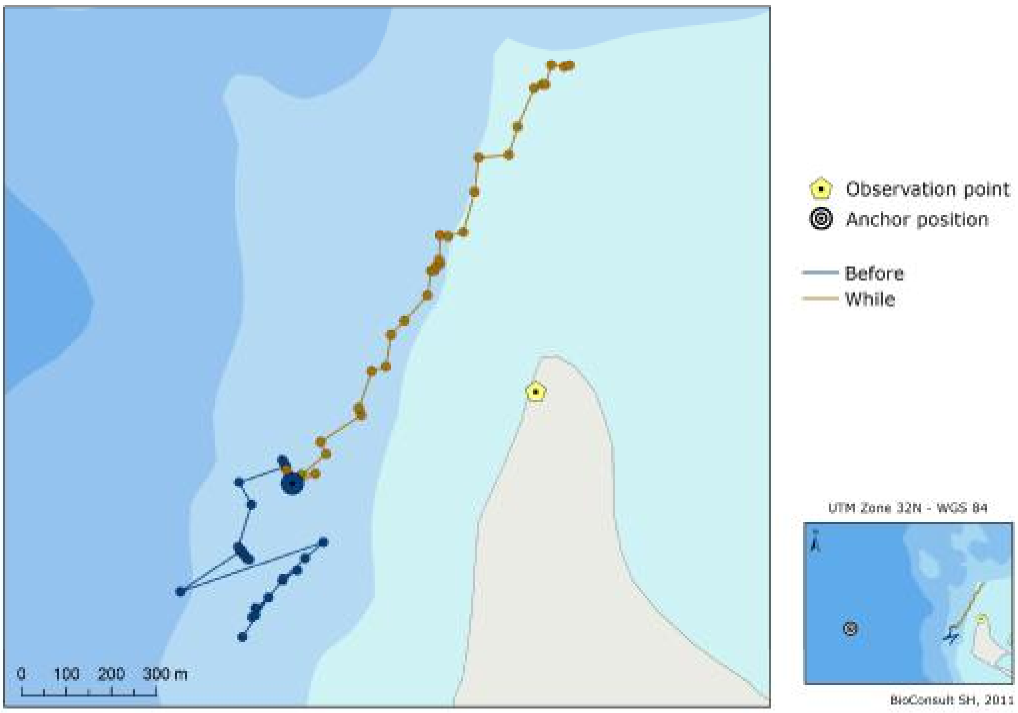

Fig. 50: Porpoise track M from 25.08.2011, when the sealscarer was deployed at 2.2 km distance (for position see inlet map) and a clear avoidance reaction was observed. The last resurfacing point before the start of the sealscarer is enlarged.

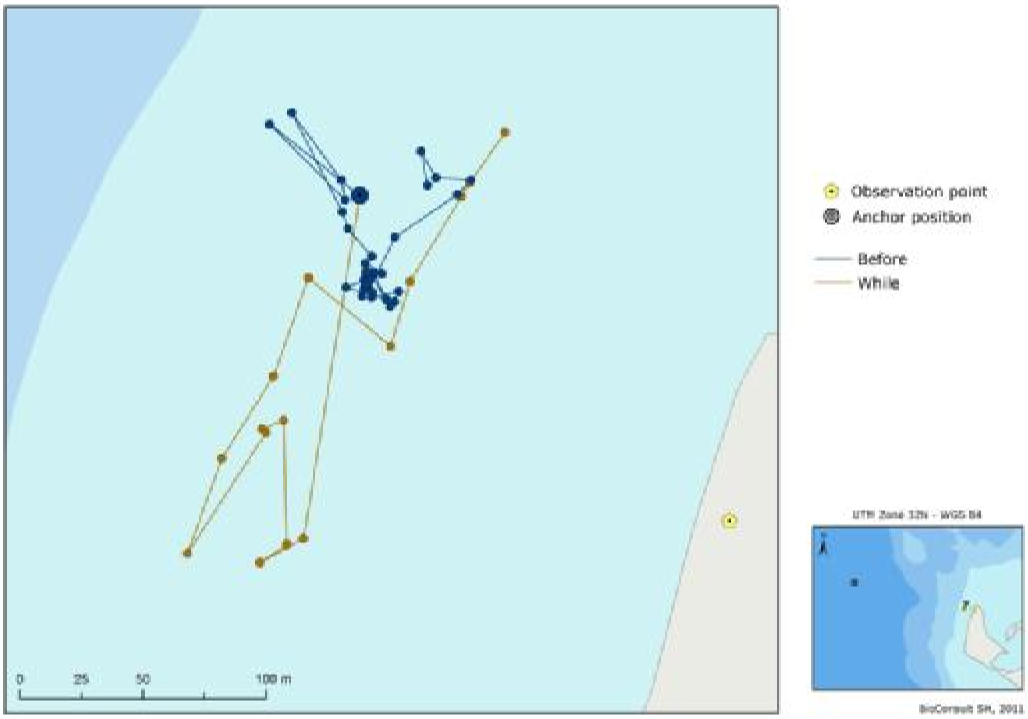

Fig. 51: Porpoise track A from 05.09.2010, where no obvious avoidance reaction was observed. The last resurfacing point before the start of the sealscarer is enlarged. The position of the sealscarer (at 2.1 km distance) can be seen in the small insert map.

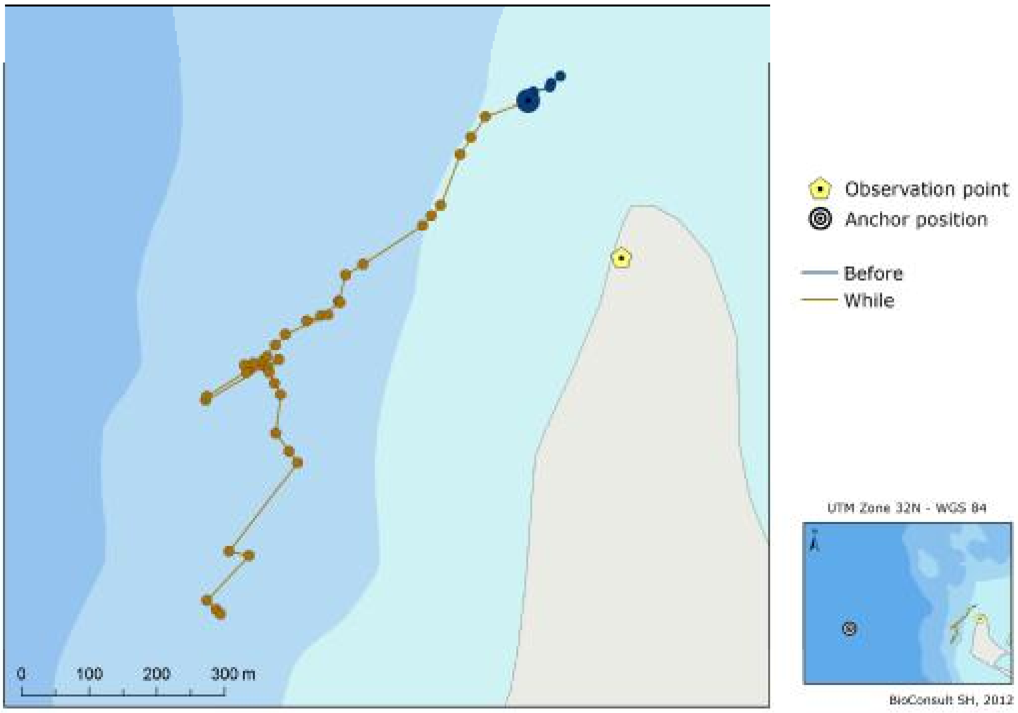

Fig. 52: Porpoise track L from 25.08.2011, when the sealscarer was deployed at 2.7 km distance (for position see inlet map) and no clear avoidance reaction was observed. The last resurfacing point before the start of the sealscarer is enlarged.

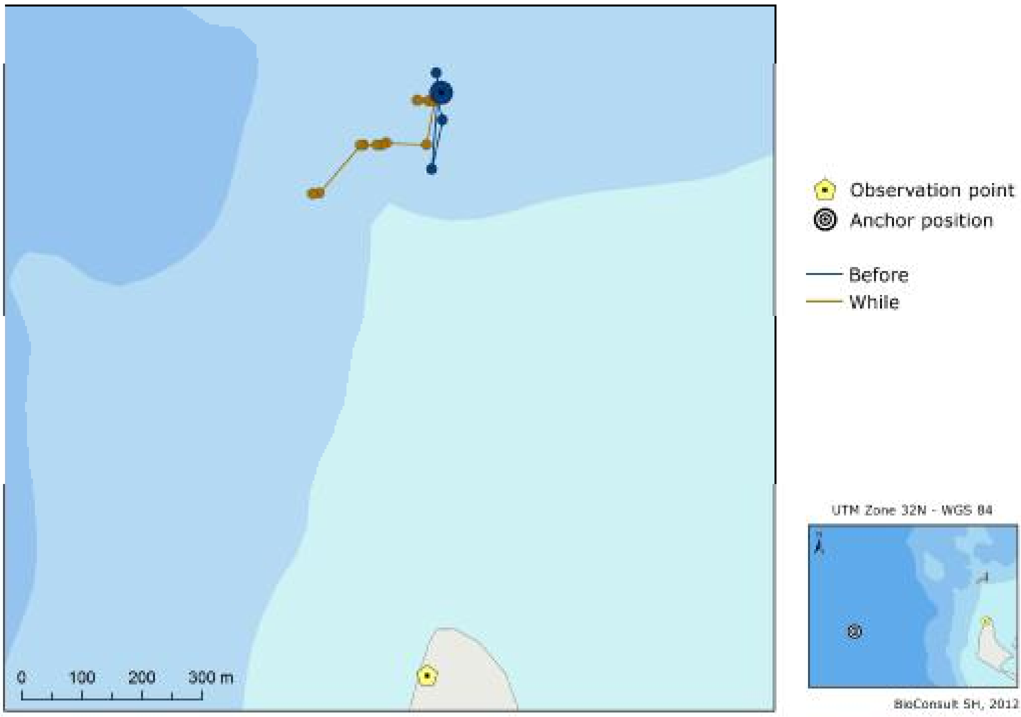

Fig. 53: Porpoise track J from 25.08.2011, when the sealscarer was deployed at 3.0 km distance (for position see inlet map) and no clear avoidance reaction was observed. The last resurfacing point before the start of the sealscarer is enlarged.

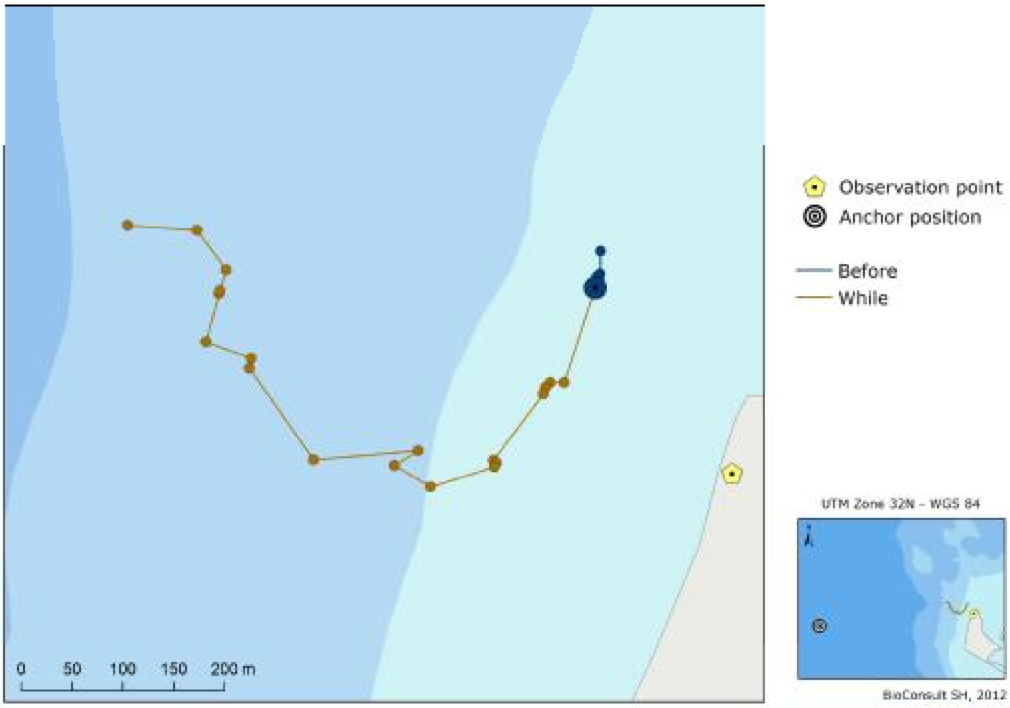

Fig. 54: Porpoise track G from 25.08.2011, when the sealscarer was deployed at 3.2 km distance (for position see inlet map) and no clear avoidance reaction was observed. The last resurfacing point before the start of the sealscarer is enlarged.

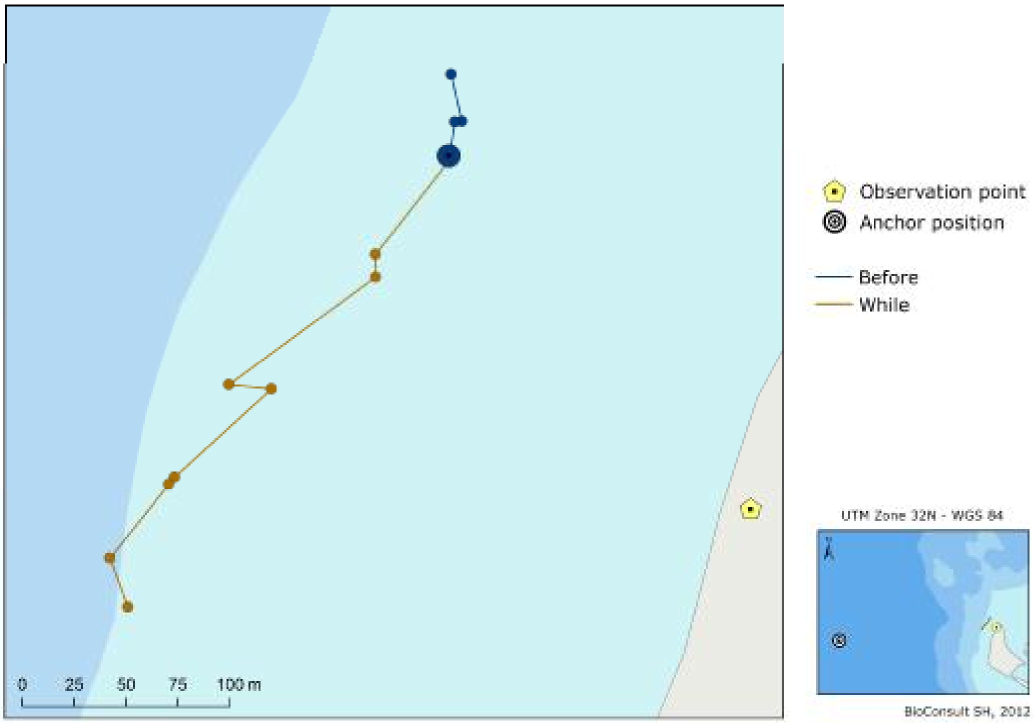

Fig. 55: Porpoise track E from 25.08.2011, when the sealscarer was deployed at 3.2 km distance (for position see inlet map) and no clear avoidance reaction was observed. The last resurfacing point before the start of the sealscarer is enlarged.

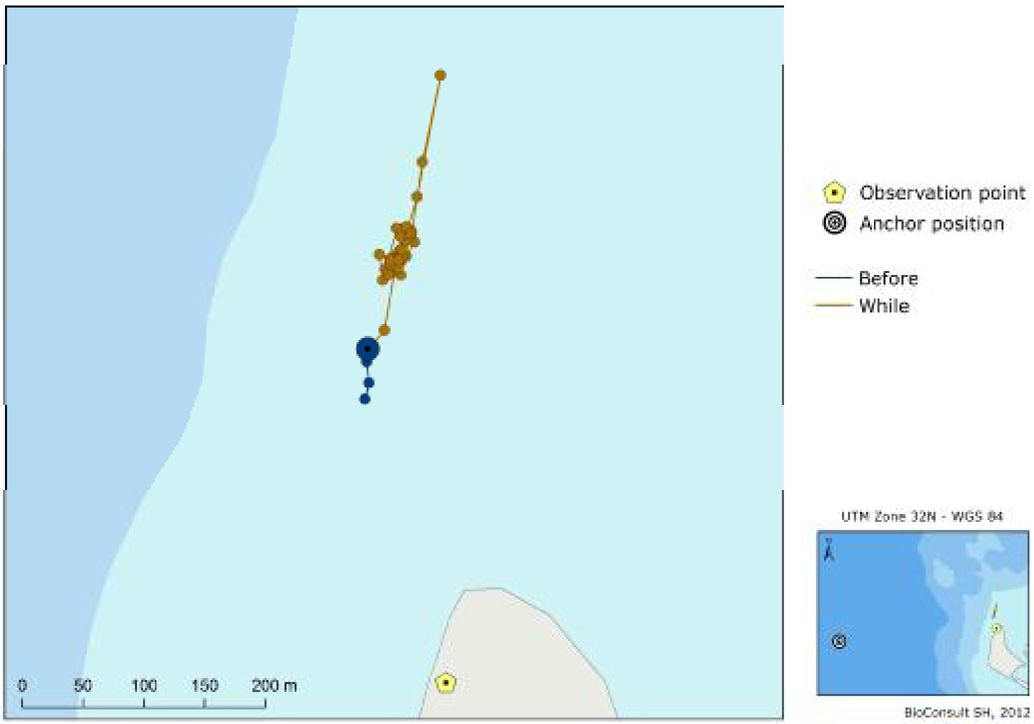

Fig. 56: Porpoise track F from 25.08.2011, when the sealscarer was deployed at 3.3 km distance (for position see inlet map) and no clear avoidance reaction was observed. The last resurfacing point before the start of the sealscarer is enlarged.

Fig. 57: Porpoise track C from 05.09.10, when the sealscarer was deployed at 0.7 km distance but not activated (baseline track) and no clear avoidance reaction was observed. The last resurfacing point before the start of the sealscarer is enlarged.

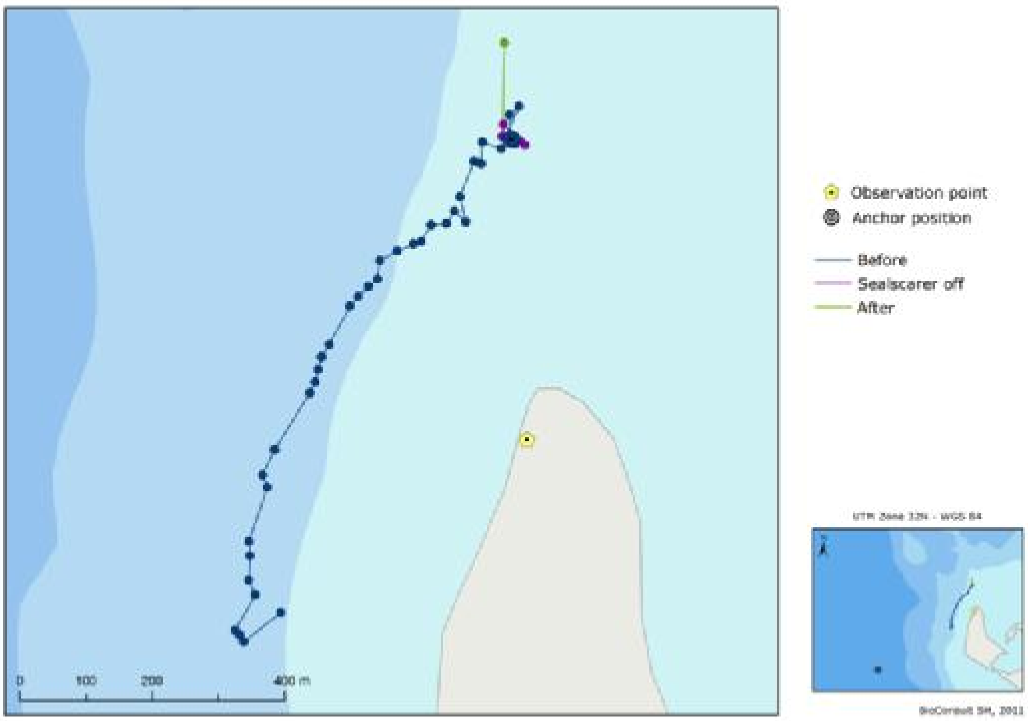

Fig. 58: Porpoise track E from 06.09.10, when the sealscarer was deployed at 2.5 km distance but not activated (baseline track) and no clear avoidance reaction was observed. The last resurfacing point before the start of the sealscarer is enlarged.

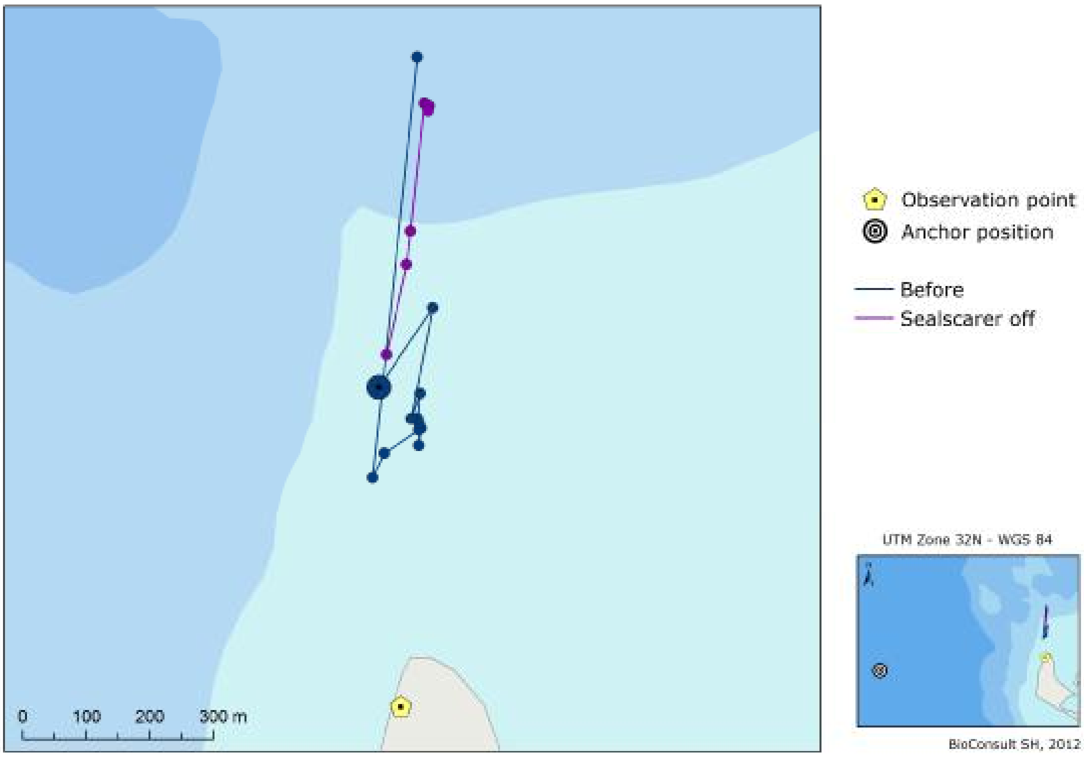

Fig. 59: Porpoise track B from 25.08.11, when the sealscarer was deployed at 3.4 km distance but not activated (baseline track) and no clear avoidance reaction was observed. The last resurfacing point before the start of the sealscarer is enlarged.

Tracks were later analysed by more objective criteria, where we chose to calculate an index for linearity, randomness, mean step length, swimming speed, distance and angles to the sealscarer. These parameters are shown in Tab. 28 -Tab. 30 and the changes when comparing the part of the track before and during sealscarer activity are summarised in Tab. 31.

In all cases that were judged as avoidance reactions or possible avoidance reactions, the porpoises' distances to the sealscarer position and their average swimming angle relative to the sealscarer increased after the sealscarer was switched on (Tab. 28, Tab. 30, Tab. 31). These estimates were only calculated for tracks where at least two positions could be obtained. All tracks that were judged as avoidance or possible avoidance reactions and where a linearity index could be calculated became more linear (which means that animals swam more directly into one direction than before) (Tab. 30, Tab. 31), and apart from track J on the 06.09.10 swimming speed also increased (Tab. 29, Tab. 31). During all tracks judged as avoidance reaction porpoises increased their distance to the sealscarer by at least 150 m and their relative swimming angle to the sealscarer by at least 58°, before they were either lost or the sealscarer was switched off (Tab. 28, Tab. 30). Only during the two cases judged as possible avoidance increase in distance and/or swimming angle was less (Tab. 28, Tab. 30). Mean step length (average distance between successive surfacings) increased during all avoidance reactions and during one of the two possible avoidance reactions (Tab. 29, Tab. 31).

The cases that were judged as no avoidance reaction porpoises did not increase their distance to the sealscarer or only by a minimal distance (<50 m) (Tab. 28Tab. 30), swimming angle relative to the sealscarer increased by a maximal 38° (Tab. 30) (in most cases far less than that) and tracks became less linear in four out of six cases (Tab. 30, Tab. 31).

During four trials the observers on the cliff told the skipper to switch the sealscarer on, which he did not do (as he was instructed to conduct one false trial per day without the observers knowing which one it was). During these times the porpoises did not show any obvious reactions and continued normally swimming around the area without constantly increasing the distance between them and the sealscarer or their heading relative to the sealscarer (Fig. 48-Fig. 58). For these baseline tracks there was also no consistent increase in swimming speed and linearity (Tab. 28-Tab. 31).

This shows that if the animals are at some further distance from the sealscarer (and thus exposed to lower noise levels) they show a more controlled avoidance reaction. Porpoises simply swam away increasing the distance between themselves and the sealscarer, while at even lower levels this avoidance reaction also ceases.

We further calculated whether tracks were more or less dispersed than randomly expected. If animals are feeding in an area one would assume them to show tracks that are more constrained than randomly expected, because they show frequent turns and stay within a smaller area for a longer time. This should also be the case if they rest or socialise, when they move less and also stay within a restrained area. On the other hand, if they only move through an area or swim away from something (in this case the sealscarer) their tracks should become more dispersed than randomly expected.

During all avoidance or possible avoidance reactions, tracks were more dispersed than randomly expected after the sealscarer was switched on (as there is a minimum number of 3 points to be able to check this, there were two cases where this could not be done). However, in two out of five cases this was already the case before sealscarer activation, while during the other three cases tracks before were either random or more constrained (Tab. 30). Furthermore, tracks when the sealscarer was not active were also often more dispersed, probably when animals only moved through the area. Therefore, this criterion is only a useful indicator of avoidance if used in combination with changes in distance and bearing to the sealscarer. It is indicative, however, that all tracks that were judged as avoidance or possible avoidance reactions and were this could be calculated (5 cases) were more dispersed than randomly expected (100 %), while this was only the case during three out of six (50 %) that were judged as no avoidance reactions and during 10 out of a total of 19 (53 %) different tracks that could be obtained before the sealscarer was switched on (or not switched on in case of baseline tracks) (Tab. 30).

Tab. 28: Summary of the 19 different trials when the sealscarer was deployed at distances above 1 km, showing date, if the sealscarer was on or off (blind trial), composition of the porpoise group, distance of the last tracking point before and during sealscarer activity to the sealscarer, change in distance and subjective description of the porpoises' reaction. Baseline trails shown in shaded rows.

Date	Trial	Distance of last point before activation to sealscarer	Distance of last tracking point to sealscarer	Change in distance to seal-scarer	Porpoise group	Estimated sound level at exposure in dB re 1 μPa_{rms}	Subjective description of porpoises' reactions
05.09.10	A on	2050 m	2103 m	+35 m	2 ad 2 juv	121 dB	no obvious reaction
05.09.10	B on	1060 m			1 ad 1 juv	128 dB	reaction (disappeared)
05.09.10	C off	751 m	779 m	+28 m	1 ad		no obvious reaction
05.09.10	F on	1721 m			1 ad	123 dB	reaction (disappeared)
06.09.10	A on	1555 m	2325 m	+770 m	1 ad	124 dB	reaction (avoidance)
06.09.10	E off	2287 m	2279 m	-8 m			no obvious reaction
06.09.10	H on	1998 m	2148 m	+150 m	1 ad 1 juv	121 dB	avoidance? (boat)
06.09.10	I on	1661 m	1301 m	-360 m	1 ad 1 juv	123 dB	unclear (glare)
06.09.10	J on	2325 m	2848 m	+523 m	2 ad 1 juv	119 dB	reaction (avoidance)
25.09.10	B on	1892 m	2495 m	+603 m	1 ad 1 juv	122 dB	reaction (avoidance)
25.09.10	E off	2506 m	2378 m	-128 m	1 ad 1 juv		no obvious reaction
25.09.10	E on	2378 m	2853 m	+475 m	1 ad 1 juv	119 dB	reaction (avoidance)
25.08.11	B off	3432 m	3518 m	+86 m	1 ad 1 juv		no obvious reaction
25.08.11	E on	3149 m	2973 m	-176 m	1 ad	116 dB	no obvious reaction
25.08.11	F on	3246 m	3289 m	+43 m	1 ad	115 dB	no obvious reaction
25.08.11	G on	3162 m	2718 m	-444 m	1 ad	116 dB	no obvious reaction
25.08.11	J on	3013 m	2754 m	-259 m	1 ad	116 dB	no obvious reaction
25.08.11	L on	2650 m	2179 m	-471 m	1 ad 1 juv	118 dB	no obvious reaction
25.08.11	M on	2207 m	2976 m	+769 m	1 ad 1 juv	120 dB	avoidance?

Tab. 29: Mean step length and swimming speed for the part of the track before and after sealscarer activity. Baseline trails are called “off” and trials with active sealscarer “on”, with the former shown in shaded rows. For sample sizes see Tab. 30.

Date	Trial	Mean step length before	Mean step length during	Swimming speed before	Swimming speed during	Total distance before	Total distance during	Estimated sound level at exposure in dB re 1 µPa$_{rms}$
05.09.10	A on	13.0 m	37.4 m	1.14 m/s	2.18 m/s	27.7 m	156.2 m	121 dB
05.09.10	B on	15.7 m		2.39 m/s		8.9 m		128 dB
05.09.10	C off	108.6 m	42.5 m	1.79 m/s	1.21 m/s	499.1 m	50.8 m	
05.09.10	F on	57.9 m		0.68 m/s		288.4 m		123 dB
06.09.10	A on	50.6 m	67.4 m	2.43 m/s	3.16 m/s	98.5 m	827.1 m	124 dB
06.09.10	E off	32.9 m	17.8 m	1.39 m/s	0.29 m/s	795.4 m	14.3 m	
06.09.10	H on	11.5 m	81.7 m	0.89 m/s	1.80 m/s	171.5 m	158.4 m	121 dB
06.09.10	I on	30.7 m	185.7 m	1.05 m/s	2.07 m/s	288.9 m	464.8 m	123 dB
06.09.10	J on	43.6 m	178.5 m	2.07 m/s	2.02 m/s	478.2 m	531.3 m	119 dB
25.09.10	B on	16.8 m	53.6 m	1.49 m/s	2.73 m/s	226.6 m	617.3 m	122 dB
25.09.10	E off	21.9 m	21.3 m	0.99 m/s	0.97 m/s	179.7 m	253.5 m	
25.09.10	E on	21.3 m	106.2 m	0.97 m/s	2.33 m/s	253.5 m	676.7 m	119 dB
25.08.11	B off	110.3 m	69.1 m	2.07 m/s	1.50 m/s	393.9 m	309.2 m	
25.08.11	E on	15.2 m	39.2 m	2.08 m/s	1.22 m/s	41.8 m	263.8 m	116 dB
25.08.11	F on	14.0 m	17.3 m	1.56 m/s	0.98 m/s	41.6 m	95.7 m	115 dB
25.08.11	G on	8.6 m	42.7 m	0.84 m/s	1.43 m/s	36.0 m	464.2 m	116 dB
25.08.11	J on	50.6 m	33.3 m	0.72 m/s	1.00 m/s	34.8 m	269.1 m	116 dB
25.08.11	L on	13.4 m	41.2 m	1.05 m/s	2.06 m/s	59.7 m	883.0 m	118 dB
25.08.11	M on	46.9 m	39.1 m	1.25 m/s	1.70 m/s	364.0 m	1109.1 m	120 dB

Tab. 30: Indices of linearity for the part of the tracks before and during the time of sealscarer (with number of points in brackets). Also shown is whether the track was random, more dispersed or more constrained than randomly expected, and the mean swimming angle relative to the sealscarer is also given. Baseline trials are called “off” and trials with active sealscarer “on”, with the former shown in shaded rows.

Date	Trial	Linearity index before	Linearity index during	Track before	Track during	Mean angle before	Mean angle during	Change in angle
05.09.10	A on	0.07 (34)	0.44 (15)	random	random	94.6	98.9	+4.3
05.09.10	B on	0.08 (8)	- (0)	random		90.4		
05.09.10	C off	0.66 (8)	0.15 (7)	random	constrained	87.2	112.2	+25.0
05.09.10	F on	1.0 (6)	- (1)	dispersed		39.7		
06.09.10	A on	0.11 (39)	0.95 (11)	constrained	dispersed	97.5	155.9	+58.4
06.09.10	E off	0.67 (37)	0.28 (5)	dispersed	random	130.0	103.6	-26.4
06.09.10	H on	0.71 (23)	- (2)	dispersed		61.6	120.9	+59,3
06.09.10	I on	0.94 (11)	0.98 (3)	dispersed	dispersed	35.3	34.2	-1.1
06.09.10	J on	0.44 (26)	0.99 (3)	random	dispersed	54.2	162.2	+108
25.09.10	B on	0.67 (21)	0.80 (14)	dispersed	dispersed	41.4	144.2	+102.8
25.09.10	E off	0.91 (10)	0.73 (16)	dispersed	dispersed	93.1	62.0	-31.1
25.09.10	E on	0.73 (16)	0.87 (7)	dispersed	dispersed	62.0	127.7	+65.7
25.08.11	B off	0.34 (11)	0.45 (9)	dispersed	dispersed	96.5	87.9	-8.6
25.08.11	E on	1.0 (5)	0.77 (18)	random	random	53.3	69.6	+16.3
25.08.11	F on	0.72 (5)	0.11 (39)	dispersed	constrained	92.5	64.8	-27.7
25.08.11	G on	0.73 (7)	0.63 (18)	random	dispersed	50.8	60.7	+9.9
25.08.11	J on	0.10 (8)	0.74 (10)	random	dispersed	73.6	45.1	-28.5
25.08.11	L on	0.93 (7)	0.49 (36)	dispersed	dispersed	35.3	73.3	+38.0
25.08.11	M on	0.19 (32)	0.73 (35)	constrained	dispersed	82.9	107.3	+24.4

Tab. 31: Changes in mean step length, swimming speed, distance to the sealscarer and angle to the sealscarer of the porpoises tracking path before and during sealscarer activation. Mean step length and swimming speed for the part of the track before and after sealscarer activity. Baseline trails are called “off” and trials with active sealscarer “on”, with the former shown in shaded rows. For sample sizes see Tab. 30.

Date	Trial	Linearity index	Mean step length	Swimming speed	Distance to Sealscarer	Angle to Sealscarer	Porpoise Reaction
05.09.10	A on	+	+	+	+	+	none?
05.09.10	B on						disappeared
05.09.10	C off	-	-	-	+	+	none
05.09.10	F on				-		disappeared
06.09.10	A on	+	+	+	+	+	avoidance
06.09.10	E off	-	-	-	-	-	none
06.09.10	H on		+	+	+	+	avoidance?
06.09.10	I on	+	+	+	-	-	?
06.09.10	J on	+	+	-	+	+	avoidance
25.09.10	B on	+	+	+	+	+	avoidance
25.09.10	E off	-	-	-	-	-	none
25.09.10	E on	+	+	+	+	+	avoidance
25.08.11	B off	+	-		+	-	none
25.08.11	E on	-	+	-	-	+	none
25.08.11	F on	-	+	-	+	-	none
25.08.11	G on	-	+	+	-	+	none
25.08.11	J on	+	-	+	-	-	none
25.08.11	L on	-	+	+	-	+	none
25.08.11	M on	+	-	+	+	+	avoidance?

As already described in section 4.3.2., porpoises were spotted during the 28 h that the sealscarer was deployed at the central anchoring position only at 4 times within the 1 km radius. Three of these animals could not be tracked because they were either too far out or only spotted once. During one time, however, a porpoise stayed in the area for longer and could be tracked over a period of 11 min. During this time we obtained 8 locations with the theodolite, and the track is shown in Fig. 60. The closest distance to the sealscarer at which this porpoise was observed was 798 m. This animal was milling, repeatedly resurfacing and changing its swimming direction. It is likely that it was feeding in the area. About 25 min later a porpoise was again spotted shortly between scans at a distance of 800 m to the sealscarer. However, this was only one sighting and therefore the animal could not be tracked. As this sighting was at a similar spot from where the porpoise before was tracked and shortly afterwards it is likely that this was the same animal again.

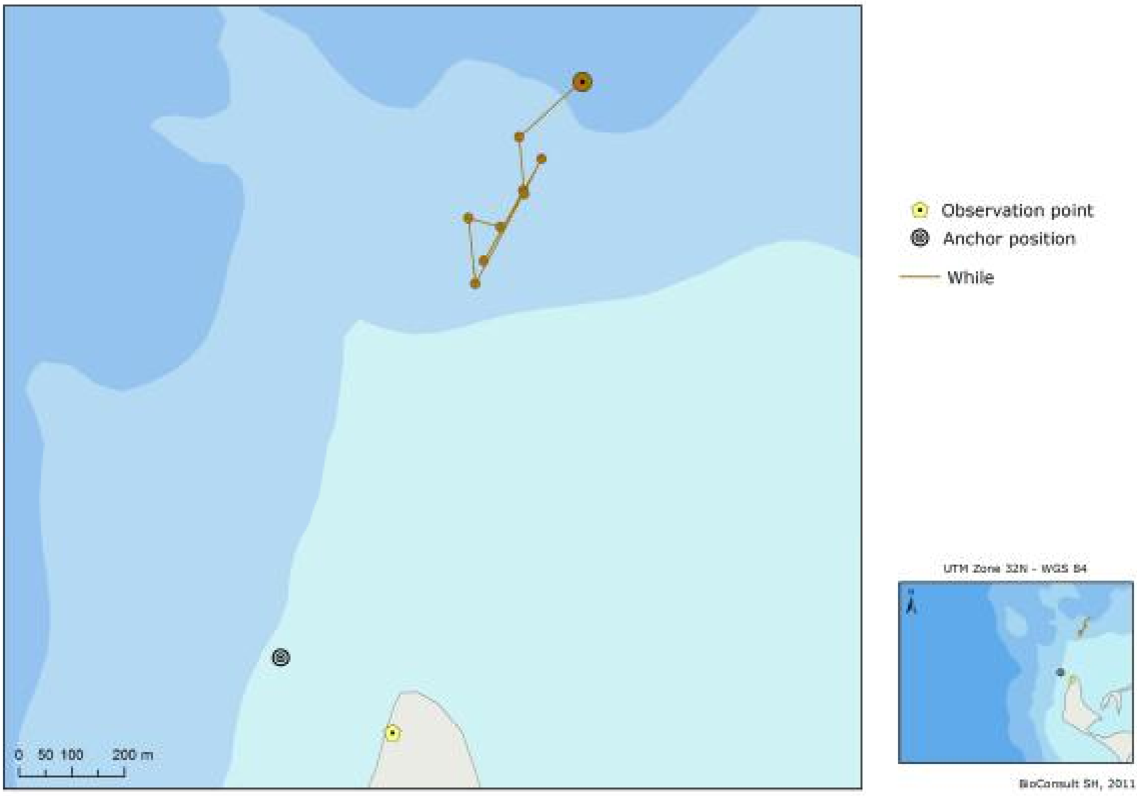

Fig. 60: Map showing the track of the one porpoise that could be tracked with the theodolite while the sealscarer was active. The sealscarer was deployed at the anchoring position. The last resurfacing position where the porpoise could be tracked is enlarged.

6. DISCUSSION

6.1. Spatial and temporal habitat use by harbour porpoises

There was a similar seasonal pattern in harbour porpoise activity at the different POD-positions in the North Sea with maximal values in Aug. This is in line with previous investigations in this area during construction of the research platform FINO3 (Brandt *et al.* 2010). The magnitude of porpoise activity, however, was markedly different between POD-positions, indicating a relatively heterogeneous usage of the area by harbour porpoises. A lot more porpoise activity was recorded at the POD-positions in the central area and along the eastern transect than at the remaining POD-positions. This is also in line with results from the previous study, where most porpoise activity was recorded at positions P1 and P2, with medians of 44 % and 22 % PP10M/day respectively, which was also much more than at any other position (Brandt *et al.* 2010). Former Positions P1 and P2 are very close to position 8 of this study and recordings are comparable. Considerably less porpoise activity recorded at the other positions also corresponds to results from the previous study. The area south and southeast of the FINO3 thus seems to be used by harbour porpoises relatively continuously also between years.

This density of 2.38 porpoises/km² found during the survey flight prior sealscarer activation lies well within the figures but below the maximal values that were found by other studies within this area: Brandt *et al.* (2010) found surprisingly high porpoise densities between 6.6 and 14.7 porpoises around the FINO 3 in Jun and Aug 2008, which were the highest densities recorded in this area until today. During the five year long MINOS + study (2003) a porpoise density of 3.5 porpoises/km² was recorded for the strata “Northern Friesland” (Gilles *et al*. 2007) in Jun/Jul while during Sep densities ranged between 0.7 (in 2004) and 0.85 (in 2005) porpoises/km². Aug was not covered during this study. During the EMSON project, which surveyed marine mammal and seabird abundance within the German economic offshore zone between 2002 and 2005, up to 5 porpoises/km² were recorded in the area “Sylter Aussenriff”, adjacent to our study area in Mai /Jun, during Aug densities ranged between 1.55 (in 2003) and 1.9 (in 2005) porpoises/km² (Gilles *et al.* 2006). During a study for the Offshore Windfarm Butendiek an area between 10 to 100 km distance to the coast west of Sylt was surveyed. This study also found maximal porpoises densities of 3.7 and 5.6 porpoises/km² in Jun between 2001 and 2003, while in Aug densities ranged between 1.9 (in 2001) and 2.3 (in 2002) porpoises/km (Grünkorn *et al*. 2002, 2004). Brandt *et al.* (2008) found up to 3.5 porpoises/km² in an area 0-45 km west of Sylt in Jun 2008, while in Aug 2007 density was about 1.4 porpoises/km.

A g(0) value of 0.34 that was used during this study is comparable to the one used during the EMSON study, that used a different methodology. Here g(0) was calculated according to the circle-back method and calculated for pooled data from Mai until Jul 2005, yielding a g(0) value of 0.37 for good sighting conditions. For moderate sighting conditions the g(0) value was only 0.14.

The four different POD-positions at Fyns Hoved showed a very similar seasonal pattern to each other, which is not surprising given that the PODs are only between 450-900 m apart. The only difference was that the POD furthest away from the coast recorded fewer porpoise activity than the other PODs at the beginning of the study period in early summer, but highest activity in late summer and autumn towards the end of the study period. While the PODs recorded highest porpoise activity towards the end of the study period, there was no clear seasonal trend in porpoise sightings during standardised scans. However, not many observation days could be conducted towards the end of the study due to weather conditions, so the days with exceptionally high porpoise activity recorded by the PODs were simply not covered by the visual scans.

6.2. Problems with background noise at POD-positions

During the previous study around FINO3 it could be shown that time periods with a lot of background noise at P1 and P2 highly coincided with high wind speed predictions for Helgoland. It was speculated that there might be a very sandy seabed at these positions. During high sea state and strong wave activity there might then be a lot of sediment movement when sand grains hit the PODs and cause a high number of raw data clicks (background noise) recorded by the PODs (Brandt *et al.* 2010). As position 8 during this study is close to the previous positions P1 and P2, it is highly likely that we again encountered the same phenomenon.

Considerably fewer problems with background noise were encountered during the study in the Danish Baltic Sea. Here, the seabed where PODs were deployed, was rather muddy and in places rocky and less sandy than in the North Sea. Also the PODs were more sheltered from wind than in the open sea. However, some periods when the sealscarer was active had to be excluded from analyses, because noise from the sealscarer was sometimes recorded by the PODs and surprisingly caused the scan limit to be exceeded. This was a problem that we did not encounter in the North Sea, where most PODs were deployed at larger distances than 450 m. However, even at the closest POD (1-100 m), signals from the sealscarer could be seen but did not lead to the scan limit being exceeded. It is surprising therefore, that this problem was encountered at Fyns Hoved and may point towards a very different sound propagation at this study site with more reflection from the seabed in shallower water.

6.3. Sealscarer effects

6.3.1. Sealscarer audibility and noise propagation

The higher transmission loss in the Baltic study area as compared to the North Sea can be explained by the muddy sea bottom, compared to hard sand in the North Sea, in conjunction with the lower water depth, and numerous stones and rocks that cause a scattering of sound in many directions.

The audibility of the sealscarer depends on several parameters: Properties of the animal's auditory system, intensity, frequency and duration of the sound, sound propagation and the level of background noise. If the signal consists of a single frequency component, and if it is not shorter than the time constant of the animals' loudness sensation, its rms level can be directly compared to narrowband hearing thresholds. For dolphins, the time constant is in the order of 100 ms (Au & Hastings 2008), as it is for other mammals, e.g. humans. The Lofitech sealscarer emits almost pure tones with 500 ms duration, so the above conditions are met. If the signal is shorter than the time constant, the hearing threshold rises, for 1.5 ms pulse width, like from the Airmar sealscarer, roughly by 15 dB (Au & Hastings 2008, p 344). However, the Airmar device emits a burst of more than 50 such pulses, spaced by approx. 45 ms. It is not clear how this affects the hearing threshold. It can be hypothesized that it lies in between the threshold for a single short pulse and the threshold for a long tone. Measured hearing thresholds for harbour porpoises vary widely. Thresholds determined from behavioural responses are usually lower than those based on auditory evoked potentials (AEP). At 16 kHz for example, the range spans at least from 44 dB re 1 µPa (Kastelein *et al*. 2002, behavioural) to about 100 dB re 1 µPa (Lucke *et al.* 2009, AEP). In the study area in the Baltic Sea, the measured rms level of the Lofitech sealscarer was about 110 dB at 5 km distance. Hence with an assumed high hearing threshold of 100 dB at the sealscarers' operating frequency of 14 kHz, the range of audibility exceeds 5 km. In the North Sea, the transmission loss was found to be lower and a range of audibility of at least 10 km can be expected.

Whether the signal is masked by background noise or not can be estimated from the noise level within the so-called critical band at 14 kHz. The critical bandwidth Δf is often expressed as critical ratio CR in dB, where CR = 10 log (Δf). For 16 kHz, Kastelein *et al.* (2009) found a CR of 26 dB ± 4 dB. Similar values are reported for other marine mammals (Au & Hastings 2008, p 348-349). With worst-case values of a noise spectral density of 60 dB re 1 µPa/$\sqrt{}$Hz (Wille & Geyer 1984, Figs. 4, 5, 6) and a critical ratio of 30 dB, the noise level in the critical band is 90 dB re 1 µPa. Hence the estimated audibility ranges are expected not to be reduced by background noise. A range reduction is possible for rough sea, when the transmission loss is increased from air bubbles in the upper water layer. An evaluation of this situation is beyond the scope of this report.

Kastelein *et al.* (2010) conducted tests with a young, adult male harbour porpoises and concluded that it can hear the sealscarer (behavioural test) at levels down to 55 dB re 1µPa. According to our sealscarer measurements in the North Sea, sound levels will only drop below this value in over 20 km distance. According to Kastelein *et al.* (2010) the Lofitech sealscarer would be audible to a harbour porpoise in up to about 18 km calculated using spherical spreading and assuming a sea state of 4 Beaufort.

6.3.2. Effectiveness and spatial extent of deterring effect

In the German North Sea the proportion of PPM and PP3H (two different parameters for harbour porpoise activity) decreased while the sealscarer was active compared to the time before at all POD-positions up to a distance of 7.5 km. This decrease was statistically significant at 0, 0.75, 3 and 7.5 km distance but not at 1.5 and 5 km distance. At 1.5 and 5 km distance porpoise activity was already very low before the start of the sealscarer, which makes it more difficult to proof a statistically significant effect. Furthermore, sample size was low, caused by problems with background noise, further complicating statistical testing. At 1.5 km distance, a decrease during sealscarer activity was observed eight times, while there was only one increase. During this increase, however, porpoise activity reached a very high value, one that was never seen during the baseline period. Such an outlier has strong effects in significance testing when sample size is as small as in this case and here led to a non-significant effect.

Noise levels measured in the North Sea dropped down to about 120 dB re 1µPa$_{rms}$ at 7.5 km distance according to the linear fit. However, this approximation is only valid for distances of a few kilometres, and measurements in over 2 km distance already indicate that at these further distances sound propagation is probably higher. At these distances an approximation formula after Thiele & Schellstede (1980) is probably more realistic. According to this, the sound level at 7.5 km distance would have been about 113 dB. The significant effect on porpoise activity found at 7.5 km distance are the lowest noise level at which porpoise reactions to the sealscarer were ever found. At Fyns Hoved, porpoises were found to react at a maximal distance of 2.4 km, which in this area translates to a noise level of about 119 dB re 1µPa$_{rms}$, while at 120 dB avoidance reactions were no longer observed. Similar results were reported by Kastelein *et al.* (2010), who found a male porpoise in captivity to increase its distance to the sound source, from where recorded Lofitech sealscarer sounds were played back to him, at sound levels as low as 121 dB re 1µPa$_{rms}$. At this sound level they further found the porpoise to increase his swimming speed, diving frequency and respiration rate (Kastelein *et al.* 2010). In addition, Kastelein *et al.* (2010) studied a sound level of 91 dB re 1µPa$_{rms}$, at which they no longer found any significant effects on the porpoises' behaviour. According to our measurements the sealscarer sound would only have dropped below 91 dB re 1µPa$_{rms}$ at over 10 km distance in the North Sea. However, Kastelein *et al.* (2010) conclude that with spherical spreading, a deterrence effect of the Lofitech sealscarer can only be assumed up to about 100 m, while effects on their behaviour (respiration rate, diving rate, etc.) may occur in up to 2 km. We do not follow this conclusion, because Kastelein *et al.* (2010) themselves found the porpoise to still increase its distance to the sealscarer at 121 dB re 1µPa$_{rms}$ (which with spherical spreading relates to a distance of 2 km). Instead, we assume that this shows that a deterrence effect of the Lofitech sealscarer should be expected in at least up to 2 km. Our measurements in the North Sea and a fitted Thiele approximation function showed that 121 dB re 1µPa$_{rms}$ were only reached at over 4 km in the North Sea. Because porpoises in captivity only have a very limited option of avoiding the sound source and sound levels within the pool differ only slightly, it is further probable that porpoises in the sea are deterred more easily, because they have more space and therewith more options of avoidance. Why, however, studies at Fyns Hoved and in the North Sea lead to different conclusions about the noise levels at which porpoises reacted, is unclear. As noise levels in the North Sea at distances of 7.5 Km are based on extrapolation from measurements at closer distanced, we believe that results from Fyns Hoved, where actual measurements for the relevant distanced exist are more reliable. Measurements in the North Sea also showed that there was substantial fluctuation in noise levels at over 2 km distance. Therefore, estimated noise levels at 7.5 km distance may be very imprecise. Furthermore, if high fluctuations exist at such distances, maximal values may be more important than average values, and the animals' loudness sensation may also differ substantially with e.g. ambient noise.

Less porpoise activity recorded by the PODs during sealscarer activity could either be due to porpoises leaving the area or due to some other behavioural changes in porpoises. A decrease in echolocation for example or increased directionality in the porpoises' swimming could both lead to a reduced probability of the PODs recording porpoise clicks. If porpoises leave the area once the sealscarer is switched on, they probably swim more directionally than before. Due to the strong directionality of the porpoise echolocation beam and its small opening angle (Au *et al.* 1999) this would reduce the probability that clicks are recorded by the POD. If a porpoise shows more turns and stays in a small area for a longer period of time, this will increase the probability of clicks being recorded by the POD. The effect of the sealscarer on porpoise recordings that we found is probably caused by a combination of both, the onset of behavioural differences and the consequent leaving of the area. The aerial surveys conducted at the 10.08.2010 show a distinct and significant reduction in harbour porpoise absolute density during sealscarer activity as compared to the time before. This shows that the majority of porpoises had probably indeed left the area. One may caution that behavioural changes could also cause this impression, for example if the animals spent less time at the surface when exposed to sealscarer noise. Experiments by Kastelein *et al.* (2010), however, found that harbour porpoises rather increased their respiration rate when exposed to sealscarer noise, which should lead to more time spent on the surface. Although animals in captivity could react much different from the unconfined ones in the field, we believe that the reduced densities we found during sealscarer activity are in fact a result of animals having left the area. Aerial surveys conducted during pile driving of the FINO3 also found significantly lower porpoise densities than during the day before (Brandt *et al.* 2008). We conclude that the majority of harbour porpoises indeed left the area as a result of the sealscarer being switched on. The minimal distance at which a harbour porpoise was spotted increased from 2.5 km before to 6.3 km after the sealscarer was switched on. This is more or less in line with the POD data that lead us to conclude that there is an effect (but not a total one) in up to 7.5 km distance. Results found by Johnston (2002) and Olesiuk *et al.* (2002) could also be confirmed, although both tested a different sealscarer model. Johnston (2002) found a reduction of sighting rates up to the maximal observed distance of 1.5 km. Our data show that the effect of the Lofitech sealscarer under conditions encountered in offshore North Sea waters reaches beyond this. Olesiuk *et al.* (2002) further concluded, after testing the same model as Johnston (2002), that there was still a significant effect in even up to 3.5 km distance. They found sighting rates in 2.5-3.5 km distance to still be reduced down to only 8 % relative to the baseline value.

The study conducted at Fyns Hoved provides even more detailed information on exactly how and at what distances and noise levels harbour porpoises reacted to the sealscarer. Results from sighting data further confirm our interpretation of the POD data, in that animals had left the area and did not just stay silent. We found a clear reduction in sighting rates within a 1 km radius around the sealscarer (relating to a minimal sound level of about 129 dB re 1µPa_{rms}). In fact, during the total 28 hours of sealscarer activity, harbour porpoises were observed inside the 1 km radius at only four occasions and only twice closer than 1000 m (both times at 800 m). Whenever the sealscarer was activated at distances between 300 and 700 m (relating to noise levels between 133 and 143 dB re 1µPa_{rms}) from the porpoise, porpoise almost always immediately disappeared. These observations point to a very strong reaction at close range to the sealscarer and could resemble a kind of panic reaction. They are in contrast to the observed turning and swimming away when porpoises were exposed to the sealscarer at greater distances. Even at 1.1 km distance (at about 128 dB re 1µPa_{rms}) we observed the porpoise to immediately disappear when the sealscarer was switched on (response study). Only at the greater distances between 1.5 to 2.4 km (ca. 119-124 dB re 1µPa_{rms}) porpoises could be observed to swim away from the sealscarer. A clear avoidance reaction was still observed at a distance of 2.4 km, were sound measurements at exactly the same position revealed a noise level of 119 dB re 1µPa_{rms}, in line with results found for 7.5 km distance in the North Sea. In four cases when porpoises turned around and swam further away, they actually swam around the northern tip of Fyns Hoved, where measurements revealed that due to shadowing by the coast and shallow water there, sound levels were 10-20dB lower than at comparable distances further out to the sea. It seems likely therefore, that the porpoises deliberately swam towards the quieter area around the islands' tip.

However, at two occasions porpoises approached the sealscarer at 800 m at Fyns Hoved while it was active (relating to a sound level of about 132 dB re 1µ$Pa_{rms)}$, occasionally animals did not clearly react at 1.8-2.1 km distance (120-122 dB re 1µPa_{rms}) and porpoises were also occasionally recorded by the PODs deployed at 750 m distance in the North Sea. With a POD detection radius of 200-300 m, these animals could have been anywhere between 450 and 950 m distance to the sealscarer corresponding to a noise level of 137-144 dB re 1µPa_{rms}. Furthermore, one porpoise was recorded for 2 min during one of the ten trials in the North Sea at a POD directly next to the sealscarer. As this was the only incident where a porpoise could be proven to have stayed within the 450 m radius during a total of 10 trials and 25 hours of POD-recordings with active sealscarer in the North Sea and during 4 trials with a total of 15 hours with an active sealscarer where at least one POD recorded analysable data (a total of 35 POD-hours), it has to be seen as an exception. Also, PODs at Fyns Hoved deployed at a distance of 450 m (thus recording porpoises in 150-750 m distance and corresponding to noise levels of ≤132 dB re 1µPa_{rms}) never recorded any porpoise clicks while the sealscarer was active. Results from Fyns Hoved, therefore, suggest a fairly complete deterrence effect down to noise levels of about 132 dB re 1µPa$_{rms}$. However, results from the North Sea point to higher values, but exact predictions are not possible based in the data available. Nevertheless, all results show that it cannot be completely ruled out that the occasional porpoise is not deterred by the sealscarer. Johnston (2002) observed a closest approach distance of a harbour porpoise to the Airmar sealscarer of 645 m, Olesiuk *et al.* (2002) even observed one in only 200 m distance. All this shows that the deterrence effect was not complete and points at inter-individual variation and context dependency in how harbour porpoises react to the sealscarer that could be related to age, hearing sensitivity and prior experiences with sealscarers. When Kastelein *et al.* (2010) tested the reaction of two harbour seals to a sealscarer, they found them to show quite different behavioural reactions. This should also be expected for harbour porpoises. During our response study we also had one porpoise clearly not avoiding the sealscarer at 2.1 km distance, while several others showed very clear reactions in even up to 2.4 km. This could also be due to inter-individual differences. Further, reactions of one animal to the same stimulus could also vary between different situations. How an animal reacts to predation risk for example, depends on its nutritional status, reproductive status, resource availability, personality etc. (e.g. Quinn & Creswell 2005, Skov *et al.* 2011). When applying a sealscarer before the start of pile driving, one can thus never completely rule out the possibility that the occasional harbour porpoises will still be inside the danger zone when pile driving starts. This probability of course increases with distance, as porpoises were regularly observed and recorded in distances beyond these 800 m, despite significant effects still being apparent. Nevertheless, as indicated by both, the POD studies and the response study, significant deterrence effects occurred at noise levels as low at least as low as 119 dB re 1µPa$_{rms\ and}$ maybe in some cases below this, but an almost complete deterrence effect can only be expected down to noise levels of about 132 dB re 1µPa$_{rms}$ the most.

6.3.3. Scaring mechanism

There are several theories why harbour porpoises react to sealscarers:

1) The „startle hypothesis“ assumes that animals are simply startled by the sound of the sealscarer and flee when they hear it. However, this would mean that they may quickly habituate to this sound when getting used to it.

2) The „masking hypothesis“ assumes that the sound leads to a masking of the animals‘ echolocation signals, and animals leave the area, because they can no longer use their sonar effectively.

3) The „annoying hypothesis“ assumes that animals, just like humans, perceive the sound as unpleasant and therefore avoid it,

4) while the „prey hypothesis“ assumes that prey organisms react to the noise and flee, while the reaction of porpoises is only secondary to their absence (Kraus 1999).

Several circumstances indicate that the „annoying hypothesis“ is the most likely one to apply (Kraus 1999). Investigations on seals by Götz & Janik (2010) also indicate that this hypothesis is the most likely one to apply at least for seals. We also find that the reactions we observed at Fyns Hoved are in accordance with the “annoying hypothesis”. All animals within a 1100 m radius around the sealscarer reacted by immediately diving away and were not seen again. This could point towards the startle hypothesis. However, when we observed animals to react at distances between 1.7 and 2.4 km, they simply turned around and swam into the other direction without showing signs of panic, which points more towards the “annoying hypothesis”. Probably, reactions are the result of a combination of porpoises being startled and being annoyed, depending on how loud the suddenly starting noise is. Nevertheless, reactions were immediate and not delayed as would be expect if the prey hypothesis applied. Furthermore, the main prey species of harbour porpoises like herring and cod have hearing ranges outside the main frequency of the Lofitech sealscarer (see e.g. Chapman & Hawkins 1973, Denton *et al*. 1979, Hastings & Popper 2005) and are therefore unlikely to react towards the sealscarer. However, porpoises in the study area may also largely feed on gobies. Not much is known about their hearing abilities and there is a wide range of different species. So the effects of the sealscarer on these fish remain uncertain. Sound measurements show that the noise at 2.4 km distance to the sealscarer, where a clear reactions in porpoises was found, where 119 dB re $1 \mu Pa_{rms}$, and this would not be expected to interfere with the animals’ echolocation. The masking hypothesis is therefore also not very likely.

6.3.4. Porpoise reaction times

Information about the time it took for porpoises to leave the area after the start of the sealscarer is very limited based on POD data. If porpoises needed some time to leave the area after sealscarer start, one may expect porpoise recordings during the first hour after sealscarer start but none during the three consecutive hours. We did not find this with POD-recordings within a 3 km radius around the sealscarer. However, because the area covered by the PODs is only very small and because behavioural changes (such when animals change to swim more directionally) may have a strong effect on the probability of recording, it is impossible to draw conclusions based on POD data.

Visual observations, on the other hand, offer a much better method to gain information on reaction times. These have shown that (apart from one case where the animal clearly moved away) up to an exposure distance of 1.1 km radius the porpoise was not seen again after the sealscarer was switched on, which means that it must have reacted immediately. Observations at greater distances also show that in most cases porpoises either immediately turned around and swam away, or simply did not show any obvious behavioural changes. Only in one case there may have been a slightly delayed avoidance reaction after about 1.5 min. In the four instances when animals were observed to swim away, they covered between 148 and 827 m between the first and the last tracking point after the sealscarer was started and swam at speeds between 1.3 and 3.2 m/s (on the average 1.62 m/s). When the sealscarer was activated at closer proximity than 1.3 km, they may have swum faster than that, as they could not be seen again afterwards.

Harbour porpoises are known to swim at a speed of about 4.2 m/s (Otani *et al.* 2000). Therefore, a harbour porpoise could leave the area with a 7 km radius around the sealscarer in about 30 min, given that it swims directly away from it. This would be sufficient to leave the danger zone around pile driving activities. This study also showed that reactions up to 7 km could be possible. Because a longer than necessary use of sealscarers, would lead to unnecessary disturbance of harbour porpoises, its application time should be minimised. This means that it should only be deployed for the absolute necessary time before the start of pile driving and be retrieved immediately after pile driving is complete. Our results indicate that a deployment time of 30 min before the start of pile driving should be sufficient for porpoises to leave the area of about 1 km, where clear effects have been found.

6.3.5. Duration of deterring effect

A significant reduction in harbour porpoise activity as recorded by C-PODs in the North Sea after the sealscarer was switched off, could only be shown within the first and second three three-hour-block after sealscarer activity (up to 6 hours afterwards) and even this only at some distances. After this there was no longer a statistical difference in porpoise activity from the time before sealscarer deployment. Similarly, a significant effect was still detectable at the second four-hour-block (5-8 hours after sealscarer activity) of porpoise recordings at Fyns Hoved but not later. Porpoise recordings here showed that the first porpoise click was recorded on average 131 min (73-211 min) after the sealscarer was switched off. Visual observations at Fyns Hoved found the first porpoise to be present within a 1 km radius after on average of 51 min (34-67 min) after the sealscarer was switched off. This is a shorter time than what was recorded by the PODs in that area. However, here it has to be considered that the visual observations covered a larger area than the PODs, which also increases the chances of finding porpoise presence. Bearing this in mind, indications of visual and POD data correspond reasonably well. We therefore conclude that the effect of the sealscarer does probably not last longer than 8 hours after the device is switched off again, at least not as long as it was only active for 4 hours. This is in contrast to the effects of pile driving, which were found to last considerably longer than that (Diederichs *et al.* 2010a, Brandt *et al.* 2011). This may not be surprising, as sound levels from pile driving are also louder and reach further. If animals are deterred out of a larger radius, it will inevitably also take longer for them to return. Kastelein *et al.* (2010) also did not observe any longer lasting avoidance reaction in the captive porpoise after it was exposed to the sealscarer. The animal immediately resumed with its normal behaviour once the experiment was terminated. This points to the fact that if a longer lasting effect is found in the field, this is caused by the time it takes for animals to return rather than by the animals deliberately avoiding this area afterwards or being more cautious. This would further only be expected if they perceived the sound as a kind of predatory threat but not if they simply find it annoying, which we discussed as the most likely explanation for their behaviour. While the effect of the sealscarer lasts some time beyond its activity, the risk of porpoises avoiding a site over a longer period of time after the sealscarer was deployed, is minimal, at least as long as this is done in a responsible way and not over excessive periods of time.

6.3.6. Habituation

During the course of this study we could not find any habituation effects of harbour porpoises to the sealscarer, neither during the POD study in the North Sea or during the visual study in the Baltic Sea. Quite possibly this would also not be expected for the time period over which experiments took place. In the North Sea, ten trials with active sealscarer took place over a period of three months, while at Fyns Hoved, we conducted seven trials with active sealscarer over a period of 1.5 months.

The sealscarer was always only running for a continuous four hours, so as to not disturb the animals for longer than needed while still obtaining meaningful data. Apart from two consecutive days with active sealscarer at Fyns Hoved, there were always a minimum of four days between trials with active sealscarer, and in the North Sea trials were mostly separated by more than a week. Habituation can only happen if the same individuals are repeatedly exposed the sealscarer noise. During this study this seems not very likely. Even Kastelein *et al.* (2010) did not find any habituation effect in the only porpoise they tested with repeated exposure in captivity. In contrast, there are several studies that proof such habituation effects in seals (e.g. Götz & Janik 2010). However, during these studies seals had a high motivation to ignore the sound of the sealscarer, because they were rewarded with food. This is also described by the so called „dinnerbell effect“ (Mate & Harvey 1986 cited in Kraus 1999): Because most sealscarers are used in the context of fish farms to reduce seal depredation, seals quickly learn to associate the otherwise unpleasant sealscarer sound with food. This can lead to the opposite effect of the one actually wanted, because seals may now be attracted by this sound knowing that it indicates easily available food, rather than being deterred by it. The application of sealscarers during windfarm construction, however, does not pose such risks as long as animals are not prior adapted to these devices because they are also used in fisheries within the same area. In the context of windfarm construction, sealscarers do not indicate easily available food, instead they may only indicate that soon there will be an even louder unpleasant noise. It can thus be ruled out that animals will be conditioned to the sealscarer via positive reinforcement. However, what cannot be ruled out is that construction areas contain lucrative foraging spots and that animals may thus be motivated to ignore the sealscarer noise and stay in the area. This may have happened in the one instance when a milling animal approached the sealscarer at 800 m. However, it is expected that during windfarm construction, sealscarers will be used over a period for several months for only a few days (maybe 20-50) and for only a few hours at a time. With harbour porpoises being active over a relatively large area (see for example Teilmann *et al.* 2004, Nabe-Nielsen *et al.* 2010), it is unlikely that they should not leave for alternative areas but instead endure unpleasant sound and remain there. This may only become a problem if several turbines are constructed simultaneously so that possibilities to avoid a given site become limited.

6.4. Judging the effectiveness of sealscarer deployment as a mitigation measure

The present study shows a significant deterrence effect of the Lofitech sealscarer on harbour porpoises that probably reaches down to noise levels of 119 dB re 1µPa$_{rms}$. At what distances this noise level is reached and thus how far a deterrence effect may reach, highly depends on sound propagation characteristics in the area and at Fyns Hoved was at about 2.4 km and in the North Sea at about 7.5 km distance. Almost complete deterrence, however, could only be achieved within a radius of about 800 m at Fyns Hoved corresponding to a noise level of about 132 dB re 1µPa$_{rms}$. To judge whether or not the effective range is sufficient to prevent porpoises from suffering hearing damage caused by pile driving activities, more data are needed on the onset of PTS („Permanent Threshold Shift“) in harbour porpoises. Furthermore, predictions for sound emission have to be prepared and considered individually for each particular project. Southall *et al.* (2007) expect the onset of PTS for high-frequency-cetaceans such as the harbour porpoise at around 198 dB re 1 µPa (SEL). However, Lucke *et al.* (2009) found TTS („Temporary Threshold Shift) to occur in a captive harbour porpoise exposed to an airgun stimulus at already 164 dB re 1 µPa, which is 19 dB below the value predicted for the onset of TTS by Southall *et al.* (2007). This indicates that PTS may also occur at lower levels around 179 dB re 1 µPa. During construction of the Horns Rev II offshore windfarm in Denmark cumulative M-weighted (for calculation see Southall *et al.* 2007) sound levels of 194 dB re 1 µPa and 182 dB re 1 µPa were measured at 720 m and at 2300 m distance, respectively (Brandt *et al.* 2011). Considering PTS values given by Southall *et al.* (2007), sound levels dropped below levels where PTS would occur already at distances below 720 m. Under this assumption, the spatial extent of the deterrence effect of the Lofitech sealscarer would have sufficed to greatly reduce the risk of hearing damage in harbour porpoises. However, based on measurements by Lucke *et al*. (2009), the risk of PTS in harbour porpoises might still have existed at distances beyond 2300 m. Although there was still a significant deterrence effect of the Lofitech sealscarer at this distance in the North Sea, deterrence was not complete and several porpoises were recorded by PODs deployed at this distance. This means that one has to expect a great proportion of porpoises still to be present at this distance at the start of pile driving, even if a sealscarer was deployed. However, the cumulative M-weighted SEL of 182 dB re 1 µPa was only reached after about 19 min (Betke 2008). Considering the far reaching deterrence effect of pile driving on harbour porpoises (Carstensen *et al.* 2006, Tougaard *et al.* 2009, Brandt *et al.* 2011, Diederichs *et al.* 2010a), it is not expected that animals really remain inside a 2300 m radius for 19 min after the start of pile driving, but probably leave shortly after pile driving started. A level of 179 dB re 1 µPa was reached after about 16 min in 2300 m (Betke 2008). Assuming porpoises were completely deterred to a 700 m distance by the sealscarer before the start of pile driving, they would then have about 16 min to cover the other 1600 m to leave the 2300 m radius. With a swimming speed of 4.2 m/sec as reported by Otani *et al.* (2000) and assuming that porpoises leave in a direct movement away from the sound source, they can cover this distance in about 6-7 min, which leaves them sufficient time to avoid PTS. If we base a judgement about the effectiveness of the Lofitech sealscarer on these noise measurements from Horns Rev II, its application most probably successfully prevented hearing damage in harbour porpoises regardless of which of the two published PTS levels is used. However, judgements have to be made for each project specifically, taking noise predictions and measurements into account.

Based on data by Lucke *et al.* (2009), it is possible that the sealscarer noise itself causes hearing damage in harbour porpoises at very close range, as extrapolation of the acoustic measurement indicates. An SEL level of 179 dB re 1µPa is reached after about 12 sec in 10 m distance and after about 30 min in 100 m distance. At 300 m distance this level is not reached even after 3 hours. If taking the PTS level published by Southall *et al.* (2006) as a basis (198 dB re 1µPa), PTS would be reached after about 33 min in 10 m distance and not after even 3 h in 30 m distance. This shows that a slow start up of the sealscarer should be considered. However, with a slow start up there may be a reduced startle reflex and also animals may be more likely to adapt to sealscarer noise. Therefore, the reactions of porpoises to such a procedure should first be tested before final conclusions can be made.

Furthermore, it may be considered to develop deterring devices with the prime goal of deterring harbour porpoises and not seals. Commercially available pingers produce sound at frequencies where porpoise hearing is better than at the frequency of the sealscarer. If these devices were produced with a louder source level, they may deter porpoises more effectively than the sealscarer.

Kastelein *et al.* (2008a) showed that a captive harbour porpoise avoided a pulsed 50 kHz signal down to sound levels of 108 dB re 1 µPa. This is far below the 121 dB re 1µPa$_{rms}$, where Kastelein *et al.* (2010) found him to avoid the Lofitech sealscarer signal (at 14 kHz) and also the 119 dB re 1µPa$_{rms}$, where we still found an avoidance reaction in the field. This points to a greater deterring efficiency of 50 kHz signals on harbour porpoises. Propagation loss of this high-frequency sound is comparable to that of a 14 kHz signal at close distances of a few hundred meters, however, at greater distances propagation loss is considerably greater than of a 14 kHz signal. While this may mean that deterrence would not reach as far as with a 14 kHz signal, it also means that while deterrence at smaller distances is more effective, a much further reaching unwanted deterrence effect can be avoided. It could also provide an opportunity to more easily adjust desired deterrence effects according to specific needs. Bearing in mind that sound emission from pile driving may vary greatly between projects, depending for example on foundation type, water depth and whether or not sound mitigation is used, this may be desirable, and this option may be considered and tested.

6.5. Recommendations for the application of sealscarers as a mitigation measure during offshore windfarm construction

The use of sealscarers before the start of pile driving activities during windfarm construction can greatly reduce the risk of harbour porpoises suffering hearing damage. Due to its louder noise level, the deterrence effect of sealscarers reaches much further than that of several commercially available pingers, which deterrence effects reach only up to 100-400 m. The use of sealscarers before pile driving activities is therefore recommended.

A deployment time of 30 min before the start of pile driving should be sufficient to deter harbour porpoises from a 1 km radius around the sealscarer. With an average swimming speed of 1.62 m/s, which we found for animals leaving the area around the sealscarer when at 1.3-2.4 km distance to it upon activation, they would need 27 min to cover a distance of 1 km. Most likely they swim even faster when closer to the sealscarer and a maximum swimming speed of 4.2 m/s had been reported (Otani *et al.* 2000). To avoid longer lasting disturbance effects on seals and porpoises, we recommend not deploying sealscarers earlier than 30 min before the start of pile driving and to retrieve sealscarers immediately after pile driving activities are complete. It is further desirable to slowly increase the sound level of the sealscarer so as not to induce panic reactions in porpoises, which could potentially lead to the separation of mother calf pairs (devices would have to be modified to achieve this). However, how animals react to this and whether this measure may reduce the effectiveness of a deterrence effect should first be tested.

I think this is a more complex question, and surprisingly no data exist on reactions of porpoises to ships. There are only some anecdotal observations of small scale avoidance. However, we have included the lower new paragraph in section 5.5. (p.92) to discuss this.

Another factor that may contribute to deterring harbour porpoises from the construction area is extensive ship traffic that will evidently be present before the start of pile driving. Although there is little information on how harbour porpoises react to shipping noise, there are many anecdotal observations of porpoises swimming away from approaching ships. In other toothed cetaceans several studies have shown behavioural reactions of bottlenose dolphins (*Tursiops truncates*) and killer whales to the approach of vessels in that they changed swimming direction, swimming speed, breathing patterns and / or inter-individual distances (Nowacek et al. 2001, Williams et al. 2002, Hastie et al. 2003, Lemon et al. 2006). Some studies even reported broad scale avoidance of an area with high shipping intensity by these species (e. g. Lusseau 2005, Bejder et al. 2006). However, these studies also show that responses can be more complex than simply animals swimming away from the noise source and may also only happen on a small scale. While increased ship traffic before the start of pile driving likely contributes to deterring the harbour porpoises from danger zones, this should definitely not be relied upon, and the application of specific deterring measures like the deployment of a seal scarer are highly recommended.

While predictions based on PTS levels are very vague, any risk of hearing damage caused by the sealscarer could almost certainly be avoided by slowly increasing the sealscarers' noise level. If modifying the sealscarer accordingly is not possible, we recommend to at least deploying a pinger 10 min before the start of the sealscarer at exactly the same position. To account for the danger of injury at distances where the sealscarer effect is no longer complete we further recommended a slow ramp-up procedure of pile driving in order to give the animals sufficient time to leave a wider area before full sound levels are reached.

Experiences from former pile driving activities showed that the sealscarer was not always used according to plan. During some pile driving events it was not used at all, whilst at other times it was deployed when no pile driving took place (Diederichs *et al.* 2009). During sound measurements of a pile driving event at alpha ventus the sealscarer could not be detected (Betke & Matuschek 2010), even though according to the protocol it was deployed. To ensure proper handling of the sealscarer and accurate observance of the protocol, we recommend integrating the deterrence procedure into the pile driving operation.

It is crucial, however, that propagation estimates have to be made project specifically and the needed deterrence ranges estimated accordingly. Only then can a judgement be made whether or not the application of a Lofitech sealscarer prior to pile driving may reduce the risk of injury in harbour porpoises to an acceptable level. Furthermore, current developments in sound mitigation techniques may enable the reduction of emitted sound to a much greater degree. This may then lead to significantly smaller necessary deterrence ranges than what the current sealscarer models achieve. Under these circumstances it may be investigated whether a more effective deterrence device for harbour porpoises that can more easily be adjusted to specific needs while minimising unnecessary additional disturbance could be developed.

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8. APPENDIX

Tab. 32: Sound measurement locations at Fyns Hoved. For hydrophone positions 33 through 36, there was no direct sound path to the sealscarer (i.e. no line of sight).

Meas. no.	Sealscarer position	Hydrophone position	Distance from sealscarer, m
1	25 (55°37.190'N 10°35.300'E)	27 (55°37.263'N 10°35.387'E)	130
2	"	28 (55°37.318'N 10°35.405'E)	260
3	"	29 (55°37.399'N 10°35.484'E)	390
4	"	30 (55°37.711'N 10°35.722'E)	1000
5	"	31 (55°38.220'N 10°36.086'E)	2000
6	"	32 (55°39.161'N 10°36.867'E)	3900
7	"	33 (55°37.343'N 10°35.938'E)	700*
8	"	34 (55°37.193'N 10°36.293'E)	1000*
9	"	35 (55°37.345'N 10°35.822'E)	560*
10	"	36 (55°37.326'N 10°35.629'E)	380*
11	"	37 (55°37.211'N 10°35.165'E)	160
12	"	38 (55°37.215'N 10°34.833'E)	500
13	"	41 (55°37.371'N 10°34.299'E)	1100
14	"	42 (55°37.412'N 10°33.308'E)	2200
15	"	43 (55°36.671'N 10°34.878'E)	1100
16	"	44 (55°36.980'N 10°35.121'E)	430
17	"	45 (55°37.113'N 10°35.240'E)	155
18	M2S (55°37.072'N 10°32.795'E)	45 (55°37.113'N 10°35.240'E)	2500
19	M1S (55°36.606'N 10°33.621'E)	46 (55°37.193'N 10°35.302'E)	2100

Tab. 33: Median, average, min, max and sample size of PP10M/day at the 16 POD-positions.

POD-position	median % PP10M/ day	average % PP10M/day	min. - max. % PP10M/day	n days
1	6.9	8.6	0-34.7	135
2	27.8	28.5	0-88.2	147
3	9.7	14.7	0-61.8	104
4	5.6	6.6	0-33.3	91
5	47.2	47.2	0-88.9	48
6	4.2	6.8	0-27.1	89
7	11.1	13.5	0-38.2	117
8	49.3	44.5	0-99.3	131
9	12.9	14.2	0-43.1	84
10	14.6	16.0	1.4-59.0	146
11	5.7	12.6	0-56.3	70
12	7.3	8.6	0-29.2	110
13	6.9	8.6	0-29.9	101
14	25.0	24.4	0-45.1	16
15	6.9	7.9	0-25.7	107
16	23.6	28.4	0-97.4	142
total	*11.1*	*17.8*	*0-99.3*	*1638*

Tab. 34: Absolute recording effort, absolute number of porpoise positive minutes (PPM) and proportion of PPM before, during and after sealscarer-deployment. Also shown is the change in percent at the single POD-positions and calculated over all positions of each distance. Only hours with a maximal of 10 % data loss due to noise are included.

Distance in m	Position	min before sealscarer	PPM before sealscarer	% PPM before sealscarer	min during sealscarer	PPM during sealscarer	% PPM during sealscarer	Change
0	16	1560	39	2.50	1500	2	0.13	-94.67
	sum	1560	39	2.50	1500	2	0.13	-93.09
750	1	1440	30	2.08	1800	17	0.94	-54.67
	2	1680	112	6.67	1680	6	0.36	-94.64
	3	1500	40	2.67	1380	5	0.36	-86.41
	sum	4620	182	3.94	4860	28	0.58	-85.28
1500	4	780	6	0.77	1080	0	0.00	-100.00
	5	540	27	5.00	540	26	4.81	-3.70
	6	840	24	2.86	900	0	0.00	-100.00
	sum	2160	57	2.64	2520	26	1.03	-60.99
3000	7	1440	41	2.85	1440	10	0.69	-75.61
	8	1080	293	27.13	1260	78	6.19	-77.18
	9	1080	31	2.87	1260	3	0.24	-91.71
	sum	3600	365	10.14	3960	91	2.30	-77.32
5000	10	1800	20	1.11	1800	22	1.26	+10.00
	11	540	3	0.56	540	3	0.56	0
	12	1200	10	0.83	1500	5	0.33	-60.00
	sum	3540	33	0.93	3840	30	0.78	-83.87
7000	13	1200	39	3.25	1380	1	0.07	-97.77
	15	780	20	2.56	1380	7	0.51	-80.22
	sum	1980	59	2.98	27600	8	0.03	-98.99

Tab. 35: Proportion of porpoise positive three-hour-blocks (PP3H) before and during sealscarer deployment for all POD-positions and summed up for each distance. Also shown is the relative change at the single POD-positions and at the different distance categories. Only trials in which both three-hour-blocks before and during sealscarer activity could be analysed are included.

distance in m	POD-Position	% PP3H before sealscarer	% PP3H during sealscarer	n	% change in PP3H
0	16	75	13	8	-83
750	1	57	43	7	-25
	2	100	25	8	-75
	3	100	14	7	-86
	total	86	27	22	-69
1500	4	75	0	4	-100
	5	100	67	3	-33
	6	100	0	4	-100
	total	91	18	11	-80
3000	7	75	38	8	-49
	8	100	83	6	-17
	9	100	17	6	-83
	total	90	45	20	-50
5000	10	90	30	10	-67
	11	33	67	3	+103
	12	67	33	6	-51
	total	74	37	19	-50
7000	13	100	17	6	-83
	15	50	50	2	0
	total	88	25	8	-72

Tab. 36: Averages (calculated over the number of trials) of % PPM before and during sealscarer activity, and change in % at the single POD-positions of each distance and averaged over POD-positions at each distance. Sample sizes are given in brackets. Data are similar to those in Tab. 12. The difference is that in Tab. 12 only trails are included where data could be analysed both before and during sealscarer activity. This Table includes all trials where data could be analysed before or during sealscarer activity. Therefore, sample size varies between before and during sealscarer activity.

Distance in m	POD-position	Average % PPM before sealscarer (n)	Average % PPM during sealscarer (n)	Change in %
0	16	2.62 (9)	0.12 (9)	-95.42
	average	2.62 (9)	0.12 (9)	-95.42
750	1	2.22 (9)	0.94 (10)	-57.66
	2	6.78 (10)	0.33 (10)	-95.13
	3	2.84 (9)	0.35 (8)	-87-68
	average	4.05 (28)	0.56 (28)	-86.17
1500	4	0.67 (5)	0.00 (6)	-100.00
	5	5.00 (3)	4.82 (3)	-3.60
	6	2.67 (5)	0.00 (5)	-100.00
	average	2.44 (13)	1.03 (14)	-57.79
3000	7	2.85 (8)	0.69 (8)	-75.61
	8	27.13 (6)	6.19 (7)	-77.18
	9	2.87 (6)	0.24 (7)	-91.64
	average	10.14 (20)	2.30 (22)	-77.32
5000	10	1.11 (10)	1.22 (10)	+9.91
	11	0.55 (3)	0.55 (3)	0.00
	12	0.69 (8)	0.31 (9)	-60.76
	average	0.87 (21)	0.76 (22)	-12.64
7500	13	2.99 (8)	0.07 (8)	-97.66
	15	3.29 (6)	0.49 (8)	-85.11
	average	3.12 (14)	0.28 (16)	-91.03